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DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS FOR SURFACE WATER (RIVER, ESTUARIES AND WETLANDS) AND GROUNDWATER IN THE LOWER ORANGE WMA

REPORT ON CONSEQUENCES OF SCENARIOS

water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

MAY 2017

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DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS

DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS FOR SURFACE WATER (RIVER, ESTUARIES AND WETLANDS) AND GROUNDWATER IN THE LOWER ORANGE WMA

REPORT ON CONSEQUENCES OF SCENARIOS

Approved for RFA by:

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EXECUTIVE SUMMARY

BACKGROUND

The Chief Directorate: Water Ecosystems (CD: WE) of the Department of Water and Sanitation (DWS) initiated a study for the provision of professional services to undertake the 'Determination of Ecological Water Requirements for Surface Water (Rivers, Estuaries and wetlands) and Groundwater in the Lower Orange Water Management Area (WMA). Rivers for Africa was appointed as the Professional Service Provider (PSP) to undertake this study.

PURPOSE OF REPORT

The purpose of this report is to document the consequences of the various operational scenarios in terms of its impact on the river, estuary, economics and the Ecosystem Services of the Orange River. An integration process to provide an overall recommendation is also provided.

OPERATIONAL SCENARIOS

The proposed scenarios defined in this document aim to augment previous work and avoid duplication, while considering more recent information from other water resource planning activities in the Orange River.

The EWR currently used on the Orange River was originally determined as part of the Orange River Development Project Replanning Study (ORRS), carried out in the middle 1990's based on an outdated environmental requirement methodology. These environmental flow requirements are currently still being released from Vanderkloof Dam and will be replaced once the Reserve was determined and sufficient yield capability created to be able to support the increased environmental requirements. A summary of the scenarios are as follows:

- **Scenario A** represents the present day system at 2016 development level.
- **Scenario A2** allowed for improvement to the ORRS environmental requirement in line with the latest REC defined for EWR O5. The purpose of this scenario is to improve the current EWR releases without impacting on the ORP yield (see Appendix A for more detail).
- **Scenario A3** is as Scenario A2 but using the current Namibian water allocations along the Lower Orange which is higher than the current actual water use by Namibia.
- **Scenario B** serves as the base scenario for the 2035 development level when the expected major future water resource development options are in place, but with the ORRS EWR still being released from Vanderkloof and Vioolsdrift dams.
- **Scenario C1b** is as Scenario B, but replaced the ORRS EWR with the "preferred" REC environmental flows as used in the Orange River Reconciliation Strategy Study, which was basically the Recommended EWR "without high flows" for the summer months only at EWR O3. This means that the winter months EWR in the model were set to zero, assuming that the flows released to supply the downstream users during the winter months will be sufficient for environmental purposes at EWR O3.
- **Scenario C2b** is as Scenario C1b but using the Recommended EWR "without high flows" for all the months at EWR O3, thus winter and summer months.
- **Scenario D2** is as Scenario C2b but using a smaller dam at Vioolsdrift.
- **Scenarios D2i and D2ii** are both as Scenario D2 but included slightly higher flows in the months of December and January. These higher flows were based on assessments done for the Estuary by environmental specialists based on the results obtained from Scenario D2.
- **Scenario D3** is as Scenario D2, but with some floods added to EWR O5 requirement.

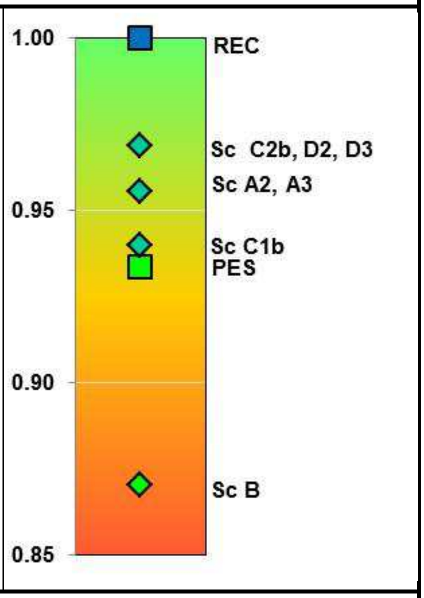
ECOLOGICAL CONSEQUENCES: RIVERS

Summary of the detailed ecological consequences determined for the EWR sites situated in the Lower Orange River

Ecological consequences as ECs	Ranked scenarios

EWR O3 (AUGRABIES)

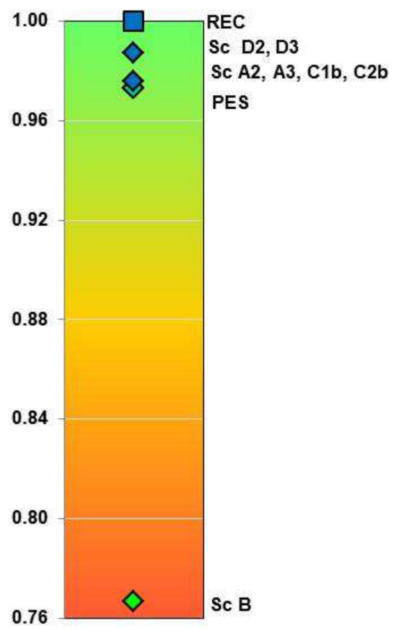
Component	PES	REC	Sc A2	Sc C2b	Sc C1b	Sc B
Physico chemical	C	C	B/C	B	C	C
Riparian vegetation	B/C	B	B/C	B/C	B/C	C
Fish	C	B	B/C	B	C	C
Inverts	C	B	B/C	B/C	C	C
EcoStatus	C (77.2%)	B (83.6%)	B/C (79.1%)	B/C (81.7%)	B/C (77.7%)	C (70.9%)



Ranking rationale: The ranking of the scenarios show that all the scenarios, apart from Sc B, result in an improvement of the PES but do not achieve the REC. The best scenarios are Sc C2b, D2/D3 followed closely by Sc A2/A3. As the recommendations are likely to be set for pre-dam situation, Sc A2/A3 will be the recommended scenario. The best post dam scenarios are Sc C2b and Sc D2 and D3.

EWR O5 (SENDLINGSDRIF)

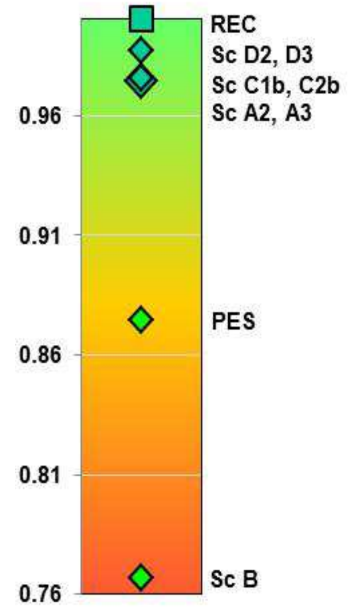
Component	PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
Physico chemical	C	C	B/C	B/C	B/C	D
Riparian vegetation	B/C	B	B	B	B	C
Fish	B/C	B	B	B	B	C
Inverts	B/C	B/C	B/C	B/C	B/C	C
EcoStatus	B/C (80.5%)	B (82.7%)	B (82.9%)	B (82.7%)	B (82.2%)	C (71.8%)



Ranking rationale: The ranking of the scenarios show that all the scenarios, apart from Sc B achieve the REC. The best scenarios are D2/D3 followed closely by Sc C2b/C1b. As the recommendations are likely to be set for a pre-dam situation, Sc A2/A3 will be the recommended scenario prior to the dam construction. When a decision is made on future dams, then the recommendation will be the scenario associated with D2/3.

EWR O4 (VIOOLSDRIFT)

Component	PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
Physico chemical	C/D	C/D	C	C	C	D
Riparian vegetation	C	B	B/C	B/C	B/C	C
Fish	C	B/C	B/C	C	C	C/D
Inverts	C	B/C	B/C	B/C	B/C	D
EcoStatus	C (69.1%)	B/C (81%)	B/C (79.9%)	B/C (78%)	B/C (77.9%)	C (62.6%)



Ranking rationale: The ranking of the scenarios show that all the scenarios, apart from Sc B achieve the REC EcoStatus. It should be noted that although the EcoStatus is met under these scenarios all the component of the REC is not met. The best scenarios are D2/D3 followed closely by Sc C1b/C2B. As the recommendations are likely to be set for pre-dam situation, A2/A3 will be the recommended scenario prior to the dam construction. When a decision is made on future dams, then the recommendation will be the scenario associated with D2/3.

INTEGRATED ECOLOGICAL RANKING

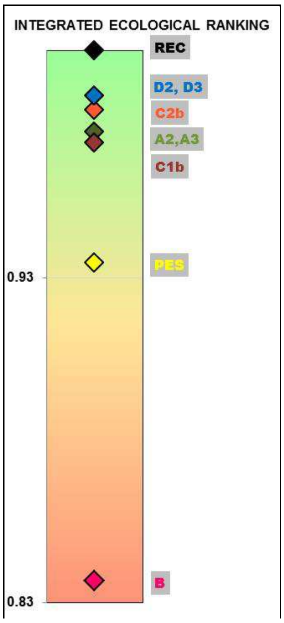
The process to determine an integrated ranking of the different scenarios is described in detail under Section 3.3. The first step was to determine the relative importance of the different EWR sites occurring in the study area. The site weight indicated that EWR O5 carried the highest weight due to the High Ecological Importance and Sensitivity (EIS) as EWR O5 is situated in the /Ai-/Ais-Richtersveld Transfrontier Park. This site is also the most downstream site in the Orange River and the accumulated impact of the scenarios will be the highest in spite of the relatively short river reach (141 km).

The weight was applied to the ranking value for each scenario at each EWR site and this provided an integrated score and ranking for the operational scenarios. The ranking of '1' refers to the REC and the rest of the ranking illustrates the degree to which the scenarios meet the REC. The results are provided below after the weights have been taken into account.

Ranking value for each scenario resulting in an integrated score and ranking

	PES	REC	A2,A3	B	C1b	C2b	D2, D3
EWR O3	0.33	0.35	0.33	0.30	0.33	0.34	0.34
EWR O4	0.22	0.25	0.24	0.19	0.24	0.24	0.25
EWR O5	0.39	0.40	0.40	0.34	0.40	0.40	0.40
Integrated	**0.93**	**1.00**	**0.97**	**0.84**	**0.97**	**0.99**	**0.99**

The above results are plotted on a traffic diagram to illustrate the integrated ecological ranking.



Rivers: Integrated ecological ranking of the scenarios on the Lower Orange River system

Scenarios D2 and D3 are the best option as it is closest to meeting the ecological objectives, with Sc C2b close behind. However, the purpose of setting the preliminary Reserve is to provide management guidance that is legally binding. Therefore, the focus is on the pre-dam situation/pre Classification study (and Reserve determination) as is relevant for a Preliminary Reserve and associated management and immediate implementation. As the recommendations are likely to be set for pre-dam situation, Sc A2/A3 will be the recommended scenario.

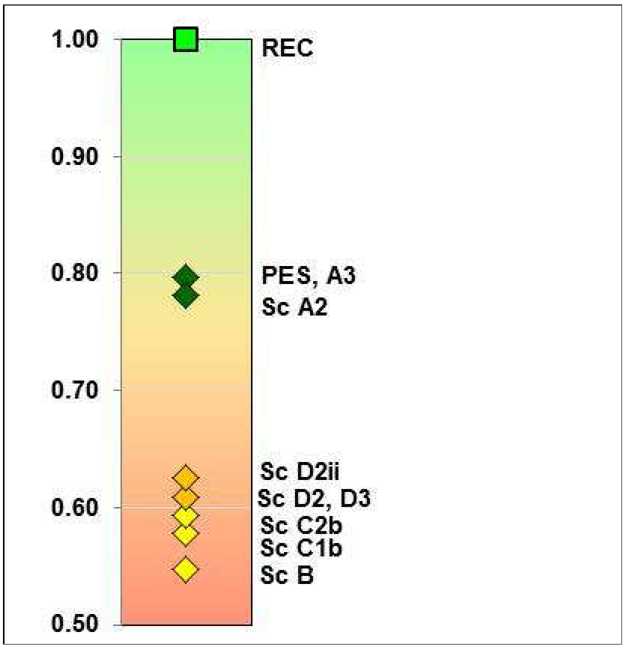
ECOLOGICAL CONSEQUENCES: ESTUARY

A comparison of the overall ecological condition of the estuary under each of the proposed scenarios relative to the PES (D Category) and REC (C Category) are presented in the Figure below. Results can be summarised as follows:

- The Ecological Categories (ECs) of the PES and all proposed scenarios are well below the REC (EC C) for the Orange Estuary.
- The PES of the estuary is currently in a D EC, but with two biotic components, i.e. microalgae and birds (a key biotic component protected under Ramsar Convention) already below the ecological functional threshold of an D Category.
- Scenario A3 shows an improvement on the Present as a result of the redistribution of flow in the low flow period and the estuary mouth conditions moving towards a more natural regime. Scenario A2 showed a slight decline in condition from the present state. The overarching condition for the A scenarios is a D EC.
- Scenario D2 results in all components showing a significant decline in health, with hydrodynamics, physical habitat, macrophytes, microalgae, invertebrates, fish and birds below a functional level of a D EC. The overarching condition is also reduced to an E EC. Of note is that the fish, an additional Ramsar listing criteria, declines to an E EC under the D scenarios. Scenario D3 represents a slight improvement on Sc D2 from a macrophyte perspective. A key driver of the decline in condition is non-flow related impacts, the loss of floods, infilling and decline in baseflows. Preliminary sensitivity testing shows that opportunities exist to improve the D scenarios by 1 or 2% by elevating some of the baseflows above $10m^3/s$. These incremental improvements would assist in reducing stagnant conditions in the estuary and reduce the risk of fish recruitment failure.
- Scenario C1b and C2b results in all components showing severe decline in health, with hydrology, hydrodynamics, Physical habitat, macrophytes, microalgae, invertebrates, fish and

birds below a functional level of a D EC. The overarching condition is also reduced to an E EC. Of note is that the fish, an additional Ramsar listing criteria, declines to an E EC under the C scenarios. A key driver of the decline in condition is non-flow related impacts, the loss of floods, infilling and decline in baseflows and potential recruitment failure of fish.

- Scenario B represents the worst case scenario with its highly regulated flows forcing most components (with the exception of water quality and hydrodynamics) below the functional level of an EC D. Abiotic components range between D to E Category, while biotic component decline to an E Category (with the exception of the Macrophyte component in a D/E EC). The overarching condition is also reduced to an E EC.



Orange Estuary: Relative ranking of the scenarios versus REC

Key findings from this assessment are:

- All the proposed dam development scenarios will reduce the ecological condition of the Orange Estuary from the present state in one or more of the individual abiotic and biotic components significantly. The small dam development (D scenarios) is associated with 12% decline in health (D/E EC), while large dam developments (scenarios B and C) are associated with a 13 to 16% decline in health (E EC).
- As with the PES, the ecological condition associated with all proposed scenarios are well below that required for the REC, also for most of the individual abiotic and biotic components.
- Scenario A3 is the operational scenario associated with the least ecological degradation.
- A key flow related requirement to achieve the REC will be to reduce present winter base flows sufficiently to allow for mouth closure and related back-flooding of the saltmarshes with brackish water to reduce soil salinities, but not to the point where the estuary mouth remains closed for longer than 2 to 4 times in 10 years by decreasing river inflow to less than 5 m^3/s. An additional requirement is the need to elevate base flows above 10 m^3/s from December onwards. After long periods of very low flow the instream habitat becomes very reduced and/or shallow.
- As per the 2013 Estuary EWR study (Van Niekerk *et al*., 2013a,b), the REC for the Orange Estuary cannot be achieved through flow interventions only.

Specialists estimate that the estuary condition can be improved by about 10% through non-flow related interventions. Critical non-flow related mitigation measures include:

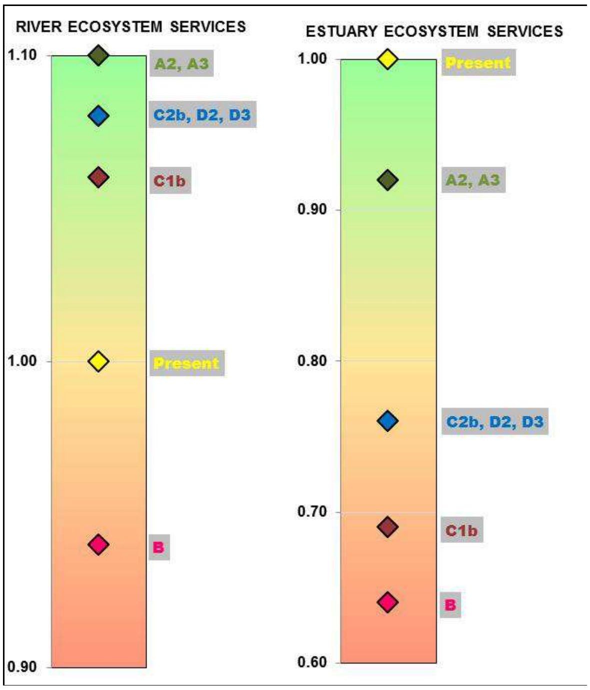
- Control the fishing effort on both the South African and Namibian side through increased compliance and law enforcement. This also requires the alignment of fishing regulations (e.g. size and bag limits) and management boundaries on either side of the transboundary estuary;
- Enhance nursery function for estuarine dependant fish species.
- Remove the remnant causeway that still transects the saltmarshes to improve circulation during high flow and floods events. This will also assist with increasing the water circulation into the lower marsh areas.
- Decrease nutrient input from the catchment downstream of Vioolsdrift, through improved agricultural practices.
- Control windblown dust and wastewater from mining activities; and
- Reduce/remove grazing and hunting pressures (which have significantly escalated in the last 5 years).

The recommendation is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the REC. The recommended scenario for the Orange Estuary for the pre-dam situation is the Present or Sc A3 that maintains the D EC.

ECOSYSTEM SERVICES CONSEQUENCES

The consequences of the scenarios at all three EWR sites situated in the Orange River indicated that scenario groups A2, C1b and C2b were positive with Sc B being negative. Provisioning services remained constant against the status quo score or improved under all scenarios at the EWR sites. Regulating and Cultural services were negatively impacted by Scenario B while these services improved under the rest of the scenarios. No discernible change was noted for Supporting services under any scenario. Scenario A2, A3, B, C1b, C2b, D2 and D3 were deemed to be negative in terms of ecosystem services associated with the estuary with Sc D3, D2 and C1b regarded as particularly negative.

The results of the scenarios for the Orange River were ranked with the EWR sites weighted (Figure below). The Ecosystem Services ranking for the estuary is also provided.



Ranking of impact of scenarios on Ecosystem Services in the Orange River system

ECONOMIC SERVICES CONSEQUENCES

The Table below presents the economic results associated with the different volumes available for production purposes after the removal of the volume of water to maintain the EWR.

Economic production per Scenario

Scenario	GDP (Rand Million)		Employment (Number)		Household Income (Rand Million)	
	Direct	Total	Direct	Total	Total	Low
2016 Baseline	3.472	5.617	27.380	40.110	4.501	1.325
Impact Sc A2	3.472	5.617	27.380	40.110	4.501	1.325
Impact Sc A3	4.008	6.484	31.604	46.297	5.196	1.529
2035 Baseline	13 011.02	21 048.02	102 596	150 294	16 866.29	4 964.44
Impact Sc C1b	10 718.44	17 339.31	84 519	123 812	13 894.41	4 089.69
Impact Sc C2b	8 560.73	13 848.76	67 504	98 887	11 097.35	3 266.40
Impact Sc D2	8 560.73	13 848.76	67 504	98 887	11 097.35	3 266.40
Impact Sc D3	8 776.50	14 197.81	69 205	101 379	11 377.05	3 348.73

In the evaluation of the results it must be kept in mind that the 2016 Baseline and Sc A2 and A3 is only based on the Lower Orange. The results of the 2035 baseline and accompanying results is representative of the total river basin and the Table below presents the economic impacts of the different scenarios.

Economic impacts of the Scenarios

Scenario	GDP (Rand Million)		Employment (Number)		Household Income (Rand Million)	
	Direct	Total	Direct	Total	Total	Direct
2016 Baseline	0	0	0	0	0	0
Impact Sc A2	0	0	0	0-	0	0
Impact Sc A3	535.65	866.53	4 224	6 187	694.37	204.38
2035 Baseline	0	0	0	0	0	0
Impact Sc C1b	-2 292.57	-3 708.71	-18 078	-26 482	-2 971.88	-874.75
Impact Sc C2b	-4 450.29	-7 199.26	-35 092	-51 406	-5 768.94	-1 698.04
Impact Sc D2	-4 450.29	-7 199.26	-35 092	-51 406	-5 768.94	-1 698.04
Impact Sc D3	-4 234.51	-6 850.21	-33 391	-48 914	-5 489.24	-1 615.71

The above results indicate that Sc A2 has no negative or positive economic impact measured in terms of the 2016 Baseline in the Lower Orange. Scenario A3 produces a positive economic impact and in line with the defining parameters of the scenario the impacts will be mostly on the Namibian side of the river. The economic impacts measured in 2016 prices in terms of 2035 projected water demand for all the scenarios indicate a negative economic impact. Using just the economic impact it appears as if Sc C1 is the preferable scenario, followed by Sc D3 and then Sc C2 and D2 indicating the same economic impact. The estimated social and economic impacts of the different scenarios based on the 2035 baseline is drastic and it is necessary to also take into consideration the costs of the identified additional infrastructure to maintain the EWR and the economic activities.

The Table below provides the results for the scenarios applicable over the total river expressed in terms of the capital and operational costs involved.

Selected data applied and results estimated in the CBA model

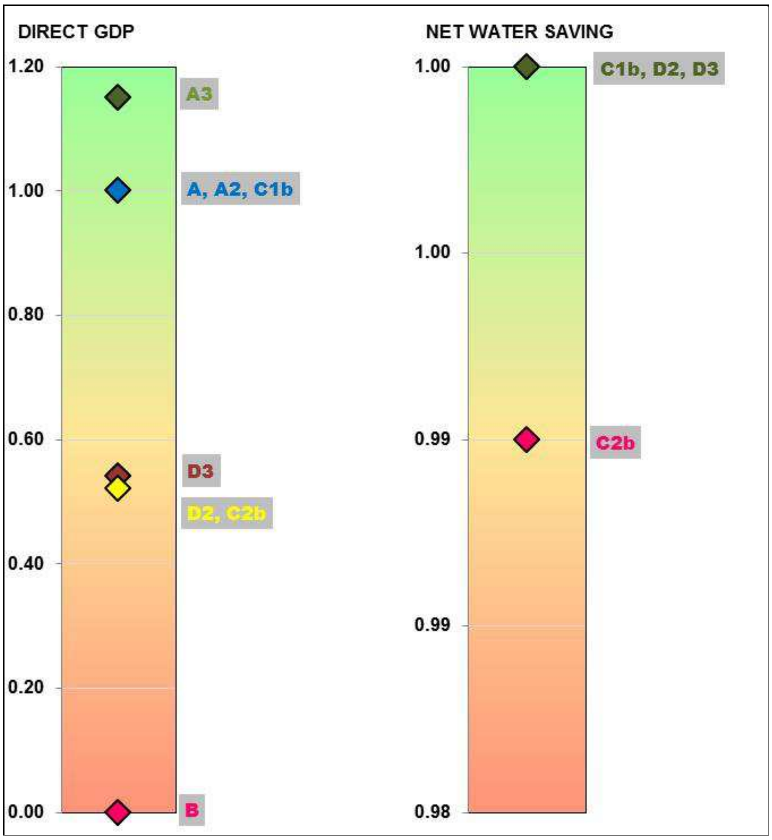
Scenario	Volume Involved (mm^3)	Capital Cost (Rand million)	Operational Cost (Rand million)	NPV[1]: Direct Discounted GDP Benefit (Rand million)	Benefit (Net GDP)/Water Savings (Rand/m^3)
C1 – Large Dam	425	1,715.22	7.44	15,161.9	3.36
C2 – Large Dam	825	1,715.22	7.44	32,035.9	3.66
D2 – Small Dam	825	1,102.79	1.14	32,653.4	3.73
D3 – Small Dam	785	1,102.79	1.14	30,966.0	3.72

1 Net Present Value.

The benefit/m^3 metric is used to express the benefit saved, expressed in terms of the GDP, per cubic metre of water, if the supply of the irrigation and urban water is not reduced. The 3.73 Rand/m^3 is there for the more beneficial value and therefore Sc D2 is the best economic feasible option using this approach.

From the above it appears that Sc C1 will be the most beneficial in economic terms if only the negative impact on the economy is measured. However, if the cost of the provision of the infrastructure to maintain the EWR as well as the economic activities is considered, Sc D2 is the most beneficial. The only difference between Sc D2 and C2 is that benefit/m^3 metric of Sc D2 is slightly better than Sc C2 as the rest of the parameters are similar. When only evaluating the scenarios with the infrastructure costs component, Sc D3 is the most preferred with the net water savings indicator followed closely by Sc D2 and C1b. The larger the savings ratio, the better the economics of scale is applied.

The economic impact comparisons of GDP for all the scenarios as well as the water saving benefit using the Nett Benefit and volume involved as drivers are presented below.



Ranking of scenarios in terms of Direct GDP and Net Water Saving benefit

CONCLUSIONS AND RECOMMENDATIONS

The determination of the Reserve and the National Water Resources Classification is a legal requirement according to the National Water Act. The Reserve can only be gazetted once the Classification has been determined and gazetted. The Act allows for a Preliminary Reserve to be determined prior to Classification. Although not gazetted, the Preliminary Reserve is signed off by the Minister (or the delegated authority) and is legally binding. As such, the Preliminary Reserve is undertaken prior to Classification or as part of a Classification study. The decisions taken can be reviewed and updated during Classification as detailed consideration is given to the socio-economic issues.

The Orange River study is a Preliminary Reserve study prior to Classification. Further development of the Orange River is being investigated. This will allow for more management options of amongst others, the EWRs. The scenarios and recommendations which are made for this phase pertain to the post-dam recommendations. Immediately applicable is the provision of EWRs through the operation of the system without additional storage. These scenarios represent the pre-dam recommendations. This will be legally binding until the Classification has been determined and gazetted. The Reserve will then follow and be gazetted. Therefore, the focus of this Preliminary Reserve study is on pre-dam situation. Recommendations are also made for the post-dam situation regarding scenarios as well as further work required in preparation for Classification.

Yield Implications

For each scenario, the results in the form of a time series of monthly average flows past each site dating from 1920 to 2004 were provided to the study team for further assessment. A summary of those flows is presented in the table below, representing the average annual flow in million m^3/a at the given site and representative scenario. The reduction in yield refers to the decrease in yield of the ORP as result of the different EWRs included for the specific scenario.

Average annual flow (million m^3/a) at the given site and representative scenario

Scenario	EWR O3	Vioolsdrift	EWR O5	Estuary	Yield reduction (million m^3/a)
A	4280.45	3984.34	4430.61	4346.46	Current base
A2	4287.76	3991.62	4437.89	4353.74	0*
A3	4306.79	3925.12	4371.37	4285.71	0*
B	3531.35	2953.75	3183.12	3059.03	2035 Base
C1b	3708.39	3110.33	3298.13	3173.97	425**
C2b	3708.39	3110.33	3375.86	3251.63	825**
D2	3747.05	3205.22	3493.33	3369.03	825**
D2i	3747.05	3205.63	3493.50	3369.19	825**
D2ii	3747.05	3205.76	3493.62	3369.32	825**
D3	3747.15	3206.49	3494.21	3369.90	825**

* Yield reduction relative to Sc A. ** Yield reduction relative to Sc B.

Pre-dam recommendations

Prior to the development of additional storage, the only option for improving the estuary and rivers are to improve on the distribution of the existing EWR allocation. These are scenarios A2 and A3. These scenarios will improve the rivers significantly, especially at EWR O5 where the REC may be achieved. The A2/3 scenario will only maintain the PES at the estuary, but it is likely that with the improvement at EWR O5, that some improvement may be noted at the estuary. If the anthropogenic issues are addressed, the estuary status will improve to a C/D. The Ecosystem Services show no negative impact of the implementation of the A scenarios. As the A scenarios are a marked improvement for the rivers, these scenarios rather than the current EWR allocation would be strongly recommended from an ecological perspective.

The impact on yield of Sc A2 and A3 are very low. Scenario A2 versus the 2016 Base Scenario shows no difference in yield. A relative small reduction in yield due to potential full use of Namibian allocations of 92 million m^3/a is applicable to Sc A3. The recommendation is that Sc A2 or A3 be immediately implemented.

Post-dam development scenarios

Five scenarios were evaluated that included future dam development. The scenarios (D range) that represent a small Vioolsdrift Dam (35m) scored the highest. One of the D scenarios, Sc D2 was further optimised for the estuary (Sc D2ii) and showed a slight improvement. The Ecosystem Services showed an improvement of all the scenarios over the present provisioning. The recommendation from an ecological perspective is therefore Sc D2ii. It must be noted that the REC for the EcoStatus is achieved at both EWR O4 (Vioolsdrift) and O5 (Sendelingsdrift) and that the PES is improved at EWR O3. Although there is no improvement and even further degradation at the estuary, it is possible that with monitoring to better understand conditions under low flows and with further optimisation during the National Water Resources Classification study a scenario can be devised that maintains or improves the estuary.

It must be noted that the Sc C2b that represents the large Vioolsdrift Dam is only marginally worse than the small dam scenarios. However, these rankings do not take into account the severe impact of the barrier effect of the dam for fish and other biota as well as the sedimentation impacts on the estuary and in general, the marine environment. Mitigation measures such as fishways are a possibility for the smaller dam but are unlikely to be structurally feasible or cost effective for the large dam.

From a yield perspective, it is important to note that there is a significant difference between Sc C1b and C2b. Both scenarios include the large Vioolsdrift Dam with the main difference being that for Sc C1b no winter low flows are supplied at EWR O3 (Augrabies) and for Sc C2b both summer and winter low flows were supplied. This resulted in a reduction in yield of Gariep and Vanderkloof dams by 400 million m^3/a. Although the yield for the large Vioolsdrift Dam also increased due to the higher inflows into Vioolsdrift, this increased yield cannot be utilized downstream of Vioolsdrift Dam, due to limited downstream demands. Sc C1b (supply of inter flows at EWR O3) therefore eliminates the option of a large Vioolsdrift Dam as a smaller Vioolsdrift will be able to provide sufficient yield for downstream users. This leads to Sc D2, using a smaller Vioolsdrift Dam, that was able to provide sufficient yield for the expected future demands downstream, similar to that of the large Vioolsdrift Dam for the option when no winter low flow were supplied at EWR O3 (Sc C2b).

When the summer and winter low flows are supplied at EWR O3, the deficit in the upstream yield from Gariep and Vanderkloof is just too much to overcome with a dam at Verbeeldingskraal. During the Orange Reconciliation Strategy Study, the Boskraai Dam was discarded due to various reasons and Verbeeldingskraal Dam, which unfortunately produces a much lower yield, was recommended. Environmental concerns related to Boskraai Dam contributed to this decision, but these environmental implications were not weighed against the environmental implications in the lower Orange River and Estuary. It is likely that the presence of a National Park, a Transfortier Park and a Ramsar Site (the estuary) could play an important role in the analysis.

The ecological consequences of the large dam based purely on proposed flow regimes that will be achieved at the EWR sites and estuary seems to be not that much worse than the small dam scenarios. It must be acknowledged though that some detailed studies on flood routing and sedimentation, migration, marine impacts etc. are still required to, with mitigatory flow releases, understand the consequences. In essence, an ecological cost-benefit and an economic cost-benefit analysis must be undertaken in conjunction and then to weigh the different possible combination of scenarios.

To make a decision on the small versus the large dam, a decision must be required on the two main EWR related options:

- 1. With releases for winter low flows at EWR O3 included.
- 2. Without releases for winter low flows at EWR O3.

For option 1 above, a smaller Vioolsdrift Dam can be used and the ecological benefit against high capital expenditure for Boskraai Dam must be evaluated or the impact of upstream irrigation reduction (400 million m^3/a reduction) must be investigated. If option 2 is considered, a larger Vioolsdrift Dam is used and the full impact on ecology for a larger dam (system in balance, no additional expenditure required for upstream resource development) should be evaluated. Or the smaller Vioolsdrift Dam can be used and the ecological benefit against capital expenditure for a raised Gariep Dam wall should be evaluated or the impact of irrigation reduction (approximately 200 million m^3/a reduction) should be investigated.

In conclusion and taking into account the implications on yield of supplying winter flows at EWR O3, the following is recommended: A scenarios without winterflows at EWR 3 with a small Vioolsdrift Dam and additional storage upstream should be investigated. Further optimisation of the flow scenarios to achieve the estuary improvement is also essential.

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ABBREVIATIONS

AOA	Annual Operating Analysis
BHN	Basic Human Needs
BAS	Best Attainable State
CD: WE	Chief Directorate: Water Ecosystems
CERM	Comprehensive Ecological Reserve Methodology
CBA	Cost-Benefit Analysis
DWA	Department of Water Affairs
DWAF	Department of Water and Forestry
DWS	Department of Water and Sanitation
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
DO	Dissolved Oxygen
EC	Ecological Category
EC	Ecological Category
EIS	Ecological Importance and Sensitivity
EWR	Ecological Water Requirements
EBSA	Ecologically or Biologically Significant Marine Areas
EFR	Environmental Flow Requirements
EHI	Estuary Health Index
EIS	Estuary Importance Score
FRAI	Fish Response Assessment Index
FROC	Frequency of Occurrence
GAI	Geomorphological Driver Assessment Index
GDP	Gross Domestic Product
ha	Hectare
HF	Hydraulic fracturing
IFR	Instream Flow Requirement
IWRM	Integrated Water Resource Management
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
MCB	Macro Channel Bank
MIRAI	Macroinvertebrate Response Assessment Index
MRU	Management Resource Unit
MAR	Mean Annual Runoff
MSL	Mean Sea Level
MOL	Minimum Operating Level
NPV	Net Present Value
ORP	Orange River Project
ORRS	Orange River Replanning Study
ORASECOM	Orange-Senqu River Commission
PAI	Physico-chemical Driver Assessment Index
PD	Present Day
PES	Present Ecological State
PSP	Professional Service Provider
REC	Recommended Ecological Category
RSA	Republic of South Africa
VEGRAI	Riparian Vegetation Response Assessment Index

Sc	Scenario
Sc	Scenario
TOR	Terms of Reference
UNDP-GEF	United Nations Development Programme-Global Environment Facility
WC/WDM	Water Conservation/Water Demand Management
WIM	Water Impact Model
WMA	Water Management Area
WRPM	Water Resource Planning Model
Velocity Depth Classes: Fish	
FD	Fast Deep fish habitat
FI	Fast Intermediate fish habitat
FS	Fast Shallow fish habitat
SS	Slow Shallow
SD	Slow Deep

1 INTRODUCTION

1.1 BACKGROUND

The Chief Directorate: Water Ecosystems (CD: WE) of the Department of Water and Sanitation (DWS) initiated a study for the provision of professional services to undertake the 'Determination of Ecological Water Requirements for Surface Water (Rivers, Estuaries and Wetlands) and Groundwater in the Lower Orange WMA'. Rivers for Africa was appointed as the Professional Service Provider (PSP) to undertake this study.

As per the Terms of Reference (TOR), there is a need to undertake detailed Ecological Water Requirement (EWR) and Basic Human Needs (BHN) studies for various water resource components due to mainly:

- Hydraulic fracturing (HF) that will be undertaken in the Water Management Area (WMA).
- Various water use licence applications.
- The conservation status of various Resources in this catchment; and
- The associated impacts of proposed developments will have on the availability of water.

1.2 STUDY AREA

As indicated in the TOR, the study area is the Lower Orange River WMA (the old WMA 14). It is the largest WMA in the country, and covers almost the entire Northern Cape Province. This core area forms part of the Orange-Senqu River Basin, which straddles four International Basin States with the Senqu River originating in the highlands of Lesotho, Botswana in the north-eastern part of the Basin, the Fish River in Namibia and the largest area situated in South Africa. The focus area of the study comprises only the South African portion of the Lower Orange River Catchment. The Eastern Boundary starts where the Vaal River Tributary enters the Orange River, and the Western Boundary is the Atlantic Ocean. The study area is downstream of the Upper Orange, Senqu and the Integrated Vaal River System and as such, is affected by the upstream activities in the highly developed river basin. The Orange River forms the border between the Republic of South Africa (RSA) and Namibia to the west of the 20 degrees longitude over a distance of approximately 550 km.

1.3 PURPOSE OF THIS REPORT

The purpose of this report is to document the consequences of the various operational scenarios in terms of its impact on the river, estuary, economics and the Ecosystem Services of the Orange River. An integration process to provide an overall recommendation is also provided.

1.4 OUTLINE OF THIS REPORT

The report outline is provided below.

Chapter 1: Introduction
This Chapter provides general background to the project, study area and purpose of the report.

Chapter 2: Scenario descriptions
This Chapter provides a summary of the different scenarios assessed.

Chapter 3: Approach and methodology

This Chapter outlines the general approach and methodology to determining ecological consequences of operational scenarios on the riverine environment, the estuary, ecosystem services and the economy.

Chapter 4: Ecological Consequences: Rivers
Detailed consequences of the operational scenarios on the various ecological riverine components at EWR O3 – O5 are provided.

Chapter 5: Ecological Consequences: Orange Estuary
The scenario evaluation process and the Orange Estuary response to the scenarios are provided.

Chapter 6: Ecosystem Services Consequences
The results of the different operational scenarios are presented in terms of the Ecological Goods and Services Attributes values that were assessed.

Chapter 7: Economic Consequences
The results of the different operational scenarios are presented in terms of the total discounted Gross Domestic Product and employment values as well as the Unit Reference Value values.

Chapter 8: Conclusions and Recommendations
The consequences of the operational scenarios are summarised and recommendations are provided.

Chapter 9: References

Chapter 10: Appendix A: Scenario water resources modelling
Detail regarding the water resource modelling is provided.

Chapter 11: Comments Register
Comments from the Client are provided.

2 SCENARIO DESCRIPTIONS

2.1 GENERAL

Although scenario (Sc) evaluation and comparison of alternatives will be dealt with comprehensively in the subsequent Classification of the water resources of the Lower Orange, a preliminary assessment of scenarios was undertaken in this study to estimate how proposed scenarios (changes in the operation of the system) could influence the ecological flows at key EWR sites along Orange River and its Estuary.

Scenarios, in context of water resource management and planning are plausible definitions (settings) of all the factors (variables) that influence the water balance and water quality in a catchment and the system as a whole. The scale (resolution) of the analysis requires the aggregation of land use effects and therefore individual and localised small scale developments will not significantly influence the study results.

The recommended intervention options described in the Orange Reconciliation Strategy study represent the most likely future water resource developments or scenarios that may change the flow regime along the Orange River. DWS is progressively implementing this strategy and is currently undertaking the Vioolsdrift Dam Feasibility study jointly with Namibia.

The proposed scenarios defined in this document aim to augment previous work and avoid duplication, while considering more recent information from other water resource planning activities in the Orange River. To this end, a recently completed study carried out for the Lesotho Highlands Development Authority, with report titled “Instream Flow Requirements for the Senqu River” (LHDA, 2016) was completed and made available only by the end of 2016. Results from this report indicate that both the hydrological time series and the recommended Ecological Water Requirements to be released from Polihali Dam (Phase 2 of the Lesotho Highlands Water Project) is different to those applied in the parallel Vioolsdrift Dam Feasibility study.

Due to the fact that the recalibrated hydrology has not been reviewed, nor accepted for use by ORASECOM, it was decided that the new recalibrated hydrology would not be used, however that the new EWR would be included along with the ORASECOM hydrology to drive it. This approach was also agreed to be used in the current parallel study for the LHWC titled “Determination of the operating rule for the operation of Phase II – LHWC contract no. 15”.

2.2 NATURAL HYDROLOGY

The natural flow forms the baseline against which all scenarios will be assessed and Figure 2.1 presents the summarised Mean Annual Runoff (MAR) for the indicated sub-catchments as well as the contributions from the Vaal and Upper Orange WMAs. The bulk of the natural flows (6 695 million m^3/a on average) is generated in the Upper Orange which includes the entire country of Lesotho where the Orange is known as the Senqu River. The second largest contribution is from the Vaal River catchment which contributes 4 024 million m^3/a on average under natural conditions.

The Ongers and Hartbees rivers are the two main RSA tributaries along the Lower Orange and contribute respectively 50 and 92 million m^3/a on average under natural conditions. Although runoff under natural conditions is generated in the Molopo River catchment, none of these flows reach the main Orange River, as they disappear in the Kalahari Desert.

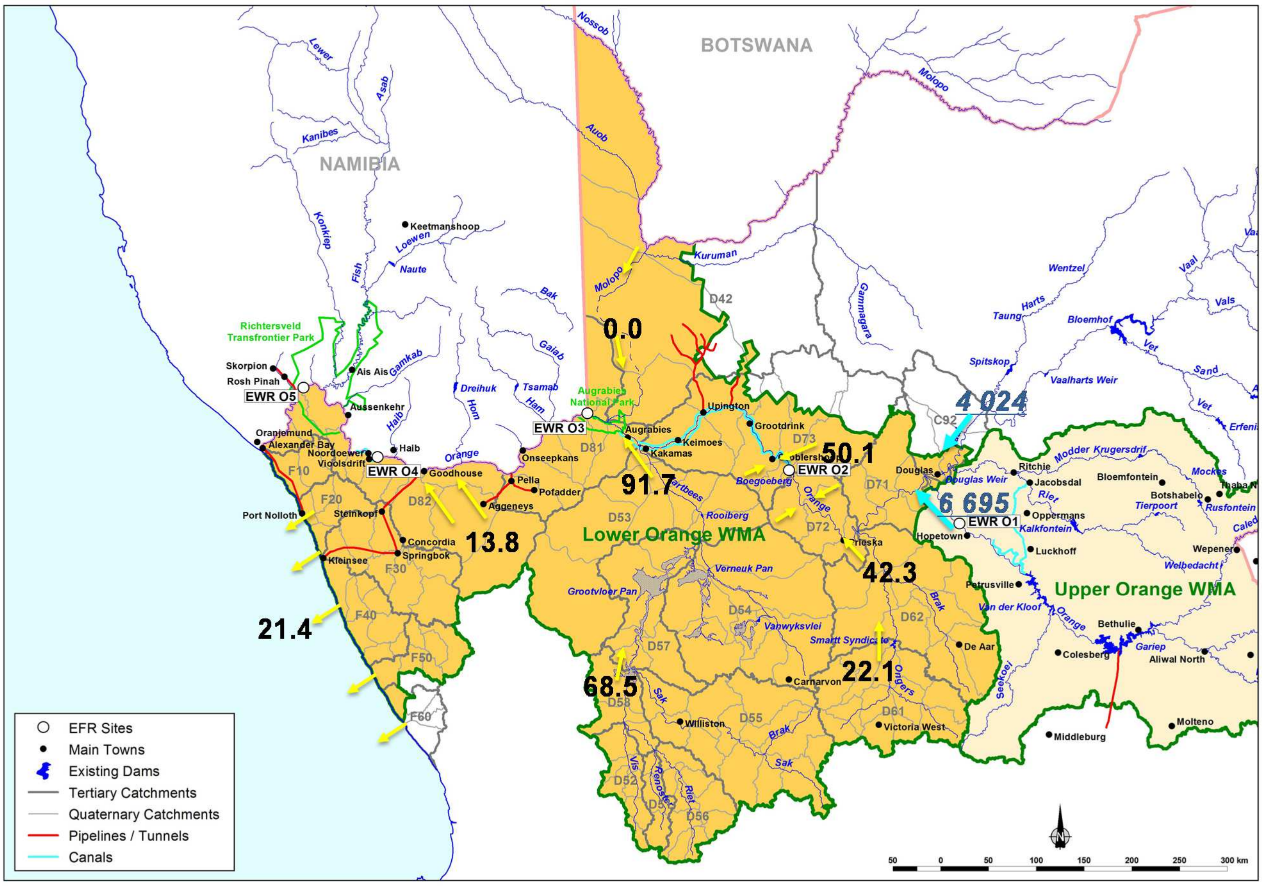

Figure 2.1 Natural flows generated from the Lower Orange within the RSA (flows in million m^3/a)

2.3 IDENTIFICATION OF OPERATIONAL SCENARIOS

A large number of water resource related studies for the Orange River Basin were carried out over time, with some only focussing on specific areas within the basin. The most recent of these completed studies is the Orange River Reconciliation Strategy Study (Development of Reconciliation Strategies for Large Bulk Water Supply Systems: Orange River) (DWA, 2014a). The purpose of this study was to develop a reconciliation strategy for the bulk water resources of the Orange River System, to ensure that sufficient water can be made available to supply the current and future water needs of all the users up to the year 2040.

The outcome of the Orange River Reconciliation Strategy Study included specific interventions with particular actions that will be required to balance the water needs with the availability of water through the implementation of regulations, demand management measures as well as infrastructure development options. One of the main tasks of the Orange River Reconciliation Strategy Study was to produce a Literature Review Report which lists and briefly describes past reports that were reviewed with the aim of capturing relevant information that can be used in the Orange River Reconciliation Strategy Study, as well as to prepare a list of augmentation schemes, management measures and planned bulk infrastructure options that were investigated in the past. All previous water resource related work done within the Orange River basin was thus taken into account and used where appropriate for the development of the Orange River Reconciliation Strategy Study.

The next major water resource development to take place within the Orange River Basin is Phase II of the Lesotho Highlands Water Project (LHWP). Phase II of the LHWP comprise of Polihali Dam located in the Lesotho Highlands. This dam will be connected to the existing Katse Dam by means of a tunnel and will increase the yield capability of the LHWP to be able to supply in the ever-growing water requirements within the Integrated Vaal System with Gauteng as the main water user. It is expected that Polihali Dam will start inundating water by around 2025. This will immediately cut off a significant portion of the runoff currently entering Gariep Dam that will in turn result in significant deficits in water supply from the Orange River Project (Gariep and Vanderkloof Dams and related supply area). The Orange River Reconciliation Strategy Study had to address this problem to ensure a positive water balance within the Orange River Project (ORP) at least until 2040.

Various measures and intervention options form part of the recommended Orange River Reconciliation Strategy. The following are the main intervention options and measures recommended from the Orange River Reconciliation Strategy:

- The existing EWR needs to be maintained and to avoid immediate large negative socio-economic implications additional releases towards an alternative EWR can only be implemented as soon as a new dam is commissioned. Further optimisation of the EWR in combination with the proposed augmentation options is recommended. That is to achieve an acceptable balance between protection of the ecology and use of water for socio-economic purposes.
- All water requirements can be balanced by availability through the implementation of the following measures:
  - Shared utilisation of LHWP Phase II between the Vaal River and Orange River systems is an essential measure to postpone large capital expenditure that would otherwise be required at the same time Polihali Dam becomes operational.
  - Plan and implement Water Conservation/Water Demand Management (WC/WDM) in the domestic and irrigation water use sectors.
  - Limit operational losses through real time monitoring of river flows in the Orange and Vaal rivers to maximise the beneficial use of the spillages from the Vaal River System.
  - Utilising a greater portion of Vanderkloof Dam's storage capacity by lowering the minimum operating level in the dam.
  - Commission Vioolsdrift Dam at the decided date for alternative EWR implementation. This dam is located on the lower Orange just upstream of Vioolsdrift and Noordoewer irrigation schemes.
  - Creating additional yield in the system by raising Gariep Dam by 10 m or by building the Verbeeldingskraal Dam located on the main Orange River upstream of Aliwal North.
  - Investigating further management measures, such as lowering the assurances of supply, eliminating unlawful water use and eradicating invasive alien plants in the Kraai River catchment.

The above mentioned development and intervention options and measures will result in significant changes in the flow patterns along the Orange River over time, and in particular downstream of Gariep and Vanderkloof dams. To be able to determine possible impacts of these developments and measures on the environment, specifically at the selected EWR sites along the Lower Orange, it is important to capture these developments and intervention options in the scenarios to be analysed as part of this study.

Currently the Vioolsdrift Feasibility Study as recommended by the Orange River Reconciliation Strategy Study is almost completed. More detailed information on the expected size of the proposed future Vioolsdrift Dam as well as the operating rules required for this dam, can be obtained from the Vioolsdrift Feasibility Study. Two types of possible dams are considered at Vioolsdrift:

- A smaller dam with the main purpose to re-regulate water released from Vanderkloof Dam to reduce the operational losses within the ORP.
- A larger dam that will increase the yield of the ORP system and at the same time also be used for re-regulation purposes to reduce the operational losses.

The above mentioned two studies therefore contain the information and recommendations on the most possible future developments within the Orange River that will impact on future flows in the Lower Orange main river. This information was used as the basis for the development and defining of the operational scenarios to be considered for the purpose of this study, as summarised in Table 2.1.

The EWR currently used on the Orange River was originally determined as part of the Orange River Development Project Replanning Study (ORRS), carried out in the middle 1990's based on an outdated environmental requirement methodology. These environmental flow requirements are currently still being released from Vanderkloof Dam and will be replaced once the Reserve was determined and sufficient yield capability created to be able to support the increased environmental requirements. **Scenario A** represents the present day system at 2016 development level.

Scenario A2 allowed for improvement to the ORRS environmental requirement in line with the latest REC defined for EWR O5. The purpose of this scenario is to improve the current EWR releases without impacting on the ORP yield (see Appendix A for more detail).

Scenario A3 is as Scenario A2 but using the current Namibian water allocations along the Lower Orange which is higher than the current actual water use by Namibia.

Scenario B serves as the base scenario for the 2035 development level when the expected major future water resource development options are in place, but with the ORRS EWR still being released from Vanderkloof and Vioolsdrift dams.

Scenario C1b is as Scenario B, but replaced the ORRS EWR with the "preferred" REC environmental flows as used in the Orange River Reconciliation Strategy Study, which was basically the Recommended EWR "without high flows" for the summer months only at EWR O3. This means that the winter months EWR in the model were set to zero, assuming that the flows released to supply the downstream users during the winter months will be sufficient for environmental purposes at EWR O3.

Scenario C2b is as Scenario C1b but using the Recommended EWR "without high flows" for all the months at EWR O3, thus winter and summer months.

Scenario D2 is as Scenario C2b but using a smaller dam at Vioolsdrift.

Scenarios D2i and D2ii are both as Scenario D2 but included slightly higher flows in the months of December and January. These higher flows were based on assessments done for the Estuary by environmental specialists based on the results obtained from Scenario D2.

Scenario D3 is as Scenario D2, but with some floods added to EWR O5 requirement.
Table 2.1 presents the scenario definition matrix indicating the identified variables as columns and the selected variable settings for the proposed scenarios in the respective rows. The matrix content primarily originates from the recommendation of the Orange River Reconciliation Strategy and also reflects the likely outcomes from the current Vioolsdrift Feasibility Study. For easy interpretation, the main change between a given Scenario and the previous Scenario was underlined and in italic format. Appropriate explanatory notes are provided in the notes following Table 2.1.

Several of the scenarios were developed as result of the findings and evaluation of results from other preceding scenarios. Details in this regard are given in Appendix A where the results from all the analyses are documented and discussed.

Table 2.1 Scenario Definition Matrix

Sc	Scenario Variables									Comment
	Development Horizon (year)	Limit operational losses	Adjust Vanderkloof Dam's storage capacity	Polihali Dam	Vioolsdrift/ Noordoewer Dam	Verbeel-dingskraal Dam	Ecological Water Requirements			
							EWRO3: Augrabies	EWRO5: Sendelingsdrift	Estuary	
	(a)	(b)	(c)	(d)	(e)	(f)	(i)	(j)	(h)	
A	2016(*)	N	N	N	N	N	-	-	Current (ORRS)	
A2	2016(*)	N	N	N	N	N	Monitor	*ORRS/REC 5 scaled*[1]	Monitor	REC at EWR O5 scaled according to ORRS.
A3	2016(*)	N	N	N	N	N	Monitor	*ORRS/REC 5 scaled*[1]	Monitor	Sc A2 *with current Namibian allocations resulting in an increase of 92.5 million m^3/a (A2 was with current Namibian use).*
B	**2035**	Y	Y	Y	Y	Y	-	-	*Current (ORRS)*	*With Namibia 2035*[2] *demand.*
C1b	2035	Y	Y	Y	Y	Y	*REC (summer low flows only, no winter flows)*	*REC (excl. high flows)*	Monitor	With Namibia 2035[2] demand (ORP System yield reduced by 425 million m^3/a in comparison with Sc B).
C2b	2035	Y	Y	Y	Y	Y	*REC (excl. high flows)*	REC (excl. high flows)	Monitor	With Namibia 2035[2] demand (ORP System yield reduced by 825 million m^3/a in comparison with Sc B).
D2	2035	Y	Y	Y	*Y (smaller)*	Y	REC (excl. high flows)	REC (excl. high flows)	Monitor	With Namibia 2035[2] demand.
D2i	2035	Y	Y	Y	Y (smaller)	Y	REC (excl. high flows)	REC (excl. high flows) *Increase December EWR*	Monitor *and Improve*	With Namibia 2035[2] demand.
D2ii	2035	Y	Y	Y	Y (smaller)	Y	REC (excl. high flows)	REC (excl. high flows) *Increase December and January EWR*	Monitor *and Improve*	With Namibia 2035[2] demand.
D3	2035	Y	Y	Y	Y (smaller)	Y	REC (excl. high flows)	*REC (excl. high flows with Class I flood (60m^3/s) releases)*	Monitor	With Namibia 2035[2] demand.

1 - REC at EWR O5, scaled according to ORRS EWR volume, with yield impact similar to ORRS EWR.
2- Namibia 2035 demand based on data from the Vioolsdrift Feasibility Study.
(*)Present Day scenario based on the 2016 Annual Operating Analysis (AOA) configuration. The systems model configuration that was received from the Vioolsdrift feasibility study was used to incorporate changes in the 2016 AOA configuration.
(a) Development level or development horizon defines the water requirement and return flows to be imposed on the system. (Note that the scenario simulations was carried out at the indicated constant development level.) Revised water requirement information for the Lower Orange WMA was provided by the current Vioolsdrift Feasibility Study.
(b) Application of real time monitoring and operations to reduce the operating losses by an estimated 80 million m^3/a.
(c) Vanderkloof Dam to be operated at a lower Minimum Operating Level (MOL) with an increase in live storage and estimated system yield increase of approximately 137 million m^3/a.
(d) Polihali Dam with conveyance infrastructure to augment the Vaal River System (LHWP Phase II). The latest EWR releases from Polihali Dam as confirmed by LHDA and DWS representatives were used (same as used in the current LHWP Operating rule study).

(e) The function of the dam at Vioolsdrift is either to only regulate the river flow (small dam size) or to also increase the system yield by constructing a large storage dam. The water loss that can be saved if Vioolsdrift is used as a regulating dam is 120 million m^3/a. The current Vioolsdrift feasibility study indicated a 73.5 m high yield dam or alternatively a 35 m high re-regulation dam. Scenario D2 and D3 used a relative small Vioolsdrift Dam with a storage of 470 million m^3.
(f) Options (f) Verbeeldingskraal Dam and option (g) raising of Gariep Dam are alternatives and the selection of the appropriate option and dam size for these analyses is dependent on the findings (optimisation) of the current Vioolsdrift Feasibility Study. The Vioolsdrift Feasibility Study recommended the use of Verbeeldingskraal Dam. The (g) (g) - raising of Gariep Dam was thus excluded from the scenario analysis.
(i) EWRs for the river supported by releases from the existing and proposed dams upstream of Vioolsdrift in the Orange River System. “Low flows only” means low flows for winter and summer months.
(j) EWRs for the river supported primarily from the future Vioolsdrift Dam, with support from the existing and proposed dams upstream of Vioolsdrift in the Orange River System. “Low flows only” means low flows for winter and summer months.

3 APPROACH AND METHODOLOGY

3.1 DETERMINING RIVERINE ECOLOGICAL CONSEQUENCES

3.1.1 Available data

Twelve detailed EWR studies (also previously called IFR and EFR) as well as several smaller, desktop studies were undertaken over a period of approximately 16 years for different parts of the Orange-Senqu Basin (ORASECOM, 2014a;b). ORASECOM studies mostly refer to the term Environmental Flow Requirements (EFR) rather than EWR. Previous EFR studies that only focused on the Lower Orange WMA included the following ORASECOM studies and were used in this study as baseline information:

- GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) Integrated Water Resource Management (IWRM) Phase 2*:* EFR study focussing on the Orange River (Vaal River excluded) by Louw and Koekemoer (eds.) (2010) (referred to in this report as the 2010 EFR study*).*
- UNDP-GEF (United Nations Development Programme-Global Environment Facility) EFR Study*:* Covering the Fish River in Namibia, Orange River downstream of the Fish River confluence and the Orange-Senqu River Mouth by Louw *et al.* (2013) (referred to as the 2013 EFR study*).*
- GIZ IWRM Phase 3*:* Consolidation of Environmental Flow Requirements Report focussing on the Orange-Senqu Basin, by Rivers for Africa (ORASECOM, 2014a).

Both the 2010 and 2013 studies were assessed using the Comprehensive Ecological Reserve Methodology (CERM) (DWAF, 1999) and the only difference between the two studies was the study area.

The ORASECOM (2014a) study consolidated the findings, especially from UNDP-GEF and Integrated Water Resource Management (IWRM) Phase 2 work, and included the testing of different flow scenarios based on existing and possible future infrastructure and demands at a desktop level. During the 2013 EFR study and the recent Vioolsdrift study (PWC, 2016), further scenario analysis was undertaken. The focus on these operational scenarios evaluated in this Reserve study build on to the previous evaluations where relevant and incorporates all recent data and information.

3.1.2 EWR sites affected by operational scenarios

The impact of operational scenarios in a river system is assessed at EWR sites located within the river system. Based on the previous studies outlined in Section 3.1, three EWR sites, located in the Orange River, were identified which could possibly be impacted by the operational scenarios and that could be managed. Various other scenarios were modelled that impacted on the Orange River Mouth and the consequences will be discussed in detail in Chapter 5 of this report. Details of the EWR sites are provided in Table 3.1 and discussed in detail in Louw and Koekemoer (eds.) (2010) and Louw *et al.* (2013). The location of the EWR sites within the study area is provided in Figure 2.1.

Table 3.1 EWR sites where operational scenarios will be evaluated

EWR site name	River	MRU[1]	EcoRegion	Longitude	Geomorphic zone	Latitude	Longitude
EFR O3	Orange	MRU Orange E	28.01	19.9983	Lowland	-28.4287	19.9983
EFR O4	Orange	MRU Orange F	28.01	17.71696	Lowland	-28.7553	17.71696
EFR O5	Orange	MRU Orange G	28.01	16.9604	Lower Foothills	-28.0726	16.9604

1 Management Resource Unit

3.2 DETERMINING RIVERINE ECOLOGICAL CONSEQUENCES

The suite of EcoStatus models used during this task was:

- Physico-chemical Driver Assessment Index (PAI): Kleynhans *et al*. (2005); DWAF (2008a).
- Fish Response Assessment Index (FRAI): Kleynhans (2007).
- Macro Invertebrate Response Assessment Index (MIRAI): Thirion (2007).
- Riparian Vegetation Response Assessment Index (VEGRAI): Kleynhans *et al*. (2007).

The process to determine ecological consequences of scenarios is shown in the following chronological steps:

- The operational scenarios were modelled and a hydrological time series was provided for each scenario at each EWR site.
- The time series for the scenarios were converted to flow duration tables and exceedance graphs and provided to the specialists, through the use of a Scenario Comparison Evaluation Tool. This tool was developed to evaluate a series of scenarios for the use of the ecological river team by Mr Pieter van Rooyen and Dr Andrew Birkhead. Time series data can be evaluated at a particular EWR site for a particular month (e.g. the dry season month, May – Figure 3.1), or at a percentage exceedance for all the months in the flow record (e.g. the 95% drought exceedance flow – Figure 3.2).
- The driver components, i.e. physico-chemical (or water quality), provided a first assessment of consequences, which were provided to the rest of the team. The consequences and resulting Ecological Category (EC) of each operational scenario for physico-chemical variables were assessed at each EWR site and the PAI was populated to determine the result EC.
- The riparian vegetation specialist then assessed the response on the marginal and other riparian zones and supplied this information to the instream biota specialists (i.e. fish and macro-invertebrates) as well. This was done prior to the instream biota assessment as riparian vegetation is a driver in terms of important habitat for the instream biota.
- The riparian vegetation specialist ran the VEGRAI model to predict the EC for the operational scenarios.

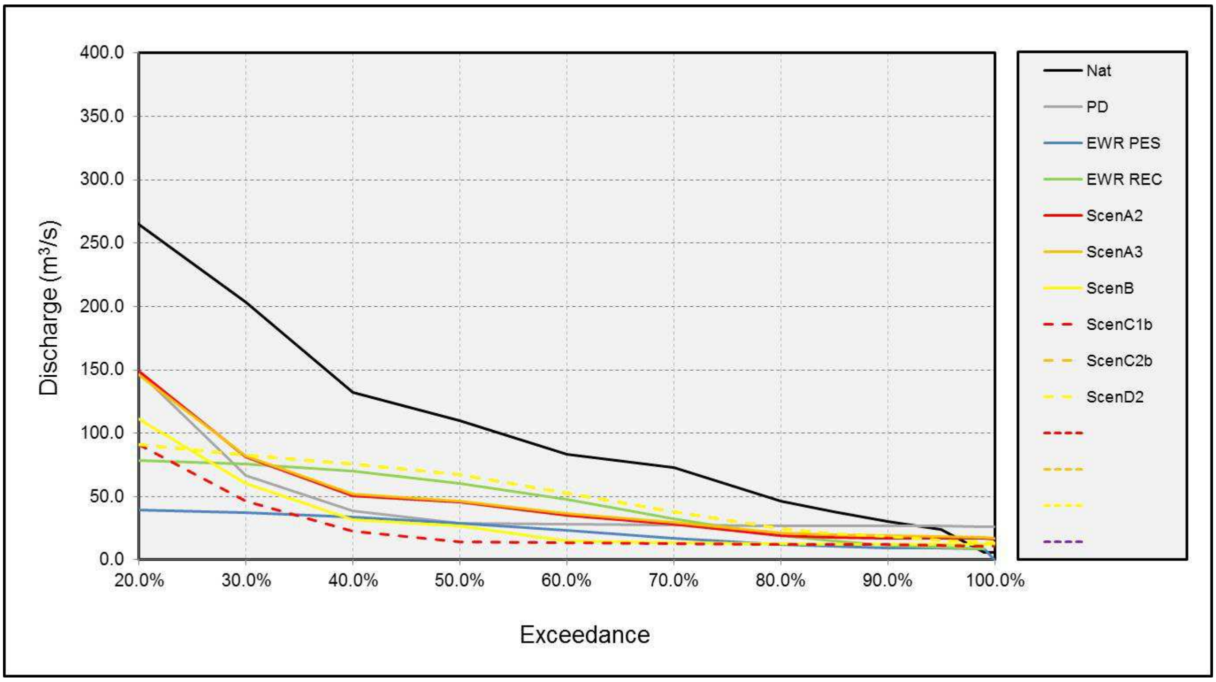

Figure 3.1 Use of the Scenario Comparison Evaluation Tool to assess changes under operational scenarios at EWR O4 for May

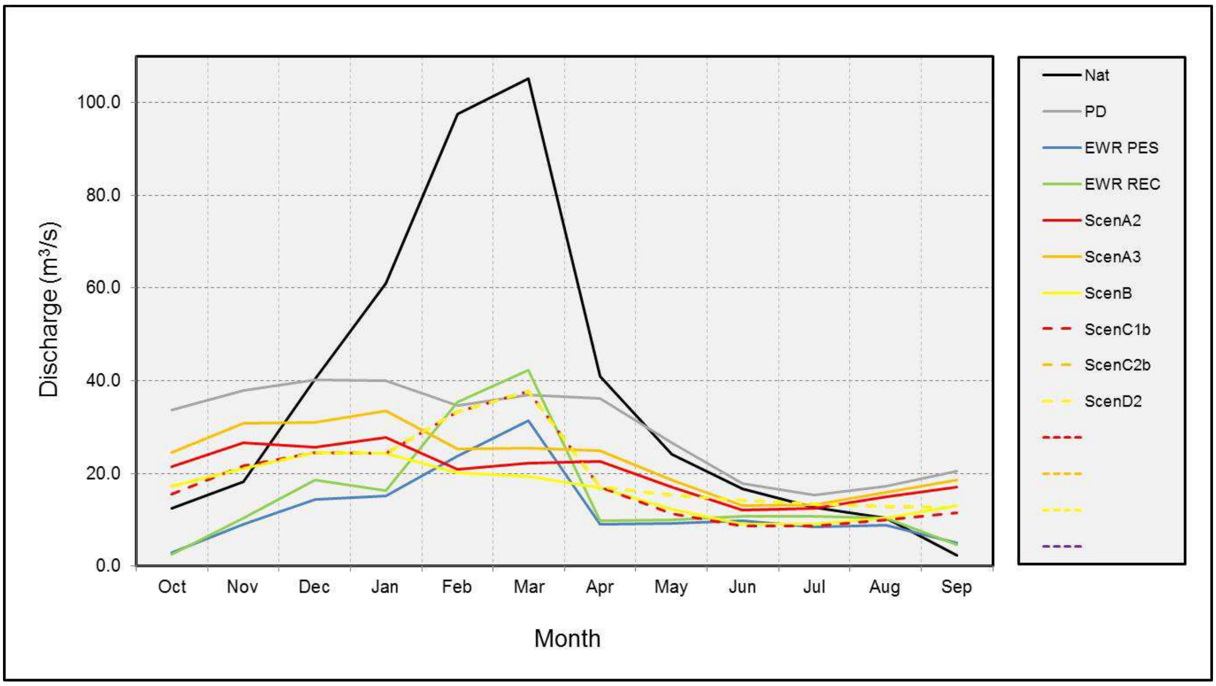

Figure 3.2 Use of the Scenario Comparison Evaluation Tool to assess changes under operational scenarios at EWR O4 during the drought period (95% exceedance)

This information formed the basis for the instream assessment to determine the responses to these driver changes for each scenario:

- The operational scenarios were compared to the EWRs set for various ECs. For example, if the operational scenario lies between the B EC and C EC for fish for a flow in the dry season, the operational scenario could either be a B, a B/C or a C.
- The information on the driver responses were also used to interpret the response to the operational scenarios.
- The responses were modelled in the FRAI and MIRAI to determine the EC.

- The VEGRAI, MIRAI and FRAI results (EC percentages and confidence evaluation) was used to determine the EcoStatus per scenario and compared to the Present Ecological State (PES) and Recommended Ecological Category (REC) set during the 2010 and 2013 studies.

The component-specific approaches to determine ecological consequences are provided below.

3.2.1 Water Quality

The water quality approach is heavily reliant on the results of EcoClassification done during previous studies. The PAI model, water quality tables and associated text describes the driving variables for the assigned water quality state. The PES flow exceedance curves therefore represent the flow conditions linked to the present state PAI table, and the values assigned to the metrics used in the PAI model. The metrics include salts, nutrients, pH, Dissolved Oxygen (DO), turbidity, temperature and toxics. Toxics and nutrients are therefore an integrated measure, with salts generally represented by Electrical Conductivity. The Scenario Comparison Evaluation Tool is used to evaluate changes to the flow regime under all months and exceedance percentages, and linked to expected changes in water quality driving variables. The PAI model is rerun for each set of scenarios to arrive at an integrated water quality category per scenario or set of scenarios.

3.2.2 Fish

The estimated change from PES in the fish assemblage under each scenario was assessed based on the expected change in various aspects of importance (drivers/stressors), i.e. flow, habitat, water quality:

- ***Flow***: The change in fast (fast-shallow (FS), fast-intermediate (FI) and fast-deep (FD)) and slow (slow-shallow (SS) and slow-deep (SD)) habitats were considered for the maintenance and drought flows during both wet and dry seasons (MS Excel based). This change was considered for each species using its specific “preference rating for different velocity-depth categories”.
- ***Substrate***: Geomorphological change (based on the especially changes in flood regimes) was used to determine the estimated percentage change in substrate quality and availability for fish. This change was considered for each species using its specific “preference rating for substrate as cover”.
- ***Vegetation***: The change in the marginal vegetation was estimated based on the marginal zone section of the VEGRAI and vegetation specialist input. The marginal zone change was applied to the relevant species based on their “preference rating for overhanging vegetation as cover”.
- ***Water quality***: The change in water quality under each scenario was based on input from the PAI and water quality specialist and the expected change in water quality was applied for each species based on their “requirement for unmodified water quality intolerance rating”.
- ***Seasonality/Seasonal variability***: The change in seasonality and seasonal variability was assessed using the hydrological comparing facility.

The expected change of these aspects/metrics (or sub-components of these metrics) was rated as follows:

- 5: Extreme/critical increase/improvement (>80%).
- 4: Serious increase/improvement (60 - 80%).
- 3: Large increase/improvement (40 - 60%).
- 2: Moderate increase/improvement (20 - 40%).
- 1: Slight increase/improvement (<20%).
- 0: No change.
- -1: Slight decrease/deterioration (0 - 20%).

- -2: Moderate decrease/deterioration (20 - 40%).
- -3: Large decrease/deterioration (40 - 60%).
- -4: Serious decrease/deterioration (60 - 80%).
- -5: Extreme/critical decrease/deterioration (>80%).

The overall change in these variables (metrics) were then used to change the present Frequency of Occurrence (FROC) (Kleynhans and Louw, 2007) ratings of each fish species in the FRAI (only considering the variable relevant to the specific species (e.g. eels would for instance be more impacted by migratory impacts than potadromous species, a rheophilic species would be more intolerant to alterations in fast habitats than a limnophilic species, etc.).

The overall change, considering all these aspects, were then reflected by the change in FRAI score (%). This approach ensured that the change under each scenario will be relative to the actual change in the various drivers/stressors for the fish, and also considering the specific requirements and intolerance of each fish species to different aspects in its environment.

The current scenario assessment for fish primarily focussed on the response of the fish assemblage to different flow scenarios and its associated secondary responses. The impacts directly associated with the construction and operation of the dams, mentioned in the flow scenarios, was not considered. Special reference must be made to the migration barrier effect of any dam in a system. It was established (from previous similar studies) that when the migration impact of the dams were also considered in the scenarios it masked the actual potential improvement of certain flow scenarios. The migration barrier impact of the dams may certainly result in changes in the ecological status of the fish under the different scenarios. The impact of the migration barrier should however be assessed in detail during the environmental impact assessment phase of any proposed dam since various other factors need to be considered that falls outside the current scope of work (such as species specific migratory requirements and abilities, reason for migration, presence of viable habitats upstream of barrier, etc.). It is also advisable that existing migration barriers in the system should be further investigated to determine their potential migration barrier effect. Migration barrier specific specialist studies should ideally follow the proposed methodology as stated in Bok *et. al.* (2007):

- Determining the need for providing a fishway at the said barrier (necessity protocol): Assess the ecological need for a fishway and the feasibility of providing a successful and cost- effective fishway.
- Determining the priority of fishway provision (priority protocol): Quantify the ecological impact of the barrier on migratory species present – i.e. importance of providing a fishway at the barrier.
- Provide biological consideration for the design of fishways at the barrier.
- Detailed investigation into the best design for the fishway based on all applicable considerations and the design of the fishway
- Overseeing and auditing during construction as well as a design and implementation of a fishway monitoring programme.

3.2.3 Macroinvertebrates

The approach to assess macro-invertebrates was similar to the approach used for fish. The same sources of information as described above were used to assess the proportion of change from present under each scenario for aspects relating to flow modification, habitat, water quality, connectivity and seasonality. Average velocity and maximum velocity were additionally considered for the invertebrate assessment. Flow modification, connectivity and seasonality change were based on a detailed assessment of the change in flow. Habitat changes were based on the geomorphological and riparian (marginal zone) vegetation input from the GAI and VEGRAI models and relevant specialist input. Water quality change was based on the PAI and water quality specialist input. The changes were then used to alter the relevant metrics in the MIRAI to calculate the altered MIRAI score and category expected under each scenario.

3.2.4 Riparian vegetation

The following steps comprise the process employed to assess the ecological consequences of various scenario flow regimes for riparian vegetation:

- An overall qualitative description of differences between the applicable scenario and natural, present day and EWR flows is provided utilising log charts of monthly flow at the following percentiles: 1%, 5%, 10%, 50%, 90% and 99%. Differences in quantity of water (overall, high flows and low flows) are noted as well as changes to the seasonal distribution of flows. General statements regarding the response of riparian vegetation are then made based on these qualitative overviews (see Figure 3.3 as an example).
- Seasonality is critical for biological cues, even vegetation. A check of seasonality is conducted by expressing the monthly flow regime as a fraction of the natural annual flow (see Dettinger & Diaz, 2000). Should a significant change to seasonality apply to any of the scenarios, then a response by riparian vegetation is predicted and used to make changes to the scores within VEGRAI (Kleynhans *et al.*, 2007) for the applicable site (see Figure 3.4 as an example).

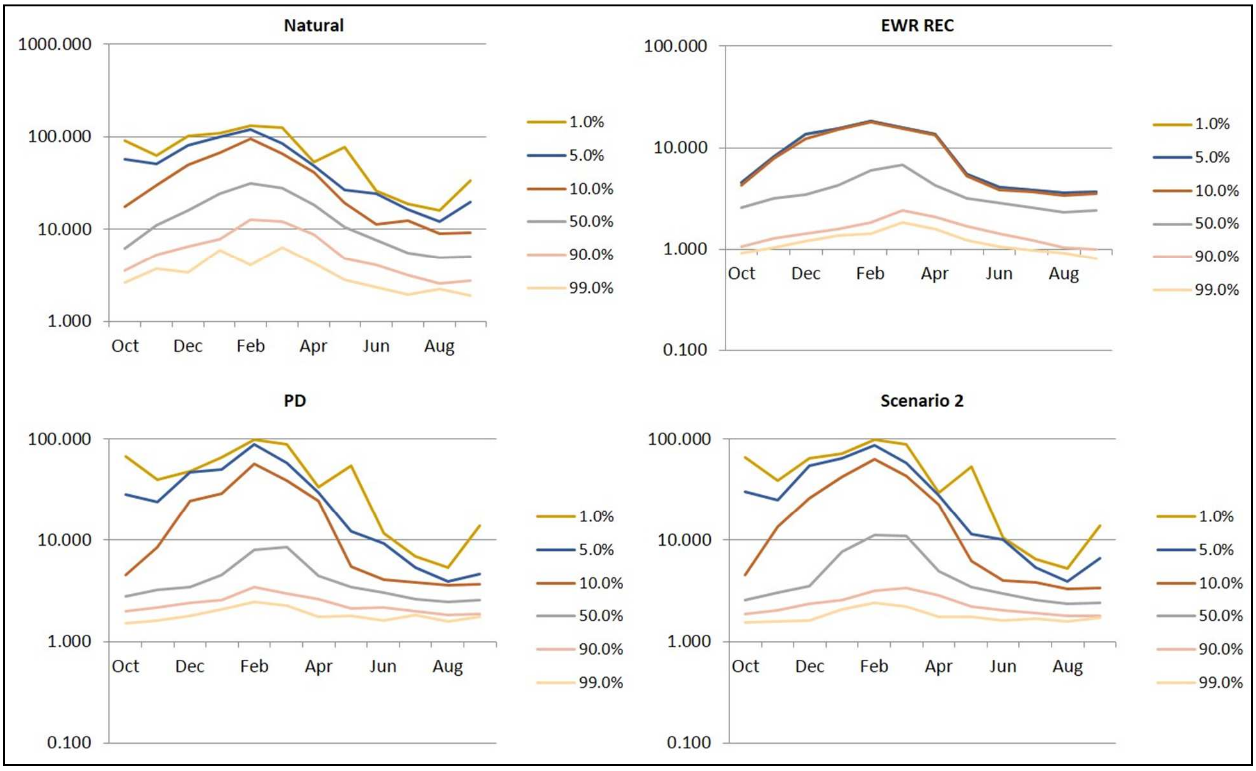

Figure 3.3 An example of the comparison of average monthly hydrological data (log plots)

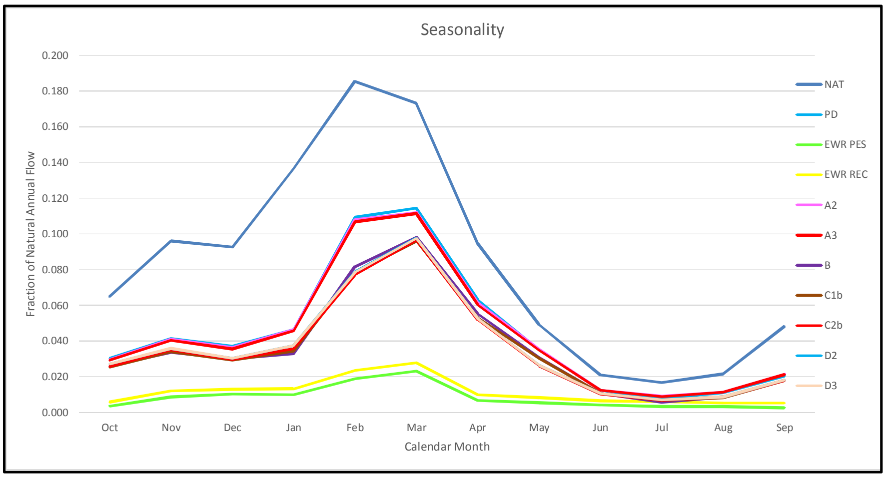

Figure 3.4 An example of seasonality check

- A month-by-month comparison of the exceedance curves of the applicable scenario to natural, Present Day (PD) and EWR flows is conducted. General statements are made concerning the probable response of riparian vegetation (usually indicator or guild specific) taking specific cognisance of seasonal and phenological requirements of vegetation. The example below shows a comparison between February and July (Figure 3.5). Response appropriate changes are made to scores within the VEGRAI in order to score the scenario's effect on the EcoStatus.

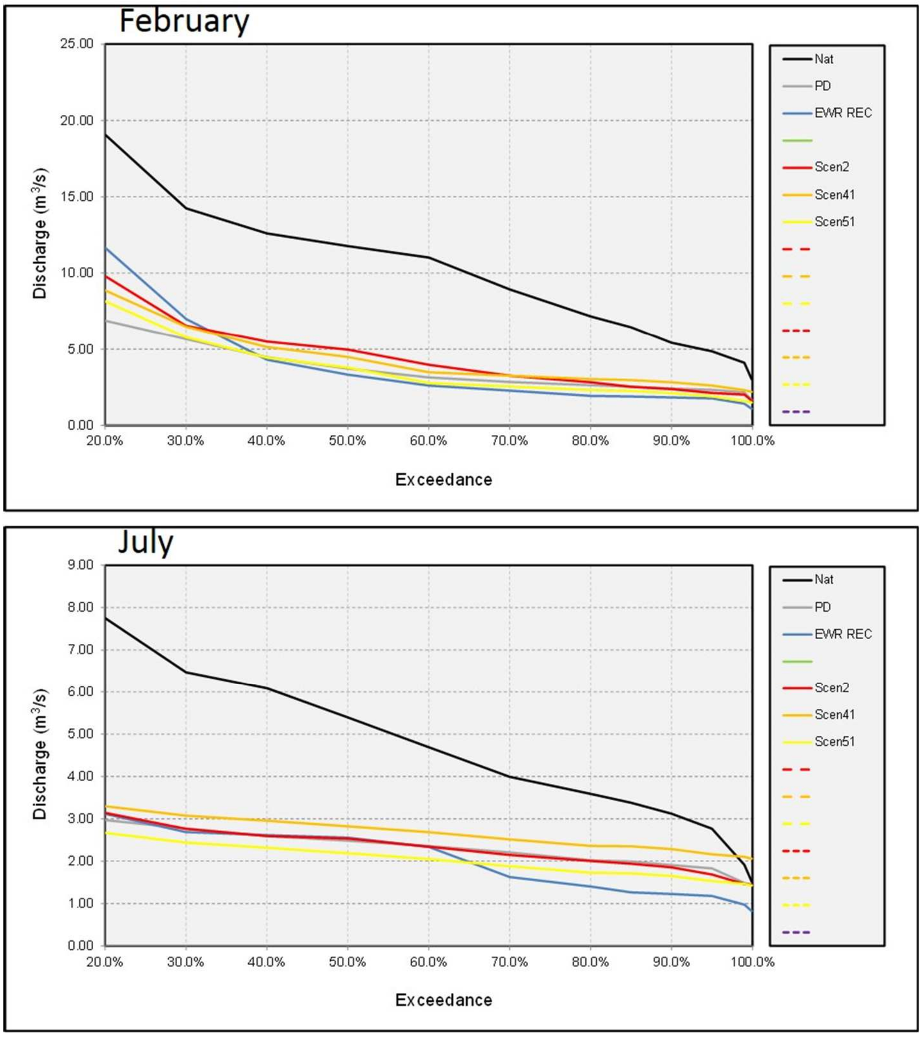

Figure 3.5 An example of the comparison of discharge exceedance patterns for wet (represented by February) and dry (Represented by July) season

- A similar comparison is conducted at select percentiles (1%, 5%, 10%, 20%, 40%, 50%, 60%, 80%, 90% and 95%) to assess changes of seasonality i.e. compare temporal distribution over an average hydrological year (Figure 3.6 as an example).

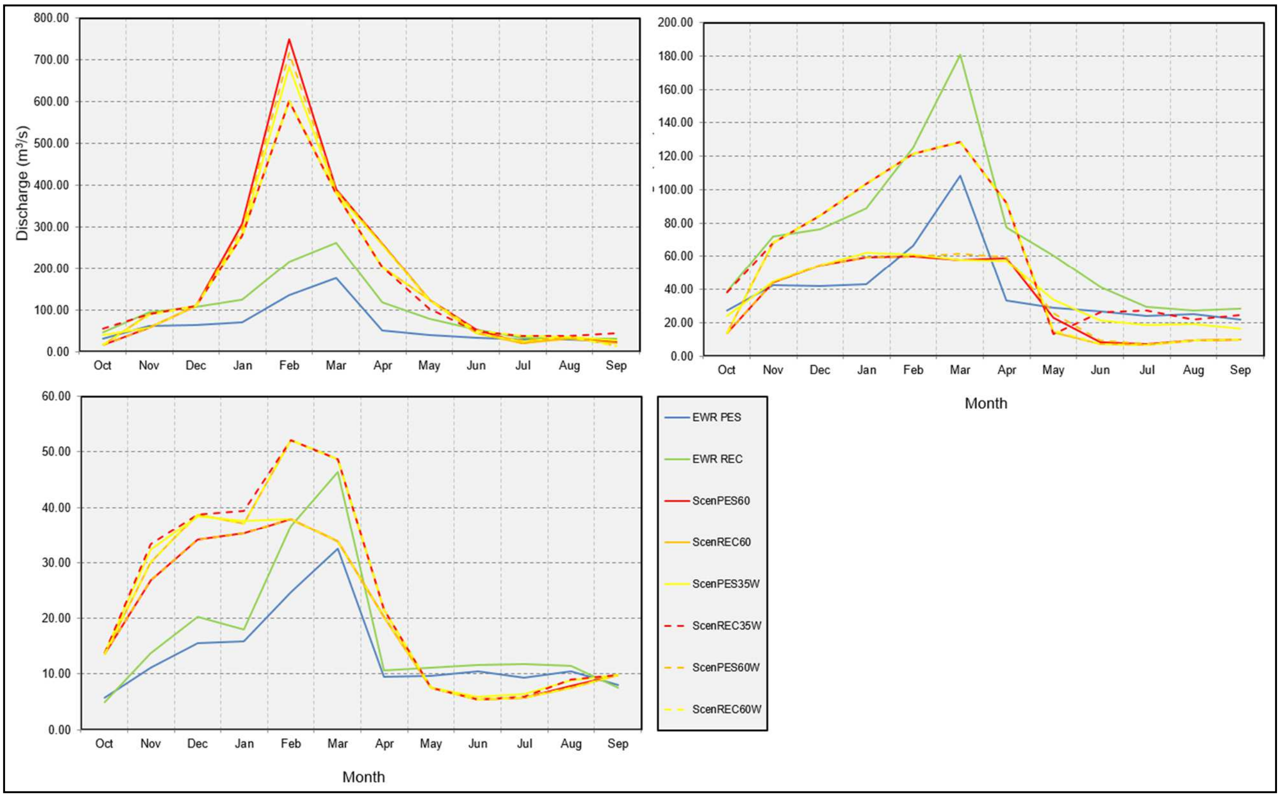

Figure 3.6 Average yearly temporal distribution of discharge at the 20 (top left), 50 (top right) and 90 (bottom) percentiles

- Stream permanency has been shown to be important for the persistence of riparian vegetation in perennial rivers (Lite and Stromberg, 2007; modified, Leenhouts *et al*., 2006). Once stream permanency declines below 10%, population density declines and once stream permanency declines below 20% many species likely disappear or are replaced by other hardy drought tolerant or terrestrial species. Each scenario is assessed for stream permanency (expressed as the % of an average year where flow does not cease) and compared to values for natural, PD and EWR flows. Scenarios are also checked against natural flows to ascertain whether flow ever exceeds natural. Such an increase in inundation may also elicit a vegetation response such as zone shrinkage and changes to species composition.
- The flooding range for each riparian indicator (species or guild) is then used for a site-specific comparison of the scenario in order to determine to what extent the inundation or activation of each indicator changes and whether indicator drought tolerance is exceeded. This comparison is usually done for both the wet and dry season (using two or three representative months for each), and at percentiles representative of base flows (50% for the Orange River). Knowledge of indicator specific drought tolerance, maximum rooting depths and inundation requirements is used to assess whether changes will result in a response from the indicator. Likely responses of all indicators are then considered within respective sub-zones (such as marginal and lower zones) and (additional) changes made within the VEGRAI (Kleynhans *et al*., 2007) to translate a vegetative response into a change in ecological state or category (Ecological Category - EC). The example below shows a comparison of the proportion of inundation of reeds at the 50th percentile for wet and dry seasons at a site on the Orange River (Table 3.2). The example data shown in Table 3.2 are also provided to the fish specialist using all marginal zone vegetation indicators.

Table 3.2 Example of assessment showing the proportion (%) of the reed population inundated in the wet and dry season for different flow regimes of operational scenarios

Indicator	Month	Natural	PD	Proportion of each population (%) inundated at the 50% for different scenarios							
				EWR PES	EWR REC	PES60	REC60	A2	A3	B	C1b
Phragmites australis	**Wet season**										
	Jan	57.58	13.64	15.15	21.21	18.18	24.24	18.18	24.24	18.18	24.24
	Feb	66.67	15.15	18.18	27.27	18.18	25.76	18.18	25.76	18.18	25.76
	Mar	66.67	25.76	24.24	33.33	16.67	27.27	16.67	27.27	18.18	27.27
	Dry season										
	Jul	15.15	9.09	12.12	12.12	9.09	9.09	10.61	12.12	9.09	9.09
	Aug	13.64	10.61	12.12	12.12	9.09	9.09	10.61	12.12	9.09	9.09
	Sep	15.15	10.61	12.12	12.12	9.09	9.09	10.61	12.12	9.09	9.09

- The final check is to determine whether flood requirements that were specified for the EWR are met and if not, to what extent this is likely to affect riparian vegetation. Where applicable and available, data from a spill analysis are also assessed. The occurrence of flood events (as defined by the EWR) as well as timing and duration, are assessed over the given hydrological period. Any inferred responses by riparian vegetation are additionally captured in VEGRAI for a final assessment of ecological response, and a score produced for each scenario.

3.3 DETERMINING THE RANKING OF SCENARIOS

Deriving a single metric (one number), that reflects the ecological health relative to the REC for the river, requires several steps, sub-steps and the application of various tools. Broadly, the rationale to achieve this single rating is based on the following.

- Scenarios at each EWR site are ranked on the basis of the degree to which the scenarios meet the REC.
- Comparing the impact of the scenarios at the different EWR sites to determine a ranking from a system context depends both on the degree to which the scenario meets the REC, as well as the relative ecological importance of the sites.

To further explain this, if a scenario is ranked highest at a site of low importance, but lower at a site of high importance, this scenario will not carry the same weight as the scenario that scored the highest at the sites of high importance.

The steps and sub-steps to derive a single number are discussed below.

3.3.1 Step 1: Rank scenarios at each EWR site

- Apply the EcoClassification (Kleynhans and Louw, 2007) process at each EWR site where the scenario influences the flow or water quality to determine the EC for each component[1].

[1] Component: Habitat drivers (geomorphology and water quality (hydrology is a given)); Biological responses (fish, macroinvertebrates, riparian vegetation).

- Provide the associated percentage that represents the category.
- Calculate the degree to which the scenario meets the ecological objectives which is represented by the REC. I.e., if the REC for a component is 62% and the scenario results in this component being at 62%, then the resulting score would be a 1 (or a 100% successful in meeting the REC). If a scenario's rating for the component is 48%, then the score would be 0.77 (or 77% successful in meeting the REC).
- Average the score at each component to obtain a score for the scenario at the site.
- Each site's score is then normalised to obtain a rating that is 1 if the REC is achieved, above one if the REC is exceeded (i.e. 1.1) or between 1 and zero if the score (EC) is below the REC.
- Rank the scenarios in terms of a numerical scale with values 0 and 1 (typically, where one (1) indicates the scenario that achieves the REC and a zero (0) representing the situation where the scenario results in a F Category).

3.3.2 Step 2: Determine the relative importance of EWR sites to each other

The following aspects are considered when determining the relative importance of the EWR sites to each other:

- PES: The higher the PES the more important the EWR site. The PES percentage is used in this calculation.
- Ecological Importance and Sensitivity (EIS): The higher the EIS rating, the more important the EWR site. The EIS score is used in this calculation.
- Conservation importance: The locality of the site within a declared conservation area is highlighted. A site within a Transfrontier Park or a Wilderness Area or representing these will be more important than a National Park which in turn will be more important than a provincial Nature Reserve.

The above metrics are averaged. The following is then also rated:

- Length of the river reach represented by the respective EWR sites, i.e. the longer the reach the higher the importance of the scenario impacts.
- Relative position of the EWR sites in the system and how they affect the simulated operation. The ranking of the sites is dependent on the key sites in the modelling context which dictates the driver EWR site in terms of the 'releases' in the model. These key sites are sometimes the most downstream site (as is the case in this study), or could be site which has a higher REC (or PES) than other sites and therefore a higher flow requirement.

The above values are then averaged again including the averaging of the initial metrics. The score is then normalised out of 1.

3.3.3 Step 3: Rank the scenarios in a system context

All the scores from the EWR sites are then combined into a single score by accounting for the above site importance ranking. This is achieved by assigning different weights (factors) to each site to reflect the importance relative to the others. The individual ranking and consequences at each EWR site have therefore been integrated into one ranking and consequences applicable to the specific river system.

All rankings are illustrated by means of traffic diagrams. A traffic diagram is a bar graph that is shaded according to the colours of a traffic light. This implies that the items at the top (in the green section) are better than the ones below. The scale of the bar graph is not relevant as it is the ranking and relative difference between the scenarios that provides the information. Therefor the major advantage of showing all consequences on a traffic diagram is that one can visually assess the rankings for all the different components using different scales of measurements.

3.4 DETERMINING ESTUARINE ECOLOGICAL CONSEQUENCES

3.4.1 Estimating ecological condition

The health condition (also called the PES) of an estuary is typically defined on the basis of current condition (i.e., the extent to which it differs from its reference or natural condition). Based on the above, estuary condition is described using six ECs, ranging from natural (A) to critically modified (F). The Estuarine Health Index was calculated through consideration of the components listed in 7 (DWAF, 2008b).

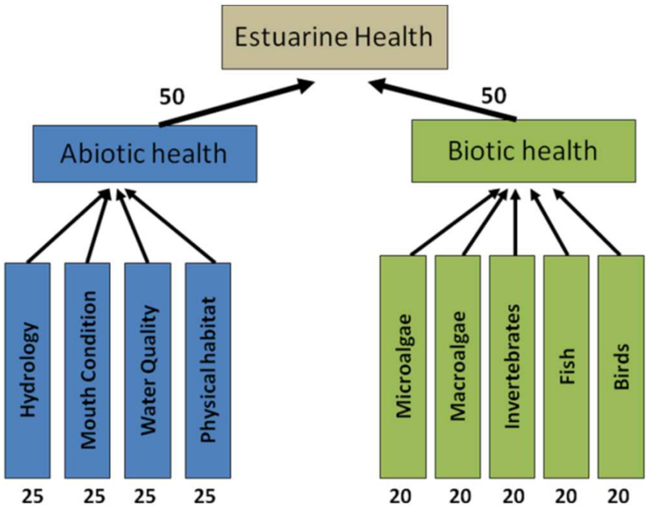

Figure 3.7 Components and weightings of the Estuarine Health Index (DWAF, 2008b)

The assessment was undertaken by a multidisciplinary group of estuarine scientists in a workshop setting, based on their collective understanding of the likely impacts affecting each system. Expert knowledge and available information were used to build a "picture" of the probable pristine state of each estuary and the changes under current conditions. The Estuarine Health Index is applied to all levels of ecological water requirement studies (comprehensive, intermediate or rapid), with only the level of information supporting the study and level of confidence varying. For each variable, the conditions are estimated as a percentage (0 – 100%) of the pristine health. Scores are then weighted and aggregated so that the final score reflects the present health of the estuary as a percentage of the pristine state (Figure 3.8). Both abiotic and biotic variables are included as the relationships between the abiotic and biotic variables are often not well understood and because the biotic response to certain abiotic variables can be lagging.

For comparative reasons (with previous assessments) the individual health scores were aggregated as illustrated in Figure 3.7 and Table 3.3. In estuaries, unlike the terrestrial environment, degradation or loss of habitat seldom means a complete loss of system health or function. This can only happen if an estuary becomes completely degraded, e.g. changed into a parking lot or golf course. In most cases, degradation means loss of processes or loss of biological functionality, e.g. the estuarine space is filled with a different salinity condition or different species composition. This loss of functionally happens on a continuum, with estuaries which retain more than 90% of their natural processes and pattern being rated as Excellent and estuaries degraded to less of 40% of natural functionality rated as Poor. The fact that the physical conditions in estuarine systems are more dynamic than those of other aquatic ecosystems means that severe degradation of an estuary may involve a shift from a dynamic to a more stable, or unidirectional, system. This means that the loss of dynamic function *per se* is an important indication of declining estuarine health (DWAF, 2008b). Thus, in an estuarine health assessment, measures of these different states need to be sufficiently robust so that different practitioners/disciplines will arrive at the same categorisation.

Table 3.3 Schematic illustration of the relationship between loss of ecosystem condition and functionality

Condition	≥91%	90-75	75 - 61	60 - 41	40-21	≤20
Category	A Natural	B Largely natural with few changes	C Moderately modified	D Largely modified	E Highly degraded	F Extremely degraded
State	Excellent	Good	Fair		Poor	
Functionality	Retain Process & Pattern (representation)		Loss of Process or Pattern		No Process & Pattern	

The ecological importance of an estuary is an expression of its importance to the maintenance of biological diversity and ecological functioning on a regional, national or global scale. The national Estuary Importance Score (EIS) for an estuary takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity and functional importance of the estuary into account (DWAF, 2008b). Biodiversity importance, in turn is based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices. These importance scores ideally refer to the system in its natural condition.

The REC represents the level of protection assigned to an estuary. The first step is to determine the 'minimum' EC, based on its PES. The relationship between Estuary Health Index (EHI) score, PES and minimum REC is given in Table 3.4.

Table 3.4 Relationship between the EHI, PES and minimum REC for SA estuaries

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

Thus, the PES sets the minimum REC. The degree to which the REC needs to be elevated above the PES depends on the level of **importance** and level of **protection or desired** protection of a particular estuary (Table 3.5).

Table 3.5 Estuary protection status and importance, and the basis for assigning a recommended ecological reserve category (modified from DWAF, 2008b)

Protection status and importance	REC	Policy basis
Protected area	A or BAS*	Protected and desired protected areas should be restored to and maintained in the best possible state of health.
Desired Protected Area		
Extremely important	PES + 1, min B	Highly important estuaries should be in an A or B Category.
Very Important	PES + 1, min C	Important estuaries should be in an A, B or C Category.
Of low to average importance)	PES, min D	Estuaries to remain in a D Category.

* BAS = Best Attainable State

3.4.2 Recommended Ecological Category

The ‘recommended Ecological Flow Requirement’ scenario, is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the REC. Where any component of the health score is less than 40, then modifications to flow and measures to address anthropogenic impacts must be found that will rectify this.

3.5 DETERMINING ECOSYSTEM SERVICES CONSEQUENCES

3.5.1 Overview of Ecosystem Services

Natural habitats and ecosystems provide a range of environmental goods and services that contribute enormously – and are even essential – to human well-being. Protecting these areas is essential to achieve sustainable development. River and estuarine systems and their associated use values are of importance.

Use values associated with environmental goods and services accrue to humans from the use of the environment consumptively or productively. They have historically been classified into direct-use values, indirect-use values and option values.

The direct-use values refer to values associated with direct consumption, production, viewing of landscapes, bird watching, or even viewing of photographic products. Hunting and slaughter of wildlife for meat or skins constitute direct consumption of species from the environment. Grazing by livestock, harvesting medicinal plants and animals, and harvesting indigenous or endemic plants for roadside sale constitute productive activities whose economic values are realised in the form of profits from sale of final goods such as livestock, medicinal services, and the natural resources themselves.

The indirect-use values refer to ecological or ecosystem values such as production of nutrients, maintenance of well-functioning riverine ecosystems, water purification, maintenance of specific gaseous qualities and hydrological cycles, and formation of soil and organic matter. These values do not accrue directly to users but support production of resources that bear direct use to people. Very important in the context of the Orange River is the capacity of a water body to assimilate or dilute wastes. This represents a real economic value when the costs of water-quality impacts are considered.

Option values are values attached by individuals to the maintenance and preservation of environmental goods in order to reserve an option to use them, directly or indirectly, in the future. A different notion of option value known as vicarious value relates to creating use options for contemporary generations. Value is not derived from use but from creating an option for use by others in the same generation. It is in this vicarious sense that option value is also seen as a non-use value.

Although all three use values make up the range of goods and services that are pertinent to our work, option values are not directly considered within the context of this present study. Although it is theoretically possible to generate option values this is both a time-consuming and expensive task.

3.5.2 Approach

For the purposes of this report and in order to analyse the Ecological Goods and Services Attributes (EGSA) within a scenario context the Millennium Ecosystems Assessment (MEA) approach was largely followed. The MEA approach partitions ecosystems services into four broad categories:

- Provisioning services are the most familiar category of benefit, often referred to as ecosystem 'goods', such as foods, fuels, fibres, bio-chemicals, medicine, and genetic material, that are in many cases: directly consumed; subject to reasonably well-defined property rights (even in the case of genetic or biochemical material where patent rights protect novel products drawn from ecosystems); and are priced in the market.
- Cultural services are the less familiar services such as religious, spiritual, inspirational and aesthetic well-being derived from ecosystems, recreation, and traditional and scientific knowledge that are: mainly passive or non-use values of ecological resources (non-consumptive uses); that have poorly-developed markets (with the exception of ecotourism); and poorly-defined property rights (most cultural services are regulated by traditional customs, rights and obligations); but are still used directly by people and are therefore open to valuation.
- Regulating services are services, such as water purification, air quality regulation, climate regulation, disease regulation, or natural hazard regulation, that affect the impact of shocks and stresses to socio-ecological systems and are: public goods (globally in the case of disease or climate regulation) meaning that they "offer non-exclusive and non-rival benefits to particular communities" (Perrings, 2006); and are thus frequently undervalued in economic markets; many of these are indirectly used being intermediate in the provision of cultural or provisioning services.
- Supporting services are an additional set of ecosystem services referred to in the MEA, such as nutrient and water cycling, soil formation and primary production that capture the basic ecosystem functions and processes that underpin other services. (Mander *et al.*, 2007).

Goods and Services are further scrutinised to generate an overview of the likelihood that they will change given anticipated trajectories of modification to the system once flow scenarios are developed. The list of Goods and Services were then further scrutinised to generate an overview of the likelihood that they will change given anticipated trajectories of modification to the system once scenarios are developed. If no change is expected, then further research into the value of these Goods and Services will not be pursued.

The method that was employed is essentially linked to EWR sites and then scenario-based. Assessment of the impacts of the various scenarios – in this case largely hypothetical notions of deviation from PES at the EWR sites – essentially identifies the direction of change (either positive or negative), and estimates the "relative magnitude" of the change in benefits and costs that may be experienced within the Orange River System. The process adopted is as follows:

- The analysis of potential economic changes is based on the present-day situation, that is, the value of the Goods and Services currently provided by the water in the Orange River system.
- Ecosystem services are listed in a spreadsheet and categorised in terms of services as defined by the MEA (provisioning, supporting, regulating, cultural).
- The biophysical specialists then identified the potential change that each of the key Goods and Services may undergo in each of the scenario clusters. The potential change is noted as a factor, and used in later calculations. For example, no change = 1, a 50% increase = 1.5, and a 20% decrease = 0.8.
- Populated spreadsheet/table with analysis of changes to key ecosystem services per scenario with narrative description of reasons for change are been produced. These are categorised into provisioning, supporting, regulating, cultural services and a score per service is generated.
- Ecosystem Services and their categories are then weighted to reflect importance within the context of the geographical areas (EWR sites and the reach they represent) under consideration.
- A final score per scenario expressed against the status quo value of 1 is produced.

With respect to consideration of context it should be noted that the Lower Orange River is home to far fewer people than the Upper Orange-Senqu and Vaal River basins. This is driven mainly by climatic, physiographic and historical socio-economic factors. Economic activity is focused mostly around the small- to medium-sized towns located along or close to the river.

Given that the central issue with respect to a consideration of Goods and Services is to ensure that vulnerable social groupings are not prejudiced by development trajectories, the social categories and economic activities largely linked to the formal market economy are not considered. This is not to say that all groupings linked to the formal economy are necessarily buffered against scenario-induced change. An argument could be made that farming communities and associate labour forces are potentially highly vulnerable to changes in river management regimes, particularly in the context of the Orange River system. However, these changes and allied impacts are represented in more formal economic analyses, while those dependent on Goods and Services and who are perceived as being outside of the formal market economy, are often overlooked.

3.6 DETERMINING ECONOMIC CONSEQUENCES

The main aim of the scenario evaluation process is to determine the appropriate balance between the level of environmental protection and the use of the water to sustain the status quo socio-economic activities. Firstly, the economic baseline was determined based on the present day water utilisation in the Study Area. The economic consequences of possible water volume changes associated with a specific scenario were estimated in terms of the deviation from this baseline. However, the reality is that if demand for out of river uses is growing over time the allocation to maintain the river environment could come under pressure and then other steps will become necessary to maintain the allocation. This would necessitate the application of the 2016 and 2035 baselines in the appropriate scenarios to accommodate the projected increased demand.

3.6.1 Approach

Economic impacts are usually estimated, using the allocated water volumes for a specific catchment during EWR studies. This basic approach was followed in determining the economic consequences of Sc A (Baseline 2016), A2, A3 and B (Baseline 2035), C1b, C2b, D2 and D3. However, it must be noted that Sc C1b, C2b, D2 and D3 includes a cost element in order to obtain the required ecological demand that will service the river and estuary in future. To accommodate the inclusion of this cost element for the estimation of the impact, an additional approach, namely a Cost-Benefit Analysis (CBA) was applied. The focus of the study objective is however EWRs, of which a monetary income cannot be identified as input in a standard component as a benefit for a CBA. Therefore, an alternative monetary benefit indicator, namely Gross Domestic Product (GDP), was used.

The identified scenarios allow for the provision of the water from two sources. The first group of scenarios accept that the recommended EWR can be supplied from current available resources (Sc A2 and A3). The second set of scenarios (Sc C1, C2, D2 and D3) indicates that as demand on the out of river water increases the need to maintain the EWR volume will result in the provision of other resources outside of the Lower Orange.

For both sets of scenarios an economic baseline was established in terms of the economic and social benefits supported by the current activities in the Lower Orange River, using the following parameters:

- Economic Impact – Gross Domestic Impact (GDP); and
- Social Impact – Employment and salaries and wages paid to households.

The data used to estimate the economic baseline was sourced from the 2013 ORASECOM study with additional data related to the production of palm dates and citrus production that was established after the completion of the study. A set of multipliers was then calculated in terms of the volume of water utilised, namely:

- GDP = Rand/m^3.
- Employment = Number/million m^3.
- Payment to Households = Rand/m^3.

GDP and Employment is expressed in terms of Direct, Indirect/Induced and Total impacts, while payment to Households is expressed in terms of Low Income, Medium/High and Total Households and defined below:

- **Direct Impacts:** Refer to the effect of the activities that take place in the water use activities like irrigation agriculture and industries. It refers to the income and expenditure that is associated with the everyday operation of each of the components of the relevant industry. The direct impacts therefore measure the impact in the operational area.
- **Indirect Impacts:** Refer to economic activities that arise in the sectors that provide input to the irrigation agriculture and industry components and other backward linked industries.
- **Induced Impacts:** Refer, inter alia, to the economic impacts that result from the payment of salaries and wages to people who are (directly) employed at the various consecutive stages of beneficiation of the irrigation agriculture and industry. In addition, the induced impact also includes the salaries and wages paid by businesses operating in the sectors indirectly linked to these industries through the supply of inputs. These additional salaries and wages lead to an increased demand for various consumable goods that need to be supplied by other sectors of the economy that then have to raise their productions in tandem with the demand for their products and services.
- For purposes of this study the Indirect and Induced results are presented as a single number. Payments to Households are presented as the impact on Low Income Households and combine Medium and High Income provided as a single number.

- To provide an estimation of the impacts of a specific scenario the change in volume of water available is multiplied with the specific economic parameter.

3.6.2 Methodology

The economic impact of the EWR scenarios must be calculated for each of the developed operational scenarios. It is however obvious that the economic impact of the different scenarios will differ in size and also impact at different stretches of the Orange River.

In the case of the Sc A2 and A3, the impact was restricted to the Lower Orange. The result being that, the Lower Orange activities serve as baseline and the impact was measured in terms of the impact on the Lower Orange economy expressed in 2016 values and prices.
For Sc A2 and A3, the 2016 baseline together with the estimated multipliers was used based on the Lower Orange Catchment. The multipliers that were calculated and applied are the following:

- Gross Domestic Product (GDP) – Rand/m^3.
- Impact on Employment – Number/million m^3.
- Payments to Households (Salaries and Wages) – Rand/m^3.

The other scenarios, i.e. Sc C1b, C2b, D2 and D3 take into consideration the projected impact of the Vioolsdrift/Noordoewer and the Verbeeldingskraal dams. The construction of these dams, if constructed will also have an economic impact on the total catchment and as a result, a different approach was followed to estimate the economic impact.

A different approach was followed as the difference in supply will impact over the total river and the possibility of the construction of the two additional dams will add economic benefits. The construction cost of the two dams was taken into consideration as well as the possible size of the Vioolsdrift Dam as identified.

The methodology adapted was to use an adapted CBA model with the capital and operational costs as the cost items in the analysis, and only the direct GDP conserved from the possibility that a specific volume could be lost for production purposes. The reason for the use of only the direct GDP is that the generation is in the immediate project area by the use of the available water. By definition a percentage of the indirect and induced GDP will be outside of the project area because of the different forward and backward linkages involved. The GDP value used was estimated by multiplying the appropriate multiplier with the different projected volumes as provided.

3.6.1 Scenario A, A2 and A3

The baseline for the current demand on the Lower Orange was calculated and used for the determination of the different multipliers. These multipliers were then used to estimate the impact of the availability of the additional 100 mm^3/a, which was then presented as the positive economic impact.

The 2016 Baseline and Scenario A2 provide the same economic benefit except that Sc A2 could have a long term impact on the “Security of Supply” operating the Vanderkloof Dam at lower levels. This fact was not taken into account for the current calculations. In defining Sc A3 it is indicated that additional water will be available on the Namibian side of the river which would have a positive social and economic impact.

3.6.2 Dams and Scenarios

An estimation of the growth in demand was made for the period 2016 to 2035. The projected demand for irrigation and urban increased from 2 021 mm^3/annum to 2 413 mm^3/annum, an increase of 392 mm^3/annum.

The construction costs of the Verbeeldingskraal Dam are presented in Table 3.6, as listed in DWA (2014b) and updated to 2016 prices. The Vioolsdrift construction data for the two dams have been obtained from AECOM.

Table 3.6 Vioolsdrift and Verbeeldingskraal Dam construction and operational costs

Dam	Capital Cost 2016 (R million)	Operational Costs 2016 (R million/a)
Vioolsdrift - Large	1.715	4.25
Vioolsdrift - Small	1.103	2.92
Verbeeldingskraal	1.178	3.12

As the preliminary study of the Vioolsdrift Dam has been completed the updated information was used in the analysis.

3.6.3 Scenario C1 and C2

In Sc C1 the projections show that, as a result of the REC EWR during the summer months, a drop in yield in the system of 425 mm^3 over the Augrabies will be experienced, that has to be supplied by a large Vioolsdrift Dam, 2100 million m^3 live storage. However, the analysis show that Vioolsdrift Dam is, in this case not fully utilised, and the Verbeeldingskraal Dam will also be utilised.

In Sc C2 the projections show that as a result of the REC EWR during the summer and winter months, a drop-in yield in the system of 825 mm^3 over the Augrabies will be experienced, that has to be supplied by a large Vioolsdrift Dam. However, the analysis show that Vioolsdrift Dam is, in this case not fully utilised, and the Verbeeldingskraal Dam will also be utilised.

The applied CBA model includes the construction and operational costs of the different sizes for Vioolsdrift Dam and the corresponding costs for the Verbeeldingskraal Dam as presented in Table 3.6. The different scenarios were evaluated in terms of the Water Savings Benefit of the different scenarios and presented together with the macro-economic parameters. The Water Savings Benefit is an econometric parameter comparing the benefit of a specific scenario with the volume water involved. The benefit is the direct discounted direct GDP over the 20 year period.

3.6.4 Scenario D2 and D3

The only difference between Sc D2 and D3 is that Sc D3 is from a smaller dam. The economic interpretation of this is that Sc C2 and D2 produces the same negative economic impacts. However, Sc D3 supplies another 40 mm^3 less than Sc D2, in effect instead of saving GDP supported by 825 mm^3 it only saves GDP supported by 785 mm^3.

4 ECOLOGICAL CONSEQUENCES: RIVERS

4.1 EWR O3 (AUGRABIES)

4.1.1 EWR O3: EcoClassification results

EWR O3 (AUGRABIES)

EIS: HIGH
Highest scoring metrics are instream and riparian rare /endangered biota, unique instream and riparian biota, taxon richness of riparian biota, diversity of riparian habitat types, critical riparian habitat, refugia, migration corridor, National Park.

PES: C
Decrease in large flood frequency. Agricultural return flows, agricultural activities and associated water quality impacts. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. The presence of alien fish and vegetation species. Barrier effect of dams. Decreased sedimentation.

REC: B
Reinstate droughts (i.e., lower flows than present during the drought season). Improve (higher) wet season base flows. Clear alien vegetation. Improve agricultural practices.

Driver Components	PES	TREND	REC
IHI HYDROLOGY	E		
WATER QUALITY	C		C
GEOMORPHOLOGY	C	0	C
INSTREAM IHI	D		
RIPARIAN IHI	C/D		
Response Components	**PES**	**TREND**	**REC**
FISH	C	0	B
MACRO INVERTEBRATES	C	0	B
INSTREAM	C	0	B
RIPARIAN VEGETATION	B/C	-	B
RIVERINE FAUNA	C	0	B
ECOSTATUS	C	0	B
EIS	HIGH		

4.1.2 EWR O3: Evaluated scenarios

Scenario A2, B, C1b and C2b were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecological responses could be differentiated:

- **Sc A2** = Sc A3.
- **Sc C2b** = Sc D2 = Sc D3.

4.1.3 EWR O3: Consequences

A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in Table 4.1.

Table 4.1 EWR O3: Consequences of the scenarios on the driver and response component ECs

Physico-chemical variables					
PES	**REC**	**Sc A2**	**Sc C2b**	**Sc C1b**	**Sc B**
C: 72.4%	C: 72.4%	B/C: 79.8%	B: 84.2%	C: 72.4%	C: 69.2%

Water quality drivers at this site are elevated nutrient loads and expected toxicant loads.

- Sc A2 should result in an improvement in water quality state due to higher flows during the dry season, when the worst water quality state is normally experienced. Changes in high flows are not seen as significant as the impact of higher flows during the dry season, when accumulated nutrient and toxicant loads will decrease.
- Sc C1b may result in a slight deterioration in water quality during lowest flows, but flushing flows during the high flow season will probably result in the integrated category remaining in a C.
- Sc C2b results in higher flow throughout the year, but particularly during the dry season where impacts of elevated nutrients and toxics are ameliorated.
- Sc B shows a similar pattern of expected water quality state to Sc C1b during low flow periods, although with some expected impact on nutrients, with lower flows during the high flow period. The flows may result in slightly elevated nutrients due to lower dilution, although high flows are considered sufficient to flush out accumulated nutrient loads. The toxicant score has not been changed as higher levels will

place water quality in an E/F Category due to the automatic override when the toxic score reaches an E in the PAI. Due to the uncertainty and low confidence of the toxicant score, this was not considered a reasonable assumption.

Riparian vegetation					
PES	**REC**	**Sc A2**	**Sc C2b**	**Sc C1b**	**Sc B**
B/C: 78%	B: 82.4%	B/C: 78.9%	B/C: 81.5%	B/C: 78.6%	C: 70.2%

- Sc A2: The MAR is the same as PD, but distribution of volume differs. Base flows (generally those flows that occur for 50% of the time or more) appear to have a skewed distribution towards the summer months of November, December and January where the flow is higher that flood months of February, March and April, and higher still than the dry season. Dry season flows are higher than PD as well as the EWR for both the PES and REC, while flows from November to January occur between EWR PES and REC requirements. Flows are low in flood months of Feb, Mar and April, lower than PD and both EWR PES and REC requirements. This "lack of peak" in the flood months dissipates at lower percentiles and is similar to PD for flows that occur for 1 - 40% of the time. Overall, seasonality is maintained, but marginal zone vegetation will experience more inundation in the dry season. Grasses (notably *Cynodon dactylon*), sedges (notably *Cyperus marginatus*) and reeds (*Phragmites australis*) in the marginal and lower zones will be favoured and likely increase in cover and abundance where substrates allow, while rocky-dependent shrubs such as *Gomphostigma virgatum* will likely decline due to increased and prolonged inundation stress. Reeds in the upper zone are unlikely to expand but will likely increase in density and vigour. Other vegetation in the uppers zone and Macro Channel Bank (MCB) are unlikely to be affected.
- Sc B: The MAR is 82% of PD but seasonality is maintained. Generally, flows are lower than PD and EWR requirements (both PES and REC) for most flows, but tend to go higher than EWR requirements above the 90th percentile. High flows (1% - 10%) in the wet season are similar to PD. Marginal and lower zone reeds, grasses and sedges are inundated less during the wet season (e.g. 13.5% of the population is inundated in February at the 50th percentile for Sc B, while 18% and 27% of the population is inundated during the same period for EWR PES and REC requirements respectively). A similar situation occurs in the winter low flows (assessed during July and August) when 9% of the population is inundated on average compared to 12% should the EWR PES or REC requirements be met. The upper limits of the reed population extend beyond 3 m above water level during winter flows which may result in some desiccation, but it is also likely that reeds will encroach towards the channel. *G. virgatum* and *Salix mucronata* are largely unaffected.
- Sc C1b: The MAR is 85% of PD and seasonality is largely maintained below the 30th percentile. In the dry season Sc C1b is similar to Sc B i.e. less inundation than PD and EWR requirements (PES and REC), where 9% of the population is inundated on average compared to 12% should the EWR PES or REC requirements be met. The upper limits of the reed population extend beyond 3 m above water level during winter flows which may result in some desiccation, but it is also likely that reeds will encroach towards the channel. Base flows in the wet season are generally higher than PD as well as the EWR (PES) requirement, where 24% of the reed population is inundated compared to 15% during PD and 18% and 27% during EWR requirements (PES and REC respectively). Overall, it is likely that the reed and grass population will remain healthy and largely unchanged from the current state, or will slightly encroach on the channel. Both *G. virgatum* and *S. mucronata* remain unchanged.
- Sc C2b: The MAR is 87% of PD and seasonality is largely maintained below the 30th percentile. Generally, flows are similar to Sc C1b from November to April i.e. higher than PD and PES EWR (are close to REC EWR), but are much higher in the dry season; higher than PD as well as both PES and REC EWRs. In the dry season, marginal and lower zone grasses, reeds and sedges are more inundated (13.5% of the population) than during PD flows (10.5%) or both PES and REC EWRs (12%). Base flows in the wet season are generally higher than PD as well as the EWR (PES) requirement, where 24% of the reed population is inundated compared to 15% during PD and 18% and 27% during EWR requirements (PES and REC respectively). Overall it is likely that reeds and grasses will decline slightly along the marginal zone interface with the channel due to dry season inundation, while marginal and lower zone woody will likely remain unchanged.

More detailed data of comparisons are provided electronically.

Fish					
PES	**REC**	**Sc A2**	**Sc C2b**	**Sc C1b**	**Sc B**
C: 76.9%	B: 84.1%	B/C: 79.5%	B:82.7%	B/C: 77.5%	C: 74.3%

- Sc. A2: A slight improvement can be expected towards a category B/C. Flows are generally better than present (and EWR PES) for most seasons resulting in improved habitat conditions for fish. Slight substrate quality deterioration and slightly altered seasonal distribution of flows may limit conditions slightly. Slight improvement in water quality and vegetative cover contribute to an improved PES

Category.

- Sc C1b: No significant change is expected from the PES. The slight improvement, in especially wet season (fast and slow) habitat suitability (abundance in fast and slow habitats as well as substrate quality), contribute to improvement. Vegetative cover, water quality and seasonal distribution remain unchanged.
- Sc B: A slight deterioration in the fish from a high C EC C towards a very lower C EC. The most significant impacts responsible for deteriorated fish conditions is associated with deterioration of fast and slow habitat during maintenance flows in wet and dry season. Substrate quality and deceased availability of undercut banks due to lower wet season flows and slightly altered seasonal distribution of flows (wet season) and deterioration in water quality and vegetative cover will furthermore contribute to the slight deterioration.
- Sc C2b: A notable improvement in the REC of the reach can be expected. Most flows are better (only dry season drought lacking) than the PES resulting in notable improvement in fish habitat conditions. Improvement in water quality, as well as vegetative cover, also contributes greatly to improved conditions for fish.

Macroinvertebrates					
PES	**REC**	**Sc A2**	**Sc C2b**	**Sc C1b**	**Sc B**
C: 75.9%	B: 85%	B/C: 79.2%	B/C: 81.1%	B/C: 76.7%	C: 69%

- Sc A2: There is an overall improvement in habitat due to improved flows during most seasons for both maintenance and drought flows. There is an improvement in the shallow habitats during the wet season maintenance, from 0.0 m of perimeter (PES), to 0.3 m of perimeter during this scenario. This will benefit the macroinvertebrate communities as they prefer shallow fast habitats to fast-deep habitats. mprovements in water quality and marginal vegetation cover, as well as little change in seasonality will enhance the integrity of this scenario, which results in an EC of 79.2% (B/C), somewhat higher than the PES EC (75.9%; C).
- Sc C2b: Flows are similar to Sc C1b, however the dry season maintenance flows improve. The definite improvement of fast shallow flows (not to the detriment of the fast deep flows) create good habitat for the rheophilic macroinvertebrates. Additionally, with water quality and marginal vegetation improving and seasonality and substrate quality remaining unchanged, the EC improves from the PES.
- Sc C1b: Although the preferred fast-shallow habitats for macroinvertebrates do not change from the PES, some improvement of slow-shallow habitats will benefit invertebrate communities as there there is more habitat present for those macroinvertebrates that prefer the slow-shallow biotope. There are also some changes in the deep water habitats, but this will not influence the macroinvertebrate much. The slight improvement of habitat created by flows, which also improve cover in the marginal vegetation due to inundation for extended periods, and no change in water quality, will result in an improvement in the PES.
- Sc B: There is an overall deterioration in flows, especially flows providing deeper habitats. However, the changes in deep habitats (fast and slow) will not affect the macroinvertebrate communities significantly. On the other hand, the overall deterioration of fast habitat (shallow and intermediate) during most seasons for both maintenance and drought flows, will ultimately impact adversely on the aquatic invertebrates. During all the flow periods (maintenance and drought), the fast habitats (shallow and intermediate) never improves from the PES. There are some shallow habitats present during the wet season maintenance that will benefit macroinvertebrate communities to some extent. With the added adverse effect of increased sedimentation, slightly altered seasonal distribution of flows, and slight deterioration in water quality, the EC in this scenario will drop to a lower EC.

4.1.4 EWR O3: ECOSTATUS

The resulting ECs for each component and EcoStatus is provided in Table 4.2. The ranking of the scenarios is provided as a traffic diagram (Figure 4.2).

Table 4.2 EWR O3: Ecological consequences

Component	PES	REC	Sc A2	Sc C2b	Sc C1b	Sc B
Physico chemical	C	C	B/C	B	C	C
Riparian vegetation	B/C	B	B/C	B/C	B/C	C
Fish	C	B	B/C	B	C	C
Invertebrates	C	B	B/C	B/C	C	C
EcoStatus	C (77.2%)	B (83.6%)	B/C (79.1%)	B/C (81.7%)	B/C (77.7%)	C (70.9%)

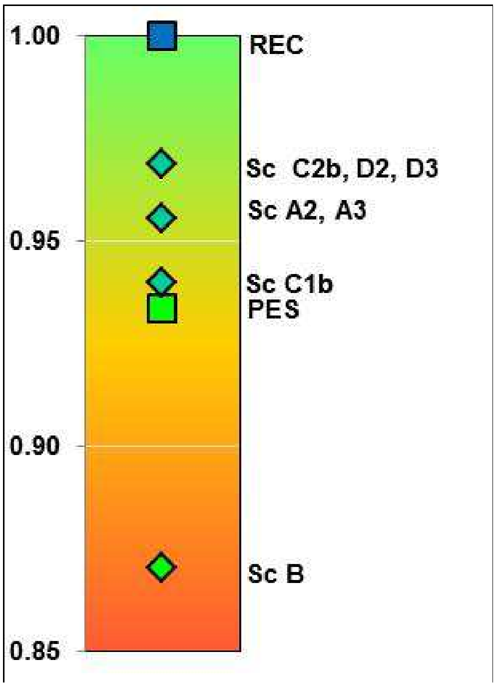

Figure 4.1 EWR O3: Ecological ranking of operational scenarios

4.1.5 EWR O3: Conclusion

The ranking of the scenarios show that all the scenarios, apart from Sc B, result in an improvement of the PES, but do not achieve the REC. The best scenarios are Sc C2b, D2/D3 followed closely by Sc A2/A3. As the recommendations are likely to be set for pre-dam situation, Sc A2/A3 will be the recommended scenario. The best post-dam scenarios are Sc C2b, Sc D2 and D3.

4.2 EWR O5 (SENDELINGSDRIFT)

4.2.1 EWR O5: EcoClassification results

<table>
<tr><th colspan="2">EWR O5 (SENDLINGSDRIF)</th></tr>
<tr><td>
EIS: HIGH
Highest scoring metrics are rare and endangered instream and riparian species. Unique instream and riparian species. Important migration corridor for various species. The site is situated in the /Ai-/Ais–Richtersveld Transfrontier Park.

PES: B/C
Decreased small and moderate flood frequency. Agricultural return flows and mining activities – water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. The presence of alien fish and vegetation species. Barrier effect of dams.

REC: B
Increased (from present) wet season base flows. Reinstate dry season droughts.
</td><td>
<table>
<tr><th>Driver Components</th><th>PES</th><th>REC</th></tr>
<tr><td>IHI HYDROLOGY</td><td>C</td><td>C</td></tr>
<tr><td>WATER QUALITY</td><td>C</td><td>C</td></tr>
<tr><td>GEOMORPHOLOGY</td><td>B/C</td><td>B</td></tr>
<tr><td>INSTREAM IHI</td><td>C</td><td></td></tr>
<tr><td>RIPARIAN IHI</td><td>C</td><td></td></tr>
<tr><th>Response Components</th><th>PES</th><th>REC</th></tr>
<tr><td>FISH</td><td>B/C</td><td>B</td></tr>
<tr><td>MACRO INVERTEBRATES</td><td>B/C</td><td>B</td></tr>
<tr><td>INSTREAM</td><td>B/C</td><td>B</td></tr>
<tr><td>RIPARIAN VEGETATION</td><td>B/C</td><td>B</td></tr>
<tr><td>RIVERINE FAUNA</td><td>B</td><td>B</td></tr>
<tr><td>ECOSTATUS</td><td>B/C</td><td>B</td></tr>
<tr><td>EIS</td><td colspan="2">HIGH</td></tr>
</table>
</td></tr>
</table>

4.2.2 EWR O5: Evaluated scenarios

Scenarios A2, B, C1b and D3 were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecological responses could be differentiated:

- **Sc A2** = Sc A3.
- **Sc C2b** = Sc C1b.
- **Sc D3** = Sc D2.

4.2.3 EWR O5: Consequences

A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in Table 4.3.

Table 4.3 EWR O5: Consequences of the scenarios on the driver and response component ECs

<table>
<tr><th colspan="6">Physico-chemical variables</th></tr>
<tr><th>PES</th><th>REC</th><th>Sc D3</th><th>Sc C2b</th><th>Sc A2</th><th>Sc B</th></tr>
<tr><td>C: 74.2%</td><td>C: 74.2%</td><td>B/C: 81.8%</td><td>B/C: 81.8%</td><td>B/C: 81.8%</td><td>D: 55.0%</td></tr>
<tr><td colspan="6">Water quality drivers at this site are elevated nutrient and salt loads, and some elevated metals and expected toxicants (e.g. fertilizers from upstream agricultural use). The river is deep with long runs at this point and a substantial distance from upstream dams, meaning that temperature, oxygen and turbidity impacts are not likely to be significant.

▪ Sc C2b and Sc A2 are very similar, although Sc A2 has more flows in the low flow season and in the high flow period at times (e.g. 40% exceedance). Higher flows in the low flow season will result in improvements in nutrient and toxicant levels. A small positive impact is also expected on oxygen and temperature levels. As Sc D3 is similar to Sc A2 for much of the time, it was not possible to distinguish between Sc A2, C2b and D3 for water quality. All three scenarios will result in an improvement in integrated water quality.
▪ Although Sc B is showing higher flows during the driest season (August-September) as compared to other scenarios and the PES and REC, and therefore an improved integrated water quality state at this time, flows are substantially lower under this scenario for the rest of the year. Note that the elevated flows in the dry season results in the absence of habitat stress that should be experienced by instream biota at these times. Although water quality improves at this time, it is further away from the natural</td></tr>
</table>

state.

Riparian vegetation					
PES	**REC**	**Sc D3**	**Sc C2b**	**Sc A2**	**Sc B**
B/C: 81.9%	B: 82.8%	B: 83.1%	B: 83.1%	B: 82.4%	C: 67.2%

- Sc A2: The MAR is the same as PD and seasonality is maintained. High flows and floods are similar to PD and appear in the expected months. Dry season flows are the same as REC EWR flows and higher than PD and PES EWR flows. Flows only appear to be lower than expected in February and March from the 50^{th} to the 90^{th} percentile. Marginal and lower zone vegetation is inundated more than PD and the EWRs (PES and REC) in the dry season (July at 50^{th} percentile) e.g. 54% of sedge population inundated while inundation is expected to be 12%, 19% and 49% during PD, PES and REC ERWs respectively. The change from REC EWR is slight however and often less than this. During the wet season, base flows inundate 100% of reeds, grasses and marginal zone shrubs as expected, but inundation depths increase relative to what is expected for PD and EWRs (PES and REC) e.g. inundation depth of 1.6 m for sedges (*Cyperus longus*) while depth for PD is expected to be 1.7 m, EWR REC is 1.2 m and EWR PES is 1.25 m. Overall, seasonality is maintained, but marginal zone vegetation will experience slightly more inundation in the dry season at times. Grasses (notably *C. dactylon*) and reeds (*P. australis*) in the marginal and lower zones will be favoured and likely increase in cover and abundance where substrates allow, while rocky-dependent shrubs such as *G. virgatum* and sedges (notably *C. marginatus*) are unlikely to change. Reeds in the upper zone are unlikely to expand but will likely increase in density and vigour. Other vegetation in the uppers zone and MCB are unlikely to be affected.
- Sc B: The MAR is 71.8% of PD and seasonality is generally maintained, although slightly skewed towards April at the 30^{th} and 40^{th} percentiles. Floods are supplied about 50% of the time. Flows in the dry season are always less than PD and less than EWRs between the 20^{th} and the 80^{th} percentiles. At the 50^{th} percentile flows are less than PES EWR and markedly less than REC EWR. Marginal zone sedges, reeds and shrubs do not get inundated in the dry season although some inundation is expected: 19% and 44% of the sedge population is expected to inundate during EWR flows (PES and REC respectively), while 100% of the reed population is expected to inundate and 30% and 76% of the *G. virgatum* population. Since elevation above water level is never extreme it is expected that marginal vegetation will encroach towards the channel. During the wet season flows are always less than PD and less than EWR (PES and REC) flows up to the 90^{th} percentile. Reeds get inundated completely, as expected, but only 35% of the sedge population and 55% of the *G. virgatum* population are inundated, both of which are expected to completely inundate during PD and EWR flows. Flows are less but water stress will be absent so it is highly likely that marginal and lower zone vegetation will increase, and in the absence of much flooding upper zone woody species (including aliens and terrestrial species) will also likely increase.
- Sc C2b: The MAR is 76.2% of PD and scenario is similar to Sc C1b. Seasonality is maintained and floods generally occur in months where they are expected. Floods are supplied from 66% to 72% of the time from spills from Vioolsdrift Dam. Dry season flows are very similar to EWR REC, but slightly more during droughts. Mostly more than PD except at the higher percentiles (near drought flows). Marginal and lower zone vegetation inundation is essentially the same as that specified for EWR REC flows, so no response is expected (assessment done for July at 50%). In the wet season, flows are generally less than EWR REC, similar to EWR PES and more than PD at 40^{th} to 60^{th} percentiles, but at lower percentiles (below 20^{th}) flows tend to equal EWRs or exceed them. Inundation of vegetation is essentially the same as that expected for EWR REC flows (assessment at 40% in March). Differences are small and a response from vegetation is not easily justified. Reduced flooding frequencies may result in an increase in overall cover, especially woody species.
- Sc D3: The MAR is 78.8% of PD. Similar to Sc D2, floods are supplied from 76% to 83% of the time from spills from Vioolsdrift Dam. Seasonality is maintained and floods generally occur in months where they are expected. This scenario is very similar to Sc C2b and vegetation response will be the same.

More detailed data of comparisons are provided electronically.

Fish					
PES	**REC**	**Sc D3**	**Sc C2b**	**Sc A2**	**Sc B**
B/C: 79.9%	B: 83.3%	B: 83.8%	B: 84.4%	B: 84.4%	C: 76.2%

- Sc A2: The wet season (December) and dry season (September) flows are generally higher than the PES and REC flows, and an overall improvement in the fish assemblage can be expected. Abundant fast and slow habitats will be created in especially the wet season conditions to allow for overall improvement towards a Category B.
- Sc D3: Habitat conditions for fish will be improved from present conditions with most flows falling above the PES and even REC requirements. Water quality improvement will furthermore result in improved

physico-chemical habitat conditions for fish. Seasonality slightly skewed from 70% FD upwards with higher flow months occurring earlier in summer (November to January rather than March/April).

- Sc B: In absence of water stress marginal zone vegetation expected to increase, resulting in improved vegetative cover for some fish species. Floods supplied only 50% of time may result in some increase in sedimentation resulting in deterioration of substrates. General low water level will also result in loss of undercut bank habitat for fish. Notable water quality deterioration will also impact negatively on especially fish species with a requirement for unmodified water quality (such as *Labeobarbus kimberleyensis*). Seasonality notably altered with higher flows occurring during early summer and general lack of high flows in late wet season (March/April). Deterioration in slow and fast habitats during the dry season (maintenance) furthermore reduces conditions for fish to result in an overall decrease towards a lower Category C.
- Sc C2b: Reduced flooding may result in slightly reduced conditions of substrates for fish. No change is expected in the vegetative cover for fish. Improved water quality will furthermore improve conditions for fish species with a preference for good water quality. A slight change in natural seasonal distribution of flow is evident from 60% FD, with higher flows occurring in early summer rather than late summer. This could impact negatively on natural fish movement, cues for migration and nursery areas for fish. Wet season maintenance flows similar to Sc A2, wet season drought and dry season maintenance flow similar to Sc D3 and dry season drought same response as Sc B. Overall conditions for fish will improve the PES to a Category B (similar to Sc A2).

Macroinvertebrates

PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
B/C: 78%	B/C: 82%	B/C: 82%	B/C: 81%	B/C: 80%	C: 74%

- Sc D3: During both the December wet season and the September dry season, the flows generally improved in relation to the PES and REC. The seasonality may be somewhat skew, but the water quality improves and no sediment problems are envisaged. The marginal vegetation cover remains unaffected. This results in an improvement in the PES within the B/C EC.
- Sc. C2b: The flows have a number of similarities with other scenarios. Wet season maintenance is similar to Sc A2; wet season drought and dry season maintenance is similar to Sc D3; and dry season drought is similar to Sc B. Overall the flows create good habitat for the macroinvertebrates, and together with improved water quality, the EC improves to a B/C. Although the seasonal distribution is marginally skew, and a degree of sedimentation is present in the river due to fewer floods, this will not impact significantly on the habitat. The marginal vegetation cover is similar to the PES.
- Sc A2: During both the December wet season and the September dry season, the flows generally improve in relation to the PES and REC. Additionally, due to good floods, the substrate will be in a good condition along with improved water quality. The marginal vegetation cover will also not be affected adversely by the conditions. This results in an improvement from the PES.
- Sc B: Variations in flows and especially the deterioration of fast flows will impact on the macroinvertebrate habitat. Floods are less frequent (50%) and sedimentation of habitats might become a problem. Although marginal vegetation encroachment will supply good habitat for the invertebrates, poor water quality will impact on their abundance. The combination of the adverse influences results in a deterioration in the PES.

4.2.4 EWR O5: ECOSTATUS

The resulting ECs for each component and EcoStatus is provided in Table 4.4. The ranking of the scenarios is provided as a traffic diagram (Figure 4.2).

Table 4.4 EWR O5: Ecological consequences

Component	PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
Physico chemical	C	C	B/C	B/C	B/C	D
Riparian vegetation	B/C	B	B	B	B	C
Fish	B/C	B	B	B	B	C
Invertebrates	B/C	B/C	B/C	B/C	B/C	C
EcoStatus	B/C (80.5%)	B (82.7%)	B (82.9%)	B (82.7%)	B (82.2%)	C (71.8%)

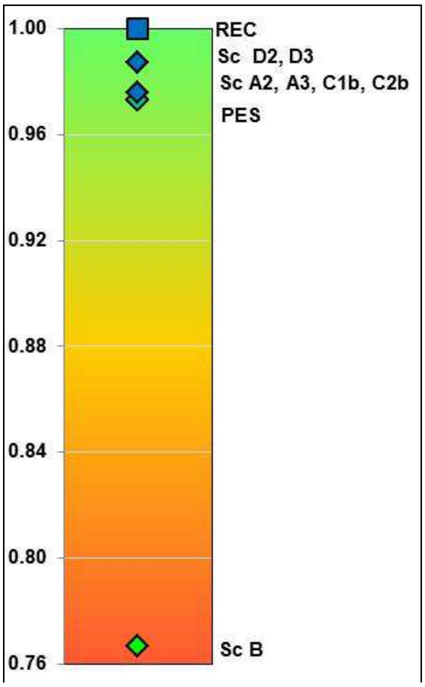

Figure 4.2 EWR O5: Ecological ranking of operational scenarios

4.2.5 EWR O5: Conclusion

The ranking of the scenarios show that all the scenarios, apart from Sc B achieve the REC. The best scenarios are D2/D3 followed closely by Sc C2b/C1b. As the recommendations are likely to be set for a pre-dam situation, Sc A2/A3 will be the recommended scenario prior to the dam construction. When a decision is made on future dams, then the recommendation will be the scenario associated with D2/3.

4.3 EWR O4 (VIOOLSDRIFT)

4.3.1 EWR O4: EcoClassification results

EWR O4 (VIOOLSDRIFT)

EIS: HIGH
Highest scoring metrics are instream and riparian rare /endangered biota, unique instream and riparian biota, migration corridor, Transfortier Park in the MRU.

PES: B/C
Decreased large flood frequency. Agricultural return flows and mining activities – water quality problems. Higher low flows than natural in the dry season, drought and dry periods. Decreased low flows at other times. The presence of alien fish and vegetation species. Barrier effect of dams. Decreased sedimentation due to upstream dams and lack of large floods.

REC:
Improved (higher) wet season base flows. Clear alien vegetation. Control grazing and trampling.

Driver Components	PES	TREND	REC
IHI HYDROLOGY	D		
WATER QUALITY	C/D		C/D
GEOMORPHOLOGY	C	0	C
INSTREAM IHI	D		
RIPARIAN IHI	D		
Response Components	**PES**	**TREND**	**REC**
FISH	C	0	B/C
MACRO INVERTEBRATES	C	0	B/C
INSTREAM	C	0	B/C
RIPARIAN VEGETATION	C	-	B
RIVERINE FAUNA	C	-	B/C
ECOSTATUS	C	-	B/C
EIS	HIGH		

4.3.2 EWR O4: Evaluated scenarios

No EWRs were supplied for EWR O4 as the downstream EWR O5 provided the results being more critical. The flows that pass EWR O4 were evaluated to determine the consequences. Scenario A2, B, C1b and C2b were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecological responses could be differentiated:

- **Sc A2** = Sc A3.
- **Sc C2b** = Sc C1b.
- **Sc D3** = Sc D2.

4.3.3 EWR O4: Consequences

A summary explanation of the consequences of the scenarios compared to the PES and the REC are provided in Table 4.5.

Table 4.5 EWR O4: Consequences of the scenarios on the driver and response component ECs

Physico-chemical variables					
PES	**REC**	**Sc D3**	**Sc C2b**	**Sc A2**	**Sc B**
C/D: 58.2%	C/D: 58.2%	C: 63.2%	C: 63.2%	C: 64.8%	D: 44.4
Water quality drivers at the site are elevated salts and nutrients (from irrigation return flows and evaporative losses along the river), with some evidence of elevated toxicants from pesticide use and mining activities. ▪ Sc A2 appears to be the best scenario in terms of flow requirements and integrated water quality state, and exceeds PES requirements at the lowest flows. None of the scenarios meet requirements between January and March/April period. This scenario will result in a small improvement in toxics, nutrients, oxygen and temperature levels at the time of lowest flows. ▪ The water quality state under Sc D3 and C2b cannot be separated, so these two scenarios are considered together. The scenarios meet flow requirements for the PES at times of lowest flows, with Sc C2b being slightly better than Sc D3. The water quality state under these scenarios is similar to those of Sc A2, although the impact on flushing flows in the wetter season is unlikely to move the nutrient category. ▪ Although Sc B is showing higher flows during the driest season (August - September) as compared to other scenarios as well as as the PES and REC, and therefore an improved integrated water quality state at this time, flows are substantially lower under this scenario for the rest of the year. Note that the elevated flows in the dry season results in the absence of habitat stress that should be experienced by instream biota at these times. Although water quality improves at this time, it is further away from the natural state. The simulation for toxics under this scenario has been run without utilising the override function in the PAI, which would drop the Category down to an E/F.					
Riparian vegetation					
PES	**REC**	**Sc D3**	**Sc C2b**	**Sc A2**	**Sc B**
C: 74%	B: 84.3%	B/C: 80.2%	B/C: 79.5%	B/C: 78.5%	C: 68.5%
▪ Sc A2: The MAR is the same as PD and seasonality is maintained. Stream permanency is 100% compared to 100% for PD and 97% for natural. High flows and floods are similar to PD and appear in the expected months, although flows seem to be low in February at times. Dry season flows are generally similar to the REC EWR, often similar to PD but frequently more than PD, and always more than the PES EWR. Drought flows are always higher than both the PES and REC EWRs, but are less than PD. An assessment of vegetation indicators in July at the 50th percentile shows that marginal and lower zone grasses (*C. dactylon*), shrubs (*G. virgatum*) and reeds (*P. australis*) are inundated more than they would be for PD and PES EWR, but are similar to the REC EWR. The higher dry season base flows of Sc A2 also inundate areas where *Prosopis glandulosa* saplings occur, which will also help prevent their recruitment and invasion. Other vegetation in the upper zone and MCB are unlikely to be affected. Wet season flows are mostly similar to PD, but are frequently lower than PES and REC EWRs, especially from February to April at 50th to 70th percentiles i.e. wet season base flows seem lower than EWRs in months when floods would be expected. Lower percentiles where the floods occur are always more than EWRs (PES and REC) and similar to PD. Wet season drought flows are higher than EWRs but lower than PD. An assessment of vegetation indicators in March at the 50th percentile shows that marginal and lower zone grasses (*C. dactylon*), shrubs (*G. virgatum*) and reeds (*P. australis*) are inundated less than PD and EWRs (PES and REC) e.g. 37% of *P. australis* population inundated compared to 42% for PD, 60% for PES EWR and 73% for REC EWR. Similarly, the *S. mucronata* population does not get inundated while inundation is expected to be at 16.5% and 34% for PES and REC EWRs respectively.					

This reduced inundation in the wet season is likely to be mitigated by the floods which generally occur, but overall it is expected that some reed and woody species encroachment may occur.

- Sc B: The MAR is 74.1% of PD. Stream permanency is 100% compared to 100% for PD and 97% for natural. Seasonality is generally maintained at lower percentiles, although slightly skewed towards April. Floods are supplied about 50% of the time from spills from Vioolsdrift Dam. Dry season base flows are always less than PD and less than EWRs (PES and REC) for most flows except drought flows where they are higher than EWRs. An assessment of vegetation indicators in July at the 50th percentile shows that marginal and lower zone grasses (*C. dactylon*), shrubs (*G. virgatum*) and reeds (*P. australis*) are inundated much the same as the PES EWR and PD and less than the REC EWR e.g. 28% of the reed population gets inundated compared to 28% for PD and PES EWR and 34% for REC EWR. Wet season base flows are generally lower than PD and much lower than PES and REC EWRs. An assessment of vegetation indicators in March at the 50th percentile shows that marginal and lower zone grasses (*C. dactylon*), shrubs (*G. virgatum*) and reeds (*P. australis*) are inundated less than PD and EWRs (PES and REC) e.g. 31% of *P. australis* population inundated compared to 43% for PD, 52% for PES EWR and 57% for REC EWR. Similarly, the *S. mucronata* population does not get inundated while inundation is expected to be at 16.5% and 34% for PES and REC EWRs respectively. This reduced inundation in the wet season is likely to be mitigated somewhat by the floods which occur about 50% of the time, but overall it is expected that some reed and woody species encroachment may occur.
- Sc C1b: The MAR is 76% of PD and similar to Sc C2b. Floods are supplied from 52% to 54% of the time from spills from Vioolsdrift Dam. Stream permanency is 99% compared to 100% for PD and 97% for natural. Slight differences in March do not result in measurable response differences by riparian vegetation.
- Sc C2b: The MAR is 77.6% of PD and seasonality is maintained below the 30th percentile. At the 40th and 50th percentile flows seem low for March and this skews seasonality. Stream permanency is 100% compared to 100% for PD and 97% for natural. Floods are supplied from 66% to 72% of the time from spills from Vioolsdrift Dam. Dry season base flows are similar to the REC EWR, mostly higher than PD and always more than the PES EWR. Drought flows are slightly higher than the PES EWR, mostly the same as REC EWR, and are always less than PD. An assessment of vegetation indicators in July at the 50th percentile shows that marginal and lower zone grasses (*C. dactylon*), shrubs (*G. virgatum*) and reeds (*P. australis*) are inundated more than they would be for PD and the PES EWR, but are similar to the REC EWR. The higher dry season base flows Sc C2b also inundate areas where *P. glandulosa* saplings occur, which will also help prevent their recruitment and invasion. Other vegetation in the uppers zone and MCB are unlikely to be affected, although reduced floods may promote woody species cover and abundance along banks. Wet season flows are generally more than PD and the PES EWR, except for February and March where they are frequently lower, and are mostly less than the REC EWR. An assessment of vegetation indicators in March at the 50th percentile shows that marginal and lower zone grasses (*C. dactylon*), shrubs (*G. virgatum*) and reeds (*P. australis*) are inundated less than PD and EWRs (PES and REC) e.g. 40% of *P. australis* population inundated compared to 43% for PD, 52% for PES EWR and 57% for REC EWR. Similarly, the *S. mucronata* population is not inundated while inundation is expected to be at 16.5% and 34% for PES and REC EWRs respectively. This reduced inundation in the wet season is likely to be mitigated by the floods which generally occur, but overall it is expected that some reed and woody species encroachment may occur.
- Sc D3: The MAR is 80.5% of PD and seasonality is maintained. Stream permanency is 100% compared to 100% for PD and 97% for natural. Class I floods are supplied as a release and other floods are supplied from 77% to 79% of the time from spills from Vioolsdrift Dam. Similar to Sc C2b but slightly higher summer base flows. Dry season base flows are similar to the REC EWR, mostly higher than PD and always more than the PES EWR. Drought flows are slightly higher than the PES EWR, mostly the same as REC EWR, and are always less than PD. An assessment of vegetation indicators in July at the 50th percentile shows that marginal and lower zone grasses (*C. dactylon*), shrubs (*G. virgatum*) and reeds (*P. australis*) are inundated more than they would be for PD and the PES EWR, but are similar to the REC EWR. The higher dry season base flows of Sc D3 also inundate areas where *P. glandulosa* saplings occur, which will also help prevent their recruitment and invasion. Other vegetation in the uppers zone and MCB are unlikely to be affected, although reduced floods may promote woody species cover and abundance along banks. Wet season flows are generally more than PD and the PES EWR, and are mostly less than the REC EWR. An assessment of vegetation indicators in March at the 50th percentile shows that marginal and lower zone grasses (*C. dactylon*), shrubs (*G. virgatum*) and reeds (*P. australis*) are inundated less than PD and EWRs (PES and REC) e.g. 37% of *P. australis* population inundated compared to 43% for PD, 52% for PES EWR and 57% for REC EWR. Similarly, the *S. mucronata* population does not get inundated while inundation is expected to be at 16.5% and 34% for PES and REC EWRs respectively. This reduced inundation in the wet season is likely to be mitigated by the floods which generally occur, but overall it is expected that some reed and woody species encroachment may occur.

More detailed data of comparisons are provided electronically.

Fish

PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
C: 65.2%	B/C: 77.6%	B/C: 77.4%	C: 74.7%	C: 75.2%	C/D: 60%

- Sc D3: Slight improvement in water quality (temperature, oxygen and toxics) should have positive impact on the fish assemblage (especially fish species intolerant to water quality alterations). Improved vegetative cover in dry and possibly also wet season is expected for fish. The seasonal distribution is mostly maintained (slight changes from 80% FD upwards). Changes in sediment regime will be both positive and negative for fish species and overall cancel each other out and hence no significant change in the fish assemblage is expected. All flow aspects (wet and dry season maintenance and drought flows) will improve fast and slow habitat conditions, leading to overall improvement of PES and fall within the REC of B/C.
- Sc C2b: The slight improvement in water quality (temperature, oxygen and toxics) should have positive impact on the fish assemblage (especially fish species intolerant to water quality alterations). Changes in sediment regime will be both positive and negative for fish species and overall cancel each other out and hence no significant change in the fish assemblage is expected. Improved vegetative cover in dry and possibly wet season (due to encroachment) is expected for fish. Al flow aspects (wet and dry season maintenance and drought flows will improve fast and slow habitat conditions, leading to overall improvement, falling in a much higher Category C.
- Sc A2: A slight improvement in water quality (temperature, oxygen, nutrients and toxics) should have a positive impact on the fish assemblage (especially fish species intolerant to water quality alterations). Changes in sediment regime will be both positive and negative for fish species and overall cancel each other out and hence no significant change in the fish assemblage is expected. Improved vegetative cover in dry (more inundation) and wet (encroachment of reeds) season is expected for fish. All flow aspects (wet and dry season maintenance and drought flows) will improve fast and slow habitat conditions, leading to overall improvement, falling in a much higher Category C.
- Sc B: A large serious deterioration in water quality is expected (most variables assessed) and most fish species will be negatively impacted. Vegetative cover will be slightly less due to less inundation during most seasons. Reduced floods may result in some negative changes in sediment regime at site with slight negative impact on the fish assemblage expected. Dry season maintenance flows will be limiting to the fish assemblage and overall a notable deterioration can be expected towards a Category C/D.

Macroinvertebrates

PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
C: 63.3%	B/C: 77.7%	B/C: 81.6%	B/C: 78.5%	B/C: 79.2%	D: 56.1%

- Sc D3: Improved flows for dry and wet season (maintenance and drought) will benefit all macroinvertebrate populations, but it is especially the sensitive rheophilic macroinvertebrate populations which will benefit from the fast flows in the shallow and intermediate habitats. With water quality improving (better oxygen and temperature, less toxics) and seasonality maintained, circumstances improve. Moderate fluctuation in the inundation of marginal vegetation will create moderate habitats, and the substrates will be influenced by the dam upstream and flooding, however, there are both positive and negative influences and it will cancel each other out.
- Sc C2b: Improved flows for dry and wet season (maintenance and drought) will benefit all macroinvertebrate populations, but it is especially the sensitive rheophilic macroinvertebrate populations which will benefit from the fast flows in the shallow and intermediate habitats. Improved water quality parameters (better oxygen and temperature, less toxics) will also improve conditions. Moderate fluctuation in marginal vegetation inundation will create moderate habitats, and the only adverse condition lies in the fact that seasonality is slightly skewed.
- Sc A2: Improved flows for dry and wet season (maintenance and drought) will benefit all macroinvertebrate populations, but it is especially the sensitive rheophilic macroinvertebrate populations which will benefit from the fast flows in the shallow and intermediate habitats. Improved water quality parameters (better oxygen and temperature, less toxics and nutrients) and maintained seasonality, will also improve circumstances. Due to regulated flows from the dam, there will be a lowering in flow variation, which in turn will influence the inundation levels of the marginal vegetation and consequently impact on the macroinvertebrate habitat. Furthermore, the changes in flooding regime due to the dam upstream will have an influence the quality of the downstream substrates. However, there are both positive and negative influences and it will cancel each other out.
- Sc B: Deterioration in certain flows, especially in the dry season, as well as a regression of flow levels from the natural state, impact adversely on the macroinvertebrate integrity. Circumstances regarding substrate and water quality are deteriorating and seasonality is slightly skewed. Amplified variation in the inundation of marginal vegetation will impact adversely on the macroinvertebrate populations utilising these habitats.

4.3.4 EWR O4: ECOSTATUS

The resulting ECs for each component and EcoStatus is provided in Table 4.6. The ranking of the scenarios is provided as a traffic diagram (Figure 4.3).

Table 4.6 EWR O4: Ecological consequences

Component	PES	REC	Sc D3	Sc C2b	Sc A2	Sc B
Physico chemical	C/D	C/D	C	C	C	D
Riparian vegetation	C	B	B/C	B/C	B/C	C
Fish	C	B/C	B/C	C	C	C/D
Invertebrates	C	B/C	B/C	B/C	B/C	D
EcoStatus	C (69.1%)	B/C (81%)	B/C (79.9%)	B/C (78%)	B/C (77.9%)	C (62.6%)

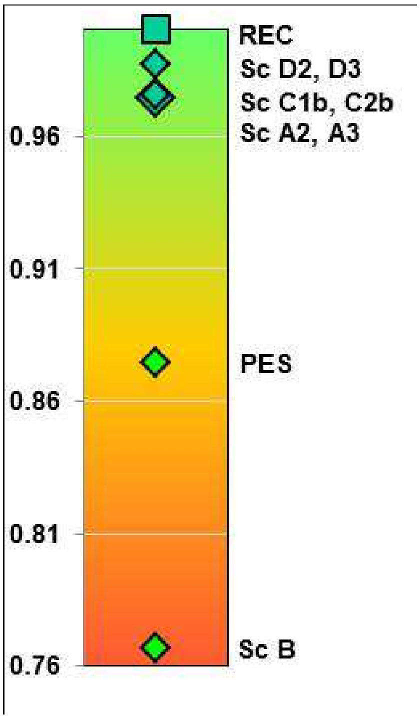

Figure 4.3 EWR O4: Ecological ranking of operational scenarios

4.3.5 EWR O4: Conclusion

The ranking of the scenarios show that all the scenarios, apart from Sc B, achieve the REC EcoStatus. It should be noted that although the EcoStatus is met under these scenarios all the components of the REC are not met. The best scenarios are D2/D3 followed closely by Sc C1b/C2B. As the recommendations are likely to be set for pre-dam situation, A2/A3 will be the recommended scenario prior to the dam construction. When a decision is made on future dams, then the recommendation will be the scenario associated with D2/3.

4.4 INTEGRATED ECOLOGICAL RANKING

The process to determine an integrated ranking of the different scenarios is described in detail under Section 3.3. The first step was to determine the relative importance of the different EWR sites occurring in the study area. The site weight (Table 4.7) indicated that EWR O5 carried the highest weight due to the High EIS as EWR O5 is situated in the /Ai-/Ais-Richtersveld Transfrontier Park. This site is also the most downstream site in the Orange River and the accumulated impact of the scenarios will be the highest despite the relatively short river reach (141 km). The importance of EWR O4 is slightly lower, due to less accumulated impacts of scenarios although the EIS is High and the river reach length is relatively similar. EWR O3 has a lower weight, as the site is upstream of the scenario related impacts although there will be impact in terms of user requirements.

The weights are provided in the Table 4.7. The weight is based on the conversion of the PES and EIS to numerical values to determine the normalised weight.

Table 4.7 Weights allocated to EWR sites relative to each other

EWR site	PES	EIS	Locality in protected areas	Distance	Normalised weight
EFR O3	**C**	Moderate	4	0.54	0.35
EFR O4	**C**	High	5	0.23	0.25
EFR O5	**B/C**	High	5	0.23	0.40

The weight was applied to the ranking value for each scenario at each EWR site and this provided an integrated score and ranking for the operational scenarios. The ranking of '1' refers to the REC and the rest of the ranking illustrates the degree to which the scenarios meet the REC. The results are provided in Table 4.8 after the weights have been considered.

Table 4.8 Ranking value for each scenario resulting in an integrated score and ranking

	PES	REC	A2,A3	B	C1b	C2b	D2, D3
EWR O3	0.33	0.35	0.33	0.30	0.33	0.34	0.34
EWR O4	0.22	0.25	0.24	0.19	0.24	0.24	0.25
EWR O5	0.39	0.40	0.40	0.34	0.40	0.40	0.40
Integrated	**0.93**	**1.00**	**0.97**	**0.84**	**0.97**	**0.99**	**0.99**

The above results are plotted on a traffic diagram (Figure 4.4) to illustrate the integrated ecological ranking.

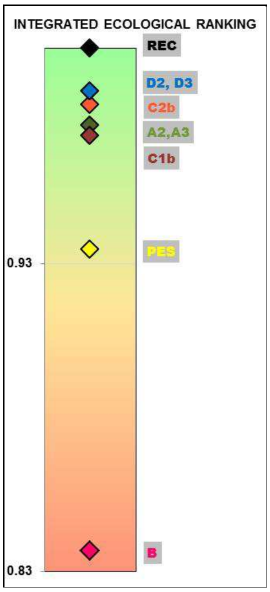

Figure 4.4 Rivers: Integrated ecological ranking of the scenarios on the Lower Orange River system

Scenarios D2 and D3 are the best option as it is closest to meeting the ecological objectives, with Sc C2b close behind. However, the purpose of setting the preliminary Reserve is to provide management guidance that is legally binding. Therefore, the focus is on the pre-dam situation study (and Reserve determination) as is relevant for a Preliminary Reserve and associated management and immediate implementation. As the recommendations are likely to be set for pre-dam situation, Sc A2/A3 will be the recommended scenario.

5 ECOLOGICAL CONSEQUENCES: ORANGE ESTUARY

5.1 DESCRIPTION OF THE ORANGE ESTUARY

The Orange Estuary, situated between the towns of Alexander Bay in the Northern Cape Province, South Africa and Oranjemund in Namibia has an area of about 2700 ha. The estuary of the Orange River comprises an (almost) permanently open river mouth, a 2 to 3 m deep tidal basin, a braided channel system (located between sand banks covered with pioneer vegetation) and a severely degraded saltmarsh on the south bank of the river mouth. A satellite image of the estuary is shown in Figure 5.1.

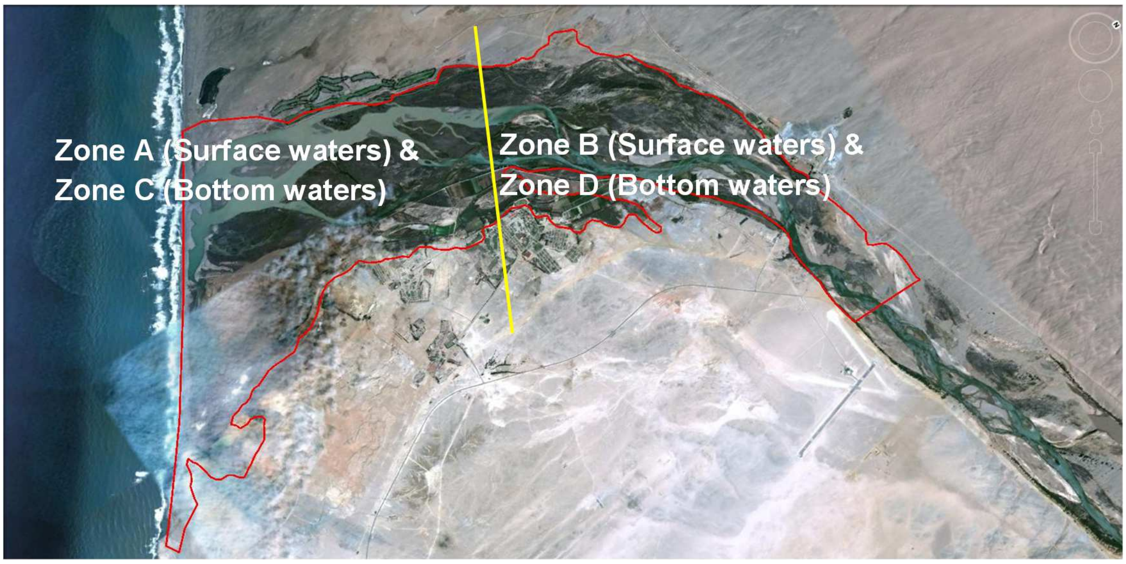

Figure 5.1 Satellite image of the Orange Estuary showing the contour for 5 m above mean sea level contour in red (Source: Google Earth)

Previous freshwater requirement studies indicated that the Orange Estuary extends from the Sir Ernest Oppenheimer Bridge to the mouth, approximately 11 km upstream (CSIR, 2004). For the purposes of the Orange Estuary flow requirement study, the geographical boundaries of the systems are estimated as follows:

- Downstream boundary: The estuary mouth (28°37'58.91"S, 16°27'16.02"E).
- Upstream boundary: Head of tidal influence at the Sir Ernest Oppenheimer Bridge, approximately 11 km for mouth (28°33'43.63"S, 16°31'23.02"E).
- Lateral boundaries: Five meter above Mean Sea Level (MSL) contour along the banks.

5.2 MAJOR PRESSURES ON THE ORANGE ESTUARY

Flow related pressures include:

- **Flow modification (damming and regulation of flows in catchment):** Water resource development in the Orange-Senqu River basin has reduced runoff to the Orange Estuary by more than 50%.

Non flow related pressures include:

- **Structures (e.g. weirs, bridges, mouth stabilisation):** The estuary has been disturbed by human development such as the agricultural developments at Alexander Bay, the levees protecting these developments, the oxidation pond system near the village of Alexander Bay, the road across the salt marsh to the river mouth on the south bank and the golf course, protected by a dyke on the north bank.

- **Wastewater discharges affecting water quality (e.g. dump sites, storm water, sewage discharges):** Agricultural activities in the catchment are the most likely sources of inorganic nutrients (nitrogen and phosphate) to the river. Although some enrichment can occur in the estuary, it is expected that river vegetation largely acts as a filter of inorganic nutrients. Anthropogenic activities in the catchment are also likely to result in pH levels occasionally increasing to about 9. It has been reported on occasion that algal blooms occur. These algal blooms can make their way downstream, resulting in river water entering the estuary being almost anoxic.
- **Wastewater discharges from the mining** activities at Alexander Bay also tend to modify interstitial/groundwater salinity levels in the adjacent salt marsh area.
- **Input of toxic substances from catchment:** There is no information on the toxic inputs from mining operations and adjacent towns and developments or agriculture practices (e.g. pesticide use). This will have to be confirmed through measurements.
- **Fishing effort in the Orange Estuary:** Legal gill netting and seining in South Africa ceased with the Marine Living Resources Act (No. 18 of 1998, South Africa) and South African government policy to phase out all netting in estuaries countrywide. Unfortunately there is still significant fishing effort in the form of illegal gill netting and an order of magnitude increase in recreational angling in the mouth region and adjacent surf-zone. The latter arose from a redistribution of effort that occurred after Namibian authorities implemented more stringent catch control measures including bag limits specifically aimed at anglers leaving the country's borders. Comparable catches and limited fisheries control saw an increase in angling effort on the Alexander Bay side. Local compliance enforcement on the Namibian side is also hampered by the demarcation of the formal protected area only up to the high water mark (i.e. the park does not include the estuary open water area). There has also been a slight increase in interest in flyfishing from Brand Kaross to the mouth for freshwater species as well as for flathead mullet *Mugil cephalus*, elf *Pomatomus saltatrix* and leervis *Lichia amia*. This aspect of recreational angling has potential for a low-key tourist activity. The Total catch from the Orange Estuary, comprising both legal and illegal take is estimated at 5 - 10 tonnes per annum.
- **Grazing:** Domestic livestock, cattle and goats, regularly graze in the South African side of the Ramsar site and frequently cross over the river into the Namibian section of the site. Grazing further degrades the salt marshes, compete with indigenous herbivores and detract from the tourism value of the site.
- **Hunting**: Since the cessation of mining activities and access control on the South African side, hunting with dogs has become a regular occurrence on the islands of the estuary. Apart from the quarry, this hunting is also causing death by stampede and drowning of Oryx and cattle grazing in the floodplain of the system (*Pers. Comm.*, Dr SJ Lamberth, 2013).

5.3 ECOLOGICAL IMPORTANCE OF THE ORANGE ESTUARY

Following South Africa's accession to the Ramsar Convention, the Orange Estuary was designated a Ramsar Site, i.e. a wetland of international importance, on 28/06/1991. Namibia ratified the Ramsar Convention in 1995, after which the designated area was enlarged and the Namibian part of the wetland was designated too. In September 1995, the South African Ramsar Site was placed on the Montreux Record (a list of Ramsar Sites around the world that is in a degraded state) as a result of a belated recognition of the severely degraded state of the saltmarsh on the south bank. The implication is that the Orange Estuary may lose its status as a Ramsar Site unless the condition of the saltmarsh can be restored.

The Namibian section of the Orange Estuary was recently included in the proclamation of the Sperrgebiet National Park in Namibia. However, the section in South Africa is still in the process of being formally protected through legislation. The Orange Estuary also forms part of the core set of estuaries in need of formal protection to achieve biodiversity targets in the region (Van Niekerk and Turpie, 2012). The Orange Estuary is also one of only two estuaries on the Namibian coast, the other being the Kunene River mouth.

Turpie *et al*. (2002) ranked the Orange as the seventh most important system in South Africa in terms of conservation importance. The prioritisation study calculated conservation importance on the basis of size, habitat diversity, zonal type rarity and biodiversity importance. Estuary importance is an expression of the value of a specific estuary to maintaining ecological diversity and functioning of estuarine systems on local and wider scales. The estuary importance score takes size, the rarity of the estuary type within its biographical zone, habitat, biodiversity importance and functional importance of the estuary into account. The biodiversity importance score is in turn based on the assessment of the importance of the estuary for plants, invertebrates, fish and birds, using rarity indices.

During the 2013 Estuary EWR study (Van Niekerk *et al*., 2013a, b), the Ecological Importance of the Orange Estuary was scored in accordance with South Africa methods (DWAF, 2008b). The ecological importance of the Orange Estuary was estimated to be 99 out of 100 and is therefore rated as highly important (Table 5.1). These scores have already been determined for all South African estuaries (DWAF, 2008b), apart from the functional importance score, which was derived by specialists at the EWR workshop. In the case of the Orange Estuary, the functional importance of the system was deemed to be very high (100), since the sediment supply from its catchment feeds the beaches to the north of the mouth. The sediment input from the river is also very important for flatfish in the nearshore environment in the vicinity of the mouth as it provides the habitat on which they depend.

Table 5.1 The importance scores for the Orange Estuary

Criterion	Weight	Score
Estuary size	15	100
Zonal rarity type	10	90
Habitat diversity	25	100
Biodiversity importance	25	99
Functional importance	25	100
Estuary importance score		**99**

5.4 PRESENT ECOLOGICAL STATE

The EHI score for the Orange Estuary is 51, thus a PES of Category D (Table 5.2).

Table 5.2 Estuary: PES (Van Niekerk *et al*., 2013a,b)

Variable	Weight	EHI core	Confidence
Hydrology	25	45	Low/Medium
Hydrodynamics and mouth condition	25	70	Low
Water quality	25	54	Medium
Physical habitat alteration	25	59	Medium
Habitat (abiotic) health score		61	
Microalgae	20	40	Low

Variable	Weight	EHI core	Confidence
Macrophytes	20	50	Medium
Invertebrates	20	45	High
Fish	20	50	Medium
Birds	20	22	Medium
Biotic health score		42	
OVERALL ESTUARY HEALTH SCORE		51	
ECOLOGICAL CATEGORY (PES)		D	Medium

The PES of the Orange Estuary, Category D, reflects a largely modified system. This is primarily attributed to the following factors:

- Significant freshwater flow modification – both loss of floods and increased base-flows.
- Lack of estuary mouth closure and resulting back-flooding of salt marshes with fresher water.
- Road infrastructure such as the old causeway crossing the saltmarshes and old bridge supports.
- Nutrient input from catchment downstream of Vioolsdrift.
- Gill netting of indigenous fish species and considerable fishing effort at the mouth on both sides of the estuary.
- Riparian infrastructure - levees preventing back-flooding.
- Grazing and hunting;
- Mining activities; and
- Wastewater disposal (sewage (recently removed) and mining return flow).

Estimates of the contribution of non-flow related impacts on the level of degradation of each component led to an adjusted PES score of 62 (Category C) that would reflect a moderately modified estuary. This suggests that non-flow impacts play a significant role in the degradation of the Orange Estuary although modification of flows (both floods and base flow) remains the main cause of its degradation.

5.5 RECOMMENDED ECOLOGICAL CATEGORY

The REC represents the level of protection assigned to an estuary based on the PES and Ecological Importance in accordance with the South Africa methods (Table 5.3).

Table 5.3 Relationship between the estuary health score, PES and minimum REC

PES Category	Description	Minimum REC
A	Unmodified, natural	A
B	Largely natural with few modifications	B
C	Moderately modified	C
D	Largely modified	D
E	Highly degraded	-
F	Extremely degraded	-

The PES (in this case Category D) set the minimum REC for an estuary. The degree to which the REC was the elevated above the PES depended on the importance and the level of protection, or desired protection, of a particular estuary. The Orange Estuary is rated as ‘highly important’, being a designated Ramsar Site, a Protected Area on the Namibian side; and a desired protected area in the South African Biodiversity Plan for the 2011 National Biodiversity Assessment (Van Niekerk and Turpie, 2012). The REC for the estuary therefore should be aimed at a Category A or at least its best attainable state. In the case of the Orange Estuary the best attainable state, based on reasonable reversibility of pressures was estimated as a Category C. These translated as follows for the various abiotic and biotic components (Table 5.4).

Table 5.4 Comparison between PES categories and REC for the various abiotic and biotic components in the Orange Estuary, as well as key interventions needed for improvement

Component	PES	REC	Key intervention required for improvement
Hydrology	D	D	Decrease base flows in winter.
Hydrodynamics	C	B	Facilitate mouth closure in winter 2 to 4 time in 10 years.
Water quality	D	C	Reduce nutrient input in lower Orange River catchment.
Physical habitat alteration	B	B	No intervention.
Microalgae	E	D	Reduce base flows in winter and decrease nutrient input.
Macrophytes	D	C	Reduce soil salinities, reduce nutrient input, remove cause way, control grazing and alien vegetation.
Invertebrates	D	B	Reduce base flows in winter and facilitate mouth closure.
Fish	D	C	Reduce baseflows in winter and facilitate mouth closure, control fishing.
Birds	E	D	Reduce baseflows in winter and facilitate mouth closure.
Overall	D	C	Reduce flows, facilitate mouth closure, improve vegetation cover and food sources (invertebrates and fish).

From a flow perspective, this could be achieved primarily by reducing the winter base flows sufficiently to allow for mouth closure and related back-flooding of the salt marshes with brackish water to reduce soil salinity. The recommended distribution of the abiotic states (and associated flow ranges) is captured in Figure 5.2 (Van Niekerk *et al*., 2013a,b).

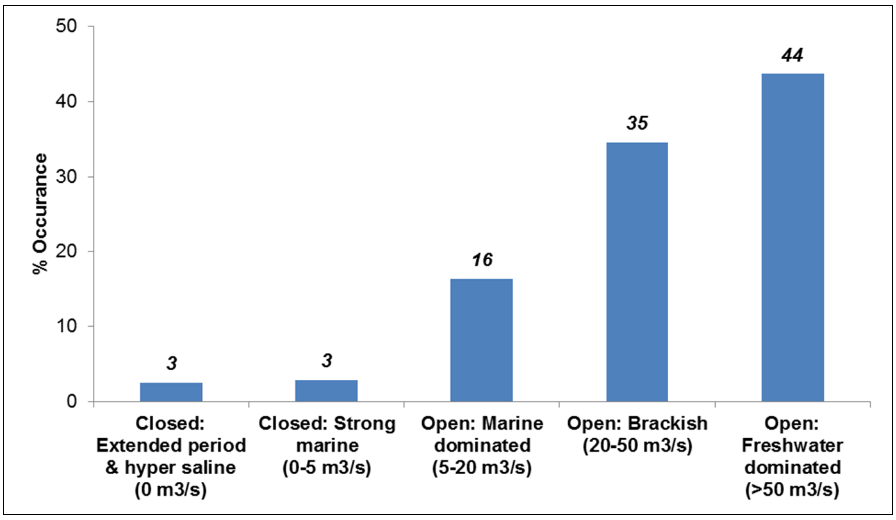

Figure 5.2 The recommended distribution of abiotic states

5.6 ECOLOGICAL CATEGORIES ASSOCIATED WITH SCENARIOS

The ecological condition of the individual abiotic and biotic components, for both the PES and REC, was used as environmental objectives against which the various operational scenarios on the Orange Estuary were assessed as part of this study. As per South Africa's EWR method (DWAF, 2008b), it is assumed undesirable to manage an estuary in less than 40% of its original condition (i.e. below a Category D) as estuarine ecosystems are viewed ecological non-functional at lower levels (e.g. Van Niekerk and Turpie, 2012). This assumption was also applied in the assessment of the individual abiotic and biotic components as per this study.

Eight additional scenarios (Sc) were evaluated as part of this study. The occurrences of the flow distributions (mean monthly flows in m^3/s) under the future scenarios of the Orange Estuary, derived from a 85-year simulated data set are provided in Tables 5.5 to 5.13. Abiotic state colour coding applicable to these tables is as follows:

- Red = Closed: Extended periods and hypersaline.
- Orange = Closed: Strong marine.
- Green = Open: Marine dominated
- Blue = Open: Brackish
- White = Open: Freshwater dominated.

Table 5.5 Summary of the monthly flow (in m^3/s) distribution under Reference Conditions

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	580.8	919.9	1011.9	1317.2	2103.4	1634.0	958.6	388.0	218.5	140.8	156.1	232.3
80%	301.1	624.4	686.8	918.3	1411.1	1030.4	722.2	267.9	141.4	104.3	94.0	128.1
70%	214.8	461.0	493.7	652.4	871.6	731.3	470.8	205.8	97.9	75.8	77.9	73.6
60%	141.3	341.3	395.0	474.5	543.9	635.3	349.5	136.7	71.0	52.4	49.3	50.4
50%	88.8	221.4	305.4	378.4	420.4	516.3	304.3	108.6	57.6	40.0	32.0	34.7
40%	57.2	181.0	258.9	258.1	321.8	367.3	250.2	84.1	52.0	31.2	21.4	22.1
30%	41.8	138.4	185.4	208.3	273.2	286.1	182.3	69.2	38.9	24.1	17.9	12.3
20%	15.2	96.9	88.4	157.3	204.1	194.5	135.9	43.9	26.0	17.4	12.6	4.3
10%	5.6	33.9	61.1	79.2	144.8	122.8	79.1	28.7	17.9	11.6	7.3	0.0
1%	0.0	0.0	12.0	18.3	22.3	29.5	16.3	2.2	6.2	7.6	2.8	0.0

Table 5.6 Summary of the monthly flow (in m^3/s) distribution under Present State

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	72.8	214.2	233.9	527.5	1436.4	837.7	679.5	204.7	127.9	49.1	64.2	23.6
80%	18.9	99.6	112.4	211.6	505.8	591.0	393.2	145.6	48.7	18.3	13.6	8.8
70%	17.3	22.4	51.2	99.8	152.6	434.4	190.3	68.9	32.2	11.7	10.5	7.9
60%	16.8	19.1	26.2	39.0	115.3	231.0	94.4	37.1	16.7	10.4	10.1	7.6
50%	16.6	17.8	19.0	29.6	49.9	123.2	68.6	24.6	15.1	10.1	9.9	7.6
40%	16.5	17.5	17.6	20.1	27.5	60.5	47.1	21.1	13.5	9.9	9.8	7.5
30%	16.4	17.4	16.7	16.8	20.8	32.7	35.8	19.8	13.0	9.8	9.7	7.5
20%	16.4	17.1	16.4	16.4	17.0	28.6	28.0	19.2	12.0	9.5	9.7	7.5
10%	16.3	16.9	16.3	16.3	15.0	23.4	26.4	18.4	11.6	8.9	8.2	7.5
1%	16.3	16.4	16.2	16.2	14.9	21.2	25.5	17.9	11.5	8.8	7.9	7.4

Table 5.7 Summary of the monthly flow (in m^3/s) distribution under Sc A2

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	65.7	224.7	240.8	535.2	1427.8	817.7	652.7	207.9	127.9	58.5	64.1	33.3
80%	30.6	106.6	121.6	235.2	418.1	590.5	383.9	143.6	54.1	34.2	27.7	26.8
70%	29.9	38.1	58.3	105.8	148.9	419.7	191.8	77.0	35.7	27.8	26.0	26.6
60%	29.7	36.2	36.7	50.4	100.8	195.4	80.7	44.3	33.0	27.0	25.5	24.8

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
50%	25.1	33.7	33.8	39.5	43.2	108.4	56.8	39.6	29.0	25.9	24.1	22.0
40%	20.2	27.3	24.5	30.9	30.0	45.8	35.8	31.7	22.2	21.7	17.7	16.2
30%	14.8	18.8	15.0	22.0	19.7	17.9	24.3	22.3	11.9	14.8	12.8	9.9
20%	7.3	11.6	8.1	10.0	12.1	13.8	15.1	14.1	9.1	11.2	7.5	4.4
10%	4.3	5.6	4.3	4.5	6.7	10.2	13.2	9.3	6.7	6.3	6.1	4.0
1%	4.0	4.6	4.0	4.0	4.9	8.7	12.9	8.7	5.5	5.2	4.4	4.0

Table 5.8 Summary of the monthly flow (in m3/s) distribution under Sc A3

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	63.6	224.6	199.4	529.5	1425.9	804.9	645.2	207.3	127.0	48.9	58.9	32.6
80%	30.5	61.9	117.3	215.5	372.8	592.0	384.1	127.6	54.2	34.2	27.6	26.8
70%	29.8	38.0	58.2	104.2	148.9	419.7	189.6	75.8	34.6	27.8	26.0	26.6
60%	29.6	36.1	36.6	49.7	100.8	189.9	80.7	42.1	33.0	27.0	25.5	24.7
50%	25.0	33.6	33.7	39.3	43.1	106.7	55.0	38.4	29.0	25.9	24.1	21.9
40%	20.1	27.1	23.0	30.8	30.0	47.5	28.5	31.5	22.3	21.7	17.7	16.2
30%	14.7	18.7	14.9	21.8	19.7	19.0	23.1	22.2	11.9	14.8	12.8	9.9
20%	7.2	11.5	7.9	9.8	12.1	15.5	15.2	14.0	9.1	11.2	7.5	4.4
10%	4.3	5.6	4.3	4.4	6.6	10.2	13.2	9.3	6.8	6.3	6.1	4.0
1%	4.0	4.6	4.0	4.0	4.8	8.7	12.9	8.7	5.5	5.2	4.4	4.0

Table 5.9 Orange Estuary: Simulated monthly flows (in m^3/s) for Sc B

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	14.5	82.2	114.1	251.7	1022.2	678.7	541.4	153.0	88.4	27.0	22.6	5.8
80%	14.5	14.1	14.7	17.1	319.4	434.4	287.4	91.1	30.3	7.7	6.0	5.7
70%	14.5	14.0	14.5	14.5	13.9	189.3	109.3	43.6	9.2	6.5	5.9	5.7
60%	14.5	14.0	14.4	14.4	13.3	17.3	51.3	14.4	9.0	6.5	5.9	5.7
50%	14.5	14.0	14.4	14.4	13.2	17.1	19.3	14.1	9.0	6.5	5.8	5.7
40%	14.5	14.0	14.4	14.4	13.2	17.1	19.0	14.0	9.0	6.5	5.8	5.7
30%	14.5	14.0	14.4	14.4	13.2	17.0	19.0	14.0	9.0	6.5	5.8	5.7
20%	14.5	14.0	14.4	14.4	13.2	17.0	19.0	14.0	9.0	6.5	5.8	5.7
10%	14.5	14.0	14.4	14.4	13.2	17.0	19.0	14.0	9.0	6.5	5.8	5.7
1%	14.5	14.0	14.4	14.4	13.2	17.0	19.0	14.0	9.0	6.5	5.8	5.7

Table 5.10 Orange Estuary: Simulated monthly flows (in m^3/s) for Sc C1b

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	29.9	64.5	110.8	237.0	715.0	673.3	535.0	146.3	68.6	29.7	27.5	27.6
80%	29.5	36.5	41.1	67.0	267.1	434.9	272.7	66.9	38.2	28.9	27.1	27.5
70%	28.8	35.6	39.5	49.6	76.8	252.4	109.4	50.0	36.8	28.2	26.4	26.8
60%	27.1	34.0	37.1	44.3	64.0	74.1	69.9	45.0	34.2	27.0	25.2	25.3
50%	24.2	30.4	31.1	37.0	53.6	46.7	58.6	39.9	29.3	24.7	22.6	22.4
40%	19.1	24.8	21.7	26.4	38.2	28.3	42.7	31.6	23.2	20.8	18.3	16.8
30%	12.5	16.9	12.5	19.0	21.3	13.9	21.8	20.7	15.4	15.5	12.9	9.4
20%	4.9	8.2	4.1	5.5	11.2	9.4	14.1	11.7	8.7	9.2	6.6	1.7
10%	0.0	0.3	0.0	0.0	6.4	7.3	5.8	6.2	4.5	4.0	1.9	0.0
1%	0.0	0.0	0.0	0.0	4.3	6.7	3.9	1.4	2.7	1.7	0.5	0.0

Table 5.11 Orange Estuary: Simulated monthly flows (in m³/s) for Sc C2b

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	29.9	82.2	113.9	359.5	700.1	668.4	452.4	146.3	54.7	29.1	27.5	27.6
80%	29.5	36.6	41.1	68.3	251.0	451.6	261.5	87.4	43.3	28.9	27.1	27.5
70%	28.8	35.6	39.6	49.6	77.5	258.7	109.2	65.3	42.0	28.3	26.4	26.8
60%	27.1	34.0	37.6	44.3	64.0	113.8	78.0	58.9	36.2	27.0	25.2	25.3
50%	24.2	30.4	31.1	37.0	53.6	57.0	60.6	42.4	32.1	24.7	22.6	22.4
40%	19.1	24.8	21.7	26.4	38.2	30.8	48.6	34.0	24.6	20.8	18.3	16.8
30%	12.5	16.9	12.5	19.0	21.3	13.9	21.8	21.0	16.1	15.5	12.9	9.4
20%	4.9	8.2	4.1	5.5	11.2	9.4	12.3	11.6	8.7	9.2	6.6	1.7
10%	0.0	0.3	0.0	0.0	6.4	7.3	5.7	6.2	4.5	4.1	1.9	0.0
1%	0.0	0.0	0.0	0.0	4.3	6.7	3.9	1.4	2.7	1.7	0.5	0.0

Table 5.12 Orange Estuary: Simulated monthly flows (in m³/s) for Sc D2

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	29.9	88.7	119.9	389.3	706.1	671.9	455.3	148.2	56.3	29.9	28.2	27.6
80%	29.5	36.7	41.2	90.6	272.9	457.1	265.3	88.6	45.2	29.0	27.2	27.5
70%	28.8	35.6	39.6	50.7	101.8	274.7	115.9	69.7	43.4	28.3	26.4	26.8
60%	27.1	34.0	37.6	44.4	65.4	134.2	95.8	63.7	40.1	27.0	25.2	25.3
50%	24.2	30.4	31.1	37.0	55.5	78.9	72.7	51.8	34.3	24.7	22.6	22.4
40%	19.1	24.8	22.8	26.4	42.9	57.4	57.1	36.4	28.0	20.8	18.3	16.8
30%	12.5	16.9	12.5	21.6	21.3	17.3	26.5	21.5	17.3	15.5	12.9	9.4
20%	4.9	8.2	4.4	5.5	11.2	11.8	14.9	11.7	10.0	9.4	6.6	1.7
10%	0.0	0.3	0.0	0.0	6.4	8.0	5.7	6.2	5.1	4.6	1.9	0.0
1%	0.0	0.0	0.0	0.0	4.3	6.7	3.9	1.4	2.7	1.7	0.5	0.0

Table 5.13 Orange Estuary: Simulated monthly flows (in m³/s) for Sc D3

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
90%	29.9	88.7	119.9	389.3	706.1	671.9	455.3	148.2	56.3	29.9	27.5	27.6
80%	29.5	41.4	45.9	88.6	271.2	457.1	264.9	88.6	45.2	29.0	27.1	27.5
70%	28.8	40.4	44.3	54.3	88.1	274.0	112.6	69.7	43.4	28.3	26.4	26.8
60%	27.1	38.8	42.3	49.1	70.1	128.1	86.6	63.7	40.1	27.0	25.2	25.3
50%	24.2	35.2	35.8	41.7	58.9	68.0	69.8	51.8	33.8	24.7	22.6	22.4
40%	19.1	28.0	26.1	29.3	42.2	50.4	55.5	36.4	26.0	20.8	18.3	16.8
30%	12.5	18.7	14.1	24.0	22.7	16.5	25.3	21.5	17.3	15.5	12.9	9.4
20%	4.9	9.0	5.0	6.1	11.8	11.6	14.9	11.7	10.0	9.4	6.6	1.7
10%	0.0	0.4	0.0	0.0	6.6	8.1	5.7	6.2	5.1	4.6	1.9	0.0
1%	0.0	0.0	0.0	0.0	4.3	6.7	3.9	1.4	2.7	1.7	0.5	0.0

In general, the scenarios (except for Sc A2 and A3) involve further reductions in freshwater inflow to the estuary. Details and motivations of the ecological consequences of proposed scenarios on the individual abiotic and biotic components are provided in Table 5.14. The individual health scores for the various abiotic and biotic components are used to determine the ecological status or ecological category for the Orange Estuary under each of the future scenarios (Table 5.15), again using the EHI.

Table 5.14 Orange Estuary: EHI score and corresponding ECs under present and operational scenarios

Parameter	Scenarios								Motivations
	Present	A2	A3	B	C1b	C2b	D2	D3	
a. % similarity in low flows	62	64	63	39	58	60	63	63	All the scenarios represent a slight improvement in low flow conditions from the present, with Sc A2, D2 and D3 offering the best distribution.
b. % similarity in floods	20	20	20	18	18	18	19	19	The A scenarios are all similar to present, with a further decrease under the B and C scenarios. The D scenario seems to represent a slight improvement.
Hydrology scores	**45**	**46**	**46**	**31**	**42**	**43**	**45**	**45**	
Change in mean duration of closure	70	70	80	50	40	40	40	40	Sc A3 represents improvements on the present conditions with associated opportunities for mouth closure. Sc A2 maintains the present situation – no mouth closure. Sc C and D represent a decline in open mouth conditions. Scenario B represent a permanently open mouth condition similar to present, but an additional 20% was subtracted to reflect the stagnant conditions that would develop under the steady-state flows provided under the scenario. A concern that has only be raised as a result of recent field surveys is that under extended periods of low flow (>3 months) the in-stream habitat is severely reduced, i.e. channel area becomes very constricted and/or shallow.
Hydrodynamics and mouth condition	**70**	**70**	**80**	**70**	**40**	**40**	**40**	**40**	
Salinity	61	72	72	51	59	72	61	61	Generally increase in salinity from reference due to the overall reduction in low flow conditions to the system. Scenario B and C1b especially show a marked decline in saline conditions.
Inorganic nutrients (N and P)	52	53	53	55	56	53	54	54	Present: ⇧⇧ due to nutrient enrichment from catchment especially during high flow conditions, as well as stronger marine influence also introducing nutrient (upwelling) to lower estuary. Scenarios: ⇧⇧ The slight shifts in nutrients from Present to Scenarios primarily relate to slight shifts in occurrence of high flow conditions. Major shift in nutrients occurred from Reference to Present as a result of anthropogenic inputs in the catchment (e.g. agriculture).

Parameter	Scenarios								Motivations
	Present	A2	A3	B	C1b	C2b	D2	D3	
Turbidity	71	72	71	59	65	71	69	70	Present: ⇩ due to a marked reduction in high flows (decrease in State 5) and stronger influence of clear marine waters in the lower reaches (increase in State 3). Catchment naturally introduced high turbidity in estuary during high flows. Scenarios: ⇩The slight shifts in turbidity from Present to Scenarios primarily relate to slight shifts in occurrence of State 5. Major shift in turbidity occurred from Reference to Present as a result of the large reduction in high flow (e.g. State 5).
Dissolved Oxygen (DO)	98	99	99	96	98	99	98	98	Present: Slight ⇩ in bottom water DO in upper estuary due to increase closed state (State 2). Scenarios: ⇩Similar to Present, shifts in state not large enough to show affect in DO. The water column is relatively shallow and exposed to strong wind mixing.
Level of toxins	85	85	85	85	85	85	85	85	⇧ in toxic input associated with agricultural activity in catchment.
Water quality Score	**54**	**61**	**61**	**53**	**57**	**61**	**57**	**57**	
% similarity in intertidal area exposed	65	65	65	44	44	44	46	46	For the dam scenarios the estuary channels will become shallower due to sediment deposition related to the loss of small frequent floods. In the upper reaches (4 – 7 km from the mouth) 7 – 11 km from the mouth) the main channel could become 40% shallower on average, in the middle reaches (3 to 7 km from the mouth) the channel could become 50% shallower, and in the lower reaches (0 – 3 km from the mouth) the channel could become 60 % shallower. The main channel width will also decrease in the Upper river dominated reach by about 10 to 20% for the dam scenarios compared to the present day.
% similarity in sand fraction relative to total sand and mud	50	50	50	20	20	20	25	25	
% similarity of sub-tidal area (depth, bed, channel)	60	60	60	39	39	39	41	41	
Physical habitat alteration	**59**	**59**	**59**	**36**	**36**	**36**	**38**	**38**	
HABITAT (ABIOTIC) HEALTH SCORE	**61**	**59**	**61**	**47**	**44**	**45**	**45**	**45**	
Benthic Microalgae Species richness	60	62	64	55	50	50	55	55	For Sc A2 and A3 there is a slight improvement in mouth closure from present and salinity is closer to natural with some small improvement in benthic microalgae. Benthic microalgal biomass responds to decrease in floods, intertidal and subtidal habitat and health decreases away from reference conditions.
Benthic Microalgae Abundance	40	42	44	30	30	30	35	35	
Benthic Microalgae Community	80	82	84	75	70	70	75	75	

Parameter	Scenarios								Motivations
	Present	A2	A3	B	C1b	C2b	D2	D3	
composition									
Microalgae: Benthic Microalgae	40	42	44	30	30	30	35	35	
Phytoplankton Species richness	70	72	74	65	60	60	60	60	Under Sc A2 and A3 there is a slight improvement in mouth closure from present and salinity is closer to natural with some small improvement in phytoplankton score. For the other scenarios phytoplankton responds to the mouth condition. Extended mouth closure under Sc C and D will change the phytoplankton biomass and composition.
Phytoplankton Abundance	64	66	68	60	55	55	55	55	
Phytoplankton Community composition	60	62	64	55	50	50	50	50	
Microalgae: Phytoplankton	**60**	**62**	**64**	**55**	**50**	**50**	**50**	**50**	
Overall Microalgae	**40**	**42**	**44**	**35**	**30**	**30**	**35**	**35**	
Macrophytes Species richness	50	52	53	40	42	42	45	45	Under Sc A2 and A3 there is a slight improvement in mouth closure from present and salinity is closer to natural with some resultant improvement in macrophytes. Large floods no longer reset the system for the other scenarios (B - D) leading to sand bank development and vegetation encroachment in the lower reaches. For Sc B the mouth remains open, no back flooding occurs and the salt marsh remains saline. In the lower reaches, the channel could become 60% shallower. In addition, an increase in mouth closure will lead to stagnant and eutrophic conditions where macroalgal blooms are common. Nutrient concentrations remain high for all scenarios. Higher salinity conditions in Sc C1b, D2 and D3 i.e. approximately 25 ppt for 13% of the time may reduce reed and sedge growth. Scenario D includes some small floods resulting in less stagnant conditions and a slight improvement downstream.
Macrophytes Abundance	67	68	69	40	38	40	42	45	
Macrophytes Community composition	63	65	67	40	42	42	42	45	
Macrophytes scores	**50**	**52**	**53**	**40**	**38**	**40**	**42**	**45**	
Invertebrate Species richness	50	50	50	48	48	50	50	50	Sc A2 and A3 is similar to the present. Under Sc B, C and D the reduction in floods and severer overall decrease in flow variability, coupled with significant increase in sediment stability will severely affect the invertebrates of the Orange Estuary. The highly regulated flow of the Sc B will lead to dominance of a select few species and lead to overall reduction in species richness.
Invertebrate Abundance	45	45	45	30	37	38	40	40	
Invertebrate Community composition	45	45	45	30	37	38	40	40	
Invertebrates scores	**45**	**45**	**45**	**30**	**37**	**38**	**40**	**40**	

Parameter	Scenarios								Motivations
	Present	A2	A3	B	C1b	C2b	D2	D3	
Fish Species richness	60	50	50	35	25	30	30	30	Reduction in floods will see a drop in species richness associated with a reduction in recruitment signal strength in the nearshore. Marginal increase in opportunistic mullet associated with rise in benthic microalgal biomass but numbers very similar to present day. Mouth closure and back-flooding will temporarily increase fish nursery area but increase in the frequency and duration of mouth-closure over the spring-early summer recruitment period will severely impact recruitment of estuary-dependent marine species. Reduced freshwater inflow and intrusion of seawater will limit freshwater species to the upper reaches of the estuary so overall deviation from 50/50 marine/freshwater community structure under reference.
Fish Abundance	50	40	40	35	25	25	30	30	
Fish Community composition	60	40	40	25	30	30	40	40	
Fish scores	**50**	**40**	**40**	**25**	**25**	**25**	**30**	**30**	
Bird Species richness	85	85	85	85	85	85	85	85	Birds respond to the availability of physical habitat, mouth state, microalgae, macrophytes, invertebrates and fish. Sc A2 is similar to present. Birds show a slight improvement under Sc A3 and a further decline in heath under the B, C and D scenarios.
Bird Abundance	22	22	23	18	18	18	19	19	
Bird Community composition	36	36	36	36	30	30	31	31	
Birds scores	**22**	**22**	**23**	**18**	**18**	**18**	**19**	**19**	
BIOTIC HEALTH SCORE	**42**	**40**	**41**	**29**	**30**	**30**	**33**	**34**	
ESTUARY HEALTH SCORE	**51**	**50**	**51**	**35**	**37**	**38**	**39**	**39**	
ESTUARY ECOLOGICAL CATEGORY	**D**	**D**	**D**	**E**	**E**	**D/E**	**D/E**	**D/E**	

A comparison of the overall ecological condition of the estuary under each of the proposed scenarios relative to the PES (D Category) and REC (C Category) are presented in Figure 5.3. Results can be summarised as follows:

- The ECs of the PES and all proposed scenarios are well below the REC (EC C) for the Orange Estuary.
- The PES of the estuary is currently in a D EC, but with two biotic components, i.e. microalgae and birds (a key biotic component protected under Ramsar Convention) already below the ecological functional threshold of an D Category.
- Scenario A3 shows an improvement on the Present as a result of the redistribution of flow in the low flow period and the estuary mouth conditions moving towards a more natural regime. Scenario A2 showed a slight decline in condition from the present state. The overarching condition for the A scenarios is a D EC.
- Scenario D2 results in all components showing a significant decline in health, with hydrodynamics, physical habitat, macrophytes, microalgae, invertebrates, fish and birds below a functional level of a D EC. The overarching condition is also reduced to an E EC. Of note is that the fish, an additional Ramsar listing criteria, declines to an E EC under the D scenarios. Scenario D3 represents a slight improvement on Scenario D2 from a macrophyte perspective. A key driver of the decline in condition is non-flow related impacts, the loss of floods, infilling and decline in baseflows. Preliminary sensitivity testing shows that opportunities exist to improve the D scenarios by 1 or 2% by elevating some of the baseflows above $10m^3/s$. These incremental improvements would assist in reducing stagnant conditions in the estuary and reduce the risk of fish recruitment failure.
- Scenario C1b and C2b results in all components showing severe decline in health, with hydrology, hydrodynamics, Physical habitat, macrophytes, microalgae, invertebrates, fish and birds below a functional level of a D EC. The overarching condition is also reduced to an E EC. Of note is that the fish, an additional Ramsar listing criteria, declines to an E EC under the C scenarios. A key driver of the decline in condition is non-flow related impacts, the loss of floods, infilling and decline in baseflows and potential recruitment failure of fish.
- Scenario B represents the worst case scenario with its highly regulated flows forcing most components (with the exception of water quality and hydrodynamics) below the functional level of an EC D. Abiotic components range between D to E Category, while biotic component decline to an E Category (with the exception of the Macrophyte component in a D/E EC). The overarching condition is also reduced to an E EC.

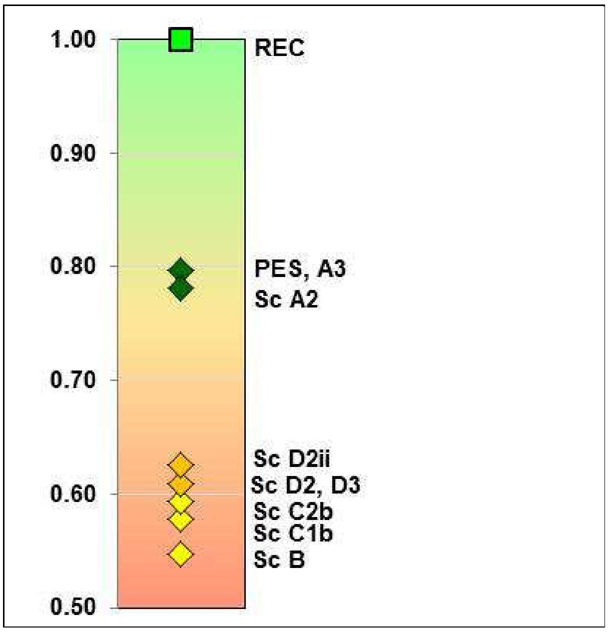

Figure 5.3 Orange Estuary: Relative ranking of the scenarios versus REC

Key findings from this assessment are:

- All the proposed dam development scenarios will reduce the ecological condition of the Orange Estuary from the present state in one or more of the individual abiotic and biotic components significantly. The small dam development (D scenarios) is associated with 12% decline in health (D/E EC), while large dam developments (scenarios B and C) are associated with a 13 to 16% decline in health (E EC).
- As with the PES, the ecological condition associated with all proposed scenarios are well below that required for the REC, also for most of the individual abiotic and biotic components.
- Scenario A3 is the operational scenario associated with the least ecological degradation.
- A key flow related requirement to achieve the REC will be to reduce present winter base flows sufficiently to allow for mouth closure and related back-flooding of the saltmarshes with brackish water to reduce soil salinities, but not to the point where the estuary mouth remains closed for longer than 2 to 4 times in 10 years by decreasing river inflow to less than 5 m^3/s. An additional requirement is the need to elevate base flows above 10 m^3/s from December onwards. After long periods of very low flow the instream habitat becomes very reduced and/or shallow.
- As per the 2013 Estuary EWR study (Van Niekerk *et al*., 2013a,b), the REC for the Orange Estuary cannot be achieved through flow interventions only.

A particular concern is the impact additional flood reduction will have on the system. With the large dam development scenarios (>30 m dam wall) associated with a significant decrease in the frequency and size of floods which in turn will reduce resetting events. This is likely to lead to significant infilling of the estuary, increased sediment stability, less meandering, less habitat diversity, loss of diversity in invertebrate population, and less recruitment of fish.

In addition to modification as a result of changes in river flow, infra-structure associated with the building of a dam can also have ecological impacts on the downstream estuary, such as isolating freshwater and estuarine biota from the lower river and area above Vioolsdrift.

The flow requirements of the marine environment were not assessed as part of this study. Given that the proposed Vioolsdrift Dam development will impact on the sediment load, organic input, nutrients and persistence of freshwater fronts in the nearshore marine environment this aspect urgently needs additional consideration.

5.7 MITIGATIONS AND RECOMMENDATIONS

The REC for the Orange Estuary cannot be achieved through flow interventions only. Specialists estimate that the estuary condition can be improved by about 10% through non-flow related interventions. Critical non-flow related mitigation measures include:

- Control the fishing effort on both the South African and Namibian side through increased compliance and law enforcement. This also requires the alignment of fishing regulations (e.g. size and bag limits) and management boundaries on either side of the transboundary estuary;
- Enhance nursery function for estuarine dependant fish species.
- Remove the remnant causeway that still transects the saltmarshes to improve circulation during high flow and floods events. This will also assist with increasing the water circulation into the lower marsh areas.
- Decrease nutrient input from the catchment downstream of Vioolsdrift, through improved agricultural practices.
- Control windblown dust and wastewater from mining activities; and
- Reduce/remove grazing and hunting pressures (which have significantly escalated in the last 5 years).

It should be noted, however, that some of these proposed mitigation measures, such as the reduction in fishing pressure, would be difficult to achieve in the short-term. It is therefore strongly recommended that the Estuary Management Plan currently being developed for the Orange Estuary prioritise these actions for future implementations.

It is also recommended that the management of the estuary proactively addresses potential issues stemming from estuary mouth closure such as:

- Determining the water level (relative to mean sea level) at which critical infrastructure and developments will be inundated if mouth closure occurs (e.g. by means of a Lidar survey of both South African and Namibian estuary floodplains).
- Investigating the protection of the aforementioned infrastructure (e.g. golf course on the Namibian side).
- Developing a mouth breaching protocol based on ‘Guidelines for the mouth management of the Orange Estuary (CSIR, 2005); and
- Monitor water quality during the closed period.

Lastly, the flow requirements of the nearshore Orange Marine Environment (declared a South African Ecologically or Biologically Significant Marine Areas (EBSA) under the Convention on Biodiversity Conservation) needs to be assessed to quantify the impact of the proposed Vioolsdrift dam development on the provision of sediments, organics, nutrients and freshwater fronts to the beaches and nearshore marine environment.

5.8 RECOMMENDED SCENARIO

The recommendation is defined as the flow scenario (or a slight modification thereof to address low-scoring components) that represents the highest change in river inflow that will still maintain the estuary in the REC. The recommended scenario for the Orange Estuary is the Present or Sc A3 that maintains the D EC.

6 ECOSYSTEM SERVICES CONSEQUENCES

6.1 EWR O3 (AUGRABIES)

6.1.1 Overview of Ecosystem Services

The reach includes 375 km of river from the uppermost part of the Augrabies National Park to Vioolsdrift. The stretch includes substantial areas of commercial farming activity on the South African side of the border, which has a favourable topography for farming. Agriculture is focussed around high value cash crops such as grapes and dates. In contrast, the Namibian side of the border is generally steeper and thus less suitable for farming. Furthermore, the desert strip on the Namibian side makes this area less accessible to migration down to the river. Regulation of the river has changed the natural flow regime to be more consistent throughout the year. The flow has been regulated to support the agricultural activities on the South African side. Black Fly (*Simulium* spp.) is a significant problem in the area. Due to regulation, elevated water base flows have created the conditions necessary for their proliferation to pest levels. Extensive modification of the floodplain has taken place as levees have been created to colonise the floodplain and protect the standing crop. Population densities are higher on the South African side than on the Namibian, but are relatively low at a national scale. The only significant settlement is Vioolsdrift at the bottom end of the reach. The next largest settlement is Onseepkans, a secondary settlement with a very low population. Augrabies National Park occupies some 50 km of the river reach. The Park was developed around the Augrabies Waterfall, but also stocks some game and is home to a variety of water-dependant avifauna. Canoeing is a popular recreational activity in this part of the river.

A range of ecological Goods and Services have been considered for the Augrabies river reach, and summarised below:

- Subsistence fishing is important in the context of the river, but only to a small number of people. These are largely the people associated with the farming activities in the area. The species targeted for subsistence fishing are the larger species including carp, barbel/catfish, yellowfish, and tilapia.
- Recreational fishing in the area is largely restricted to fly-fishing.
- Recreational hunting in the area is not part of a larger enterprise but mostly small-scale. The area is more accessible than the upstream area, so the incidence of small-scale recreational hunting and poaching (mainly geese and ducks) is likely to be higher in this area than sites in the upper reaches of the river. There are, however, limited riparian animals that are utilised for hunting.
- Sedges are available but usage is low. *Cyperus marginatus* is one of the common sedge species found along the river stretch.
- Reeds are important for building temporary structures for seasonal labourers. *Phragmites australis* is one of the common reed species found that is used for this purpose.
- *Cynodon dactylon* is one of the important species for grazing on this river stretch.
- Geophytes are important for floral decoration and medicinal purposes. Floral decorative value would be linked to aesthetics of the area as well as decorative purposes in tourism accommodation but it is likely that many substitutes to geophytes are available. Medicinal usage would be limited to seasonal agricultural labourers in the area. *Crinum bulbispermum* is one of the most common geophytes in this river stretch.
- The main indigenous timber and fuel wood species are *Acacia erioloba*, *Acacia karoo*, *Prosopis glandulosa*, and *Ziziphus mucronata*. The main uses of exotics in the area are timber and fuel

wood. Common exotic species in the area include *P. glandulosa*, *Eucalyptus camuldensis* and *Nicotiniana glauca*.

- *Tamarix usneoides* is the indigenous plant species that is used by cattle and game as a natural salt lick.
- Commercial cultivation of flood terraces ("floodplain pockets") is widespread.
- Recreational canoeing is important in the river sections under consideration.
- Ritual use of the river is low, given the low densities of people.
- The river is central to the Augrabies area and the aesthetic attraction is largely linked to the amount of water flowing over the falls and has aesthetic value.
- Bird watching is an important recreational activity and tourism draw card in the area. Under the REC, improved flows would eventually result in more open areas in the marginal and lower zone. This will lead to the return of avifaunal species that prefer grassy grazing lawns (ducks, geese), mudflats (waders), alluvial sandbars (plovers) and shallow edge habitats for waders. Increased abundance and diversity of bird species would improve the value of the area for bird watching. Under the AEC, the wader component of bird species occupying the area would decrease due to habitat loss. Furthermore, waders are always a challenge to bird watchers. Value of the area for bird-watching would decrease.
- The main eco-tourism activity in the area is riparian game viewing associated with water holes.
- Flooding leads to more deposition of fine sediments on the terraces. This will lead to improved soil quality for agriculture.
- Black Fly has become a major pest on the river, and their presence is a cost or a disservice.

6.1.2 Consequences of scenarios

Scenario A2, B, C1b and C2b were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecosystem services responses could be differentiated:

- **Sc A2** = Sc A3.
- **Sc C2b** = Sc D2 = Sc D3.

Each of the services that related to the defined categories i.e. provisioning, regulating, cultural and supporting were collated and scored. Under all four scenario sets considered, the provisioning services were deemed to remain constant against the status quo score of “1” or improve. Regulating services improved under all scenarios bar Sc B where they were marginally negative. Cultural Services were likewise potentially improved under all scenarios bar Sc B. Supporting services were unlikely to change in any discernible manner. These results are detailed in Table 6.1.

Ecosystem Services were then weighted to generate an overall sore. Weights, as a percentage of 100, were generated based on the context of the site and reach. The following weights were given:

- Provisioning Services = 20%.
- Regulating Services = 35%.
- Cultural Services = 25%.
- Supporting Services = 15%.

Table 6.1 EWR O3: Consequences of scenarios on Ecosystem Services

Service Category		Sc A2, A3	Sc B	Sc C1b	Sc C2b, D2, D3
Provisioning	Normative Score	1.07	1.00	1.05	1.07
Regulating	Normative Score	1.24	0.99	1.06	1.26
Cultural	Normative Score	1.10	0.90	1.08	1.18
Supporting	Normative Score	1.00	1.00	1.00	1.00
Provisioning	Weighted Score	0.21	0.20	0.21	0.21
Regulating	Weighted Score	0.44	0.35	0.37	0.44
Cultural	Weighted Score	0.33	0.27	0.32	0.35
Supporting	Weighted Score	0.15	0.15	0.15	0.15
Total		**1.13**	**0.96**	**1.05**	**1.16**

Overall Scenario Groups A2, C1b and C2b are positive with Sc B being negative.

6.2 EWR O4 (VIOOLSDRIFT)

6.2.1 Overview of Ecosystem Services

The reach under consideration includes 150 km of river from Vioolsdrift to the confluence with the Fish River. The river marks the border between South Africa and Namibia. The river sections include parts of the Richtersveld National Park. Downstream of Vioolsdrift and upstream of the Park there are pockets of irrigated agriculture developed near the river. Irrigation appears on both sides of the river, in both South Africa and Namibia. The Richtersveld National Park is a harsh and barren area where the Orange River is the central water feature. It is prized for its remoteness and aesthetic appeal. The local community, which owns the entire area located in South Africa, manages the National Park in conjunction with South African National Parks and is entirely responsible for management of the World Heritage Site. Both sides of the river are used by traditional nomadic herders to practice their ancient lifestyle and culture. It is the last place where the traditional way of life of the KhoiKhoi (of whom the Nama are the surviving clan), who once occupied the entire south-western part of Africa, survives to any great extent.

Canoeing is a popular recreational activity in this part of the river. As with the upstream parts, regulation of the river has changed the natural flow regime to be more consistent throughout the year. Black Fly (*Simulium* spp.) is a significant problem in the area.

A range of ecological Goods and Services have been considered for the river reach downstream of Vioolsdrift and detailed below:

- Subsistence fishing is important in the context of the river but only to a small number of people in the Vioolsdrift – Richtersveld area. Poaching of fish is highly evident. The species targeted for subsistence fishing are the larger species, including carp, barbel/catfish, yellowfish, and tilapia.
- Recreational fishing in the area is largely restricted to fly-fishing.
- Recreational hunting in the area is not part of a larger enterprise but mostly small-scale.
- Sedges are available but usage is low. *C. marginatus* is one of the common sedge species found along the river stretch
- *C. dactylon* is one of the important species for grazing in this river stretch.

- The main uses of exotics trees in the area are timber and fuel wood. Common exotic species in the area include *P. glandulosa, E. camuldensis* and *N. glauca*.
- The main indigenous timber and fuelwood species are *A. erioloba*, *A. karoo*, *P. glandulosa*, and *Z. mucronata*.
- At present there is indiscriminate browsing by goats, but *Seasia pendulina, Diospyros lycioides* and *A. karoo* are the main plant species grazed.
- *T. usneoides* is the indigenous plant species that is used by cattle and game as a natural salt lick.
- The river has waste assimilation and dilution attributes linked closely to base flows and flooding. Even at this point the impacts associated with the upstream farming and mining-related water-quality issues are evident.
- Recreational canoeing is an extremely important activity in these river sections. Many canoe-tour operators base their operations in the area.
- Ritual use in terms of magnitude of use is low given the low densities of people. However, the makeup of the area is such that the significance of ritual use, for those people resident in and around the area, is high.
- The river is central to the Richtersveld National Park and to the Fish River section of Namibia and is an important aesthetic feature. The main eco-tourism activity in the area is riparian game viewing.
- Bird watching is an important recreational activity and tourism drawcard in the area.
- Pathogens exist largely as blue-green algae, and two outbreak incidents were reported in 2008.
- Black Fly has become a large pest on the river and their presence is a cost or a disservice.

Production and utilisation of Goods and Services is of moderate to high importance at this site. It would be of high importance if population densities were higher.

6.2.2 Consequences of scenarios

Scenario A2, B, C1b and C2b were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecosystem services responses could be differentiated:

- **Sc A2** = Sc A3.
- **Sc C2b** = Sc D2 = Sc D3.

Each of the services that related to the defined categories i.e. provisioning, regulating, cultural and supporting were collated and scored. Under all four scenario sets considered, the provisioning services were deemed to remain constant against the status quo score of “1” or improve. Regulating services improved under all scenarios bar Sc B where they were marginally negative. Cultural Services were likewise potentially improved under all scenarios bar Sc B. Supporting service were unlikely to change in any discernible manner. These results are detailed in Table 6.2.

Ecosystem services were then weighted to generate an overall sore. Weights, as a percentage of 100, were generated based on the context of the site and reach. The following weights were given:

- Provisioning Services = 30%.
- Regulating Services = 25%.
- Cultural Services = 30%.
- Supporting Services = 15%.

Table 6.2 EWR O4: Consequences of scenarios on Ecosystem Services

Service Category		Sc A2, A3	Sc B	Sc C1b	Sc C2b, D2, D3
Provisioning	Normative Score	1.09	1.01	1.08	1.12
Regulating	Normative Score	1.11	0.85	1.07	1.08
Cultural	Normative Score	1.15	0.95	1.13	1.08
Supporting	Normative Score	1.00	1.00	1.00	1.00
Provisioning	Weighted Score	0.33	0.30	0.32	0.33
Regulating	Weighted Score	0.28	0.21	0.27	0.24
Cultural	Weighted Score	0.35	0.29	0.34	0.32
Supporting	Weighted Score	0.15	0.15	0.15	0.15
Total		**1.10**	**0.95**	**1.08**	**1.04**

Overall Scenario Groups A2, C1b and C2b are positive with Sc B being negative.

6.3 EWR O5 (SENDELINGSDRIFT)

6.3.1 Overview of Ecosystem Services

This section of the /river includes the stretch from the confluence with the fish river to the Estuary. The Orange River from its confluence with the Fish River to the Estuary covers some 140 kilometres. For this section of the report this constitutes the “Study Area”. The mouth and estuary are analysed within the context of a separate section as per below. The river forms the boundary, over this entire length, between South Africa (to the South) and Namibia (to the North). The river meanders through an area regarded as arid and in parts very difficult to access. As such the population densities are low. Population densities would be much lower were it not for several economic activities that act as attractors. Significant socio-economic features of the river include the following:

- The Richtersveld Trans Frontier Park with associated infrastructure in close proximity to the River.
- A series of mining operations either alongside the river or drawing on river resources. These include the Trans Hex Operations, Baken, Rosh Pinah, and Daberas.
- The Sendlingsdrif Border Post and associated settlement.
- The Brandkaros Alexcor development with associated agricultural business.
- The town of Sanddrif associated with the mining operations.
- The Grootderm settlement – located just above the Estuary.

The entire South African Section of the study area falls within the Richtersveld Local Municipality. The Richtersveld Municipality had a population of around 15 000 people according to the 2011 Census. Most this population live in the larger towns of Port Nolloth and Alexander Bay. The only settlement of any appreciable size within the defined Study Area is Sanddrif.

On the Namibian side of the border the Study area for this section of the report falls within the Oranjemund Constituency of the Karas Region. The population dynamics of the Namibian side of the Study Area mirror those of the South African. Current estimates are that the bulk of the population in the Oranjemund constituency are in the towns of Oranjemund itself and then Rosh Pinah.

Although population densities are low and it may be argued that utilisation of Ecosystem Services is therefore likely to be relatively insignificant there are several features that make the region unique. These include recreational usage of the natural environment and resources generated by the Orange River as a central feature of the Richtersveld Trans Frontier Park as well as the reliance on resources by people of Nama descent and by people who find themselves otherwise resident in the area. The Richtersveld Trans Frontier Park is an important tourist destination.

Adjoining the Richtersveld, across the border inside Namibia, is the Sperrgebiet which is considered to be of global biodiversity importance and contains a wide variety of endemic plants.

As indicated the Orange River is a key feature. In terms of delivering services to this sector the key aspects are:

- Recreational canoeing and rafting on the Orange River has become a substantial commercial enterprise.
- Recreational fishing as an activity associated with the Orange River is increasingly popular. Several specialized operations now offer fishing safaris on parts of the River within the Study Area and camps have been established for the purposes of catering for fishing parties. Fly-fishing, particularly for the large mouth and small mouth yellowfish is increasingly popular. In addition to organised fishing safaris, interviews in Sendlingsdrif and Sanddrif indicated that residents of these settlements undertake recreational fishing as a key recreational past-time. Over and above the large mouth and small mouth yellowfish the Sharptooth Catfish is also regarded as desirable species for recreational fishing. Other species of note with regard to fishing include barb species, tiliapia, and carp.
- Recreational hunting in the area is not part of a larger enterprise but mostly small-scale and outside of the Park. Small-scale recreational hunting and poaching (mainly geese and ducks) takes place on a very restricted basis. There are, however, limited riparian animals that are utilised for hunting.
- Swimming in the river is popular. Swimming is associated both with the organised rafting and fishing tours as well as with residents who make use of the cooling effects of the River during the particularly hot summer months.
- The importance of the River as an aesthetic attractor in the context of the Transfrontier Park should not be underestimated. It plays a role in the overall enjoyment that tourists take out of visits to what is essentially a wilderness area. Further the river is central to some of the bird species and bird watching is an important part of the tourist experience for many.
- In addition to the recreational use of the river and its associated resources by tourists and those resident in settlements adjacent to the river the wider area is home to the Nama people and others who have become associated with their communities. The Namas were traditionally a nomadic people moving their home, stock (predominantly goats) and family in search of grazing. The Nama people of the Richtersveld today remain transhumant pastoralists, moving their livestock between stock posts with the changing of seasons. The total population of Nama, and associated communities, in the greater Richtersveld area probably number around 4000 people. For the most part they are associated with the settlements of Eksteenfontein, Lekkersing, Khubus and to some extent, Sanddrif. Except for Sanddrif these are largely outside of the Study Area. While these communities do make use of the resources in the Study Area this utilisation is less pronounced than the use that is made of resources within the Community Conservation Area.

- Subsistence fishing is carried out using line with hooks or with nets. Larger returns of catches are associated with nets and those who rely on fish as a primary or substantial source of income usually use nets.
- The harvesting of reeds (*P. australis*) from the River banks for the traditional *matjieshuis* (or *haru oms* in Nama) is important. Reeds are harvested and woven into mats. Mats are laid over wooden frames (usually *Tamarix s*pp.) that have been bent into the required shape.
- In addition to the *Tamarix* other tree species are harvested. The main indigenous timber and fuelwood species are *A. erioloba, A. Karoo, P. glandulosa*, and *Z. Mucronata*. The main uses of exotics in the area are timber and fuel wood. Common exotic species in the Study Area include *P. glandulosa*, *E. camuldensis* and *N. glauca*. Respondents were asked about the utilisation of medical plants in the area. While a significant utilisation of these was reported the bulk were not deemed to be associated with the riparian zones. The only species mentioned was the locally named *Xhoba* but it could not be traced back to its scientific name.
- *C. dactylon* is one of the important species for grazing in this river stretch. Pressure appears to be relatively low. At present there appears to be a greater pressure on browsing by goats, particularly of *S. pendulina, D. lyceoides* and *A. karoo*. *T. usneoides* is an indigenous plant species that is used by cattle and small game as a natural salt lick. Usage is reported in the literature but could not be verified during the site visit.
- Ritual use in terms of magnitude of use is low given the low densities of people. However, the makeup of the area is such that the significance of ritual use, for those people resident in and around the area, is high and the central place that the Orange River occupies as a feature in people's lives. Purification rituals were mentioned as of importance with respect to the river. The river also plays an important role in local mythologies.
- The river has waste assimilation and dilution attributes linked closely to base flows and flooding. Even in the Study Area the impacts associated with the upstream farming are evident as are some mining-related water quality issues. Outbreaks of blue-green algae have been reported in recent years. With respect to the river delivering a "dis-service" the presence of the black fly (*Simulium chuteri*) is a noted pest that is a major irritant for livestock.

In summary, the unique nature of the area combined with the nature of utilisation renders Ecosystems service delivery more important than might otherwise be assumed given the low population densities. The presence of the Transfrontier Park and its status as unique makes it a prime tourist area. The value of tourism in the area, linked in part to the Orange River, is of considerable benefit to the economy of the region and the nation. The utilisation of key resources by people who occupy a status as descendants of first inhabitants makes the need to consider this aspect as a critical factor in decision making around the management of the resource.

6.3.2 Consequences of scenarios

Scenario A2, B, C1b and D3 were evaluated. The analysis of the operational scenarios indicated that the following scenarios were similar and no distinguishable ecosystem services responses could be differentiated:

- **Sc A2** = Sc A3.
- **Sc C2b** = Sc D2 = Sc D3.

Each of the services that related to the defined categories i.e. provisioning, regulating, cultural and supporting were collated and scored. Under all four scenario sets considered the provisioning services were deemed to remain constant against the status quo score of "1" or improve. Regulating services improved under all scenarios bar Sc B where they were negative. Cultural

Services were likewise potentially improved under all scenarios bar Sc B. Supporting services were unlikely to change in any discernible manner. These results are detailed in Table 6.3.

Ecosystem services were then weighted to generate an overall sore. Weights, as a percentage of 100, were generated based on the context of the site and reach. The following weights were given:

- Provisioning Services = 30%.
- Regulating Services = 25%.
- Cultural Services = 30%.
- Supporting Services = 15%.

Table 6.3 EWR O5: Consequences of scenarios on Ecosystem Services

Service Category		Sc A2, A3	Sc B	Sc C1b	Sc C2b, D2, D3
Provisioning	Normative Score	1.03	0.94	1.03	1.06
Regulating	Normative Score	1.08	0.66	1.08	1.08
Cultural	Normative Score	1.05	0.93	1.05	1.05
Supporting	Normative Score	1.00	1.00	1.00	1.00
Provisioning	Weighted Score	0.31	0.28	0.31	0.32
Regulating	Weighted Score	0.27	0.17	0.27	0.24
Cultural	Weighted Score	0.32	0.28	0.32	0.32
Supporting	Weighted Score	0.15	0.15	0.15	0.15
Total		**1.04**	**0.87**	**1.04**	**1.02**

Overall Scenario Groups A2, C1b and C2b are positive with Sc B being negative.

6.4 ORANGE ESTUARY

6.4.1 Overview

The Orange River Estuary is defined as the portion of the river that is influenced by the sea, and extends some 13 km upstream from the river mouth. Because of the marine influence and the dynamics of the estuary mouth, the estuary has a greater range of habitats and is more variable in character than the river upstream of it. The estuary is taken to include the channel, the islands within the channel, and the estuary-associated wetland vegetation, including reedbeds and saltmarsh, which extends into a supratidal floodplain area. All of these habitats occur within the 5m contour, and thus for management purposes the area within the contour is taken to be the ‘estuarine functional zone’.

Features of the area include:

- The towns of Oranjemund and Alexander Bay.
- Desert and diamond mining operations on either side of the estuary.
- A bridge spanning the estuary.
- Sports fields and golf course within the estuary floodplain on both sides.
- Agricultural fields within the estuary floodplain on the South African side.
- Several roads and canals constructed within the floodplain area.
- Sewage oxidation ponds within the estuary floodplain area on the South Africa.
- The Pachtvlei picnic area/campsite on the south bank of the estuary near its head.

- A coastal sandspit in the mouth area which is accessible to 4x4 vehicles.

While the estuary offers provisioning services in the form of sand, pebbles, fish, grazing and plant resources such as *Phragmites* reeds, currently there is little demand for these services, and hence they have low value.

There is no legal fishery on the estuary. Illegal gillnetting in the Orange Estuary catches an estimated 5 - 10 t per annum, of which about 80% is harders *Liza richardsonii* and the rest is made up of mainly *Mugil cephalus, Pomatomus saltatrix, Argyrosomus inodorus* and various freshwater species.

In addition, some illegal hunting reportedly takes place from time to time on the islands, with Gemsbok, *Oryx gazella* being the main target.

Regulating services provided by estuaries typically include nursery functions for species utilised in fisheries beyond the estuary, exports of nutrients and sediments, water treatment functions and carbon sequestration. The level of carbon sequestration is dependent on the plant growth forms in the estuary, and their extent and productivity, and is typically significant for highly productive mangrove estuaries in tropical climes. Carbon sequestration is not likely to be a significant function of the Orange River Estuary.

Rivers carry nutrients from their catchments which they discharge into the marine zone. This function is particularly important in tropical areas where it might be the main source of nutrients in trophic systems, but is unlikely to be important in the upwelling zones of the west coast of southern Africa, which are already very high in nutrients. Sediment outputs from rivers can play an important role in maintaining benthic habitats offshore, which has knock-on effects for demersal fisheries. Theses linkages are not well understood. It is important to note, though, that the sediment output of the Orange River has been dramatically reduced by impoundments (Clark, 2010).

Estuaries provide nursery areas and habitat for several fish species that are exploited in recreational and commercial fisheries (Lamberth and Turpie, 2003). The Orange River Estuary is thought to be particularly important as a nursery area since it is one of only four permanently open systems, and it accounts for about 32% of the estuarine area on the west coast of South Africa. Furthermore, the high diversity and abundance of estuarine dependant and marine species suggests that the Orange is a more important nursery area than was previously thought (Van Niekerk *et al*., 2008).

Some 19 species of fish that occur in the estuaries of the west coast region are utilised in coastal fisheries.

Cultural services are those that rely on the attributes of the estuary area, such as scenic beauty, rare species and other features such as water depth and flow rates. Values generated from this category of services include the recreational, spiritual and aesthetic values gained because of these attributes, which can manifest in a variety of ways ranging from the intangible, such as sense of wellbeing or happiness, to tangible benefits, such as property value premiums gained from estuary views, or income from tourism.

It appears that very little use is made of the estuary for recreational purpose. The locals do fish in the estuary from time to time for recreational purposes, and like to catch the yellowfish, especially at Easter time, where it makes a traditional cultural contribution to the table in many homes. This is just regular rod-and-reel fishing, not flyfishing.

The estuary and adjacent coastal area also attract visitors who come to see the river mouth or for bird watching. The river mouth is an impressive site, particularly with its setting in a desert landscape, and is also a 'must-see' for some as the most westerly point and the north-west 'corner' of South Africa. However, reaching it is somewhat of a challenge and it is not widely visited.

6.4.2 Consequences of Scenarios

Scenario A2, A3, B, C1b, C2b, D2 and D3 were considered. The following weights were given:

- Provisioning Services = 15%.
- Regulating Services = 60%.
- Cultural Services = 30%.
- Supporting Services = 5%.

The nursery function as a regulating service was given extra weight within the list of other services in this category.

Table 6.4 Estuary: Consequences of scenarios on Ecosystem Services

Service Category		Sc A2	Sc A3	Sc B	Sc C1b	Sc C2b	Sc D2	Sc D3
Provisioning	Normative Score	1.00	1.00	0.54	0.61	0.64	0.74	0.74
Regulating	Normative Score	0.89	0.89	0.64	0.59	0.60	0.74	0.74
Cultural	Normative Score	0.92	0.92	0.65	0.66	0.66	0.78	0.76
Supporting	Normative Score	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Provisioning	Normative Score	0.15	0.15	0.08	0.09	0.10	0.11	0,11
Regulating	Normative Score	0.53	0.53	0.38	0.35	0.36	0.45	0,45
Cultural	Normative Score	0.18	0.18	0.13	0.13	0.13	0.16	0,15
Supporting	Normative Score	0.05	0.05	0.05	0.05	0.05	0.05	0,05
Total		**0.92**	**0.92**	**0.64**	**0.63**	**0.64**	**0.76**	**0.76**

All scenarios were deemed to be negative in terms of ecosystem services associated with the estuary. Scenarios D3, D2 and C1b were regarded as particularly negative.

6.5 CONCLUSIONS

The consequences of the scenarios at all three EWR sites situated in the Orange River indicated that scenario groups A2, C1b and C2b were positive with Sc B being negative. Provisioning services remained constant against the status quo score or improved under all scenarios at the EWR sites. Regulating and Cultural services were negatively impacted by Scenario B while these services improved under the rest of the scenarios. No discernible change was noted for Supporting services under any scenario. Scenario A2, A3, B, C1b, C2b, D2 and D3 were deemed to be negative in terms of ecosystem services associated with the estuary with Sc D3, D2 and C1b regarded as particularly negative.

The results of the scenarios for the Orange River were ranked with the EWR sites weighted (Figure 6.1). The Ecosystem Services ranking for the estuary is also provided.

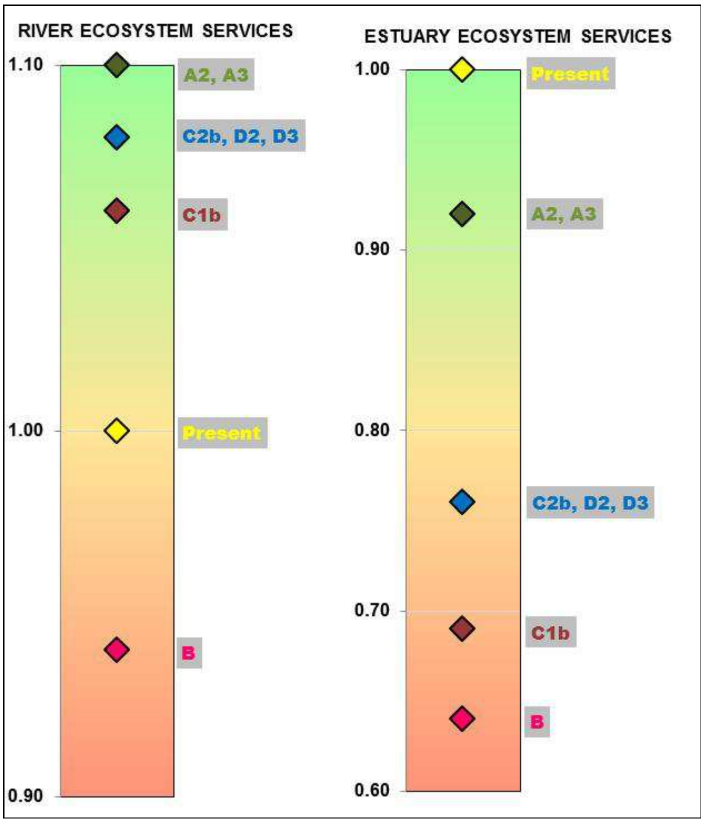

Figure 6.1 Ranking of impact of scenarios on Ecosystem Services in the Orange River system

7 ECONOMIC CONSEQUENCES

7.1 ECONOMIC BASELINE

The economic activities analysed includes the irrigation agriculture and the light industry activities, specifically the light industry activities in an around Upington.

7.1.1 Irrigation Data

Table 7.1 lists the water and hectare (ha) data as used during the Orange River Reconciliation Strategy (DWA, 2013), including the Boegoeberg Dam canals.

Table 7.1 Irrigation areas and water demands

River Reach	Description	Irrigation demands (Mil m³/a)	Irrigation areas (ha)	Irrigation demand (m^3/ha)
16	Boegoeberg Dam to Gifkloof	161.2	11 173	15 000
17	Gifkloof weir to Neusberg	222.8	14 855	15 000
18	Neusberg to Namibian border	180.2	12 016	15 000
19	Namibian border to Onseepkans weir	28.6	1 905	15 000
20	Onseepkans weir to Vioolsdrift weir	33.6	2 237	15 000
21	Vioolsdrift weir to Orange Fish confluence	9.0	600	15 000
22	Orange Fish confluence to river mouth	8.3	553	15 000
	Total	**643.7**	**43 339**	

Table 7.2 presents the crop division used in the analysis. The distribution of the crop data is based on the original ORASECOM data and the only areas that could be confirmed were:

- Fresh Table Grape - South African Table Grape Industry – Statistics 2016 Booklet.
- Wine Grape – 2016 – SA Wine Industry Statistics.
- Dry Grapes – Hartgro – Growing Fruit IQ – Key Deciduous Fruit Statistics 2015.
- Citrus – Karsten Boerdery – The total area is not under control of Karsten Boerdery.
- Palm Dates – Karsten Boerdery - The total area is not under control of Karsten Boerdery.

The total area of 32 166 ha as used in the Orange River Reconciliation Strategy (DWA, 2013), makes no provision for any possible expansion in the irrigation area because of improved management and technology and therefore available water.

Table 7.2 Crop Distribution per sub-area

Crop	Boegoeberg Canals	Gifkloof to Neusberg	Neusberg to Namibian border	Namibian border to Onseepkans weir	Onseepkans weir to Vioolsdrift weir	Vioolsdrift weir to Orange Fish confluence	Orange Fish confluence to river mouth	Total
Maize	1 833	764	192					**2 789**
Table grapes		1 595	1 322	933	1 190	347		**5 386**
Dry beans		294	238		428	198		**1 158**
Pastures	1 266	829	1 047		381		253	**3 776**

Crop	Boegoeberg Canals	Gifkloof to Neusberg	Neusberg to Namibian border	Namibian border to Onseepkans weir	Onseepkans weir to Vioolsdrift weir	Vioolsdrift weir to Orange Fish confluence	Orange Fish confluence to river mouth	Total
Vegetables					238	55	300	**594**
Wheat		3 101	1 109					**4 291**
Wine grapes	1 466	2 466	1990					**5 922**
Citrus			655	144				**799**
Dry grapes	6 608	5 807	5 383	209				**18 006**
Palm dates								**619**
Total		**14 855**	**12 016**	**1 905**	**2 237**	**600**	**553**	**43 339**

7.1.2 Urban Baseline

The only town and large urban settlement below the Boegoeberg Dam canals is Upington which is part of the //Ikhara Hais Local Municipality and except for wine cellars the only light industries are currently situated in Upington. The following data (Table 7.3) is drawn from Conningarth database as collected for the different municipalities.

Table 7.3 Upington Data

GDP			Manufacturing		Employment		
Food production (Rand mil.)	**Other Manufacturing (Rand mil.)**	**Total (Rand mil.)**	**Food**	**Other**	**Total**	**Semi- and Skilled**	**Unskilled**
21.03	149.44	2 310.98	0.8%	6.9%	19 537	11 267	8270

From Table 7.3 it appears that GDP food and other manufacturing only contributes 0.8% and 6.9% respectively for a total of 7.7%. Employment numbers were not available for the small manufacturing and the assumption was made that the number of Employment in these sectors would also be in line with the food and the rest of the manufacturing sectors. Applying this assumption, the following employment figures were allocated to the food and other manufacturing:

- Food Manufacturing: 166.
- Other Manufacturing: 1 176.

The water demand used in the calculations is 8.93 million m^3 per annum, originally sourced from data provided for the establishment of database for use by local municipalities.

7.2 BASELINE RESULTS

7.2.1 Irrigation

After feeding the data into the Water Impact Model (WIM) the following set of results were obtained for the total area as defined (Table 7.4). The multipliers were then calculated by dividing the value of each parameter by the volume of water, 643.7 million m^3.

Table 7.4 Lower Orange Irrigation baseline parameters expressed in 2016 prices

GDP (R Mil)			Employment (Numbers)			Household Income (R Mil)		
Direct	Indirect and Induced	Total	Direct	Indirect and Induced	Total	Total	Medium	Low
2016 Parameters								
4066.9	1887.6	5954.5	27 380	11 092	38 472	3610.3	2539.4	1070.9
2035 Parameters								
5 031.8	2 335.5	7 367.3	33 877	13 723	47 600	4 466.9	3 141.9	1 325.0
Multipliers								
R/m^3	R/m^3	R/m^3	No/Mm^3	No/Mm^3	No/Mm^3	R/m^3	R/m^3	R/m^3
6.32	2.93	9.25	42.54	15.06	57.60	5.61	3.94	1.66

From Table 7.4, the 2016 results show that the baseline direct GDP is R 4 066.9 million expressed in 2016 Rand values with an average multiplier of R6.32 per cubic metre all in the project area. The baseline direct employment is estimated at 27 380 with a multiplier of 42.54 opportunities per million cubic metres, also in the project area. The baseline total low household income is R 1070.9 million with a R1.66 per cubic metre multiplier.

The 2035 results show the estimated results for the Lower Orange expressed in 2016 prices. A number of the indirect and induced impacts will also per definition take place in the project area, however it is not always possible to provide a specific answer with the WIM.

7.2.2 Industry

Table 7.5 Lower Orange baseline parameters for Light Industry (2016 prices)

Sector	GDP (R Mil)			Employment (Numbers)			Household Income (R Mil)		
	Direct	Indirect and Induced	Total	Direct	Indirect and Induced	Total	Total	Medium	Low
Other manufacturing	149.47	95.51	244.98	1 176	676	1 852	59.39	118.84	40.55
Fruit juice	21.02	18.92	39.94	166	139	304	32.97	24.60	8.37
Total	**170.49**	**114.43**	**284.92**	**1 342**	**815**	**2 157**	**192.46**	**143.44**	**48.92**
Multipliers									
	R/m^3	**R/m^3**	**R/m^3**	**No/m m^3**	**No/m m^3**	**No/m m^3**	**R/m^3**	**R/m^3**	**R/m^3**
	7.60	5.10	12.70	59.83	24.50	84.32	8.58	6.40	2.18

According to Table 7.5, the direct GDP is R 7.60 per cubic metre and 59.83 direct employment opportunities are created per million cubic metres.

7.3 SCENARIOS

The following operational scenarios and the associated impact on the available water volumes was received from WRP and as such used in the appropriate model as necessary (Table 7.6). As this part of the report is only concerned with the economic impact of the different scenarios the data as provided were used in the calculations.

Table 7.6 Economic evaluation: Important elements of the Scenarios

Scenarios	Important points for economists from Water Resources Team
A	This is present day demands, infrastructure and current standard EWR release made for environment, 2016 demands are used.
A2	This is an attempt to improve current release for the environment based on more recent knowledge. No effect on dam yields between Sc A and A2.
A3	Namibian demand increased from current Irrigation use: 37.5 million m^3/a, current urban/mine use: 22.3 million m^3/a to current urban allocation: 122 million m^3/a, current urban/mine allocation: 30.3 million m^3/a. No impact on system yield.
B	Increased demands between 2016 and 2035.
C1b	The drop in yield of system as a result of REC EWRs (Augrabies summer only) is 425 million m^3/a. This needs to be supplied with a LARGE Vioolsdrift Dam (modelled as 2100 million m^3/a live storage as per Vioolsdrift Study requirement).
C2b	The drop in yield of system as a result of REC EWRs (Augrabies summer and winter) is 825 million m^3/a. If this is modelled with a LARGE Vioolsdrift Dam, the results show the Dam is not utilised in full.
D2	The yield drop is still 825 million m^3/a between the current release and the REC, however because the REC both for summer and winter is active at Augrabies, it effectively pulls more water into Vioolsdrift Dam, resulting in a smaller size of Vioolsdrift Dam. Exact capacity has not been analysed, but for now a 470 million m^3/a live storage is shown to be sufficient. Economic Benefit as a result of building a smaller dam.
D3	And same size dam and cost between Sc D2 and D3, but the yield of that dam will drop by about 40 million m^3/a. However, that dam is still supplying all Namibian possible future growth in demands.

From Table 7.6, it can be deducted that Sc A2 is providing increased volumes to the EWR by applying a distribution to the EWR which effectively takes less water in dry times and more in wet times, and therefore does not impact on the yield of the Orange River. The increased EWR would also impact positively on the tourism at Augrabies and the canoe activities lower down in the river.

The economic interpretation of Sc A3 is that further water can be provided for the Namibian demands without impacting on the existing yield should the recommended EWR distribution be applied.

In terms of economic interpretation the two scenarios will have exactly the same impact and as such one set of answers will be provided. However, should the Vanderkloof Dam be operated at a lower level than “Security of Supply”, it is recommended that a study is conducted in future to determine what the possible impact on crops yields over the long term might be.

Scenario B refers to the estimation of the increase in demand from 2016 to 2035. This is based on the reality that demand will increase over time. The increased demand will put pressure on the current infrastructure to supply the estimated volumes.

The different Sc C and D therefore takes into consideration the possible construction of the Polihali, Vioolsdrift and Verbeeldingskraal Dams as it will be impossible to maintain the proposed EWR volume without major economic impacts with the current infrastructure. However, there are differences in terms of the size of the Vioolsdrift Dam. The proposed site of the Vioolsdrift Dam is part of the Lower Orange while the Verbeeldingskraal Dam is above the Gariep Dam.

Based on the information received from WRP, the differences between Sc C and D are:

- C1b: The "smaller" version of Augrabies REC is used (i.e. summer months only). The system is "firm" with the 2412 million m^3 being fully supplied, however a 425 million m^3 shortfall will be experienced over the total river.
- C2b: The full Augrabies REC for both summer and winter months are supplied, and reduces the supply to the 2035 demands by 825 million m^3, and effectively not supplied in full.
- Sc D2: Identical economic benefits between C2b and D2, except that a much smaller (cheaper) Vioolsdrift Dam can be built in the case of D2.
- Sc D3: The same size dam and cost between D2 and D3, but the yield of that dam will drop by about 40 million m^3/a. However, that dam is still supplying all Namibian possible future growth in demands.

7.4 CONSEQUENCES OF SCENARIOS

In the following section the results of the analysis of the different scenarios are presented. Table 7.7 presents the economic results associated with the different volumes available for production purposes after the removal of the volume of water to maintain the EWR.

Table 7.7 Economic production per Scenario

Scenario	GDP (Rand Million)		Employment (Number)		Household Income (Rand Million)	
	Direct	Total	Direct	Total	Total	Low
2016 Baseline	3.472	5.617	27.380	40.110	4.501	1.325
Impact Sc A2	3.472	5.617	27.380	40.110	4.501	1.325
Impact Sc A3	4.008	6.484	31.604	46.297	5.196	1.529
2035 Baseline	13 011.02	21 048.02	102 596	150 294	16 866.29	4 964.44
Impact Sc C1b	10 718.44	17 339.31	84 519	123 812	13 894.41	4 089.69
Impact Sc C2b	8 560.73	13 848.76	67 504	98 887	11 097.35	3 266.40
Impact Sc D2	8 560.73	13 848.76	67 504	98 887	11 097.35	3 266.40
Impact Sc D3	8 776.50	14 197.81	69 205	101 379	11 377.05	3 348.73

In the evaluation of the results it must be kept in mind that the 2016 Baseline and Sc A2 and A3 is only based on the Lower Orange. The results of the 2035 baseline and accompanying results is representative of the total river basin. Table 7.8 presents the economic impacts of the different scenarios.

Table 7.8 Economic impacts of the Scenarios

Scenario	GDP (Rand Million)		Employment (Number)		Household Income (Rand Million)	
	Direct	Total	Direct	Total	Total	Direct
2016 Baseline	0	0	0	0	0	0
Impact Sc A2	0	0	0	0-	0	0
Impact Sc A3	535.65	866.53	4 224	6 187	694.37	204.38
2035 Baseline	0	0	0	0	0	0
Impact Sc C1b	-2 292.57	-3 708.71	-18 078	-26 482	-2 971.88	-874.75
Impact Sc C2b	-4 450.29	-7 199.26	-35 092	-51 406	-5 768.94	-1 698.04
Impact Sc D2	-4 450.29	-7 199.26	-35 092	-51 406	-5 768.94	-1 698.04

Scenario	GDP (Rand Million)		Employment (Number)		Household Income (Rand Million)	
	Direct	Total	Direct	Total	Total	Direct
Impact Sc D3	-4 234.51	-6 850.21	-33 391	-48 914	-5 489.24	-1 615.71

The results from Table 7.8 indicate that Sc A2 has no negative or positive economic impact measured in terms of the 2016 Baseline in the Lower Orange. Scenario A3 produces a positive economic impact and in line with the defining parameters of the scenario the impacts will be mostly on the Namibian side of the river.

The economic impacts measured in 2016 prices in terms of 2035 projected water demand for all the scenarios indicate a negative economic impact. Using just the economic impact it appears as if Sc C1 is the preferable scenario, followed by Sc D3 and then Sc C2 and D2 indicating the same economic impact.

The estimated social and economic impacts of the different scenarios based on the 2035 baseline is drastic and it is necessary to also take into consideration the costs of the identified additional infrastructure to maintain the EWR and the economic activities.

Table 7.9 provides the results for the scenarios applicable over the total river expressed in terms of the capital and operational costs involved.

Table 7.9 Selected data applied and results estimated in the CBA model

Scenario	Volume Involved (mm^3)	Capital Cost (Rand million)	Operational Cost (Rand million)	NPV[1]: Direct Discounted GDP Benefit (Rand million)	Benefit (Net GDP)/Water Savings (Rand/m^3)
C1 – Large Dam	425	1,715.22	7.44	15,161.9	3.36
C2 – Large Dam	825	1,715.22	7.44	32,035.9	3.66
D2 – Small Dam	825	1,102.79	1.14	32,653.4	3.73
D3 – Small Dam	785	1,102.79	1.14	30,966.0	3.72

1 Net Present Value.

The benefit/m^3 metric is used to express the benefit saved, expressed in terms of the GDP, per cubic metre of water, if the supply of the irrigation and urban water is not reduced. The 3.73 Rand/m^3 is there for the more beneficial value and therefore Sc D2 is the best economic feasible option using this approach.

As explained in Section 3.6, Sc A2 and A3, and Sc C1b, C2b, D2 and D3 cannot all be compared in the same vain. Scenario A2 and A3 is measured in terms of the Lower Orange section of the river while the other scenarios consider the projected impact of the Vioolsdrift/Noordoewer and the Verbeeldingskraal dams.

All economic impacts were determined from the input variables water volume, Enterprise Budgets, and municipal information. Scenario Sc C1b, C2b, D2 and D3 include a building cost element that immediately distinguished them from final comparisons to Sc A2 and A3. The estimated growth in water demand over time has, as a result, the possible implosion of the EWR and it is therefore necessary to introduce infrastructure, i.e. Verbeeldingskraal and Vioolsdrift dams, to maintain the EWR and the economic activities.

From the above it appears that Sc C1 will be the most beneficial in economic terms if only the negative impact on the economy is measured. However, if the cost of the provision of the infrastructure to maintain the EWR as well as the economic activities is considered, Sc D2 is the most beneficial. The only difference between Sc D2 and C2 is that benefit/m^3 metric of Sc D2 is slightly better than Sc C2 as the rest of the parameters are similar. When only evaluating the scenarios with the infrastructure costs component, Sc D3 is the most preferred with the net water savings indicator followed closely by Sc D2 and C1b. The larger the savings ratio, the better the economics of scale is applied.

A traffic diagram (Figure 7.1) depicts the economic impact comparisons of GDP for all the scenarios as well as the water saving benefit using the Nett Benefit and volume involved as drivers.

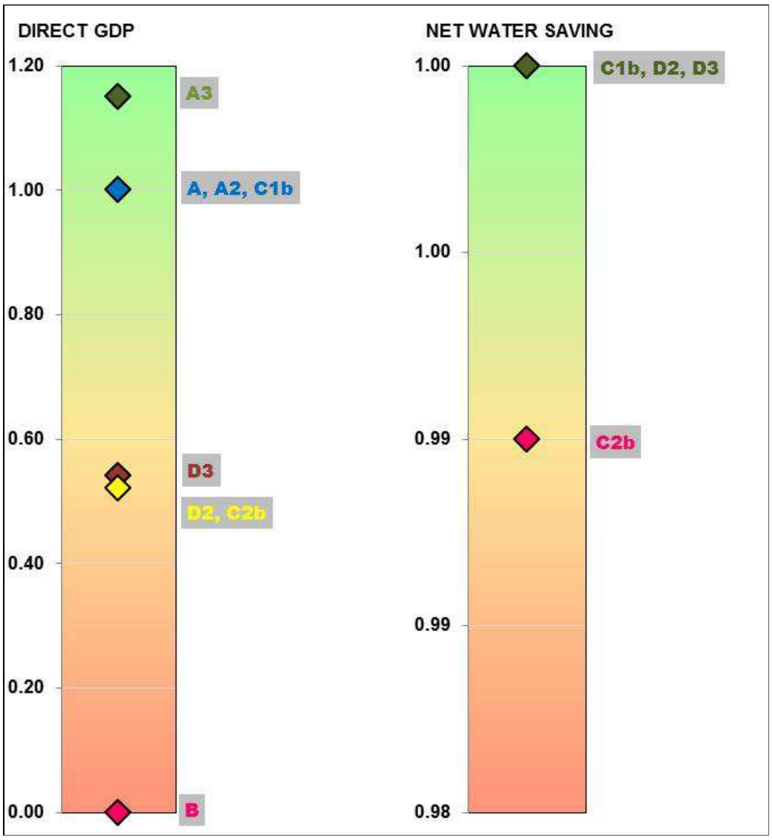

Figure 7.1 Ranking of scenarios in terms of Direct GDP and Net Water Saving benefit

8 CONCLUSIONS AND RECOMMENDATIONS

The determination of the Reserve and the National Water Resources Classification is a legal requirement according to the National Water Act. The Reserve can only be gazetted once the Classification has been determined and gazetted. The Act allows for a Preliminary Reserve to be determined prior to Classification. Although not gazetted, the Preliminary Reserve is signed off by the Minister (or the delegated authority) and is legally binding. As such, the Preliminary Reserve is undertaken prior to Classification or as part of a Classification study. The Preliminary Reserve can be reviewed and updated during Classification as detailed consideration is given to the socio-economic issues.

This study is therefore essentially the determination of a Preliminary Reserve prior to Classification. Further development of the Orange River is being investigated. This will allow for more management options of amongst others, the EWRs. The scenarios and recommendations which are made for this phase pertain to the post-dam recommendations. Immediately applicable is the provision of EWRs through the operation of the system without additional storage. These scenarios represent the pre-dam recommendations. This will be legally binding until the Classification has been determined and gazetted. The Reserve will then follow and be gazetted. Therefore, the focus of this Preliminary Reserve study is on the pre-dam situation. Recommendations are also made for the post-dam situation regarding scenarios as well as further work required in preparation for Classification.

8.1 YIELD IMPLICATIONS

For each scenario, the results in the form of a time series of monthly average flows past each site dating from 1920 to 2004 were provided to the study team for further assessment. A summary of those flows is presented in the table below, representing the average annual flow in million m^3/a at the given site and representative scenario. The reduction in yield refers to the decrease in yield of the ORP as result of the different EWRs included for the specific scenario.

Table 8.1 Average annual flow (million m^3/a) at the given site and representative scenario

Scenario	EWR O3	Vioolsdrift	EWR O5	Estuary	Yield reduction (million m^3/a)
A	4280.45	3984.34	4430.61	4346.46	Current base
A2	4287.76	3991.62	4437.89	4353.74	0*
A3	4306.79	3925.12	4371.37	4285.71	0*
B	3531.35	2953.75	3183.12	3059.03	2035 Base
C1b	3708.39	3110.33	3298.13	3173.97	425**
C2b	3708.39	3110.33	3375.86	3251.63	825**
D2	3747.05	3205.22	3493.33	3369.03	825**
D2i	3747.05	3205.63	3493.50	3369.19	825**
D2ii	3747.05	3205.76	3493.62	3369.32	825**
D3	3747.15	3206.49	3494.21	3369.90	825**

* Yield reduction relative to Sc A. ** Yield reduction relative to Sc B.

8.2 PRE-DAM RECOMMENDATIONS

Prior to the development of additional storage, the only option for improving the estuary and rivers are to improve on the distribution of the existing EWR allocation. These are scenarios A2 and A3. These scenarios will improve the rivers significantly, especially at EWR O5 where the REC may be achieved. The A2/3 scenario will only maintain the PES at the estuary, but it is likely that with the improvement at EWR O5, that some improvement may be noted at the estuary. If the anthropogenic issues are addressed, the estuary status will improve to a C/D. The Ecosystem Services show no negative impact of the implementation of the A scenarios. As the A scenarios are a marked improvement for the rivers, these scenarios rather than the current EWR allocation would be strongly recommended from an ecological perspective.

The impact on yield of Sc A2 and A3 are very low. Scenario A2 versus the 2016 Base Scenario shows no difference in yield. A relative small reduction in yield due to potential full use of Namibian allocations of 92 million m^3/a is applicable to Sc A3.

Based on the above, it can be seen that there are no negative consequences which would result from the implementation of Sc A2 or A3. Taking into account that Sc A3 is marginally better than Sc A2 from an ecological viewpoint and that Sc A3 caters for Namibian irrigation allocation, it is recommended that this be put in place as soon as possible.

8.3 POST-DAM DEVELOPMENT SCENARIOS

Five scenarios were evaluated that included future dam development. The scenarios (D range) that represent a small Vioolsdrift Dam (35m) scored the highest. One of the D scenarios, Sc D2 was further optimised for the estuary (Sc D2ii) and showed a slight improvement. The Ecosystem Services showed an improvement of all the scenarios over the present provisioning. The recommendation from an ecological perspective is therefore Sc D2ii. It must be noted that the REC for the EcoStatus is achieved at both EWR O4 (Vioolsdrift) and O5 (Sendelingsdrift) and that the PES is improved at EWR O3. Although there is no improvement and even further degradation at the estuary, it is possible that with monitoring to better understand conditions under low flows and with further optimisation during the National Water Resources Classification study a scenario can be devised that maintains or improves the estuary.

It must be noted that the Sc C2b that represents the large Vioolsdrift Dam is only marginally worse than the small dam scenarios. However, these rankings do not take into account the severe impact of the barrier effect of the dam for fish and other biota as well as the sedimentation impacts on the estuary and in general, the marine environment. The spill and flood regime from the large dams have also major implications. Mitigation measures such as fishways are a possibility for the smaller dam but are unlikely to be structurally feasible or cost effective for the large dam.

From a yield perspective, it is important to note that there is a significant difference between Sc C1b and C2b. Both scenarios include the large Vioolsdrift Dam with the main difference being that for Sc C1b no winter low flows are supplied at EWR O3 (Augrabies) and for Sc C2b both summer and winter low flows were supplied. This resulted in a reduction in yield of Gariep and Vanderkloof dams by 400 million m^3/a. Although the yield for the large Vioolsdrift Dam also increased due to the higher inflows into Vioolsdrift, this increased yield cannot be utilized downstream of Vioolsdrift Dam, due to limited downstream demands. Sc C1b (supply of inter flows at EWR O3) therefore eliminates the option of a large Vioolsdrift Dam as a smaller Vioolsdrift will be able to provide sufficient yield for downstream users. This leads to Sc D2, using a smaller Vioolsdrift Dam, that was able to provide sufficient yield for the expected future demands downstream, similar to that of the large Vioolsdrift Dam for the option when no winter low flow were supplied at EWR O3 (Sc C2b).

When the summer and winter low flows are supplied at EWR O3, the deficit in the upstream yield from Gariep and Vanderkloof is just too much to overcome with a dam at Verbeeldingskraal. During the Orange Reconciliation Strategy Study, the Boskraai Dam was discarded due to various reasons and Verbeeldingskraal Dam, which unfortunately produces a much lower yield, was recommended. Environmental concerns related to Boskraai Dam contributed to this decision, but these environmental implications were not weighed against the environmental implications in the lower Orange River and Estuary. It is likely that the presence of a National Park, a Transfortier Park and a Ramsar Site (the estuary) could play an important role in the analysis.

The ecological consequences of the large dam based purely on proposed flow regimes that will be achieved at the EWR sites and estuary seems to be not that much worse than the small dam scenarios. As mentioned before, it must be acknowledged though that some detailed studies on flood routing and sedimentation, migration, marine impacts etc. are still required to, with mitigatory flow releases, understand the consequences. In essence, an ecological cost-benefit and an economic cost-benefit analysis must be undertaken in conjunction and then to weigh the different possible combination of scenarios.

To make a decision on the small versus the large dam, a decision must be required on the two main EWR related options:

- 1. With releases for winter low flows at EWR O3 included.
- 2. Without releases for winter low flows at EWR O3.

For option 1 above, a smaller Vioolsdrift Dam can be used and the ecological benefit against high capital expenditure for Boskraai Dam must be evaluated or the impact of upstream irrigation reduction (400 million m^3/a reduction) must be investigated. If option 2 is considered, a larger Vioolsdrift Dam is used and the full impact on ecology for a larger dam (system in balance, no additional expenditure required for upstream resource development) should be evaluated. Or the smaller Vioolsdrift Dam can be used and the ecological benefit against capital expenditure for a raised Gariep Dam wall should be evaluated or the impact of irrigation reduction (approximately 200 million m^3/a reduction) should be investigated.

In conclusion and taking into account the implications on yield of supplying winter flows at EWR O3, the following is recommended: A scenarios without winterflows at EWR 3 with a small Vioolsdrift Dam and additional storage upstream should be investigated. Further optimisation of the flow scenarios to achieve the estuary improvement is also essential.

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10 APPENDIX A: SCENARIO WATER RESOURCES MODELLING

The Water Resources Planning Model (WRPM) was used to undertake the scenario analyses and in this study. A summary of the background to determining the final scenario selection has been provided in Section 2 of this report. Further details relating to the water resources modelling and flow determination under various conditions are provided in this Appendix.

10.1 CONFIGURATION OF BASE DATA SET

The WRPM data set used for the May 2016/2017 annual operating analyses (AOA) for the Orange River system was obtained for use as a base data set for the scenario analyses of this study. The following updates/modifications were made to the data set obtained (modification dependant on particular scenario):

- The original data set was configured for stochastic simulations (1000 sequences) as used for annual operating analyses simulations. The demands in the configuration started at the 2016 development level and were set to grow over time as required for projection analyses. This was modified for these analyses such that the model was set to operate in historical mode (single sequence dating from 1920 to 2004). The demands were set at a constant development level (year selected depending on scenario), implying the demands were set as constant for the entire record period 1920 to 2004.
- The allocation procedure which implements restrictions in the model when resources are running low was turned off, therefore no restrictions were implemented throughout the simulation period.
- The May 2016/2017 AOA data set was compared with the final data set obtained from the Vioolsdrift Dam Feasibility Study Team. Relevant changes relating to higher Namibian demands in 2016 (allocations vs actual use) were incorporated into the data set.
- An updated area capacity relationship based on the Feasibility Study was included for Vioolsdrift Dam.
- Due to the fact that the starting storage levels for the major dams were abnormally low in May 2016 as a result of the drought, it was decided to use the starting storages used in the Reconciliation Strategy Study, which reflected more realistic starting conditions.
- The hydrology for the Namibian Fish River was set to start at 1930. A method was used to extend the hydrology in order to start the simulation in 1920, to cover a longer record period.
- Metolong Dam in Lesotho was turned on for the entire simulation period.
- The configuration around the LHWP Phase 2 was updated to reflect the latest available from the Operating Rules Study. This was specifically related to the EWR and hydrology at Polihali Dam.

Two approaches to simulations exist in the Integrated Orange Vaal River System model which are important to understand when configuring the model and interpreting the results. These are as follows:

- **Vaal tributary inflows:** Though a large river in its own right, the Vaal is a tributary of the Orange River. The two are, however, operated independently of each other, with Bloemhof Dam not used to support users on the Lower Orange River. Spills from the Vaal do occur, however, these are few and far between, and are therefore not relied on in terms of the Orange River resource. The model is therefore configured such that the Vaal River enters the Orange River just prior to the river mouth. This allows all Lower Orange users to “pull” their full requirement from the Orange River Project (Gariep and Vanderkloof dams). The Vaal flows are however taken into consideration at the various EWR sites along the way, and their contribution is included to the total flow passed the sites. When Vioolsdrift Dam is in place, the configuration is adjusted slightly, such that the Vaal flows are set to enter Vioolsdrift Dam. This is because, in reality, the dam will capture the Vaal spills, and downstream users will then be able to use these flows as they are stored in the dam. The operation of the system will be able to account for water from the Vaal as a result of the Vioolsdrift Dam.

- **Operating Losses:** The stretch of the Orange River between Vanderkloof Dam and the most downstream users is very long. As a result, it is difficult to manage releases in such a way that the Lower Orange demands are satisfied. Losses are therefore configured into the model to account for this management difficulty, where additional water is often released than the actual demand. Some calibration work has previously been done on the losses along the way, however, it is still fairly unclear as to the extent of these losses that reach the Orange River mouth from year to year. The losses are configured such that they are abstracted as a demand downstream of Vanderkloof Dam. They are, however, added back to the total flows at all sites along the way, as if they are passing the sites. Again, it should be noted that the full losses, or maybe only a portion of them reach the estuary. The loss demand currently, prior to any intervention on the Orange River is set as 180 million m^3/a. For the future scenarios, when real time monitoring and operations will be taking place, and Vioolsdrift Dam will also be in place, the operating losses are overall reduced to 20 million m^3/a, and the losses are configured to enter Vioolsdrift Dam to obtain the increased savings. They are therefore not added to the EWR O5 and Estuary flows as these occur downstream of Vioolsdrift.

Comparisons were done with the flows obtained using the updated model and present day flows supplied to the environmental team in a previous study, in order to confirm the model was operating correctly. The comparison showed similar flows and the base data set was deemed satisfactory.

10.2 EWR STRUCTURES

Recommended EWR structures had previously been determined during the 2010 EFR study (Louw and Koekemoer (eds.), 2010). The recommended classes for both EWR O3 and O5 were set as a B. These structures were obtained from the study report (DWS, 2016). On closer inspection of the EWR and natural flow duration tables, it was found that the natural duration tables presented in the report differed from the updated natural duration tables produced as part of this task. As it was not clear how the previous natural duration tables had been produced, and whether the correct natural losses had been removed, it was decided to rather updated the natural tables with what is currently configured in the model, and what was presented as natural flows at the sites in this study. There were, however, a few cases where the EWR required was higher than the natural flow, and in these cases, the EWR was slightly reduced.

The approach used in the model was to include two natural hydrological time series files (the total of all natural incremental hydrologies less the natural losses) for EWR O3 and O5. These hydrologies were included on the side such that they did not impact the system. Only these nodes were referenced as part of the F14 file used to drive the EWR determination. All the relevant tables follow.

Table 10.1 Original REC and natural flows: EWR O3

Data are given in m³/s mean monthly flow

% Points

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Reserve flows without High Flows										
Oct	45.572	45.145	44.182	42.204	38.529	32.471	23.869	13.822	4.967	0.000
Nov	70.979	70.350	68.922	65.968	60.464	51.397	38.599	23.865	11.267	5.409
Dec	84.098	82.892	80.214	75.005	66.273	53.924	39.637	26.736	18.370	15.536
Jan	103.110	101.496	97.887	90.845	79.047	62.456	43.491	26.736	16.275	13.217
Feb	144.274	140.567	132.809	119.202	99.485	76.310	54.774	39.537	31.822	30.044
Mar	146.201	142.472	134.667	120.979	101.143	77.829	56.164	40.836	33.074	31.285
Apr	121.675	118.015	110.355	96.921	77.453	54.571	33.308	18.264	10.647	8.890
May	79.624	78.350	75.503	69.947	60.639	47.550	32.588	19.369	11.116	8.703
Jun	52.356	51.609	49.950	46.724	41.316	33.667	24.818	16.828	11.646	9.891
Jul	33.211	32.985	32.471	31.410	29.431	26.171	21.571	16.274	11.745	9.639
Aug	30.269	30.071	29.624	28.707	27.003	24.195	20.207	15.549	11.443	9.272
Sep	30.834	30.741	30.397	29.686	28.290	25.729	21.438	15.107	7.476	1.735
Natural Duration curves										
Oct	625.022	339.729	238.616	164.643	103.756	76.240	57.239	34.909	18.821	0.000
Nov	914.267	664.780	492.404	364.016	246.127	219.066	162.211	129.147	50.710	8.954
Dec	1012.929	715.192	532.706	406.933	331.291	290.737	204.794	105.802	74.175	24.985
Jan	1262.321	923.439	638.792	513.740	386.914	298.574	219.079	163.956	87.623	34.476
Feb	2068.130	1297.202	903.282	548.251	432.614	313.600	268.556	222.359	128.001	38.447
Mar	1579.234	1029.312	705.279	602.210	475.821	337.481	248.693	196.181	122.525	38.041
Apr	909.772	633.503	413.584	324.093	285.313	244.904	175.428	122.145	72.234	25.667
May	355.152	262.418	195.744	130.589	107.056	81.851	69.739	45.669	32.053	8.793
Jun	190.698	138.897	89.664	74.742	60.035	54.333	41.539	33.013	20.652	11.323
Jul	147.345	99.836	89.595	65.315	45.613	36.989	31.127	24.709	17.085	12.851
Aug	149.029	112.541	83.065	62.724	48.092	34.629	25.291	20.535	14.938	11.137
Sep	224.877	120.988	81.709	60.116	44.159	34.688	26.505	16.725	8.252	3.221

Table 10.2 Original REC and natural flows: EWR O5

Desktop Version 2, Printed on 2013/02/05 Regional Type: Vaal REC = B
Data are given in m3/s mean monthly flow

%Points

Reserve flows

Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Reserve flows without High Flows										
Oct	35.029	34.703	33.945	32.348	29.346	24.417	17.605	10.149	4.433	2.595
Nov	43.614	43.229	42.357	40.553	37.19	31.651	23.833	14.832	7.137	3.306
Dec	48.908	48.131	46.407	43.053	37.43	29.478	20.278	11.972	6.584	4.759
Jan	60.182	59.212	57.043	52.81	45.719	35.746	24.347	14.276	7.988	6.151
Feb	85.176	82.754	77.684	68.791	55.906	40.76	26.686	16.729	11.687	10.524
Mar	69.877	66.8	60.319	49.912	37.162	25.247	16.752	12.132	10.216	9.817
Apr	71.412	69.309	64.908	57.189	46.005	32.858	20.642	11.999	7.622	6.613
May	52.044	51.22	49.379	45.787	39.768	31.305	21.63	13.082	7.746	6.186
Jun	39.877	39.25	37.858	35.15	30.611	24.191	16.764	10.058	5.709	4.235
Jul	30.665	30.401	29.8	28.559	26.244	22.432	17.051	10.856	5.559	3.096
Aug	29.593	29.322	28.69	27.36	24.859	20.754	15.08	8.87	4.109	2.747
Sep	30.715	30.575	29.966	28.505	25.455	20.092	12.551	4.848	0.192	0.192
Natural Duration curves										
Oct	706.187	309.569	217.611	156.519	98.212	64.191	44.605	22.252	10.749	2.595
Nov	805.208	601.728	474.263	354.198	245.224	191.331	158.225	114.363	37.176	3.306
Dec	994.388	659.939	506.724	396.744	317.003	284.468	223.029	87.582	49.231	21.001
Jan	403.872	16.473	786.376	510.682	382.09	257.68	208.964	130.974	72.405	28.129
Feb	300.566	709.974	229.638	824.417	482.684	362.913	285.189	211.959	132.593	25.765
Mar	869.067	69.474	744.004	656.25	538.777	350.317	277.666	203.409	148.309	42.832
Apr	962.813	876.034	474.672	353.646	302.431	247.5	193.769	146.231	100.536	26.424
May	367.182	276.96	220.154	157.672	118.492	107.116	79.025	48.596	30.597	6.803
Jun	186.485	141.049	92.886	72.184	57.681	54.414	45.71	30.077	17.662	7.928
Jul	147.991	100.553	80.276	59.054	41.237	33.819	28.342	21.39	14.639	10.055
Aug	158.065	112.351	82.131	53.566	34.476	24.739	20.845	17.365	12.227	7.781
Sep	213.492	130.305	73.453	52.558	37.681	24.41	14.892	5.883	2.188	2.033

Table 12.3 to 12.5 provide the updated natural duration tables, and EWR structure as configured into the model for the scenario analyses. The blue columns refer to the natural flows, and the yellow columns are the EWR flows. The cases where the EWR flows are shown in red indicate the times when the EWR flow is greater than the natural flow. In these “red” cases, the EWR flow was reduced to equal the natural flow.

Table 10.3 REC and natural flows used at EWR O3 (summer flows only)

	OCT		NOV		DEC		JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP	
100%	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000
99%	0000.000	0000.000	0003.693	0005.409	0014.567	0015.536	0028.796	0013.217	0033.614	0030.044	0032.715	0031.285	0019.586	0008.890	0006.148	0000.000	0009.349	0000.000	0010.923	0000.000	0007.996	0000.000	0000.000	0000.000
90%	0015.315	0000.000	0047.022	0011.267	0073.424	0018.370	0092.025	0016.275	0122.788	0031.822	0116.704	0033.074	0074.730	0010.647	0029.801	0000.000	0020.270	0000.000	0015.136	0000.000	0012.022	0000.000	0005.586	0000.000
80%	0025.515	0000.000	0106.998	0023.865	0102.255	0026.736	0163.874	0026.736	0204.499	0039.537	0185.529	0040.836	0112.315	0018.264	0046.266	0000.000	0029.097	0000.000	0020.893	0000.000	0017.466	0000.000	0012.292	0000.000
70%	0052.121	0000.000	0149.012	0038.599	0197.603	0039.637	0214.412	0043.491	0262.021	0054.774	0246.169	0056.164	0160.525	0033.308	0072.110	0000.000	0040.000	0000.000	0026.934	0000.000	0023.133	0000.000	0020.370	0000.000
60%	0067.503	0000.000	0190.903	0051.397	0264.763	0053.924	0270.535	0062.456	0297.370	0076.310	0314.016	0077.829	0217.346	0054.571	0082.714	0000.000	0051.867	0000.000	0033.341	0000.000	0026.404	0000.000	0030.147	0000.000
50%	0099.164	0000.000	0234.259	0060.464	0319.183	0066.273	0379.630	0079.047	0406.178	0099.485	0477.337	0101.143	0281.752	0077.453	0108.460	0000.000	0058.449	0000.000	0041.816	0000.000	0036.514	0000.000	0042.747	0000.000
40%	0151.493	0000.000	0353.912	0065.968	0405.929	0075.005	0479.898	0090.845	0518.420	0119.202	0591.002	0120.979	0321.242	0096.921	0129.480	0000.000	0070.625	0000.000	0053.629	0000.000	0054.458	0000.000	0058.418	0000.000
30%	0225.172	0000.000	0471.350	0068.922	0504.182	0080.214	0642.563	0097.887	0820.624	0132.809	0688.366	0134.667	0431.744	0110.355	0200.515	0000.000	0098.704	0000.000	0077.218	0000.000	0081.317	0000.000	0081.728	0000.000
20%	0311.350	0000.000	0637.184	0070.350	0697.162	0082.892	0912.493	0101.496	1263.856	0140.567	1009.162	0142.472	0633.364	0118.015	0256.332	0000.000	0141.011	0000.000	0107.721	0000.000	0099.141	0000.000	0131.836	0000.000
10%	0591.092	0000.000	0931.451	0070.979	1013.269	0084.098	1284.312	0103.110	2057.129	0144.274	1574.201	0146.201	0936.366	0121.675	0389.076	0000.000	0221.628	0000.000	0144.198	0000.000	0160.506	0000.000	0239.275	0000.000
0%	9999.000	0000.000	9999.000	0070.979	9999.000	0084.098	9999.000	0103.110	9999.000	0144.274	9999.000	0146.201	9999.000	0121.675	9999.000	0000.000	9999.000	0000.000	9999.000	0000.000	9999.000	0000.000	9999.000	0000.000

Table 10.4 REC and natural flows used at EWR O3 (summer and winter flows)

	OCT		NOV		DEC		JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP	
100%	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000
99%	0000.000	0000.000	0003.693	0005.409	0014.567	0015.536	0028.796	0013.217	0033.614	0030.044	0032.715	0031.285	0019.586	0008.890	0006.148	0008.703	0009.349	0009.891	0010.923	0009.639	0007.996	0009.272	0000.000	0001.735
90%	0015.315	0004.967	0047.022	0011.267	0073.424	0018.370	0092.025	0016.275	0122.788	0031.822	0116.704	0033.074	0074.730	0010.647	0029.801	0011.116	0020.270	0011.646	0015.136	0011.745	0012.022	0011.443	0005.586	0007.476
80%	0025.515	0013.822	0106.998	0023.865	0102.255	0026.736	0163.874	0026.736	0204.499	0039.537	0185.529	0040.836	0112.315	0018.264	0046.266	0019.369	0029.097	0016.828	0020.893	0016.274	0017.466	0015.549	0012.292	0015.107
70%	0052.121	0023.869	0149.012	0038.599	0197.603	0039.637	0214.412	0043.491	0262.021	0054.774	0246.169	0056.164	0160.525	0033.308	0072.110	0032.588	0040.000	0024.818	0026.934	0021.571	0023.133	0020.207	0020.370	0021.438
60%	0067.503	0032.471	0190.903	0051.397	0264.763	0053.924	0270.535	0062.456	0297.370	0076.310	0314.016	0077.829	0217.346	0054.571	0082.714	0047.550	0051.867	0033.667	0033.341	0026.171	0026.404	0024.195	0030.147	0025.729
50%	0099.164	0038.529	0234.259	0060.464	0319.183	0066.273	0379.630	0079.047	0406.178	0099.485	0477.337	0101.143	0281.752	0077.453	0108.460	0060.639	0058.449	0041.316	0041.816	0029.431	0036.514	0027.003	0042.747	0028.290
40%	0151.493	0042.204	0353.912	0065.968	0405.929	0075.005	0479.898	0090.845	0518.420	0119.202	0591.002	0120.979	0321.242	0096.921	0129.480	0069.947	0070.625	0046.724	0053.629	0031.410	0054.458	0028.707	0058.418	0029.686
30%	0225.172	0044.182	0471.350	0068.922	0504.182	0080.214	0642.563	0097.887	0820.624	0132.809	0688.366	0134.667	0431.744	0110.355	0200.515	0075.503	0098.704	0049.950	0077.218	0032.471	0081.317	0029.624	0081.728	0030.397
20%	0311.350	0045.145	0637.184	0070.350	0697.162	0082.892	0912.493	0101.496	1263.856	0140.567	1009.162	0142.472	0633.364	0118.015	0256.332	0078.350	0141.011	0051.609	0107.721	0032.985	0099.141	0030.071	0131.836	0030.741
10%	0591.092	0045.572	0931.451	0070.979	1013.269	0084.098	1284.312	0103.110	2057.129	0144.274	1574.201	0146.201	0936.366	0121.675	0389.076	0079.624	0221.628	0052.356	0144.198	0033.211	0160.506	0030.269	0239.275	0030.834
0%	9999.000	0045.572	9999.000	0070.979	9999.000	0084.098	9999.000	0103.110	9999.000	0144.274	9999.000	0146.201	9999.000	0121.675	9999.000	0079.624	9999.000	0052.356	9999.000	0033.211	9999.000	0030.269	9999.000	0030.834

Table 10.5 REC and natural flows used at EWR O5

	OCT		NOV		DEC		JAN		FEB		MAR		APR		MAY		JUN		JUL		AUG		SEP	
100%	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000	0000.000
99%	0000.000	0002.595	0000.000	0003.306	0014.610	0004.759	0021.068	0006.151	0024.957	0010.524	0031.235	0009.817	0017.381	0006.613	0003.051	0006.186	0006.847	0004.235	0008.348	0003.096	0003.926	0002.747	0000.000	0000.192
90%	0007.848	0004.433	0036.682	0007.137	0064.061	0006.584	0082.109	0007.988	0148.509	0011.687	0124.574	0010.216	0080.324	0007.622	0029.585	0007.746	0018.542	0005.709	0012.373	0005.559	0008.363	0004.109	0000.000	0000.192
80%	0017.384	0010.149	0099.722	0014.832	0091.353	0011.972	0160.170	0014.276	0208.309	0016.729	0196.237	0012.132	0137.130	0011.999	0044.766	0013.082	0026.659	0010.058	0018.130	0010.856	0013.769	0008.870	0005.995	0004.848
70%	0044.011	0017.605	0141.173	0023.833	0188.314	0020.278	0210.641	0024.347	0278.065	0026.686	0287.858	0016.752	0183.488	0020.642	0070.087	0021.630	0039.599	0016.764	0024.828	0017.051	0019.056	0015.080	0014.005	0012.551
60%	0059.364	0024.417	0183.850	0031.651	0261.820	0029.478	0261.059	0035.746	0327.016	0040.760	0369.019	0025.247	0251.474	0032.858	0084.961	0031.305	0052.631	0024.191	0031.989	0022.432	0022.506	0020.754	0023.781	0020.092
50%	0091.024	0029.346	0224.228	0037.190	0308.318	0037.430	0380.750	0045.719	0426.581	0055.906	0517.996	0037.162	0305.556	0046.005	0109.543	0039.768	0058.295	0030.611	0040.733	0026.244	0033.079	0024.859	0036.381	0025.455
40%	0143.526	0032.348	0344.136	0040.553	0397.939	0043.053	0477.419	0052.810	0551.147	0068.791	0636.925	0049.912	0350.463	0057.189	0137.642	0045.787	0071.466	0035.150	0053.196	0028.559	0050.373	0027.360	0052.099	0028.505
30%	0217.033	0033.945	0463.804	0042.357	0496.573	0046.407	0655.369	0057.043	0881.711	0077.684	0733.057	0060.319	0471.775	0064.908	0206.623	0049.379	0098.634	0037.858	0076.583	0029.800	0079.017	0028.690	0075.363	0029.966
20%	0303.300	0034.703	0627.168	0043.229	0689.703	0048.131	0921.229	0059.212	1425.893	0082.754	1032.109	0066.800	0723.110	0069.309	0268.638	0051.220	0142.060	0039.250	0105.033	0030.401	0095.072	0029.322	0129.799	0030.575
10%	0582.953	0035.029	0922.647	0043.614	1014.770	0048.908	1320.131	0060.182	2124.451	0085.176	1635.118	0069.877	0959.468	0071.412	0388.926	0052.044	0219.174	0039.877	0141.547	0030.665	0157.146	0029.593	0234.005	0030.715
0%	9999.000	0035.029	9999.000	0043.614	9999.000	0048.908	9999.000	0060.182	9999.000	0085.176	9999.000	0069.877	9999.000	0071.412	9999.000	0052.044	9999.000	0039.877	9999.000	0030.665	9999.000	0029.593	9999.000	0030.715

10.3 SCENARIOS

10.3.1 Scenario A

Scenario A was known as the present day scenario. All the changes reflected in Section 12.1 relevant to the base data set were made in order to configure Sc A. The EWR currently used on the Orange River was set as a constant demand on the Orange River Project, as per the Orange River Development Project Replanning Study (ORRS).

10.3.2 Scenario A2

It has long been understood that the ORRS EWR currently used for the system is unsatisfactory from both a river and estuary ecological perspective. However, it has always been assumed that an improvement can only be made to the existing release when the next augmentation scheme is implemented. Due to the fact that this is likely to only be in about 2025, it was decided to determine whether or not an improvement could be made to the current ORRS EWR release without a detrimental effect on the rest of the system in terms of yield.

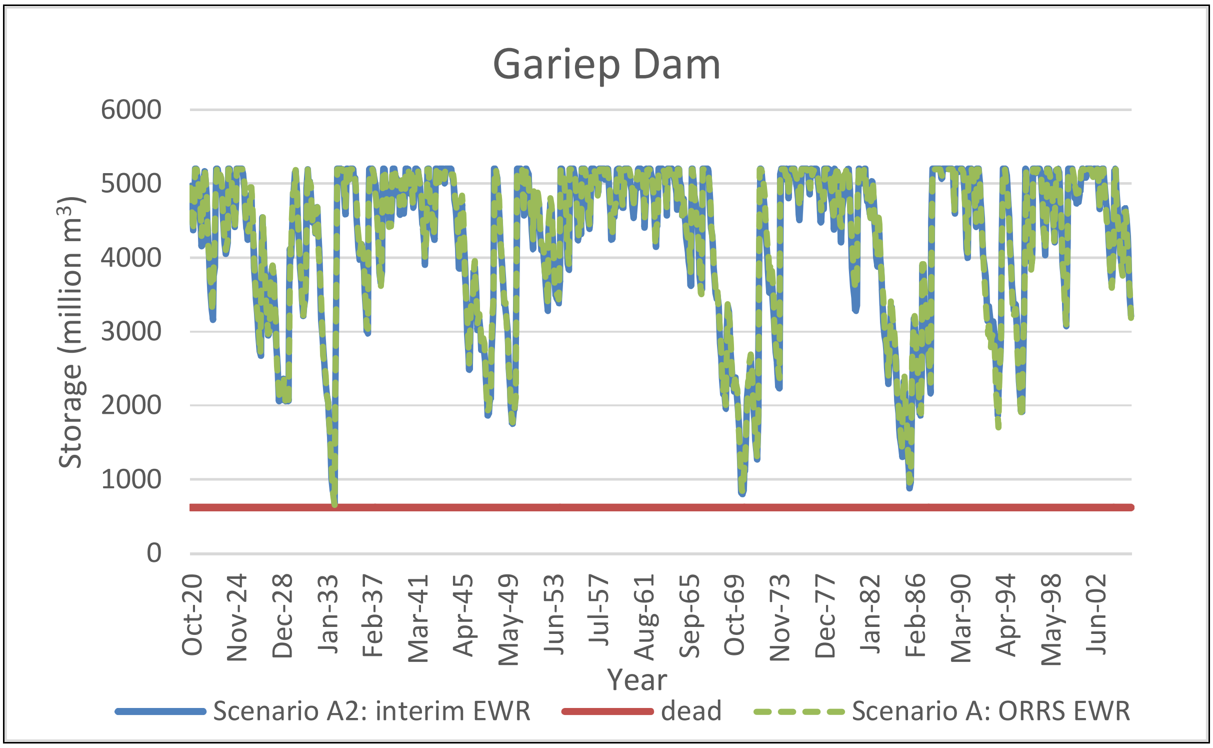
Scenario A2 was then developed in order to assess this possibility. For the Scenario, the ORRS EWR used in Sc A was removed completely. An EWR channel was configured in the current location of EWR O5. The REC for EWR O5 was used as a base to produce an interim EWR solution. The current ORRS EWR requires an annual average of 288 million m^3/a. The REC EWR at EWR O5, though varying year to year, required an annual average over the historic period of 991 million m^3/a. The first iteration of Sc A2 merely scaled the EWR O5 REC down by a factor of 0.29 (288/991). The results were checked and it showed that the storage trajectories of Gariep and Vanderkloof dams improved. This was due to the fact that in dry years, the EWR required less water than the original ORRS EWR.

Further iterations were then carried out, using various scaling factors in combination with the original REC at site EWR O5, until the dam storage trajectories looked similar to the current Scenario A status. In the end, the overall average EWR flow was 523 million m^3/a. This is significantly higher than the current ORRS average, however, the benefit is possible as a result of the lower requirement in dry years.

The following figure provides an indication of the final EWR structure configured into Sc A2.

	OCT	OCT	NOV	NOV	DEC	DEC	JAN	JAN	FEB	FEB	MAR	MAR	APR	APR	MAY	MAY	JUN	JUN	JUL	JUL	AUG	AUG	SEP	SEP
	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00
99	0000.00	0000.00	0000.00	0000.00	0014.61	0001.90	0021.07	0002.46	0024.96	0004.74	0031.24	0000.00	0017.38	0000.00	0003.05	0000.15	0006.85	0000.85	0008.35	0000.62	0003.93	0000.27	0000.00	0000.00
90	0007.85	0001.77	0036.68	0003.57	0064.06	0003.29	0082.11	0003.99	0148.51	0005.26	0124.57	0000.00	0080.32	0000.00	0029.58	0000.77	0018.54	0001.43	0012.37	0001.67	0008.36	0000.41	0000.00	0000.00
80	0017.38	0006.60	0099.72	0010.38	0091.35	0008.38	0160.17	0009.99	0208.31	0008.36	0196.24	0000.00	0137.13	0000.00	0044.77	0002.62	0026.66	0003.02	0018.13	0006.51	0013.77	0003.55	0006.00	0001.45
70	0044.01	0014.08	0141.17	0016.68	0188.31	0014.19	0210.64	0017.04	0278.06	0017.35	0287.86	0000.00	0183.49	0000.00	0070.09	0010.82	0039.60	0005.03	0024.83	0010.23	0019.06	0009.05	0014.00	0008.79
60	0059.36	0019.53	0183.85	0025.32	0261.82	0022.11	0261.06	0026.81	0327.02	0024.46	0369.02	0000.00	0251.47	0000.00	0084.96	0018.78	0052.63	0016.93	0031.99	0016.82	0022.51	0013.49	0023.78	0015.07
50	0091.02	0023.48	0224.23	0029.75	0308.32	0029.94	0380.75	0036.58	0426.58	0027.95	0518.00	0000.00	0305.56	0000.00	0109.54	0027.84	0058.29	0022.96	0040.73	0021.00	0033.08	0019.89	0036.38	0020.36
40	0143.53	0029.11	0344.14	0034.47	0397.94	0034.44	0477.42	0039.61	0551.15	0027.95	0636.93	0000.00	0350.46	0000.00	0137.64	0032.05	0071.47	0028.12	0053.20	0022.85	0050.37	0021.89	0052.10	0022.80
30	0217.03	0029.11	0463.80	0034.47	0496.57	0034.44	0655.37	0039.61	0881.71	0027.95	0733.06	0000.00	0471.77	0000.00	0206.62	0032.05	0098.63	0028.12	0076.58	0022.85	0079.02	0021.89	0075.36	0025.47
20	0303.30	0029.11	0627.17	0034.47	0689.70	0034.44	0921.23	0039.61	1425.89	0027.95	1032.11	0000.00	0723.11	0000.00	0268.64	0032.05	0142.06	0028.12	0105.03	0022.85	0095.07	0021.89	0129.80	0025.47
10	0582.95	0029.11	0922.65	0034.47	1014.77	0034.44	1320.13	0039.61	2124.45	0027.95	1635.12	0000.00	0959.47	0000.00	0388.93	0032.05	0219.17	0028.12	0141.55	0022.85	0157.15	0021.89	0234.00	0025.47
	9999.00	0029.11	9999.00	0034.47	9999.00	0034.44	9999.00	0039.61	9999.00	0027.95	9999.00	0000.00	9999.00	0000.00	9999.00	0032.05	9999.00	0028.12	9999.00	0022.85	9999.00	0021.89	9999.00	0025.47

The following plot provides the storages of Gariep Dam for Sc A and Sc A2. The differences are negligible, indicating that the system can be operated with an improved EWR without an impact on other users.



10.3.3 Scenario A3

Scenario A3 was identical to Sc A2, except that the Namibian demands were set at 2016 allocations as opposed to 2016 estimated use. This resulted in a 92.5 million m^3/a increase in requirement by Namibian users. The scenario was included in order to determine whether there would be an impact on the system using the “interim” EWR if Namibian users suddenly took up all of their allocations in the interim period before Vioolsdrift Dam was built. The results showed a slight impact in the storage at Gariep Dam, but not significant enough to require an adjustment in the scaled interim EWR O5 used in Sc A2.

10.3.4 Scenario B

Scenario B was the first of all the remaining scenarios that required a 2035 development level. This development level involved including all future augmentations for the entire simulation period, (1920 – 2004), as well as setting all demands as they would be in the year 2035. For Sc B, the only EWR on the Lower Orange that was included was the ORRS constant release for the estuary, as was used in Sc A.

The Vioolsdrift Dam Feasibility Study was used as a guide for configuring Vioolsdrift Dam. The following table provides the area capacity relationship used for the dam. Though not obvious from the table, the feasibility study team indicated that these characteristics represent the 73.5 m dam size recommended as a final option in the feasibility study.

	Bottom		Dead											Full
Elevation	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235
Volume	0	1.162	5.493	15.459	32.591	58.017	95.227	152.475	232.178	337.219	470	705	1065	1550	2100
Area	0	0.465	1.267	2.719	4.134	6.036	8.848	14.051	17.829	24.187	28.925	44.066	65	76	91

It is assumed that by 2035, the real-time monitoring and operation of the system will be in place. This reduces the operating losses by 80 million m^3/a from 180 to 20 million m^3/a. When Vioolsdrift Dam is in place, these losses are assumed to be captured in the dam resulting in a total reduction in operating losses of 160 million m^3/a. Additional adjustments to the 2035 development horizon year include:

- Polihali Dam in place and transfers full yield to Vaal system.
- Vaal tributary outflows enter Vioolsdrift Dam and can be used for downstream requirements.
- Neckartal Dam in Namibia is turned on.
- Reduced minimum operating level of Vanderkloof Dam.
- Configured Verbeeldingskraal Dam into system and turned on.
- Novo/Tienfontein capacities increased as per future plans.
- Mine dewatering in Vaal system on.
- Transfer from Gariep Dam to Bloemfontein in place.

10.3.5 Scenario C1b

The Orange River Reconciliation Strategy concluded with a "Preferred EWR" at EWR O3, which was basically the Recommended EWR "without high flows" for the summer months only. Scenario C1b was undertaken in order to repeat the Orange Reconciliation Preferred EWR Scenario option using all the updated information obtained after completion of the Reconciliation study, specifically relating to the Vioolsdrift Dam characteristics updated in the Feasibility Study. The Reconciliation Strategy Study had previously determined that the full impact in yield of the ORP of the total EWR including the summer only EWR at EWR O3 and the current ORRS was 712 million m^3/a, with a net drop in yield from the current situation of 425 million m^3/a, considering that the ORRS requirement was 287 million m^3/a.

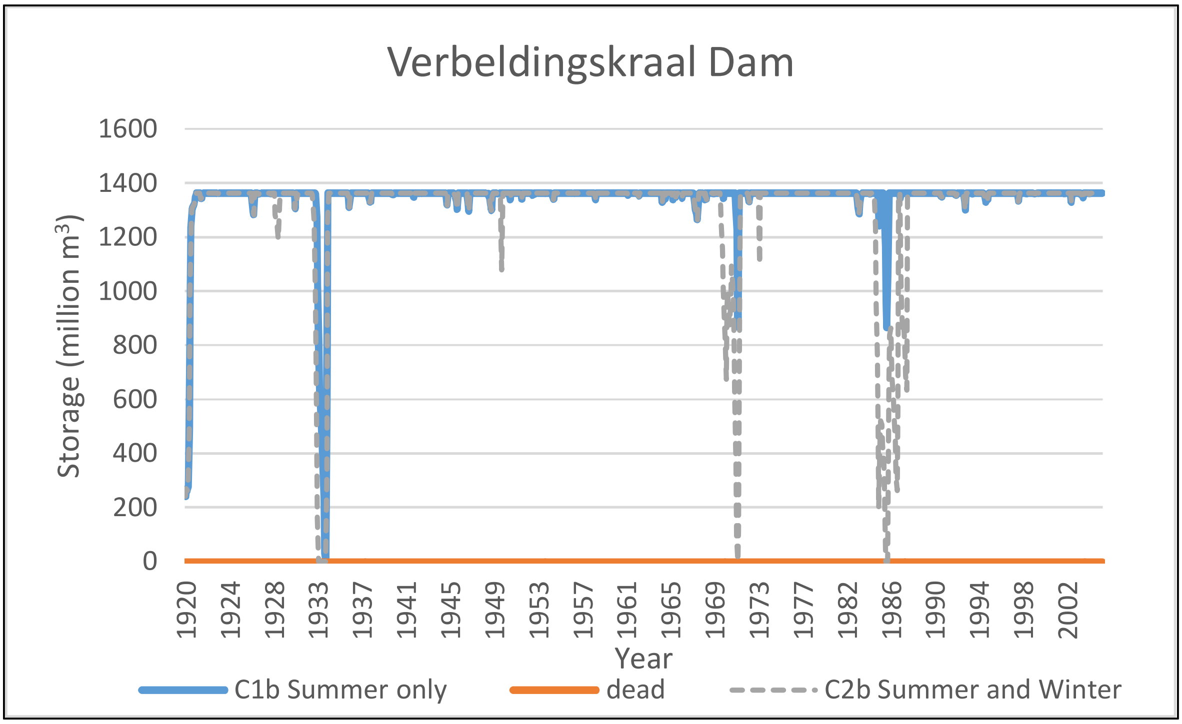
The Preferred EWR at EWR O3 as used in the Reconciliation Strategy Study only included EWRs for the summer months (November to April). This was a result of a previous assessment of flows that had taken place (Louw *et al*., 2013) in which it was determined that the flow passed the site was too high in the low flow winter months if the REC EWR was pulling, resulting in too high flows at the estuary in the winter months. This was partly due to the way the model was configured which did not allow for users downstream of the EWR site to access the water released for the EWR. This is the normal approach for simulating EWRs and other demands. However, in the case of the Lower Orange, the other users were drawing significantly more water in the winter months, resulting in more base flows than those required at the site and the estuary occurring. The solution at the time was to remove the winter month requirements, and to have the flows in the winter months based purely on the requirements of the users. It was not an ideal solution but was seen as the best at the time.

10.3.6 Scenario C2b

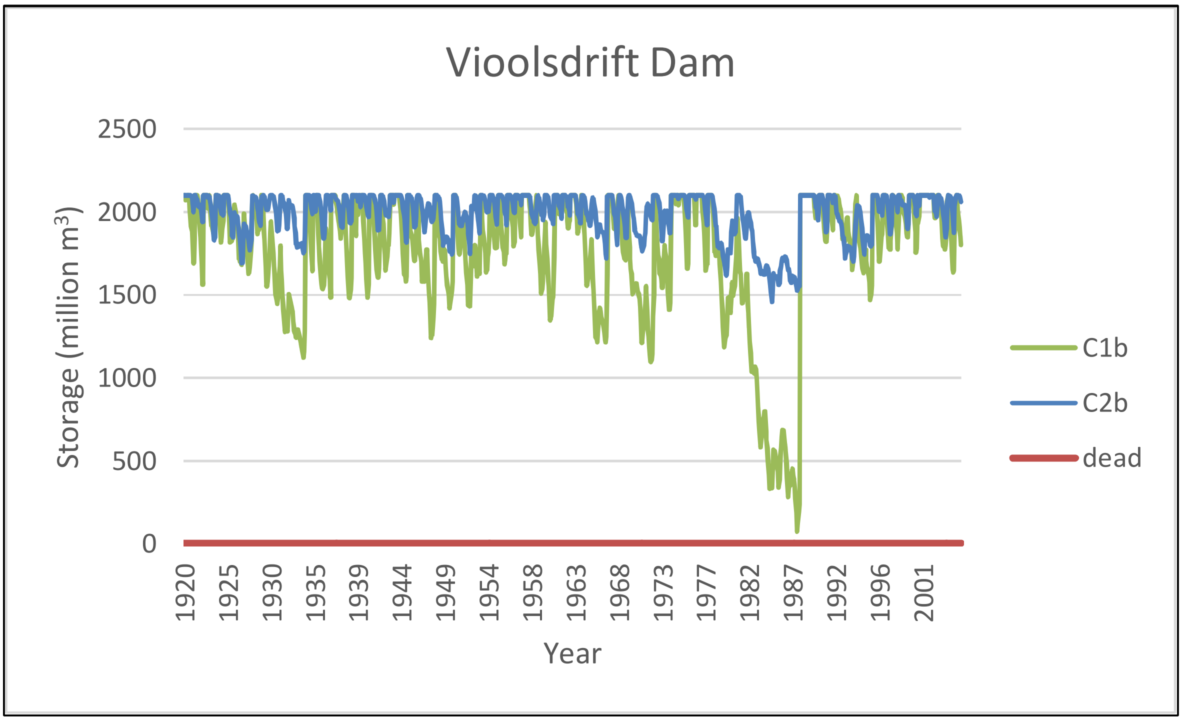
Feedback on the results of Sc C1b indicated that the Augrabies EWR for EWR O3 was performing poorly as a result of only including the summer month requirements and relying on the base flow as a result of other demands in the winter months. It was therefore decided to undertake Sc C2b to understand the impact that the full EWR at EWR O3 had on the system, and to see whether an improvement on the previous assessment could be achieved. Including both summer and winter month requirements at EWR O3 impacted the system twofold as described below.

- Due to the increase in EWR demand at EWR O3, increased pressure was put on Gariep and Vanderkloof dams, which required additional support from Verbeeldingskraal Dam which failed more times over the historical period. In order to obtain a system balance, the demands on the

ORP required a reduction of 400 million m^3/a as a result of the winter flow requirements being included.



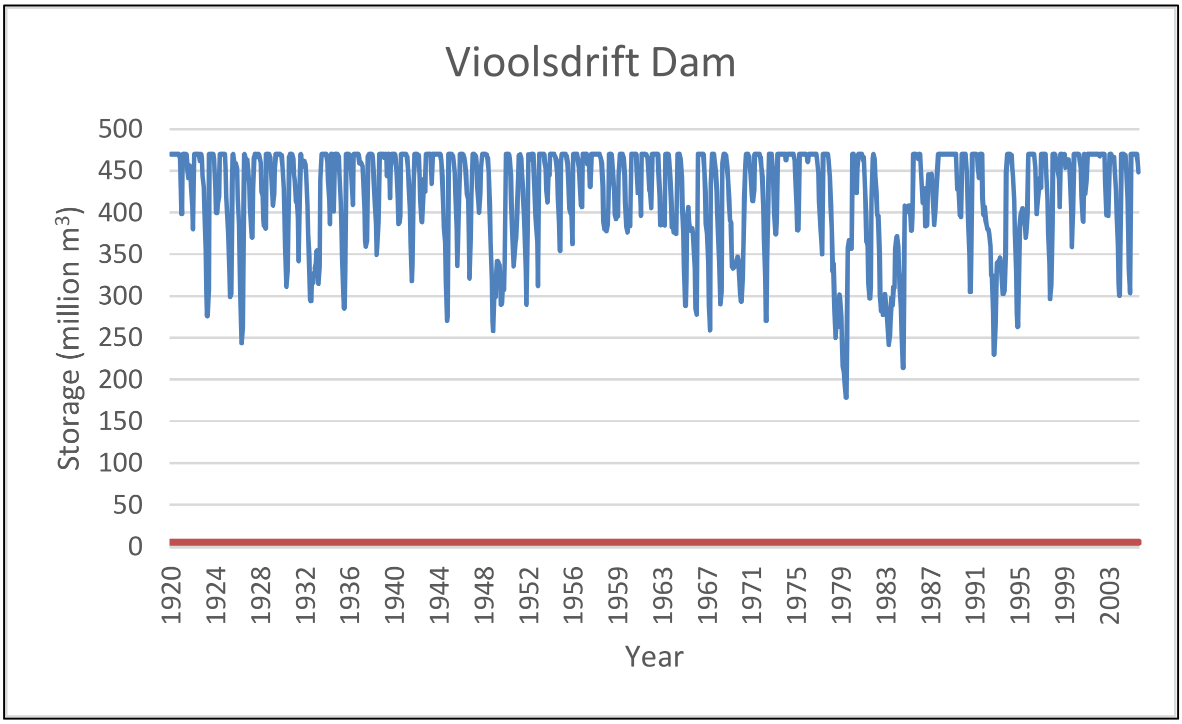
- The increased flow requirement (including the winter months) however created a positive impact in the lower Orange, whereby significantly water was released into Vioolsdrift Dam, which now showed considerable under utilisation of the large storage dam at Vioolsdrift.



A different approach was used to simulate the EWR at EWR O3 than what has been used in the past, which contributed to the yield reduction as a result of the winter flows (400 million m^3/a) being less than previous analyses. It also allowed for lower flows past the sites and at the estuary in the low flow months than previously assessed which had been problematic before. The model was configured such that the EWR pulled through EWR O3 was able to supply demands of users between EWR O3 and Vioolsdrift Dam. This eliminated the previous problem of significantly higher flows than desired passing EWR O3, which were caused in a sense by duplication of demands, i.e. EWR and abstractions. If it is operated as such in reality, one would find a decrease in flows between EWR O3 and Vioolsdrift Dam, as the users abstract the EWR flows. The anomaly was weighed up of having higher flows than desired in the low flow months at EWR O3, or a decreasing EC in the river reach downstream of EWR O3.

10.3.7 Scenario D2

Scenario D2 was considered after the results of Sc C2b were assessed and it was determined that Vioolsdrift Dam size was too large if the summer and winter flows were included at EWR O3. The Dam was not fully utilised by the demands and requirement of EWR O5 downstream of it, and operated at high storage levels due to the higher requirements from EWR O3 captured and stored in the Dam. A smaller Dam was then considered to determine the impact. Smaller sizes were iteratively input into the model, and a final size of 470 million m^3 gross storage was used for the scenario. The following plot presents the plot of the smaller dam, and it can be seen that it is utilised more. Neither users, nor the EWR downstream of Vioolsdrift Dam were at a disbenefit as a result of the smaller dam used, and in fact the result shows that the dam could be even smaller. Further work on determining the optimal size should take place, however was outside the scope of this study.



10.3.8 Scenario D2i and ii

Two further options of Sc D2 were considered after assessment of the results by the Estuary specialists indicated that some improvements could be made. The specialists requested that a few higher flows be included in the month of December (Sc D2i) and as a second option in both December and January (Sc D2ii). Scenario D2 was used with the following adjustments:

- D2i: Increase the flow into the estuary where the flow is below 8 m^3/s, to 8 m^3/s for the December months where the exceedance probability of natural flows is greater than 90%.

- D2ii: Increase the flow into the estuary where the flow is below 8 m^3/s to 8 m^3/s for December as well as January months where the exceedance probability of natural flow is greater than 90% for the two months respectively.

The Scenarios resulted in slight increases in flows in the indicated months, where required. Very little impact on Vioolsdrift Dam was visible as a result of the adjustment.

10.3.9 Scenario D3

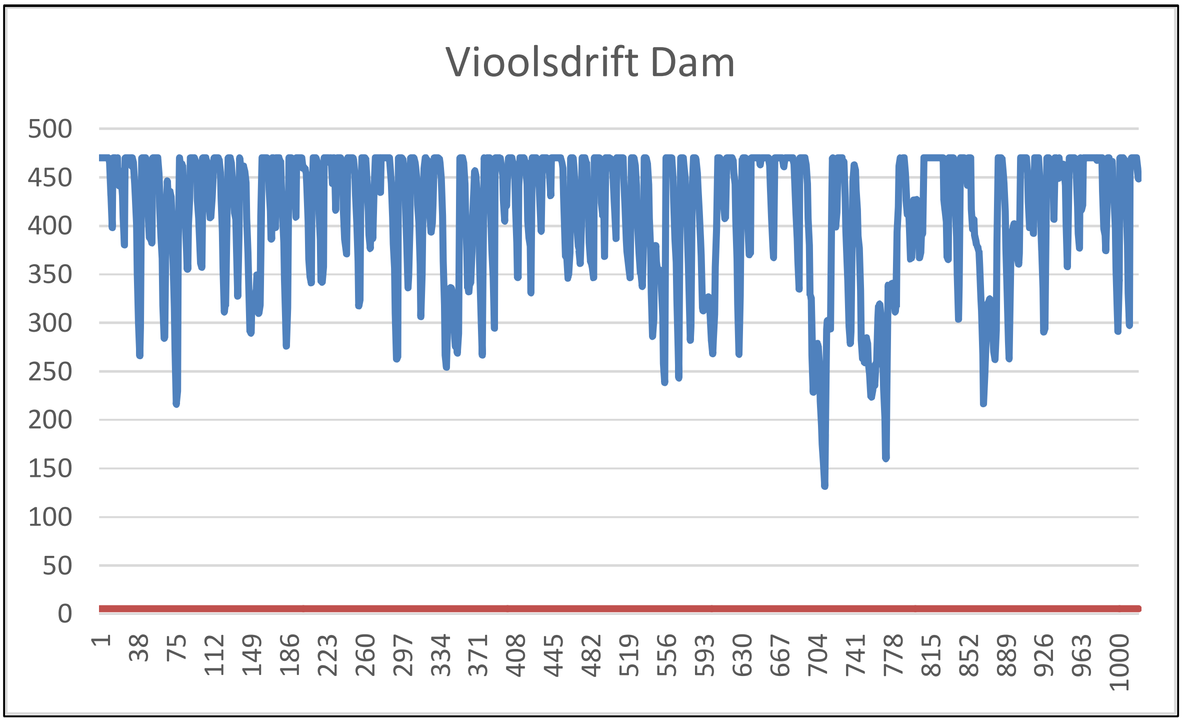
Scenario D2 was used as a base for Sc D3, with the modification being the addition of some floods at EWR O5. Again, the original report was used as a guide of what size floods to include, as seen in the table below.

Desktop version:		2	Virgin MAR (Mm^3)	11373
BFI	0.301	Distribution type		Vaal
MONTH	LOW FLOWS		HIGH FLOWS	
	Maintenance (m^3/s)	Drought (m^3/s)	Daily average (m^3/s) on top of base flow	Duration (days)
October	22.9	2.6		
November	30.5	3.3	190	7
December	34.5	4.5	60 190	5 7
January	45.7	5.9	60 190	5 7
February	65.1	10.0	60 300	5 10
March	61.0	9.4	60 500	5 12
April	54.6	6.2		
May	39.5	5.9		
June	28.2	4.0		
July	21.4	2.9		
August	19.3	2.6		
September	18.8	0		
Total Mm^3	1154.46	149.64	512.85	

A 60 m^3/s flood over five days for the months December to March was included. This was run through a hydrograph creating model, and a total cumulative volume to add to each month for this flood requirement was determined to be 12.286 million m^3 volume. This equated to 4.74 m^3/s. This volume was added to the EWR structure for the 50 – 10 percentile values only for the months November, December, January, February and March. A scaled factor of this value was then added for the other percentiles, with the 99 percentile factor being 0. The EWR flows including floods compared with the original REC without floods are shown below. The shaded area indicates the differences.

new with floods	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
99	0.000	0.000	4.759	6.151	10.524	9.817	6.613	3.050	4.235	3.096	2.747	0.000
90	4.433	7.319	6.751	8.154	11.885	10.477	7.622	7.746	5.709	5.559	4.109	0.000
80	10.149	15.588	12.578	14.868	17.296	12.751	11.999	13.082	10.058	10.856	8.870	4.848
70	17.605	25.656	21.819	25.862	28.044	18.034	20.642	21.630	16.764	17.051	15.080	12.551
60	24.417	34.878	32.464	38.711	43.525	27.823	32.858	31.305	24.191	22.432	20.754	20.092
50	29.346	41.930	42.170	50.459	60.646	41.902	46.005	39.768	30.611	26.244	24.859	25.455
40	32.348	45.293	47.793	57.550	73.531	54.652	57.189	45.787	35.150	28.559	27.360	28.505
30	33.945	47.097	51.147	61.783	82.424	65.059	64.908	49.379	37.858	29.800	28.690	29.966
20	34.703	47.969	52.871	63.952	87.494	71.540	69.309	51.220	39.250	30.401	29.322	30.575
10	35.029	48.354	53.648	64.922	89.916	74.617	71.412	52.044	39.877	30.665	29.593	30.715
original REC												
99	0.000	0.000	4.759	6.151	10.524	9.817	6.613	3.050	4.235	3.096	2.747	0.000
90	4.433	7.137	6.584	7.988	11.687	10.216	7.622	7.746	5.709	5.559	4.109	0.000
80	10.149	14.832	11.972	14.276	16.729	12.132	11.999	13.082	10.058	10.856	8.870	4.848
70	17.605	23.833	20.278	24.347	26.686	16.752	20.642	21.630	16.764	17.051	15.080	12.551
60	24.417	31.651	29.478	35.746	40.760	25.247	32.858	31.305	24.191	22.432	20.754	20.092
50	29.346	37.190	37.430	45.719	55.906	37.162	46.005	39.768	30.611	26.244	24.859	25.455
40	32.348	40.553	43.053	52.810	68.791	49.912	57.189	45.787	35.150	28.559	27.360	28.505
30	33.945	42.357	46.407	57.043	77.684	60.319	64.908	49.379	37.858	29.800	28.690	29.966
20	34.703	43.229	48.131	59.212	82.754	66.800	69.309	51.220	39.250	30.401	29.322	30.575
10	35.029	43.614	48.908	60.182	85.176	69.877	71.412	52.044	39.877	30.665	29.593	30.715

Again, the addition of the floods did not have a large impact on the smaller sized Vioolsdrift, with the conclusion drawn that further floods could be catered for if required.



10.4 RESULTS

For each scenario, the results in the form of a time series of monthly average flows past each site dating from 1920 to 2004 were provided to the study team for further assessment. A summary of those flows are presented in the table below, representing the average annual flow in million m^3/a at the given site and representative scenario. The reduction in yield refers to the decrease in yield of the ORP as result of the different EWRs included for the specific scenario.

Scenario	EWR O3	Vioolsdrift	EWR O5	Estuary	Yield reduction (million m^3/a)
A	4280.45	3984.34	4430.61	4346.46	Current base
A2	4287.76	3991.62	4437.89	4353.74	0*
A3	4306.79	3925.12	4371.37	4285.71	0*
B	3531.35	2953.75	3183.12	3059.03	2035 Base
C1b	3708.39	3110.33	3298.13	3173.97	425**
C2b	3708.39	3110.33	3375.86	3251.63	825**
D2	3747.05	3205.22	3493.33	3369.03	825**
D2i	3747.05	3205.63	3493.50	3369.19	825**
D2ii	3747.05	3205.76	3493.62	3369.32	825**
D3	3747.15	3206.49	3494.21	3369.90	825**

* Yield reduction relative to Sc A. ** Yield reduction relative to Sc B.

11 APPENDIX B: COMMENTS REGISTER

	Section	Report statement	Comments	Changes made?	Author comment