DEPARTMENT: **WATER AFFAIRS AND FORESTRY**
DIRECTORATE: **RESOURCE DIRECTED MEASURES**

OLIFANTS/DORING CATCHMENT ECOLOGICAL WATER REQUIREMENTS STUDY –

DELINEATION REPORT

FINAL REPORT
2 JUNE 2004

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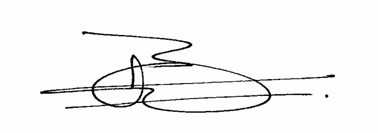

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Milestone (Reporting) List

Milestone Report		Due Date	Date first draft submitted	Date final report submitted
Project Report 1:	Inception Report	October 2003	September 2003	December 2003
Project Report 2:	Delineation Report	March 2004	April 2004	July 2004
Project Report 3:	Groundwater TOR	May 2004	December 2003	March 2004
Project Report 4:	Riverine RDM Report.	March 2005		
Project Report 5:	Estuarine RDM Report.	July 2005		
Project Report 6:	Scenario Report	May 2005		
Project Report 7:	Monitoring Appendix	October 2005		
Project Report 8:	Main Summary Report.	December 2005		
Scenario-creation database for the rivers (in electronic format).		December 2005		

EXECUTIVE SUMMARY

OLIFANTS/DORING CATCHMENT ECOLOGICAL WATER REQUIREMENTS STUDY –

DELINEATION REPORT

INTRODUCTION

This Delineation Report is the second in a series of eight project-related reports. The aims of the report are:

- to provide an overview of the present habitat integrity of the study rivers and estuary;
- to describe the delineation of the study river reaches into Resource Units;
- to describe the EWR sites that were selected, and how and why they were selected;
- to delineate the boundaries of the estuary.

THE STUDY AREA

The Olifants/Doring River catchment is situated in the south-west of South Africa. Significant portions of the catchment fall within the Northern Cape Province, in particular the upper reaches of the Doring River, and some of its northern tributaries, such as the Tankwa River. The remainder, generally wetter portions of the catchment fall within the Western Cape Province.

GEOGRAPHICAL BOUNDARIES OF THE ESTUARY

The geographical boundaries of the Olifants River Estuary are as follows:

Downstream boundary:	Estuary mouth (31^{o} 42.00'S; 18^{o}11.34'E).
Upstream boundary:	Extent of tidal influence, i.e. the causeway at Lutzville - about 36 km from the mouth (31^{o}33.80'S; 18^{o}19.78'E).
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank.

The 5 m contour above MSL is indicated on the provided on 1:10 000 orthophotos (Olifants River Estuary spans about 10 1:10 000 orthophotographs). Although the 1:10 000 orthophotos are electronically available, the 5 m contour above MSL is not yet available on the electronic versions.

WATER QUALITY RESOURCE UNITS

Olifants River

WQU OR1

Unit defined by water quality as determined from the DWAF site E1H013Q01 – (Olifants River at Citrusdal).

Provisional definition with reference to EWR Site 1:
Upstream: 30 km south (upstream) of EWR Site 1.
Downstream: The point of inflow into the Clanwilliam Dam.
WQU length: 60 km.

WQU OR2

Unit defined by water quality as determined from the DWAF sites E1R002Q01 (Clanwilliam Dam, near the wall) and E1H011Q01 (Clanwilliam Dam on the Olifants River, downstream weir).

Provisional definition (no EWR within this WQU):
Upstream: Clanwilliam Dam.
Downstream: The point of inflow to Bulshoek Barrage.
WQU length: 22 km.

WQU OR3

As there are currently no data available sufficient to describe the water quality of this reach, this unit is defined provisionally by the water quality as determined from the DWAF E1H006Q01 (Jan Dissels River).

Provisional definition with reference to EWR Site 3:
Upstream: Rondegat River from source.
Downstream: Confluence with Olifants River.
WQU length: 26 km.

WQU OR4

Unit defined by the water quality as determined from the DWAF sites E1R001Q01 (Bulshoek Barrage, near the wall) and E1H007Q01 (Bulshoek Barrage on the Olifants River, left canal).

Provisional definition with reference to EWR Site 2:
Upstream: Bulshoek Barrage.
Downstream: Confluence of Olifants and Doring Rivers.
WQU length: 18 km.

Doring River

WQU DR1

Unit defined by the water quality as determined from the DWAF site E2H007Q01 (Leeuw River/Upper Groot River).

Provisional definition with respect to EWR Site 6:
Upstream: To source of the Leeu River.
Downstream: To the confluence of the Groot and Doring Rivers.
Unit length: 55 km.

WQU DR2

Unit defined by the water quality as determined from the DWAF site E2H002Q01 (Doring River at Aspoort).

Provisional definition (no EWR within this WQU).
Upstream: Aspoort Gauging Weir (E2H002).
Downstream: Confluence of the Doring and Tankwa Rivers.
Unit length: 28 km.

WQU DR3

Unit not currently defined by any available water quality data. Provisional definition with reference to EWR Site 4.

Upstream: Confluence of the Doring and Tankwa Rivers.
Downstream: Midway between the confluences of the Doring with the Brak and Koebee Rivers.
Unit length: 55 km.

WQU DR4

Unit defined by the water quality as determined from the DWAF site E2H003Q01 (Doring River at Melkboom).

Provisional definition with reference to EWR Site 5:

Upstream: Confluence of the Doring and Kobee Rivers.
Downstream: Confluence of the Doring and Olifants Rivers.
Unit length: 40 km.

GEOMORPHOLOGICAL RESOURCE UNITS

Olifants River

1 Bulshoek Barrage to the confluence with the Doring River: Shallow gradient, braided with occasional anabranching.

2 Clanwilliam Dam to Bulshoek Barrage: Where valley is confined and slope is steep, single thread pool/rapid/riffle channel type. Where valley is wider and slope is flatter, channel type is braided with extensive overbank deposits and sand splays. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Channel pathway often structurally controlled.

3 Citrusdal to Clanwilliam Dam. Where valley is narrower and slope is flat, channel type is braided with extensive overbank deposits and sand splays. In slightly steeper, but wider, unconfined valleys, channel type is anabranching. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Extensive sand bed load.

4 Keerom to Citrusdal. Extensive anabranching. Multiple channels, unconfined valley. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Combination of bedrock influence and vegetation important in maintaining anabranching planform. Exposed sediment not as evident in anabranching channel type.

5&6 Downstream end of the Olifants River Gorge. Single thread pool/rapid.

7 Very steep. Olifants River Gorge. Pool/rapid/bedrock canyon. Channel pathway exploiting lines of structural weakness.

8 Kouebokkeveld.

Doring River

1 Kouebokkeveld. Large sand bed load. Braided channel type associated with flat slope and wide, unconfined valleys. Riparian and in-channel vegetation plays a very important role in sediment transport processes.

2 Groot River Gorge. Single thread pool/rapid/riffle associated with narrow, confined valleys and steep slopes. Bedrock influence strong, creating local upstream hydraulic controls, rapids and pools. Extensive mid-channel, lateral and point bars. Riffles consist of coarse bed material, pools associated with sand load.

3 Aspoort to *d/s* Oudrif. Anabranching channel type associated with multiple channels, unconfined valley and flatter slope. Riparian and in-channel vegetation

plays a very important role in sediment transport processes and in the stabilization of various morphological units. Combination of bedrock influence and vegetation important.

5 *D/s* Oudrif to Melkboom. Abrupt change of channel type to bedrock pool/rapid. Steep, confined valley with strong bedrock influence, dominance of structural control on channel pattern and bedrock influence on channel morphology.

6 Melkboom to the confluence with the Olifants River. Anabranching channel type associated with multiple channels, unconfined valley and flatter slope. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Combination of bedrock influence and vegetation important.

HABITAT INTEGRITY (MAIN STEMS)

Figure 6.1 provides a summary of the overall habitat integrity assigned to each segment, and thus for the rivers as a whole.

KEY WATER MANAGEMENT UNITS

Olifants River

Kouebokkeveld- Olifants:	The headwater regions of the Olifants Rivers are heavily utilized for agriculture, and form a distinct management unit.
Keerom to Clanwilliam Dam:	The presence of the towns of Citrusdal and Clanwilliam, and of Clanwilliam Dam makes this a vitally important management unit.
Clanwilliam Dam to Bulshoek Barrage:	Releases from Clanwilliam Dam to ensure sufficient water enters the agicultural canals at the Bulshoek Barrage makes this the most ‘managed’ section of the entire system.
Bulshoek Barrage to the confluence with the Doring River:	The importance of this section for water resource management stems from the fact that it is the section that defines the contribution of the upper Olifants River to the lower river and estuary.
Confluence with the Doring River to Lutzville:	The lower reaches of the Olifants Rivers are heavily utilized for agriculture, and form a distinct management unit.

Doring River

Kouebokkeveld- Doring:	The headwater regions of the Olifants Rivers are heavily utilized for agriculture, and form a distinct management unit.
Groot from Mount Cedar to Aspoort:	The possibility of an inchannel storage dam at Aspoort makes this a potentially important management unit.
Doring from Elandsvlei to Melkbosrug:	The possibility of an inchannel storage dam at Melkbosrug and/or a diversion weir to storage on the Brandewyn, make this a potentially important management unit.
Doring from Melkbosrug to Melkboom:	The possibility of an inchannel storage dam at Melkboom makes this a potentially important management unit. It is also the section that

defines the contribution of the Doring River to the lower Olifants River and estuary.

KEY RESOURCE UNITS

The different river reach delineations given for the mainstem of the Olifants and Doring Rivers in this report were compared and rationalised to arrive at seven broad resource units for the Olifants River, and five broad resource units for the Doring River.

Olifants River

Olifants RU1: Kouebokkeveld.
Olifants RU2: Olifants River Gorge.
Olifants RU3: Olifants River Gorge to Citrusdal.
Olifants RU4: Citrusdal to Clanwilliam Dam.
Olifants RU5: Clanwilliam Dam to Bulshoek Barrage.
Olifants RU6: Bulshoek Barrage to the confluence with the Doring River.
Olifants RU7: The confluence with the Doring River to the estuary.

Doring River

Doring RU1: Kouebokkeveld.
Doring RU2: Groot River Gorge.
Doring RU3: Groot/Doring River Confluence to Tankwa/Doring River Confluence.
Doring RU4: Tankwa/Doring River Confluence to Doringbos.
Doring RU5: Doringbos to Olifants/Doring River Confluence.

Rondegat River

The Rondegat River was also included as a tributary for which EWR assessment data could be extrapolated to the Huis, Hex and Jan Dissels Rivers. The Rondegat River is in the best ecological condition of the four tributaries.

Groot River

The Groot River is included in the RUs delineated for the Doring River. It was also included as a tributary for which EWR assessment data could be extrapolated to the Riet, Matjies and possibly Tra-Tra Rivers.

LOCATION OF EWR SITES

DWAF (1999) suggest that, for a Comprehensive Reserve determination, four EWR sites, selected correctly, will normally cater for a river length of 100 - 200 km. However, the number of EWR sites influences the cost and time required for the study and, in this study (as is often the case), site number was dictated by financial considerations. The total number of sites for the study was limited to six, with two of these being on key tributaries. ***This equated to approximately two sites EWR sites per 200 km of river.*** This meant that the priority assigned to the different RUs became one of the most important determining factors and EWR sites were selected only in priority RUs, *viz*.:
Olifants RU4: Citrusdal to Clanwilliam Dam.
Olifants RU6: Bulshoek Barrage to the confluence with the Doring River.
Doring RU2: Groot River Gorge.
Doring RU4: Tankwa/Doring River Confluence to Doringbos.
Doring RU5: Doringbos to Olifants/Doring River Confluence.
and: Rondegat River.

The locations of the EWR sites, and the cross-sections selected at each are given in Table E1.

Table E.1 Locations of each of the six EWR sites selected.

Site No.	River	Site Name	Description	Latitude	Longitude
1a 1b	Olifants	Olifants at Hex River	N7 downstream of the confluence with the Hex River.	32°26.764 32°26.680	18°57.601 18°57.504
2	Olifants	Olifants at Alwynskop	Downstream of Bulshoek Barrage, just downstream of Cascade Pools.	31°57.974	18°44.463
3a 3b	Rondegat	Rondegat at Algeria	Upstream of the Algeria staff accommodation, on the road between Algeria and Clanwilliam.	32°21.760 32°21.739	19°02.618 19°02.593
4a 4b	Doring	Doring at Biedou	On the Doring mainstem, immediately upstream of the confluence with the Biedou River	32°02.410 32°02.416	19°24.896 19°24.783
5	Doring	Doring at Oudrif	At Oudrif.	31°51.446	18°54.754
6a 6b	Groot	Groot at Mount Cedar	Upstream of the bridge at Groot Rivier.	32°39.552 32°39.377	19°23.786 19°23.982

HYDROLOGY FOR THE EWR SITES

There is a paucity of functioning DWAF gauging weirs in the Olifants/Doring catchment, which makes both the estimation of mean annual runoff, and the provision of daily flow records for the EWR sites extremely difficult. While every effort will be made to provide the best hydrological information on which to base the environmental flow determinations, it is essential that those using the data are aware of the inherent shortcomings thereof.

The monthly flow data for the EWR sites on the Olifants/Doring River are simulated data sets that were constructed as part of the Olifants/Doring Basin Study, which modelled run-off in the rivers on a sub-catchment basis. The data were then adjusted to the EWR sites by adding and subtracting sub-catchments.

The summary statistics for the sites are provided in Table E.2.

Table E.2 Simulated naturalised and present day runoff for EWR sites.

EWR Site	Naturalised MAR (MCM a^{-1})	Present Day MAR (MCM a^{-1})	Aspect of the flow regime most affected by development
EWR Site 1	320.23	276.52	Summer low flows; Dry season floods.
EWR Site 2	509.56	277.88	All, except very large floods.
EWR Site 3	7.67	7.45	Very little – mainly lowflows.
EWR Site 4	417.22	317.84	Summer low flows.
EWR Site 5	507.16	398.28	Summer low flows.
EWR Site 6	120.33	92.78	Summer low flows.

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Glossary and Abbreviations

AQUIFER	Water-bearing soil or rock layer.
BIOTA	A collective term for all the organisms (plants, animals, fungi and bacteria) in an ecosystem.
BIOTOPE	The place in which a certain assemblage of organisms live.
BM	Bench Mark.
Ca	Calcium (mg l^{-1}).
Cl	Chloride (mg l^{-1}).
D: RDM	Directorate: Resource Directed Measures.
DWAF	Department of Water Affairs and Forestry.
EC	Electrical conductivity (mS m^{-1}).
ENVIRONMENTAL WATER REQUIREMENT	Flow in a river, or into a wetland or coastal zone (which may be groundwater) that maintains the ecosystem in a negotiated ecological condition.
EWR	Ecological Water Requirements.
GROUNDWATER	Water in a porous medium, beneath the soil surface, with a pressure greater than or equal to atmospheric pressure, and where all the voids are filled with water
HABITAT INTEGRITY	The maintenance of an integrated composition of physicochemical and habitat characteristics on a temporal and spatial scale that is comparable to the characteristics of natural habitats of the region.
HABITAT	The place in which a plant or animal lives. (See BIOTOPE.)
HARD	Total hardness, as $CaCO_3$, (mg l^{-1}).
HYDRAULICS	The branch of science and technology concerned with the mechanics of fluids.
HYDROLOGY	Science dealing with properties, distribution and circulation of water in the biosphere.
INVERTEBRATE	An animal without a backbone - includes insects, snails, sponges, worms, crabs and shrimps.
K	Potassium (mg l^{-1}).
LB	Left Bank (looking downstream).
MACRO-REACH	A length of river channel along which the structural characteristics are uniform. Reach boundaries were defined by changes in channel structure, slope, streambed, valley floor width and bank material.
MAP	Mean Annual Precipitation.
MAR	Mean Annual Runoff.
MCM	Millions of Cubic Metres.
Mg	Magnesium (mg l^{-1}).
Mm^3	Millions of Cubic Metres.
MSL	Mean Sea Level.
Na	Sodium (mg l^{-1}).
NO_3-N	Nitrate nitrogen, as N (mg l^{-1}).
NH_4-N	Ammonium nitrogen, as N (mg l^{-1}).

NUTRIENT	In aquatic biology, usually a limiting nutrient – an element whose scarcity can limit plant growth (e.g. compounds of nitrogen, phosphorus).
PES	Present Ecological State.
pH	The negative log of the hydrogen ion activity; a measure of acidity (pH<7) or alkalinity (pH>7).
PMC	Project Management Committee.
POLLUTION	Unfavourable alteration of our surroundings, normally as a result of human actions; the presence of any substances that impairs the usefulness of water.
PO_4-P	Orthophosphate, as P (mg l^{-1}).
RB	Right Bank (looking downstream).
RDM	Resource Directed Measures.
RESOURCE QUALITY OBJECTIVE (RQO)	Quantitative and auditable statements about water quantity, water quality, habitat integrity and biotic integrity that specify the requirements (goals) needed to ensure a particular level of resource protection.
RESOURCE QUALITY	The quality of all the aspects of a water resource including (a) the quantity, pattern, timing, water level and assurance of instream flow; (b) the water quality, including the physical, chemical and biological characteristics of the water; (c) the character and condition of the instream and riparian habitat; and (d) the characteristics, condition and distribution of the aquatic biota.
RESOURCE UNIT	Stretches of river that are sufficiently ecologically distinct to warrant their own specification of Ecological Water Requirements.
RIPARIAN HABITAT	The physical structure and associated vegetation of the areas associated with a watercourse which are commonly characterised by alluvial soils, and which are inundated or flooded to an extent and with a frequency sufficient to support vegetation of species with a composition and physical structure distinct from those of adjacent land areas.
RIPARIAN	Pertaining to the river bank.
SEGMENT [GEOMORPHOLOGICAL]	A length of river channel along which there is no significant change in the flow or sediment load. Segment boundaries were defined by major tributary junctions.
TALK	Total alkalinity, as $CaCO_3$, (mg l^{-1})
TERRACE	Relic floodplain or valley floor deposits above the present river level representing a former floodplain level prior to incision.
TKN	Total (Kjeldahl) nitrogen, as N (mg l^{-1}).
TP	Total phosphorus, as P (mg l^{-1}).

SO_4	Sulphate ($mg\ l^{-1}$).
WETLAND	Land that is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which, in normal circumstances supports or would support, vegetation typically adapted to life in saturated soil.

1. BACKGROUND

This report forms part of a Comprehensive Assessment of the Ecological Water Requirements of the Olifants/Doring River Catchment, initiated and funded by the Department of Water Affairs and Forestry: Directorate Resource Directed Measures (RDM). The project is being managed for the Client by Ninham Shand Consulting Services. The main technical consultant for the project is Southern Waters Ecological Research and Consulting cc, with the following main sub-consultants:

- CSIR;
- DH Environmental Services;
- Freshwater Consulting Group;
- GEOSS;
- Ninham Shand Consulting Services;
- Streamflow Solutions;
- Stellenbosch University;
- University of Cape Town;
- University of Port Elizabeth;
- A. Bok and Associates.

Project duration is from July 2003 to March 2006.

1.1 OBJECTIVES AND LAYOUT OF THIS REPORT

This Delineation Report is the second in a series of eight project-related reports. The aims of the report are:

- to provide an overview of the present habitat integrity of the study rivers and estuary;
- to describe the delineation of the study river reaches into Resource Units;
- to describe the EWR sites that were selected, and how and why they were selected;
- to delineate the boundaries of the estuary[1].

1.1.1 Layout of the report

This report is divided into several discrete sections. Each deals with one aspect of the delineation. The sections are as follows:

Section 1: Provides some background to the Comprehensive Assessment of the Ecological Water Requirements of the Olifants/Doring River Catchment, explains the methods used in the delineation and details the main assumptions and limitations of the study as they pertain to delineation.

Section 2: Comprises a general description of the Olifants/Doring River Catchment, including the estuary, but excluding groundwater and wetlands.

Section 3: Provides the geographical boundaries of the Olifants/Doring Estuary.

Section 4: Delineates the Olifants/Doring River in terms of its driving water quality characteristics, and indicates the reaches that will form the focus of the Water Quality Reserve Determination.

Section 5: Details the macro-reach classification of the study rivers, done with the purpose of contextualising the final geomorphology and potential bed material transport report for the EWR assessment.

Section 6: Summarised the ecological condition, or habitat integrity, of the Olifants and Doring Rivers and key tributaries using previously collected data on the systems, augmented with data collected during the EWR site selection trip.

Section 7: Summarises the information from Sections 4, 5 and 6 for each reach, adds some indication of key management units (in terms of water resource

[1] The estuary will be delineated into representative sections during the course of the study, once data from the field investigations become available.

	management) and combines it to provide an overall delineation of Resource Units for the Olifants/Doring Rivers.
Section 8:	Presents the location, characteristics, basic hydrology, cross-sectional selections and fixed-point photography information for the six EWR Sites selected for this project.
Section 9:	References.
Section 10:	Annexures.

1.2 METHODS USED

The delineation of the study area into ecologically distinct units (i.e., Resource Units) is based on a general knowledge of the study area and consideration of factors relating to:

- hydrology;
- geology and sediment yield;
- water chemistry;
- system operation, i.e., the position of structures that regulate flow;
- ecoregional classification, i.e., an integration of physical variables such as topography, landscape, geology, soils and vegetation cover, which are deemed to influence the character of river ecosystems;
- the ecological condition of the different river reaches themselves, i.e., habitat integrity;
- the geomorphological zonation of the rivers, based on the system proposed by Rowntree *et al.* (2000);
- landuse and social utilisation;
- landscape units.

1.3 ASSUMPTIONS AND LIMITATIONS

1.3.1 Dividing a river into discrete units

In an ecological sense, rivers should be viewed as continuous longitudinal systems. They possess continuous gradients of physical and chemical conditions that are progressively and continuously modified downstream from the headwaters to the sea (Davies and Day 1998). Any changes taking place in the upstream reaches will influence downstream processes, and different sections of a river should never be viewed in isolation. This is one of the underlying theories in river ecology known as the River Continuum Concept (Vannote *et al.* 1980).

However, different sections of a river can have different natural flow patterns, and can react differently to stresses according to their individual sensitivities (Louw 2004). As a result they each require individual specifications of their EWRs. Also, in order to facilitate the best management of a river, it needs to be broken down into discrete, manageable units. Although both natural and artificial barriers, which cause sudden changes in the characteristics of the river, do occur along rivers, it is not always possible to identify distinct units on a biophysical basis. Biophysical considerations, the practicalities of a certain number of units and expert judgement, all need to be taken into account when identifying discrete management units. As such, it is important to remember that the discrete units are primarily artificial distinctions to aid in the management of a river and not ecologically independent reaches.

1.3.2 EWR Sites

Ideally, within each Resource Unit at least one site that is representative of conditions within that Unit should be selected. This is seldom possible because of financial constraints (restricting the number of sites that can be addressed in a study), access and/or because representative sites are not always suitable for use as EWR sites. In this study, funds were available for the consideration of six sites.

1.3.3 Tributaries

The Olifants and Doring Rivers together boast numerous tributaries. A detailed delineation of all of these into Resource Units is outside the scope of this study. Nonetheless, where possible and appropriate, comment has been provided on characteristics of the main tributaries (Section 5) and the similarities between them (Section 6.3).

2. DESCRIPTION OF THE STUDY AREA

The Olifants/Doring River catchment is situated in the south-west of South Africa. Significant portions of the catchment fall within the Northern Cape Province, in particular the upper reaches of the Doring River, and some of its northern tributaries, such as the Tankwa River. The remainder, and wetted portions of the catchment fall within the Western Cape Province.

2.1 THE OLIFANTS RIVER

Most of general information for the Olifants River provided in this section is summarised from King and Tharme (1994) in Dallas (1997). The information has, however, been checked and updated where deemed necessary.

The Olifants River has a catchment area of 2825 km^2, which is about 6% of the total Olifants/Doring River catchment, and has a total length of 280 km. The Olifants River rises on the Agter Witzenberg plateau, which is an agricultural area situated between the Skurweberge, the Groot Winterhoekberge and the Witzenberg at an altitude of approximately 800 m (see map in Annexure D). It rises as a network of small mountain streams and wetland areas. Whilst most of these smaller streams do not flow during summer, the main river is naturally perennial. From the plateau the river flows northwards for 12 km before entering a narrow gorge for 30 km. It emerges into a wide valley at Keerom after which it flows northwards for a further 100 km between the Olifantsrivierberge, Swartberg and the Cederberg mountain ranges.

Numerous small tributaries join the Olifants River in its upper reaches and two major tributaries, the Doring and the Hol Rivers, join the river near the towns of Klawer and Vredendal respectively. The river reaches the sea at Papendorp. Human activity at the estuary is limited and, save for some diamond mining, it is still in a relatively unspoilt condition (Morant 1984). However, activities in the catchment, and abstraction of water in particular, have probably affected the estuary more than activities in its immediate environs (Morant 1984).

Physiographically, the catchment is complex with several high mountains running in a north-south direction and with steep slopes over much of the area. Numerous smaller steep and mountainous valleys lie in a north-easterly direction and further dissect the catchment. Altitudes range from 1800 m in the Groot Winterhoek to 200 m at Clanwilliam Dam and 20 m downstream of the confluence with the Doring River at Klawer. Although the Olifants River catchment lies in the winter rainfall region, and most rainfall occurs between May and September, the physiographic diversity leads to highly variable climatic conditions throughout the catchment. The range mean annual precipitation is equally dramatic: from > 1400 mm y^{-1} in the Groot Winterhoek mountains to < 300 mm y^{-1} at Clanwilliam Dam (see map in Annexure D).

See Section 2.3 for a description of the Olifants River Estuary.

2.1.1 Geology of the Olifants River catchment

The Olifants River drains a catchment consisting largely of resistant, quartzitic sandstones of the Table Mountain Series (TMS). Waters flowing over such strata are characteristically acidic and low in nutrients and dissolved solids. Approximately 170 km downstream, the underlying formation becomes Malmesbury Shale (Fourie 1976), which contains larger quantities of leachable ions (see map in Annexure D). Waters draining these rocks have a higher total dissolved solid concentration than that draining TMS. Sparse indigenous mountain fynbos dominates the mountain slopes while, at lower altitudes, lowland fynbos is the natural vegetal cover (see Section 5).

2.1.2 Hydrology of the Olifants River

The Olifants River is a naturally perennial river. Under both virgin and present-day conditions, flow in the Olifants River is distinctly seasonal, with a high-flow period in June, July and August (winter), a low-flow period from November to April (summer), and intermediate-flow periods in September, October (spring) and May (autumn). Accurate daily flow data are not available for the Olifants River nor for any of its tributaries upstream of Clanwilliam Dam. On the basis of simulated monthly flows, present-day discharges are generally lower than the virgin discharges, particularly in the middle reaches of the rivers and surface flow now ceases in the summer months.

2.1.3 Landuse in the Olifants River catchment

The dominant landuse is commercial agriculture, particularly orchards for the production of citrus fruit, and vineyards for wine production (see map in Annexure D). Irrigation water is abstracted from two dams, the Clanwilliam Dam (storage capacity of 127 Mm^3), and the Bulshoek Barrage (storage capacity of 7.5 Mm^3; Pitmann *et al*. 1981). The latter is coupled with an extensive irrigation canal system, which runs adjacent to the river in places and forms part of the Olifants River Government Water Scheme (ORGWS, Pitmann *et al*. 1981).

2.1.4 Impoundments and flow modifications in the Olifants River

Two major instream impoundments are situated on the Olifants River, namely Clanwilliam Dam and Bulshoek Barrage. They are both located in the middle reaches of the Olifants River. Clanwilliam Dam is the larger of the two impoundments, with a storage capacity of 127×10^6 m^3 and drains a catchment area of 2033 km^2 (Pitman *et al.* 1981). It was built in 1932 and raised in 1966. Studies are currently underway to investigate the potential for further increasing the height of Clanwilliam Dam wall.

Bulshoek Barrage is located 23 km downstream of Clanwilliam town and was constructed in 1919. It has a storage capacity of 7.5×10^6 m^3 and its level is regulated by releases from Clanwilliam Dam. From Bulshoek Barrage water is diverted into a canal system, which forms part of the Olifants River Government Water Scheme (ORGWS) (Pitman *et al*. 1981). This canal system supplies irrigation water to roughly 90 km of the lower Olifants River and ends some 15 km before the estuary, at Papendorp (King and Tharme 1994). Bulshoek Barrage functions mainly as a diversion weir for the ORGWS, while Clanwilliam Dam is the principal storage dam designed to supply Bulshoek Barrage (King and Tharme 1994). Bulshoek Dam also maintains a water supply for the agricultural areas in the middle reaches of the Olifants River.

Large amounts of water are currently abstracted from run-of-river, particularly in the middle reaches of the Olifants River. This abstraction is mainly for agricultural purposes, resulting in severely depressed flows in the summer months, so much so that the river sometimes stops flowing all together during the summer (King and Tharme 1994).

PROPOSED IMPOUNDMENTS

Studies are currently underway to investigate the potential for increasing the height of Clanwilliam Dam wall. Other dams on the mainstem that have been considered in the past include dams at Keerom and Rosendal.

Various off-channel storage possibilities have also received attention in recent years, with dams on the Troe-Troe, Wiedouw and Moedverloor Rivers receiving the most attention, however none of these locations have been deemed favourable.

2.1.5 General descriptions of significant tributaries of the Olifants River

With the exception of the Doring River, the tributaries of the Olifants River are generally short, steep systems that drain the mountainous slopes to the east and west. The tributaries draining the mountains to the west are generally seasonal systems, while those flowing in from the east are typically perennial (King and Tharme 1994).

THE RATEL RIVER

The Ratel River is a naturally perennial river that drains the eastern slopes of the Groot Winterhoekberge. It has a narrow channel dominated by bedrock rapids and wide deep pools. The natural vegetation in the catchment is fynbos, and the river has a fairly well developed riparian zone with stands of palmiet. Moderate levels of agriculture take place in the catchment and water is abstracted from the Ratel River for agricultural purposes.

THE THEE RIVER

The Thee River is a naturally perennial, cobble-bed river that drains the western slopes of the Kouebokkeveldberge. It has a mountainous catchment with little anthropogenic disturbance except in the lower reaches. Vegetation in the catchment is mountain fynbos. Riparian vegetation consists of low fringing vegetation alternating with wooded banks and closed canopy.

THE NOORDHOEK TRIBUTARY

The Noordhoek Tributary is a naturally perennial river that drains the western slopes of the Kouebokkeveldberge. There is limited anthropogenic disturbance in the catchment, with agriculture confined to the region of confluence with the Olifants River. Water diversion and abstraction does take place for farming purposes. The slopes are vegetated with mountain fynbos and there is well-developed riparian fynbos.

THE BOONTJIES RIVER

The Boontjies River is a naturally perennial river that originates in the Middelberge to the east of Citrusdal. Its confluence with the Olifants River is c. 5 km downstream of Citrusdal. The lower reaches on the floor of the Olifants River valley are intensively farmed while the upper reaches are mountainous and relatively undisturbed.

THE RONDEGAT RIVER

The Rondegat River is naturally perennial and originates in the Cedarberge to the east of the Olifants River. The Rondegat River flows directly into the headwaters of the Clanwilliam Dam. The upper reaches are relatively undisturbed, except for limited pine plantations in the region around Algeria, which are in the process of being removed (Southern Waters Study Team *pers. obs.*). The upper reaches of the Rondegat River consist of pool-rapid sequences, with a well-developed riparian zone, with low fringing vegetation and at times a closed canopy. In the lower reaches the riparian zone is dominated by alien infestations of Black Wattle *Acacia mearnsii*. Agriculture is prevalent in the lower reaches of the Rondegat River.

THE JAN DISSELS RIVER

The Jan Dissels is a perennial river that drains the western slopes of the Cederberge. The mountainous upper reaches are undisturbed, with well-developed riparian vegetation. The upper reaches are typical of a mountain stream, with pool-rapid sequences. The lower reaches are heavily impacted by agriculture (mainly citrus farming) and abstraction is high.

THE SEEKOEIVLEI RIVER

The Seekoeivlei River is a seasonally-flowing tributary of the Olifants River and originates in the Uitkomsberg to the west of the Olifants River. The confluence between the Seekoeivlei and Olifants Rivers is c. 14 km downstream of the Clanwilliam Dam wall, and upstream of the Bulshoek Barrage. The Seekoeivlei River is comprised of a wide, rocky channel with occasional bed-rock outcrops. Occasional wetland areas associated with lateral seeps occur in the channel. The surrounding landuse is predominantly natural veld which is used for grazing.

2.2 THE DORING RIVER

The general information for the Doring River provided in this section is taken from Brown and Day (1997). The information has, however, been checked and updated where deemed necessary.

The mainstream of the Doring River (see map in Annexure D) rises on the northern slopes of the Hex River Mountains. It flows in a north-easterly direction through Karoopoort and into the dry region to the east of the Cedarberg Mountains. In its upper reaches, several small, seasonal tributaries join the Doring River. The largest of these is the Beukesfontein River, which drains the eastern slopes of the Swartrug Mountains. For most of its first *c*. 150 km, the Doring River is a naturally seasonal river (Morant 1984). However, the upper section of the river now receives an interbasin transfer from Lakenvlei Dam near Ceres and, as a result, the upper section only flows for much of the year (Department of Water Affairs and Forestry (DWAF), pers. comm.).

Approximately 150 km from its source, the Doring River receives its first major tributary, the Groot River, a perennial river that drains the eastern slopes of the Kouebokkeveld and Skurweberge Mountain Ranges. The character of the Doring River changes markedly downstream of its confluence with the Groot River. Downstream of the confluence, the Doring River becomes a large, often-braided river, which flows torrentially in winter, and maintains some flow for most of the year. At Elandsvlei, c. 50 km downstream of the Groot River confluence, the Tankwa River, a large seasonal river that drains a vast section of the Great Karoo, joins the Doring River. A further 5 km downstream of this confluence, another seasonal river, the Tra-tra River, enters the Doring River from the eastern slopes of the Cedarberg. Downstream of Elandsvlei and its confluence with the Tankwa and Tra-tra Rivers, the Doring River enters a deep, relatively inaccessible gorge c. 60 km in length. As it leaves the gorge, c. 220 km from its source, the river is the joined by the Biedou River, which enters from the west. The last major tributaries entering the Doring River are, from the west, the Brandewyn River, which enters c. 250 km from its source and, from the east, the Koebee River, which enters c. 30 km further downstream.

Approximately 65 km downstream of its confluence with the Brandewyn River, and c. 310 km from its source, the Doring River enters the Olifants River, just upstream of the town of Klawer.

The lower sections of the Doring River cease to flow in the summer months for periods ranging from several days to several weeks.

2.2.1 Geology of the Doring River catchment

The western and extreme southern parts of the Doring River catchment drains standstones and quartzites of the Table Mountain Group, shales of the Bokkeveld Group shales and quartzites and shales of the Witzenberg Group (Morant 1984; (see map in Annexure D). These three stratigraphic groups belong to the Cape Supergroup. This sequence of quartzite-rich rocks is the source of the rounded boulders and cobbles in the upper reaches of the system. The eastern and northern parts of the catchment drain Dwyka Formation tillites and shales, and ancient marine sediments of the Ecca Group and, in the eastern-most section, eroding rocks of the Beaufort Group. These rocks all belong to the Karoo Supergroup and are the main source of clay-rich sediments in the system. The marked differences in erodability between these two supergroups are a driving factor in determining the character of the Doring River system (see Section 5). Tributaries draining the relatively hard rock of the Cape Supergroup contribute clear, acidic water to the Doring river, whereas those draining the easily-eroded rock of the Karoo Supergroup contribute turbid, saline water.

2.2.2 Hydrology of the Doring River

The catchment of the Doring River straddles the divide between winter and summer rainfall regions. The relatively high rainfall areas in the south west of the catchment are, however, situated in the winter rainfall region. The seasonal variation in runoff in the Doring River is therefore dominated by winter rainfall events. Winter baseflows in the Doring River are naturally high but these drop sharply at the beginning of summer. Flow ceases in the lower portions of the river for a couple of days to several weeks each year (DWAF 1994).

Most of the flow in the Doring River is derived from the small steep tributaries draining the eastern area of the Kouebokkeveld and the Cedarberg. A significant amount of water is also captured in the Bontberg and the Klein Roggeveld Mountains in the south of the catchment. The Groot River, covering only 7126 km^2 of the catchment area, should contribute more than half (*c*. 278.6 x 10^6 m^3) of the total virgin flow (c. 500 x 10^6 m^3) in the system (DWAF 1994).

The south-western corner of the catchment forms part of the Kouebokkeveld, a mountainous area with a mean annual rainfall (MAP) in excess of 500 mm (see map in Annexure D). The MAP decreases sharply to around 200 mm to the north and east. As a result, the virgin Mean Annual Runoff (MAR) at Aspoort (DWAF gauging weir E2H002.

The records from E2H002, downstream of the confluence of the Groot and Doring Rivers, reveal perennial flow there, and there has been some confusion about which river provides this water. Local knowledge, together with on-site assessments of discharges, channel type, and vegetation distribution and types, indicate that the upper Doring River flows sporadically after rain in winter and does not flow in summer even after rain (pers. comm.: A. Marais, Grootrivier; K. Hough, Elandsvlei; M. Thiart, Calvinia Town Council; Southern Waters, field trips; C. Boucher, Stellenbosch University). Thus, it would appear that virtually all the water in the Doring River at Aspoort (E2H002), outside of flood events, flows down the Groot River.

Mean annual evaporation rates range from 1650 mm in the south, to 1900 mm y^{-1} in the north, to 1700 - 1800 mm y^{-1} in the middle areas.

2.2.3 Landuse in the Doring catchment

The total area under irrigation in the catchment is small, and limited to the upper reaches (see map in Annexure D). There is cultivation in the upper reaches, on the well-watered mountain slopes and in the valley bottoms alongside tributaries. There are some tree plantations in the high-rainfall, mountainous parts of the catchment. Farmlands in the Karoo are extensive to allow for the low carrying capacity of the veld. Downstream, cultivation is confined to the hilltops and the flatter areas adjacent to the major tributaries. With the exception of settlements at Elandsvlei, Bos River and Doringbos, there is very little cultivation alongside the Doring River itself (C. Brown, Southern Waters, pers. obs.). The western side of the river is mostly too rugged for agricultural purposes.

2.2.4 Impoundments and flow modifications in the Doring River

The upper portion of the Groot River (Kouebokkeveld) is extensively impounded with numerous small dams, the majority of which have a surface area of 0.02 to 0.3 km^2, the largest being Oudeboskraal Dam, 1.877 km^2.

There appears to be only limited abstraction from the Doring River itself. The main reason for this is that farmers often cannot afford the expense of pumping water uphill from the gorge through which the river runs for much of its length. This is borne out by the fact that wherever cultivated lands are located alongside the river, e.g., near Elandsvlei, Doringbos and Uitspanning, the number of pumps increases.

Although the amount of water abstracted from the main channel is probably relatively small, many of the tributaries are subjected to considerable abstraction pressure. For instance, there are two large farm dams on the Beukesfontien River, a significant tributary of the Doring River upstream of the confluence with the Groot River. Abstraction also takes place in the upper reaches of the Groot River (Koue Bokkeveld), the Tankwa River (the largest privately-owned dam in South Africa is situated on the Tankwa River), the Tra-Tra River (Wuppertal), the Bos River, the Biedou River (Biedou Valley) and the Brandewyn River (Study Team, Southern Waters, pers. obs.).

Most of the abstraction of irrigation water from the Doring River itself takes place during early and mid winter. Abstraction ceases when flows drop in spring and the water tastes salty (Mr Ron Cole, Doringbos Farmer, pers. comm.).

Although farmers have extensively dammed several of the major tributaries of the Doring River, there are presently no major instream dams on the Doring River itself. Hence, floods pass unimpeded through the system. A single instream dam (wall height 3-4 m) does occur at Brakfontein, roughly 10 km downstream of Aspoort. It has however almost completely silted up and does not affect flows. The dam does impact upon the movement of fish in this section of the river.

PROPOSED IMPOUNDMENTS

Three potential dam sites on the mainstream of the Doring River, namely the Aspoort, the Melkboom and the Melkbosrug Dams, have been investigated. Currently none of these is a favoured option for development, each being ruled out on a combination of economic and environmental grounds.

Various off-channel storage possibilities have also received attention in recent years, with dams on the Brandewyn, Troe-Troe, Wiedouw Rivers emerging as the most favourable off-channel storage sites being investigated further. The Moedverloor River site was also assessed due to its favourable location in terms of Ebenhaezer.

2.2.5 General descriptions of significant tributaries of the Doring River

THE BEUKESFONTEIN RIVER

The Beukesfontein River is a seasonal river that rises in the Swartruggens Mountains. Although it drains a more westerly portion of the catchment than does the Doring River itself, the riparian vegetation along the Beukesfontein River suggests that it is an arid-land river with intermediate salinities.

THE GROOT RIVER

The Groot River is formed by a number of small tributaries flowing off the eastern slopes of the Cedarberg south-east of Citrusdal, including the Twee and Lang Rivers. The Groot River flows in an easterly direction, through the Skurweberge, before its confluence with the Riet

River. The latter rises as the Winkelhaak and Houdenbeks Rivers in the Kouebokkeveld to the north of Ceres. Immediately downstream of its confluence with the Riet River, the Groot River is joined by the Brandkraals River and, a further 10 km downstream, by the Matjies River, both of which flow in a south-easterly direction off the Cederberg Mountain Range. The Matjies River, itself, is formed by the confluence of the Driehoeks, Krom, Breekkrans, Dwars and Hek Rivers, among others. After its confluence with the Matjies River, the Groot River joins the Doring River approximately 2 km upstream of the farm Aspoort. As a general rule the tributaries forming the Groot River rise on a high-altitude plateau and their catchments are subjected to farming (i.e. removal of catchment vegetation) and water abstraction for irrigation, which in many cases results in them ceasing to flow during the summer months (J. King, Southern Waters, pers. obs.).

The Groot River and its tributaries share many characteristics with rivers draining fynbos vegetation elsewhere in the Western Cape, while at the same time having some attributes of rivers in the drier areas to the east of the Cedarberg Mountains. For instance, the presence of *Prionium serratum*, *Metrosideros angustifolia*, *Myrica serrata*, *Scirpus membranaceus* and *Ischyrolepis subverticillatus* give evidence of fresh, acid waters found in Western Cape mountain streams, whereas the invasion of the channel by *Nerium oleander* is typical for rivers in arid areas (C. Boucher, Stellenbosch University, pers. comm.).

THE TANKWA RIVER

The Tankwa River drains a vast catchment in the western Karoo. It flows in a north-easterly direction and has its confluence with the Doring River at Elandsvlei, where once there was a vast system of wetlands that have been all but destroyed to create fields for cultivation. The Tankwa is a highly seasonal, predominately sand-bed, river, which carries large loads of fine-grained sand into the Doring River during spates. Presumably, in the past, the wetlands at Elandsvlei impeded flow in the Tankwa River and captured some of this silt load, thereby reducing the sediment input into the Doring River. The water in the Tankwa River tends to be turbid and brackish (Study team, Southern Waters, pers. obs.). The largest dam in the Doring River catchment occurs on the Tankwa River. It is a privately owned instream dam, with a capacity of 34 MCM.

THE TRA-TRA RIVER

The Tra-tra River rises on the eastern slopes of the Cedarberg Mountain Range. Approximately 10 km from its source it flows through the settlement of Wuppertal. Thereafter, it flows through a relatively arid catchment, where the main landuse is sheep farming, although there is some cultivation along the river in its upper reaches. Although it shares some characteristics with fynbos mountain streams, such as clear, pure water and a cobble substratum, the Tra-tra River is also a seasonal system (Study team, Southern Waters, pers. obs.). It has its confluence with the Doring River some 35 km from its source and *c.* 5 km downstream of the confluence of the Tankwa and Doring Rivers.

THE BOS AND WOLF RIVERS

The Bos and Wolf Rivers are seasonal rivers that drain an area to the east of the Doring River. The confluence of the Wolf River with the Bos River is *c*. 5 km upstream of the confluence of the Bos River with the Doring River, *c*. 200 km from the source of the latter.

THE BIEDOU RIVER

The Biedou River rises as the Heiningvlei and Klien-Doring Rivers, which flow off the eastern slopes of the Cedarberg Mountains and the northern slopes of the Tra-tra Mountains, respectively. The Biedou River valley is less laterally confined than many of those of many of the other tributaries draining into the Doring River, with the result that there is also more agriculture (wheat and citrus) alongside the river. The Biedou River joins the Doring River just downstream of Uitspanning.

THE BRANDEWYN RIVER

The Brandewyn River is a seasonal river, rising in the Pakhuisberge, and flowing north to its confluence with the Doring River, east of Melkbosrug. In its middle and lower reaches water is abstracted and the flow manipulated for agricultural purposes. The Brandewyn River has been targeted as a potential site for an in-channel storage dam supplied from a weir on the Doring River.

THE KOEBEE RIVER

Two main tributaries, namely the Klein Koebee and the Oorlogskloof Rivers, form the Koebee River. They drain the Bokkeveldberge to the north of the Doring River in the vicinity of Niewoudtville. In its upper reaches, the Koebee is relatively undisturbed, while agricultural impacts occur in the lower reaches. The Koebee is a naturally perennial river. However, due to abstraction for agriculture in the lower reaches, the river now forms standing pools in summer. The Koebee and Oorlogskloof Rivers have a high conservation status in terms of indigenous fish species. The Oorlogskloof River in particular is a refuge for indigenous fish populations as there is no invasion by alien species.

2.3 THE OLIFANTS RIVER ESTUARY[2]

The Olifants Estuary is approximately 250 km north-west of Cape Town. It is, with the Great Berg Estuary, one of the two major estuaries on the west coast of South Africa.

The estuary itself is still largely in a pristine state, but it is estimated that the mean annual run-off has been reduced by *c.* 34% per cent, from 1042 x 106 m^3 a^{-1} under natural conditions to 691 106 m^3 a^{-1} at present. The run-off from the catchment area shows strong seasonal variations with high flows and major floods during the winter months and low flows during the summer months. The baseflow during the summer months is strongly influenced by return flow from irrigation water along the river.

The estuary mouth is permanently open and bounded by a stable sand spit on the southern side and a rocky bluff "Die Punt" on the northern side (Morant 1984). A rocky spillway, the "Hartebees Kanaal" bisects Die Punt. Until recently this channel was blocked by rubble from the diamond works on the northern side of the mouth, but since then has been blasted clear at the request of the local fishers (Sowman *et al*. 1997). The upper regions of the estuary are regarded as being stable, whereas the lower region is relatively dynamic with estuarine channels changing their course during floods (Morant 1984). The estuary splits into three arms approximately 2 km from the sea. The northern and central arms encircle Die Eiland, the latter only carrying water during floods. The southern arm ends blindly at the Papendorp saltpan and remains dry throughout most of the year. Water depths in the upper estuary range from 1-3 m whereas in the lower 2 km from 0.5-7 m along the southern and northern bank respectively. The estuary has a strong tidal influence with a tidal difference of 1 m being recorded at the Lutzville causeway 36 km upstream. Saline water has been recorded at the Lutzville causeway but the tidal prism seldom extends further than Ebenhaeser situated 15 km upstream (Morant 1984).

Considerable tidal variation has been recorded at the low water bridge at Lutzville 36 km upstream of the mouth and during low flow periods intrusion of saline water from the sea has been measured a few km upstream of Olifantsdrif, approximately 13.5 km from the mouth.

[2] This section is summarised from the information given in the Inception Report.

Agricultural developments have taken place along the Olifants River between the Bulshoek Barrage and Olifantsdrif. Water for irrigation is being transported from the Bulshoek Barrage along the valley through irrigation canals. Saltworks are found near the mouth of the estuary.

In 1997 a preliminary investigation on the effect of future changes in runoff on the Olifants Estuary (DWAF 1997; Adams and Bate 1997; Bickerton and Wooldridge 1997; Huizinga and Van Niekerk 1997; Lamberth and Whitfield 1997; Taljaard 1997; Turpie 1997).

2.3.1 Topography

The estuary is up to 545 m wide near the mouth and gradually becomes narrower further upstream with a width of 19 m just below the low water bridge at Lutzville. The depths are mostly between 2 and 3 m below mean sea level (MSL). A maximum depth of 6.6 meters below MSL is observed at 18.5 km from the mouth (CSIR 1995).

2.3.2 Sedimentation and Erosion

Sedimentation of the estuary is relatively high at c. 6.5 x 10^6 m^3 a^{-1} (Morant 1984) and which soil erosion caused by agricultural activity in the catchment area.

2.3.3 Water Level Variations

There are strong vertical tidal variations along the whole estuary and, for example, a water level variation of almost one meter at springtide below the low water bridge at Lutzville (Huizinga and Van Niekerk 1997).

2.3.4 Salinity and Temperature Profiles

The thermohaline regime is strongly seasonal. In winter after heavy rainfall, the estuary can become fresh (salinity of 2,8 ppt) throughout. Conversely, in summer, when there is little river flow, seawater can penetrate as far as Ebenhaeser on occasions (Morant 1984; CSIR 1999). The upstream extent of saline intrusion, like in any estuary, is a function of tidal conditions, river inflow and the length of time any particular set of conditions has persisted (CSIR 1990).

3 GEOGRAPHICAL BOUNDARIES OF THE OLIFANTS RIVER ESTUARY

S. Taljaard and L. van Niekerk

The geographical boundaries of the Olifants River estuary are provided in Figure 3.1.

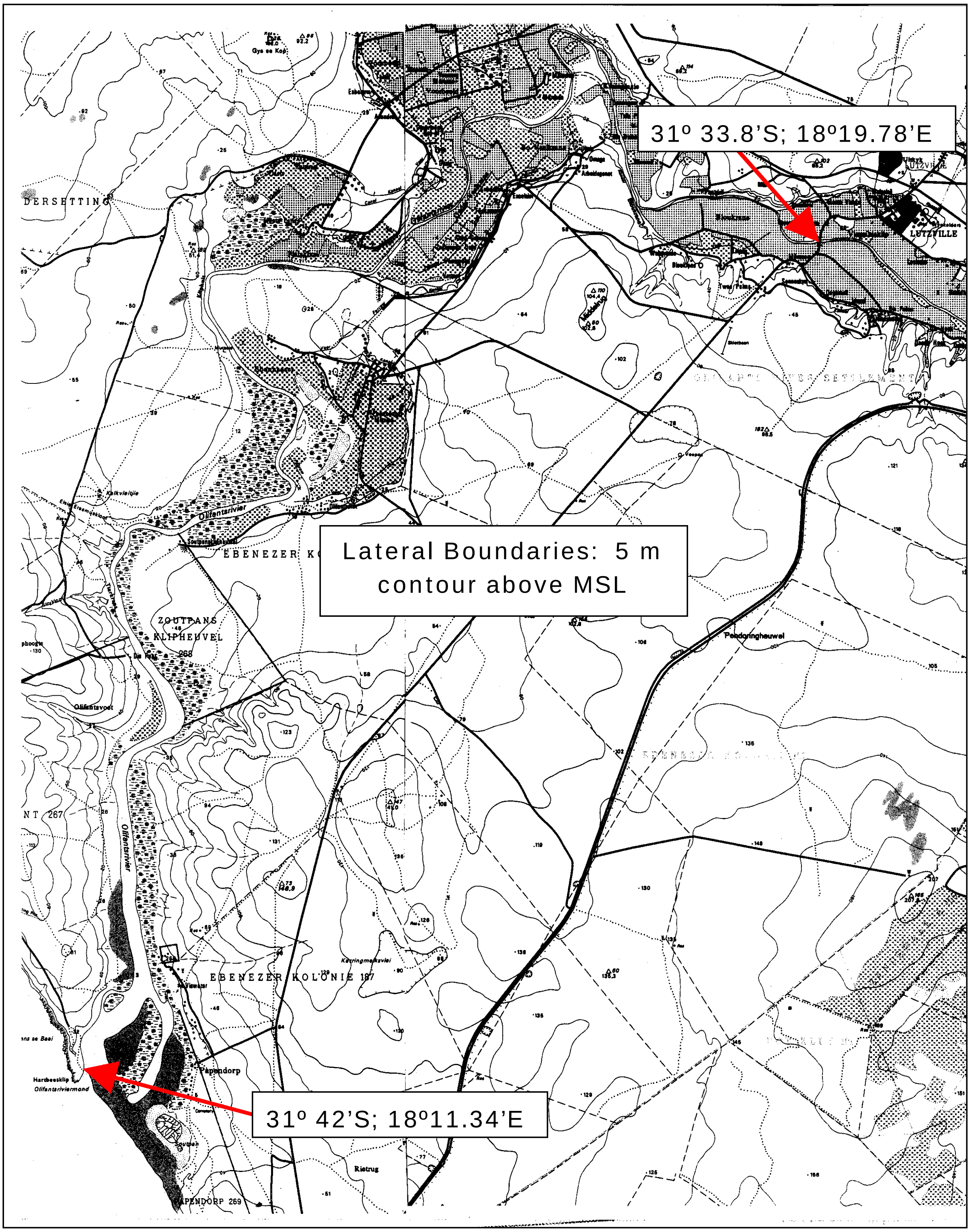

Figure 3.1 Map showing the boundaries of the Olifants River estuary.

The geographical boundaries are as follows:

Downstream boundary:	Estuary mouth (31° 42.00’S; 18 °11.34’E).
Upstream boundary:	Extent of tidal influence, i.e. the causeway at Lutzville - about 36 km from the mouth (31°33.80’S; 18 °19.78’E).
Lateral boundaries:	5 m contour above Mean Sea Level (MSL) along each bank.

The 5 m contour above MSL is indicated on the provided on 1:10 000 orthophotos (Olifants River Estuary spans about 10 1:10 000 orthophotographs). Although the 1:10 000 orthophotos are electronically available, the 5 m contour above MSL is not yet available on the electronic versions.

4 WATER QUALITY REACHES: RIVER QUALITY DETERMINATION

W.R. Harding and I. Morrison

4.1 INTRODUCTION

The aim of this Section is to determine river units (reaches) homogenous in terms of water quality. These reaches will be termed water quality units (WQUs). This assessment is focused on the desktop determination of WQUs that will inform water quality conditions at each of the Ecological Water Requirement (EWR) sites. Six sites have been selected and are described in Section 8. They are depicted in this Section in Figure 4.1.

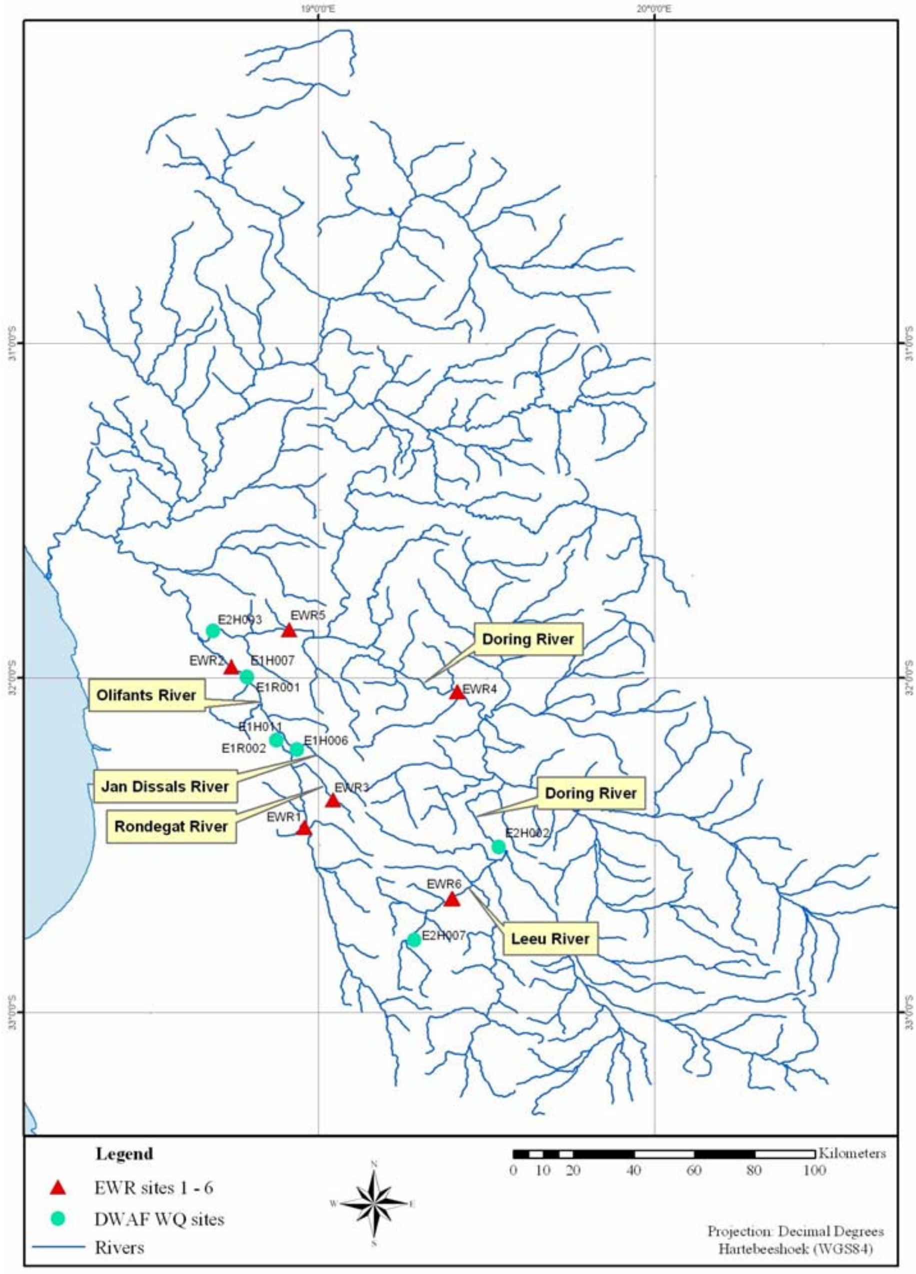

Figure 4.1 Locations of EWR and water quality sites.

4.1.1 Methodology

There does not appear to be a formally prescribed methodology for the determination of WQUs at any level of Reserve Determination. Accordingly this assessment has been based on a logical analysis of the available data and known conditions. The provisional of Present Ecological Status Categories (PESC) for each of the reaches has made (guideline) use of the provisional assessment procedure developed by DWAF (EWRQCalc Version 2.2).

4.2 AVAILABLE WATER QUALITY DATA

The Department of Water Affairs and Forestry (DWAF) maintains, or has historical data for, several monitoring sites in the Olifants/Doring catchment. The coverage provided by these data, insofar as informing the water quality in each of the defined WQUs, is dealt with hereunder. It is important to note that the general nature of these data is fragmented, or comprising relatively short chronological periods. In addition, two sites (EWR Site 3 and 4) are virtually unsupported by data, especially for EWR Site 4 (Doring River at Biedou).

Other constraints in force at the time of preparing this Section were:

- an understanding of the seasonal hydrology of the system;
- data still awaited for the quality of effluent discharged from the Clanwilliam Wastewater Treatment Works (WWTW). The water quality implications of this discharge, and of that emanating from the Citrusdal WWTW, will be addressed once details of the hydrology become available, and as the monitoring and water quality analysis proceeds;
- field identification of any other point or diffuse runoff to the river, or landuse activities proximal to the river, that may influence the water quality in any of the identified WQUs. This understanding will be refined during the course of the project by consultation with field monitors, *ad hoc* visits to the study area, by viewing of the video material available for same, and other relevant information;
- in several cases, as will be apparent from the analysis hereunder, continuous data records are between 10 and 20 years old, with more recent data being of a highly fragmented nature;
- A stepwise increase in recorded (DWAF) pH data, starting in 1989. The reason for this has not yet been identified, but has been queried at DWAF-RQS. In the interim the validity of these data in making any interpretations has been ignored.

4.2.1 Validity of the WQU definitions

The validity of the WQUs as described in this section should be regarded as provisional until such time as the constraint factors described above have been addressed. This is particularly relevant to the Doring River downstream of the confluence with the Tankwa River.

4.2.2 Monitoring requirements

In addition to the collection of water quality samples, additional monitoring requirements have been identified for three EWRs (3, 4 & 5). This need has been communicated to the Project Manager, and arrangements made for samples to be collected (14-day intervals) and preserved for later analysis. These needs are discussed in more detail below where relevant to the individual WQUs.

4.2.3 Monitoring site registration

Each of the EWRs as defined by the Project Manager (November 2003 site visits) have been registered with the DWAF as part of their Water Management System (WMS) database. The locations and WMS identities for each are provided in Annexure A.

4.3 IDENTIFICATION AND DEFINITION OF WATER QUALITY DATA

The following analysis is made with reference to Figure 4.1, and to other supporting data / figures as indicated. Reference to the cyclical nature of the data is made in terms of electrical conductivity. The data are presented chronological, and as monthly frequency distributions. A glossary of the measured components and the units used are provided at the end of this section. The water quality units are depicted in Figure 4.2.

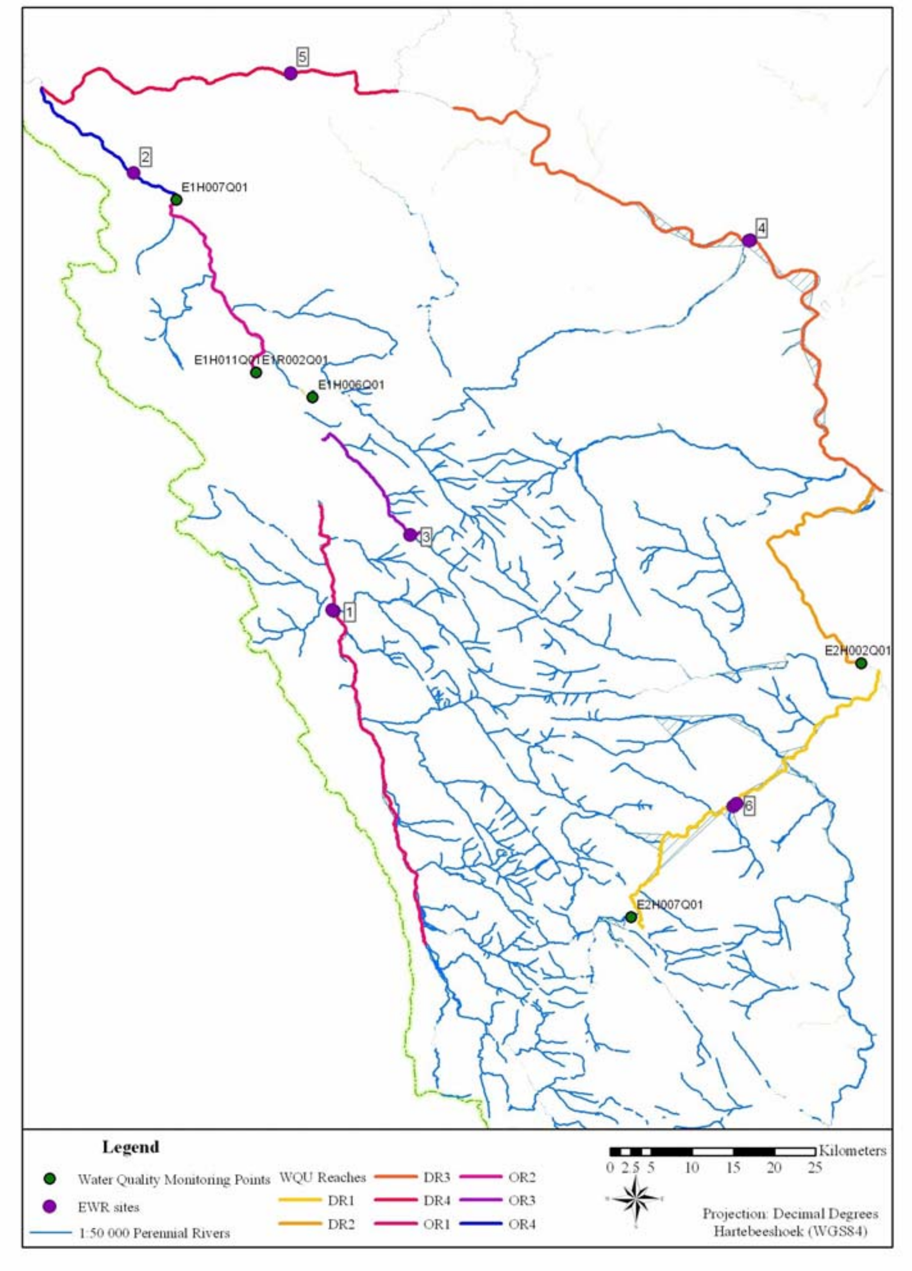

Figure 4.2 Water quality units in the Olifants/Doring catchment

4.4 OLIFANTS RIVER (OR) UPSTREAM OF THE CONFLUENCE WITH THE DORING RIVER

4.4.1 WQU OR1

Unit defined by water quality as determined from the DWAF site E1H013Q01 – (Olifants River at Citrusdal).

Provisional definition with reference to EWR Site 1:
Upstream: 30 km south (upstream) of EWR Site 1.
Downstream: The point of inflow into the Clanwilliam Dam.
WQU length: 60 km.

WATER QUALITY CHARACTERISTICS

Data coverage: Two full years, three partial years, two fragments of data for 2001 and 2002. No data for 2003. No apparent trends or cycles.
Nutrients: Ammonia negligible, nitrates and phosphates low with winter to early spring maxima, summer minima.
Impacts in WQU: Winter effluent discharge from Citrusdal WWTW (Table 4.1).

The water quality conditions for WQU OR1 are summarised in Table 4.1 and graphically in Annexure B1.

Table 4.1 Summarised water quality data for E1H013Q01 (Olifants River at Citrusdal).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	51		51	51	51	51	51		51	51	51	51	51	51	8
Minimum	6.1		0.020	0.020	2.0	3.8	0.5		0.003	2.0	5.0	0.3	0.5	4.5	7.3
5% Percentile	6.5		0.031	0.020	2.0	4.1	0.8		0.005	2.0	7.4	0.4	1.4	4.9	7.5
25% Percentile	6.8		0.067	0.020	6.9	5.2	1.5		0.007	2.0	8.8	0.5	1.8	5.9	9.6
L95% Conf Limit (median)	6.9		0.110	0.021	8.4	5.9	1.7		0.014	4.3	10.4	0.8	2.1	6.6	9.1
Median	7.0		0.100	0.020	9.3	5.6	1.7		0.013	5.0	10.7	0.7	2.2	6.6	10.5
U95% Conf Limit (median)	7.0	No data	0.175	0.033	11.9	7.7	2.2	No data	0.021	6.0	12.9	1.1	2.7	8.2	12.0
75% Percentile	7.2		0.177	0.020	11.6	7.0	2.0		0.023	6.5	12.3	1.0	2.8	7.7	12.4
95% Percentile	7.4		0.358	0.058	25.8	11.7	3.8		0.050	10.4	18.8	2.2	4.7	13.6	12.9
Maximum	7.7		0.595	0.150	34.7	22.5	5.4		0.059	15.3	32.1	3.1	7.1	19.2	13.1
Mean	7.0		0.142	0.027	10.1	6.8	1.9		0.017	5.2	11.6	0.9	2.4	7.4	10.6
Standard Deviation	0.3		0.117	0.021	6.6	3.3	0.9		0.014	3.1	4.5	0.6	1.1	2.9	2.1
% Variation Coefficient	4.5		82.4	77.1	64.7	49.1	48.4		78.1	60.4	38.2	66.5	46.5	39.5	20.0

4.4.2 WQU OR2

Unit defined by water quality as determined from the DWAF sites E1R002Q01 (Clanwilliam Dam, near the wall) and E1H011Q01 (Clanwilliam Dam on the Olifants River, downstream weir).

Provisional definition (no EWR within this WQU):
Upstream: Clanwilliam Dam.
Downstream: The point of inflow to Bulshoek Barrage.
WQU length: 22 km.

WATER QUALITY CHARACTERISTICS

Data coverage: Dam: Complete record for 1978-1982, and 2003. Remainder = scattered fragments. The data for the dam suggest slight upward trending, cycles not apparent.
Weir: Complete record for 1980-1989, and 2003. Remainder = scattered fragments. No visible trends. Cycles indicate peaks in March, minima in October.
Nutrients: No recent data set but values for ammonia, nitrates and phosphorus are low, but with a slight upward trend.
Impacts in WQU: Effluent from Clanwilliam WWTW discharged into Jan Dissels River (no data available, see Section 4.2).

The water quality conditions for WQU OR2 are summarised in Tables 4.2 and 4.3, and graphically in Annexure B).

Table 4.2 Summarised water quality data for E1R002Q01 (Clanwilliam Dam, near the wall).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	141	3	141	114	108	105	105	3	121	106	105	87	105	147	16
Minimum	4.9	0.15	0.020	0.020	2.0	3.0	0.5	0.016	0.003	2.0	8.0	0.4	0.5	1.0	11.3
5% Percentile	5.2	0.16	0.020	0.020	2.0	6.3	1.0	0.016	0.003	2.0	13.0	0.5	0.6	5.7	12.5
25% Percentile	6.0	0.20	0.020	0.020	5.2	8.7	1.4	0.017	0.003	2.0	16.0	0.7	1.6	7.7	13.9
L95% Conf Limit (median)	6.5	0.15	0.060	0.031	7.2	9.7	1.8	0.016	0.009	3.6	18.0	0.7	1.9	9.0	14.3
Median	6.8	0.26	0.020	0.020	7.6	9.8	2.0	0.017	0.010	2.0	18.0	0.7	2.0	9.4	15.6
U95% Conf Limit (median)	6.7	0.30	0.095	0.103	8.9	10.7	2.1	0.019	0.025	4.8	19.8	0.9	2.4	9.9	17.4
75% Percentile	7.0	0.26	0.090	0.057	9.8	12.1	2.3	0.018	0.020	5.5	21.0	0.9	2.4	11.0	16.9
95% Percentile	7.9	0.27	0.329	0.152	14.8	14.0	2.9	0.019	0.039	10.0	27.9	1.2	3.2	14.4	19.8
Maximum	8.5	0.27	0.562	1.980	31.7	16.0	4.0	0.019	0.485	17.8	30.3	2.9	10.3	15.7	25.3
Mean	6.6	0.23	0.077	0.067	8.0	10.2	1.9	0.017	0.017	4.2	18.9	0.8	2.2	9.5	15.9
Standard Deviation	0.8	0.07	0.106	0.196	4.5	2.5	0.7	0.002	0.044	3.4	4.5	0.3	1.3	2.7	3.1
% Variation Coefficient	11.4	29.7	137.5	292.4	56.5	24.2	34.2	8.8	250.4	80.0	23.7	38.6	60.0	28.0	19.7

Table 4.3 Summarised water quality data for E1H011Q01 (Clanwilliam Dam on Olifants River, downstream weir).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	151	10	150	145	150	148	148	10	147	148	148	147	148	152	33
Minimum	3.9	0.14	0.020	0.020	2.0	2.9	0.5	0.003	0.003	2.0	10.3	0.2	0.5	4.8	6.1
5% Percentile	4.7	0.14	0.020	0.020	2.0	6.8	1.0	0.003	0.003	2.0	12.3	0.4	0.5	6.4	9.9
25% Percentile	5.5	0.16	0.020	0.020	6.3	8.4	1.5	0.004	0.003	2.0	15.9	0.6	1.5	7.7	14.5
L95% Conf Limit (median)	6.0	0.14	0.055	0.045	8.1	9.7	1.9	0.005	0.009	4.0	18.6	0.7	1.9	9.1	15.6
Median	6.0	0.18	0.040	0.045	8.3	9.7	2.0	0.007	0.007	3.0	18.2	0.7	2.1	9.0	17.5
U95% Conf Limit (median)	6.2	0.43	0.084	0.073	9.4	10.6	2.1	0.010	0.014	5.0	20.3	0.8	2.3	10.0	19.1
75% Percentile	6.9	0.23	0.077	0.070	11.1	11.8	2.3	0.011	0.016	6.4	22.0	0.9	2.5	10.9	20.1
95% Percentile	7.3	0.72	0.338	0.154	16.3	14.7	2.9	0.014	0.030	10.3	29.5	1.1	4.0	14.6	25.8
Maximum	8.3	0.78	0.450	0.890	23.9	17.8	4.1	0.015	0.163	16.1	31.0	3.0	7.0	17.9	29.2
Mean	6.1	0.29	0.070	0.059	8.7	10.1	2.0	0.008	0.011	4.5	19.5	0.8	2.1	9.6	17.4
Standard Deviation	0.9	0.23	0.092	0.083	4.0	2.6	0.6	0.005	0.016	3.1	5.1	0.3	1.1	2.6	5.1
% Variation Coefficient	14.0	80.5	131.7	140.5	45.3	25.4	30.4	59.2	136.8	67.9	26.3	42.1	51.7	27.3	29.4

4.4.3 WQU OR3

As there are currently no data available sufficient to describe the water quality of this reach, this unit is defined provisionally by the water quality as determined from the DWAF E1H006Q01 (Jan Dissels River).

Provisional definition with reference to EWR Site 3:
Upstream: Rondegat River from source.
Downstream: Confluence with Olifants River.
WQU length: 26 km.

WATER QUALITY CHARACTERISTICS

Note: There is no DWAF monitoring point within this WQU. Until such time as site specific data have been collected, it has been decided to define water quality at this site using the DWAF E1H006Q01 (Jan Dissels River) monitoring point. The Jan Dissels River runs parallel to the Rondegat, approx. 5 km to the north.

Data coverage: Regular monitoring between 1978-1982, three fragments of data between 1997-2000, and a complete record for 2003. Slightly upward trends are apparent, cycles reflect peak values in January and minima in October.

Nutrients: None available.

Impacts in WQU None identified. Wastewater treatment plant at Algeria is understood to be septic/conservancy tank based. Hiking trail chalets have septic tank systems with assumed sound integrity.

The water quality conditions for WQU OR3 are summarised in Table 4.4 and graphically in Annexure B.

Table 4.4 Summarised water quality data for E1H006Q01 (Jan Dissels River).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	203		203	202	173	172	172		202	172	172	172	172	354	20
Minimum	3.5		0.020	0.020	2.0	1.0	0.5		0.003	2.0	1.5	0.2	0.5	2.4	3.3
5% Percentile	4.4		0.020	0.020	2.0	3.9	0.5		0.003	2.0	6.2	0.2	0.5	3.2	5.1
25% Percentile	5.2		0.020	0.020	2.0	4.9	0.5		0.003	2.0	8.5	0.2	0.5	4.1	7.0
L95% Conf Limit (median)	5.7		0.031	0.037	5.3	5.7	0.8		0.011	3.4	10.2	0.3	1.1	5.0	8.4
Median	5.9		0.020	0.020	5.5	5.8	0.5		0.010	2.0	10.3	0.4	1.1	5.1	10.1
U95% Conf Limit (median)	5.9	No data	0.048	0.049	6.6	6.2	1.0	No data	0.017	4.3	11.3	0.5	1.4	5.5	12.0
75% Percentile	6.5		0.040	0.050	8.0	6.9	1.2		0.016	5.0	12.2	0.5	1.7	5.9	13.7
95% Percentile	7.0		0.118	0.129	12.6	8.2	1.7		0.038	10.2	17.3	0.8	2.9	8.7	17.5
Maximum	7.9		0.550	0.260	31.9	16.5	5.5		0.211	18.1	29.3	9.7	10.4	28.6	18.5
Mean	5.8		0.040	0.043	6.0	6.0	0.9		0.014	3.9	10.7	0.4	1.3	5.3	10.2
Standard Deviation	0.8		0.061	0.044	4.2	1.7	0.6		0.020	3.0	3.6	0.7	1.1	2.0	4.1
% Variation Coefficient	14.4		153.2	100.9	70.0	28.4	67.1		138.4	77.5	33.0	172.0	84.3	38.8	40.3

4.4.4 WQU OR4

Unit defined by the water quality as determined from the DWAF sites E1R001Q01 (Bulshoek Barrage, near the wall) and E1H007Q01 (Bulshoek Barrage on the Olifants River, left canal).

Provisional definition with reference to EWR Site 2:
Upstream: Bulshoek Barrage.
Downstream: Confluence of Olifants and Doring Rivers.
WQU length: 18 km.

WATER QUALITY CHARACTERISTICS

Data coverage: Dam: Complete 1980-1982, weekly from 1998-2001, remainder fragmented. No trends evident in baseline data, but peak values show an increase. Cycles evident as peaks from May to June, minima between November and March
Canal: Complete 1983-1989 and 2000-2001. Remainder fragmented. Same trend pattern and cycles as for the dam;

Nutrients: Upward trends evident in the dam, phosphorus levels have reached the threshold at which problematical blooms of algae are likely to occur, and be discharged to the river during spring and summer. Maxima during spring, minima during late summer, autumn;

Impacts in WQU: None identified.

The water quality conditions for WQU OR4 are summarised in Tables 4.5 and 4.6, and graphically in Annexure B).

Table 4.5 Summarised water quality data for E1R001Q01 (Bulshoek Barrage, near the wall).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	225	1	225	221	225	223	223	1	223	223	223	222	223	225	107
Minimum	4.6	0.25	0.020	0.020	2.0	6.3	0.5	0.026	0.003	2.0	11.1	0.3	0.5	4.8	11.9
5% Percentile	5.4	0.25	0.020	0.020	2.0	9.9	1.6	0.026	0.003	2.0	17.2	0.6	1.3	8.4	14.5
25% Percentile	6.6	0.25	0.020	0.020	6.3	11.5	2.3	0.026	0.007	5.1	22.4	0.8	2.4	10.8	17.1
L95% Conf Limit (median)	6.7	0.25	0.113	0.029	8.1	15.2	2.9	0.026	0.012	7.0	28.6	0.9	3.0	13.8	21.1
Median	7.0	0.25	0.098	0.020	8.2	14.0	2.8	0.026	0.011	7.1	26.7	0.9	3.0	12.6	20.8
U95% Conf Limit (median)	6.9	0.25	0.157	0.046	9.1	16.9	3.2	0.026	0.015	8.2	31.7	1.0	3.3	15.2	23.8
75% Percentile	7.2	0.25	0.193	0.040	10.9	18.6	3.5	0.026	0.017	9.6	34.6	1.1	3.8	16.9	25.7
95% Percentile	7.4	0.25	0.379	0.090	14.5	28.1	5.3	0.026	0.031	14.5	54.0	1.6	5.2	24.8	34.5
Maximum	9.0	0.25	1.892	0.860	25.9	43.4	8.1	0.026	0.094	32.5	82.1	2.5	7.1	37.2	50.9
Mean	6.8	0.25	0.135	0.038	8.6	16.0	3.0	0.026	0.013	7.6	30.2	1.0	3.2	14.5	22.5
Standard Deviation	0.6	0.00	0.168	0.062	3.7	6.3	1.1	0.000	0.011	4.2	11.9	0.3	1.2	5.5	7.0
% Variation Coefficient	9.3	0.0	124.1	165.3	43.1	39.6	36.2	0.0	84.4	55.8	39.4	32.0	38.1	37.8	31.3

Table 4.6 Summarised water quality data for E1H007Q01 (Bulshoek Barrage, left canal).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	100	2	100	96	100	100	100	2	100	100	100	100	100	100	19
Minimum	4.6	0.17	0.020	0.020	2.0	1.0	0.5	0.003	0.003	2.0	4.5	0.2	0.5	3.7	14.1
5% Percentile	4.8	0.17	0.020	0.020	2.0	9.2	1.6	0.003	0.003	2.0	17.7	0.6	1.5	8.8	14.4
25% Percentile	5.6	0.17	0.020	0.020	6.3	11.0	2.1	0.004	0.006	2.0	21.1	0.7	2.2	10.2	17.2
L95% Conf Limit (median)	6.1	0.16	0.089	0.039	8.0	12.6	2.5	0.002	0.011	5.3	24.0	0.8	2.6	11.6	18.6
Median	6.3	0.17	0.076	0.040	8.3	12.4	2.5	0.004	0.011	5.6	23.8	0.9	2.6	11.3	18.9
U95% Conf Limit (median)	6.4	0.17	0.131	0.078	9.8	14.3	2.8	0.006	0.017	6.8	27.4	0.9	3.0	13.1	25.6
75% Percentile	7.0	0.17	0.145	0.070	11.2	14.7	3.0	0.005	0.016	8.4	27.9	1.0	3.1	13.2	24.0
95% Percentile	7.4	0.17	0.360	0.108	17.1	22.9	3.9	0.005	0.039	13.3	40.8	1.3	4.4	19.6	37.0
Maximum	8.1	0.17	0.564	0.930	24.0	34.8	5.4	0.005	0.092	17.9	64.0	1.6	9.4	32.1	42.3
Mean	6.3	0.17	0.110	0.058	8.9	13.5	2.6	0.004	0.014	6.1	25.7	0.9	2.8	12.3	22.1
Standard Deviation	0.9	0.00	0.106	0.098	4.4	4.5	0.8	0.001	0.015	3.7	8.5	0.3	1.1	3.9	7.7
% Variation Coefficient	13.8	2.5	96.2	166.8	49.5	33.1	30.1	35.4	108.5	60.8	32.9	28.9	40.9	31.2	35.0

4.5 DORING RIVER (DR) UPSTREAM OF THE CONFLUENCE WITH THE OLIFANTS RIVER

4.5.1 WQU DR1

Unit defined by the water quality as determined from the DWAF site E2H007Q01 (Leeuw River/Upper Groot River).

Provisional definition with respect to EWR Site 6:
Upstream: To source of the Leeu River.
Downstream: To the confluence of the Groot and Doring Rivers.
Unit length: 55 km.

WATER QUALITY CHARACTERISTICS

Data coverage: Complete from 1979 to 2003, with odd short gaps. Trends upwards from 1997, mostly in respect of nitrate concentrations. Peak values during early to mid-winter, and minima in summer. High frequency monitoring appears to have been applied to track rapidly increasing nitrate levels, from 0.2 to 6 mg l^{-1}.
It would appear that in terms of dissolved salts the quality improves with distance downstream towards Aspoort.

Nutrients: Increasing concentrations of nitrate since 1998, phosphorus levels negligible.

Impacts in WQU: None identified.

The water quality conditions for WQU DR1 are summarised in Table 4.7 and graphically in Annexure B.

Table 4.7 Summarised water quality data for E2H007Q01 (Leeuw/Groot River).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	362	1	362	361	362	361	361	1	361	361	361	361	361	451	44
Minimum	3.7	0.21	0.020	0.020	2.0	2.9	0.5	0.077	0.003	2.0	1.5	0.2	0.5	1.5	17.0
5% Percentile	5.1	0.21	0.020	0.020	4.4	4.9	1.0	0.077	0.003	2.0	8.6	0.5	0.5	4.7	18.5
25% Percentile	5.8	0.21	0.020	0.020	8.5	8.4	2.1	0.077	0.006	2.0	15.3	0.7	2.3	8.4	24.6
L95% Conf Limit (median)	6.4	0.21	0.205	0.035	11.5	10.9	2.9	0.077	0.016	7.2	20.6	1.1	3.7	11.3	29.4
Median	6.8	0.21	0.100	0.020	11.7	10.3	2.8	0.077	0.011	6.4	20.3	1.0	3.4	10.6	30.6
U95% Conf Limit (median)	6.6	0.21	0.316	0.057	12.8	12.2	3.3	0.077	0.029	8.4	23.4	1.3	4.3	12.6	40.1
75% Percentile	7.2	0.21	0.291	0.050	14.4	13.0	3.8	0.077	0.019	10.8	26.0	1.4	4.9	14.3	40.5
95% Percentile	7.5	0.21	0.983	0.090	21.0	20.9	6.0	0.077	0.052	19.8	40.5	2.6	9.2	21.7	53.6
Maximum	8.2	0.21	7.052	1.810	66.0	59.0	18.5	0.077	0.754	41.2	130.0	13.8	21.7	61.5	130.7
Mean	6.5	0.21	0.261	0.046	12.2	11.5	3.1	0.077	0.023	7.8	22.0	1.2	4.0	12.0	34.8
Standard Deviation	0.9	0.00	0.539	0.108	6.5	6.3	1.9	0.000	0.062	6.0	13.6	1.0	2.8	6.9	18.0
% Variation Coefficient	13.2	0.0	206.7	234.0	53.5	54.8	62.1	0.0	269.8	76.4	62.0	80.9	69.0	57.0	51.9

4.5.2 WQU DR2

Unit defined by the water quality as determined from the DWAF site E2H002Q01 (Doring River at Aspoort).

Provisional definition (no EWR within this WQU).
Upstream: Aspoort Gauging Weir (E2H002).
Downstream: Confluence of the Doring and Tankwa Rivers.
Unit length: 28 km.

WATER QUALITY CHARACTERISTICS

Data coverage: Continuous 1982-1983 and 1989-2003. No visible trends. Peaks during October to March, minima during late winter.

Nutrients: Upward trends for both nitrate and phosphorus, phosphorus markedly so. Phosphorus concentrations approaching the level at which algal blooms may become problematical in impounded water, or isolated pools during the summer and autumn.

Impacts in WQU: None identified.

The water quality conditions for WQU DR2 are summarised in Table 4.8 and graphically in Annexure B.

Table 4.8 Summarised water quality data for E2H002Q01 (Doring River at Aspoort).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	187		186	183	187	184	184		183	184	184	184	184	233	39
Minimum	4.5		0.020	0.020	2.0	2.2	0.5		0.003	2.0	5.0	0.2	0.5	3.6	9.0
5% Percentile	5.3		0.020	0.020	2.6	4.8	1.1		0.003	2.0	8.6	0.4	1.1	4.7	11.8
25% Percentile	6.6		0.020	0.020	7.3	6.3	1.6		0.008	4.5	12.1	0.6	2.3	6.8	14.3
L95% Conf Limit (median)	6.8		0.044	0.028	10.3	8.8	2.3		0.015	6.5	17.1	1.0	3.1	9.4	16.6
Median	7.0		0.020	0.020	10.0	8.3	2.2		0.014	6.8	16.1	0.8	2.9	8.7	16.0
U95% Conf Limit (median)	7.0	No data	0.066	0.035	12.6	10.8	2.7	No data	0.019	7.7	21.1	1.1	3.9	11.0	23.0
75% Percentile	7.3		0.052	0.041	13.0	11.0	2.9		0.022	8.9	21.7	1.3	3.9	11.2	21.2
95% Percentile	7.6		0.208	0.072	24.6	18.0	4.5		0.041	12.9	34.7	2.5	6.6	19.9	38.8
Maximum	8.3		0.586	0.283	62.1	80.2	12.0		0.114	41.1	154.0	3.8	27.5	62.3	57.9
Mean	6.9		0.055	0.031	11.4	9.8	2.5		0.017	7.1	19.1	1.0	3.5	10.2	19.8
Standard Deviation	0.7		0.077	0.026	8.0	7.1	1.3		0.015	4.3	13.8	0.7	2.8	6.4	10.1
% Variation Coefficient	10		139	82	70	73	53		86	61	73	63	81	62	51

4.5.3 WQU DR3

Unit not currently defined by any available water quality data.

Provisional definition with reference to EWR Site 4.

Upstream: Confluence of the Doring and Tankwa Rivers.
Downstream: Midway between the confluences of the Doring with the Brak and Koebee Rivers.
Unit length: 55 km.

WATER QUALITY CHARACTERISTICS

No data currently available.

4.5.4 WQU DR4

Unit defined by the water quality as determined from the DWAF site E2H003Q01 (Doring River at Melkboom).

Provisional definition with reference to EWR Site 5:

Upstream: Confluence of the Doring and Kobee Rivers.
Downstream: Confluence of the Doring and Olifants Rivers.
Unit length: 40 km.

WATER QUALITY CHARACTERISTICS

Data coverage:	Continuous when flowing since 1984. No apparent trends. Peaks in summer and minima in winter;
Nutrients:	Slight upward trend for nitrate, more apparent for phosphorus – see comment for WQU DR3. Summer minima and winter peaks.
Impacts in WQU:	None identified.

The water quality conditions for WQU DR4 are summarised in Table 4.9 and graphically in Annexure B.

Table 4.9 Summarised water quality data for E2H003Q01 (Doring River at Melkboom).

Type of Statistics	pH	TKN	NO_3-N	NH_4-N	TALK	Na	Mg	TP	PO_4-P	SO_4	Cl	K	Ca	EC	HARD
Number of analyses (n)	419		419	410	419	419	419		417	419	419	412	419	615	69
Minimum	5.4		0.020	0.020	4.7	6.5	1.3		0.003	2.0	11.1	0.5	2.7	6.5	16.7
5% Percentile	6.2		0.020	0.020	10.0	11.0	2.7		0.003	7.0	19.7	0.8	3.9	11.7	22.6
25% Percentile	7.2		0.020	0.020	15.9	17.6	4.2		0.008	11.4	31.2	1.1	5.8	17.9	31.7
L95% Conf Limit (median)	7.4		0.066	0.026	27.8	37.0	7.2		0.017	21.0	64.5	1.9	10.5	35.1	55.4
Median	7.5		0.020	0.020	21.2	26.3	5.8		0.014	16.6	47.4	1.6	8.2	26.5	52.1
U95% Conf Limit (median)	7.5	No data	0.097	0.037	32.9	45.1	8.3	No data	0.022	25.2	77.4	2.2	12.2	40.2	80.1
75% Percentile	7.8		0.073	0.020	34.9	47.0	9.3		0.022	25.4	84.0	2.4	13.7	43.7	80.2
95% Percentile	8.2		0.350	0.074	86.1	137.7	19.3		0.058	73.3	209.0	5.7	34.0	113.0	187.4
Maximum	9.0		1.840	1.054	267.0	285.0	47.3		0.217	170.0	509.0	8.9	61.3	211.0	249.1
Mean	7.4		0.082	0.031	30.4	41.0	7.7		0.019	23.1	70.9	2.1	11.4	37.6	67.7
Standard Deviation	0.6		0.159	0.054	26.6	42.5	5.9		0.024	21.9	67.3	1.5	9.0	31.8	52.4
% Variation Coefficient	7.5		193.4	169.7	87.6	103.6	76.6		120.7	95.0	94.8	74.0	78.5	84.6	77.4

4.6 NATURE OF THE OBSERVED TRENDS IN CONDUCTIVITY (TOTAL DISSOLVED SOLIDS)

The observed cycles may be accounted for as follows: In late winter, fresh water fills the dams and flushes the rivers. Then, in late summer, when the dams are low, evaporation results in a steadily increasing salt content that is once again reduced by the slow re-filling of the dams with fresh water. The storage of water in the dams is the critical factor, delaying the peak and smoothing it out somewhat. The nitrate peak is delayed relative to that of EC by several months, presumably because agricultural run-off requires some time to build up.

On the Doring River we are dealing with a low(er) storage capacity, a winter flush of fresh water and a summer influx of high EC water from rains in the Karoo. The result is the observed sudden seasonal change.

4.7 CHARACTERISATION OF WATER QUALITY BASED ON RELATIONSHIP BETWEEN CONDUCTIVITY AND INDIVIDUAL IONS

An examination of the relationship between electrical conductivity and the ions sodium, calcium, magnesium and chloride (see Table 4.10) reveals a very similar set of relationships for all the DWAF stations on the Olifants River. However on the Doring River, three distinct sets of relationships are apparent, reflecting the mix of water quality characteristics that prevail with progression down the system.

Table 4.10 Relationships between electrical conductivity and selected major ions and cations for the various DWAF monitoring stations on the Olifants and Doring River systems.

	Factor for calculating mg l^{-1} of substance from given EC			
OLIFANTS	**Na**	**Ca**	**Mg**	**Cl**
Citrusdal	0.93	0.320	0.261	1.54
Jan Dissels	1.06	0.234	0.181	1.93
Clanwilliam Dam	1.11	0.240	0.204	2.06
Clanwilliam Weir	1.05	0.223	0.204	2.02

Bulshoek Barrage	1.10	0.211	0.207	2.08
Bulshoek Canal	1.09	0.225	0.210	2.09
Weighted mean	*1.06*	*0.230*	*0.200*	*1.99*
DORING	**Na**	**Ca**	**Mg**	**Cl**
Leeuw	0.94	0.326	0.264	1.86
Aspoort	1.00	0.347	0.232	1.95
Melkboom	1.27	0.308	0.209	2.10

4.8 CHARACTERISATION OF WATER QUALITY BASED ON THE PROVISIONAL EWRQCALC PROCEDURE FOR ASSIGNING PRESENT ECOLOGICAL STATUS CATEGORIES TO EACH OF THE WQUS

The use of the EWRQCalc procedure has not been developed to support the Comprehensive level of Reserve Determination. Notwithstanding this the procedure provides an indication of which parameters exceed generally accepted water quality conditions. The outputs from the procedure, calculated using the data from the indicated DWAF water quality monitoring stations, are shown in Table 4.11.

Table 4.11 Present Ecological Status Categories, as indicated by water quality conditions, and generated using EWRQCalc Version 2.2.

DWAF Monitoring Point	**Olifants River**			**Doring River**		
	E1H013	**E1H011**	**E1R001**	**E2H007**	**E2H002**	**E2H003**
Relevant to WQU #	**OR1**	**OR2**	**OR4**	**DR1**	**DR2**	**DR4**
$MgSO_4$	A	A	B	B	A	E/F
Na_2SO_4	A	A	A	A	A	A
$MgCl_2$	A	A	A	A	A	B
$CaCl_2$	A	A	A	B	A	D
NaCl	A	A	B	A	A	D
$CaSO_4$	A	A	A	A	A	A
pH	B/A	A	A	A	A	B
NH_4	No allocations					
NO_2-NO_3						
PO_4	B	B	B	B	B	C
TIN	B	B	B	B	A	B
NH_3		No allocations				

The results concur with expert assessment of the water quality, i.e. that the water chemistry for all of the monitored sites, and with the exceptions as noted above for individual sites, is generally good to excellent. pH values lie within a narrow range spanning neutral. Ratios of major ions in both systems are Na>Ca>Mg>K, Cl>$S0_4$. While the use of the EWRQCalc procedure indicates a decline in water quality, based on magnesium sulphate and chloride salts, in the lower Doring, use of the procedure in its present format is not deemed suitable for systems that evidence naturally-elevated levels of salinity. The validity of the PES, based on an analysis of major anions and cations, for the lower Doring will need to be borne out through discussion with the biotic specialists, and the known ionic conditions that pertain to the organisms present or expected to be present. It is predicted that a C or C/B condition will be applicable to the WQU DR4.

5 GEOMORPHOLOGICAL ZONATION OF THE STUDY RIVERS

E. Dollar

5.1 INTRODUCTION

The aim of this Section is to detail the macro-reach classification exercise for the study. This is done with the purpose of contextualising the final geomorphology and potential bed material transport report for the EWR assessment. The Section is divided into six sub-sections: geology, geomorphology, potential sediment yield and hydrology; macro-reaches; methods; results and discussion and conclusions.

5.2 GEOLOGY, GEOMORPHOLOGY, POTENTIAL SEDIMENT YIELD AND HYDROLOGY

The quaternary catchments of the study area together with the location of the selected EWR sites are shown in the map in Annexure D.

The geology, geomorphology, potential sediment yield and hydrology of the Olifants/Doring catchment have been described in numerous previous reports (cf. SACS 1980, Rooseboom *et al.* 1992, Gresse and Theron 1992, CSIR 1995, Nolte 1995, McGregor 1997, DWAF 1997, PGWC 2001, De Beer *et al.* 2002). A short description is provided here. A geological map of the area is available in Annexure D. The Olifants River predominantly drains Cape Supergroup sediments: quartzites and sandstones of the Table Mountain Group and shales of the Bokkeveld Group. Occasionally the main stem flows through Tertiary and Quaternary alluvium, punctuated by Nama Group outcrops (SACS 1980). There is considerable structural control on the channel, with direction changes and pathways determined by lithology, jointing/fracturing and lineaments. The country rock weathers to produce mainly quartzitic sand, and consequently the bed material, in-channel and over bank storage is dominated by the sand-sized fraction, except in the upper reaches of river where a coarse bed load is dominant.

Although the Doring River main stem also rises off sediments from the Cape Supergroup, the majority of the basin is underlain by sediments of the Karoo Supergroup; including tillites of the Dwyka Group, ancient marine sediments of the Ecca Group, and in the east, shales of the Beaufort Group. Consequently, the sediment load of the Doring River system is somewhat different to that of the Olifants system. The bed load is still mainly represented by the sand-sized fraction (derived mainly from tributaries draining the Table Mountain Group sediments to the west), however, there is also a high-suspended sediment load derived from the weathering of the Karoo sediments. The Doring River contributes a very large proportion of the silt carried to the Olifants River estuary (Morant 1984). Structural control is also a dominant feature of the Doring River main stem. It is interesting to note that the Orange River system exited through the Doring main stem and discharged into the Atlantic through the mouth of the present-day Olifants River into the Cape Canyon during the Tertiary (Dollar 1998).

The estimated erodibility indices together with the estimated quaternary sub-catchment potential sediment yield for the study area are illustrated in Annexure D. The Olifants River catchment is characterised by a medium to low erodibility index (index of 14) and consequently a low sub-catchment potential sediment yield per unit area (1-8 $x10^3\ t^{-1}\ a^{-1}$ per quaternary catchment). It also has a perennial, regular (mean hydrological index[3] of 9.32) flow regime (Table 5.1), although there is a marked seasonal variation.

[3] The hydrological index represents an index of hydrological variability. It was developed by Hughes and Hannart (2003).

Table 5.1 Hydrological index calculated for the Olifants and Doring River catchments using monthly virgin data from WR90. Hydrological index after Hughes and Hannart (2003).

Mean Hydrological Index	Standard deviation	Contributory catchments
9.32	1.06	Olifants River main stem to junction with the Doring River
16.78	6.89	Doring River Cape Supergroup drainage
39.80	10.01	Doring River Karoo Supergroup drainage (south and east)
47.25	12.33	Doring River Karoo Supergroup drainage (north)

In contrast, the Doring River catchment, unlike the sub-catchments draining the Cape Supergroup sediments to the southwest, has a much higher erodibility index and potential sediment yield than the Olifants River main stem, especially in the northern parts of the catchment that are underlain by the Karoo sedimentary rocks (Annexure D). The catchment is also characterized by marked variability in the hydrological index (Table 5.1). Variability increases from the west to the east to the north respectively, with the mean hydrological index for the western part of the Doring catchment at 16.78, the south and east at 39.80 and the north at 47.25 (Table 5.1). The standard deviation also reflects this trend (Table 5.1) The same pattern is evident for the erodibility index and potential sediment yield, with increasing erodibility indices and higher potential sediment yields per unit area (19-90 x 10^3 $t^{-1}a^{-1}$) in the south, east and north respectively. The result is a high-suspended load delivered by the Oorlogskloof/Koeboe and Hantams/Sout tributaries to the main stem Doring and Olifants River respectively. High-magnitude, low frequency events are probably critical in this regard. Similarly, the eastern parts of the Doring catchment also have a higher potential sediment yield (20-33 x 10^3 $t^{-1}a^{-1}$ per quaternary catchment), although this is not as high as for the northern parts of the basin (see map in Annexure D).

It is important to caution that sediment delivery is spatially and temporally highly variable and requires hillslope-channel coupling. Furthermore, buffering, especially in larger basins, such as the Doring River system, complicates any interpretation of sediment delivery. Sourcing sediment is also critical for targeted management. The results presented here (based on the Rooseboom *et al.* 1992 potential sediment yield map) are based on modelled, potential sediment yield derived from incomplete information and a number of untested assumptions. It is critical to recognize this point in interpreting the aforementioned results as well as in recommending flows to meet desired ecological objectives.

Nevertheless, these physical template characteristics provide an important context within which the effects of a recommended regulated flow regime need to be interpreted, as different macro-reaches of the respective rivers may respond differently to the imposed change. Interpreting cause and effect, form and process is also a function of spatial and temporal scale, as well as initial system state.

Hydrological index = Combination of coefficient of variation of calendar month total flow volumes (CV) /base flow index (BFI)

These two indices complement each other as there are some rivers that have large base flow (High BFI) contributions and are in regions subject to drought that affect both high and low flows (high CVs). Other regions consist of ground water contributions that buffer the flow against droughts and therefore have more sustained base flow contributions (high BFI and lower CVs). The CV index therefore reflects climatic variability (cycles of wet and dry periods), while the BFI reflects the runoff generation processes that dominate in the catchment of the river.

For South African rivers for CV < 1, BFI < 1 (adapted from Hughes and Hannart (2003))

Hydrological index close to 1	Regions of low variability
Hydrological index > 50	Semi-arid regions of high variability

5.3 MACRO-REACHES

Macro-reaches can be defined as stretches of river within which inherited controls (see Section 5.2) are sufficiently uniform so as to result in a similar channel type. Nested within macro-reaches can be a variety of channel types (Dollar *et al.* 2004a). Macro-reaches are nested within drainage basins. Drainage basins are characterized by river longitudinal profiles. These are idealised as logarithmic curves from the source to drainage basin exit. An idealized profile occurs where an equilibrium condition is attained between the processes of erosion, transport and deposition along the profile, in response to elevation. A similar concept can be applied to individual slopes (cf. Blight 1994). This ideal, however, is seldom evident except over short sections. Divergence from the idealised curve provides useful clues as to the evolutionary path of the fluvial system.

In South Africa most rivers cross a variety of geological strata that also have intrusions of more resistant rocks (dolerite for example). Furthermore, over time, tectonic action, river capture and changes in base level alter the equilibrium level toward which the profiles tend. This results in profiles that are far from the ideal and are consequently irregular along their length. The overall profile can be therefore be sub-divided into shorter macro-reaches that extend between ‘controls’ or ‘break points’ such as exposed resistant rock formations, knick points, or significant changes in lithology. Reaches between these break points usually denote a macro-reach.

Within a macro-reach, the profile tends toward the ideal over time. Characteristics of the river channel within a single macro-reach are also similar. For example, over a macro-reach the channel type might be described as ‘anabranching’ or ‘braided’. These characteristics are as a result, in part, of the overall slope of the reach (an inherited characteristic), sediment flux and river discharge. Ideally, in an EWR detetrmination, one EWR site should be selected per macro-reach. The assumption is made that the EWR site will represent the variety of geomorphic and hydraulic conditions of the macro-reach and its potential response to changes in energy. However, given time and resource constraints, this is often not possible (See Section 8).

5.4 METHODS

Macro-reach boundaries are defined on the basis of major breaks in valley slope and/or lithology in the longitudinal profile, and where possible, an analysis of channel type from a video helicopter survey of the channel. It has been demonstrated that valley slope correlates well with many other channel characteristics such as pattern, type and bed material calibre (Dollar *et al.* 2004b). Boundaries are often related to significant changes in average slope, geology (lithology and structure) and/or knick points. While it is clear that there are no abrupt changes in channel type along a longitudinal profile (there is a continuum of change), and that channel types tend to grade into each other, changes in average slope around a point provides a useful means to discriminate between macro-reaches, especially when no other data are available.

The use of slope as an independent variable in the analysis of fluvial systems also has a strong theoretical (Lacey 1930, Blench 1952, Chang 1988) and empirical basis (Walters *et al.* 2003, Rãdoane *et al.* 2003). Furthermore, the relationship between channel type and/or pattern and slope has been reported by numerous researchers (van Niekerk *et al.* 1995, Rowntree and Wadeson 1999, Tooth *et al.* 2002, Dollar and Rowntree 2003, Tooth and McCarthy 2004, Tooth *et al.* 2004).

The macro-reach analysis is performed on the main stem of the river under consideration. A number of techniques can be utilized to generate macro-reach boundaries (cf. Rowntree 2000, Heritage *et al.* 2000, Dollar and Dollar 2003, Dollar *et al.* 2004b). For the purposes of this report, the following approach was adopted:

1. Longitudinal profiles were generated from 1:50 000 topographical maps for the main stem Olifants River, main stem Doring River, as well as the Houdenbek/Riet/Groot/Doring rivers and Doring/Groot rivers. CUSUM plots (S^*_k) were calculated for the Olifants River profile and the Houdenbek/Groot/Doring profile. This technique identifies the boundaries through plotting the cumulative standard deviations of slope. Major breaks of slope can easily be identified from the plot. This, together with the geological information and classification of 'channel type' from the aerial survey video provides a basis for defining macro-reach boundaries.

$$S_k^* = \sum_{i=1}^{k} (Y_i - \overline{Y})$$
$$where\ k = 1, 2, ..., n$$

2. An adaptation of the Worsley Likelihood Ratio Test (WLRT) was applied (for a successively bifurcated sample set) to find the most likely position of a change in mean in the data set (slope) [see Dollar and Dollar (2004) for a full description of the method]. The WLRT method calculates a sum of deviations from the mean and weights them according to their position in the series. The partial sums are rescaled and adjusted by dividing through by the sample's standard deviation. The advantage of the Worsley method is that it can determine the position of the change point whereas a Student t-test can only test whether the hypothesis of a change point is true if the position of the change point is known. The test is therefore statistically defensible.

   The derivation presented below was applied (Buishand 1982) since it is easier to apply than the rigorous proof presented in Worsley (1979).

$$Z_k^* = S_k^* / \left[k(n-k)\right]^{1/2}$$
$$where\ k = 1, 2, ..., n-1$$

   Z_k^{**} is the weighted rescaled adjusted partial sum and is obtained by dividing Z_k^* by the sample standard deviation.

   Then:
$$V = \max_{0 \le k \le n-1} \left|Z_k^{**}\right|$$
$$W = (n-2)^{1/2} V / \left(1 - V^2\right)^{1/2}$$

   There is a unique relationship between *V* and the test statistic *W* derived by Worsley (1979). If only the position of the change point is required, then it is unnecessary to calculate *W*, but if the level of significance is also required, then *W* is computed. Critical values for the test statistic *W* are presented in Worsley (1979). As with the $Q/\sqrt{n}$ critical values (Buishand, 1982), *W* decreases as the number of data points in the set grows and increases with the required level of significance.

The two methods described above, together with professional judgement were applied to define the macro-reaches for the study area longitudinal profiles.

5.5 RESULTS

5.5.1 Olifants River longitudinal profile

Table 5.2 presents the results from the mid-point (adapted) WLRT approach utilizing a 20 m Digital Elevation Model (DEM) for the Olifants River main stem. Table 5.3 presents the macro-reach analysis from the 1:50 000 topographical map survey, 1:250 000 geological map survey and aerial survey video.

Table 5.2 Macro-reach analysis for the Olifants River main stem using adapted WLRT approach from the 20m DEM.

Change point chainage (km)	Elevation (m)	Reach length (km)	Average slope (m/m)	Shape
0	917			
25	584	25	0.01315	Moderately concave
38	300	13	0.02235	Averagely concave
57	190	19	0.00553	Mildly concave
187	16	129	0.00135	Mildly concave
287	0	101	0.00016	Averagely convex

Table 5.3 Macro-reach analysis for the Olifants River main stem. Different shades represent different macro-reaches.

Chainage	amsl(m)	Slope	CUSUM	Average Slope	Channel type
276.44	0				Braided
174.34	20	0.00020	0.00020		Anabranching (Junction with Doring River)
161.29	40	0.00153	0.00173	**0.00086**	Anabranching/single thread pool/rapid/riffle (EWR Site 2)
158.74	60	0.00784	0.00957		single thread pool/rapid/riffle (Bulshoek Barrage)
132.34	80	0.00076	0.01033		single thread pool/rapid/riffle/braided
131.99	100	0.05714	0.06747	**0.02912**	**Braided**
106.04	120	0.00077	0.06824		**Anabranching with braids (Clanwilliam Dam)**
97.39	140	0.00231	0.07055		Braided with anabranching
75.39	160	0.00091	0.07146	**0.00133**	Braided with anabranching **(EWR Site 1)**
66.99	180	0.00238	0.07384		Anabranching
59.59	200	0.00270	0.07655		Anabranching
52.14	220	0.00268	0.07923		Anabranching
47.69	240	0.00449	0.08373		Anabranching
40.79	260	0.00290	0.08663	**0.00303**	Anabranching
37.89	280	0.00690	0.09352		Pool/rapid/riffle
34.64	300	0.00615	0.09968		Pool/rapid/riffle
33.94	320	0.02857	0.12825		Pool/rapid/riffle
32.54	340	0.01429	0.14253		Pool/rapid/riffle
30.29	360	0.00889	0.15142		Pool/rapid/riffle
29.49	380	0.02500	0.17642		Pool/rapid/riffle
28.14	400	0.01481	0.19124		Pool/rapid/riffle
26.54	420	0.01250	0.20374		Pool/rapid/riffle
26.04	440	0.04000	0.24374		Pool/rapid/riffle
25.84	460	0.10000	0.34374		Pool/rapid/riffle
25.24	480	0.03333	0.37707		Pool/rapid/riffle
24.84	500	0.05000	0.42707		Pool/rapid/riffle
24.34	520	0.04000	0.46707		Pool/rapid/riffle
24.09	540	0.08000	0.54707		Pool/rapid/riffle
23.79	560	0.06667	0.61374		Pool/rapid/riffle
23.39	580	0.05000	0.66374	**0.03607**	Pool/rapid/riffle
22.09	600	0.01538	0.67912		Pool/rapid
18.94	620	0.00635	0.68547		Pool/rapid
17.49	640	0.01379	0.69926		Pool/rapid
15.54	660	0.01026	0.70952		Pool/rapid
13.99	680	0.01290	0.72242		Pool/rapid
11.64	700	0.00851	0.73093		Pool/rapid
10.14	720	0.01333	0.74427		Pool/rapid
8.29	740	0.01081	0.75508		Pool/rapid
7.09	760	0.01667	0.77174		Pool/rapid
5.89	780	0.01667	0.78841		Pool/rapid
3.64	800	0.00889	0.79730		Pool/rapid
2.99	820	0.03077	0.82807		Pool/rapid
1.44	840	0.01290	0.84097	**0.01363**	Pool/rapid
1.04	860	0.05000	0.89097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.96	880	0.25000	1.14097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.88	900	0.25000	1.39097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.8	920	0.25000	1.64097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.72	940	0.25000	1.89097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.64	960	0.25000	2.14097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.56	980	0.25000	2.39097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.48	1000	0.25000	2.64097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.4	1020	0.25000	2.89097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.32	1040	0.25000	3.14097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.24	1060	0.25000	3.39097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.16	1080	0.25000	3.64097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0.08	1100	0.25000	3.89097		Pool/rapid/ bedrock canyon exploiting lines of structural weakness
0	1120	0.25000	4.14097	**0.23571**	Pool/rapid/ bedrock canyon exploiting lines of structural weakness

Table 5.4 Summary table of the macro-reaches for the Olifants River mainstem.

Macro-reach	~ chainage break from source (km)	~ amsl break (m)	Average macro-reach slope (m/m)	Dominant channel type	Dominant lithology	Description
1			0.00086	Braided with occasional anabranching	Red Aeolian sand; Quaternary sediments; sandstone, conglomerate and siltstone	Large sand bed load component; anabranching associated with flatter slopes, wider valleys and lower transport competence. Where there is valley confinement, channel steepens and attains a single thread planform. Numerous lateral bars and sand splays. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Occasional bedrock intrusions create upstream hydraulic controls. Channel pathway often structurally controlled. EWR Site 2 is situated in macro-reach 1.
2	160	60	0.02912	Single thread pool/rapid/riffle with occasional braiding	Quartzitic sandstone	Section is mainly between Bulshoek Barrage and Clanwilliam Dam. Consequently, likely to be supply-limited section in the active channel. Where valley is confined and slope is steep, single thread pool/rapid/riffle channel type. Where valley is wider and slope is flatter, channel type is braided with extensive overbank deposits and sand splays. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Channel pathway often structurally controlled.
3	106	120	0.00133	Braided with anabranching	Quartzitic sandstone	Where valley is narrower and slope is flat, channel type is braided with extensive overbank deposits and sand splays. In slightly steeper, but wider, unconfined valleys, channel type is anabranching. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Extensive sand bed load. Extensive lateral deposits. Channel pathway often structurally controlled. EWR Site 1 situated in macro-reach 3.
4	67	180	0.00303	Anabranching	Alluvium and quartzitic sandstone	Extensive anabranching. Multiple channels, unconfined valley. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Combination of bedrock influence and vegetation important in maintaining anabranching planform. Exposed sediment not as evident in anabranching channel type. Piedmont zone.
5	38	280	0.03607	Pool/riffle/rapid	Quartzitic sandstone	Abrupt change of channel type to single thread pool/riffle/rapid. Coarse bed material and overbank deposits. Confined valley, localized flood plain development. Channel pathway often structurally controlled.
6	22	600	0.01363	Pool/rapid	Quartzitic sandstone	Single thread pool/rapid. Coarse bed material and overbank deposits. Confined valley, localized flood plain development. Channel pathway often structurally controlled. Channel pathway exploiting lines of structural weakness
7	1	860	0.23571	Pool/rapid/bedrock canyon	Shale and mudstone	Pool/rapid/bedrock canyon. Channel pathway exploiting lines of structural weakness.

Good general agreement was found between the break points identified using the statistically defensible adapted WLRT approach and the desktop approach. Three of the break points identified using the desktop approach and the adapted WLRT approach matched (break points at ~ 180m, 600m and 860m). However, the desktop approach provided a more sensitive delineation of the macro-reaches (based on channel type and CUSUM) as would be expected. A description of the final macro-reaches for the Olifants River main stem is presented in Table 5.3. Figure 5.1 presents the macro-reaches and longitudinal profile in diagrammatical form.

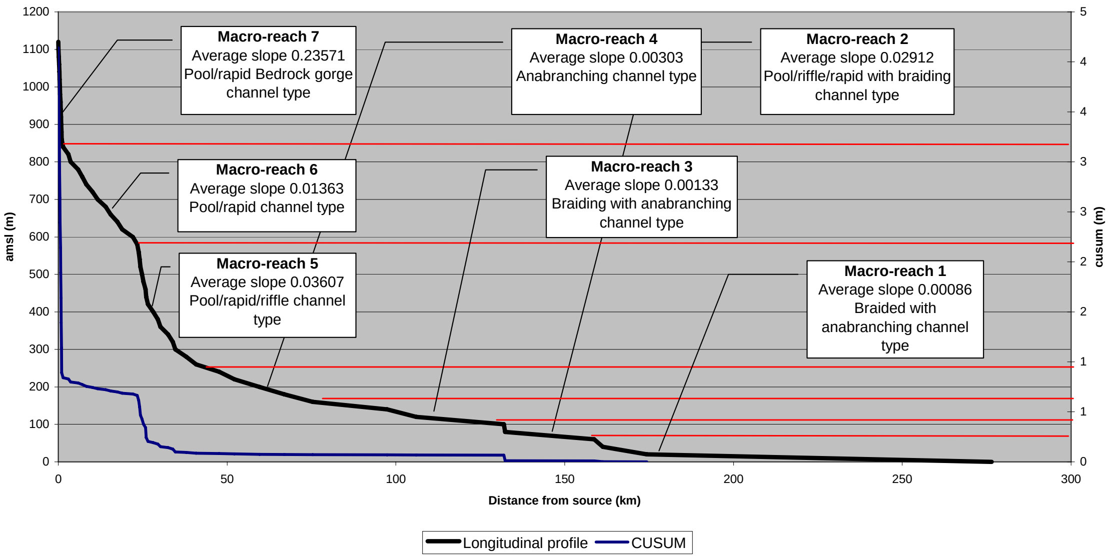

Figure 5.1 Olifants River longitudinal profile.

5.5.2 *Houdenbek/Riet/Groot/Doring River longitudinal profile*

Table 5.5 presents the macro-reach analysis from the 1:50 000 topographical map survey, 1:250 000 geological map survey and aerial survey video for the Houdenbek/Riet/Groot/Doring River. This section of the Doring River system was chosen for the macro-reach analysis as the aerial survey video taken in 1997 was for this section of the system. The longitudinal profiles of the main stem Doring River, as well as the Doring/Groot system were also generated (see Figure 5.2). They were not, however, considered in their entirety for macro-reach analysis, as no aerial survey video was available for their upper reaches. The lower 170km of the Doring River main stem, however, incorporates all these systems. No DEM was available for this section of the system.

A description of the final macro-reaches for the Houdenbek/Riet/Groot/Doring River is presented in Table 5.6. Figure 5.2 presents the macro-reaches and longitudinal profile in diagrammatical form.

Table 5.5 Macro-reach analysis for the Houdenbek/Riet/Groot/Doring River. Different shades represent different macro-reaches.

Chainage (km)	amsl(m)	Slope	CUSUM	Average Slope	Channel type
0	20				Braided with anabranching
10.85	40	0.00184	0.00184	**0.00184**	Braided with anabranching
24.6	60	0.00145	0.00330		Single thread pool/rapid/riffle
32.25	80	0.00261	0.00591		Single thread pool/rapid/riffle **(EWR Site 5)**
42.95	100	0.00187	0.00778		Single thread pool/rapid/riffle
50.95	120	0.00250	0.01028		Single thread pool/rapid/riffle
62.2	140	0.00178	0.01206		Single thread pool/rapid/riffle
74.9	160	0.00157	0.01363	**0.00197**	Single thread pool/rapid/riffle
88.1	180	0.00152	0.01515		Alternating Pool/riffle/rapid/anabranching
98.05	200	0.00201	0.01716		Single thread pool/rapid/riffle **(EWR Site 4)**
108.8	220	0.00186	0.01902		Alternating Pool/riffle/rapid/anabranching
120.95	240	0.00165	0.02067		Single thread pool/rapid/riffle
134.6	260	0.00147	0.02213		Alternating Pool/riffle/rapid/anabranching
144.75	280	0.00197	0.02410		Anabranching
153.15	300	0.00238	0.02648		Alternating Pool/riffle/rapid/anabranching
156.95	320	0.00526	0.03175		Single thread pool/rapid/riffle
160.85	340	0.00513	0.03687		Alternating Pool/riffle/rapid/anabranching
168.45	360	0.00263	0.03951		Single thread pool/rapid/riffle
171.5	380	0.00656	0.04606		Single thread pool/rapid/riffle **(EWR Site 6)**
185.35	400	0.00144	0.04751		Anabranching
187.25	420	0.01053	0.05803		Anabranching
193.45	440	0.00323	0.06126		Anabranching
195.8	460	0.00851	0.06977		Alternating Pool/riffle/rapid/anabranching
200.55	480	0.00421	0.07398		Alternating Pool/riffle/rapid/anabranching
203.95	500	0.00588	0.07986		Alternating Pool/riffle/rapid/anabranching
205.85	520	0.01053	0.09039		Alternating Pool/riffle/rapid/anabranching
208.45	540	0.00769	0.09808		Alternating Pool/riffle/rapid/anabranching
212.2	560	0.00533	0.10341	**0.00449**	Alternating Pool/riffle/rapid/anabranching
214.95	580	0.00727	0.11069		Bedrock pool/riffle/rapid
216.1	600	0.01739	0.12808		Bedrock pool/riffle/rapid
218.4	620	0.00870	0.13677		Bedrock pool/riffle/rapid
219.6	640	0.01667	0.15344		Bedrock pool/riffle/rapid
220.3	660	0.02857	0.18201		Bedrock pool/riffle/rapid
221.1	680	0.02500	0.20701		Bedrock pool/riffle/rapid
221.5	700	0.05000	0.25701		Bedrock pool/riffle/rapid
222.35	720	0.02353	0.28054		Bedrock pool/riffle/rapid
222.95	740	0.03333	0.31387		Bedrock pool/riffle/rapid
223.7	760	0.02667	0.34054		Bedrock pool/riffle/rapid
224.25	780	0.03636	0.37691		Bedrock pool/riffle/rapid
224.75	800	0.04000	0.41691		Bedrock pool/riffle/rapid
225.4	820	0.03077	0.44767		Bedrock pool/riffle/rapid
225.8	840	0.05000	0.49767		Bedrock pool/riffle/rapid
226.75	860	0.02105	0.51873		Bedrock pool/riffle/rapid
227.15	880	0.05000	0.56873	**0.02908**	Bedrock pool/riffle/rapid
228.5	900	0.01481	0.58354		Alternating Pool/riffle/rapid/anabranching
239.4	920	0.00183	0.58538		Alternating Pool/riffle/rapid/anabranching
262.9	940	0.00085	0.58623		Anabranching
276.55	960	0.00147	0.58769		Anabranching (highly modified)
281.25	980	0.00426	0.59195		Anabranching (highly modified)
284.05	1000	0.00714	0.59909	**0.00506**	Single thread meandering (highly modified)

Table 5.6 Summary table of the macro-reaches for the Houdenbek/Riet/Groot/Doring River.

Macro -reach	~ chainage break from source (km)	~ amsl break (m)	Average macro-reach slope (m/m)	Dominant channel type	Dominant lithology	Description
1			0.00184	Braided with anabranching	Red Aeolian Sand	Large sand bed load. Braided channel type associated with flat slope and wide, unconfined valleys. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units.
2	25	60	0.00197	Single thread pool/rapid/riffle	Sandstone	Single thread pool/rapid/riffle associated with narrow, confined valleys and steep slopes. Bedrock influence strong, creating local upstream hydraulic controls, rapids and pools. Extensive mid-channel, lateral and point bars. Riffles consist of coarse bed material, pools associated with sand load. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Channel pathway often structurally controlled. EWR Site 6 in macro-reach 2.
3	88	180	0.00449	Alternating pool/riffle/rapid and anabranching	Quartzitic sandstone, shale and alluvium	Anabranching channel type associated with multiple channels, unconfined valley and flatter slope. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Combination of bedrock influence and vegetation important in maintaining anabranching planform. Exposed sediment not as evident in anabranching channel type. This channel type alternates with a single thread pool/rapid/riffle channel type that are nested within steeper, more confined valleys. Channel pathway often structurally controlled. EWR Sites 4 and 5 in macro-reach 3.
4	215	580	0.02980	Bedrock pool/riffle/rapid	Quartzitic sandstone	Abrupt change of channel type to bedrock pool/rapid. Steep, confined valley with strong bedrock influence, dominance of structural control on channel pattern and bedrock influence on channel morphology.
5	228	900	0.0056	Alternating pool/riffle/rapid and anabranching	Shale, siltstone, mudstone and alluvium	Anabranching channel type associated with multiple channels, unconfined valley and flatter slope. Riparian and in-channel vegetation plays a very important role in sediment transport processes and in the stabilization of various morphological units. Combination of bedrock influence and vegetation important in maintaining anabranching planform. Exposed sediment not as evident in anabranching channel type. This channel type alternates with a single thread pool/rapid/riffle channel type that are nested within steeper, more confined valleys.

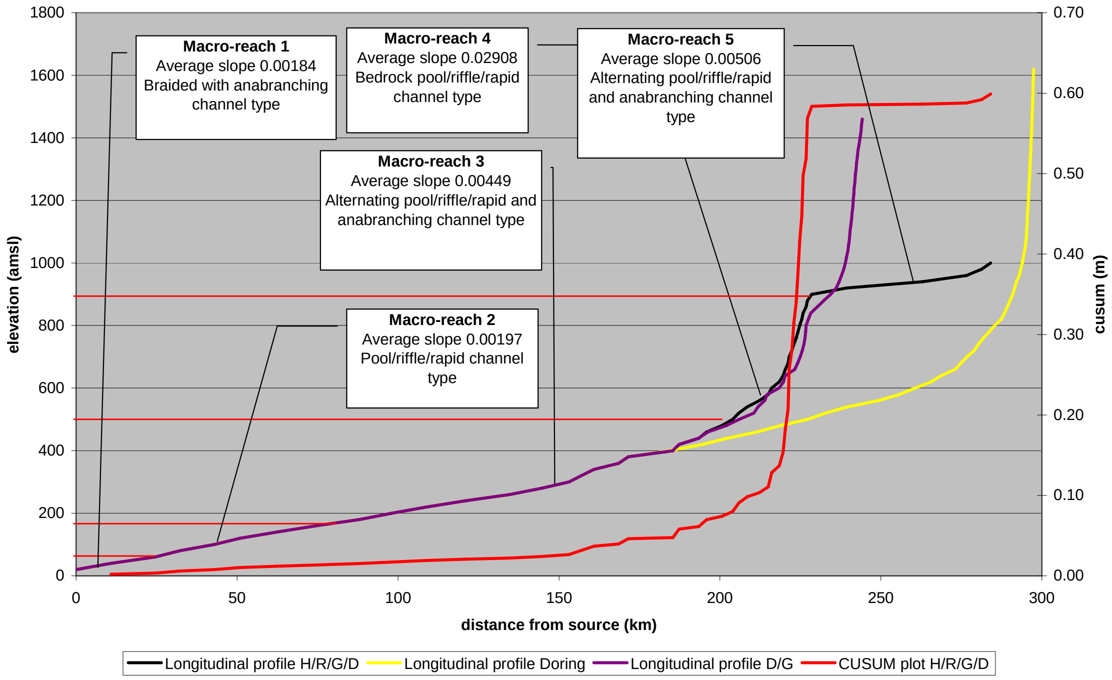

Figure 5.2 Houdenbek/Riet/Groot/Doring River longitudinal profile.

5.6 DISCUSSION AND CONCLUSION

Given the homogeneity of the physical catchment characteristics of the Olifants River, it is suggested that the macro-reach divisions adequately represent the physical diversity of the Olifants River main stem. A limitation of the current study is, however, that only two of the seven macro-reaches are represented by EWR sites (EWR Site 1 representing macro-reach 3 and EWR Site 2 representing macro-reach 1). The upper macro-reaches (5, 6 and 7) that are predominantly characterized by pool/riffle/rapid channel types are not represented. Furthermore, although EWR Site 2 is located within a macro-reach (1) that is dominated by anabranching, it is located below Bulshoek Barrage, South Africa's oldest impoundment (1913). This means that the site is supply-limited and has probably adjusted to the imposed change. Furthermore, it probably does not adequately represent the widespread anabranching channel type common in macro-reaches 1, 3 and 4, as the site is upstream of the hydraulic control that impounds the pool through which the cross-section runs. It therefore does not represent an anabranching channel type. EWR Site 1 is a good representation of macro-reach 3, although it is clear that the channel morphology has been considerably altered, mainly through river engineering works. It is likely that the pre-development Olifants River main stem was characterized, in places (especially macro-reaches 1 to 4), by widespread channel anabranching, avulsions, sand splays and lateral flood plain connectivity. A detailed study is this regard would be necessary to better understand this impact.

In-channel and riparian vegetation plays an important role in both the Olifants River main stem and Doring Rivers. At finer scales, this is achieved through its influence on local hydraulics that determines sediment transport. At this scale, vegetation reduces bed shear through absorbing momentum by drag on the stems. At larger temporal scales, decades to millennia for example, vegetation is also of importance. It is generally accepted that riparian vegetation increases bank stability, although this is seldom quantified. This would suggest that in considering the effects of riparian vegetation of bank stability, hydrological, mechanical and ecological criteria should be jointly considered in determining the potential stabilizing and destabilizing impacts of vegetation. Recommending flows that meet certain flow objectives in terms of the relationship between in-channel and riparian vegetation, channel form and processes and flood plain connectivity are critical for the Olifants River main stem, but particularly so for the anabranching channel types nested within macro-reaches 1 to 4.

The Houdenbek/Riet/Groot/Doring River is represented by five macro-reaches. Three EWR sites have been chosen to represent this system, with one site representing macro-reach 2 (EWR Site 5), and two sites representing macro-reach 3 (EWR Sites 4 and 6). The longitudinal profile of this river appears to be approaching an equilibrium form, especially for the main stem Doring River. The dominant channel type for this profile is pool/riffle/rapid (macro-reaches 2, 3 and 4). The anabranching channel type is also represented on this system (macro-reaches 1, 3 and 5). No anabranching channel has been selected to represent this system, a limitation of this study, neither has a bedrock pool/rapid channel type been chosen.

In conclusion, it is critical that the recommended EWR for each site be understood within a spatial and temporal context that considers the key hierarchical links between geomorphology, hydrology and ecology. The EWR must consider complex, multi-scale interactions between biota, physical template and hydrological processes. Furthermore, it is important that the scale at which the potential hydrological changes are to be imposed is understood, so that the prediction of potential biological and physical responses are appropriately defined. This is critical so that the measurement of the response to the imposed change is at a scale appropriate to the scale of manipulation, and that management intervention considers the spatial and temporal complexity within the study basins.

6. HABITAT INTEGRITY OF THE OLIFANTS AND DORING RIVERS

C. Kleynhans and C. Brown

6.1 INTRODUCTION

The ecological integrity of a river is defined as its ability to support and maintain a balanced, integrated composition of physico-chemical and habitat characteristics, as well as biotic components on a temporal and spatial scale that are comparable to the natural characteristics of ecosystems of the region. This definition is based on the concept of biological integrity that has been described as “the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural habitat of the region” (Karr and Dudley 1981, in Kleynhans 1997). Habitat integrity in this sense then refers to the maintenance of a balanced, integrated composition of physico-chemical and habitat characteristics on a temporal and spatial scale that are comparable to the characteristics of natural habitats of the region (Kleynhans 1996).

Essentially, the habitat integrity status of a river will provide the template for a certain level of biotic integrity to be realized. In this sense, the assessment of the habitat integrity of a river can be seen as a precursor of the assessment of biotic integrity. It follows that in this context habitat integrity and biotic integrity together constitutes ecological integrity

The methods that were used in the collation and interpretation of data and the final assessment of the habitat integrity are essentially those in Kleynhans (1996). In essence the procedure involves the separate assessment of the instream habitat integrity and the riparian zone habitat integrity according to a number of key criteria. The riparian zone integrity is, however, assessed primarily based on the impact it is surmised to have on the instream component of the river. The observed or deduced condition of these criteria as compared to what it could have been under unperturbed conditions is surmised to indicate a change in the habitat integrity. A rating system based on differing weights for each criterion (according to its perceived importance in determining habitat integrity) is used to assess the total habitat integrity for the instream and riparian zone facets of the river. The final estimate of the criteria for the riparian zone and the water abstraction, flow modification, bed modification, channel modification, water quality and inundation criteria for the instream component, receive an additional weight if impacts on these were considered large, serious or critical. The sum of these ratings is used to classify the instream and riparian zone facets according to a descriptive integrity class (Table 6.1).

6.2 DATA USED IN THIS ASSESSMENT

6.2.1 Video material

Part of the information used here for the Habitat Integrity determination was obtained from a video recording of the rivers during a low level helicopter survey conducted during October 1997, and the resultant report (Kleynhans 1997). This survey was based on numbered 5-km sectors of the river and was conducted in a downstream direction, starting at the Houdenbek River, downstream with the Riet River, the Groot River and the Doring River up to its confluence with the Olifants River, and then up the Olifants River from its confluence with the Doring River to upstream of the Olifants River Gorge. A continuous video recording was made of the total length of the river. Navigation was done using 1:50 000 maps.

Table 6.1 Habitat integrity assessment categories.

Category	Description	Score (percent of total)
A	Unmodified, natural.	100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	80-99
C	Moderately modified. A loss and change of natural habitat and biota have occurred but the basic ecosystem functions are still predominantly unchanged.	60-79
D	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	40-59
E	The loss of natural habitat, biota and basic ecosystem functions are extensive.	20-39
F	Modifications have reached a critical level and the lotic system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances, the basic ecosystem functions have been destroyed and the changes are irreversible.	0-19

6.2.2 Past studies

Past reports that were used in the assessment include:

- Preliminary classification of the ecological importance of riverine ecosystems in the Western Cape Province (Eekhout and Brown 1996);
- Olifants/Doring Basin Study (Dallas 1997, Brown and Day 1997);
- Olifants/Doring River Health Assessment (Day *et al.* 1998);
- Western Cape Olifants/Doring River Irrigation Study (Brown *et al*. 2003).

6.2.3 Ground-truthing

Notes on overall river condition, and perceived impacts to ecological condition were made during the various field trips that have been undertaken. These were used to:

1. update the assessments that were available in the literature;
2. fill in the gaps, particularly for the key tributaries.

The assessments presented here will be updated, and superseded, by the site-specific information from the specialists used to determine the Present Ecological Status (PES) at the EWR Workshop.

6.3 RESULTS

The scores assigned to each of the 5-km segments assessed are provided in Annexure C. Figure 6.1 provides a summary of the overall habitat integrity assigned to each segment, and thus for the rivers as a whole.

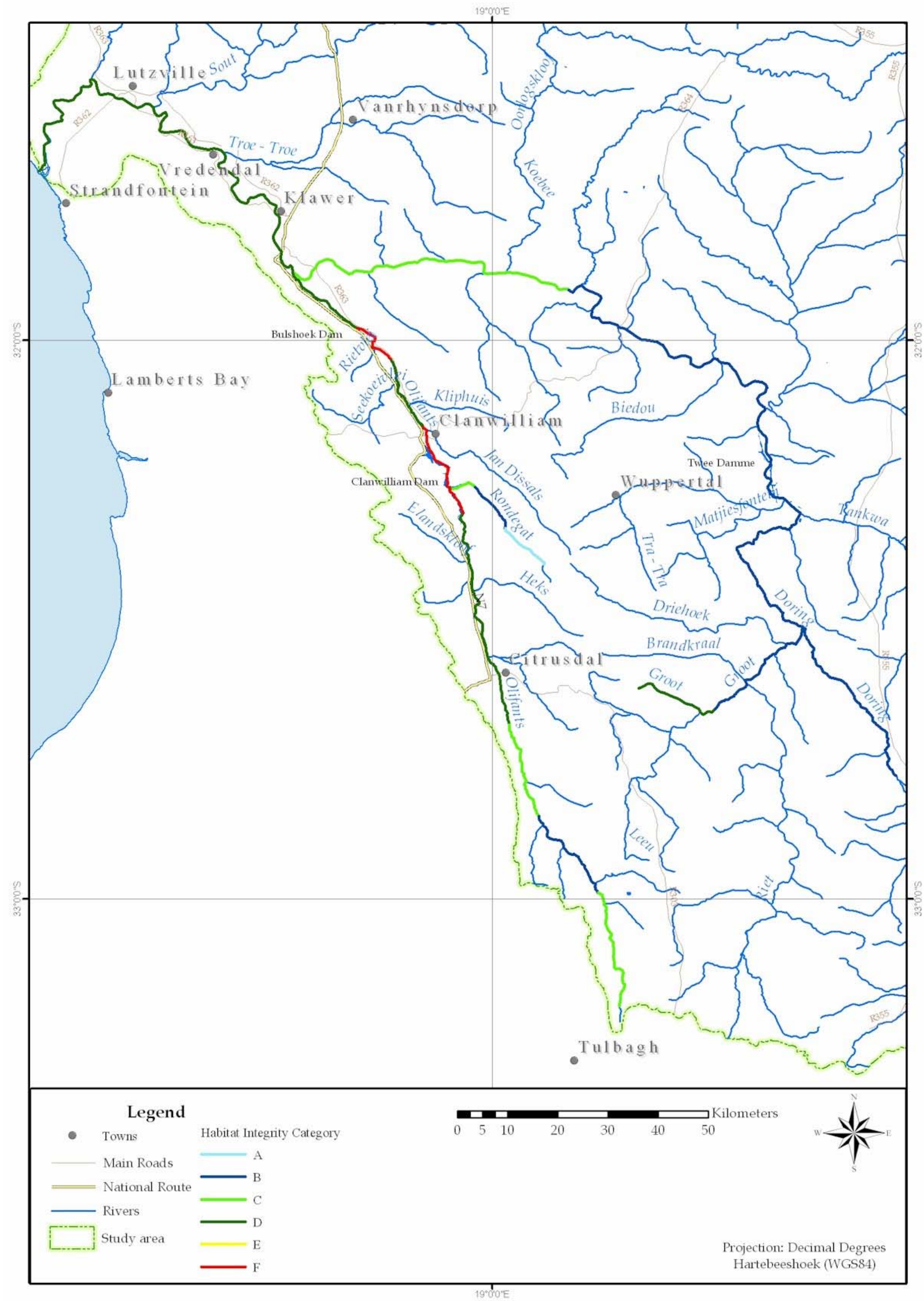

Figure 6.1 Summary of the overall habitat integrity assigned to each segment.

7 DELINEATION OF RESOURCE UNITS

7.1 KEY WATER MANAGEMENT UNITS

The following key water management units were identified:

OLIFANTS

Kouebokkeveld- Olifants:	The headwater regions of the Olifants Rivers are heavily utilized for agriculture, and form a distinct management unit.
Keerom to Clanwilliam Dam:	The presence of the towns of Citrusdal and Clanwilliam, and of Clanwilliam Dam makes this a vitally important management unit.
Clanwilliam Dam to Bulshoek Barrage:	Releases from Clanwilliam Dam to ensure sufficient water enters the agicultural canals at the Bulshoek Barrage makes this the most 'managed' section of the entire system.
Bulshoek Barrage to the confluence with the Doring River:	The importance of this section for water resource management stems from the fact that it is the section that defines the contribution of the upper Olifants River to the lower river and estuary.
Confluence with the Doring River to Lutzville:	The lower reaches of the Olifants Rivers are heavily utilized for agriculture, and form a distinct management unit.

DORING

Kouebokkeveld- Doring:	The headwater regions of the Olifants Rivers are heavily utilized for agriculture, and form a distinct management unit.
Groot from Mount Cedar to Aspoort:	The possibility of an inchannel storage dam at Aspoort makes this a potentially important management unit.
Doring from Elandsvlei to Melkbosrug:	The possibility of an inchannel storage dam at Melkbosrug and/or a diversion weir to storage on the Brandewyn, make this a potentially important management unit.
Doring from Melkbosrug to Melkboom:	The possibility of an inchannel storage dam at Melkboom makes this a potentially important management unit. It is also the section that defines the contribution of the Doring River to the lower Olifants River and estuary.

7.2 KEY RESOURCE UNITS IN THE MAIN STEMS

The different river reach delineations given for the mainstem of the Olifants and Doring Rivers in this report are summarised in Figures 7.1 and 7.2. These have been compared and rationalised to arrive at seven broad resource units for the Olifants River, and five broad resource units for the Doring River. Please note that the summaries are illustrative only, the exact lengths and divisions for the different reaches should be obtained from the relevant sections. The tributaries that were selected for this study were selected from specific reasons, which are also given here.

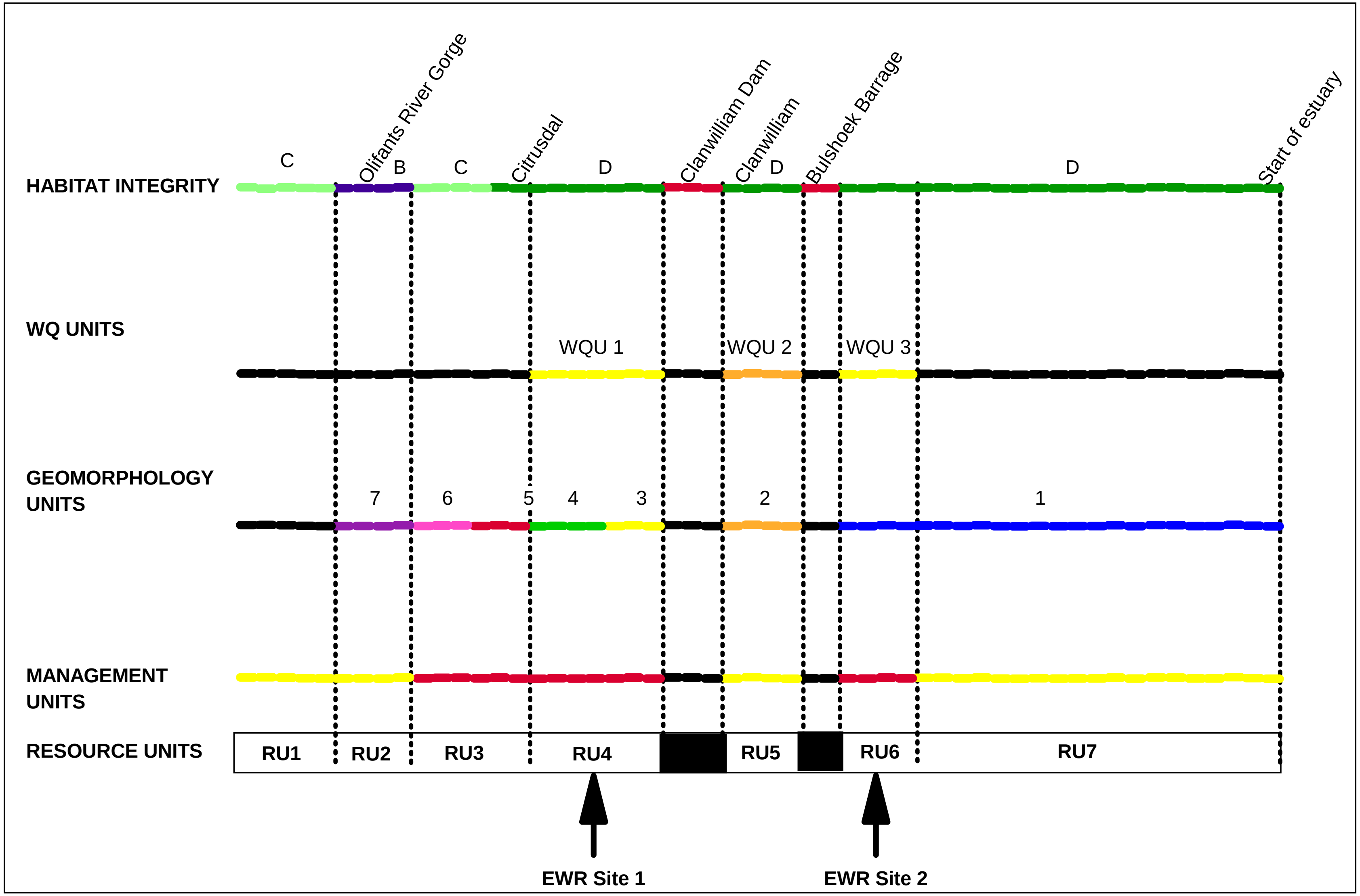

Figure 7.1 Summary of each of the different river reach delineations given for the mainstem of the Olifants River in this report.

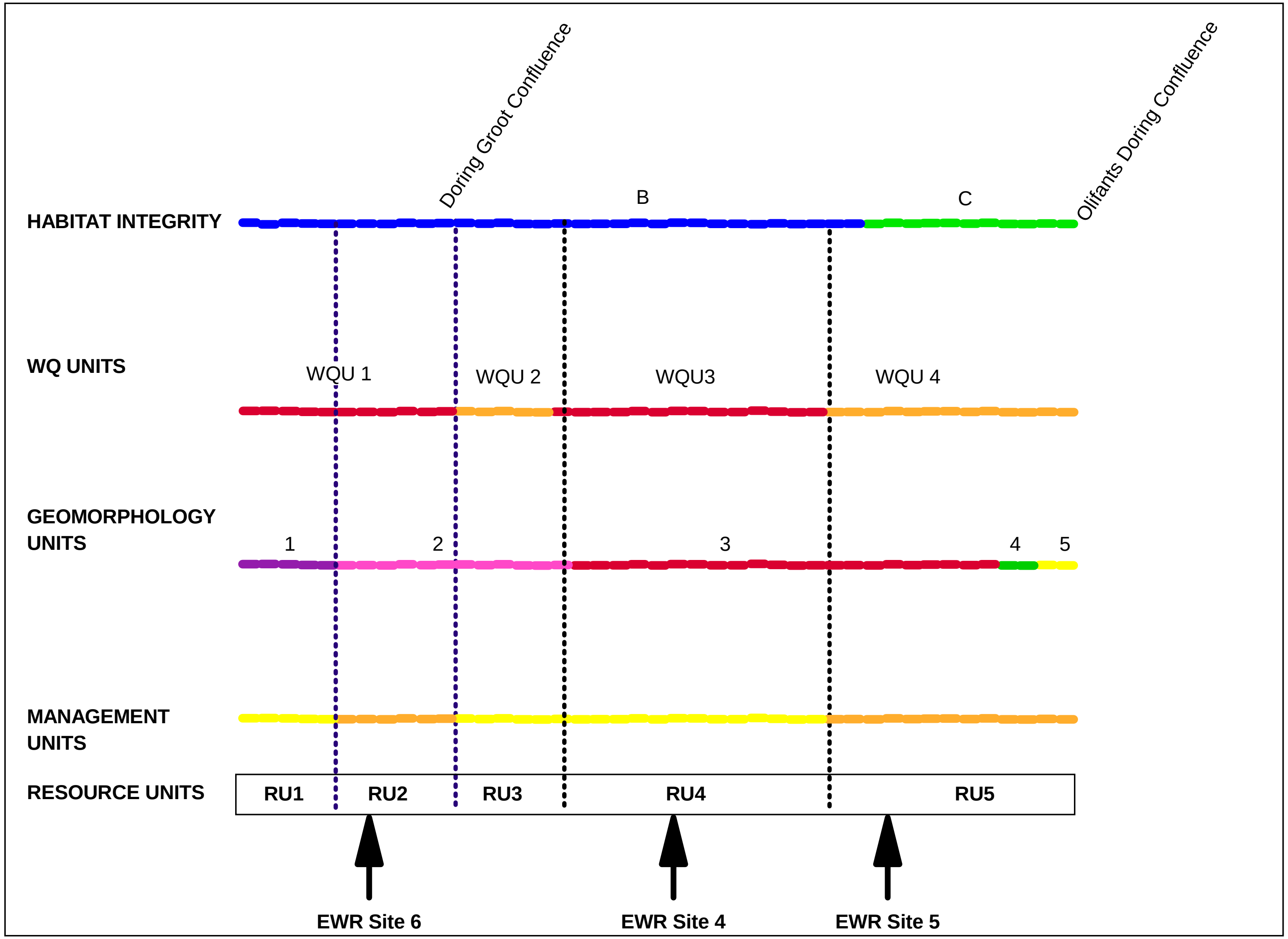

Figure 7.2 Summary of each of the different river reach delineations given for the mainstem of the Doring River in this report[4].

[4] Note: Since the Groot River provides the bulk of the water to the Doring River, we have followed the Groot River upstream.

OLIFANTS RIVER

Olifants RU1: Kouebokkeveld.
Olifants RU2: Olifants River Gorge.
Olifants RU3: Olifants River Gorge to Citrusdal.
Olifants RU4: Citrusdal to Clanwilliam Dam.
Olifants RU5: Clanwilliam Dam to Bulshoek Barrage.
Olifants RU6: Bulshoek Barrage to the confluence with the Doring River.
Olifants RU7: The confluence with the Doring River to the estuary.

DORING RIVER

Doring RU1: Kouebokkeveld.
Doring RU2: Groot River Gorge.
Doring RU3: Groot/Doring River Confluence to Tankwa/Doring River Confluence.
Doring RU4: Tankwa/Doring River Confluence to Doringbos.
Doring RU5: Doringbos to Olifants/Doring River Confluence.

RONDEGAT RIVER

The Rondegat River was also included as a tributary for which EWR assessment data could be extrapolated to the Huis, Hex, Jan Dissels – and because of the four the Rondegat River is in the best ecological condition.

GROOT RIVER

The Groot River is included in the RUs delineated for the Doring River. It was also included as a tributary for which EWR assessment data could be extrapolated to the Riet, Matjies and possibly Tra-Tra Rivers.

7.3 PRIORITISATION OF THE RESOURCE UNITS

As only six EWR sites will be considered in the Olifants/Doring Comprehensive Reserve Determination (i.e., considerably fewer than the number of Resource Units delineated), the Resource Units were priorities to aid in EWR site selection. Tables 7.1 and 7.2 give the prioritisation of each of the identified Resource Units, for the Olifants and Doring Rivers, respectively, plus some comment on the need/desirability for locating one of the six EWR sites in that Resource Unit.

Consideration was also given to the position of existing and potential regulatory structures, including points of abstraction or return flows, and river reaches where DWAF expected pressure in terms of license applications (PMC Committee, pers. comm.).

7.3.1 Concerns with respect to the omission of key resource units

The PMC Steering Committee has repeatedly expressed its concern that the Kouebokkeveld rivers, and the key downstream reaches, e.g., the Olifants River Gorge, have not been prioritised for EWR site selection as there has been considerable development leading to many licence applications in the region. It is clear from the prioritisation above that the Kouebokkeveld would have been a target area had the scope of the study allowed for more than six EWR sites. Key locations for these sites would be on the Riet or Leeu Rivers.

Table 7.1 Prioritisation of the Resource Units on the Olifants River.

Priority	Resource Unit #	Reason
1	Olifants RU 6: Bulshoek Barrage to the confluence with the Doring River.	The resource unit is key in terms of determining environmental water releases from Clanwilliam Dam (i.e., spills from Bulshoek Barrage). At present no environmental releases are made from these structures, and although Bulshoek Barrage has leaked in the past, these leaks are under repair. EWR Site 2 is situated in this RU.
2	Olifants RU 4: Citrusdal to Clanwilliam Dam.	DWAF specifically requested that an EWR Site be located in this reach as it is a priority reach for them in terms of water resource management (see PMC Meeting # 1 Minutes). EWR Site 1 is situated in this RU.
3	Olifants RU 2: Olifants River Gorge	See discussion in Section 7.6.1.
4	Olifants RU 1: Kouebokkeveld	
5	Olifants RU 7: The confluence with the Doring River to the estuary.	This unit is in relatively poor condition (Figure 7.1), and the ecological water requirements for this units will be 'driven' by the requirements of the estuary. For this reason it was deemed unnecessary to locate an EWR site here. Furthermore, it is likely that the EWRs for the sites on the Olifants and Doring Rivers immediately upstream of their confluence with one another will be higher than the EWR for the river in RU 8.
6	Olifants RU 3: Olifants River Gorge to Citrusdal	EWR requirements will be dictated by RU 3 (EWR Site 1).
7	Olifants RU 5: Clanwilliam Dam to Bulshoek Barrage	EWR requirements will be dictated by RU 6 (EWR Site 2).

Table 7.2 Prioritisation of the Resource Units on the Doring River.

Priority	Resource Unit #	Reason
1	Doring RU 2: Groot River Gorge.	The resource unit is key in terms of determining environmental water releases from farm dams in the Kouebokkeveld. It can also be used to extrapolate to the Riet and Matjies Rivers. EWR Site 6 is situated in this RU.
2	Doring RU 5: Doringbos to Olifants/Doring River Confluence.	The resource unit is key in terms of determining the environmental water contributions from the Doring River to the estuary and lower Olifants River. It is also the reach that would determine EWRs from the proposed Melkboom Dam and/or Weir. EWR Site 5 is situated in this RU.
3	Doring RU 4: Tankwa/Doring River Confluence to Doringbos	The resource unit is key as it is the RU where the influence of the Tankwa River and the other Karoo tributaries is most felt. This influence is extremely important given the past proposals for dams to capture the freshwater supply from the Groot River (e.g. the proposed Aspoort Dam) as changes in water quality could be extreme where this to happen. EWR Site 4 is situated in this RU.
4	Doring RU 1: Kouebokkeveld	See discussion in Section 7.6.1. Although partially covered by EWR Site 6, there is clearly a need for more attention to be paid to the Koebokkevled Rivers.
5	Doring RU 3: Groot/Doring River Confluence to Tankwa/Doring River Confluence.	EWR requirements will be dictated by RU 3 (EWR Site 4).

8 EWR SITES: RIVER QUANTITY DETERMINATION

8.1 WHY SELECT EWR SITES?

The river water quantity determinations that are required as part of the ecological Reserve determination require descriptions of flow characteristics at a site, such as depth and velocity, linked to habitat requirements for key biota at that site. Flows are converted to depth and velocity by means of stage-discharge curves for specific cross-sections determined by a hydraulic modelling procedure. Usually, one or more cross-sections are selected at each of a series of representative sites along a river. These sites are referred to as EWR Sites. To facilitate determination of the consequences for the riverine ecosystem of changes in flow, and thus changes in parameters such as depth or velocity, such EWR sites should ideally meet many criteria, the most important being that the sites should represent critical and varied habitats. Other criteria include:

- they should provide as much information as possible about the variety of conditions in a river reach;
- the habitats/characteristics should provide opportunity for as many specialists as possible to provide input to the EWR determination;
- they should allow for accurate hydraulic measurements and computations.

More than one IFR site is usually selected within the system for a number of reasons:

- tributaries entering the system may introduce different channel, bank and/or habitat conditions which may need to be considered separately (see Section 6: Geomorphological Reach Classification);
- the ecological condition and thus recommended Ecological Category of reaches may differ from one another;
- a single EWR site is unlikely to adequately reflect the range of biological diversity along the length of a river;
- various hydrological stage points are required within the system to cater for the inflows of tributaries and losses down the length of the system.

8.1.1 Number of EWR Sites

Confidence in the final ecological flow assessments/determinations is related to, among other factors, the number of EWR sites representing a river reach, and the suitability of these sites for hydraulic calibration and the habitats represented by them.

DWAF (1999) suggest that, for a Comprehensive Reserve determination, four EWR sites, selected correctly, will normally cater for a river length of 100 - 200 km. However, the number of EWR sites influences the cost and time required for the study and, in this study (as is often the case), site number was dictated by financial considerations. The total number of sites for the study was limited to six, with two of these being on key tributaries. ***This equated to approximately two sites EWR sites per 200 km of river.*** This meant that the priority assigned to the different RUs became one of the most important determining factors (see Section 7.2), and from the start site selection concentrated ONLY on priority RUs (see Section 6.3).

8.2 SELECTION OF EWR SITES

8.2.1 Site selection

The selection of EWR sites should be guided by consideration of the following criteria (from DWAF 1999)[5]:

- The locality of priority RUs.
- The locality of gauging weirs with good quality hydrological data.

[5] The criteria in boldface are the most important.

- The locality of the proposed and existing developments.
- The locality and characteristics of tributaries.
- The habitat integrity of the different river reaches.
- The boundaries of Level II ecotypes within the study area.
- The reaches where social communities depend on a healthy river ecosystem.
- The suitability of the sites for follow-up monitoring.
- **The habitat diversity for aquatic organisms, marginal and riparian vegetation.**
- **The suitability of the sites for accurate hydraulic modelling throughout the range of possible flows, especially low flows.**
- **Accessibility to the sites.**
- **An area or site that could be critical for ecosystem functioning. These are often represented by riffle units, where low flow conditions or the cessation of flow constitutes a break in the functioning of the river. Pools are not usually considered critical habitats in perennial system (Louw and Birkhead 1998).**
- The locality of geomorphologically representative sites.

8.2.2 Site selection team

The people who were involved in selecting the sites for this study are experienced in the use of EWR sites in Reserve determinations. The site selection team comprised:

Dr Cate Brown	Project Leader and River Task Team Leader
Mr Charles Pemberton	Deputy Project Leader and Deputy River Task Team Leader
Mr Rodney February	Deputy Water Quality Task Leader
Dr Andrew Birkhead	Hydraulic engineer
Dr Evan Dollar	Geomorphologist
Dr Charlie Boucher	Botanist
Mr John Kereko	Assistant botanist
Ms Geordie Ractliffe	Invertebrate specialist
Mr Bruce Paxton	Fish specialist
Ms Toni Belcher	DWAF Study Manager.

Site selection took place on 24, 25 and 26 November 2003. Flow in the rivers at the time of site selection was low but, importantly, the seasonal Doring River was still flowing. The weather was excellent, and several alternative sites were visited in each river reach before an EWR site was finally selected.

8.2.3 Placing of cross-sections at selected EWR sites

The positions of the cross-sections at each EWR site were determined through discussion with the site selection team. In some cases more than one cross-section was required for use by different disciplines, and the cross-sections selected at each site are clearly indicated in Section 8.4. Where appropriate, non-hydraulic information was also collected for each cross-section, this included riparian vegetation zones, instream habitat types and substratum types. Hydraulic benchmarks (BM) were surveyed in for each cross-section and labelled with a unique number comprised of the EWR site and cross-section number.

8.2.4 Evaluating the EWR sites for suitability for three-dimensional habitat modelling

The site selection team evaluated each of the EWR sites in terms of their suitability for hydraulic modelling. However none were deemed suitable, as they were too complex to allow cost-effective modelling using presently-available tools, i.e., the cost of modelling the sites would not improve confidence to the level that would warrant the additional expenditure. In the absence of habitat modelling, changes in habitat availability will be recorded using fixed-point and close up photographs taken at different discharges, in addition to the hydraulic information for the selected cross-sections.

8.2.5 Fixed-point photography locations

Following discussion between members of the site selection team, the positions for fixed-point photographic records were decided upon and recorded in terms of their GPS coordinates and the required direction of shot. Fixed-point photographs will be taken at different discharges and collated into a file for the EWR Workshop.

8.3 CHARACTERISTICS OF SELECTED EWR SITES

Table 8.1 and Figure 8.1 provide the locations of each of the six EWR site selected. See also Annexure A for more detailed map locations.

Table 8.1 Locations of each of the six EWR site selected.

Site No.	River	Site Name	Description	Latitude	Longitude
1a 1b	Olifants	Olifants at Hex River	N7 downstream of the confluence with the Hex River.	32°26.764 32°26.680	18°57.601 18°57.504
2	Olifants	Olifants at Alwynskop	Downstream of Bulshoek Barrage, just downstream of Cascade Pools.	31°57.974	18°44.463
3a 3b	Rondegat	Rondegat at Algeria	Upstream of the Algeria staff accommodation, on the road between Algeria and Clanwilliam.	32°21.760 32°21.739	19°02.618 19°02.593
4a 4b	Doring	Doring at Biedou	On the Doring mainstem, immediately upstream of the confluence with the Biedou River	32°02.410 32°02.416	19°24.896 19°24.783
5	Doring	Doring at Oudrif	At Oudrif.	31°51.446	18°54.754
6a 6b	Groot	Groot at Mount Cedar	Upstream of the bridge at Groot Rivier.	32°39.552 32°39.377	19°23.786 19°23.982

8.3.1 EWR Site 1 - Olifants at Hex River

Coordinates : S 32°26.764; E 18°57.601.

Locality : Adjacent to the N7 downstream of Citrusdal and upstream of the confluence with the Hex River.

Hydrology: There is no DWAF gauging weir but flows in the river can be determined from Clanwilliam Dam.

Access: From a layby on the N7. Permission to work the site has been obtained from the owner, Mr Visser, at Hex Rivier.

Cross-sections: Two cross-sections were selected at EWR Site 1 (Figure 8.2). These were:
CS 1a: Across a riffle.
CS 1b: Across a pool section.

Photographs: See Annexure E.

EWR SITE 1: GENERAL SITE DESCRIPTION

The plan layout of EWR Site 1 is provided in Figure 8.2. The top portion of the site near Transect 1a is composed of shallow riffle and run habitat, overlying small to medium sized cobbles. This cobble bed section is uncharacteristic of the reach. The banks in this section are relatively steep, and appear to have been bulldozed. They are composed of large cobbles and boulders, interspersed with patches of palmiet, with light infestation of *Eucalyptus* and *Acacia saligna* at the tops of the banks. The lower portion of the site (Transect 1b) is a sand bed river and is bound by sandbanks and dense stands of palmiet on the right bank, and a steep bulldozed boulder bank (supporting the N7) on the left. This lower section of the site consists of deep sandy runs and pools, which are characteristic of this reach of the Olifants River. The site is approximately 250 m in length.

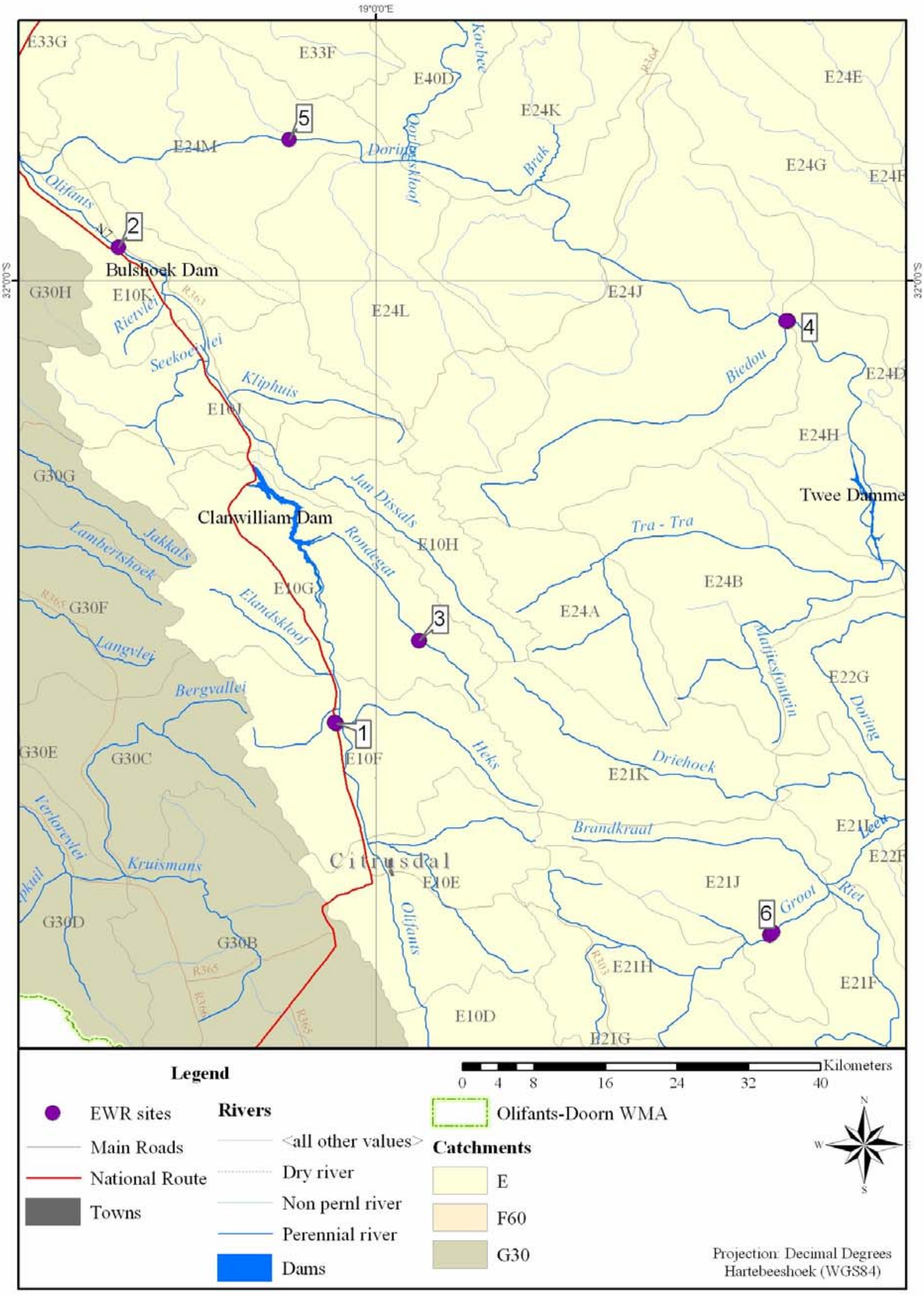

Figure 8.1 Map of the study area showing the location of the six EWR sites.

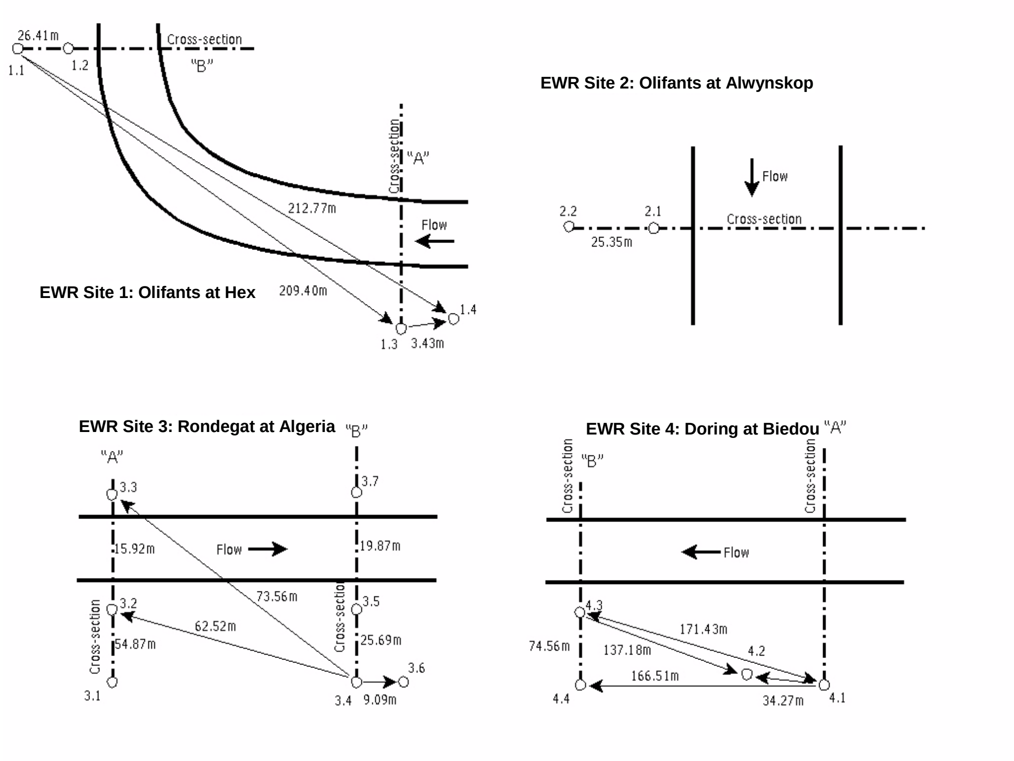

Figure 8.2 Plan layouts for EWR Sites 1-4.

Discipline-specific comments on EWR Site 1 are provided in Table 8.2, and the coordinates for the fixed-point photography positions are provided in Table 8.3.

Table 8.2 Discipline specific comments on EWR Site 1.

Discipline	Sect.	Advantages	Disadvantages
Hydrology	a & b	Some hydrological information available from Clanwilliam Dam.	No gauging weir near to the site. See Section 8.4.1.
Hydraulics[6]	a & b	Reasonably extensive riffle feature (approx. 50m in length).	Riffle and pool cross-sections located upstream and downstream of river bend, respectively. Non-horizontal water surface across the riffle section. Resistance difficult to estimate at high flows due to influence of levees (artificial bank modification) and trees on banks. Bank modification likely to produce complex flow patterns when overtopped during flooding. Stage of zero discharge difficult to determine for downstream pool section due to influence of palmiet constricting flow in the downstream channel.
Geomorphology	a	Representative of riffles of pool-riffle channel types for macro-reach 3. In-channel active bench for pinning flows to.	Engineered channel. Embedded riffle, but may be temporary.
	b	Representative of riffles of pool-riffle channel types for macro-reach 3. In-channel features for pinning flows to.	Engineered channel.
Botany	a	The Wetbank vegetation has recovered to some degree from river manipulation and is in an acceptable condition for the determination of low flow conditions. The riffle habitat is currently being invaded by riparian vegetation, which is thought to be related to the current dry climatic cycle being experienced aided by considerable water abstraction for irrigation. This will aid with description of consequences of river flow reductions.	The Drybank vegetation is not acceptable for flow determinations. Extensive disturbance by levee building have disrupted the Drybank plant communities in particular. *Acacia saligna* has invaded parts of the Drybank and has recently been burnt. Large *Eucalyptus sp.* individuals are present on the LB. The Back Dynamic Lateral Zone is tending to characteristics of non-riparian terrestrial vegetation.
	b	1b offers more opportunities than 1a for a flow assessment. *Prionium serratum* clumps in the pool appear to be enlarging, which is associated with lower flows in a dry cycle. The RB has back channels that carry water during flood events. The developing vegetation is in an acceptable condition to assess high flow volumes.	The LB (outside of bend) is dominated by a sandstone rock sill that limits the development of lateral vegetation zones because the soil is shallow. A fire has burnt the area in the recent past. Burnt *A. saligna* skeletons are common (but see advantages).
Invertebrate ecology	a & b	Good range of biotopes, with some that are sensitive to flow changes. Submerged moss biotope may be a good indicator of minimum summer baseflows	Water quality impacts on invertebrates.
Fish ecology	a & b	Presence of a cobble-bed riffle suitable for Clanwilliam yellowfish spawning. Presence of a deep pool suitable as adult habitat	Invasive species present. The river is heavily regulated here and may not reflect reference conditions for fish habitat. Few data are available on indigenous fish populations at this site.
Safety	EWR Site 1 is easily visible from the N7, and this significantly increases the risk of trouble from criminal elements. All specialists and their assistants will be urged to visit the site in pairs, at a minimum.		

[6] Dr Birkhead makes the point that a concrete channel would be the most advantageous channel for hydraulic measurements! Hydraulic measurements for EWRs tend, however, to concentrate on more natural river systems, which are far more difficult to calibrate. Hence the preponderance of disadvantages listed for each site.

Table 8.3 Fixed-point photography positions for EWR Site 1.

Position No.	Subject	Latitude	Longitude
EWR 1.1	Looking across 1a from RB.	S	E
EWR 1.2	Looking upstream of 1a from RB.	S	E
EWR 1.3	Looking downstream of 1a from RB.	S	E
EWR 1.4	Submerged moss in pool downstream of 1a.	S	E
EWR 1.5	Submerged moss in pool downstream of 1a.	S	E
EWR 1.6	Looking across 1b from RB.	S	E
EWR 1.7	Looking downstream of 1b from RB.	S	E
EWR 1.8	Upstream of 1b.	S	E
EWR 1.9	Upstream of 1b.	S	E

8.3.2 EWR Site 2 - Olifants at Alwynskop

Coordinates : S 31°57.974; E 18°44.463

Locality :	Downstream of Bulshoek Barrage, just downstream of Cascade Pools. Key obtainable from the owner at Cascade Pools.
Hydrology:	There is no DWAF gauging weir but flows in the river can be determined from Bulshoek Barrage.
Access:	Through a farm gate off the Clanwilliam/Klawer dirt road. The key for the gate is obtainable from the owner (Mr Worsie Lamprechts) at Cascade Pools. Permission to work the site has been obtained from the owner at Cascade Pools.
Cross-sections:	One cross-section was selected at EWR Site 2 (Figure 8.2). This was: CS 2a: Across the pool/run.
Photographs:	See Annexure E.

EWR SITE 2: GENERAL SITE DESCRIPTION

The plan layout of EWR Site 2 is provided in Figure 8.2. EWR Site 2 is a slow flowing pool section of the lower Olifants River located downstream of the rapids known as Cascade Pools, below Bulshoek Barrage. The site consists of a single deep (+- 6 m), wide (+- 60 m) channel. The site length is approximately 100 m, and the bed is comprised of embedded cobbles in sand and silt. Emergent vegetation on the margins of the river is composed of inundated grasses and patches of Palmiet and *Phragmites*. Floating macrophytes are also present along the river margins in backwater areas.

Discipline-specific comments on EWR Site 2 are provided in Table 8.4, and the coordinates for the fixed-point photography positions are provided in Table 8.5. Several specialists commented on the fact that the site did not have rocky substrate, despite this being present in the reach. The site selection team spent a considerable length of time trying to find a suitable site where there was rocky substrate but encountered the following problems:

- The rocky stretches were too hydraulically complex for the required modelling of cross-sections. The complexity would have significantly reduced the accuracy of any modelling, and returned an extremely low confidence.
- The repair work on Bulshoek Barrage had resulted in an algal bloom in the river, which at the time of sampling extended to Cascade Pools and was still moving downstream.

Given the hydraulic and water quality problems associated with the more upstream reaches, it was decided to select the site at Alwynskop, where at least some information would be available to determine the ecological water requirements.

Table 8.4 Discipline specific comments on EWR Site 2.

Discipline	Cross-section	Advantages	Disadvantages
Hydrology	a	Some hydrological information available from Clanwilliam Dam.	No gauging weir near to the site. See Section 8.4.1.
Hydraulics	a	Uniform flow conditions along river reach.	Difficult to measure flows due to depth (max. depth of 4.6 m at 0.2m^{3} s^{-1}). Depth and velocity insensitive to changes in flow at low discharges.
Geomorphology	a	Partially representative of anabranching channels for macro-reach 4. In-channel active bench for pinning flows to.	Engineered channel on left bank. Below Bulshoek Barrage, therefore likely to be incised, sediment starved and therefore modified. Not fully representative of anabranching channels for macro-reach 4.
Botany	a	Changes in the Wetbank riparian vegetation indicates tendencies to increased salinity levels. Unusually the Drybank has *A. karoo* trees growing on it that indicate that the Doring River may push back into the Olifants River when it floods. This would account for increased salinity levels and silt loads.	None given.
Invertebrate ecology	a	Fairly diverse emergent marginal vegetation; long pool represents most of the reach.	No rocky substratum-biotopes, despite being present in the reach. High water quality impacts on invertebrates – low biodiversity. Limited sensitivity to flow changes.
Fish ecology	a	Long deep run, suitable habitat for adult Clanwilliam yellowfish. Fish surveys have been carried out in these reaches – information on fish community composition.	Absence of hydraulic controls, unable to evaluate the consequences for spawning fish. The reach is heavily regulated and does not reflect reference conditions for fish habitat.
Safety	EWR Site 2 is relatively safe from criminal elements. It is also unnecessary to cross the river and all survey points are easily accessible.		

Table 8.5 Fixed-point photography positions for EWR Site 2.

Position No.	**Subject**	**Latitude**	**Longitude**
EWR 2.1	Looking downstream from BM 2.2 (at back).	S31.96598	E18.74137
EWR 2.2	Looking upstream from BM 2.2.	S31.96598	E18.74137
EWR 2.3	Looking across 2a from BM 2.2.	S31.96598	E18.74137
EWR 2.4	Emergent vegetation upstream of 2a.		
EWR 2.5	Emergent reeds and *Phragmites* upstream of 2a.		
EWR 2.6	Looking across 2a from BM 2.1.	S31.96618	E18.74109

8.3.3 EWR Site 3 - Rondegat at Algeria

Coordinates : S 32°21.760; E 19°02.618

Locality : Upstream of the Algeria staff accommodation, on the road between Algeria and Clanwilliam Dam.

Hydrology: There is no DWAF gauging weir.

Access: Take the dirt road at the cemetery on the Algeria/Clanwilliam road, on the Clanwilliam side of the bridge across the river.

Cross-sections: Two cross-sections were selected at EWR Site 3 (Figure 8.2).
CS 3a: Across a pool/run.
CS 3b: Across a riffle/cascade.

Photographs: See Annexure E.

EWR SITE 3: GENERAL SITE DESCRIPTION

The plan layout of EWR Site 3 is provided in Figure 8.2. EWR Site 3 has a relatively steep gradient and is made up of a narrow channel forming a pool/rapid sequence. The top portion of the site (Transect 3a) consists of a shallow pool with cobble/boulder bed interspersed with sand. The lower portion of the site (Transect 3b) consists of a series of shallow runs and riffles over small and medium cobbles. *Isolepis* is present on the river margins and in the instream areas of slower flow. Riparian vegetation is made up of dense stands of trees and shrubs. The channel varies in width from 1.5 – 3 m, and the site is approximately 60 m long.

Discipline-specific comments on EWR Site 3 are provided in Table 8.6, and the coordinates for the fixed-point photography positions are provided in Table 8.7.

Table 8.6 Discipline specific comments on EWR Site 3.

Discipline	Cross-section	Advantages	Disadvantages
Hydrology	a & b	None given.	No gauging weir near to the site.
Hydraulics	a & b	None given.	Non-uniform flow conditions in pool-step channel type morphology with multiple channels. Difficult to measure discharge and estimate flow resistance when active low-flow channel is overtopped due to multiple channels and densely vegetated river banks.
Geomorphology	a & b	Representative of many higher order tributaries in Western Cape rivers with a step-pool system. Largely undisturbed. Vegetation, sediment, hydraulics interaction very important in active channel. In-channel active bench for pinning flows to. Number of terraces (paired) for pinning higher flow requirements to.	Sediment transport modelling does not account for widespread in-channel vegetation.
Botany	a & b	The Wetbank vegetation is in a suitable condition for lower flow assessments.	The Drybank has been disturbed by agriculture in the past (benches for tilling and crop planting have been cut on both banks). Alien plant control has been practiced here, and past density of infestations is know known. Numerous seedlings of *A. melanoxylon* are present.
Invertebrate ecology	a & b	Good range of biotopes, with some sensitive to flow changes. Stream fauna reflects natural conditions.	
Fish ecology	a & b	Invasive species absent. Habitat for fiery and Clanwilliam minnow, as Clanwilliam yellowfish and rock catlet. Research on native and non-native fish species is ongoing in this river.	No deep pools suitable as habitat for large adult Clanwilliam yellowfish.
Safety	EWR Site 3 is relatively safe from criminal elements. There is however some danger associated with crossing the river to reach the survey point for 3a, especially if the discharge is high. All specialists and their assistants will be urged to visit the site in pairs, at a minimum. All specialists and their assistants will be urged to visit the site in pairs, at a minimum.		

Table 8.7 Fixed-point photography positions for EWR Site 3.

Position No.	Subject	Latitude	Longitude
EWR 3.1	Looking downstream from BM 3.3, showing hydraulic habitat 1.	S32.36276	E19.04365
EWR 3.2	Looking across 3a from BM 3.3.	S32.36276	E19.04365
EWR 3.3	Looking upstream from BM 3.3.	S32.36276	E19.04365
EWR 3.4	Looking upstream from backwater on RB.	S32.36275	E19.04364
EWR 3.5	Close-up of hydraulic habitat 1 from Point 3.4.	S32.36275	E19.04364
EWR 3.6	Looking upstream from large rock in the middle of the river.		
EWR 3.7	Looking across at step upstream of 3b.	S32.36236	E19.04326
EWR 3.8	Looking across 3b.	S32.36236	E19.04326
EWR 3.9	Looking downstream from 3b.	S32.36236	E19.04326
EWR 3.10	Large rock in the middle of the river.	S32.36236	E19.04326

8.3.4 EWR Site 4 - Doring at Biedou

Coordinates : S 32°02.410; E 19°24.896

Locality : On the Doring River, immediately upstream of the confluence with the Biedou River.

Hydrology: There is no DWAF gauging weir.

Access: The site can be accessed through a farm gate on the right hand site of the Biedou Valley road just before the Doring River crossing. The farm road follows the river upstream for about 500 m, before petering out. The site is immediately ahead at the end of the road.

Cross-sections: Two cross-sections were selected at EWR Site 4 (Figure 8.2). These was:
CS 4a: Across the pool habitat near the caves.
CS 4b: Across the rapid/riffle downstream of the pool.

Photographs: See Annexure E.

EWR SITE 4: GENERAL SITE DESCRIPTION

EWR Site 4 is bordered by a steep rocky outcrop on the right bank, and a low gradient sandy/boulder bank on the left. *Acacia karoo* and *Oleander* sp. dominate the riparian vegetation, with bands of *Phragmites* sp. occurring along the sandy banks. Transect 4a traverses a pool in the top portion of the site. The pool bed is comprised of mixed cobbles and boulders, with patches of bedrock and sandy margins. The pool exits into a rapid/riffle section (Transect 4b) made up of large cobbles and boulders. Backwater areas above the riffle consist of small to medium cobbles, which are covered in algae and interspersed with silt. The site is approximately 170 m long.

The plan layout of EWR Site 4 is provided in Figure 8.2.

Discipline-specific comments on EWR Site 4 are provided in Table 8.8, and the coordinates for the fixed-point photography positions are provided in Table 8.9.

Table 8.8 Discipline specific comments on EWR Site 4.

Discipline	Sect.	Advantages	Disadvantages
Hydrology	a & b	DWAF gauging weir at Melkboom.	No gauging weir near to the site.
Hydraulics	a & b	Reasonably uniform flow conditions.	Short riffle feature (approx. 20m in length) consisting predominantly of cobble and boulder-sized sediments. Riffle feature likely to become drowned-out at reasonably low flows.
Geomorphology	a	Representative of pool-riffle/rapid channel types for macro-reach 4. Strong bedrock influence - representative of macro-reach. In-channel active bench for pinning flows to, but disturbed so questionable reliability.	Disturbed active channel and banks.
	b	Representative of pool-riffle/rapid channel types for macro-reach 4. In-channel active bench for pinning flows to. Number of terraces (paired) for pinning higher flow requirements to.	Disturbed active channel and banks. In-channel vegetation resulting in potential directional change to bedrock core-bar.
Botany	a & b	A pool and a riffle habitat were selected for evaluation. Both the Drybank and the Wetbank vegetation have been negatively influenced by heavy grazing, yet enough vegetation remains to assess flow requirements of the river here.	The site is exposed to heavy grazing by goats, as are most sites in this area. *Nerium oleander*, a typical invasive of karroid rivers in the Fynbos Biome, is extensive here in the Wetbank Zone. *Acacia* karoo lining the Drybank Zone appears to be dying back, possibly because of a dry climatic cycle coupled with heavy grazing.
Invertebrate ecology	a & b	Diverse biotopes, including extensive cobble secondary channel that will provide good links between invertebrates and hydraulics at higher and low flows.	Riffle biotope almost all disappeared at time of summer sampling, which may have impacts on the completeness of species lists for the site. Marginal vegetation limited and impacted by grazing – negatively impacts on the natural extent of this biotope. Water quality impacts, especially sediment deposition.
Fish ecology	a & b	Fish surveys have been done in these reaches and there is information on species and size classes present. Pools provide habitat for Clanwilliam sandfish and these fish have been known to use these reaches for spawning.	Invasive species present. Pool is shallow, not deep enough for adult fish to over-summer.
Safety	EWR Site 4 is safe from criminal elements. It is also unnecessary to cross the river and all survey points are easily accessible. The substrate at 4b is however slippery and care is required to prevent falling when sampling in the river. All specialists and their assistants will be urged to visit the site in pairs, at a minimum.		

Table 8.9 Fixed-point photography positions for EWR Site 4.

Position No.	Subject	Latitude	Longitude
EWR 4.1	Habitat detail at 4b.	Not applicable.	
EWR 4.2	Habitat detail at 4b.		
EWR 4.3	Habitat detail at 4b.		
EWR 4.4	Habitat detail at 4b.		
EWR 4.5	Habitat detail at 4b.		
EWR 4.6	Looking downstream at 4b riffle.	S32.04034	E19.41283
EWR 4.7	Landscape shot across 4a.	S32.04020	E19.41423
EWR 4.8	Riffle above 4a.	S32.04018	E19.41441
EWR 4.9	Looking across 4a	S32.04020	E19.41423
EWR 4.10	Looking downstream at 4b.	S32.04029	E19.41429

8.3.5 EWR Site 5 - Doring at Oudrif

Coordinates : S31.51.446; E18.54.754.

Locality :	On the Doring River at Oudrif. The solar pump delimits the upstream extent of the site.
Access:	Direct access to the site from Oudrif Farm. Permission to work the site has been obtained from Mr Bill Mitchell at Oudrif Farm.
Hydrology:	The DWAF gauging weir at Melkboom is c. 20 km downstream of the site.
Cross-sections:	Two cross-sections were selected at EWR Site 5 (Figure 8.3). These were: CS 5a: Across the pool habitat. CS 5b: Across the riffle downstream of the pool.
Photographs:	See Annexure E.

EWR SITE 5: GENERAL SITE DESCRIPTION

The top section of the site near Transect 5a consists of a deep pool, bound by a rocky outcrop on the right bank, and steep boulder/sandbank on the left bank. The bed of the pool is comprised of boulders and bedrock, with sandy margins occurring in the backwater sections. A band of *Phragmites* sp. interspersed with *Isolepis* borders the lower portion of the pool. The bed in this section is comprised of medium to large cobbles. Submerged *Potamogeton* was present in the lower portion of the pool during the November fieldtrip. The pool is approximately 25 m wide and extends for roughly 270 m downstream from transect 5a. The river exits the pool via a riffle/rapid section made up of large cobbles and boulders. Transect 5b traverses this riffle/rapid section. The total length of the site is approximately 290 m.

The plan layout of EWR Site 5 is provided in Figure 8.3.

Discipline-specific comments on EWR Site 5 are provided in Table 8.10, and the coordinates for the fixed-point photography positions are provided in Table 8.11.

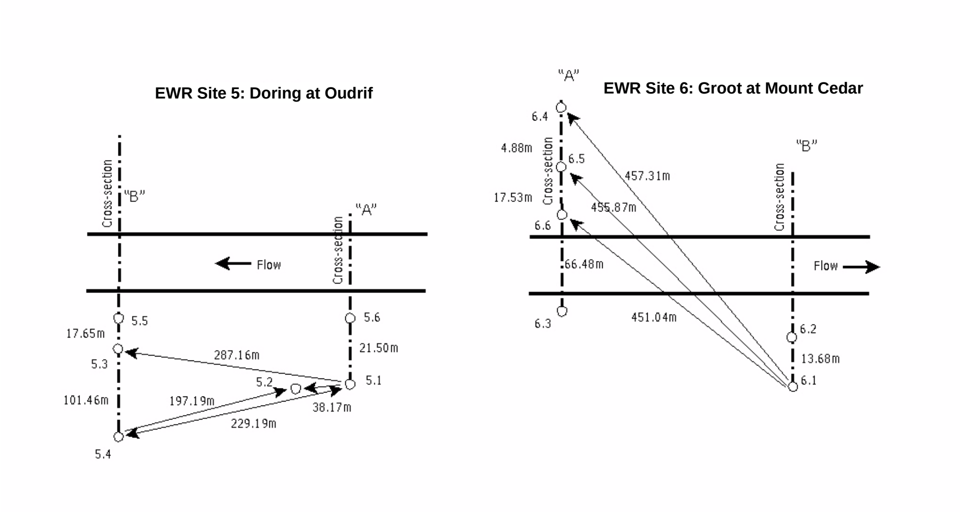

Figure 8.3 Plan layouts for EWR Sites 5 and 6.

Table 8.10 Discipline specific comments on EWR Site 5.

Discipline	Sect.	Advantages	Disadvantages
Hydrology	a & b	None given.	No gauging weir near to the site.
Hydraulics	a & b	None given.	Steep riffle feature (*c*. 40 m long) dominated by large sediments and it is difficult to estimate flow resistance. Riffle located at river bend with non-horizontal water surface.
Geomorphology	a	Representative of pool-riffle/rapid channel types for macro-reach 4. Strong bedrock influence - representative of macro-reach. Stable channel, only concern may be sedimentation of pool.	
	b	Representative of pool-riffle/rapid channel types for macro-reach 4. In-channel active bench for pinning flows to. Ancient RB terrace represents old river bed perched 5 m above present bed. Number of terraces (paired) for pinning higher flow requirements to.	
Botany	a	The vegetation is clearly influenced by sporadic dramatic flood events. Heavy scouring and large sand banks are present at the site. The vegetation is in a good natural condition here with little negative influence of stock grazing. The Drybank and Wetbank should give a good idea of the EWR for this part of the river.	
Invertebrate ecology	a & b	Good range of biotopes. Some biotopes sensitive to flow changes.	Riffle biotope almost disappeared at time of summer sampling, which may impact on the completeness of species lists for the site. Water quality impacts.
Fish ecology	a & b	Fish surveys have been carried out in these reaches – information on species and size classes present. Bedrock pools provide habitat for sawfin.	Invasive species present. Very deep pools, sampling difficult.
Safety	EWR Site 5 is safe from criminal elements. It is also unnecessary to cross the river and all survey points are easily accessible.		

Table 8.11 Fixed-point photography positions for EWR Site 5.

Position No.	Subject	Latitude	Longitude
EWR 5.1	Water level at 5a.	Not available.	
EWR 5.2	Looking across 5b from BM 5.5 (no zoom).	S31.858	E18.910
EWR 5.3	Looking across 5b (no zoom).	S31.85760	E18.90954
EWR 5.4	*Phragmites* from 5b line, RB.	S31.85760	E18.90954
EWR 5.5	Looking downstream from 5b.	S31.85760	E18.90954
EWR 5.6	Looking upstream from BM 5.5.	S31.858	E18.910
EWR 5.7	Looking upstream from BM 5.3.	S31.85761	E18.90957
EWR 5.8	Looking downstream from BM 5.3.	S31.85761	E18.90957
EWR 5.9	*Phragmites* root detail at 5b.	S31.85751	E18.90959
EWR 5.10	Looking across 5a from BM 5.1 (no zoom).	S31.85717	E18.91272
EWR 5.11	Looking up 5a from BM 5.1.	S31.85717	E18.91272
EWR 5.12	Looking down 5a from BM 5.1.	S31.85717	E18.91272
EWR 5.13	Looking upstream of 5a.	S31.85717	E18.91272
EWR 5.14	Looking downstream of 5a.	S31.85717	E18.91272
EWR 5.15	Looking up 5a from BM 5.6.	S31.85699	E18.91268
EWR 5.16	Looking downstream of 5a from BM 5.6.	S31.85699	E18.91268

8.3.6 EWR Site 6 - Groot at Mount Cedar

Coordinates : S 32°39.552; E 19°23.786.

Locality : Upstream of the bridge at Groot Rivier.

Hydrology: There is no DWAF gauging weir.

Access: Follow the Mount Cedar roads alongside the river upstream to as far as the road goes. The pool cross-section is situated slightly downstream of this point and the riffle is situated upstream of this point. Permission to work the site must be obtained from the manager at Mount Cedar at each visit.

Cross-sections: Two cross-sections were selected at EWR Site 6 (Figure 8.3). These were:
CS 6a: Across the riffle upstream of the pool
CS 6b: Across the pool habitat.

Photographs: See Annexure E.

EWR SITE 6: GENERAL SITE DESCRIPTION

EWR Site 6 is situated at the downstream end of a steep rocky gorge. The top portion of the site (Transect 6a) consists of a shallow riffle/rapid section with a mixed cobble/boulder bed. The river exits the riffle/rapid section into a long pool. The pool has a cobble/boulder bed interspersed with sandy deposits. Transect 6b is located through the pool section. There was some concern that the pool may be artificially backed-up but investigation downstream failed to indicate any weirs or dam walls. *Phragmites* and *Pennisetum* form part of the marginal vegetation in the pool. *Aponogeton* was also present at the time of the November fieldtrip. The shallow backwaters, in the top portion of the pool and riffle/rapid section, consisted of medium and large cobbles and sand, covered with rooted moss and algae. The total length of the site is roughly 400 m.

Discipline-specific comments on EWR Site 6 are provided in Table 8.12, and the coordinates for the fixed-point photography positions are provided in Table 8.13.

Table 8.12 Discipline specific comments on EWR Site 6.

Discipline	Sect.	Advantages	Disadvantages
Hydrology	a & b		No gauging weir near to the site.
Hydraulics	a & b		Riffle feature consists of predominantly cobble and boulder-sized sediments and therefore difficult to estimate flow resistance. Backing-up of downstream pool may drown-out riffle at reasonably low flows. Densely vegetated right bank with active channels (at *c.* 0.21 $m^3 s^{-1}$) and non-horizontal water surfaces. Stage of zero discharge difficult to determine for downstream pool section due to influence of palmiet constricting flow in the downstream channel.
Geomorphology	a	Representative of pool-riffle/rapid channel types for macro-reach 2. Strong bedrock influence and structural control - representative of macro-reach. Largely undisturbed. Highly mobile channel, high unit stream power, limited fines.	
	b	Representative of pool-riffle/rapid channel types for macro-reach 2. Strong bedrock influence and structural control - representative of macro-reach. Largely undisturbed and terraces can be used to pin high flows to.	
Botany	a	This vegetation is relatively lush because of the sustained year-round flows in the river. The LB is in good condition. This site generally has adequate indigenous vegetation with little exotic invasives, to provide a good indication of the flow requirements of this section of the river.	An irrigation canal constructed along the right bank diverts some of the flows from the river and has disrupted lateral zonation patterns.
Invertebrate ecology	a & b	Only rocky substrata at depths that allow for invertebrate sampling – useful for setting flow criteria and for monitoring change in biotope assemblages. Shallow riffle areas highly sensitive to lowflow changes.	Summer conditions affected by flow abstractions.
Fish ecology	a & b	Cobble-bed riffles provide potential spawning areas for native species. Large pool habitat for adult fish. Few local or upstream impacts.	Invasive species present Little information on the species present at this site.
Safety	EWR Site 6 is safe from criminal elements. There is however some danger associated with crossing the river, especially if the discharge is high. There is also some danger in reaching the survey position for 6a. All specialists and their assistants will be urged to visit the site in pairs, at a minimum.		

Table 8.13 Fixed-point photography positions for EWR Site 6.

Position No.	Subject	Latitude	Longitude
EWR 6.1	Riffle cross-section from BM 6.5.	S32.65909	E19.39615
EWR 6.2	Looking downstream from biggest rock on LB.	S32.65909	E19.39625
EWR 6.3	Looking across 6a from biggest rock on LB.	S32.65909	E19.39625
EWR 6.4	Looking upstream from biggest rock on LB.	S32.65909	E19.39625
EWR 6.5	Distributary pool # 1.	S32.65914	E19.39623
EWR 6.6	Hydraulic habitat 2 @ 6a.	S32.65918	E19.39626
EWR 6.7	Distributary pool # 2.	S32.65940	E19.39592
EWR 6.8	Distributary # 3 – opposite boulder balance on cliff on RB.	No GPS coverage	
EWR 6.9	Looking upstream of 6b from RB.	S32.65634	E19.39968
EWR 6.10	Looking across at 6b from RB.	S32.65634	E19.39968
EWR 6.11	Vegetation detail at 6b.	S32.65634	E19.39968

8.4 MONTHLY HYDROLOGY FOR EWR SITES

There is a paucity of functioning DWAF gauging weirs in the Olifants/Doring catchment, which makes both the estimation of mean annual runoff, and the provision of daily flow records for the EWR sites extremely difficult. While every effort will be made to provide the best hydrological information on which to base the environmental flow determinations, it is essential that those using the data are aware of the inherent shortcomings thereof.

The monthly flow data for the EWR sites on the Olifants/Doring River are simulated data sets that were constructed as part of the Olifants/Doring Basin Study (Basson *et al.* 1998), which modelled run-off in the rivers on a sub-catchment basis. The data were then adjusted to the EWR Sites by adding and subtracting sub-catchments.

The simulated monthly hydrological data for each EWR Site are provided in Annexure F. The summary statistics for the sites are provided in Table 8.14, and Figures 8.4 to 8.9.

Table 8.14 Simulated naturalised and present day runoff for EWR sites.

EWR Site	Naturalised MAR (MCM a^{-1})	Present Day MAR (MCM a^{-1})	Aspect of the flow regime most affected by development
EWR Site 1	320.23	276.52	Summer low flows; Dry season floods.
EWR Site 2	509.56	277.88	All, except very large floods.
EWR Site 3	7.67	7.45	Very little – mainly flood events.
EWR Site 4	417.22	317.84	Summer low flows.
EWR Site 5	507.16	398.28	Summer low flows.
EWR Site 6	120.33	92.78	Summer low flows.

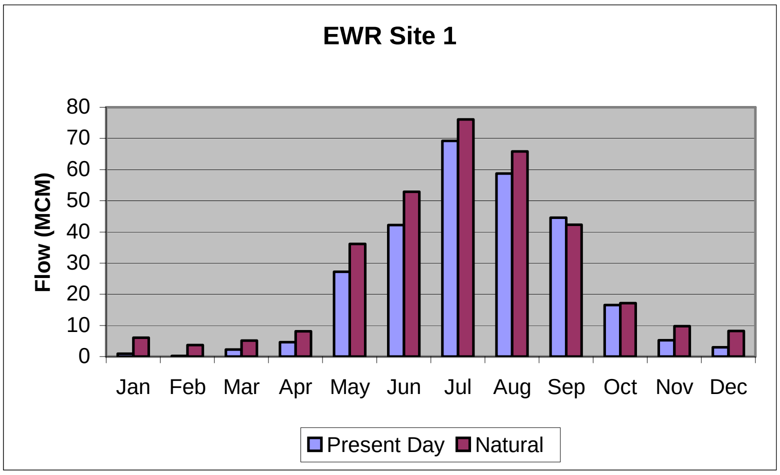

Figure 8.5 Summary monthly flows for present day and naturalised conditions at EWR 1.

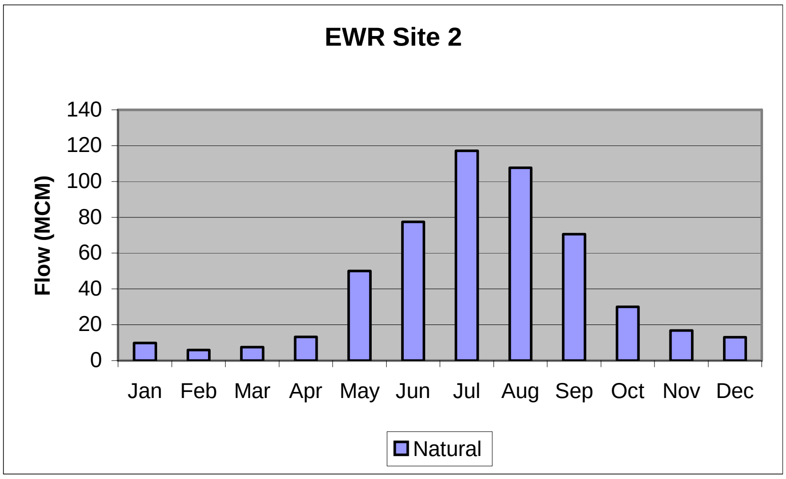

Figure 8.6 Summary monthly flows for naturalised conditions at EWR 2[7].

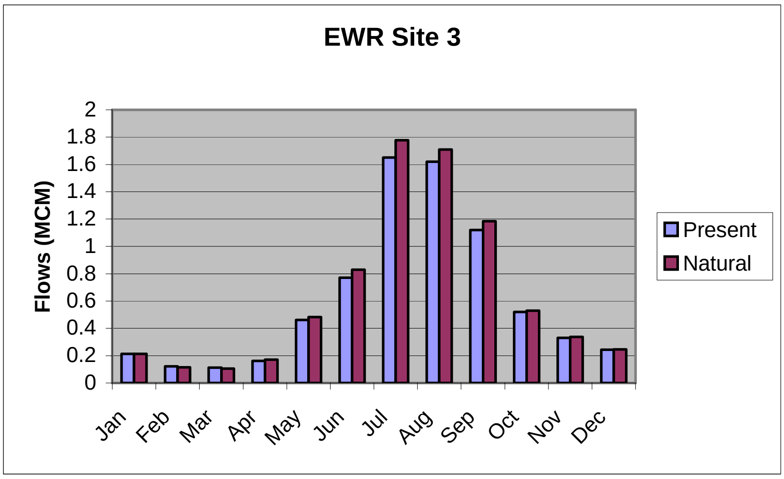

Figure 8.7 Summary monthly flows for present day and naturalised conditions at EWR 3.

[7] The summary data for present day flows at EWR Site 2 are presently not available.

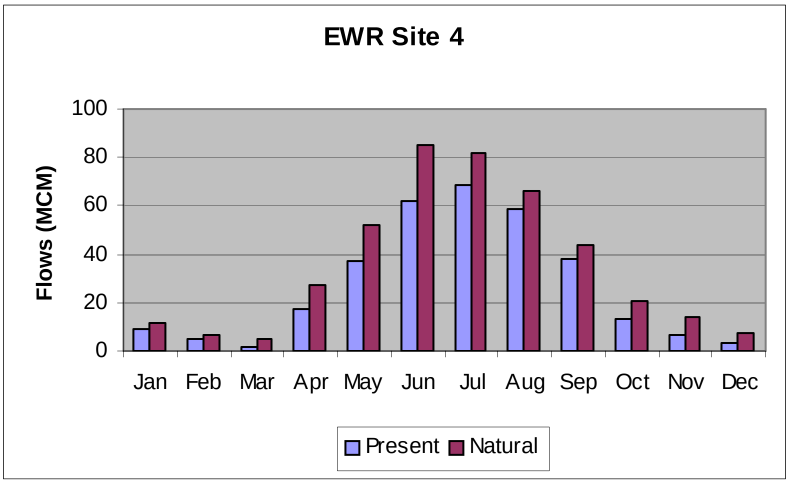

Figure 8.8 Summary monthly flows for present day and naturalised conditions at EWR 4.

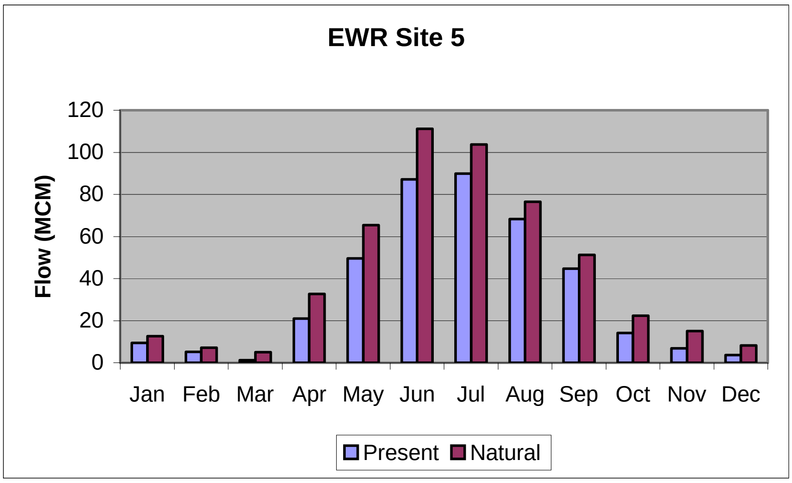

Figure 8.9 Summary monthly flows for present day and naturalised conditions at EWR 5.

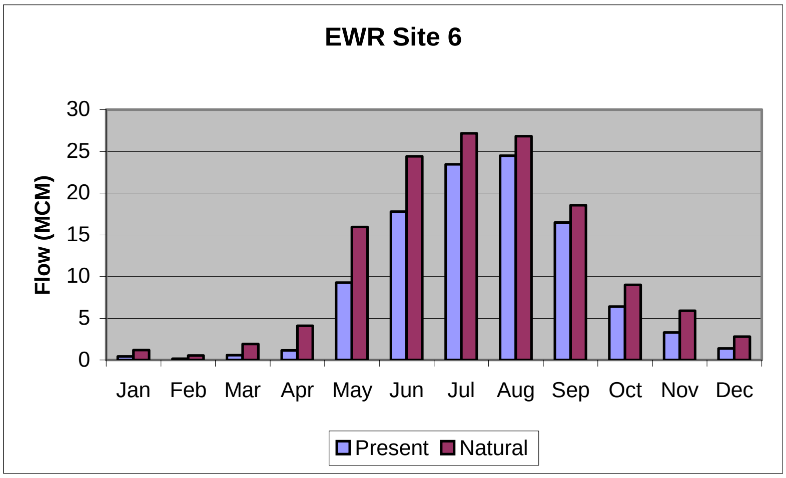

Figure 8.10 Summary monthly flows for present day and naturalised conditions at EWR 6.

8.4.1 *Pitfalls in the disaggregation of monthly data into daily flow sequences*[8]

The longest, most recent and most complete hydrological records are available from:

E2H007	Leeuw River at Leeurivier
E2H001	Doring River at Melkboom
E2H002	Doring River at Aspoort.
E2H010	Kruis River (tributary of the Riet River).

In the case of the sites in the Olifants River (EWR Sites 1 and 2) and Rondegat River (EWR Site 3), there are no long-term, run-of-river hydrological records for any locations in the catchment. Where, in the past, records were made of flows in the system, e.g., Keerom (E1H00), data collection was discontinued sometime in the late 1930s and early 1940s. The result is that there are no weirs in the catchment that can be used to disaggregate the simulated monthly flows for EWR Sites 1, 2 and 3 into daily flows. Thus the monthly flows need to be disaggregated using either 1) records from a similar catchment or 2) flow sequences cobbled together from various other records that are available for the catchment. After considerable discussion, the hydrological team has decided on the following approach:

EWR Site 1:	**Present-day:**	Disaggregation using inflows to Clanwilliam Dam backup from E2H007.
	Naturalised:	Disaggregation using E2H007 on the Groot River, with backup from G1H028, plus G1H058 on the Twenty-Fours River.
EWR Site 2:	**Present-day:**	Disaggregation using a combination of spills and releases from Clanwilliam Dam (E1R002); inflows from the Jan Dissels River (E1H006); flows down the irrigation canals from Bulshoek Barrage (E1H007).
	Naturalised:	Disaggregation using E2H007 on the Groot River, with backup from G1H028, plus G1H058 on the Twenty-Fours River.
EWR Site 3:	**Present-day:**	Disaggregation using E2H007 on the Groot River, with backup from E2H002 at Aspoort.
	Naturalised:	Disaggregation using G1H028, plus G1H058 on the Twenty-Fours River, with backup from E2H007 on the Groot River.

Monthly flows for the EWR Sites on the Doring River (EWR Sites 4 and 5) and Groot River (EWR Site 6) can be disaggregated into daily flows using the records from these gauging weirs. It also means that the disaggregation of present day flows will be reasonably accurate, as it is based on observed records in the rivers of interest. However, because there are no gauging weirs in the catchment that are upstream of the development that has occurred in the Kouebokkeveld, the records from the weirs will also have to be used to disaggregate the naturalised record, and this is likely to yield a slightly incorrect daily distribution. The expectation is that reductions in dry season lowflows and small dry season flood events will be under estimated, while the impact on the larger flood events may be over estimated, in the resultant naturalised daily hydrological dataset. The following approach will be used for these sites:

EWR Site 4:	**Present-day:**	Disaggregation using E2H001 at Melkboom with backup from E2H002 at Aspoort.
	Naturalised:	Disaggregation using E2H001 at Melkboom with backup from E2H002 at Aspoort.

[8] This section has been included here to forewarn specialists about the difficulties of providing daily flow data in a catchment where the hydrological records are poor. Additional detail will be provided in the hydrological starter documentation, and as an addendum to the hydrological data summaries that will be supplied to the specialists in April 2004.

EWR Site 5:	**Present-day:**	Disaggregation using E2H001 at Melkboom with backup from E2H002 at Aspoort.
	Naturalised:	Disaggregation using E2H001 at Melkboom with backup from E2H002 at Aspoort.
EWR Site 6:	**Present-day:**	Disaggregation using E2H007 on the Groot River, with backup from E2H002 at Aspoort.
	Naturalised:	Disaggregation using G1H028, plus G1H058 on the Twenty-Fours River, with backup from E2H007 on the Groot River.

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10 ANNEXURES

Annex A: Detailed locations of EWR Sites

Site No.	River	Site Name	Description	Latitude	Longitude
1a 1b	Olifants	Olifants at Hex River	N7 downstream of the confluence with the Hex River.	32^{o}26.764 32^{o}26.680	18^{o}57.601 18^{o}57.504
2	Olifants	Olifants at Alwynskop	Downstream of Bulshoek Barrage, just downstream of Cascade Pools.	31^{o}57.974	18^{o}44.463
3a 3b	Rondegat	Rondegat at Algeria	Upstream of the Algeria staff accommodation, on the road between Algeria and Clanwilliam.	32^{o}21.760 32^{o}21.739	19^{o}02.618 19^{o}02.593
4a 4b	Doring	Doring at Biedou	On the Doring mainstem, immediately upstream of the confluence with the Biedou River	32^{o}02.410 32^{o}02.416	19^{o}24.896 19^{o}24.783
5	Doring	Doring at Oudrif	At Oudrif.	31^{o}51.446	18^{o}54.754
6a 6b	Groot	Groot at Mount Cedar	Upstream of the bridge at Groot Rivier.	32^{o}39.552 32^{o}39.377	19^{o}23.786 19^{o}23.982

Annex B: Water Quality Data (see attached CD)

Annex C: Habitat Integrity Results

River	Kms	Category	River	Kms	Category	River	Kms	Category	River	Kms	Category
Olifants River	5	D	Doring River	5	C	Groot River	5	B	Rondegat River	5	C
Olifants River	10	D	Doring River	10	C	Groot River	10	B	Rondegat River	10	B
Olifants River	15	D	Doring River	15	C	Groot River	15	B	Rondegat River	15	B
Olifants River	20	D	Doring River	20	C	Groot River	20	B	Rondegat River	20	A
Olifants River	25	D	Doring River	25	C	Groot River	25	B	Rondegat River	25	A
Olifants River	30	D	Doring River	30	C	Groot River	30	D			
Olifants River	35	D	Doring River	35	C	Groot River	35	D			
Olifants River	40	D	Doring River	40	C	Groot River	40	D			
Olifants River	45	D	Doring River	45	C	Groot River	45	D			
Olifants River	50	D	Doring River	50	C	Groot River	50	D			
Olifants River	55	D	Doring River	55	C	Groot River	55	D			
Olifants River	60	D	Doring River	60	B	Groot River	60	D			
Olifants River	65	D	Doring River	65	B						
Olifants River	70	D	Doring River	70	B						
Olifants River	75	D	Doring River	75	B						
Olifants River	80	D	Doring River	80	B						
Olifants River	85	D	Doring River	85	B						
Olifants River	90	D	Doring River	90	B						
Olifants River	95	D	Doring River	95	B						
Olifants River	100	D	Doring River	100	B						
Olifants River	105	D	Doring River	105	B						
Olifants River	110	D	Doring River	110	B						
Olifants River	115	D	Doring River	115	B						
Bulshoek Barrage	120	F	Doring River	120	B						
	125	F	Doring River	125	B						
Olifants River	130	D	Doring River	130	B						
Olifants River	135	D	Doring River	135	B						
Olifants River	140	D	Doring River	140	B						
Clanwilliam Dam	145	F	Doring River	145	B						
	150	F	Doring River	150	B						
	155	F	Doring River	155	B						
	160	F	Doring River	160	B						
Olifants River	165	D	Doring River	165	B						
Olifants River	170	D	Doring River	170	B						
Olifants River	175	D	Doring River	175	B						
Olifants River	180	D	Doring River	180	B						
Olifants River	185	D	Doring River	185	B						
Olifants River	190	D	Doring River	190	B						
Olifants River	195	D	Doring River	195	B						
Olifants River	200	D	Doring River	200	B						
Olifants River	205	D	Doring River	205	B						
Olifants River	210-225	C	Doring River	210	B						
Olifants River	230-245	B									
Olifants River	250-270	C									

Annex D: Maps (see attached CD)

Annex E: EWR Site Photographs

EWR Site 1: Olifants at Hex (Nov/Dec 2003). Looking upstream from 1a. Width = 30 m.

EWR Site 1: Olifants at Hex (Nov/Dec 2003). Looking upstream from 1b. Width = 22 m.

EWR Site 2: Olifants at Alwynskop (Nov/Dec 2003). Looking across from 2a. Width = 61 m.

EWR Site 2: Olifants at Alwynskop (Nov/Dec 2003). Looking upstream at the site. Width = 61 m.

EWR Site 3: Rondegat near Algeria (Nov/Dec 2003). Looking upstream at 3a. Width = 5.7 m.

EWR Site 3: Rondegat near Algeria (Nov/Dec 2003). Looking downstream at 3b. Width = 3 m.

EWR Site 4: Doring River at Biedou (Nov/Dec 2003). Looking upstream from 4a. Width = 29.1 m.

EWR Site 4: Doring River at Biedou (Nov/Dec 2003). Looking across 4b. Width = 28.8 m.

EWR Site 5: Doring River at Oudrif (Nov/Dec 2003). Looking downstream across 5a. Width = 26.1 m.

EWR Site 5: Doring River at Oudrif (Nov/Dec 2003). Looking downstream across 5b. Width = 8.9 m.

EWR Site 6: Groot River at Mount Cedar(Nov/Dec 2003). Looking downstream across 6a. Width = 12.8 m.

EWR Site 6: Groot River at Mount Cedar (Nov/Dec 2003). Looking upstream from 6b. Width = 38.9 m.

Annex F: Monthly hydrological data for the EWR sites

EWR Site 1: Naturalised Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	16.02	9.01	6.54	3.80	9.40	3.93	3.77	1.91	337.24	172.94	64.36	25.84	654.74
1921	10.65	4.40	4.68	7.57	3.21	1.51	4.24	8.12	106.62	39.18	102.94	34.17	327.30
1922	7.60	4.50	1.54	1.71	0.74	0.84	7.83	63.08	166.23	61.00	35.22	20.76	371.05
1923	11.52	7.04	2.48	0.89	0.59	1.19	2.25	1.91	71.81	31.12	97.60	38.74	267.15
1924	16.60	13.79	4.03	1.16	1.25	0.81	0.49	7.94	327.13	150.97	26.39	11.21	561.76
1925	26.76	14.73	3.62	0.90	2.22	0.76	0.76	48.15	19.55	44.93	31.23	14.67	208.28
1926	35.63	14.72	2.57	0.93	2.96	0.90	4.77	11.96	16.97	11.31	60.19	25.60	188.52
1927	6.87	11.43	4.60	1.95	0.70	1.71	0.59	0.75	80.53	32.09	26.99	18.71	186.92
1928	7.87	5.65	2.10	0.47	0.51	0.77	20.75	43.31	45.72	74.41	40.45	22.78	264.79
1929	10.88	4.33	4.12	1.94	1.54	1.35	1.69	7.40	6.66	16.36	17.94	70.13	144.33
1930	26.29	9.81	3.35	0.72	0.78	0.69	12.54	28.54	13.45	16.19	116.90	54.62	283.88
1931	21.03	6.78	2.33	2.03	21.89	6.45	1.01	54.28	91.54	52.50	22.62	22.76	305.20
1932	12.02	4.52	1.90	1.11	1.82	2.43	0.85	11.28	108.15	128.72	44.11	15.71	332.62
1933	12.54	5.66	5.33	2.01	2.01	5.66	2.00	16.57	23.93	21.93	20.13	25.39	143.17
1934	23.27	33.74	10.62	0.95	0.80	2.07	8.25	28.68	31.80	31.72	77.15	44.30	293.34
1935	12.89	9.39	2.71	3.40	1.80	1.98	2.35	6.73	9.04	26.37	67.02	61.93	205.62
1936	9.12	6.98	5.97	2.72	1.06	1.80	5.97	25.39	94.51	105.41	42.77	18.84	320.55
1937	9.95	5.18	5.48	8.93	1.67	2.20	6.13	40.18	14.99	18.75	39.42	52.94	205.81
1938	22.85	5.09	1.84	1.21	1.65	1.28	3.62	28.40	9.54	9.50	42.47	19.02	146.48
1939	5.26	2.36	1.07	0.57	0.72	2.06	10.83	17.78	43.38	20.86	17.35	17.68	139.91
1940	6.81	6.54	3.74	2.80	2.02	1.67	12.07	86.16	146.02	72.59	121.31	177.45	639.19
1941	30.95	9.59	5.30	4.49	3.34	4.77	0.70	16.71	217.94	30.61	53.32	23.98	401.68
1942	13.69	6.39	1.72	5.13	3.30	3.87	3.99	4.07	14.44	96.16	136.43	23.29	312.48
1943	20.96	15.68	3.81	1.43	0.98	2.30	3.20	24.11	96.88	94.11	76.51	37.94	377.91
1944	27.40	12.40	9.13	2.26	1.86	0.89	4.03	57.76	170.73	173.26	144.69	22.07	626.49
1945	22.13	9.07	2.41	2.67	4.42	1.71	7.53	10.20	14.72	18.02	40.20	110.72	243.80
1946	16.42	7.62	3.53	1.73	1.48	3.14	2.78	15.46	12.44	111.59	43.43	27.92	247.54
1947	17.42	9.62	3.43	0.92	1.17	3.06	6.12	22.14	35.85	73.84	28.96	65.71	268.24
1948	26.14	8.57	2.90	1.13	1.42	1.38	5.23	10.38	20.80	25.18	71.08	42.63	216.85
1949	18.07	41.98	5.03	1.93	0.98	1.51	19.35	7.18	9.02	116.70	18.86	27.41	268.03
1950	33.54	11.51	9.27	1.85	1.55	8.56	0.80	10.87	86.86	109.35	57.67	46.07	377.92
1951	19.27	25.30	6.72	1.98	2.39	1.98	3.13	22.99	15.94	30.73	137.12	56.87	324.43
1952	28.30	13.24	4.57	1.76	1.57	1.40	61.10	57.93	27.52	97.44	116.46	29.57	440.87
1953	9.84	12.29	6.86	3.21	2.12	2.47	12.46	132.98	63.12	216.70	113.98	50.83	626.85
1954	23.49	10.34	13.17	4.15	11.79	5.54	8.24	6.78	46.39	135.42	191.19	52.59	509.10
1955	41.55	24.93	13.25	6.60	3.89	4.33	4.30	14.61	62.54	89.27	84.05	29.61	378.94
1956	11.92	6.30	4.92	2.51	13.75	4.99	5.61	38.49	160.27	144.61	114.40	48.66	556.43
1957	52.69	13.46	6.37	3.60	5.60	4.85	4.95	27.70	35.70	14.07	26.29	30.73	226.01
1958	13.51	9.21	3.51	2.36	4.16	4.22	5.90	133.81	61.30	21.59	59.19	21.40	340.16
1959	15.61	13.81	7.95	2.91	3.88	4.10	7.49	28.63	63.27	14.53	10.16	9.84	182.17
1960	8.31	3.67	4.99	3.48	3.51	3.39	4.03	10.87	75.18	21.40	37.81	69.32	245.96
1961	14.45	5.28	3.20	2.67	2.51	2.66	7.60	6.24	130.86	53.83	116.27	40.26	385.83
1962	61.95	15.99	7.31	4.68	3.26	3.11	4.14	4.91	19.45	44.50	241.60	30.62	441.54
1963	13.85	12.72	7.64	3.23	5.25	3.63	4.95	9.60	53.80	25.65	39.34	25.24	204.91
1964	13.24	12.17	3.87	3.50	3.66	8.50	13.22	19.91	14.55	14.13	37.54	15.41	159.69
1965	12.59	4.86	5.39	3.07	2.30	6.49	7.39	4.73	14.54	75.99	28.75	21.35	187.46
1966	6.45	3.63	2.81	3.44	2.24	2.03	6.17	7.38	159.97	33.78	41.41	30.66	299.97
1967	16.90	9.68	5.14	5.15	3.86	4.83	9.26	52.11	43.25	73.01	65.03	22.29	310.50
1968	43.09	8.38	1.30	1.40	1.16	1.03	6.04	4.87	8.87	12.60	16.34	29.87	134.96
1969	28.10	7.20	4.22	3.80	3.58	2.98	2.55	13.09	57.35	61.82	65.75	37.65	288.10
1970	16.06	7.14	5.79	4.88	3.21	3.08	2.90	6.76	7.03	69.76	45.97	14.56	187.14
1971	7.85	4.60	4.94	5.80	5.74	5.35	5.95	26.73	27.49	17.23	26.78	19.70	158.13
1972	7.76	3.41	6.91	1.55	2.01	4.70	3.03	4.71	5.07	80.71	21.04	30.79	171.69
1973	4.56	10.30	9.05	1.30	1.62	1.19	1.91	18.30	88.47	49.42	180.84	81.44	448.41
1974	6.48	11.51	6.29	23.66	3.15	1.20	9.52	86.97	18.04	31.82	38.03	20.35	257.02
1975	17.25	10.52	5.70	3.94	4.87	2.94	31.88	8.60	160.64	135.58	46.46	24.83	453.21
1976	11.48	16.86	20.01	11.15	7.18	5.05	13.94	162.20	155.15	182.05	149.52	33.93	768.50
1977	24.02	11.92	13.01	8.34	4.63	5.14	7.04	9.57	6.33	4.55	27.24	39.57	161.36
1978	18.52	7.93	9.69	5.61	3.99	3.78	2.93	10.24	61.92	31.61	36.69	22.21	215.13
1979	31.30	9.85	5.00	6.21	1.80	1.47	4.78	17.18	33.72	17.24	30.35	14.24	173.13
1980	10.01	30.00	18.23	8.77	4.61	5.71	3.86	4.44	9.01	65.68	135.39	88.89	384.60
1981	17.17	9.11	7.79	8.29	5.79	6.66	16.88	13.65	20.56	31.23	28.05	9.16	174.33
1982	18.01	6.80	6.26	4.62	6.03	5.11	2.28	70.01	97.65	122.34	29.42	30.57	399.09
1983	13.56	7.25	5.83	2.54	2.03	4.00	4.38	134.78	15.82	76.17	34.16	88.21	388.74
1984	60.94	9.91	15.37	11.81	6.28	30.55	15.55	28.70	81.82	96.04	96.88	31.57	485.42
1985	14.95	8.47	9.24	2.98	2.31	3.38	5.53	10.49	42.86	48.60	112.49	35.51	296.81
1986	13.79	8.74	3.03	3.01	2.33	1.96	4.86	39.61	55.30	54.53	53.56	40.54	281.26
1987	19.87	8.43	7.62	2.94	2.23	3.79	12.69	11.84	55.03	33.16	35.26	54.24	247.09
1988	17.27	8.71	6.17	3.15	2.75	9.23	10.78	13.71	29.25	55.10	106.44	104.25	366.81
1989	22.65	10.69	4.50	3.72	2.23	2.66	8.52	69.80	49.23	210.15	64.41	15.89	464.44
1990	7.15	3.66	3.08	3.22	2.01	1.87	1.28	10.32	90.47	184.58	82.60	88.74	479.00

EWR Site 1: Simulated Present Day Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	11.49	4.13	1.01	0.00	4.09	0.00	1.59	1.08	310.64	173.80	64.69	23.55	596.07
1921	6.79	0.00	0.00	1.45	0.00	0.00	2.07	6.61	95.52	36.50	97.85	31.63	278.42
1922	4.19	0.09	0.00	0.00	0.00	0.00	5.00	56.35	153.32	60.16	34.20	18.18	331.50
1923	7.76	2.31	0.00	0.00	0.00	0.00	0.22	1.11	62.29	29.05	90.02	36.45	229.20
1924	12.61	8.74	0.00	0.00	0.00	0.00	0.00	6.49	300.95	151.54	25.84	8.95	515.13
1925	22.24	9.40	0.00	0.00	0.00	0.00	0.00	42.58	18.31	40.10	28.94	12.21	173.79
1926	30.01	9.51	0.00	0.00	0.00	0.00	2.44	10.04	15.63	10.63	54.50	22.35	155.10
1927	3.61	6.41	0.00	0.00	0.00	0.00	0.00	0.08	69.37	30.49	25.83	16.36	152.15
1928	4.45	1.32	0.00	0.00	0.00	0.00	16.47	39.48	42.34	68.20	39.67	20.38	232.32
1929	7.17	0.00	0.00	0.00	0.00	0.00	0.00	6.06	6.08	15.29	16.80	61.65	113.04
1930	21.52	5.11	0.00	0.00	0.00	0.00	9.08	25.16	12.58	14.98	105.65	52.08	246.15
1931	16.85	2.13	0.00	0.00	14.39	2.06	0.00	48.91	85.79	49.67	21.56	20.60	261.97
1932	8.20	0.08	0.00	0.00	0.00	0.00	0.00	9.09	96.42	122.41	43.36	13.36	292.92
1933	8.82	1.13	0.00	0.00	0.00	1.35	0.00	14.30	22.19	20.55	18.68	21.01	108.04
1934	19.05	27.08	4.78	0.00	0.00	0.00	5.40	25.38	29.56	29.27	70.57	41.50	252.59
1935	9.02	4.55	0.00	0.00	0.00	0.00	0.20	5.37	7.95	24.01	60.68	57.88	169.67
1936	5.62	2.40	0.53	0.00	0.00	0.00	3.40	22.30	85.17	100.34	41.91	16.36	278.02
1937	6.34	0.68	0.07	2.90	0.00	0.00	3.53	35.21	14.00	17.39	36.20	48.99	165.31
1938	18.90	0.65	0.00	0.00	0.00	0.00	1.45	24.40	8.97	8.86	38.91	16.11	118.24
1939	2.02	0.00	0.00	0.00	0.00	0.00	7.67	15.06	38.84	19.31	15.83	14.85	113.58
1940	3.60	2.04	0.00	0.00	0.00	0.00	8.73	75.06	136.85	71.30	119.80	173.51	590.88
1941	26.38	4.58	0.00	0.00	0.00	0.48	0.00	13.68	199.29	30.20	51.26	21.41	347.27
1942	9.80	1.78	0.00	0.00	0.00	0.00	1.69	2.90	12.89	86.49	130.78	20.74	267.07
1943	16.58	10.29	0.00	0.00	0.00	0.00	1.01	19.75	87.21	90.52	73.40	35.66	334.43
1944	23.28	7.27	3.49	0.00	0.00	0.00	1.84	48.78	159.98	169.57	143.14	19.23	576.56
1945	18.00	4.23	0.00	0.00	0.00	0.00	4.82	8.78	13.74	16.93	37.35	101.05	204.90
1946	12.34	2.93	0.00	0.00	0.00	0.00	0.60	13.16	11.61	99.13	41.93	25.73	207.44
1947	13.47	4.83	0.00	0.00	0.00	0.00	3.62	18.80	33.22	67.26	27.19	63.62	232.02
1948	21.92	3.87	0.00	0.00	0.00	0.00	2.90	8.54	19.03	23.36	65.14	38.25	183.01
1949	13.99	35.80	0.00	0.00	0.00	0.00	14.04	5.78	8.31	106.12	17.38	25.32	226.73
1950	29.14	6.22	3.61	0.00	0.00	3.64	0.00	9.30	74.86	105.53	56.83	43.81	332.94
1951	15.09	19.40	1.17	0.00	0.00	0.00	1.01	19.03	14.74	27.41	131.27	54.28	283.40
1952	24.07	7.69	0.00	0.00	0.00	0.00	49.85	53.26	25.95	91.34	114.63	26.74	393.53
1953	6.06	7.19	1.44	0.00	0.00	0.00	9.04	116.98	61.15	210.49	114.62	48.28	575.26
1954	19.26	5.36	7.22	0.00	6.17	1.24	5.79	5.64	40.80	126.78	183.18	50.20	451.65
1955	37.28	19.10	7.23	0.81	0.00	0.16	2.07	12.51	55.10	84.32	82.81	26.96	328.33
1956	8.21	1.72	0.00	0.00	7.78	0.75	3.25	32.57	146.44	141.62	112.78	46.08	501.18
1957	48.89	8.18	0.84	0.00	0.74	0.62	2.70	24.18	32.85	12.95	23.87	27.07	182.90
1958	9.74	4.45	0.00	0.00	0.00	0.00	3.24	116.81	58.26	21.18	58.05	19.17	290.89
1959	11.75	8.63	2.40	0.00	0.00	0.00	5.03	25.50	58.19	13.38	9.27	7.75	141.91
1960	5.07	0.00	0.00	0.00	0.00	0.00	1.93	9.15	69.09	19.96	34.59	65.17	204.96
1961	10.44	0.77	0.00	0.00	0.00	0.00	4.89	4.88	115.25	51.25	114.01	37.58	339.07
1962	56.76	10.50	1.68	0.00	0.00	0.00	1.89	3.92	17.42	41.14	226.71	28.09	388.12
1963	9.93	7.63	2.08	0.00	0.49	0.00	2.64	8.26	47.42	23.45	37.47	22.42	161.80
1964	9.35	7.07	0.00	0.00	0.00	3.81	10.13	17.63	13.54	13.10	34.70	12.93	122.26
1965	8.88	0.43	0.09	0.00	0.00	2.14	4.72	3.72	13.07	68.54	26.43	18.44	146.47
1966	3.09	0.00	0.00	0.00	0.00	0.00	3.75	6.25	142.89	33.29	40.92	28.49	258.70
1967	12.82	4.89	0.00	0.00	0.00	0.59	6.63	45.96	39.81	67.72	63.97	19.61	262.00
1968	38.37	3.56	0.00	0.00	0.00	0.00	3.62	3.62	7.81	11.63	15.04	26.41	110.05
1969	22.48	2.54	0.00	0.00	0.00	0.00	0.38	11.15	49.77	58.54	62.15	33.65	240.66
1970	11.84	2.46	0.34	0.00	0.00	0.00	0.67	5.64	6.45	62.02	43.10	11.83	144.35
1971	4.48	0.18	0.00	0.07	0.81	1.06	3.46	23.33	25.49	15.59	24.56	16.77	115.80
1972	4.39	0.00	1.44	0.00	0.00	0.47	0.75	3.59	4.64	69.28	20.10	27.58	132.23
1973	1.50	5.31	3.40	0.00	0.00	0.00	0.00	15.09	77.86	46.81	175.46	78.72	404.15
1974	3.01	6.43	0.78	16.62	0.00	0.00	6.76	74.25	16.86	30.41	36.42	17.79	209.32
1975	13.07	5.62	0.25	0.00	0.00	0.00	27.27	7.35	144.89	134.58	45.81	22.41	401.26
1976	7.74	11.01	12.69	5.02	2.18	0.80	10.73	145.09	149.82	183.06	150.34	31.39	709.86
1977	19.83	6.96	7.07	2.45	0.00	0.90	4.68	8.37	5.87	4.21	24.13	35.25	119.73
1978	14.38	3.32	4.10	0.00	0.00	0.00	0.75	8.64	54.93	29.01	34.47	19.60	169.19
1979	26.10	5.00	0.00	0.44	0.00	0.00	2.44	14.57	30.87	15.98	27.49	11.70	134.59
1980	6.50	22.32	11.77	2.49	0.00	1.41	1.70	3.48	8.41	57.89	125.57	86.17	327.71
1981	12.83	4.31	2.21	2.34	0.84	2.16	12.63	12.08	18.74	28.93	25.72	7.04	129.84
1982	13.86	2.25	0.87	0.00	1.10	0.78	0.25	58.20	91.67	118.26	28.44	28.14	343.82
1983	9.59	2.58	0.38	0.00	0.00	0.00	2.22	116.27	14.97	73.44	33.56	83.84	336.85
1984	56.74	4.84	8.90	5.53	1.28	22.50	12.37	25.85	76.67	93.02	93.32	29.18	430.18
1985	10.70	3.77	3.56	0.00	0.00	0.00	2.97	9.14	37.88	44.59	106.86	33.12	252.60
1986	9.82	4.01	0.00	0.00	0.00	0.00	2.45	33.40	50.93	51.58	50.43	37.18	239.79
1987	15.60	3.68	2.05	0.00	0.00	0.00	9.24	10.40	49.71	30.57	31.71	51.52	204.48
1988	13.17	3.95	0.74	0.00	0.00	4.32	7.54	12.01	25.99	49.60	95.53	100.33	313.19
1989	18.05	5.71	0.00	0.00	0.00	0.00	5.45	59.34	46.33	199.69	64.06	13.21	411.83
1990	3.79	0.00	0.00	0.00	0.00	0.00	0.00	8.69	77.68	172.92	81.80	87.86	432.74

EWR Site 2: Naturalised Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	30.46	15.35	11.08	5.60	16.58	6.87	5.12	3.37	555.57	271.78	103.99	44.62	1070.39
1921	18.72	7.99	6.23	12.40	5.20	1.90	5.72	12.68	158.83	66.39	148.13	60.61	504.80
1922	14.07	8.73	2.74	2.72	1.10	0.98	11.29	99.86	267.52	100.98	59.03	37.72	606.74
1923	21.16	12.09	4.05	1.44	0.84	1.40	3.17	2.99	98.83	49.71	140.82	68.33	404.83
1924	27.15	22.64	6.98	1.78	2.07	1.38	0.75	12.81	548.25	250.51	60.24	26.50	961.07
1925	39.01	24.58	6.28	1.32	2.72	1.12	1.10	76.34	33.80	57.26	50.39	25.33	319.25
1926	53.62	25.21	4.54	1.36	4.08	1.42	7.46	18.58	23.78	18.90	81.49	42.14	282.58
1927	12.00	16.50	7.29	3.01	1.04	2.37	0.92	1.12	110.70	53.70	41.45	30.65	280.75
1928	13.67	7.58	3.10	0.73	0.62	1.02	35.19	71.12	77.09	116.62	72.36	44.46	443.56
1929	21.07	7.74	6.12	2.94	2.40	2.13	2.71	13.35	11.91	26.58	34.16	117.74	248.85
1930	47.10	14.99	5.63	1.20	0.97	0.91	20.34	45.63	22.41	26.43	172.49	93.80	451.90
1931	40.02	13.10	3.51	3.32	32.40	10.84	1.68	83.98	139.49	81.45	37.86	36.05	483.70
1932	20.65	7.77	2.97	1.70	2.17	4.07	1.42	16.80	167.35	193.77	79.71	29.11	527.49
1933	22.73	10.47	8.29	3.33	3.52	9.54	3.59	26.47	35.39	32.05	30.93	34.46	220.77
1934	33.52	60.53	18.65	1.61	1.20	2.72	12.86	43.93	45.30	49.89	133.29	84.35	487.85
1935	26.61	16.70	4.84	5.23	2.82	2.77	3.85	10.57	17.70	43.45	102.35	105.92	342.81
1936	19.11	13.90	7.81	4.59	1.64	3.50	9.35	39.13	146.07	160.58	74.73	33.02	513.43
1937	17.36	9.22	9.01	14.52	2.53	3.50	8.33	59.42	22.23	28.85	58.07	87.60	320.64
1938	39.07	8.75	2.58	1.99	3.07	2.08	5.12	46.39	15.78	15.64	73.92	35.88	250.27
1939	11.58	4.20	1.63	0.83	1.72	2.72	16.79	30.67	59.67	34.89	32.49	29.87	227.06
1940	11.70	10.37	5.98	4.80	3.29	2.68	21.64	137.29	240.55	125.28	213.68	294.01	1071.26
1941	53.88	17.52	8.73	7.43	5.42	7.78	1.63	21.07	326.17	52.81	77.97	42.95	623.36
1942	23.38	11.37	3.95	7.51	4.05	5.83	6.09	7.03	22.23	136.18	203.81	37.26	468.69
1943	35.25	27.14	6.87	2.06	1.48	3.75	4.48	36.16	131.06	163.58	105.68	64.45	581.96
1944	48.43	21.16	14.41	3.79	3.03	1.39	5.67	82.14	250.46	274.92	231.75	41.38	978.54
1945	37.72	15.78	3.85	4.39	7.20	2.63	13.56	18.22	23.49	28.89	65.01	169.17	389.91
1946	31.11	13.95	5.67	2.90	2.34	6.10	4.75	25.07	21.04	165.29	76.60	49.63	404.45
1947	28.57	16.58	5.67	1.52	1.36	5.29	9.12	31.92	56.54	108.69	52.01	101.93	419.20
1948	44.79	14.54	4.57	1.63	2.23	2.25	8.32	17.42	31.53	37.24	107.38	70.76	342.66
1949	32.53	62.66	8.21	3.18	1.55	2.30	22.71	11.36	13.32	179.79	36.76	37.56	411.93
1950	56.32	16.77	15.09	2.32	2.47	14.16	2.16	18.28	116.97	179.10	93.04	77.75	594.43
1951	33.31	40.87	11.56	3.25	3.37	2.92	4.72	34.92	25.46	51.45	221.34	100.25	533.42
1952	50.32	17.33	7.42	3.04	1.97	2.76	89.40	85.01	45.21	139.73	188.93	54.52	685.64
1953	17.96	19.74	8.89	5.39	2.74	3.52	19.93	205.33	104.01	325.44	176.10	91.14	980.18
1954	41.60	18.66	20.93	6.95	17.35	8.98	12.93	11.46	68.86	215.45	286.99	92.83	803.00
1955	64.85	41.95	21.96	10.73	6.55	7.96	7.20	21.22	82.72	137.41	138.85	54.54	595.94
1956	22.78	11.48	7.52	4.15	19.64	7.77	8.81	49.95	236.37	233.94	200.28	90.17	892.86
1957	79.71	23.45	10.80	6.06	8.44	7.78	7.39	39.65	48.48	24.93	34.18	49.78	340.65
1958	21.15	15.00	5.87	3.83	6.34	6.89	9.16	226.91	107.13	40.37	96.52	38.71	577.88
1959	22.13	23.32	12.49	4.83	6.24	5.97	11.47	45.62	99.77	25.19	16.72	16.47	290.22
1960	13.58	6.05	7.48	5.39	5.56	5.09	9.18	21.69	135.68	40.64	66.28	113.19	429.82
1961	28.45	9.82	5.38	4.22	4.10	3.91	10.37	9.55	223.17	92.72	211.69	74.88	678.26
1962	91.21	27.92	12.59	7.86	5.25	5.15	7.66	8.43	30.92	70.83	371.14	59.69	698.64
1963	26.67	20.39	11.76	5.46	8.10	6.08	7.38	14.27	80.80	41.05	58.38	41.77	322.11
1964	22.68	20.21	6.76	5.56	5.31	12.69	21.76	29.26	23.83	25.62	63.95	28.13	265.76
1965	22.03	8.52	8.36	5.20	3.77	8.14	11.82	7.23	25.54	111.54	49.78	38.19	300.12
1966	12.77	6.42	4.50	5.35	4.03	3.25	11.59	14.55	266.39	61.01	72.75	53.74	516.35
1967	28.83	16.43	8.90	8.39	6.37	7.79	14.08	78.95	63.82	115.00	111.98	43.18	503.72
1968	64.51	14.84	2.14	1.97	1.64	1.45	8.31	8.14	14.19	20.78	24.12	42.94	205.03
1969	39.06	12.36	7.15	6.35	5.51	4.94	4.34	19.30	69.58	90.58	99.45	59.48	418.10
1970	26.97	12.29	9.52	8.17	5.21	4.83	4.83	10.37	11.94	89.90	68.36	27.76	280.15
1971	14.62	8.15	8.18	9.48	9.34	8.65	7.91	35.10	40.77	26.74	46.50	32.74	248.18
1972	13.36	6.00	9.65	2.65	2.40	9.57	5.37	8.91	8.82	106.68	40.80	52.51	266.72
1973	8.70	17.95	14.29	2.23	2.09	1.66	2.95	26.50	132.98	79.00	342.51	142.56	773.42
1974	16.48	20.01	10.55	39.24	5.08	1.86	12.27	123.01	32.14	48.03	53.59	36.03	398.29
1975	26.03	17.97	9.62	6.73	9.20	4.62	63.67	17.20	249.74	226.49	86.57	45.54	763.39
1976	19.97	28.46	27.08	18.46	12.11	8.23	17.40	234.72	235.68	280.23	232.86	66.23	1181.42
1977	44.03	20.10	23.17	13.68	7.64	7.80	10.84	15.13	11.04	8.51	45.83	65.24	273.01
1978	33.78	14.21	11.28	9.10	5.68	6.53	5.02	12.72	83.03	46.73	63.81	35.01	326.90
1979	55.07	18.08	8.90	10.08	2.56	2.51	7.19	22.09	47.55	30.30	45.25	25.61	275.19
1980	16.58	44.50	30.41	12.49	7.81	9.03	5.85	7.51	13.60	90.76	207.08	149.44	595.07
1981	31.73	16.14	13.64	13.32	9.74	9.18	21.01	23.10	29.28	51.95	51.08	17.34	287.51
1982	32.25	12.39	9.93	8.04	7.39	7.61	3.52	85.11	146.23	195.88	55.30	56.29	619.94
1983	26.00	13.30	10.09	4.56	3.40	6.90	5.36	180.65	25.50	123.00	58.54	129.07	586.37
1984	91.09	18.27	23.56	18.73	10.10	38.36	23.73	47.79	120.16	143.92	152.76	50.60	739.07
1985	26.66	14.31	14.49	5.82	4.04	4.73	9.49	15.94	64.41	87.49	178.14	66.63	492.15
1986	26.27	15.57	5.67	4.76	4.07	3.65	7.40	45.96	71.54	89.12	87.38	73.08	434.47
1987	38.03	15.79	13.22	5.13	3.98	5.16	18.19	19.11	79.37	56.95	50.76	92.53	398.22
1988	31.47	15.61	10.07	4.91	4.02	10.57	18.53	21.02	41.84	74.11	140.09	151.00	523.24
1989	38.53	17.75	7.52	5.67	3.77	3.23	23.58	87.54	69.99	328.50	112.59	29.87	728.54
1990	12.50	5.62	4.51	5.02	3.61	2.99	2.58	13.73	110.64	276.13	141.05	136.31	714.69

EWR Site 2: Simulated Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	7.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	396.41	267.12	96.88	29.60	797.71
1921	4.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.42	57.15	135.65	45.22	268.67
1922	3.89	0.00	0.00	0.00	0.00	0.00	0.00	5.09	208.97	94.55	50.55	22.37	385.42
1923	5.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.83	7.54	116.10	53.30	186.22
1924	6.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	414.87	245.53	52.13	11.72	730.40
1925	16.85	0.00	0.00	0.00	0.00	0.00	0.00	3.72	5.13	25.28	39.86	9.92	100.76
1926	30.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.77	4.34	7.71	20.60	64.66
1927	2.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.29	10.23	32.35	15.32	65.92
1928	3.43	0.00	0.00	0.00	0.00	0.00	0.00	6.61	22.88	103.77	64.09	29.29	230.07
1929	5.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.70	6.30	11.06	21.09	45.38
1930	17.81	0.00	0.00	0.00	0.00	0.00	0.00	2.40	4.35	7.26	111.87	78.61	222.30
1931	18.29	0.00	0.00	0.00	0.00	0.00	0.00	1.00	106.60	73.04	29.28	21.18	249.39
1932	4.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.76	180.73	71.48	14.00	308.03
1933	5.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.13	6.46	6.62	6.24	28.34
1934	5.05	5.59	0.00	0.00	0.00	0.00	0.00	0.62	6.17	22.80	117.27	68.93	226.43
1935	7.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.81	9.57	14.84	87.57	122.61
1936	8.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	42.35	149.29	66.37	17.71	284.01
1937	3.71	0.00	0.00	0.00	0.00	0.00	0.00	0.51	4.90	6.37	7.06	68.25	90.80
1938	17.59	0.00	0.00	0.00	0.00	0.00	0.00	2.67	4.45	4.86	18.51	12.50	60.58
1939	4.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.13	7.51	7.38	6.48	33.37
1940	3.44	0.00	0.00	0.00	0.00	0.00	0.00	22.19	198.53	118.41	204.71	277.49	824.76
1941	31.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	203.81	46.78	68.48	27.55	378.49
1942	5.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	21.22	189.46	22.01	238.61
1943	13.23	0.45	0.00	0.00	0.00	0.00	0.00	1.59	38.78	152.42	95.16	49.40	351.03
1944	26.73	0.00	0.00	0.00	0.00	0.00	0.00	8.36	190.34	265.69	222.75	25.67	739.55
1945	16.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.48	4.51	6.30	135.59	163.92
1946	9.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.83	65.02	67.12	34.64	178.03
1947	7.11	0.00	0.00	0.00	0.00	0.00	0.00	0.65	6.31	54.06	42.16	87.18	197.47
1948	23.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.27	7.46	38.51	53.00	124.25
1949	10.91	22.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	89.53	27.11	22.81	172.97
1950	34.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.23	161.49	84.72	62.75	360.67
1951	11.60	6.88	0.00	0.00	0.00	0.00	0.00	1.10	5.88	13.78	176.62	84.94	300.80
1952	28.45	0.00	0.00	0.00	0.00	0.00	9.84	26.74	38.51	127.27	179.65	38.80	449.26
1953	3.67	0.00	0.00	0.00	0.00	0.00	0.00	80.64	97.04	313.78	169.33	75.82	740.27
1954	19.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13.24	166.07	271.64	77.70	548.49
1955	43.21	7.62	0.00	0.00	0.00	0.00	0.00	0.00	10.30	115.05	130.15	39.05	345.38
1956	5.89	0.00	0.00	0.00	0.00	0.00	0.00	5.54	144.25	225.41	191.22	74.82	647.13
1957	58.61	0.00	0.00	0.00	0.00	0.00	0.00	4.30	7.13	5.83	7.75	21.85	105.47
1958	2.50	0.00	0.00	0.00	0.00	0.00	0.00	92.97	98.04	34.32	87.93	23.68	339.44
1959	4.76	0.00	0.00	0.00	0.00	0.00	0.00	3.28	23.83	18.03	8.38	3.27	61.55
1960	2.10	0.00	0.00	0.00	0.00	0.00	0.00	4.23	27.47	16.90	54.70	96.57	201.98
1961	7.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	93.47	83.28	202.13	59.51	445.85
1962	68.72	1.19	0.00	0.00	0.00	0.00	0.00	0.00	6.07	15.02	316.66	44.39	452.04
1963	6.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.35	10.18	30.98	25.68	87.42
1964	4.32	0.00	0.00	0.00	0.00	0.00	0.00	0.11	3.92	6.54	8.51	11.23	34.63
1965	3.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.60	16.12	25.33	22.03	71.03
1966	3.82	0.00	0.00	0.00	0.00	0.00	0.00	4.56	123.57	54.81	64.76	38.82	290.34
1967	7.17	0.00	0.00	0.00	0.00	0.00	0.00	10.73	12.36	99.58	103.44	27.60	260.87
1968	42.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	3.43	4.66	51.11
1969	5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.98	11.32	16.38	84.65	41.77	160.60
1970	5.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.99	23.45	11.94	50.44
1971	3.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.21	9.33	8.16	6.58	35.45
1972	3.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.32	15.02	10.17	43.66
1973	4.79	0.00	0.00	0.00	0.00	0.00	0.00	3.17	31.36	50.87	327.61	127.11	544.92
1974	9.31	0.00	0.00	0.00	0.00	0.00	0.00	16.88	26.24	40.34	44.25	20.55	157.57
1975	4.55	0.00	0.00	0.00	0.00	0.00	8.45	5.11	170.97	219.93	78.40	30.29	517.71
1976	3.87	4.10	1.74	0.00	0.00	0.00	0.00	131.58	226.21	275.73	226.28	50.92	920.42
1977	22.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	11.24	11.08	45.69
1978	5.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.19	7.75	37.23	19.36	79.48
1979	32.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.31	7.04	10.92	6.42	65.76
1980	3.64	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.98	171.58	134.11	322.51
1981	9.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.17	11.12	18.63	4.79	48.43
1982	7.92	0.00	0.00	0.00	0.00	0.00	0.00	9.04	79.70	185.37	46.78	41.16	369.97
1983	6.42	0.00	0.00	0.00	0.00	0.00	0.00	41.85	20.02	113.52	50.42	112.17	344.40
1984	69.60	0.00	0.00	0.00	0.00	0.00	0.00	4.90	91.78	135.36	141.75	35.52	478.91
1985	4.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.07	21.86	163.97	51.48	256.37
1986	6.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.81	57.71	75.48	56.81	204.98
1987	16.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.46	22.32	39.32	77.11	164.23
1988	9.72	0.00	0.00	0.00	0.00	0.00	0.00	0.65	5.68	12.05	116.01	134.12	278.23
1989	16.36	0.00	0.00	0.00	0.00	0.00	5.64	13.93	22.23	309.69	104.72	14.26	486.83
1990	2.45	0.00	0.00	0.00	0.00	0.00	0.00	0.02	11.58	219.76	132.27	122.90	488.98

EWR Site 3: Naturalised Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	0.44	0.28	0.19	0.09	0.28	0.13	0.04	0.06	7.31	4.47	1.22	0.59	15.10
1921	0.31	0.17	0.06	0.19	0.10	0.01	0.03	0.15	2.35	1.19	1.75	1.22	7.54
1922	0.23	0.16	0.06	0.04	0.02	0.01	0.13	1.80	3.94	1.58	0.46	0.50	8.93
1923	0.34	0.21	0.09	0.03	0.01	0.01	0.03	0.04	1.27	0.77	1.75	1.24	5.78
1924	0.35	0.40	0.17	0.03	0.03	0.02	0.01	0.18	7.55	4.46	0.81	0.30	14.31
1925	0.43	0.43	0.14	0.03	0.02	0.02	0.01	1.31	0.62	0.24	0.64	0.33	4.22
1926	0.73	0.52	0.11	0.02	0.04	0.03	0.10	0.23	0.24	0.24	0.95	0.74	3.95
1927	0.22	0.23	0.15	0.05	0.02	0.02	0.02	0.01	1.34	0.89	0.39	0.37	3.70
1928	0.21	0.09	0.06	0.02	0.00	0.01	0.61	1.28	1.21	1.38	0.97	0.65	6.49
1929	0.39	0.16	0.08	0.05	0.04	0.03	0.03	0.18	0.14	0.29	0.39	1.83	3.62
1930	0.92	0.22	0.13	0.03	0.01	0.01	0.31	0.71	0.32	0.23	2.21	1.70	6.79
1931	0.64	0.28	0.06	0.05	0.50	0.26	0.03	1.60	2.25	1.00	0.40	0.42	7.48
1932	0.36	0.17	0.05	0.03	0.01	0.06	0.03	0.23	2.55	2.49	1.25	0.32	7.56
1933	0.34	0.21	0.13	0.07	0.05	0.14	0.08	0.45	0.47	0.27	0.32	0.25	2.76
1934	0.40	1.25	0.46	0.04	0.02	0.03	0.18	0.66	0.50	0.58	1.64	1.48	7.22
1935	0.45	0.35	0.11	0.08	0.06	0.05	0.09	0.02	0.32	0.53	1.41	1.54	5.00
1936	0.17	0.23	0.04	0.11	0.04	0.03	0.16	0.67	2.10	1.97	1.27	0.59	7.38
1937	0.30	0.22	0.20	0.29	0.04	0.08	0.02	0.93	0.17	0.28	0.82	1.62	4.97
1938	0.70	0.14	0.03	0.05	0.03	0.04	0.05	0.70	0.13	0.11	0.91	0.35	3.24
1939	0.15	0.05	0.02	0.01	0.01	0.01	0.13	0.66	0.51	0.46	0.56	0.44	3.02
1940	0.15	0.13	0.13	0.03	0.07	0.06	0.13	1.72	3.13	1.73	4.05	5.98	17.32
1941	0.76	0.34	0.20	0.19	0.14	0.20	0.01	0.09	4.67	0.71	0.65	0.75	8.71
1942	0.37	0.26	0.01	0.14	0.04	0.10	0.12	0.12	0.23	1.79	3.31	0.34	6.82
1943	0.73	0.50	0.16	0.04	0.03	0.04	0.06	0.38	1.01	3.66	0.89	1.11	8.61
1944	0.99	0.44	0.30	0.10	0.07	0.02	0.01	0.75	3.88	4.85	4.55	0.73	16.71
1945	0.75	0.36	0.08	0.11	0.18	0.03	0.23	0.34	0.39	0.45	1.28	2.49	6.70
1946	0.44	0.31	0.12	0.08	0.06	0.05	0.10	0.42	0.36	2.03	1.33	0.96	6.24
1947	0.47	0.37	0.14	0.04	0.00	0.05	0.08	0.29	0.97	1.38	0.96	1.90	6.65
1948	0.85	0.29	0.09	0.03	0.05	0.05	0.04	0.27	0.46	0.33	1.69	1.23	5.38
1949	0.46	1.11	0.17	0.08	0.03	0.04	0.05	0.19	0.17	2.01	0.57	0.09	4.99
1950	1.17	0.20	0.29	0.01	0.06	0.37	0.01	0.37	0.68	3.57	1.43	1.57	9.73
1951	0.54	0.77	0.28	0.08	0.05	0.05	0.06	0.40	0.25	0.49	3.85	1.93	8.78
1952	1.07	0.06	0.16	0.08	0.02	0.04	0.73	0.97	0.71	1.43	3.50	1.08	9.84
1953	0.35	0.38	0.10	0.13	0.04	0.05	0.09	2.26	1.82	4.46	2.32	1.80	13.80
1954	0.76	0.41	0.47	0.18	0.24	0.21	0.18	0.25	0.38	3.49	3.76	1.78	12.11
1955	1.06	0.87	0.52	0.26	0.15	0.14	0.17	0.28	0.52	2.04	2.46	1.00	9.46
1956	0.39	0.27	0.11	0.10	0.28	0.15	0.19	0.08	3.56	3.81	3.17	1.72	13.82
1957	1.14	0.51	0.27	0.16	0.13	0.17	0.14	0.19	0.39	0.36	0.06	1.00	4.52
1958	0.40	0.35	0.15	0.10	0.13	0.15	0.09	2.22	2.31	0.72	1.51	0.58	8.71
1959	0.17	0.58	0.26	0.13	0.15	0.11	0.18	0.60	1.80	0.34	0.20	0.28	4.80
1960	0.27	0.14	0.06	0.10	0.13	0.10	0.02	0.27	2.21	0.25	0.80	1.74	6.11
1961	0.49	0.22	0.14	0.10	0.09	0.07	0.10	0.15	2.13	1.14	2.76	1.15	8.54
1962	1.28	0.49	0.31	0.18	0.13	0.13	0.15	0.18	0.11	0.78	5.92	0.90	10.56
1963	0.50	0.36	0.20	0.14	0.11	0.15	0.14	0.24	0.61	0.38	0.52	0.60	3.96
1964	0.40	0.40	0.17	0.11	0.06	0.08	0.31	0.39	0.37	0.36	1.24	0.48	4.37
1965	0.42	0.19	0.12	0.13	0.10	0.03	0.20	0.13	0.23	1.32	0.67	0.58	4.13
1966	0.22	0.15	0.11	0.12	0.07	0.07	0.02	0.03	3.75	0.73	1.25	0.99	7.51
1967	0.52	0.29	0.22	0.21	0.17	0.19	0.11	0.81	0.56	1.68	1.80	0.79	7.35
1968	0.87	0.30	0.03	0.03	0.03	0.02	0.05	0.17	0.23	0.40	0.34	0.62	3.07
1969	0.42	0.26	0.18	0.17	0.12	0.13	0.11	0.03	0.07	0.85	1.37	0.96	4.68
1970	0.51	0.29	0.23	0.21	0.13	0.09	0.12	0.17	0.11	0.68	0.54	0.45	3.54
1971	0.30	0.19	0.21	0.20	0.23	0.20	0.01	0.31	0.29	0.04	0.82	0.49	3.29
1972	0.22	0.14	0.11	0.07	0.03	0.13	0.13	0.11	0.15	0.66	0.36	0.83	2.93
1973	0.01	0.43	0.29	0.05	0.01	0.02	0.07	0.02	0.89	1.13	6.51	2.91	12.35
1974	0.10	0.38	0.25	1.01	0.12	0.03	0.09	0.99	0.38	0.56	0.44	0.73	5.06
1975	0.34	0.42	0.24	0.14	0.20	0.09	1.06	0.25	3.17	4.28	1.57	0.87	12.63
1976	0.37	0.27	0.12	0.43	0.25	0.19	0.03	3.11	2.95	4.49	3.33	1.04	16.58
1977	0.93	0.43	0.50	0.31	0.19	0.13	0.17	0.23	0.20	0.16	0.54	1.03	4.82
1978	0.68	0.31	0.07	0.21	0.09	0.16	0.11	0.05	0.61	0.52	1.02	0.40	4.22
1979	1.06	0.40	0.22	0.20	0.03	0.05	0.12	0.08	0.24	0.43	0.31	0.39	3.53
1980	0.25	0.66	0.69	0.20	0.19	0.19	0.10	0.15	0.19	0.77	2.99	2.47	8.85
1981	0.55	0.34	0.32	0.28	0.24	0.13	0.16	0.35	0.28	0.67	0.91	0.28	4.52
1982	0.54	0.25	0.17	0.19	0.06	0.13	0.05	0.09	1.96	3.33	0.86	0.83	8.47
1983	0.46	0.29	0.24	0.11	0.08	0.06	0.00	1.70	0.30	2.42	0.99	1.60	8.25
1984	1.29	0.37	0.39	0.26	0.19	0.37	0.35	0.66	1.77	1.71	2.43	0.68	10.45
1985	0.51	0.26	0.19	0.13	0.09	0.04	0.20	0.25	0.31	1.27	2.58	1.11	6.93
1986	0.48	0.33	0.13	0.08	0.09	0.09	0.08	0.18	0.43	1.20	1.08	1.06	5.24
1987	0.78	0.37	0.30	0.11	0.10	0.06	0.20	0.28	0.90	0.93	0.34	1.74	6.10
1988	0.63	0.35	0.21	0.09	0.07	0.04	0.17	0.31	0.47	0.49	0.91	1.89	5.64
1989	0.63	0.32	0.18	0.12	0.07	0.03	0.13	0.27	0.15	5.86	2.36	0.58	10.71
1990	0.25	0.10	0.07	0.04	0.09	0.06	0.04	0.09	0.41	2.90	2.95	2.01	9.00

EWR Site 3: Simulated Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	0.45	0.28	0.19	0.10	0.28	0.13	0.04	0.06	7.34	4.49	1.23	0.60	15.17
1921	0.32	0.16	0.07	0.19	0.10	0.01	0.03	0.16	2.36	1.20	1.76	1.22	7.58
1922	0.23	0.16	0.06	0.04	0.02	0.01	0.14	1.80	3.96	1.59	0.47	0.50	8.97
1923	0.34	0.21	0.09	0.03	0.01	0.01	0.03	0.04	1.28	0.77	1.77	1.25	5.82
1924	0.35	0.41	0.16	0.04	0.03	0.02	0.01	0.18	7.58	4.47	0.81	0.30	14.36
1925	0.43	0.44	0.15	0.03	0.02	0.02	0.01	1.32	0.62	0.24	0.64	0.33	4.25
1926	0.73	0.51	0.11	0.02	0.04	0.03	0.11	0.23	0.24	0.24	0.96	0.75	3.97
1927	0.21	0.22	0.15	0.05	0.02	0.02	0.02	0.02	1.34	0.90	0.39	0.37	3.72
1928	0.21	0.10	0.06	0.02	0.00	0.01	0.61	1.29	1.21	1.39	0.98	0.65	6.52
1929	0.39	0.16	0.09	0.06	0.04	0.03	0.03	0.18	0.15	0.29	0.39	1.83	3.64
1930	0.92	0.22	0.13	0.03	0.01	0.01	0.31	0.71	0.32	0.22	2.22	1.71	6.82
1931	0.65	0.28	0.06	0.05	0.49	0.26	0.03	1.60	2.26	1.01	0.40	0.42	7.52
1932	0.36	0.16	0.06	0.03	0.01	0.06	0.03	0.23	2.56	2.50	1.26	0.32	7.59
1933	0.35	0.21	0.13	0.07	0.05	0.14	0.08	0.45	0.47	0.27	0.33	0.25	2.79
1934	0.41	1.25	0.47	0.04	0.02	0.03	0.17	0.66	0.50	0.58	1.64	1.48	7.25
1935	0.46	0.36	0.11	0.08	0.06	0.05	0.09	0.03	0.32	0.53	1.42	1.54	5.04
1936	0.17	0.23	0.04	0.11	0.04	0.03	0.16	0.68	2.10	1.98	1.28	0.59	7.42
1937	0.30	0.22	0.20	0.29	0.04	0.08	0.02	0.94	0.16	0.28	0.82	1.63	4.98
1938	0.71	0.14	0.03	0.05	0.03	0.04	0.05	0.71	0.13	0.12	0.91	0.35	3.28
1939	0.16	0.06	0.03	0.01	0.01	0.01	0.13	0.66	0.51	0.47	0.56	0.45	3.05
1940	0.16	0.14	0.13	0.04	0.07	0.07	0.14	1.74	3.14	1.74	4.06	6.00	17.42
1941	0.77	0.34	0.19	0.19	0.14	0.20	0.01	0.09	4.69	0.71	0.65	0.76	8.75
1942	0.37	0.26	0.01	0.14	0.04	0.11	0.12	0.13	0.23	1.79	3.32	0.34	6.87
1943	0.74	0.50	0.16	0.04	0.03	0.04	0.06	0.38	1.01	3.68	0.90	1.11	8.66
1944	1.00	0.45	0.30	0.10	0.08	0.02	0.01	0.76	3.90	4.87	4.58	0.74	16.81
1945	0.75	0.36	0.08	0.12	0.18	0.04	0.22	0.34	0.39	0.46	1.29	2.50	6.74
1946	0.45	0.31	0.12	0.08	0.06	0.05	0.10	0.43	0.37	2.04	1.33	0.96	6.29
1947	0.48	0.37	0.14	0.04	0.00	0.05	0.09	0.29	0.98	1.39	0.96	1.91	6.70
1948	0.85	0.29	0.09	0.03	0.06	0.05	0.05	0.27	0.47	0.34	1.70	1.23	5.41
1949	0.47	1.12	0.17	0.08	0.04	0.05	0.06	0.19	0.17	2.03	0.57	0.09	5.02
1950	1.17	0.20	0.29	0.01	0.06	0.38	0.01	0.37	0.69	3.59	1.44	1.58	9.78
1951	0.54	0.78	0.28	0.08	0.06	0.05	0.07	0.41	0.25	0.49	3.87	1.94	8.82
1952	1.08	0.07	0.16	0.08	0.02	0.04	0.74	0.97	0.72	1.44	3.51	1.09	9.92
1953	0.36	0.38	0.10	0.13	0.04	0.05	0.09	2.28	1.82	4.48	2.34	1.80	13.87
1954	0.77	0.42	0.48	0.18	0.24	0.21	0.18	0.25	0.38	3.51	3.78	1.78	12.15
1955	1.06	0.87	0.52	0.26	0.16	0.14	0.16	0.28	0.52	2.05	2.47	1.01	9.49
1956	0.39	0.27	0.11	0.10	0.28	0.15	0.19	0.08	3.58	3.83	3.18	1.73	13.90
1957	1.14	0.50	0.27	0.16	0.13	0.17	0.14	0.19	0.39	0.37	0.06	1.01	4.54
1958	0.40	0.35	0.16	0.10	0.14	0.15	0.10	2.23	2.32	0.73	1.52	0.58	8.77
1959	0.17	0.58	0.26	0.13	0.16	0.11	0.17	0.60	1.80	0.34	0.20	0.28	4.80
1960	0.27	0.15	0.06	0.11	0.13	0.11	0.02	0.27	2.22	0.25	0.80	1.76	6.15
1961	0.49	0.22	0.14	0.10	0.09	0.07	0.10	0.15	2.14	1.14	2.77	1.16	8.57
1962	1.29	0.48	0.31	0.18	0.13	0.13	0.16	0.18	0.11	0.79	5.94	0.90	10.61
1963	0.49	0.37	0.20	0.15	0.12	0.15	0.15	0.24	0.61	0.38	0.52	0.60	3.98
1964	0.40	0.40	0.16	0.11	0.06	0.08	0.31	0.40	0.37	0.36	1.24	0.49	4.40
1965	0.43	0.19	0.13	0.14	0.10	0.03	0.20	0.13	0.23	1.33	0.68	0.58	4.16
1966	0.22	0.15	0.11	0.12	0.07	0.08	0.02	0.04	3.76	0.74	1.25	0.99	7.56
1967	0.52	0.29	0.22	0.21	0.16	0.19	0.11	0.81	0.56	1.69	1.80	0.80	7.36
1968	0.87	0.30	0.03	0.03	0.03	0.02	0.05	0.17	0.23	0.41	0.34	0.62	3.08
1969	0.43	0.26	0.18	0.16	0.13	0.13	0.11	0.03	0.08	0.85	1.38	0.97	4.71
1970	0.51	0.29	0.23	0.20	0.14	0.09	0.12	0.17	0.12	0.69	0.54	0.46	3.55
1971	0.30	0.19	0.21	0.20	0.23	0.20	0.01	0.31	0.29	0.04	0.82	0.49	3.27
1972	0.22	0.15	0.11	0.07	0.03	0.14	0.13	0.11	0.16	0.66	0.36	0.83	2.97
1973	0.01	0.44	0.29	0.06	0.01	0.02	0.07	0.02	0.89	1.13	6.54	2.93	12.41
1974	0.11	0.38	0.24	1.01	0.12	0.03	0.09	0.99	0.38	0.56	0.45	0.73	5.10
1975	0.34	0.43	0.24	0.15	0.19	0.09	1.06	0.25	3.18	4.31	1.58	0.87	12.69
1976	0.37	0.27	0.12	0.43	0.25	0.19	0.04	3.12	2.96	4.51	3.35	1.05	16.66
1977	0.93	0.44	0.50	0.31	0.18	0.13	0.17	0.23	0.20	0.16	0.53	1.04	4.83
1978	0.68	0.31	0.07	0.21	0.10	0.16	0.11	0.05	0.61	0.52	1.03	0.41	4.25
1979	1.06	0.40	0.21	0.19	0.03	0.05	0.13	0.08	0.24	0.43	0.31	0.39	3.56
1980	0.25	0.66	0.69	0.20	0.19	0.19	0.10	0.16	0.18	0.78	3.01	2.48	8.89
1981	0.55	0.34	0.32	0.29	0.24	0.14	0.16	0.35	0.28	0.67	0.91	0.29	4.53
1982	0.54	0.25	0.16	0.19	0.07	0.14	0.05	0.09	1.97	3.35	0.86	0.83	8.51
1983	0.47	0.29	0.23	0.12	0.08	0.07	0.00	1.71	0.30	2.42	1.00	1.61	8.29
1984	1.30	0.37	0.39	0.26	0.18	0.37	0.35	0.66	1.77	1.72	2.43	0.69	10.50
1985	0.50	0.26	0.19	0.13	0.09	0.04	0.19	0.25	0.31	1.27	2.59	1.13	6.96
1986	0.49	0.33	0.14	0.09	0.10	0.09	0.08	0.18	0.44	1.20	1.08	1.07	5.28
1987	0.79	0.37	0.30	0.12	0.10	0.06	0.20	0.28	0.90	0.94	0.35	1.75	6.14
1988	0.64	0.36	0.21	0.09	0.07	0.04	0.17	0.31	0.48	0.49	0.91	1.90	5.66
1989	0.64	0.32	0.18	0.13	0.07	0.03	0.13	0.27	0.15	5.89	2.37	0.58	10.77
1990	0.25	0.11	0.07	0.04	0.09	0.07	0.04	0.09	0.41	2.91	2.96	2.02	9.06

EWR Site 4: Naturalised Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	12.70	6.00	4.58	3.50	41.29	44.71	14.22	1.97	811.01	724.00	123.90	32.59	1820.47
1921	14.07	4.79	34.39	21.22	3.91	0.45	3.90	5.58	59.39	39.24	105.93	80.79	373.66
1922	7.85	2.95	0.73	2.05	0.96	0.09	15.36	27.17	146.63	125.06	32.78	22.71	384.34
1923	10.55	7.05	2.61	0.36	0.04	0.08	0.62	0.66	52.84	31.20	33.11	24.39	163.51
1924	18.73	9.25	1.95	0.36	5.48	2.08	0.00	1.67	879.61	710.19	52.93	13.72	1695.97
1925	24.84	15.92	3.74	0.50	0.63	0.34	0.15	21.64	16.10	41.72	29.42	9.31	164.31
1926	41.91	25.15	2.02	0.32	0.22	0.12	5.12	5.93	8.14	7.00	39.81	26.64	162.38
1927	6.24	7.25	3.26	0.64	0.18	4.78	2.14	0.08	66.91	38.62	13.73	13.60	157.43
1928	9.38	4.15	1.19	0.21	0.03	0.79	2.25	9.51	27.99	98.02	69.30	38.00	260.82
1929	27.84	3.65	1.84	1.27	26.07	13.98	0.43	1.77	1.80	3.50	9.59	80.11	171.85
1930	53.19	5.70	1.60	1.23	1.02	0.08	11.72	28.66	14.37	20.57	83.34	62.29	283.77
1931	16.90	6.43	1.54	0.33	40.91	20.35	0.55	16.16	29.51	34.19	23.80	24.98	215.65
1932	15.05	7.66	3.44	0.22	0.17	1.10	0.93	29.11	72.57	124.64	73.21	22.45	350.55
1933	10.39	4.08	5.83	2.86	1.01	10.30	8.79	11.40	17.28	14.31	11.40	31.52	129.17
1934	45.46	51.34	27.77	0.54	0.16	1.02	13.86	25.13	34.79	28.70	49.84	42.65	321.26
1935	17.00	5.19	1.57	1.30	0.59	0.64	0.50	19.88	12.75	22.63	50.11	73.28	205.44
1936	36.36	17.45	26.78	6.97	1.09	6.06	6.24	14.13	80.68	108.15	43.23	14.58	361.72
1937	8.51	3.83	42.96	38.79	0.18	0.22	19.96	38.78	23.38	14.92	21.78	23.83	237.14
1938	14.84	5.77	1.72	0.37	7.94	5.70	0.58	56.86	49.46	10.23	144.60	140.06	438.13
1939	10.78	3.85	1.05	0.25	11.30	8.30	11.11	9.10	28.93	21.43	12.91	14.36	133.37
1940	8.51	7.13	3.24	6.78	3.31	0.21	30.78	140.56	177.17	100.54	54.92	88.30	621.45
1941	50.36	13.67	2.78	0.58	0.31	0.16	1.19	27.49	230.88	154.57	23.43	16.13	521.55
1942	48.80	32.23	17.31	17.42	2.01	4.34	3.20	2.96	27.92	73.23	101.73	59.73	390.88
1943	18.64	34.29	22.98	0.54	0.09	6.93	9.32	51.12	113.45	56.58	75.15	55.11	444.20
1944	21.09	11.46	3.48	0.74	0.09	1.26	4.72	73.76	131.96	133.05	93.77	32.69	508.07
1945	15.58	7.90	1.22	0.18	0.03	0.13	2.85	3.93	2.60	3.53	5.56	112.61	156.12
1946	83.74	4.48	1.01	0.16	0.01	9.98	6.79	28.37	23.67	73.72	49.17	11.28	292.38
1947	9.17	4.33	0.97	0.13	1.04	38.34	34.70	23.30	18.38	53.90	33.15	37.51	254.92
1948	25.13	7.53	1.63	0.34	0.05	0.01	3.68	4.72	6.95	12.40	26.32	21.60	110.36
1949	13.17	79.72	38.21	1.13	0.11	0.04	55.86	30.70	8.75	93.61	60.66	44.90	426.86
1950	30.82	26.90	14.81	5.17	2.24	0.10	1.18	3.65	116.28	97.90	32.01	24.02	355.08
1951	18.77	14.56	4.39	0.51	0.41	0.39	0.34	54.08	35.66	127.38	164.19	61.19	481.87
1952	13.95	83.26	60.97	0.68	4.07	3.71	93.50	88.30	23.59	84.70	71.57	23.42	551.72
1953	7.31	9.87	9.17	4.57	0.18	0.78	5.51	218.35	139.23	154.01	167.69	64.05	780.72
1954	17.72	6.82	3.77	1.34	20.25	10.26	6.18	4.96	66.99	123.08	203.03	114.84	579.24
1955	34.73	22.78	7.48	1.17	0.47	2.19	2.06	10.87	83.66	86.39	51.93	23.53	327.26
1956	9.31	3.02	0.94	0.32	28.39	19.24	2.85	73.24	155.85	148.48	107.01	44.63	593.28
1957	43.65	19.88	5.99	3.88	1.34	0.75	1.01	43.79	68.53	22.78	21.63	15.78	249.01
1958	8.22	3.97	1.12	0.17	0.55	0.57	15.45	375.50	315.66	8.16	27.49	21.93	778.79
1959	21.13	10.51	2.04	0.58	0.13	1.12	2.35	21.03	36.59	19.48	9.74	7.45	132.15
1960	4.49	1.80	3.39	3.72	0.96	6.20	162.93	150.70	66.44	89.38	42.72	45.38	578.11
1961	25.87	4.48	0.84	0.12	0.18	1.89	3.66	4.26	425.86	363.17	163.72	108.34	1102.39
1962	49.59	24.89	3.23	1.98	1.11	0.03	0.07	0.17	15.96	34.78	127.86	74.40	334.07
1963	9.46	5.59	5.06	1.72	0.38	0.21	0.41	2.43	127.49	112.68	40.03	30.18	335.64
1964	14.37	8.62	3.39	0.49	1.49	6.59	23.98	28.81	10.98	8.08	8.53	7.26	122.59
1965	5.48	2.76	1.03	0.29	0.04	1.95	2.22	1.76	22.01	53.82	29.89	14.18	135.43
1966	8.11	2.68	0.58	0.13	0.85	0.90	17.85	23.18	185.44	134.73	22.43	16.76	413.64
1967	11.61	6.35	1.97	0.34	0.10	0.08	1.69	48.49	57.22	31.47	32.63	18.31	210.26
1968	47.96	22.90	2.02	0.34	0.22	0.18	4.28	3.43	2.66	3.75	7.54	11.69	106.97
1969	21.53	10.38	1.47	0.18	0.05	0.03	0.01	15.62	79.71	80.85	68.37	36.63	314.83
1970	15.00	5.34	1.18	0.20	0.04	0.61	0.44	1.38	23.17	150.94	125.40	23.17	346.87
1971	6.96	2.11	0.45	0.60	0.56	0.37	5.82	16.30	20.35	21.96	17.45	13.24	106.17
1972	8.65	3.47	3.24	1.32	0.12	6.70	6.37	1.05	1.25	96.99	76.77	28.00	233.93
1973	14.94	5.54	2.84	1.42	6.13	6.69	1.42	22.77	96.97	84.74	367.60	252.55	863.61
1974	25.57	11.52	3.01	3.04	2.79	0.70	2.87	194.89	141.89	21.47	44.23	24.86	476.84
1975	19.00	9.12	8.85	21.75	18.98	4.59	16.48	12.92	155.28	130.19	35.08	14.93	447.17
1976	8.21	89.57	71.32	10.20	1.65	0.85	25.35	229.90	232.24	148.85	116.83	55.18	990.15
1977	16.48	6.05	15.16	10.83	0.19	1.95	3.81	3.80	2.80	2.37	50.28	38.54	152.26
1978	10.14	3.17	2.22	1.18	1.58	0.83	0.21	8.52	99.44	75.34	18.77	19.65	241.05
1979	14.61	6.19	1.19	0.45	0.37	0.21	0.92	16.51	39.02	26.83	37.66	29.53	173.49
1980	8.01	100.52	53.68	230.96	115.20	7.03	6.72	0.70	2.56	64.99	94.50	74.22	759.09
1981	26.91	6.98	1.40	0.70	0.29	3.55	49.58	36.23	17.00	22.42	15.59	7.70	188.35
1982	15.44	11.23	1.37	0.38	3.05	3.06	1.33	164.47	169.49	81.80	38.08	32.11	521.81
1983	24.09	3.76	0.93	0.17	0.03	28.72	17.70	188.36	111.90	17.42	15.03	65.83	473.94
1984	64.86	23.98	8.26	57.86	47.06	25.36	17.61	15.57	43.53	71.67	62.50	37.69	475.95
1985	17.86	6.47	24.56	19.84	0.13	2.51	2.62	4.22	167.67	163.70	87.30	52.27	549.15
1986	12.77	4.63	1.10	0.30	0.13	0.05	88.82	112.78	64.63	51.42	46.28	47.86	430.77
1987	29.18	4.05	1.08	0.30	0.05	18.71	55.65	32.72	32.54	25.34	29.31	30.17	259.10
1988	14.23	4.44	2.20	1.32	0.54	13.08	100.67	67.63	43.58	46.59	80.81	87.45	462.54
1989	36.88	10.15	2.73	0.51	1.55	1.35	247.90	240.19	71.25	92.84	52.33	16.37	774.05
1990	7.20	2.80	1.21	4.26	3.36	0.65	0.84	6.15	115.03	225.14	102.80	55.17	524.61
1991	66.06	32.22	1.84	0.25	0.74	0.84	11.49	15.25	70.31	74.59	48.26	26.56	348.41

EWR Site 4: Simulated Present Day Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	6.23	0.02	1.00	1.14	20.45	34.82	8.56	0.09	766.78	724.10	121.97	28.90	1714.05
1921	6.80	0.00	21.17	8.99	0.31	0.00	0.66	0.86	26.51	27.70	98.10	74.90	266.02
1922	2.07	0.00	0.00	0.00	0.00	0.00	3.82	5.02	106.50	121.26	31.67	18.73	289.08
1923	3.70	0.36	0.04	0.00	0.00	0.00	0.00	0.00	16.33	17.47	26.08	20.20	84.18
1924	12.78	1.28	0.00	0.00	1.49	0.17	0.00	0.63	786.45	709.53	50.62	8.85	1571.79
1925	19.64	5.66	0.00	0.00	0.00	0.00	0.00	7.38	6.75	21.40	18.40	4.59	83.83
1926	31.23	10.78	0.00	0.00	0.00	0.00	2.76	3.22	1.40	1.11	16.49	14.28	81.26
1927	0.96	0.61	0.00	0.00	0.00	1.17	0.27	0.00	25.49	22.69	7.60	9.82	68.63
1928	2.84	0.00	0.00	0.00	0.00	0.02	0.05	1.58	8.76	52.10	43.30	29.96	138.61
1929	16.45	0.00	0.00	0.02	11.81	4.88	0.00	0.80	1.09	0.45	4.07	42.88	82.44
1930	35.81	0.00	0.00	0.39	0.39	0.00	3.75	6.98	6.23	12.31	56.36	55.17	177.38
1931	10.12	0.13	0.00	0.00	12.11	7.75	0.00	7.39	18.47	31.09	21.73	21.70	130.49
1932	7.02	0.95	0.81	0.00	0.00	0.23	0.23	4.78	40.38	113.76	64.79	17.49	250.44
1933	3.54	0.00	0.33	0.09	0.24	3.87	4.09	1.71	2.92	6.68	5.82	17.37	46.65
1934	32.77	29.84	15.10	0.00	0.00	0.00	3.42	7.63	18.86	17.20	47.16	37.47	209.45
1935	8.46	0.00	0.00	0.00	0.00	0.00	0.00	3.33	2.23	12.01	29.23	65.50	120.75
1936	26.76	6.55	10.33	0.53	0.08	0.30	0.68	2.68	51.71	101.02	40.78	10.74	252.15
1937	2.53	0.00	16.07	28.83	0.00	0.00	3.17	14.51	13.37	8.58	17.88	21.15	126.09
1938	7.70	0.09	0.00	0.00	1.77	1.85	0.00	27.26	30.10	5.53	132.50	128.24	335.04
1939	3.61	0.00	0.00	0.00	2.94	2.17	2.51	2.53	9.57	11.98	6.28	6.82	48.43
1940	2.26	0.59	0.27	0.05	0.11	0.00	11.11	85.84	172.44	99.66	53.45	86.27	512.04
1941	44.29	3.80	0.00	0.00	0.00	0.00	0.39	4.88	193.46	148.69	22.33	12.12	429.96
1942	27.50	20.96	12.05	11.59	0.00	0.65	0.65	0.31	7.71	43.48	97.43	53.91	276.23
1943	11.59	18.27	13.22	0.00	0.00	2.60	3.20	17.87	97.88	52.97	73.60	50.75	341.95
1944	12.50	2.40	0.00	0.00	0.00	0.33	0.58	31.91	118.69	123.34	92.01	28.10	409.86
1945	7.24	1.08	0.00	0.00	0.00	0.01	0.83	1.17	0.31	0.44	0.76	62.38	74.22
1946	64.07	0.00	0.00	0.00	0.00	1.93	1.58	11.82	12.38	42.03	35.73	7.82	177.36
1947	3.10	0.00	0.00	0.00	0.23	13.03	19.70	8.97	10.78	38.29	30.17	35.42	159.69
1948	17.75	0.47	0.01	0.01	0.00	0.00	0.18	0.60	1.09	2.05	11.73	11.54	45.43
1949	5.17	49.20	15.79	0.00	0.00	0.00	21.55	23.02	5.31	89.52	54.99	41.72	306.27
1950	22.51	11.67	3.07	0.33	0.31	0.00	0.00	0.59	69.73	92.50	30.53	21.09	252.33
1951	11.02	4.36	0.00	0.00	0.06	0.06	0.00	18.54	21.95	100.77	158.78	55.99	371.54
1952	6.28	65.76	48.45	0.00	1.33	1.34	45.95	83.42	21.92	82.66	69.70	18.64	445.45
1953	1.69	2.18	1.26	1.39	0.00	0.18	1.84	152.44	136.41	153.80	166.76	59.16	677.09
1954	10.75	0.17	0.00	0.00	3.01	1.35	1.65	1.61	43.57	106.03	201.19	109.62	478.96
1955	28.74	10.35	1.15	0.02	0.04	0.68	0.72	1.69	43.10	79.49	48.92	19.55	234.46
1956	2.77	0.00	0.04	0.04	6.46	5.22	0.45	39.93	141.88	145.00	105.53	39.77	487.09
1957	38.29	7.43	1.38	1.38	0.00	0.00	0.12	20.55	37.37	13.71	20.85	12.26	153.34
1958	2.33	0.00	0.00	0.00	0.07	0.07	2.35	305.33	313.41	6.84	25.94	17.59	673.93
1959	12.84	1.33	0.00	0.00	0.00	0.00	0.00	3.57	16.98	10.38	5.45	3.40	53.93
1960	0.12	0.00	0.77	1.01	0.13	2.68	131.16	144.58	55.51	75.78	28.15	26.15	466.03
1961	12.81	0.00	0.00	0.00	0.00	0.00	0.18	0.49	348.98	362.16	163.86	102.44	990.94
1962	43.70	12.64	0.00	0.31	0.31	0.00	0.01	0.01	5.56	12.73	102.34	67.73	245.33
1963	2.93	0.01	0.02	0.01	0.00	0.00	0.00	0.16	73.53	91.94	31.23	26.25	226.07
1964	6.07	1.14	0.04	0.00	0.00	0.63	10.67	11.29	4.37	4.09	4.32	2.94	45.55
1965	0.74	0.11	0.03	0.00	0.00	0.00	0.03	0.10	4.37	25.35	16.72	7.01	54.46
1966	1.97	0.00	0.00	0.00	0.18	0.22	8.70	13.99	115.80	114.98	21.23	13.40	290.47
1967	4.89	0.12	0.01	0.00	0.00	0.00	0.00	24.89	29.48	18.32	20.67	14.15	112.54
1968	42.46	10.37	0.00	0.00	0.05	0.05	0.83	1.07	0.34	0.48	1.09	1.65	58.39
1969	7.48	1.70	0.00	0.00	0.00	0.00	0.00	3.72	38.01	58.76	65.09	32.82	207.58
1970	8.05	0.00	0.00	0.00	0.00	0.06	0.06	0.01	3.97	79.64	113.85	18.34	223.99
1971	1.35	0.00	0.00	0.04	0.06	0.02	0.57	2.54	4.47	12.39	9.25	6.35	37.05
1972	2.47	0.00	0.00	0.00	0.00	3.64	4.04	0.00	0.12	44.22	54.41	24.84	133.74
1973	8.16	0.00	0.19	0.18	2.86	3.44	0.43	3.92	57.51	63.94	355.02	247.47	743.11
1974	19.11	2.55	0.00	0.73	0.93	0.18	0.06	130.22	135.64	20.80	43.45	20.88	374.57
1975	13.08	1.18	2.82	13.10	14.32	1.68	6.57	6.36	111.26	128.82	32.77	11.25	343.22
1976	2.25	71.23	52.59	0.43	0.10	0.10	9.00	200.74	230.56	148.49	116.05	49.55	881.09
1977	9.21	0.05	4.41	6.04	0.01	0.10	0.58	0.65	0.40	0.25	20.39	22.89	64.97
1978	3.24	0.00	0.10	0.10	0.00	0.00	0.00	1.27	45.57	54.58	11.24	15.26	131.36
1979	7.78	0.09	0.00	0.00	0.00	0.02	0.02	3.47	16.20	16.20	24.44	19.04	87.26
1980	2.25	67.44	32.02	216.23	103.65	4.04	4.55	0.00	0.31	44.00	89.40	69.88	633.76
1981	18.66	0.31	0.01	0.01	0.00	0.00	18.54	22.96	9.78	13.93	8.88	3.08	96.15
1982	7.25	4.39	0.02	0.00	0.00	0.00	0.00	106.63	157.67	81.04	35.98	26.49	419.47
1983	13.95	0.00	0.00	0.00	0.00	7.47	4.13	140.51	107.71	16.79	13.30	62.83	366.69
1984	55.34	10.23	0.30	38.14	36.98	9.87	8.83	9.36	38.35	70.72	61.23	34.15	373.50
1985	9.44	0.66	11.81	13.79	0.00	0.00	0.27	0.63	129.83	147.01	77.33	46.97	437.73
1986	5.74	0.01	0.00	0.00	0.00	0.00	60.22	76.30	47.40	49.45	43.92	43.52	326.55
1987	17.96	0.00	0.00	0.00	0.00	7.02	25.20	19.30	19.32	14.97	24.78	26.09	154.63
1988	6.63	0.00	0.32	0.32	0.00	1.44	63.95	57.05	24.86	45.66	79.61	85.18	365.02
1989	30.01	1.93	0.00	0.00	0.38	0.38	196.69	216.14	70.73	92.65	49.43	12.36	670.70
1990	1.53	0.00	0.00	1.17	1.17	0.20	0.20	0.81	58.93	208.01	99.20	51.98	423.21
1991	55.38	19.92	0.00	0.00	0.00	0.00	1.53	2.38	39.82	72.35	47.04	23.29	261.72

EWR Site 5: Naturalised Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	12.70	6.00	5.90	4.82	44.81	49.28	15.26	1.97	1059.75	1018.59	173.12	35.97	2428.17
1921	14.07	4.81	34.41	21.28	3.97	0.45	3.90	5.58	63.44	43.29	148.59	123.45	467.24
1922	7.85	2.96	0.74	2.05	0.96	0.09	15.36	27.74	212.56	190.45	34.05	23.96	518.77
1923	10.55	7.05	2.61	0.36	0.04	0.08	0.62	0.66	53.92	32.30	34.81	26.07	169.07
1924	18.73	9.36	2.06	0.36	5.48	2.08	0.00	2.78	1095.75	940.92	70.79	15.88	2164.19
1925	24.85	15.93	3.74	0.50	0.63	0.34	0.15	26.46	20.92	47.79	35.49	9.31	186.11
1926	47.55	30.79	2.02	0.32	0.22	0.12	8.64	9.45	8.18	7.04	44.23	31.06	189.62
1927	6.24	7.25	3.26	0.64	0.18	4.78	2.14	0.08	71.27	43.16	13.92	13.89	166.81
1928	9.66	4.15	1.19	0.21	0.03	0.79	2.39	10.04	33.58	106.11	73.30	52.40	293.85
1929	41.12	3.65	1.84	1.27	26.07	13.98	0.43	3.03	3.06	3.61	13.03	107.37	218.46
1930	77.12	5.70	1.60	1.23	1.02	0.08	14.89	31.86	14.40	25.15	110.50	84.87	368.42
1931	17.00	6.53	1.54	0.33	42.76	22.20	0.55	16.40	33.62	40.06	25.80	24.98	231.77
1932	15.05	7.66	3.44	0.22	0.17	1.19	1.02	29.11	80.56	146.99	88.79	23.65	397.85
1933	10.39	4.08	5.83	2.86	1.05	13.32	11.77	11.44	17.48	14.74	11.67	31.72	136.35
1934	45.76	66.12	42.45	0.54	0.16	1.02	14.18	28.73	38.67	30.10	59.98	56.93	384.64
1935	21.96	5.19	1.57	1.30	0.59	0.64	0.50	20.32	13.19	24.06	53.10	81.07	223.49
1936	42.61	22.98	32.31	6.97	1.09	6.54	6.72	14.20	96.91	127.07	46.00	14.58	417.98
1937	8.51	3.83	43.02	38.85	0.18	0.22	20.05	40.95	25.45	14.99	21.84	24.36	242.25
1938	15.38	5.78	1.72	0.37	8.83	6.59	0.58	76.77	69.40	11.06	202.66	197.38	596.52
1939	10.83	3.85	1.05	0.25	11.69	8.69	13.03	11.02	30.22	22.72	12.96	14.59	140.90
1940	8.68	7.45	3.56	7.24	3.77	0.21	35.79	176.24	245.48	143.20	67.60	96.71	795.93
1941	51.13	13.68	2.78	0.58	0.31	0.16	1.36	27.99	311.43	234.79	23.91	16.61	684.73
1942	52.65	36.08	18.32	18.43	2.01	4.34	3.20	3.21	32.04	81.53	117.03	70.64	439.48
1943	18.66	39.04	27.73	0.54	0.09	6.98	9.37	53.30	128.20	69.20	78.25	58.53	489.89
1944	22.02	12.03	3.48	0.74	0.09	1.27	4.76	80.09	148.89	158.23	110.58	34.96	577.14
1945	15.59	7.91	1.22	0.18	0.03	0.13	3.84	4.92	2.60	3.54	5.61	148.69	194.26
1946	119.81	4.52	1.01	0.16	0.01	10.12	6.93	35.64	30.94	88.68	64.23	11.39	373.44
1947	9.18	4.33	0.97	0.13	1.09	40.28	36.70	26.17	21.18	57.42	36.64	38.37	272.46
1948	26.03	7.56	1.63	0.34	0.05	0.01	3.85	4.90	6.96	12.76	28.38	23.54	116.01
1949	13.93	81.06	39.02	1.13	0.11	0.04	57.08	31.97	8.80	117.40	84.45	47.80	482.79
1950	33.72	27.70	15.68	5.24	2.24	0.10	1.18	4.31	143.72	125.12	33.24	24.80	417.05
1951	19.52	15.39	4.48	0.51	0.41	0.39	0.34	56.59	38.29	144.60	196.43	77.05	554.00
1952	14.69	86.16	63.87	0.68	4.07	3.71	108.83	106.37	26.32	95.09	85.60	27.05	622.44
1953	7.31	9.87	10.22	5.62	0.18	0.93	7.74	235.90	154.84	180.41	204.33	74.43	891.78
1954	17.72	6.82	3.77	1.34	20.61	10.65	7.36	6.10	91.54	152.27	244.61	151.78	714.57
1955	35.91	25.07	8.61	1.17	0.47	2.71	2.58	11.04	93.78	102.57	58.98	24.33	367.22
1956	9.33	3.04	0.95	0.33	29.73	20.59	2.85	82.66	180.06	186.88	140.07	54.10	710.59
1957	44.33	20.53	6.12	4.01	1.34	0.75	1.01	56.11	80.91	22.85	21.98	16.13	276.07
1958	8.22	3.97	1.12	0.17	0.55	0.57	16.23	536.79	476.17	8.16	31.56	26.00	1109.51
1959	21.13	10.51	2.04	0.58	0.13	1.12	2.48	21.74	37.20	19.52	9.74	7.45	133.64
1960	4.49	1.80	3.82	4.45	1.26	7.50	225.19	212.13	114.74	145.15	50.97	48.26	819.76
1961	28.46	4.48	0.84	0.12	0.18	1.89	3.70	4.30	593.82	537.79	200.76	138.73	1515.07
1962	50.38	25.67	3.23	1.98	1.11	0.03	0.07	0.17	20.25	41.47	153.52	97.67	395.55
1963	9.46	5.89	5.36	1.72	0.38	0.21	0.41	2.43	174.88	160.07	40.60	30.89	432.30
1964	14.51	8.91	3.68	0.49	1.49	7.09	30.99	35.32	10.98	8.08	8.53	7.26	137.33
1965	5.51	2.79	1.03	0.29	0.04	2.02	2.29	1.76	23.25	56.96	32.01	14.42	142.37
1966	8.13	2.68	0.58	0.13	0.85	1.22	24.15	35.24	250.45	193.66	22.60	16.93	556.62
1967	11.61	6.42	2.04	0.34	0.10	0.11	1.74	65.62	75.26	34.16	34.82	18.73	250.95
1968	49.22	24.16	2.02	0.34	0.22	0.18	5.53	4.68	2.66	3.75	7.55	11.70	112.01
1969	22.07	10.92	1.47	0.18	0.05	0.03	0.01	17.83	88.35	93.33	74.81	37.01	346.06
1970	15.01	5.35	1.18	0.20	0.04	0.62	0.45	1.38	23.61	167.43	144.19	25.92	385.38
1971	6.96	2.11	0.45	1.00	0.96	0.58	6.03	16.36	21.40	23.05	17.58	13.36	109.84
1972	8.72	3.47	3.24	1.32	0.12	10.75	10.42	1.07	1.27	110.03	91.06	29.27	270.74
1973	14.95	5.55	3.44	2.02	9.20	9.91	1.56	23.00	127.07	114.62	459.90	344.83	1116.05
1974	25.81	11.78	3.02	3.60	3.36	0.75	2.91	243.73	190.76	21.58	44.66	25.21	577.17
1975	19.15	9.27	10.05	24.98	21.71	5.31	21.42	17.87	191.69	171.96	40.50	14.95	548.86
1976	8.21	102.35	84.46	10.56	1.71	0.91	27.69	311.41	319.66	165.42	131.59	61.67	1225.64
1977	16.53	6.14	15.25	10.84	0.19	2.00	3.93	3.88	2.80	2.37	57.79	46.06	167.78
1978	10.18	3.21	2.22	1.18	1.58	0.83	0.21	8.72	111.02	86.77	19.50	20.37	265.79
1979	14.96	6.49	1.19	0.45	0.37	0.21	0.92	18.14	48.10	34.30	49.12	40.99	215.24
1980	8.01	104.08	57.24	230.96	115.20	7.44	7.13	0.70	2.56	74.53	114.99	86.53	809.37
1981	28.48	7.19	1.40	0.71	0.30	3.58	54.03	40.71	19.00	27.35	18.57	7.70	209.02
1982	20.17	15.96	1.37	0.38	3.05	3.06	1.33	233.77	247.89	93.11	40.29	42.27	702.65
1983	34.26	3.76	0.93	0.17	0.03	28.92	17.90	217.25	140.79	17.67	15.29	71.08	548.05
1984	74.45	28.31	8.37	69.55	58.62	26.54	19.01	19.65	47.49	72.57	63.71	39.74	528.01
1985	19.49	7.21	33.00	27.55	0.13	2.51	2.63	4.23	259.87	258.37	97.15	59.68	771.82
1986	12.79	4.63	1.10	0.30	0.13	0.05	97.64	121.65	67.31	61.81	55.59	56.16	479.16
1987	35.93	4.05	1.08	0.30	0.05	19.27	68.46	44.98	36.29	29.10	30.95	32.20	302.66
1988	14.63	4.44	2.50	1.62	0.54	13.10	102.44	69.38	44.60	47.82	84.86	91.78	477.71
1989	37.37	10.15	2.73	0.51	1.55	1.35	294.24	293.37	83.79	105.12	58.92	16.37	905.47
1990	7.20	2.80	1.21	4.29	3.39	0.66	0.84	6.19	141.02	283.33	135.03	63.56	649.52
1991	79.83	37.60	1.84	0.25	0.74	0.84	11.49	15.25	73.74	78.77	49.11	26.67	376.13

EWR Site 5: Simulated Present Day Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	6.23	0.02	0.43	0.43	19.49	34.89	8.01	0.09	1015.19	1018.70	170.71	30.89	2305.08
1921	6.80	0.00	21.17	8.99	0.31	0.00	0.66	0.86	27.44	30.43	140.60	116.16	353.43
1922	2.07	0.00	0.00	0.00	0.00	0.00	3.82	4.90	168.65	186.21	32.36	18.65	416.66
1923	3.70	0.36	0.04	0.00	0.00	0.00	0.00	0.00	16.59	17.42	26.11	19.83	84.06
1924	12.78	1.28	0.00	0.00	1.49	0.17	0.00	0.69	999.23	940.13	67.95	9.71	2033.43
1925	19.64	5.66	0.00	0.00	0.00	0.00	0.00	8.23	10.69	27.24	23.77	4.59	99.82
1926	34.43	13.21	0.00	0.00	0.00	0.00	2.94	4.23	1.39	1.11	20.02	17.38	94.71
1927	0.96	0.61	0.00	0.00	0.00	1.17	0.27	0.00	26.48	26.19	7.51	9.69	72.88
1928	2.79	0.00	0.00	0.00	0.00	0.02	0.04	1.43	10.34	59.88	46.71	43.46	164.68
1929	27.47	0.00	0.00	0.02	11.81	4.88	0.00	0.89	1.13	0.40	4.48	69.32	120.39
1930	57.52	0.00	0.00	0.39	0.39	0.00	3.83	7.37	6.23	16.47	83.24	76.51	251.95
1931	10.12	0.13	0.00	0.00	11.14	6.57	0.00	7.33	19.19	35.82	22.98	21.70	134.97
1932	7.02	0.95	0.81	0.00	0.00	0.23	0.23	4.78	44.45	135.97	79.79	17.42	291.65
1933	3.54	0.00	0.33	0.09	0.24	3.28	3.82	1.71	2.80	6.51	5.67	17.29	45.29
1934	32.69	39.70	25.83	0.00	0.00	0.00	3.35	8.15	21.03	18.22	56.90	50.73	256.60
1935	11.18	0.00	0.00	0.00	0.00	0.00	0.00	3.17	2.16	12.08	29.52	71.71	129.82
1936	30.76	9.17	11.94	0.53	0.08	0.20	0.55	2.68	63.89	119.65	42.81	10.74	293.00
1937	2.53	0.00	16.07	28.83	0.00	0.00	3.17	14.81	13.57	8.56	17.88	20.84	126.26
1938	7.44	0.09	0.00	0.00	1.52	1.39	0.00	42.82	49.60	5.97	190.47	184.30	483.60
1939	3.61	0.00	0.00	0.00	2.90	2.10	2.22	2.47	9.65	11.99	6.28	6.76	47.98
1940	2.26	0.58	0.28	0.01	0.01	0.00	11.47	120.65	240.77	142.07	65.70	93.52	677.32
1941	43.87	3.80	0.00	0.00	0.00	0.00	0.37	4.71	270.15	228.33	22.19	11.85	585.28
1942	29.20	21.56	11.56	11.13	0.00	0.65	0.65	0.24	8.59	50.73	112.34	63.64	310.29
1943	11.59	19.20	13.98	0.00	0.00	2.60	3.20	18.15	110.02	65.08	76.18	52.97	372.98
1944	11.95	2.19	0.00	0.00	0.00	0.33	0.58	33.93	135.50	148.39	108.29	28.98	470.13
1945	7.24	1.08	0.00	0.00	0.00	0.01	0.44	0.90	0.31	0.44	0.76	93.85	105.04
1946	98.03	0.00	0.00	0.00	0.00	1.93	1.57	14.78	19.18	56.85	50.12	7.81	250.27
1947	3.10	0.00	0.00	0.00	0.23	12.22	19.27	9.19	12.66	41.52	32.87	35.14	166.21
1948	17.23	0.47	0.01	0.01	0.00	0.00	0.17	0.55	1.09	2.00	11.88	11.26	44.66
1949	4.75	48.42	15.47	0.00	0.00	0.00	21.22	22.82	5.31	110.20	77.97	43.57	349.71
1950	23.25	11.31	2.70	0.33	0.31	0.00	0.00	0.52	93.43	119.29	31.15	20.63	302.92
1951	10.62	3.97	0.00	0.00	0.06	0.06	0.00	18.90	22.26	117.57	190.67	70.71	434.82
1952	5.88	65.30	47.35	0.00	1.33	1.34	56.38	100.84	24.23	92.87	83.24	20.88	499.64
1953	1.69	2.18	0.89	0.89	0.00	0.18	1.64	166.76	151.62	180.17	203.02	68.24	777.29
1954	10.75	0.17	0.00	0.00	2.98	1.29	1.19	1.37	65.03	134.98	242.57	145.22	605.55
1955	28.00	9.62	0.60	0.02	0.04	0.56	0.55	1.62	49.09	95.44	55.37	19.06	259.97
1956	2.77	0.00	0.04	0.04	5.85	4.40	0.45	44.93	166.03	183.34	138.20	47.98	594.03
1957	37.92	7.19	1.38	1.38	0.00	0.00	0.12	28.64	49.34	13.70	20.63	12.10	172.40
1958	2.33	0.00	0.00	0.00	0.07	0.07	2.09	462.67	473.50	6.84	29.33	20.40	997.30
1959	12.84	1.33	0.00	0.00	0.00	0.00	0.00	3.51	16.85	10.38	5.45	3.40	53.75
1960	0.12	0.00	0.73	0.87	0.14	1.93	188.55	205.28	103.83	131.34	35.74	27.93	696.47
1961	13.16	0.00	0.00	0.00	0.00	0.00	0.18	0.49	513.17	536.55	200.67	131.58	1395.82
1962	43.25	12.28	0.00	0.31	0.31	0.00	0.01	0.01	6.53	18.44	127.73	89.73	298.60
1963	2.93	0.01	0.03	0.01	0.00	0.00	0.00	0.16	117.15	138.80	31.17	25.80	316.06
1964	6.07	1.14	0.05	0.00	0.00	0.53	12.56	17.03	4.37	4.09	4.32	2.94	53.09
1965	0.74	0.11	0.03	0.00	0.00	0.00	0.03	0.10	4.67	25.79	17.42	6.92	55.80
1966	1.97	0.00	0.00	0.00	0.18	0.19	9.93	25.49	180.82	173.45	21.15	13.35	426.53
1967	4.89	0.12	0.01	0.00	0.00	0.00	0.00	37.82	47.21	20.67	22.22	13.93	146.87
1968	41.67	9.66	0.00	0.00	0.05	0.05	0.51	0.83	0.34	0.48	1.09	1.65	56.33
1969	7.31	1.53	0.00	0.00	0.00	0.00	0.00	4.02	43.99	71.02	70.86	32.63	231.37
1970	8.05	0.00	0.00	0.00	0.00	0.06	0.06	0.01	4.00	92.29	132.11	19.71	256.31
1971	1.35	0.00	0.00	0.02	0.02	0.02	0.54	2.54	4.64	12.35	9.20	6.35	37.02
1972	2.47	0.00	0.00	0.00	0.00	3.28	4.74	0.00	0.12	56.59	68.11	24.83	160.14
1973	8.16	0.00	0.08	0.08	1.83	2.62	0.43	3.83	85.60	93.40	447.35	338.50	981.88
1974	19.07	2.56	0.00	0.64	0.79	0.18	0.06	174.94	184.09	20.75	43.19	20.72	466.99
1975	13.08	1.18	2.26	11.62	13.16	1.35	8.32	10.47	147.69	170.34	37.53	11.25	428.27
1976	2.25	79.77	61.91	0.43	0.10	0.10	8.87	279.45	317.83	164.86	130.37	54.77	1100.72
1977	9.21	0.05	4.41	6.04	0.01	0.10	0.58	0.65	0.40	0.25	23.73	29.16	74.58
1978	3.24	0.00	0.10	0.10	0.00	0.00	0.00	1.20	53.23	65.52	11.36	14.81	149.56
1979	7.67	0.09	0.00	0.00	0.00	0.02	0.02	3.65	22.18	23.08	35.53	29.20	121.44
1980	2.25	67.16	31.60	216.23	103.65	3.97	4.45	0.00	0.31	49.46	109.50	81.06	669.63
1981	18.15	0.31	0.01	0.01	0.00	0.00	18.90	25.64	11.51	18.54	11.18	3.08	107.32
1982	9.54	5.87	0.02	0.00	0.00	0.00	0.00	171.99	235.94	92.04	37.53	35.73	588.66
1983	21.85	0.00	0.00	0.00	0.00	7.47	4.11	165.24	136.06	16.65	13.18	66.95	431.50
1984	63.01	11.32	0.30	44.65	45.35	9.17	8.51	12.82	41.90	71.23	61.79	35.10	405.14
1985	8.97	0.33	15.91	17.39	0.00	0.00	0.27	0.63	218.62	241.38	86.74	53.17	643.41
1986	5.74	0.01	0.00	0.00	0.00	0.00	64.06	84.35	49.82	59.63	52.68	50.84	367.13
1987	22.43	0.00	0.00	0.00	0.00	6.89	32.92	30.72	22.85	18.28	25.86	26.93	186.88
1988	6.49	0.00	0.33	0.33	0.00	1.44	63.74	56.96	24.89	45.67	82.56	88.33	370.73
1989	29.79	1.93	0.00	0.00	0.38	0.38	238.29	268.76	83.09	104.70	55.26	12.36	794.95
1990	1.53	0.00	0.00	1.17	1.17	0.20	0.20	0.81	81.15	266.19	130.71	59.40	542.53
1991	67.25	22.07	0.00	0.00	0.00	0.00	1.53	2.38	40.60	74.80	47.20	23.28	279.12

EWR Site 6: Naturalised Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	6.75	3.19	0.90	0.51	2.46	1.53	1.69	1.05	95.12	75.38	30.42	15.27	234.27
1921	7.48	2.54	2.35	3.23	1.28	0.22	1.13	2.53	25.44	15.91	29.35	16.02	107.48
1922	4.16	1.56	0.38	1.07	0.51	0.05	5.82	13.19	31.94	21.06	16.65	11.31	107.70
1923	5.61	3.39	1.23	0.19	0.02	0.04	0.33	0.35	27.50	15.98	16.10	11.59	82.33
1924	9.95	4.86	0.98	0.19	0.18	0.04	0.00	0.26	83.27	54.95	14.53	5.63	174.84
1925	13.20	8.46	1.99	0.27	0.33	0.18	0.08	7.32	4.41	18.64	12.13	4.95	71.96
1926	16.62	8.20	1.07	0.17	0.11	0.07	0.67	1.11	4.08	3.54	14.00	9.27	58.91
1927	3.32	3.85	1.72	0.34	0.09	0.24	0.12	0.04	32.88	17.82	7.19	7.08	74.69
1928	4.83	2.21	0.63	0.11	0.02	0.04	0.95	4.59	11.66	23.24	17.70	9.79	75.77
1929	5.12	1.94	0.98	0.43	1.21	0.60	0.23	0.20	0.22	1.80	2.79	25.71	41.23
1930	14.07	3.03	0.85	0.13	0.03	0.04	3.57	12.98	7.61	6.60	26.09	19.34	94.34
1931	8.90	3.33	0.82	0.18	19.38	8.47	0.29	7.42	12.32	14.44	11.33	11.87	98.75
1932	7.36	2.54	0.61	0.12	0.09	0.20	0.13	15.36	31.31	48.19	24.76	10.07	140.74
1933	5.52	2.11	1.36	0.56	0.12	1.19	0.69	6.03	9.08	7.36	5.89	16.64	56.55
1934	20.49	9.97	2.23	0.29	0.09	0.54	4.89	9.15	14.42	13.36	20.54	14.49	110.46
1935	6.23	2.66	0.80	0.69	0.31	0.29	0.25	10.15	6.39	9.85	21.14	31.43	90.19
1936	14.92	3.47	4.18	1.70	0.15	2.77	3.05	7.47	29.85	42.84	21.28	7.75	139.43
1937	4.52	1.88	0.64	0.25	0.09	0.04	10.01	18.56	10.82	7.88	11.53	12.37	78.59
1938	7.59	2.93	0.87	0.20	0.53	0.28	0.31	12.09	8.12	4.85	12.76	11.62	62.15
1939	5.69	2.05	0.56	0.12	1.28	0.69	4.72	3.72	14.66	10.68	5.56	6.46	56.19
1940	4.42	2.43	0.92	3.34	1.51	0.11	7.72	40.75	47.44	27.74	21.70	42.28	200.36
1941	26.30	7.25	1.47	0.31	0.16	0.09	0.04	13.53	72.31	34.13	12.18	8.30	176.07
1942	5.66	2.47	0.62	1.19	1.07	1.16	0.75	1.45	12.09	33.62	43.93	23.92	127.93
1943	9.73	5.97	2.05	0.29	0.05	0.24	1.51	25.93	51.53	22.67	35.52	23.79	179.28
1944	8.80	4.66	1.85	0.40	0.05	0.03	1.98	34.51	56.07	48.19	35.29	16.07	207.90
1945	6.57	2.68	0.65	0.09	0.02	0.05	0.47	1.07	1.38	1.87	2.92	28.14	45.91
1946	14.63	2.36	0.54	0.09	0.01	2.59	1.33	6.46	4.32	30.46	17.40	5.94	86.13
1947	4.87	2.29	0.51	0.07	0.22	6.31	6.68	10.11	7.88	26.51	15.55	19.47	100.47
1948	12.23	3.48	0.85	0.16	0.02	0.00	1.86	2.40	3.69	6.40	12.86	10.42	54.37
1949	6.58	31.14	13.27	0.60	0.06	0.02	28.72	13.07	2.34	35.42	18.00	21.19	170.41
1950	13.75	9.42	3.85	1.24	0.44	0.05	0.63	1.49	42.48	33.55	16.24	12.34	135.48
1951	8.63	6.38	2.29	0.27	0.13	0.13	0.18	27.35	17.46	28.56	38.86	19.63	149.87
1952	7.00	7.06	2.92	0.36	0.38	0.21	36.89	33.70	11.04	35.18	27.20	10.39	172.33
1953	3.89	5.25	3.14	0.71	0.09	0.09	1.40	60.35	34.09	63.76	64.89	26.91	264.57
1954	9.41	3.62	2.00	0.71	8.93	4.13	1.47	1.11	14.19	41.24	79.41	37.27	203.49
1955	17.78	9.83	2.53	0.60	0.20	0.06	0.07	5.67	35.38	32.72	22.59	12.06	139.49
1956	4.94	1.60	0.44	0.12	9.05	4.39	0.87	33.12	58.58	47.16	32.08	16.39	208.74
1957	22.83	10.21	1.15	0.13	0.71	0.40	0.36	8.66	23.71	12.06	11.31	8.19	99.72
1958	4.37	2.11	0.60	0.09	0.16	0.19	7.76	42.44	20.09	4.34	11.95	9.01	103.11
1959	8.45	3.97	1.09	0.31	0.07	0.60	1.18	10.72	19.03	10.32	5.18	3.96	64.88
1960	2.39	0.96	0.45	0.41	0.18	0.09	1.11	1.78	6.51	7.64	11.58	19.86	52.96
1961	10.33	2.38	0.44	0.06	0.09	1.00	1.92	2.24	52.39	31.65	37.56	20.73	160.79
1962	24.99	12.11	1.72	0.33	0.08	0.02	0.02	0.07	6.05	14.49	51.31	24.89	136.08
1963	5.03	2.80	2.35	0.84	0.20	0.11	0.22	1.29	19.36	16.42	20.96	14.72	84.30
1964	6.69	4.36	1.60	0.26	0.80	2.54	3.70	7.22	5.83	4.29	4.54	3.85	45.68
1965	2.78	1.31	0.51	0.15	0.02	1.00	1.05	0.89	10.77	26.68	14.70	7.38	67.24
1966	4.29	1.43	0.31	0.07	0.03	0.01	2.53	2.50	41.91	25.45	11.83	8.82	99.18
1967	6.17	3.31	0.98	0.18	0.05	0.02	0.87	7.77	13.10	14.77	15.74	9.50	72.46
1968	24.32	11.06	1.07	0.18	0.05	0.03	1.38	0.98	1.42	2.00	4.01	6.21	52.71
1969	11.12	5.20	0.78	0.09	0.03	0.02	0.00	7.05	34.05	32.10	30.72	18.48	139.64
1970	7.96	2.83	0.63	0.11	0.02	0.20	0.14	0.73	12.04	27.28	23.49	10.71	86.14
1971	3.70	1.12	0.24	0.09	0.07	0.04	2.94	8.61	10.19	11.04	9.19	6.97	54.20
1972	4.56	1.84	1.72	0.71	0.06	0.26	0.16	0.55	0.65	36.02	26.66	14.00	87.19
1973	7.94	2.94	1.07	0.33	0.19	0.12	0.11	11.57	24.11	19.79	95.60	50.31	214.08
1974	13.46	5.98	1.60	0.38	0.11	0.05	1.45	33.80	17.04	11.21	23.28	13.02	121.38
1975	10.01	4.76	0.86	0.23	0.14	0.25	4.45	3.01	55.91	40.60	15.16	7.93	143.31
1976	4.36	30.05	22.79	5.23	0.53	0.22	4.79	59.03	66.87	67.62	46.64	20.93	329.06
1977	8.74	3.16	1.07	0.32	0.08	0.89	1.08	1.36	1.47	1.25	21.94	15.95	57.31
1978	5.37	1.67	0.84	0.42	0.84	0.44	0.11	4.41	23.07	16.80	9.12	9.65	72.74
1979	7.47	3.03	0.63	0.24	0.20	0.09	0.47	7.77	13.19	7.74	12.48	8.33	61.64
1980	4.18	29.31	13.14	9.06	3.36	0.27	0.35	0.38	1.36	28.27	30.92	27.66	148.26
1981	12.77	3.23	0.73	0.36	0.16	1.87	10.00	6.02	7.54	8.76	6.59	4.09	62.12
1982	4.23	2.16	0.71	0.20	1.62	1.63	0.71	43.23	41.72	36.93	19.00	9.37	161.51
1983	5.39	2.00	0.49	0.09	0.02	9.21	5.69	63.54	29.66	9.12	7.86	31.08	164.15
1984	24.77	7.23	4.34	4.53	1.96	12.69	8.55	5.37	19.89	36.80	32.26	18.43	176.82
1985	8.13	2.63	1.06	0.36	0.07	1.33	1.04	1.89	17.17	17.43	36.85	21.37	109.33
1986	6.77	2.45	0.58	0.16	0.07	0.02	2.64	24.43	32.09	20.38	18.48	14.87	122.94
1987	7.22	2.15	0.57	0.16	0.02	1.54	12.24	6.82	14.64	11.07	13.13	13.81	83.37
1988	7.32	2.36	0.58	0.13	0.29	6.95	8.40	5.69	22.55	24.06	40.38	43.93	162.64
1989	19.32	5.39	1.45	0.27	0.21	0.18	13.53	28.56	27.61	39.74	22.65	8.70	167.61
1990	3.83	1.49	0.64	0.29	0.10	0.04	0.16	3.25	37.17	73.42	32.67	23.01	176.07
1991	14.23	4.26	0.98	0.13	0.39	0.45	6.10	8.10	34.06	36.13	25.01	14.06	143.90

EWR Site 6: Simulated Present Day Monthly Hydrology

	O	N	D	J	F	M	A	M	J	J	A	S	TOT
1920	4.57	0.68	0.14	0.07	0.84	0.72	0.47	0.22	78.85	75.70	30.48	14.52	207.28
1921	4.94	0.51	1.03	0.89	0.21	0.02	0.21	0.59	14.56	12.64	29.55	14.52	79.65
1922	1.91	0.26	0.04	0.17	0.07	0.00	1.26	5.14	23.35	21.09	16.67	10.21	80.17
1923	3.10	0.92	0.19	0.02	0.00	0.00	0.06	0.06	12.20	10.54	15.80	10.68	53.57
1924	8.10	1.78	0.14	0.02	0.10	0.02	0.00	0.05	61.78	55.12	14.05	4.27	145.41
1925	11.76	4.70	0.35	0.03	0.05	0.01	0.01	1.52	1.08	11.81	8.76	3.71	43.78
1926	15.31	4.06	0.17	0.01	0.01	0.00	0.10	0.18	0.78	0.87	7.14	5.81	34.44
1927	1.27	1.30	0.30	0.04	0.00	0.10	0.04	0.00	15.84	11.76	5.08	6.24	41.96
1928	2.41	0.43	0.09	0.00	0.00	0.00	0.15	0.81	3.58	15.64	15.43	8.74	47.29
1929	2.50	0.37	0.15	0.07	0.46	0.17	0.03	0.03	0.04	0.33	0.68	13.18	18.02
1930	8.55	0.64	0.13	0.00	0.00	0.00	0.63	4.14	4.92	4.37	19.78	18.73	61.89
1931	6.62	0.71	0.12	0.01	8.60	4.32	0.04	4.40	9.72	14.52	11.05	11.29	71.42
1932	4.85	0.55	0.10	0.00	0.00	0.02	0.01	3.67	21.31	48.49	24.49	9.14	112.63
1933	2.98	0.42	0.27	0.10	0.00	0.19	0.12	1.34	3.45	4.81	3.72	11.35	28.74
1934	19.04	6.15	0.47	0.03	0.00	0.08	1.01	3.11	9.56	10.67	20.64	13.61	84.36
1935	3.53	0.55	0.12	0.10	0.04	0.04	0.04	2.24	2.88	6.55	15.43	31.42	62.93
1936	12.41	0.89	1.26	0.32	0.02	0.51	0.70	3.47	21.99	43.09	20.86	6.37	111.88
1937	2.22	0.37	0.18	0.06	0.00	0.00	2.17	10.14	7.13	5.88	11.46	11.76	51.37
1938	5.17	0.62	0.13	0.02	0.12	0.05	0.04	2.74	4.79	3.11	8.49	8.74	34.01
1939	3.01	0.39	0.08	0.00	0.26	0.13	0.96	0.90	7.65	6.99	3.46	4.02	27.85
1940	2.06	0.52	0.14	0.63	0.26	0.01	1.86	29.84	47.69	27.85	21.77	42.44	175.06
1941	24.53	3.38	0.23	0.03	0.01	0.00	0.00	3.16	63.92	33.91	12.11	7.04	148.33
1942	3.46	0.61	0.12	0.19	0.17	0.20	0.12	0.24	4.01	24.56	44.14	23.26	101.07
1943	7.41	2.75	0.40	0.03	0.00	0.03	0.25	12.38	47.88	22.23	35.75	23.19	152.30
1944	6.39	1.77	0.32	0.04	0.00	0.00	0.33	18.19	54.91	48.45	35.42	14.71	180.53
1945	4.26	0.55	0.09	0.00	0.00	0.00	0.08	0.18	0.23	0.32	0.65	15.22	21.58
1946	8.90	0.46	0.07	0.00	0.00	0.45	0.23	1.52	1.06	19.75	15.46	4.87	52.76
1947	2.63	0.46	0.07	0.00	0.02	1.38	1.67	5.92	5.15	22.25	14.83	19.32	73.71
1948	10.04	0.84	0.13	0.01	0.00	0.00	0.31	0.41	0.85	1.58	8.42	6.61	29.20
1949	3.60	26.44	7.93	0.08	0.00	0.00	14.85	12.19	2.19	35.72	17.06	21.15	141.22
1950	11.69	6.03	0.85	0.22	0.07	0.00	0.10	0.25	27.86	33.67	16.11	11.66	108.50
1951	6.43	2.98	0.44	0.03	0.01	0.01	0.02	12.61	13.55	28.79	39.03	18.73	122.62
1952	4.41	3.67	0.73	0.04	0.05	0.02	20.46	33.78	10.62	35.46	27.27	8.93	145.45
1953	1.69	2.27	0.64	0.10	0.00	0.00	0.23	43.88	34.14	64.23	65.16	26.11	238.46
1954	7.04	0.96	0.36	0.10	2.41	1.56	0.53	0.44	9.45	37.74	79.88	36.56	177.02
1955	16.22	6.03	0.49	0.08	0.02	0.00	0.01	1.12	22.23	32.88	22.65	10.85	112.59
1956	2.37	0.28	0.06	0.00	2.01	1.02	0.16	22.17	58.95	47.38	32.18	15.40	181.98
1957	21.57	5.72	0.19	0.00	0.11	0.05	0.06	2.01	14.08	9.51	11.36	7.13	71.77
1958	2.09	0.41	0.09	0.00	0.01	0.02	1.57	27.20	19.76	3.88	12.01	8.05	75.08
1959	6.56	1.11	0.17	0.03	0.00	0.09	0.19	2.45	12.28	6.67	4.07	2.77	36.39
1960	0.72	0.15	0.07	0.06	0.01	0.00	0.41	0.38	1.58	2.01	7.67	13.09	26.14
1961	6.92	0.48	0.06	0.00	0.00	0.16	0.31	0.38	34.40	31.71	37.77	19.65	131.84
1962	23.87	8.06	0.28	0.05	0.00	0.00	0.00	0.01	1.18	6.32	44.78	23.69	108.24
1963	2.46	0.58	0.46	0.12	0.02	0.01	0.03	0.21	8.41	10.93	19.24	13.91	56.39
1964	4.13	1.61	0.26	0.03	0.12	0.43	0.88	2.38	3.76	2.69	2.84	2.14	21.28
1965	1.00	0.21	0.07	0.01	0.00	0.16	0.17	0.15	2.48	16.52	9.55	4.61	34.93
1966	1.91	0.24	0.03	0.00	0.00	0.00	0.47	0.44	23.17	24.68	11.65	7.83	70.41
1967	3.92	0.81	0.15	0.02	0.00	0.00	0.14	1.70	6.41	9.79	13.20	8.11	44.26
1968	23.21	6.82	0.17	0.02	0.00	0.00	0.22	0.16	0.24	0.38	0.98	1.71	33.91
1969	6.78	1.96	0.12	0.00	0.00	0.00	0.00	1.36	19.33	24.85	30.87	17.74	103.02
1970	5.47	0.59	0.09	0.00	0.00	0.02	0.02	0.12	2.69	17.41	21.02	9.27	56.70
1971	1.51	0.17	0.02	0.00	0.00	0.00	0.50	1.95	4.81	7.32	5.95	4.27	26.52
1972	2.19	0.34	0.30	0.10	0.00	0.04	0.02	0.09	0.11	18.26	22.96	13.43	57.83
1973	5.57	0.61	0.17	0.04	0.03	0.02	0.01	2.57	15.16	17.08	96.27	49.70	187.23
1974	11.44	2.58	0.26	0.04	0.01	0.00	0.24	17.81	15.03	11.27	23.39	11.73	93.80
1975	8.25	1.71	0.14	0.04	0.03	0.04	0.82	0.73	41.57	40.76	14.82	6.73	115.63
1976	2.04	27.51	18.59	1.42	0.09	0.02	1.10	52.97	67.21	68.01	46.76	19.94	305.64
1977	6.19	0.67	0.24	0.06	0.00	0.14	0.19	0.23	0.27	0.29	10.99	10.35	29.61
1978	2.69	0.30	0.13	0.06	0.12	0.06	0.01	0.81	11.52	11.22	7.66	9.00	43.59
1979	5.25	0.64	0.09	0.02	0.02	0.00	0.07	1.60	6.18	4.96	8.29	5.72	32.85
1980	1.97	26.80	8.04	5.68	1.85	0.05	0.07	0.06	0.24	19.44	31.07	27.51	122.76
1981	10.27	0.69	0.11	0.04	0.01	0.31	2.48	3.17	5.00	5.78	4.14	2.26	34.25
1982	2.09	0.42	0.10	0.02	0.26	0.26	0.12	24.30	41.91	37.13	18.56	8.50	133.67
1983	2.86	0.37	0.07	0.00	0.00	2.08	1.42	53.85	29.22	9.17	7.39	31.22	137.66
1984	23.20	3.27	1.30	1.19	0.45	7.14	5.29	3.53	20.04	37.05	32.34	17.79	152.58
1985	5.44	0.53	0.21	0.06	0.00	0.21	0.17	0.32	7.30	11.59	35.13	20.53	81.47
1986	4.22	0.49	0.08	0.01	0.00	0.00	0.87	10.78	25.77	20.45	18.53	14.17	95.37
1987	4.41	0.42	0.08	0.01	0.00	0.37	2.94	3.73	9.75	7.38	13.18	13.21	55.50
1988	4.73	0.46	0.09	0.00	0.04	1.40	3.06	3.75	15.00	23.93	40.62	44.00	137.07
1989	17.04	2.19	0.23	0.03	0.02	0.02	4.70	18.89	27.74	40.00	22.33	7.31	140.49
1990	1.63	0.26	0.09	0.05	0.01	0.00	0.02	0.55	19.51	71.46	32.31	22.86	148.75
1991	12.01	1.42	0.14	0.01	0.05	0.06	1.21	2.49	25.01	36.30	25.07	13.10	116.87