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Impacts of Climate Change in Determining the Ecological Reserve

Report to the

WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

BACKGROUND

The intermediate and long-term impacts of climate change require evaluation of the adaptive capacity of the riverine ecosystems to promote sustainability. The predicted climate change impacts are the motivation behind the current research which targets the knowledge gap of the impacts of climate change on the ecological Reserve (or Ecological Water Requirements [EWR]). In order for the Department of Water and Sanitation (DWS) to meet their mandate to protect aquatic ecosystems, given the constraints of climate change, it is necessary to take cognisance of the implications of climate change and to make the necessary adjustments and changes to the ecological Reserve determination methodology. These adjustments will help ensure that sufficient water, at the right time, distributed in the right flow pattern and of adequate quality is provided, so that key ecological processes are sustained, and that biotic communities maintain their health and integrity.

RATIONALE FOR THE STUDY

The vulnerability of freshwater resources to the impacts of climate change has been recognised by the Intergovernmental Panel on Climate Change (IPCC Fourth Assessment: Parry et al. 2007). The Water Research Commission has also placed emphasis on the need for research on climate change with potential consequences on water resources through increased temperatures and increased hydrological variability (surface and groundwater) (Water Research Commission 2009). These are anticipated to manifest as changes in seasonal rainfall patterns, potential flooding and drought, and sea level changes in the coastal areas. Through the Climate Change Lighthouse (one of five WRC Lighthouses that aim to advance knowledge and solution development for priority water issues), research is being directed to align with the National Climate Change Response Policy and Strategy (http://www.gov.za/documents/national-climate-change-response-white-paper; accessed 20 June 2017) and to support the Water for Growth and Development Framework (http://www.wrc.org.za/Pages/LH2-ClimateChange.aspx; accessed 20 June 2017). However, growth and development need to occur in the context of long-term sustainability of freshwater systems, which requires the conservation of riverine ecosystems (and the associated ecosystem services) and appropriate management through implementation of tools such as the ecological Reserve, as defined under the National Water Act (NWA) No. 36 of 1998. The near future and long-term impacts of climate change require evaluation of the adaptive capacity of the riverine ecosystems to promote sustainability. This is the motivation behind this project, which targets the knowledge gap of the results of an assessment of the ecological Reserve, in light of climate change, and development of a modelling framework for incorporating climate change scenarios into ecological Reserve using the Revised Desktop Reserve model (Hughes et al. 2014).

OBJECTIVES AND AIMS

This project aimed to develop a methodology which would be able to analyse the potential impacts of climate change on present day ecological Reserve determination methods. The project focused on a single case study of the Doring River in the Western Cape because of limited time and the complexity of the case study considering various climate change scenarios.

The specific aims of the project included:

1. Determine the impacts of climate change on the ecological Reserve as set for the Doring River.
2. Assess the resulting impacts of the increased variability.
3. Identify and evaluate the adaptive response options.

This report presents the outcomes of the modelling approach, in addition to reports from five specialists (water quality [total dissolved salts], fish, invertebrates, channel geomorphology, and riparian vegetation) on their assessment of the impacts of the potential future climate on aquatic ecosystems, in addition to adaptive responses.

PROJECT METHODOLOGY

The project used the Revised Desktop Reserve Model (RDRM) of Hughes et al. (2014) which is based on the Habitat Flow Stressor Response (HFSR) (Hughes and Louw 2010) method that was adapted from the Flow Stressor Response (FSR) approach of O'Keeffe et al. (2002). Central to the development of HFSR is the increased focus on hydraulic habitat links to ecological functioning, as compared to FSR (Hughes et al. 2014). The original ecological Reserve determination undertaken for the Doring River (DWAF 2006a; DWA 2014) used the DRIFT (Downstream Response to Imposed Flow Transformation; King et al. 2003) approach. Note that both HFSR and DRIFT are two different, but equally accepted, approaches by the DWS for ecological Reserve determinations, which integrate hydrology, hydraulics, water quality and ecological data for evaluating different flow management options. How the two approaches translate the response of biotic indicators into EWRs differs in means and versatility, but not principle. DRIFT contains a Response Curve module which translates hydraulic conditions, or a set of pre-identified hydrological parameters of relevance to individual habitat and biotic indicators using a severity score which may be positive (increase in the abundance or percentage) or negative (decrease). The user is able to adjust whether this response will cause the system to move toward or away from natural (for instance an increase in a pest species might be considered a move 'away' from natural) (Brown et al. 2013). The response of an indicator is then represented as a time series represented across the historical hydrological record. In the RDRM, an organism's response to flow change is assessed on a 'stress' scale of 0 to 10 (with 0 being no stress and 10 being high stress) for a particular indicator (O'Keeffe et al. 2002). The stress index is defined by Hughes and Louw (2010: 913) as being 'thresholds of hydraulic habitat conditions (and therefore flow) that will impact on ecological functioning if they persist for certain lengths of time'. The FSR is based on the flow-depth classes. The level of stress is automatically generated by the RDRM as a score from 0 – where all flow-depth classes are present – to 10 where all fast flow-depth classes have been lost. However, where expert knowledge is available, these scores can be adjusted according to the known requirements of the target species.

The project team had two possible options for conducting the comparison between the original ecological Reserve (conducted using the DRIFT methodology) and the one determined in this project using RDRM for the Doring River EWR sites. One possible option was to use the DRIFT data to run the RDRM, i.e. calibrating the RDRM to the DRIFT model ecological Reserve. Alternatively, the RDRM could be conducted independently and then compared with the outputs from DRIFT. The project team decided to use the first approach of using the DRIFT data and calibrating the RDRM against DRIFT outputs, in order to ensure as similar as possible an outcome was produced. This was not always straightforward as the methods are quite different but much of the DRIFT output information in terms of the hydrology, hydraulic and ecological data were incorporated into the RDRM setup. The RDRM was set up for three ecological Reserve sites in the Doring River catchment (EWR sites 4, 5 and 6) using naturalised present day hydrology, and then compared with projected future hydrology. The hydrological analysis used to support the model was set up for secondary catchments E21, E22, E23, E24 and E40. *A note regarding the Reserve modelling is that EWR Site 6 was gazetted category B as Recommended Ecological Category (RSA 2018), versus category B/C in DWAF (2006a) which provided the DRIFT outputs for calibration. Since the specialist reports were written prior to RSA (2018) availability, their reports and modelling comparisons have been made with DWAF (2006a) information. One implication of this is that the actual Reserve should be higher than that set for Ecological Category B/C.*

The projected climate data was provided by Dr Piotr Wolski (Senior Research Officer, Climate System Analysis Group, University of Cape Town [CSAG, UCT]) and included data for four Representative Concentration Pathways (RCPs). Climate data from a number of Global Circulation Models (GCMs) which were associated with each RCP were provided. The data included stochastically downscaled stationary rainfall time series for each catchment for the period of January 2041 to December 2070, and a potential evapotranspiration value associated with each GCM. The base data used for the statistical downscaling were rainfall from WR2012 for the period 1981-2010.

The RCPs, their associated GCMs and the total number of climate time series for the four RCPs obtained from Dr Wolski are summarised below:

- RCP 2.6 – 47 GCMs (a total of 4,700 rainfall time series)
- RCP 4.5 – 105 GCMs (a total of 10,500 rainfall time series)
- RCP 6.0 – 47 GCMs (a total of 4,700 rainfall time series)
- RCP 8.5 – 78 GCMs (a total of 7,800 rainfall time series)

In order to process the large volume of climate data, and reduce it (since the hydrological model can accept a maximum of 500 rainfall ensembles), two new models were developed as part of this project. These included a method for selecting 500 rainfall ensembles from all the ensembles associated with each RCP, and a tool used to analyse and process the data (ensemble sorter). Due to the large range of future climate information and the associated uncertainty, the project used an uncertain framework called Global Options, which is based on the modified Pitman rainfall-runoff model (Hughes 2013). The hydrological model produced a range of potential future stream flow (100,000 possible flow ensembles) based on the range of climate data provided.

The modelling framework developed and adopted by this project is summarised in the Figure below:

Step 1: Data from UCT-CSAG:
Stochastic rainfall for various number of GCMs
Evaporation for each GCM

Step 2: Random selection of 500 rainfall time series.
Full evaporation range for all GCMs defined.

Step 3: Run hydrological model with 500 rainfall time series and evaporation range (as uncertainty) and produce 100,000 flow ensembles

Step 4: The 100,000 flow ensembles are sorted and minimum, maximum, median, 5th and 95th percentile extracted.

Step 5: Run RDRM with current day natural flows

Step 6: Incorporate current day hydrology including anthropogenic impacts, and future hydrology as scenarios in RDRM

Step 7: Outputs will be impacts of potential future hydrology on current day set Reserve – min and max ensembles from each RCP

Step 8: Output from water quality modelling:

- Current day water quality impacts on each EWR site
- Future impacts on water quality from two hydrological extremes – RCP 2.6 median and RCP 8.5 median.

PROJECT RESULTS AND DISCUSSION

Aim 1. Determine the impacts of climate change on the ecological Reserve as set for the Doring River

The future water quantity, water quality, and RDRM outputs were compared with minimum and maximum flow time series for the two extreme RCPs only (2.6 and 8.5). Both climate scenarios resulted in increased time periods with zero flows in general, with RCP 8.5 being worse than RCP 2.6. The range of uncertainty for the two RCPs generally straddles the present day zero percent flow time periods. In terms of maximum monthly flows, the range of uncertainty is large (particularly for RCP 2.6). The upstream EWR site 6 is projected to have reduced maximum flows compared to both natural and present day flow conditions. For the two EWR sites (4 and 5) in the lower catchment, the uncertainty range straddles both natural and present day maximum flows.

The water quality modelling for total dissolved salts (TDS) was conducted using the Water Quality Systems Assessment Model (WQSAM). The estimates of TDS under climate change should be interpreted with some caution as the analysis suffered from several sources of uncertainty. Dr Wolski was able to provide monthly future climate data, however this monthly time step within TDS modelling is not ideal as water quality generally responds to events occurring at shorter time scales such as daily or sub-daily.

In terms of the RDRM, the band of uncertainty under RCP 2.6 overlaps the EWR site 6 B/C category during the wet season, although the range of uncertainty band exceeds the stresses under category D. For this RCP, the dry season stresses are significantly beyond category D with stress values exceeding stress index of 7 majority of the time. The results are similar for RCP 8.5.

The results for EWR site 4 (ecological category B) showed a similar pattern with stress frequency curves exceeding the dry season stress index for both RCPs 2.6 and 8.5 with stress values above 7 or 8 for the dry season. The wet season band of uncertainty is smaller for RCP 2.6 versus RCP 8.5. The results for EWR site 5 (ecological category B) are similar to site 4 but the stress index values during the dry season are not as extreme throughout the season.

Aim 2. Assess the resulting impacts of the increased variability

Aim 3. Identify and evaluate the adaptive response options

These two aims were addressed by the specialist reports which are presented in Chapter 5. The specialists were asked to assess the impacts on their specialist group and in addition to identify some adaptive response options. Five specialist reports were obtained for this project: water quality, fish, macroinvertebrates, fluvial geomorphology, and riparian vegetation.

Climate predictions produced hydrographs for the three EWR sites in the Doring River catchment, which in general reflected reduced future flows, but these predicted future flows overlapped at times with present day flows. This made accurate assessments of the impact of flow changes by the specialists difficult, a point that was commonly made in their assessments. In general, there was consensus that changed patterns in flow would result in a future ecological category that was one half to one category below the most recent Present Ecological State (PES). A major driver of biotic change was the length of no-flow periods, and the existence and depth of appropriate pools to facilitate survival during periods of no flow. Flood flashiness following heavy rains and the increased length of dry periods both contribute to increased erosion and geomorphological degradation. Salinity variation, already noted in the system as water drains from sandstone aquifers in winter and shale aquifers in summer, is predicted to increase leading to increased seasonal salinity stress (and to reduced use of abstracted water).

The major drivers of predicted impacts are, as noted above, the length of no-flow periods, and the availability of suitable habitat to enable breeding and survival during no-flow periods. Greater erosion (which will impact habitat suitability) and seasonal salinity levels will further impact riparian and instream biota.

The most obvious solution to augmenting dry season flows would be controlled releases from upstream impoundments, should management of upstream impoundments be possible. However, the Doring River and its tributaries are relatively unimpounded. Perhaps the largest impoundment that might improve dry season flows in the mid and lower catchment is the Oubaaskraal Dam on the Tankwa River. The suitability of this impoundment for controlled releases is not known, and no data are available on water quality in this impoundment. Given that the water held here drains from the Tankwa Karroo salinity levels may not be suitable and this would need prior investigation.

Irrigation in the Kouebokkeveld consumes a significant part of the flow from this region. This is regardless of the river receiving water via a transfer scheme from the Breede River catchment. A potential source of water to augment flows in this region could be either increasing the water transferred into the catchment, or curtailing abstraction of surface or groundwater from the catchment in this region. As conflict over water use in this area has been reported, the latter option is liable to be contested, particularly where such abstraction supports economic activity.

Alien vegetation, which has been found to be a drain on South African water resources, is recorded in the Doring River catchment. An assessment of the value of removing these aliens as a means of reducing evapotranspiration and thus augmenting flow, should be undertaken. This would have the added benefit of contributing to bank stabilization where aliens are present.

It is not clear how much of these proposed responses to reduced flow might have an impact in relation to predicted climate change. Given a likely reduction in rainfall and streamflow in the catchment, some impacts are likely, both on the riverine biota and on farming and other activity in the catchment. Reduced flow in this region will also impact on agricultural activity in the lower Olifants River and sustainability of the Olifants River estuary.

RECOMMENDATIONS FOR FUTURE RESEARCH

The water quality TDS modelling presented in the report needs to be interpreted with caution because of sources of uncertainty. Further analysis could include further refinement of the TDS model to achieve an improved calibration. Other sources of data to reduce uncertainty in the calibration could be identified, such as observed borehole TDS data which could be used to validate groundwater TDS signatures. In addition, daily scale data would help improve the prediction of the model.

The Doring catchment is a relatively undisturbed catchment in an arid area with few land uses that significantly impact flow and water quality (beyond irrigated farming in the Kouebokkeveld). It also lies in an area where climate projections predict a reduced rainfall under future climate scenarios. It has few dams which might allow for controlled release of water to manage concomitant impacts in the catchment. Future research should look at catchments were many of these conditions do not apply. Assessing the impacts of climate change in a catchment with greater anthropogenic impact (and anthropogenic demand), more varied and more intense land use, and in a region with different predicted rainfall changes would be a valuable complement to the current project.

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LIST OF ACRONYMS

A-NDC	Adaptation – Nationally Determined Contribution
ASPT	Average Score Per Taxon
BHNR	Basic Human Needs Reserve
CD: WE	Chief Directorate: Water Ecosystems
COP	Conference of Parties
CSAG, UCT	Climate System Analysis Group, University of Cape
DEA	Department of Environmental Affairs
DRIFT	Downstream Response to Imposed Flow Transformation
DST	Department of Science and Technology
DWA	Department of Water Affairs
DWAF	Department of Water and Forestry
DWS	Department of Water and Sanitation
EC	Ecological Category
EcoSpecs	Ecological Specifications
EIS	Ecological Importance and Sensitivity
ET	Evapotranspiration
EWR	Ecological Water Requirements
FDC	Flow Duration Curves
FSR	Flow Stressor Response
GCM	Global Circulation Model
GHG	Greenhouse gases
HFSR	Habitat Flow Stressor Response
HSC	Habitat Suitability Criteria
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
LTAS	Long Term Adaptation Scenarios
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MCM	Million Cubic Meter
MRU	Management Resource Units

NCCR	National Climate Change Response
NDC	Nationally Determined Contribution
nMAR	natural Mean Annual Runoff
NWA	National Water Act
NWRS	National Water Resource Strategy
PAMs	Policies and Measures
pdMAR	Present Day Mean Annual Runoff
PES	Present Ecological State
RC	Reference Condition
RCP	Representative Concentration Pathways
RDM	Reserve Determination Model
RDRM	Revised Desktop Reserve Model
REC	Recommended Ecological Category
RHP	River Health Programme
RQOs	Resource Quality Objectives
RSA	Republic of South Africa
RU	Resource Unit
RVAC	Risk and Vulnerability Assessment Centre
SARVA	South African Risk and Vulnerability Atlas
SASS	South African Scoring System
SD	Standard Deviation
SPATSIM	Spatial and Time Series Information Management
SRES	Special Report on Emissions Scenarios
TDS	Total Dissolved Salts
TL	Total length
TPC	Threshold of Potential Concern
TWQR	Target water quality requirements
UN	United Nations
UNFCC	United Nations Framework Convention on Climate Change
WMA	Water Management Area
WQSAM	Water Quality Systems Assessment Model
WRC	Water Research Commission

Chapter 1 Introduction

by

Pumza Dubula

Climate change represents a key challenge to the sustainability of global ecosystems and human prosperity in the 21st century. The impacts of climate change are predominantly adverse, exacerbating environmental, social and economic issues. There are associated challenges linked to the degradation of ecosystems; loss and change in biodiversity; desertification; air, water, and land pollution, and more. Human populations are faced with two ways to reduce the effects of climate change on biodiversity and ecosystem services: mitigate the causes of climate change or adapt to the effects of climate change (Pachauri et al. 2014). These are both necessary and are generally used together as part of an overall response strategy, since single actions are unlikely to limit the impacts of climate change (Pachauri et al. 2014). Climate change goes beyond project impacts, as it affects many diverse global issues: from water, food, and energy security to impacts on human rights and vulnerable peoples (Ziervogel et al. 2014). Global climate change raises important questions of international and intergenerational justice. South Africa recognises that a global effort is essential to mitigate and adapt to the effects of climate change. It has therefore ratified different international agreements and is continuously involved in different discussions regionally and globally on sustainability and climate change response. These are crucial for the water and sanitation sector as water is central to global sustainability and climate change resilience.

1.1 The Paris Agreement

In December 2015, 195 countries ratified an international agreement at the 21st Conference of the Parties (COP) held in Paris under the United Nations Framework Convention on Climate Change (UNFCCC). The agreement is popularly known as the Paris Agreement (UN 2015). The Paris Agreement compels all developed and developing countries to make significant commitments to address the challenge of climate change. All Paris Agreement signatories should endeavour to keep global warming below 2°C above pre-industrial levels. Furthermore, signatories should strive to scale up global efforts to reduce warming to 1.5 degrees. Countries responsible for 97 percent of global emissions have already pledged their Nationally Determined Contributions (NDCs) detailing their national intent on how they will address climate change. Countries are expected to revisit their current pledges submitted to the UNFCCC by 2020 and to reinforce their emissions reduction targets for 2030.

The Paris Agreement includes a stronger transparency and accountability system for all countries requiring reporting on greenhouse gas inventories and projections that are subject to an expert technical review and a multilateral examination. Countries will continue to provide climate finance to help the most vulnerable adapt to climate change and build low-carbon economies. While the Paris Agreement does not "solve" climate change, it allows the international community to start the next wave of global climate change actions, creating a cycle for more aggressive action in the decades to come. The Paris Agreement also, for the first time in the history of the UNFCCC, further elaborates the obligation to act on adaptation, requiring the COP to periodically take stock of the collective progress made towards achieving the global goal on adaptation.

The Agreement commits all countries to contribute to an ambitious global greenhouse gas (GHG) emissions reduction goal, and associated global goals for finance and adaptation, communicated through NDCs (UN 2015). The Agreement also anticipates all Parties to put forward their best efforts through their NDCs and to report regularly on the status of their emissions, as well as implementation efforts.

South Africa has already submitted its NDCs, which applies to the period 2025 and 2030. The NDC covers adaptation, mitigation and means of implementation. South Africa's NDCs will address adaptation through six adaptation NDC (A-NDC) goals covering adaptation objectives and planning, adaptation needs and costs and adaptation investments. These adaptation NDC goals are critical for the water and sanitation sectors as the appropriate climate change response for the sector is through adaptation.

1.2 The National Climate Change Response (NCCR) White Paper

In 2011, the Cabinet approved the National Climate Change Response (NCCR) White Paper, which sets out the overall national government response to the challenge of climate change. The NCCR deals with all sectors affected by or critical to climate change mitigation and adaptation including the water sector (DEA 2011).

The NCCR recognises water as one of a number of sectors that needs immediate attention, along with health, agriculture, forestry, biodiversity and human settlements. All of these sectors have major intersections with the water sector.

The basis of the NCCR is the development of improved resilience of the country, its economy and its people. The NCCR strives to manage the transition of South Africa to a lower carbon economy in a way that does not compromise the development agenda of the country, public and environment health, poverty eradication and social equity (DEA 2011).

The NCCR also requires that all government departments review their policies, strategies, legislation, regulations and plans to incorporate climate change response. The NCCR specifies that adaptation strategies will be integrated into sectoral plans, including the National Water Resource Strategy 2 (NWRS2; http://www.dwa.gov.za/nwrs/; DWA 2013), as well as reconciliation strategies for particular catchments and water supply systems.

The NCCR White Paper (DEA 2011: p17) specifies that a two-pronged approach will be followed in which, firstly, in the short-term, climate change is used as the catalyst for addressing urgent short-comings in the water sector and implementing effective, efficient and sustainable water resources and services management measures. Secondly, a long-term strategic focus on planning, adaptation and the smart implementation of new concepts and proactive approaches to managing water resources.

1.3 The National Climate Change Bill

The Department of Environmental Affairs (DEA) has drafted and gazetted for public comments the National Climate Change Bill for South Africa (Government Gazette, 8 June 2018). The aim of the Bill is to deepen the footprint of South Africa's regulatory framework to facilitate the country's national contribution to the global effort for substantial and sustained reductions in greenhouse gas emissions (GHGs), which together with adaptation, can limit climate change risks. The overall objective of the bill is to:

- Align South Africa's national climate change response pledges to the international objectives as adopted in the UNFCCC negotiations;
- Set out a national GHG emission reduction target; and a national climate change mitigation system to facilitate GHG emission reduction;
- Provide key regulatory tools to support climate policy, including the government's adaptation planning framework; and
- Integrate into the South African environmental sector regulatory system and its already existing measures that have a direct or indirect influence on climate policy.

1.4 Current and future climate – A National level snapshot

South Africa has a warm climate, and much of the country experiences average annual temperatures above 17°C. The southern and eastern escarpments are the regions with the lowest temperatures, due to the decrease in temperature with altitude. The warmest areas are the coastal areas of KwaZulu-Natal, the Lowveld of KwaZulu-Natal and Mpumalanga, the Limpopo valley and the interior regions of the Northern Cape. The oceans surrounding South Africa have a moderating influence on the temperatures along coastal areas. The warm Agulhas current makes the East coast significantly warmer than the West coast, where the cold Benguela current and upwelling result in lower temperatures (DST 2010).

Rainfall over South Africa is highly variable in space, and there exists a West-East gradient in rainfall totals. The West coast and western interior are arid to semi-arid areas (DST 2010). Rainfall totals are higher on the east of the eastern escarpment of South Africa (DST 2010). Moist air from the warm Indian Ocean and Agulhas Current is frequently transported into eastern South Africa by easterly winds. There are also pockets of high rainfall along the southwestern Cape and Cape South coast areas, which similarly result from orographic forcing when moist frontal air is transported inland (DST 2010).

1.4.1 Future climate predictions

Climate modelling conducted for the South African Risk and Vulnerability Atlas (SARVA) indicates some broad future trends at the country-scale. SARVA is a Department of Science and Technology (DST) funded initiative with an aim to act as a catalyst that drives research in the areas of climate risks and vulnerability reduction strategies through contemporary information derived from the data (DST 2010). In South Africa, three Universities were selected for this collaboration, i.e. University of Fort Hare in Alice, and Walter Sisulu University in Mthatha, both situated in the Eastern Cape; and the University of Limpopo in Mankweng, Limpopo Province. Each university hosts a Risk and Vulnerability Assessment Centre (RVAC) for the purposes of intensive research activities on the issues surrounding risks, vulnerability, and climate change. Each RVAC is tasked to conduct research, train students, and collate information relating to global change (DST 2010).

The GCM models used for the SARVA project (dynamic regional climate models under the A2 Special Report on Emissions Scenarios [SRES] scenario, which assumes a moderate to high growth in greenhouse gas concentrations) suggest an increase in the median temperature of more than 3°C over the central and northern interior regions of South Africa for 2070-2100. Over the coastal regions of the country, a somewhat smaller increase (approximately 2°C) is projected. The largest increase in median temperature is projected to occur over the central interior of South Africa, exceeding a value of 4°C during autumn and winter. Generally, the largest temperature increases are projected for autumn and winter, with the summer and spring changes being somewhat smaller.

Rainfall projections over the same time period (by 2100) indicate that most of the summer rainfall region of South Africa will become drier in spring and autumn as a result of the more frequent formation of mid-level high-pressure systems over this region. An increase in the median rainfall is projected over eastern half of South Africa for winter and spring, with a projected decrease over northeastern South Africa during summer (DST 2010).

1.4.2 Long Term Adaptation Scenarios (LTAS) and Global Circulation Models (GCMs)

The most commonly used method for determining the impacts of climate change is to use Global Circulation Models (GCMs), which allow the simulation of most of the key features of climate on a global scale. GCMs use a very high spatial resolution (typically 250 km^2 grids or units). At this scale, GCMs are not very accurate in their projections, particularly for rainfall, which is influenced by several localised factors including physical relief. Therefore, to assess local or provincial impacts from climate scale, outputs from the GCMs are often downscaled to an appropriate resolution. The process of downscaling involves the interpretation of results from GCM models in relation to local climate factors and dynamics. The GCM downscaling for the Long Term Adaptation Scenarios (LTAS) for South Africa commissioned by the Department of Environmental Affairs (DEA 2013) provided the following findings:

- An increasing trend in temperatures across South Africa, with a higher increase in the northern interior than along the coastal region.
- There is uncertainty when it comes to rainfall trends depending on the type of downscaling (statistical versus dynamical, with the latter being more computationally complex) and specific climate scenario used.
- The increase in temperature suggests an increase in evaporation, thus even if rainfall increases, conditions may get drier and water availability may decrease overall.

Representative Concentration Pathways (RCPs)

The IPCC Fifth Assessment Report has selected four RCPs representative of total radiative forcing (i.e. cumulative greenhouse gasses from all sources) as scenarios for evaluation. These are RCPs 2.6, 4.5, 6.0 and 8.5, which represent combinations of futures economic, technological, demographic, policy and institutional changes to year 2100 (http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html; accessed 1st December 2018).

1.4.3 Projected climate trends for Western Cape and Mpumalanga

The LTAS climate models predict the intermediate future climate (2040-2060) of the Western Cape to be warmer and drier than present (DEA 2013). Temperature is projected to increase by up to 2.5°C during this period. Increasing temperature is expected to increase evapotranspiration rates of between 10-20%, thus resulting in increased dam evaporation losses and higher demands for irrigation. Historical data analysis (1960-2010) by MacKellar et al. (2014) indicated that rain days have decreased by 2.5 days in December, January and February and 3.5 days in March, April and May.

The LTAS projections for Mpumalanga indicate a 1-3°C temperature increase in the intermediate future (2040-2060) (LTAS 2013). Rainfall projections indicate a great variability and an increase in evapotranspiration.

1.5 The National Water Act (NWA)

The National Water Act (NWA) (Act No. 36 of 1998) (Republic of South Africa [RSA] 1998) amalgamated water resources as a natural asset assigned the DWS, through the Minister, as the custodian of water resources. The NWA gives the Reserve priority right for the use of water resources. The Reserve ascertains water requirements in terms of quantity, quality and reliability of supply for basic human needs and the functioning of aquatic ecosystems (Hughes 2005). The Reserve consists of two parts: "*Basic Human Needs Reserve*" and "*ecological Reserve*". The Basic Human Needs Reserve provides for the essential needs of individuals served by the water resource in question and includes water for drinking, food preparation and personal hygiene. The aim of the Basic Human Needs Reserve (BHNR) is to satisfy basic human needs by securing a basic water supply, as prescribed under the Water Services Act 1997 (Act No. 108 of 1997) (RSA 1997), for people now and into the future. Implementation of the NWA requires that an ecological Reserve be determined for all significant resources, with those for which development is planned receiving priority attention.

The ecological Reserve refers to the quantity, quality and reliability of water for aquatic ecosystem functioning. It specifies the flow and water quality requirements that are necessary to keep the water resource in a certain state of ecological health. It does not only indicate the amounts but also determines the required frequency and duration of the required flows.

The water resource that remains in excess after Reserve requirements have been met, becomes the total allocatable resource (Figure 1.1) which may be distributed to different users based on social and economic objectives. Based on the NWA, the aquatic ecosystems requirements must be met before any allocation for productive use is made.

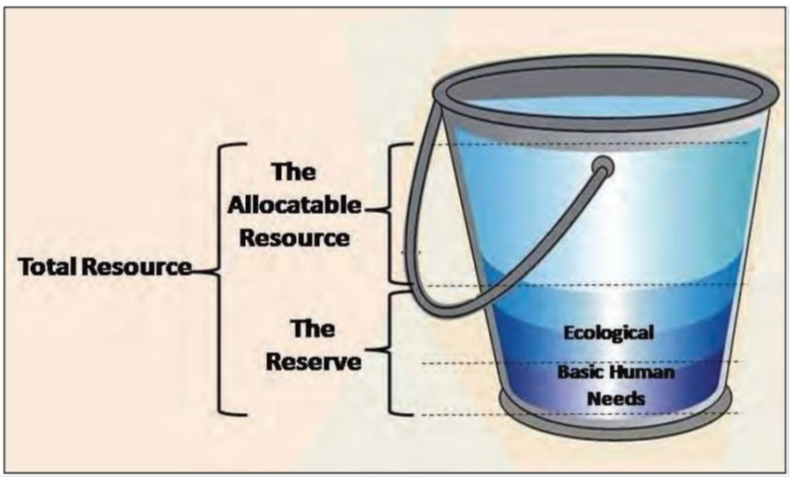


Figure 1.1 Depiction of the total water resource, consisting of the BHNR, ecological Reserve and allocatable resource (WRC 2013)

The DWS Chief Directorate: Water Ecosystems (CD: WE) is tasked with the responsibility of ensuring that the Reserve requirements, which have priority over other uses in the terms of the NWA, are determined before licence applications are processed, particularly in stressed catchments (Brown et al. 2006). The process for determining the Reserve for river ecosystems comprises of eight steps as depicted below (Figure 1.2):

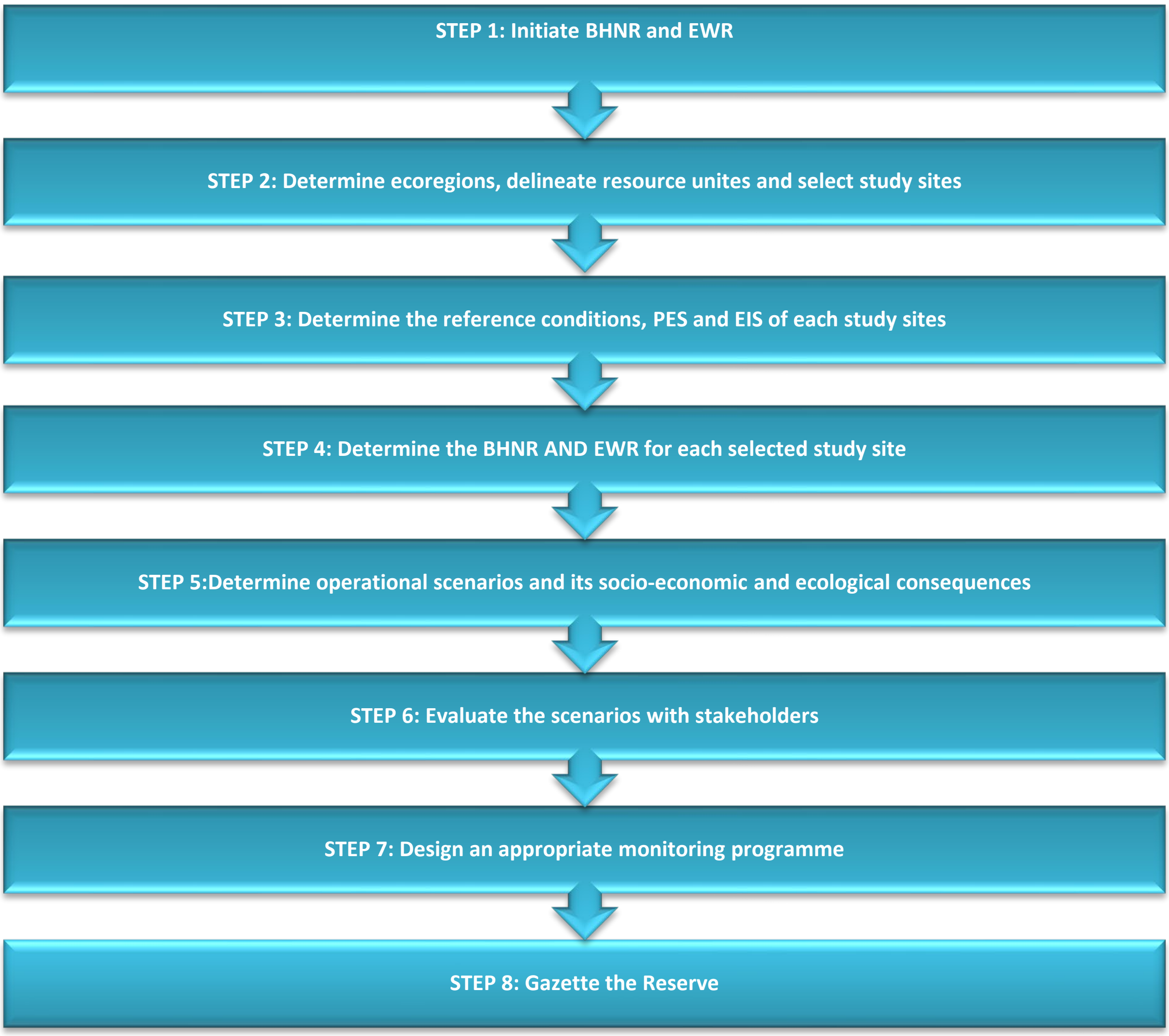


Figure 1.2 The generic eight steps process for the Reserve Determination (adapted from DWAF 1999)

Step 1: Initiate the basic human needs and ecological water requirements assessment. Of importance is the timeframe for which the Reserve would be applicable.

Step 2: Determine eco regions, delineate Resource Units (RUs), select study sites and, where appropriate, align with Step 1 of the water resource classification procedure.

Step 3: Determine the Reference Condition (RC), PES and the Ecological Importance and Sensitivity (EIS) of each of the selected study sites. The reference conditions are at the heart of the assessment.

Step 4: Determine the basic human needs and Ecological Water Requirements (EWR; or ecological Reserve) for each of the selected study sites and, where appropriate, align with Step 3 of the water resource classification procedure.

Step 5: Determine operational scenarios and its socio-economic and ecological consequences.

Step 6: Evaluate the scenarios with stakeholders and align with Step 3 of the water resource classification procedure.

Step 7: Design an appropriate monitoring programme. The monitoring programmes should specifically consider key parameters (quantity, quality, habitat and biota).

Step 8: Gazette and implement the Reserve.

There is now an integrated framework for the EWR and Water Resource Classification (DWS 2017).

A Reserve determination study is undertaken at different levels based on need and the availability of required resources. The **Desktop Reserve** is conducted using existing and/or modelled information and uses the Desktop Reserve Model to set flow requirements. The results produced at the desktop level have low confidence. The Rapid **Reserve** level is undertaken through data collection to verify modelled information from the Reserve model. It can be undertaken at three levels, i.e. **Rapid I, II or III**. A quick field assessment to assess the overall ecological condition is undertaken during low flows for a Rapid III assessment, although not all specialists are used and a habitat integrity score is produced. The results produced for a Rapid III Reserve is low to medium confidence, while Rapids I and II, which have no field component, are of lower confidence. The **Intermediate Reserve** study is undertaken through the collection of field data to verify modelled information through the reserve model. One site visit during low flow is undertaken to assess the current status of the resource in terms of fish, invertebrates, riparian vegetation, geomorphology, hydrology, hydraulics and water quality (i.e. all drivers and response components). There is medium to high confidence in results produced through an Intermediate Reserve study. The **Comprehensive Reserve** study consists of extensive field data collection to verify the modelled results. Two site visits during low flows and high flows are undertaken. Either the HFSR or DRIFT approaches are used to verify low flow and flood requirements for intermediate and comprehensive studies. There is generally highest confidence in results collected through a Comprehensive Reserve Study (Louw 2004; WRC 2013). Note that the number of field visits has changed from what was proposed in the 1999 Reserve documents for the Intermediate and Comprehensive Reserve assessments, due to resource constraints. What is now presented serves as best practise.

1.6 Project rationale

The ecological Reserve is the quantity and quality of water required to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource (NWA 1998). Climate change, however, poses a significant threat to this allocation of water and hence the sustainability of aquatic ecosystems and ecosystem services to society. This is largely due to substantial uncertainty in terms of rainfall scenarios, how it will differ across South Africa and what the subsequent long-term hydrological and water quality changes and implications will be for the ecological Reserve in different parts of the country. The changes in the quantity of water in these ecosystems are due to changes in run-off patterns, frequency and intensity of extreme events (e.g. droughts and flooding) and groundwater recharge rates (Dallas and Rivers-Moore 2014).

A change in the hydrological character and regime of aquatic ecosystems due to climate change is triggering a chain of cascading effects with subsequent intrinsic changes that will be observed in the different components of these ecosystems (water quality, instream and riparian habitat and instream biological communities), and overall in its functioning (Dallas and Rivers-Moore 2014). Managing and meeting the ecological Reserve within the current complexities and constraints posed by climate change, is of utmost importance in ensuring the long-term sustainable management of these resources and to contain the widespread degradation of these resources.

Water quality is also affected directly through changes to temperature, runoff regimes and instream hydrology (Dallas and Rivers-Moore 2014) The ecological integrity of these systems are subsequently at risk due to the character of instream and riparian habitats that are changed, a loss in the hydrologic connectivity between stream compartments that occurs, and higher water temperatures which result in greater evaporative loss and a change biogeochemical processes (Le Quesne et al. 2010). This ultimately affects the structure and function of these systems and their resilience to change. It is therefore crucial to be able to predict the likely consequences of climate change on aquatic ecosystems and the ecological Reserve in particular, to characterise the potential changes in stream flow, given changes in rainfall and temperature (evaporation), but also changes to runoff due to changes in terrestrial vegetation, for instance. The most obviously demonstrable changes to water quality would be for conservative water quality variables such as dissolved salts, as instream salt concentrations are primarily a function of diluting natural flow, the relative contribution of baseflow to total flow and evaporation. Changes in water quality could also include changes to water temperature, pH (e.g. acidification), solubility (e.g. oxygen having different solubility at different temperatures, but also for other chemicals), and due to increased variability (e.g. higher sediment loads). Changes in biota may be driven by changes in flow and water quality, but also as a result of instream habitat alteration (due to flow changes) and riparian habitat through changes in riparian vegetation, for instance (Le Quesne et al. 2010).

The intermediate and long-term impacts of climate change require evaluation of the adaptive capacity of the riverine ecosystems to promote sustainability. The predicted climate change impacts are the motivation behind the current research, which targets the knowledge gap of the impacts of climate change on the ecological Reserve. In order for the DWS to meet their mandate to protect aquatic ecosystems, given the constraints of climate change, it is necessary to take cognisance of the implications of climate change and to make the necessary adjustments and changes to the Reserve determination methodology. These adjustments help to ensure that sufficient water, at the right time, distributed in the right flow pattern and of adequate quality is provided, so that key ecological processes are sustained, and that biotic communities maintain their health and integrity.

Considering the different climate scenarios expected for the different parts of the country, the proposed study had planned to investigate two South African catchments, the Doring River in the Western Cape and the Crocodile River in Mpumalanga using the RDRM as they are representative of different current climates (winter rainfall versus summer rainfall) and they are also important water source areas. However, due to the significant amount of work needed to set up the RDRM to match the DRIFT model outputs and to process the large number of climate ensembles, the project team could only conduct this project on the Doring River in the project time allocated.

Chapter 2 Study Catchment and Previous EWR Research

by

Neil Griffin, Pumza Dubula, Bruce Paxton and Sukhmani Mantel

2.1 The Doring River catchment

2.1.1 Background

The Doring, or Doorn, River is a river in the Western Cape Province, South Africa (Figure 2.1). The Doring River rises in the south and flows in a northerly direction. The Doring River drains the eastern slopes of the Cedarberg, the Swartruggens and the western Roggeveld Mountains. The Doring catchment is situated in a winter rainfall area, which is naturally arid as it receives less than 200 mm rain per annum (Brown et al. 2006). It is a semi-permanent river whose flow varies considerably: in winter, the flow is very strong, whereas in summer the river is reduced to a chain of pools. It is first joined by the Groot River and then by the Tra-Tra River flowing from the west and the Tankwa River from the east, before flowing in a westerly direction to its confluence with the Olifants River just upstream of Klawer. It is part of the Olifants-Doring river system and is the main tributary of the Olifants River. It receives 2.5 million $m^3.a^{-1}$ of water in the upper reaches via the Inverdoorn Canal from the Breede River Catchment (DWAF 2004a).

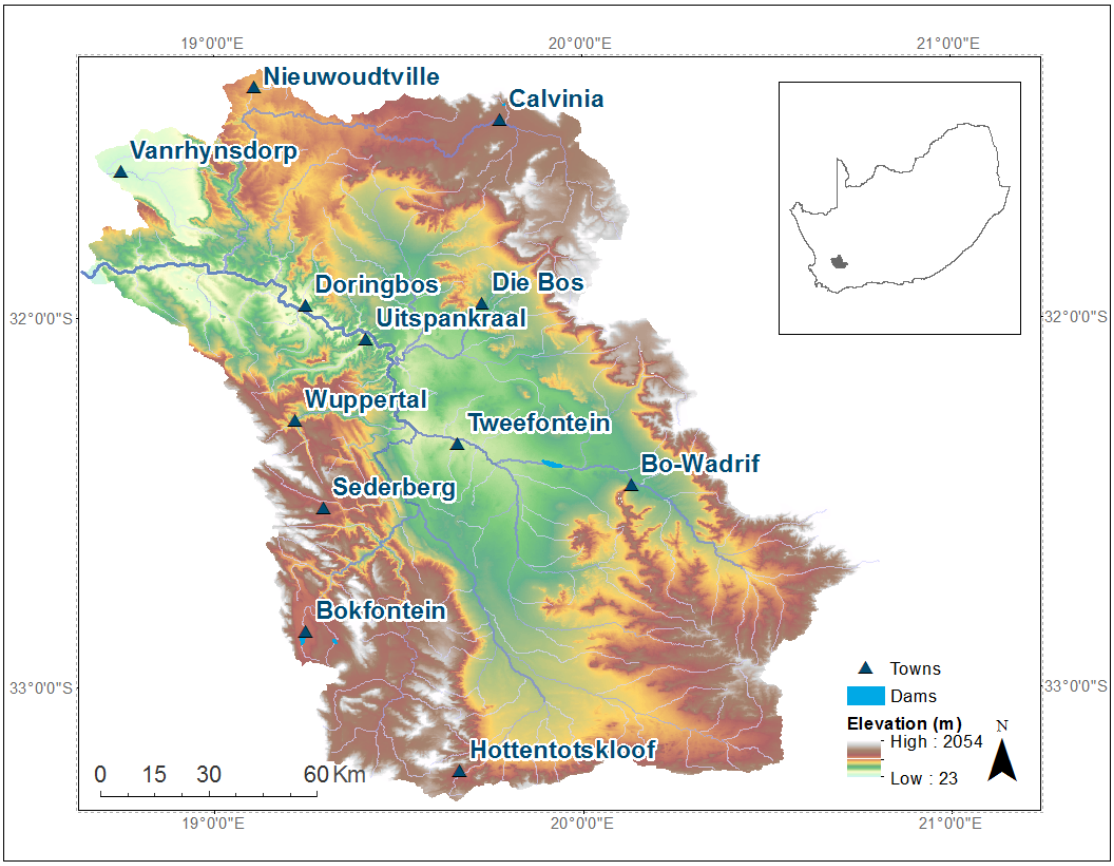


Figure 2.1 Map of Doring River catchment in the Western Cape

A variable flow regime is known to be causal to the development of diversity in riparian vegetation (Boucher 2002). This river contributes a very large proportion of the silt carried down to the Olifants River. Silt deposits support different vegetation to that found on bedrock substrates and aquatic vegetation is more developed in clear water than in turbid water. The quality of water in the upper Doring River (tertiary E22), when flowing, is suitable for agriculture and domestic water supplies, however, at the end of summer the quality deteriorates. Water quality changes as summer flows originate from catchments dominated by shales and are saline, while winter flows derive from mountains where sandstones are dominant are far fresher than saline summer water (RHP 2006). The Doring River catchment is important from a conservation perspective because it contains a number of species of indigenous and endemic fish that occur in no other river systems, and that are endangered.

Land use in the region is largely agricultural, with cultivation of lucerne and vegetables where water is available, and livestock farming elsewhere (RHP 2006). There are no large dams on the Doring River, though several tributaries are dammed (DWAF 2004b). The area has significant tourism and conservation potential (DWAF 2004b, RHP 2006). The area supports nine indigenous fish, seven of which are endemic to the catchment. The area also supports an unusual macroinvertebrate fauna, with several local endemics, not all of which have been described as species (De Moor 2011).

The Ecostatus of sites in the Doring catchment was in general good to fair, with only two sites in the Koue Bokkeveld being classed as poor (RHP 2006). The latter rivers are high in the catchment in an area experiencing intensive farming which has led to flow modifications. Some agricultural nutrient loading of water was also found (RHP 2006).

The State of Rivers report assessed water quality in terms of total phosphate, total nitrogen, ammonia and dissolved oxygen (RHP 2006). Using these measures, the water quality in the river was judged to be good to fair. It is important to note that these measures were chosen as being useful for assessing the suitability of water for ecosystem functioning, and that several widely used and important parameters such as pH and salinity do not contribute to the index.

In other work, the water quality was found to be in general suitable for all uses, though salinity levels varied widely depending on whether the water came from the Cedarberg or the Tankwa Karoo. Along with increased salinity, water from the Karoo also had higher pH levels, more nutrients, and a greater sediment load (as suspended solids) (DWAF 2005a). These are largely a function of the differing geologies in the two regions. The influence of agriculture on water quality was also apparent. Although the seasonal changes in salinity generally left the water suitable for use, cumulative changes along the length of the Doring River and subsequent increases in salinity with distance downstream may cause some farmers to curtail irrigation towards the end of summer when salinity levels are high (DWAF 2005a).

Although usually water in the catchment is suitable for all end users, there are some exceptions. The most notable of these is the area around Op-die-Berg, which is dominated by Malmesbury shales (DWAF 2005a). The water in the Kruis and Houdenbek rivers is saline, and this is exacerbated by agricultural activity in the area. This water feeds into the Riet River, where water quality is not monitored and the impact of the saline input water is not known. These rivers correspond with the sites where river Ecostatus was found to be low.

In the northern catchment, water in the Karee Dam near Calvinia was found to be ideal for domestic use, acceptable for irrigation, and tolerable for aquatic ecosystems (DWA 2012). Slightly elevated salt and pH levels negatively affected its suitability for irrigation, and elevated nutrients that will have a negative effect on its ecological state. Notwithstanding its relatively small catchment, this site was used as representative of a large area that included other rivers as no other data were available in the area (DWA 2012).

Water in the upper Doring River, just after the confluence with the Groot River that drains the Koue Bokkeveld, was found to be ideal for domestic use and irrigation, and liable to have an acceptable impact on ecological state (DWA 2012). Elevated nutrient and fluoride levels will have a limited impact on the ecological state (DWA 2012). This is despite elevated salinities in the Kruis and surrounding rivers and the high agricultural activity in the area. DWS data from the Kruis River for the period 1982-2015 have a median salinity of 109 $mS.m^{-1}$, which, according to guidelines used in the water resource classification of the catchment, is tolerable for irrigation and acceptable for domestic use (DWA 2012). Median dissolved phosphate levels were 0.012 mg $P.l^{-1}$, which according to the same guidelines was acceptable for aquatic ecosystems, and median inorganic nitrogen levels were 0.065 mg $N.l^{-1}$, which was ideal for both domestic use and aquatic ecosystems. The 95^{th} percentile fluoride level was 0.32 $mg.l^{-1}$, which was ideal regardless of the user standards. Water quality in the Kruis River changed seasonally, and high salinities with elevated sodium, calcium, magnesium and chloride levels occurred regularly in the dry season and throughout dry years.

The 2012 classification did not use data from the Leeu River, which feeds into the Groot River, in the high upper catchment (DWA 2012). Like the Kruis River (which lies to the south), it drains a catchment with intensive agriculture. The data set assessed from this site ranged from 1977 to 2017. Median salinity levels were ideal for domestic use, and acceptable for irrigation, again with seasonal variation. Median phosphate levels were 0.012 mg $P.l^{-1}$, which was may have minor impacts on the aquatic ecosystems. Inorganic nitrogen levels were ideal for aquatic ecosystems and domestic use, but these also peaked seasonally and so would regularly change use class.

The central Doring River, in an area where rangelands are the major land use and livestock is the predominant agricultural form, was found to have water that was ideal for domestic use and irrigation, and acceptable for aquatic biota (DWA 2012). DWS data from the monitoring point used for the classification reveal that this was caused by slightly elevated phosphate levels giving a median phosphate level of 0.012 mg $P.l^{-1}$.

The lowest site on the Doring River was approximately 7 km upstream of the confluence with the Olifants River, near Klawer. The water quality at this point was mostly ideal for domestic use, though seasonal high levels of sodium and chloride led to elevated salinities which caused the water quality to shift towards acceptable or tolerable (DWA 2012). DWS data from 1972 to 2017 show that seasonal variation is liable to exacerbate this effect during the dry season (although seasonal variation has damped since around 2000). For irrigation, the levels of salinity encountered, and in particular the sodium and chloride levels, make the water unsuitable for irrigation. For aquatic ecosystems, phosphate levels were (marginally) ideal, though DWA data from the monitoring point show occasional unacceptable levels of total phosphorus at the site. DWA (2012) indicate that nitrate-nitrite levels are only acceptable though, which data from the monitoring site contraindicates. DWA (2012) also indicates that the pH levels found lead to the water being acceptable for aquatic ecosystems.

Finally, it is important to note that water quality monitoring in the rivers in this catchment is limited, and there are several rivers where the water quality is not monitored. It is also important to note that flow in many of these is ephemeral (DWAF 2005a).

DWA (2014) made several recommendations for priority resource units in the catchment. Node R14 (quaternary E24M), in the lower Doring River, is a riffle/run-pool sequence, with deep pools, and should have macroinvertebrate community dominated by the relatively sensitive taxa Ephemeroptera and Trichoptera, as well as fish including at least one of *Labeobarbus capensis*, *Barbus serra* and *Labeo seeberi.* The same criteria were recommended for site R37 (quaternaries E21K/E21L) in the Groot River. Although no recommendations were made for macroinvertebrates, at least one of the same fish species should be found at R17 (quaternary E40D) in the Koebee River. R41 (quaternary E21G) in the Leeu River should have at least one of *Labeobarbus capensis* and *Galaxias zebratus*. From a water quality perspective, all sites should match the target water quality requirements (TWQR) for aquatic ecosystems after DWAF (1996a), and several also had to meet the DWAF (1996b) recommendations for irrigation (see RSA [2016] for details on water quality requirements). Where indicated, riparian vegetation should be intact and dominated by indigenous vegetation, with *Nerium oleander* invasion controlled.

Several authors have indicated the importance of the catchment for indigenous and often threatened fish taxa, and the Olifants/Doring catchment has been identified as a hotspot for conservation, as eight out of its ten species are endemic and threatened (Skelton et al. 1995). The most threatened of these is *Barbus erubescens*, which is confined to the Twee River catchment (Impson et al. 2007). Habitat loss and introduced taxa have often been associated with impacts on indigenous fish in the catchment (Woodford et al. 2005). Shelton et al. (2008) described changes in habitat selection in *Galaxias zebratus* in response to largemouth bass invasion. Van der Walt et al. (2016) reviewed the impact of bass (*Micropterus*) species on native fish in the Olifants/Doring catchment in the Cape Floristic Region, and indicated its role in localised extinction of small-bodied cyprinid minnows (*Barbus calidus* and *Pseudobarbus phlegethon*). They found that more extensive fish extinctions were averted through the presence of physical barriers in rivers (weirs, etc.), which limited further bass invasion.

2.1.2 Climate

Climatic conditions vary considerably as a result of the variation in topography. Rainfall occurs in winter in the south-western parts, whilst the north-eastern parts experiences winter rainfall as well as occasional summer thunderstorms. The mean annual precipitation is up to 1 500 mm in the Cederberg Mountains in the south-west, decreasing sharply to about 200 mm to the north, east and west thereof, and to less than 100 mm in the far north (Figure 2.2). Important conservation areas include the Tankwa-Karoo National Park, the Verlorenvlei wetland in the Sandveld (with Ramsar status), the Cederberg Wilderness Area, and the northern section of the Groot Winterhoek Wilderness Area. Mean Annual Precipitation (MAP) over much of the catchment is less than 200 mm, with the result that, except in the wetter south-west, the climate is not suitable for dryland farming on a large scale. Temperatures also vary widely (3°C in winter to 44°C in summer) and evaporation is high (*c*. 1,500 mm a^{-1} in the south-west to 2,200 mm a^{-1} in the north-west; Figure 2.3). The potential evaporation is more than an order of magnitude higher than the rainfall over most of the catchment.

Water use in the Water Management Area (WMA) is completely dominated by the irrigation sector. Extensive irrigation development, mainly supported by farm dams, also takes place in the upper reaches of both the Olifants and Doring rivers in the Witzenberg and Kouebokkeveld areas. One of the largest private dams in the country, the Oudekraal Dam, was built on the Tanqua River in the Karoo, a tributary of the Doring River. Some of the irrigation in the Doring and Knersvlakte sub-areas is at a very low assurance of supply, where the full area developed for irrigation may only be planted in years when sufficient water is available. A specific feature along the lower Tanqua River (tributary to the Doring River) is the use of flood irrigation.

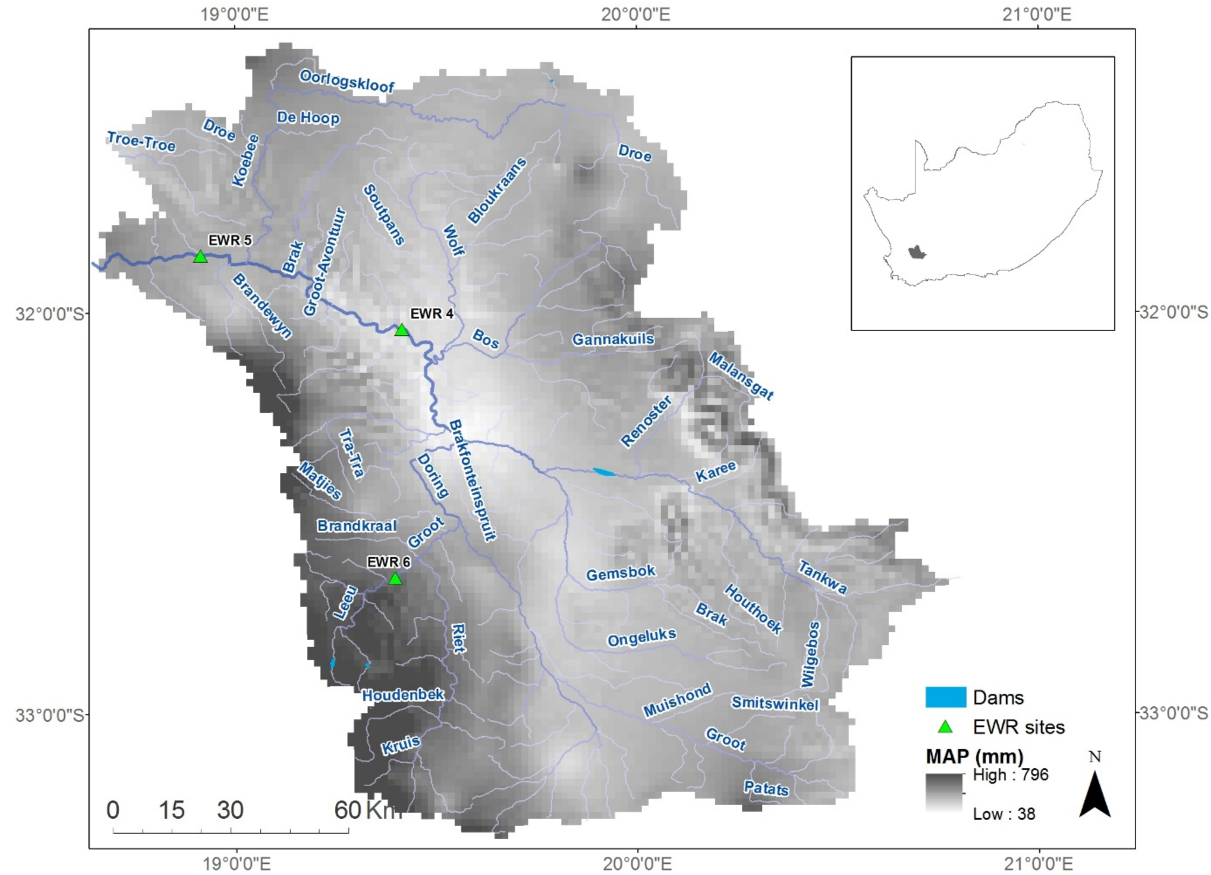


Figure 2.2 Mean Annual Precipitation (MAP) data for Doring catchment derived from the South African Atlas of Climatology and Agrohydrology (Schulze 2007)

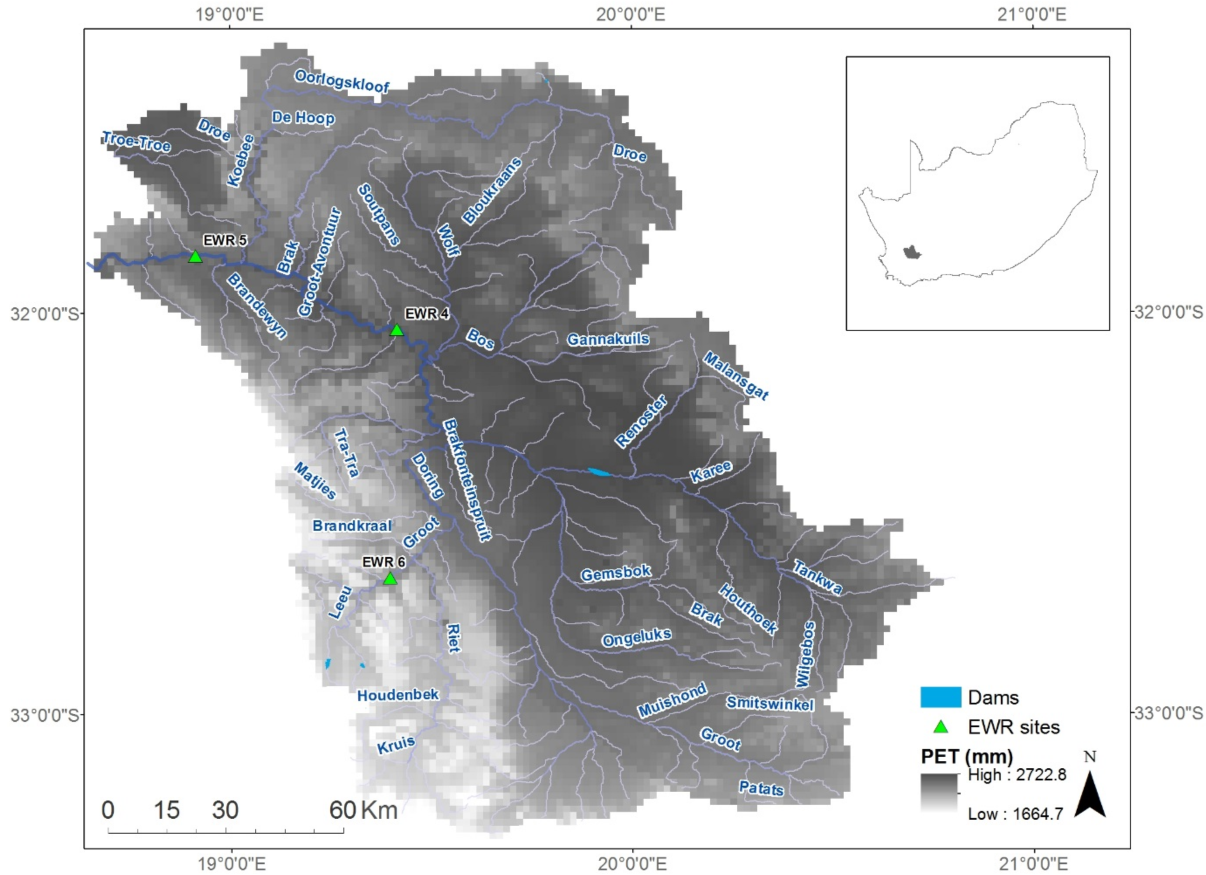


Figure 2.3 Potential evapotranspiration (PET) data for Doring catchment derived from the South African Atlas of Climatology and Agrohydrology (Schulze 2007)

2.2 Olifants/Doring ecological Reserve Determination Study

The Chief Directorate: Resource Directed Measures (now CD: WE) initiated and funded a Comprehensive Reserve Assessment of the Olifants/Doring River Catchment. Southern Waters ER & C cc undertook the study from July 2003 to June 2006. The study utilised the DRIFT methodology, which similar to RDRM, translates the response of biotic indicators into EWR, although the process itself is different. DRIFT contains a Response Curve module which translates hydraulic conditions, or a set of pre-identified hydrological parameters of relevance to individual habitat and biotic indicators using a severity score which may be positive (increase in the abundance or percentage) or negative (decrease). The user is able to adjust whether this response will cause the system to move toward or away from natural (for instance an increase in a pest species might be considered a move 'away' from natural) (Brown et al. 2013). The response of an indicator is then represented as a time series represented across the historical hydrological record. In the RDRM, an organism's response to flow change is assessed on a 'stress' scale of 0 to 10 (with 0 being no stress and 10 being high stress) for a particular indicator (O'Keeffe et al. 2002). The stress index is defined by Hughes and Louw (2010: 913) as being 'thresholds of hydraulic habitat conditions (and therefore flow) that will impact on ecological functioning if they persist for certain lengths of time'. The FSR is based on the flow-depth classes. The level of stress is automatically generated by the RDRM as a score from 0 – where all flow-depth classes are present – to 10 where all fast flow-depth classes have been lost (Hughes, pers. comm.). However, where expert knowledge is available, these scores can be adjusted according to the known requirements of the target species.

2.2.1 Resource Units and EWR sites

The total number of EWR sites for the Southern Waters' Comprehensive Reserve Assessment study was limited to six. This equated to approximately two EWR sites per 200 km of the river. The EWR sites were selected only in high priority RUs (DWAF 2006a). The RUs with EWR sites included in this study are given below in Table 2.1.

Table 2.1 Resource units and EWR sites in the Doring River (after DWAF 2006a). EWR sites are for high priority RU only.

Resource Unit		EWR Sites		
Name	Description	Number	Name	Description
RU2	Groot River Gorge	EWR4	Doring at Biedou	On the Doring mainstem immediately upstream of the confluence with the Biedou River
RU4	Tankwa/Doring River Confluence to Doringbos	EWR5	Doring at Oudrif	At Oudrif
RU5	Doringbos to Olifants/Doring River Confluence	EWR6	Groot at Mount Cedar	Upstream of the bridge at Groot Rivier

Table 2.2 Details of the three EWR sites selected for the Doring Study (DWAF 2006a)

Site No.	River	nMAR (MCM[2])	pdMAR[1] (MCM)
EWR4	Doring	420	320
EWR5	Doring	511	401
EWR6	Groot	138	104

[1] *pdMAR: present day MAR*

[2] *MCM: Million cubic metres*

The EWR sites in the Doring River in the DWAF (2006a) ecological Reserve study are given above in Table 2.1 and Table 2.2. EWR sites were only identified for high priority RUs. The locations of the sites are shown in Figure 2.4.

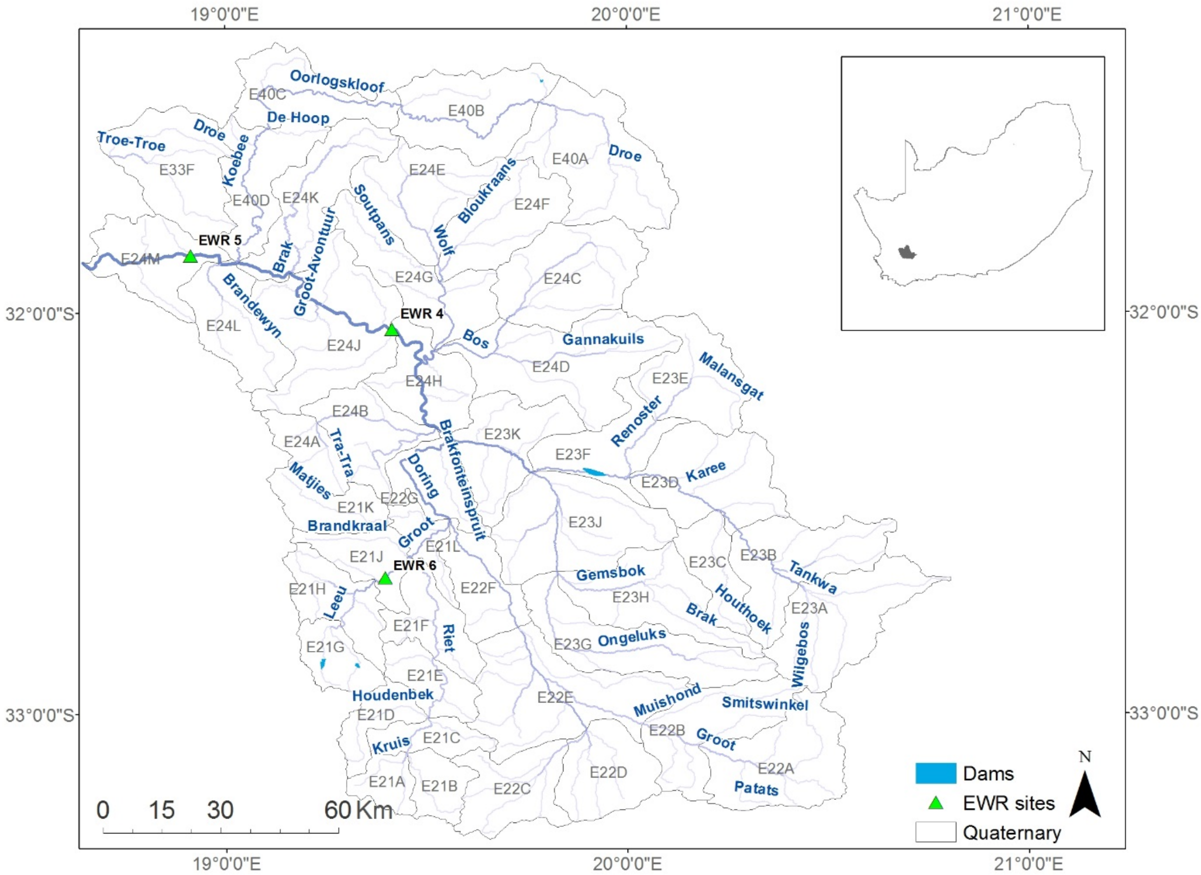


Figure 2.4 Location of EWR sites in the Doring River catchment (DWAF 2006a)

2.2.2 Doring EWR study findings

The PES, the Recommended Ecological Category (REC), and EIS for pertinent EWR sites in the Doring River catchment are presented in Table 2.3 using information from DWAF (2006a) as well as the gazette (RSA 2018). Note that the Site 6 gazetted category (B) is different than the EWR category listed in DWAF 2006a (B/C). The specialist reports were written prior to RSA (2018) availability and therefore their reports and modelling comparisons have been made with DWAF (2006a) information which provides the EWR rule curves and EcoSpecs that are used in the report and provided in the Appendices. This has implications for the comparisons presented in this report for evaluating the RDRM model outputs with DRIFT outputs using category B/C (Appendix Table A3) and with the specialist reports, and that the actual Reserve should be higher than that set for category B/C. The PES from the Reserve study that was finalized and gazetted in 2018 is largely natural (after Kleynhans and Louw 2008) overall. Ecological importance and sensitivity ranged from low to high.

Table 2.3 The PES, REC, and EIS of sites for which ecological Reserves were determined (DWAF 2006a with RSA 2018 data in brackets). Only sites pertinent to the current study are shown. Note that the specialist reports were written prior to RSA (2018) availability and therefore their reports and modelling comparisons have been made with DWAF 2006a information (see text).

EWR Site	PES	REC	EIS
Site 4 (E24H)	B/C (A/B)	B (B)	Very High (High)
Site 5 (E24K)	B (A/B)	B (B)	Very High (High)
Site 6 (E21J)	B/C (B)	B/C (B)	Very High (Low)

A more detailed breakdown of the PES is presented in Table 2.4. The hydrology, geomorphology and fish components consistently scored as C, or moderately modified, across all sites in the catchment. Water quality, riparian vegetation and macroinvertebrate scores were more variable across sites, and scored slightly better, leading to overall PES scores of B and B/C. Water quality PES scores are presented in Table 2.54, while other relevant EcoSpecs are covered in the text.

Table 2.4 Present Ecological State (PES) for different ecological Reserve components (from DWAF 2006a)

	Driver components			Response components		
Site	Hydrology	Geomorphology	Water Quality	Vegetation	Macroinvertebrates	Fish
EWR 4	C	C	B	C	B	C
EWR 5	C	C	B	B	C/B	C
EWR 6	C	C	A/B	A/B	C	C

Figure 2.5 to 2.7 show the natural duration curves and the total ecological Reserve flows for the three sites for an easy visual comparison of the two flow volumes (full details of the flow values are presented in Appendix A).

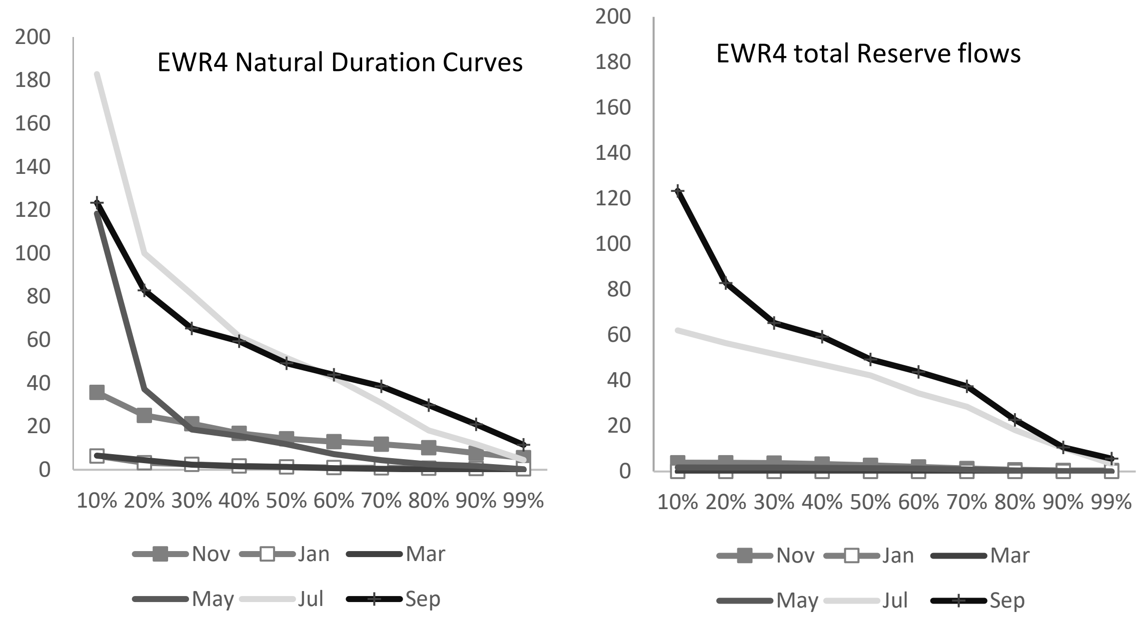


Figure 2.5 Comparison of natural duration flows and ecological Reserve (Ecological Category: B) (10^6 m^3) for some months of the year for Doring EWR site 4 (data in Appendix A)

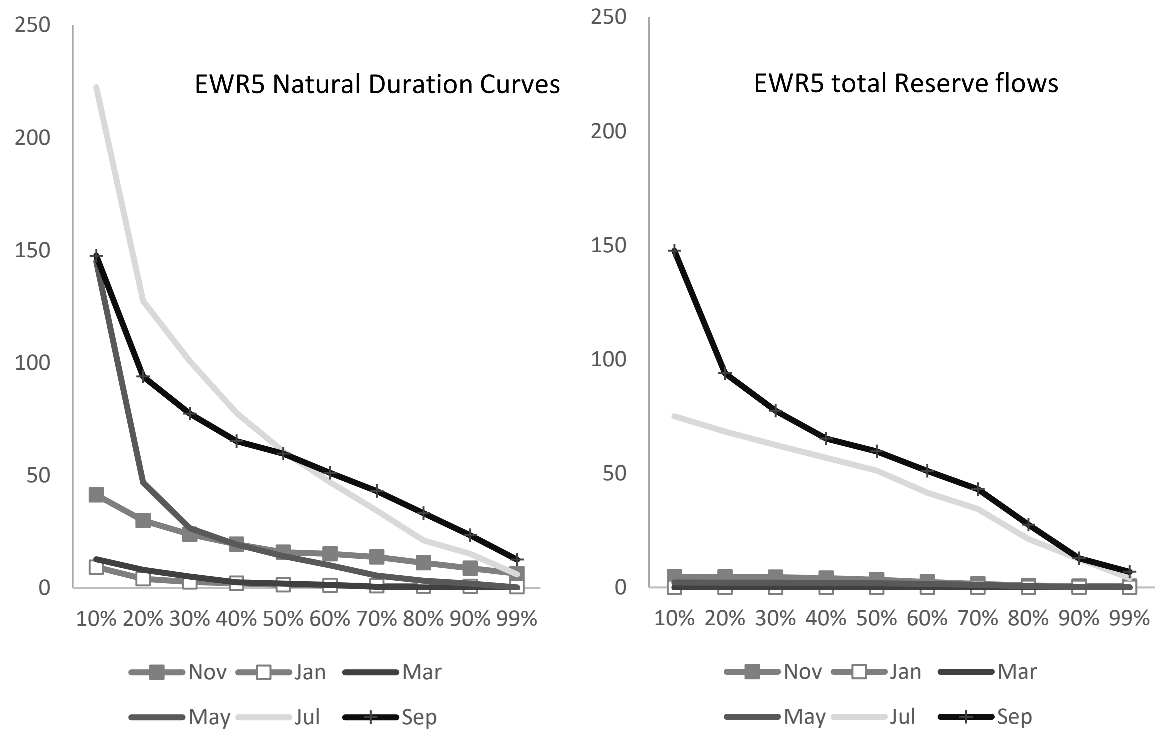


Figure 2.6 Comparison of natural duration flows and ecological Reserve (Ecological Category: B) (10^6 m^3) for some months of the year for Doring EWR site 5 (data in Appendix A)

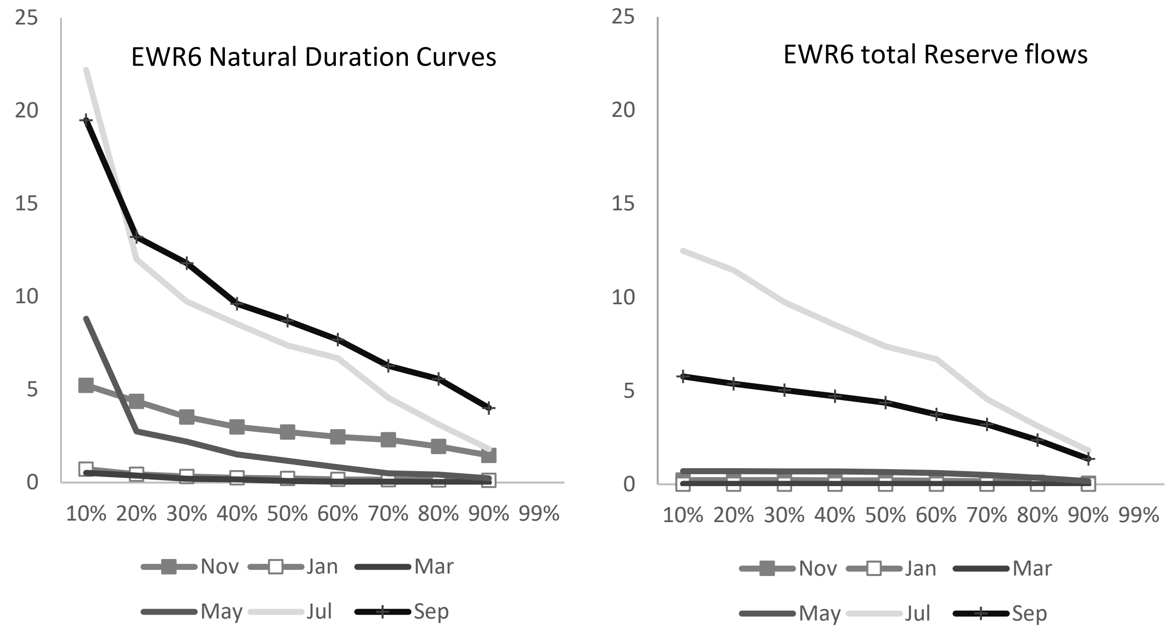


Figure 2.7 Comparison of natural duration flows and ecological Reserve (Ecological Category: B/C; DWAF 2006a) ($m^3.s^{-1}$) for some months of the year for Doring EWR site 6 (data in Appendix A). Note the different units ($m^3.s^{-1}$) compared to sites 4 and 5 (MCM). The units are different from Figures 2.5 and 2.6 so as to match the data units in the DRIFT model report.

DWAF (2006b) states that EWR Site 4, just upstream of the confluence of the Biedou and Doring rivers, is of considerable importance as this point combines the effects of Karoo tributaries. Alien vegetation in the form of *Azolla filiculoides*, *Paspalum urvillei*, *Acacia longifolia*, *A. mearnsii*, *A. melanoxylon* and *Eucalyptus camaldulensis* need to be controlled, while mature *Vachelia karroo* populations need to be maintained. Appropriately structured populations of *Cyperus textilis* and *Phragmites australis* should also be maintained. Water quality should conform to the limits presented in Table 2.5. Adult *Labeobarbus seeberi* and *Labeo seeberi* populations should be maintained, while invasive *Micropterus dolomieu* and *Lepomis macrochirus* populations should not increase. River macroinvertebrates should reflect a SASS (South African Scoring System) score of more than 125, and an ASPT score of more than six. Summer or dry season ASPT (Average Score Per Taxon) scores may be lower than this level owing to lack of flow. Two families out of Ecnomidae, Philopotamidae (in the winter), Hydropsychidae, and Hydroptilidae need to be present, Leptophlebiidae need to be present in stones in or out of current at least 80% of the time, and Simuliidae need to be present in 50% of samples from the stones in current habitat. Finally, changes to the site or upstream should not impact on submerged aquatic vegetation or the vegetation habitat out of the current, and should ensure that stones are present in flowing current (including fast-flowing riffles) at a minimum during spring and early summer.

Table 2.5 Water quality specifications for all EWR Sites in the Doring River system (DWAF 2006a; DWA 2013). Additional details in Appendix B.

EWR Site		4	5	6
EcoStatus		B	B	B/C
Water quality PES		B	B	A/B
Parameter		Recommended range		
Salts	$MgSO_4$ (mg.l^{-1})	<23	<23	<23
	Na_2SO_4 (mg.l^{-1})	<33	<33	<33
	$MgCl_2$ (mg.l^{-1})	<30	<30	<30
	$CaCl_2$ (mg.l^{-1})	<57	<57	<57
	NaCl (mg.l^{-1})	<191	<191	<191
Temperature (°C)		Max daily mean 40°C Spawning min 19°C, ideal 25-28°C (Nov-Jan)		
pH		6.5-8.5	6.5-8.5	6.0-8.5
Electrical conductivity (mS.m^{-1})		<20	<50	<15
Dissolved Oxygen (DO) (mg.l^{-1})		>6.0	>6.0	>6.0
Toxics	Ammonia as NH_3 (mg.l^{-1})	<0.007	<0.007	<0.007
Nutrients	Nitrate as NO_3-N (mg.l^{-1})	<0.020	<0.020	<0.050
	Phosphorus as PO_4-P (mg.l^{-1})	<0.020	<0.020	<0.020

EWR Site 5 is the most downstream site on the Doring River, and is important in assessing EWRs for the lower Olifants River and the estuary (DWAF 2005b). The EcoSpecs for riparian vegetation (Appendix E) at this point are the same as at EWR Site 4 viz. alien taxa need to be controlled, mature *Vachelia karroo* populations need to be maintained, and appropriately structured populations of *Cyperus textilis* and *Phragmites australis* need to be present. Water quality EcoSpecs are similar to those at EWR Site 4, except that higher salinity levels are acceptable (Table 2.5). Likewise, similar fish EcoSpecs (Appendix C) with respect to adult *Labeobarbus seeberi* and *Labeo seeberi*, as well as *Pseudobarbus serra*, with evidence of breeding in all three, and *Micropterus dolomieu* and *Lepomis macrochirus* as at EWR Site 4 apply at Site 5. REC EcoSpecs also indicate that juveniles of native taxa that are mentioned should be present. In addition, adult populations of the endangered *Pseudobarbus serra* need to be maintained at this site. The macroinvertebrate EcoSpecs (Appendix D) for this site are the same as at EWR Site 4, with the caveats that Blephariceridae are not expected here, and the presence of Notonemouridae in winter through to early summer may reflect summer low-flows.

EWR Site 6 is the uppermost EWR Site in the Doring River catchment, and is located in the Groot River draining the Kouebokkeveld towards the north (DWAF 2005b). The site is important in assessing EWR releases from farm dams in the region. Most of the riparian vegetation EcoSpecs at EWR Site 6 are the same as at Sites 5 and 4, although the maintenance of populations of *Salix mucronata* and *Brabejum stellatifolium* are included as EcoSpecs. Water quality specifications, given in Table 2.5, are similar to those at EWR Sites 4 and 5, except that EcoSpecs for salinity are somewhat lower, slightly more acidic water is acceptable, and EcoSpecs for nitrate are higher. The fish EcoSpecs at this site are similar to downstream sites and list *Labeobarbus seeberi* and *Pseudobarbus serra* as native taxa to be maintained (and REC EcoSpecs specify larvae of these taxa should be present), and *Micropterus dolomieu* and *Lepomis macrochirus* as invasive taxa to be controlled. Macroinvertebrate EcoSpecs indicate that SASS Scores should be greater than 170, and ASPT should be greater than 7.5. At least three families of cased caddisflies should be recorded, with two of these coming from the Ecnomidae, the Leptoceridae, the Philopotamidae and the Sericostomatidae. Three families from the Coleoptera should also be found. Leptophlebiidae should be present in 90% of samples, Heptageniidae in 80% of samples, and Corydalidae in 40% of samples collected over time. Blephariceridae and Notonemouridae should be present until early summer in most years. Finally, the stone-in-current habitat, including fast-flowing, turbulent and run, needs to be present.

Chapter 3 Hydrological, Water Quality and RDRM Modelling of the Doring Catchment

by

Jane Tanner, Andrew Slaughter and Sukhmani Mantel

3.1 Hydrological modelling

The project team had two possible options for conducting the comparison between the original ecological Reserve (conducted using the DRIFT methodology) and the one determined in this project using RDRM. This affected the hydrological modelling which needed to be calibrated to the hydrology used for DRIFT. One possible option for was to use the DRIFT data to run the RDRM, i.e. calibrating the RDRM to the DRIFT model ecological Reserve. Alternatively, the RDRM could be conducted independently and then compared with the outputs from DRIFT. The project team decided to use the first approach of using the DRIFT data and calibrating the RDRM against DRIFT outputs, in order to ensure as similar as possible an outcome was produced. This was not always straightforward as the methods are quite different but much of the DRIFT output information in terms of the hydrology, hydraulic and ecological data were incorporated into the RDRM setup. The RDRM was set up for three ecological Reserve sites in the Doring River catchment (EWR sites 4, 5 and 6) using naturalised present day hydrology, and then compared with projected future hydrology. The hydrological analysis used to support the model was set up for secondary catchments E21, E22, E23, E24 and E40.

An overview of the hydrological component of the project includes:

- Adjust the updated natural flows against the natural hydrology used in the DRIFT ecological Reserve determination study in order to compare the outputs.
- Calibrate present day flows against observed flow gauge data (incorporating limited water use information and small farm dams).
- Process future (years 2040 to 2070) climate data which included between 4700 and 10 500 rainfall ensembles and associated evapotranspiration for each RCP (2.6, 4.5, 6.0 and 8.6). Detailed in Chapter 4.
- Use future climate data, together with present day Pitman model setup under uncertainty to generate 100 000 potential flow time series using the range of future climate.

3.1.1 Methodology and results

The modified Pitman rainfall-runoff model (Hughes 2013) was used to derive hydrological flows for both natural, present day and future hydrology. The hydrological model is a version of the Pitman monthly time step, semi-distributed, rainfall-runoff model (Pitman 1973), that has been updated on a regular basis and has seen wide use within the country over the last several decades (summarized in Hughes 2013). The version of the model used in this study is currently implemented as a flexible uncertainty model within a more general water resources modelling framework. The full details of the model are available in recent publications (Hughes 2013) and the structure of the model is illustrated in Figure 3.1; however, the further relevant details of the model are included below.

The model is semi-distributed with each sub-catchment containing its own rainfall and evapotranspiration demand time series and its own parameter set used to signify the main hydrological processes. The full model also includes interception, infiltration, surface runoff and routing components, as well as groundwater and interflow functions.

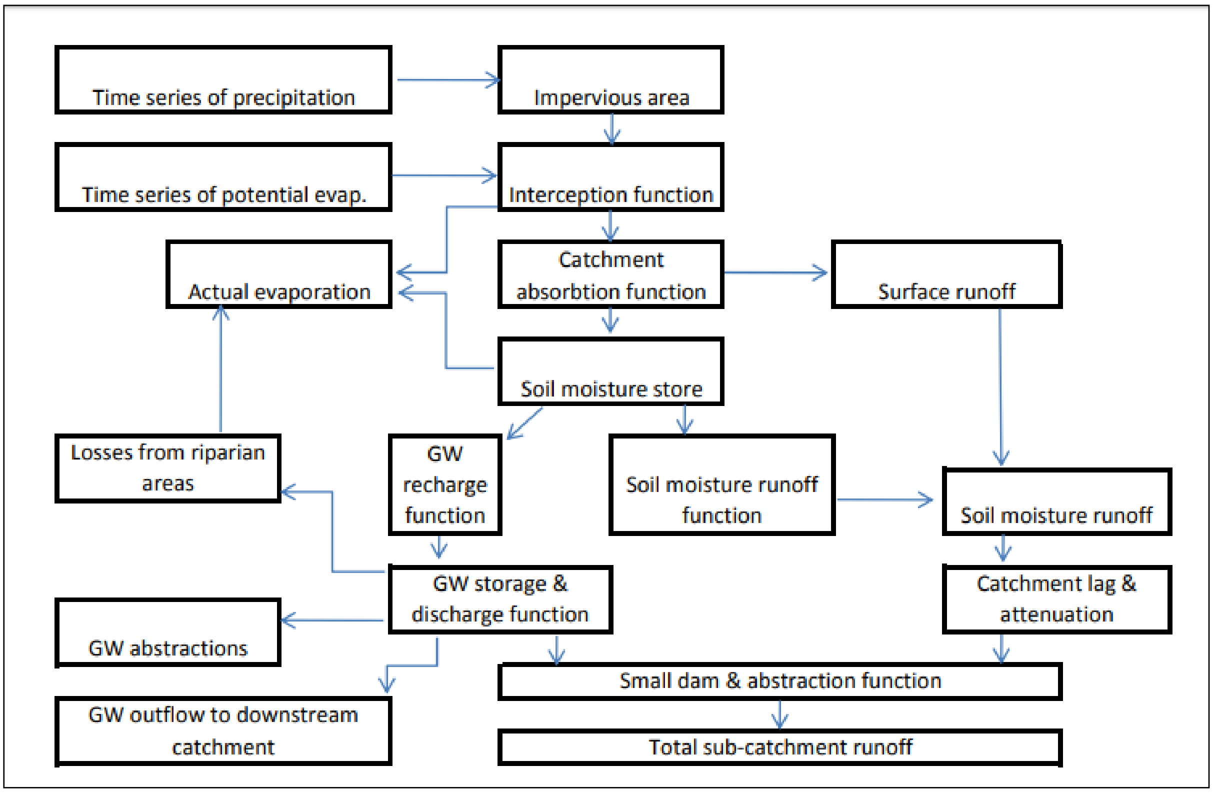


Figure 3.1 Conceptual Pitman model structure (Tanner 2013). (GW: groundwater)

Calibration of the natural and present day hydrology was undertaken using the more traditional single run version of the model. This means the model parameters are calibrated and one hydrological time series of flow is produced. The future hydrology was processed using an uncertainty framework version of the model. This means that the model will explore uncertainty ranges (in this case future rainfall and evapotranspiration possibilities) and produce a series of potential flow (100 000 flow time series for this project). Figure 3.2 illustrates the uncertainty framework that was used within this project.

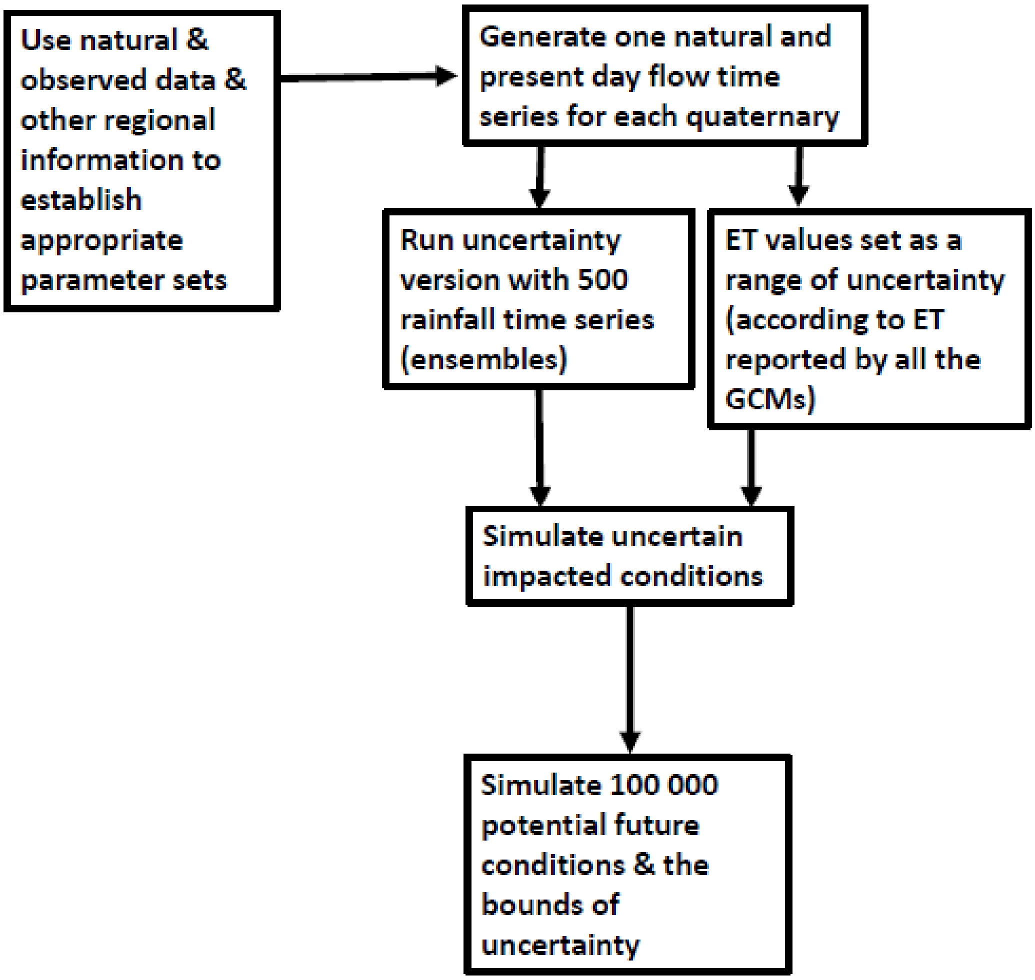


Figure 3.2 Uncertainty methodology followed in this project (ET: evapotranspiration; GCM: Global Circulation Model)

This method ensures that the significant uncertainty inherent in forecasting future climate data, is captured by the model and a range of potential stream flows based on this climate data is produced. This results in a band of uncertainty in the flows.

Natural hydrology

The natural hydrology used in this process was adjusted to match the natural hydrology / flows used in the DRIFT ecological Reserve. Information regarding the comparisons are given in the RDRM outputs in Section 4.2.

Present day hydrology

The present day hydrology was calibrated against available observed flow data (Table 3.1). Small dams, which are concentrated mainly in the E21 catchments, were included in the simulations.

Table 3.1 Flow gauge data used for calibrating current day hydrology

Quaternary catchment	Flow gauge number	Date
E21E	E2H008	1935-1948
E21G	E2H007	1930-2018
E22G	E2H002	1923-2018
E24M	E2H003	1908-2018

The hydrology at the outlet of the entire catchment (E24M) compared to the observed data are shown in Figure 3.3 below.

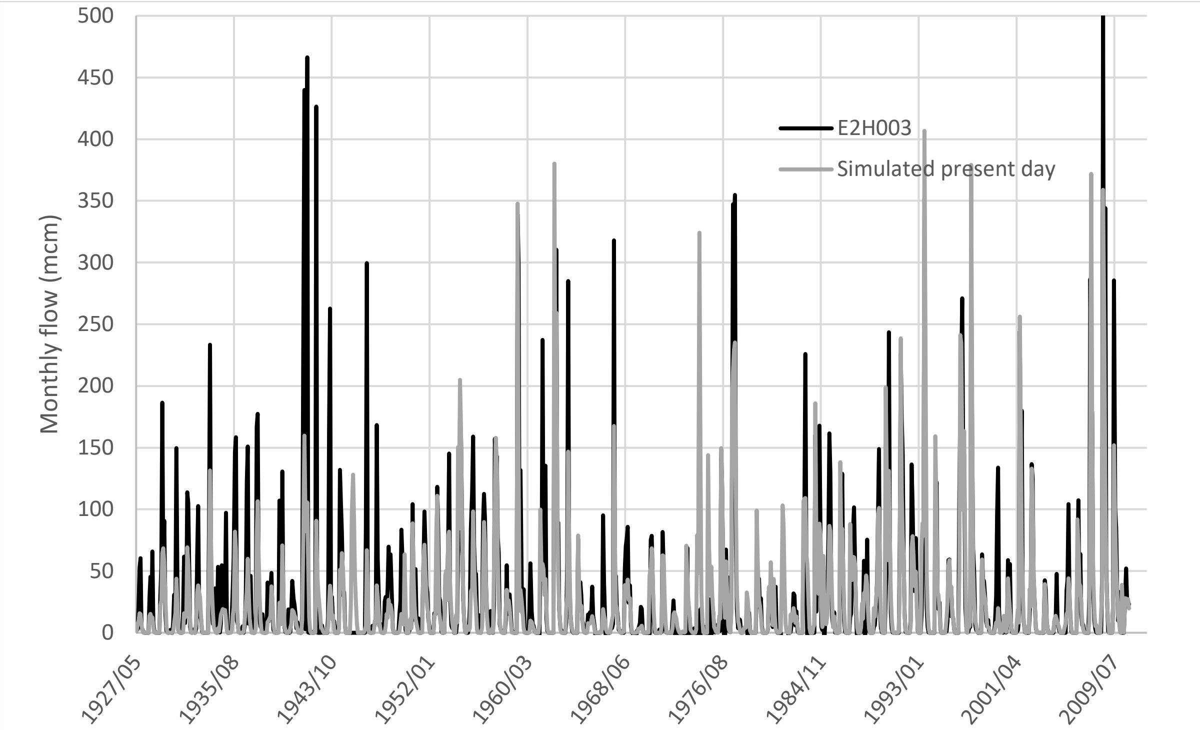


Figure 3.3 Hydrograph comparing observed flow from flow gauge E2H003, and simulated present day flow using the Pitman rainfall-runoff model

There is significant non-stationarity, which resulted in an undersimulation of flow pre-1950, therefore the flow was calibrated against the observed flow post 1950. A comparison of the observed and simulated flow time series for quaternary catchment E24M (post 1950) is provided as a flow duration curve in Figure 3.4 below. The flow duration curve ranks the flow time series as volume over time (which is given as a percentage). The duration curve indicates that the two time series are similar when compared as volumes although the simulated data underestimate the peaks in high flow conditions. These two time series were also compared statistically using common objective functions. While several objective functions were calculated, the Nash Coefficient (Nash and Sutcliffe 1970) based on untransformed (CE) and natural logarithmic transformed data (CE{ln}) were found to be the best measure of performance across the full range of flows and these were used together percentage bias statistics. The objective functions for the comparisons of flow are provided in Table 3.2 below.

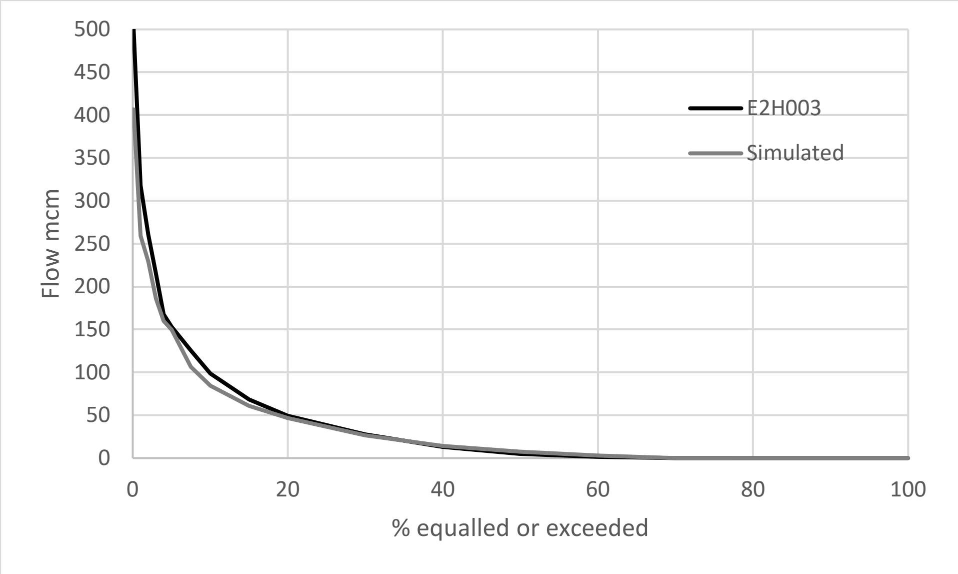


Figure 3.4 Flow duration curve comparing observed data with simulated data (1959 to 2010) for quaternary catchment E24M

Table 3.2 Objective functions for the comparisons of flow (post 1950) for the three quaternary catchments corresponding to the EWR sites

Quaternary catchment	Flow gauge number	Nash Coefficient (Untransformed)	Nash Coefficient (Ln transformed)	% Bias in simulated monthly flows	% Bias in simulated monthly ln(flows)
E21E	E2H008	0.744	0.566	3.313	6.363
E21G	E2H007	0.740	0.552	-13.061	-62.417
E22G	E2H002	0.664	0.659	-14.074	-9.135
E24M	E2H003	0.747	0.700	-10.842	1.110

3.2 Water quality (TDS) modelling

3.2.1 Methodology

The Doring River catchment was modelled in a lumped manner with the catchment divided into three parts, the upper, middle and lower Doring River catchments. This approach was adopted to utilise monitoring gauges with water quality data. The upper catchment represented all quaternary catchments upstream of E22G and water quality at the catchment outlet was calibrated against electrical conductivity data for the gauge E2H002. To be clear, electrical conductivity data were not used directly in the model calibration as it is not a mass measure, which is needed to route loads through a catchment in a water quality model. Instead, electrical conductivity (in mS m^{-1}) were converted to TDS (mg ℓ^{-1}) by the multiplication factor of 6.5 for catchments dominated by NaCl salts (DWAF 1996a). The salinity data provided by the DWS is typically in the form of electrical conductivity rather than TDS. The middle catchment corresponded with all quaternary catchments between E24H and E22G; the catchment outlet corresponded with the EWR4 site. The lower catchments represented all quaternary catchments between E24M and E24H and water quality at the catchment outlet was calibrated against conductivity data for the gauge E2H003.

Water quality modelling for conductivity was conducted on a monthly time step. Incremental flow for the upper, middle and lower Doring River catchments were separated into surface water, interflow and groundwater flow according to the simple statistical baseflow separation method of Hughes et al. (2003), with the alpha and beta parameters set to 0.97 and 0.95, respectively. The approach of separating incremental flow into flow fractions was adopted as these flow fractions represent the different routes for salt input from the catchment into the river. For example, to represent the input of salt into the river from groundwater input, a salt concentration signature can be assigned to groundwater flow. The same approach can be applied to interflow and surface water flow to represent salt input from the soil layer and catchment surface, respectively. The sum of salt input into the river is converted to a load and passed down to the next catchment downstream, where incremental salt inputs are added to the load and the instream conductivity value is updated.

The conductivity signatures assigned to surface water, interflow and groundwater flow can be calibrated by comparing model simulated instream conductivity against observed data. Generally, we can expect groundwater flow to have a much higher electrical conductivity signature compared to interflow and surface water flow. Typically, the interflow conductivity signature would be higher than that of the surface water signature. An update of the surface water and interflow conductivity signatures can allow the model to more accurately represent the variability of conductivity observations as these flow fractions are more variable than groundwater. Calibration of the groundwater signature can allow the model to represent the highest conductivity measures in the observed record during low flows.

Since the observed data measured by the DWS are in electrical conductivity in mS m^{-1}, and the model requires a mass measurement in order to transfer loads from upstream to downstream, electrical conductivity measures were converted to TDS using the simple multiplication conversion of DWAF (1996a) for catchments dominated by NaCl:

$$\text{TDS (mg } \ell^{-1}) = \text{electrical conductivity (mS m}^{-1}) \times 6.5 \qquad (3.1)$$

It was assumed that the contribution of organic salts to EC would be negligible relative to that of inorganic salts.

3.2.2 Model calibration

Table 3.3 shows the final flow fraction signatures applied to best represent the observed data.

Table 3.3 Model parameter values used for the monthly TDS model

Sub- Catchment	Surface Water Flow TDS Concentration (mg ℓ^{-1})	Interflow TDS Concentration (mg ℓ^{-1})	Ground Water Flow TDS Concentration (mg ℓ^{-1})
Upper	10	500	600
Mid	50	1000	3000
Lower	100	2000	6000

The model struggled to represent the higher TDS measures in the observed data record. Figure 3.5a shows the model simulated versus observed TDS as a time series graph whereas Figure 3.5b shows the flow time series as a reference.

Figure 3.5 Calibration of the monthly TDS model for the upper Doring catchment. a) Time series of observed TDS (coloured black) versus model simulated (coloured green); b) Time series of simulated monthly flow.

Unfortunately, no observed data are available for the middle catchment. This part of the catchment was included as a separated lumped portion of the model as the outlet corresponds with the EWR4 site. The TDS signatures of flow fractions were therefore calibrated against the observed data for the lower catchment. Figure 3.6a shows the time series of TDS over the simulation period, and shows a high variability of TDS, with some peaks reaching as high as 800 mg ℓ^{-1}. Figure 3.6b shows the time series of flow as a reference, where it is evident that higher peaks in TDS correspond to periods of low flow. Figure 3.6c shows the frequency distribution of simulated TDS where it is evident that concentrations above 100 mg ℓ^{-1} occur approximately 20% of the time.

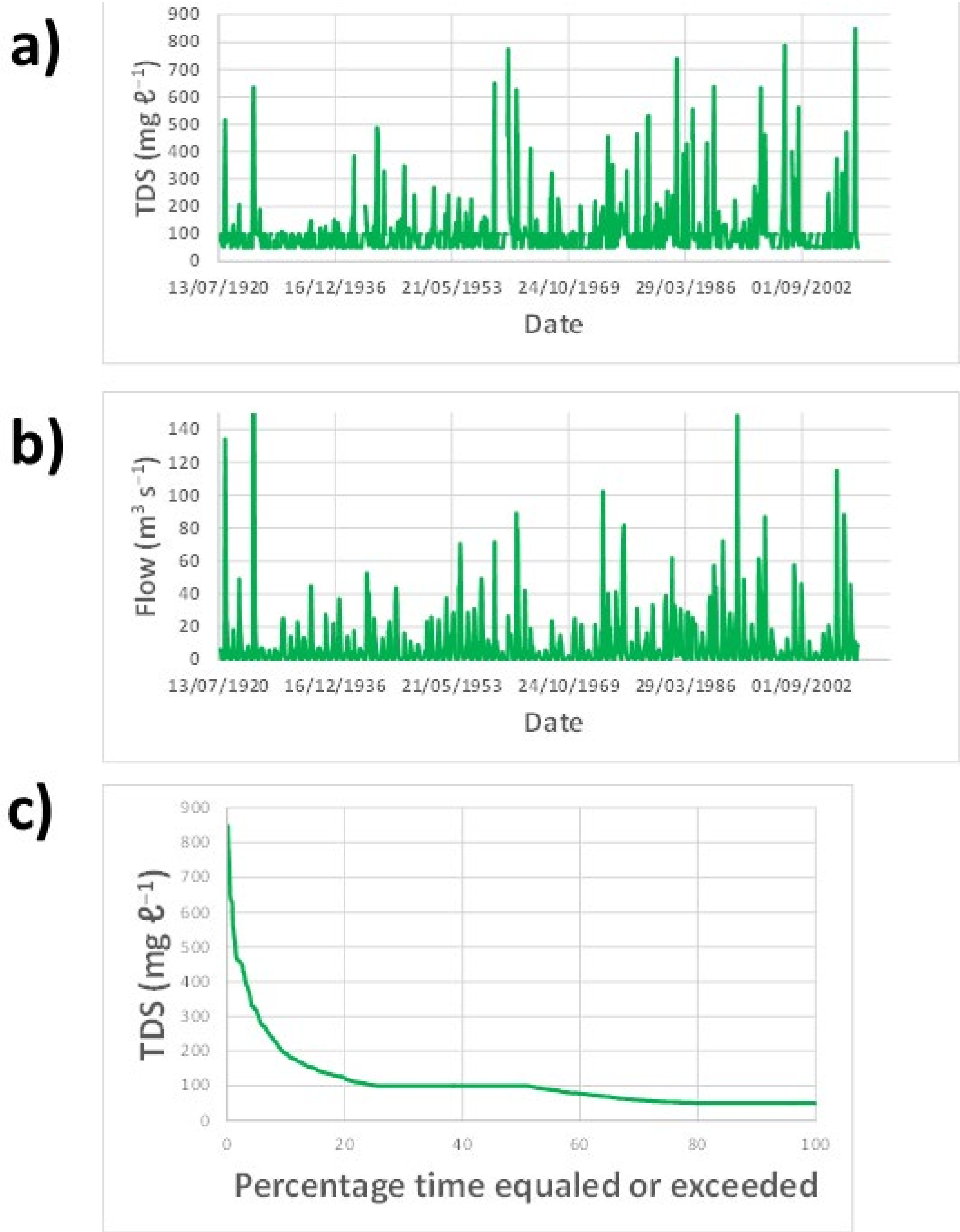


Figure 3.6 Calibration of the monthly TDS model for the middle Doring catchment. a) Time series of model simulated TDS; b) Time series of simulated monthly flow; c) Frequency distribution of model simulated TDS.

The model was calibrated against the available observed data for the lower catchment. Figure 3.7a shows the time series of simulated and observed TDS at the outlet of the lower catchment. It is evident that while the model was generally able to represent the full variability of the observed data in terms of quantity, the timing of the simulations did not match the observed data well. Figure 3.7b shows the time series of simulated flow over the same period as Figure 3.7a and illustrates that higher TDS concentrations correspond in general with lower flows. Figure 3.7c shows the frequency distributions of both observed and simulated TDS for the outlet of the lower catchment, and illustrates that although in general, the model was able to represent the variability and frequency of TDS in the observed data, the maximum simulated TDS at very low frequency spikes was considerably higher than that of the observed at 1,600 mg ℓ$^{-1}$ and 1,100 mg ℓ$^{-1}$, respectively.

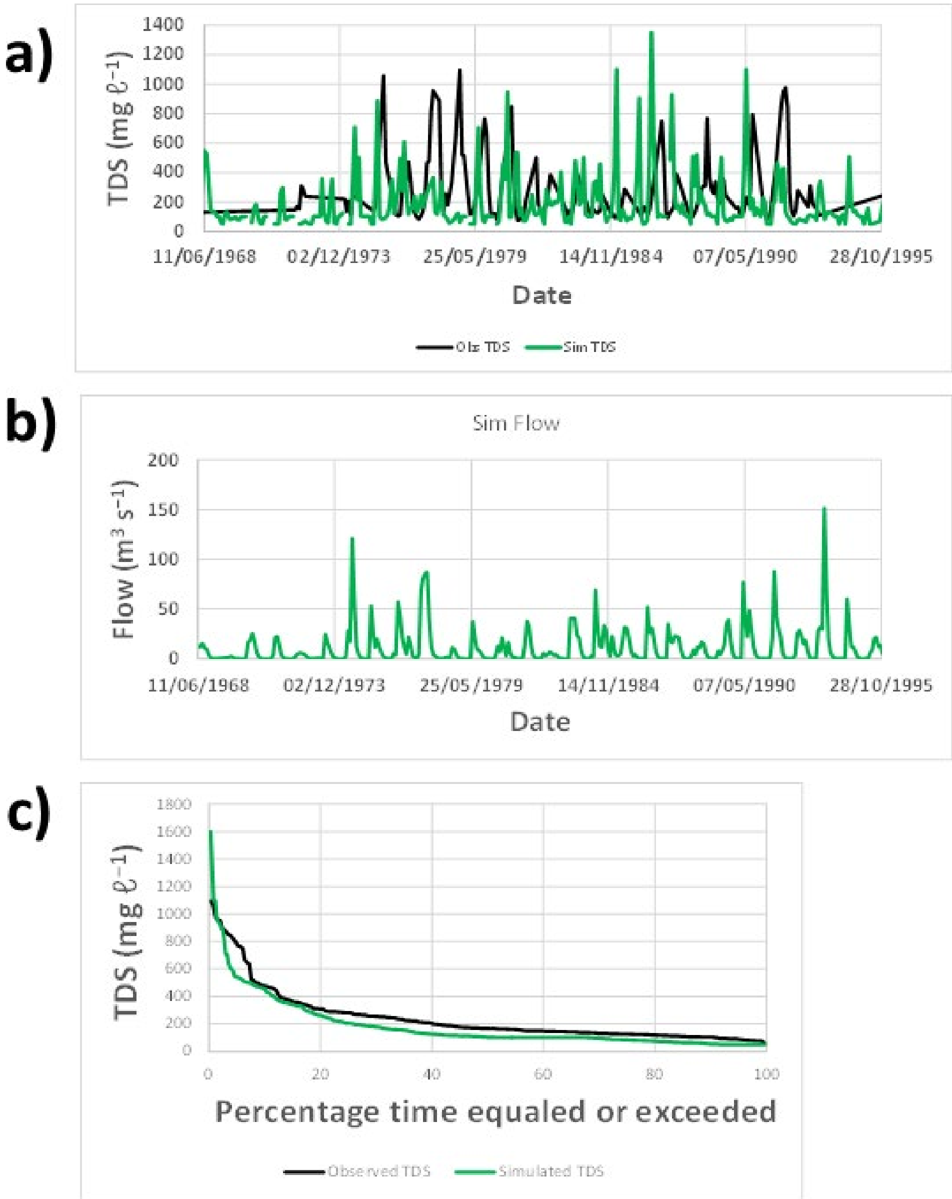


Figure 3.7 Calibration of the monthly TDS model for the lower Doring catchment. a) Time series of observed TDS (coloured black) verses model simulated (coloured green); b) Time series of simulated monthly flow; c) Frequency distribution of observed TDS (coloured black) verses model simulated (coloured green).

3.3 Revised Desktop ecological Reserve model

This section details the initial set up of the RDRM using natural hydrological flows. Chapter 5 includes final outputs of the model including the future climate data. An overview of the RDRM part of the investigation (both for the current chapter and results given in Chapter 4) is provided below:

- Set up RDRM with natural hydrology, and include minimum and maximum of 100 000 future flow time series as scenarios in the model.

- Outputs from the RDRM included in this report therefore include:
    - EWR site 6 ecological Reserve including comparison between minimum and maximum flow time series for RCP 2.6.
    - EWR site 6 ecological Reserve including comparison between minimum and maximum flow time series for RCP 8.5.
    - EWR site 5 ecological Reserve including comparison between minimum and maximum flow time series for RCP 2.6.
    - EWR site 5 ecological Reserve including comparison between minimum and maximum flow time series for RCP 8.5.
    - EWR site 4 ecological Reserve including comparison between minimum and maximum flow time series for RCP 2.6.
    - EWR site 4 ecological Reserve including comparison between minimum and maximum flow time series for RCP 8.5.

3.3.1 Introduction

The RDRM of Hughes et al. (2014) is based on the Habitat Flow Stressor Response (HFSR) (Hughes and Louw 2010) method, which was adapted from the Flow Stressor Response (FSR) of O'Keeffe et al. (2002). Central to the development of HFSR is the increased focus on hydraulic habitat links to ecological functioning compared to FSR (Hughes et al. 2014).

Habitat Flow Stressor Response was developed in South Africa as an integrative method that incorporates hydrology, hydraulics, water quality and ecological data, involving specialists in these fields and has been refined over the years. It specifies habitat stress values between 0 (upper discharge limit for critical wet and dry season months, i.e. habitats that provide optimal low flow habitat conditions for the biota) and 10 (zero flow conditions) for different discharges and then assesses the stress frequency characteristics associated with natural and present day regimes. The habitats which are appropriate to use depends on the fish guilds expected in that specific river in addition to the requirements for the macroinvertebrates. Time constraints and financial resources were the main reasons behind the development of desktop approaches that can be applied in situations where both data and ecological expertise are limited (Hughes et al. 2014). The desktop method's outputs are less certain than those of complex and data intensive methods but the time and effort required in their generation is highly reduced.

The RDRM is a recently developed desktop approach developed in South Africa for setting ecological water requirements. The overall model is characterised by three main components: hydrology; hydraulics and ecology, which are incorporated as sub-models of the RDRM (Figure 3.8). The fourth sub-model produces monthly high flow requirements based on natural hydrological regime with no linkages yet to the hydrological, hydraulic, and ecological regimes (Hughes et al. 2014).

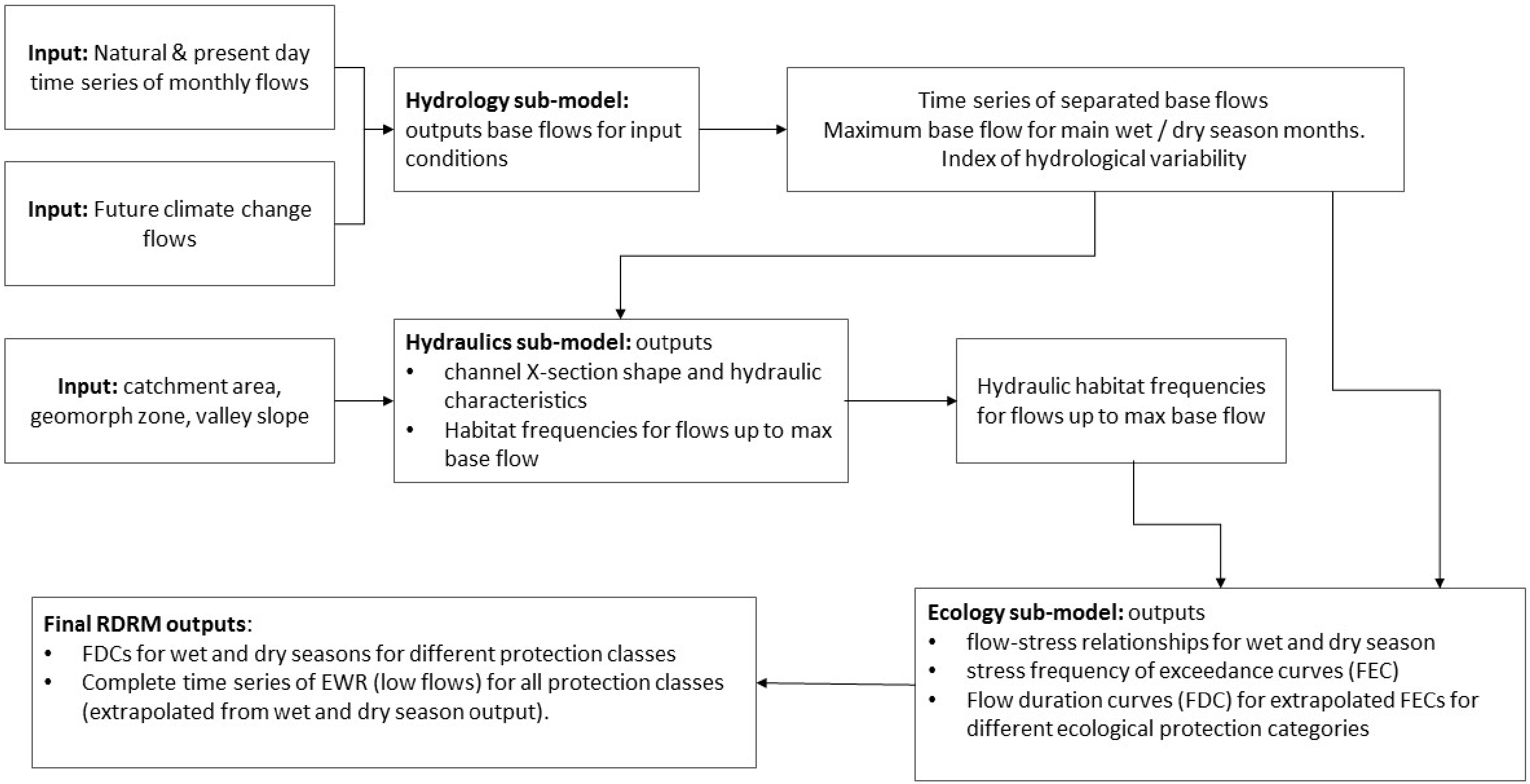


Figure 3.8 Flow diagram of the RDRM and the three sub-models (modified from Hughes et al. 2014)

The RDRM is a robust scientifically sound method for desktop estimates of EWRs, an improvement over the previous Reserve Determination Model (RDM) in which the relationship between flow and ecological response was implicit (and thus low confidence) instead of being explicit as it is in RDRM which incorporates the HFSR (Hughes and Louw 2010). The integration of the ecosystem drivers (hydrology, geomorphology and water quality) and the ecosystem response components (fish, macroinvertebrates, riparian vegetation) results in a management design of operating rules specific to the level of protection for the river (Hughes and Louw 2010: p. 911).

3.3.2 RDRM model parameters

For the hydrology sub-model, the data inputs are time series of monthly streamflow volumes representing natural and present-day flows and regional baseflow separation parameters (Hughes et al. 2014). There is also an option to include scenario flows as a third time series of flow. The baseflow time series are used to generate flow duration curves (FDC) for each month at a 20% default percentage point which is used to determine the maximum baseflow in the model (Hughes et al. 2012: 81). The model also calculates high flows percentage for each month for a range of FDC percent points. For the hydraulic sub-model, the data inputs are catchment area, geomorphic zone, the flood zone and the valley longitudinal gradient. These variables are used to generate the shape and hydraulic characteristics of the river channel cross-section.

The methods used for the ecology sub-model involves specifying habitat stress values between 0 and 10 for different discharges. A stress of 0 is associated with an upper discharge limit and a stress of 10 is associated with low flow conditions for the critical wet and dry season months. The biological functioning of aquatic biota is assumed to be affected by changes to stress variations associated with changes in flow patterns (O'Keeffe et al. 2002 in Hughes et al. 2014). The quantification of the flow stress relationship for RDRM involves the use of weighting factors for frequencies of three velocity-depth habitats (fast-deep FD, fast-intermediate FI and fast-shallow FS) in addition to a parameter specifying the maximum stress (Smax, with a default value of 9) when all three habitats disappear. An example of weighting of the different habitats is assigning FD higher values than FI and FS if large fish are dominant. Conversely, if small fish are dominant, then FI and FS are assigned higher weights in addition to Smax (dry season) set to a value less than nine because of the reduced importance of fast flowing water during the dry season. After the stress-frequency relationship is determined for the critical wet and dry season months, the curves for different ecological protection categories (categories A to D) are estimated by shifting the stress-frequency curve upwards from the natural curve. Ecological categories E and F are considered unsustainable and curves are not produced.

There are two main parameter set inputs to the model: the hydrology/hydraulic parameters and the ecology parameters. Many of these parameter values are automatically estimated when the model is run for the first time on a specific site. Other parameters can be set and/or edited during the model run, while some need to be preset before the model runs. It is assumed that some of these parameters will be estimated through links to the national ecological databases (such as the vegetation data available from the SANBI BGIS database, and the River Health Programme). Table 3.4 shows the hydrology and hydraulic parameter sets, while Table 3.5 shows the ecology parameters.

Table 3.4 Hydrology and hydraulic parameter explanation for RDRM

Parameter	Explanation
Baseflow separation (Alpha)	Obtain from national database
Baseflow separation (Beta)	
Geom. Zone (1-6)	Geomorphological zone, from upland (1) to lowland (6) rivers. Must be preset.
Width/Depth Scaling	Scaling parameter c in the width – depth hydraulic geometry equation. The default value is 0.5, but it can be changed by ±0.1 if the estimated depth is too high or low.
Hydro. Variability	Does not need to be pre-set and will be calculated by the hydrology sub-model.
Valley slope (fraction)	Can be estimated from Google Earth and should be compatible with Geom. Zone. This should be preset.
Catchment Area (km^2)	Used in the flood calculations and hydraulic sub-model. (if not set, it defaults to 200 km^2)
Maximum Width (m)	Can be estimated from Google Earth. Should be preset, but will default to 40 m.
Maximum Depth (m)	Currently calculated using hydraulic geometry relationships.
Bed width (Fraction)	These parameters are all calculated from the Geomorph Zone and do not need to be preset.
Macro Roughness (m)	
Micro Roughness (m)	
Max. Gradient (fraction)	
Min. Gradient (fraction)	
Gradient variability factor	
Max. Manning n	
Min. Manning n	
Manning n variability factor	
Obs Max. Gradient	These are only used when an observed channel cross-section is used. If an observed stage-discharge rating curve is available, these values should be calibrated to match the observed curve in the hydraulic sub-model.
Obs Min. Gradient	
Gradient variability factor	
Obs Max. Manning n	
Obs Min. Manning n	
Manning n variability factor	

Obs: observed; Min: minimum; Max: maximum

Table 3.5 Ecology parameter explanation for RDRM

Parameter	Value	Explanation
Max. baseflow FDC	20	Part of the hydrology sub-model. Must be preset.
Perennial Index (0-2)	0	A parameter used to force (or not) perenniality in the ecological Reserve flows.
Alignment Index (0-7)	0	A parameter used to align the stress frequency curves to present day conditions (rather than being based on natural flow and stress conditions)
High Shift Wet A	2	These are used to define the shapes of the stress frequency curves for the different ecological protection categories. Default values are calculated by the model, but they can be adjusted by the user, where appropriate and if there is additional information available to suggest changes.
High Shift Wet B	2.903	
High Shift Wet C	4.257	
High Shift Wet D	6.062	
High Shift Dry A	3.8	
High Shift Dry B	4.529	
High Shift Dry C	5.622	
High Shift Dry D	7.079	
Low Shift Wet A	0.4	
Low Shift Wet B	0.485	
Low Shift Wet C	0.613	
Low Shift Wet D	0.783	
Low Shift Dry A	0.3	
Low Shift Dry B	0.434	
Low Shift Dry C	0.636	
Low Shift Dry D	0.904	
Wet Stress at 0 FS	9	These define the way in which the Flow-stress relationships are estimated using the hydraulic habitat data. The weights should be based on the type of fish and invertebrates that are expected to be present in the river. These should be pre-set and the default values shown to the left can be used. They can be edited within the model.
Wet FS Weight	1	
Wet FI Weight	1	
Wet FD Weight	2	
Dry Stress at 0 FS	9	
Dry FS Weight	1	
Dry FI Weight	1	
Dry FD Weight	2	

Data related to some of the parameters mentioned above are listed below as they help with visualising the sites. The channel width (parameter 8 for RDRM) was estimated from Google Earth Pro. Figure 3.9 shows the channel width calculation for Doring EWR sites 4, 5, 6.

(a) (b) (c)

Figure 3.9 Channel width for Doring EWR sites 4 (a), 5 (b) and 6 (c) obtained from Google Earth

Other data for input into RDRM were obtained from the previous ecological Reserve reports including the Government Gazette (DWA 2006a; DWS 2016). Catchment area was estimated using ArcGIS and WR90 database. The Geomorphological zone-related information was determined from PES data derived from the DWS website http://www.dwa.gov.za/iwqs/rhp/eco/peseismodel.aspx (Table 3.6).

Table 3.6 Data relevant for the three Doring study sites that were entered into the RDRM. Note that Ecological Category B/C was used for EWR site 6 in order to compare the RDRM output with DRIFT output (Appendix Table A3)

Quat-ernary	EWR site	Geoclass	Slope	nMAR	pdMAR	Ecological category	Catchment area (km^2)
E24J	4	4	0.006	420	320	B	18543.4
E24M	5	4	0.006	511	401	B	23511.3
E21J	6	3	0.030	138	104	B/C	750.0
Quat	EWR site	Max depth (m)	Max width (m)	Baseflow (alpha)	Baseflow (beta)		
E24J	4	7.5	150	0.97	0.42		
E24M	5	14	120	0.97	0.42		
E21J	6	7	95	0.97	0.42		

3.3.3 RDRM EWR Site 6

EWR site 6 is a headwater site with flows from quaternary E21G and E21H (Figure 2.4). The EWR site is located in the upper reaches of quaternary E21J, therefore outflows from E21H were used in the RDRM.

Hydrology sub-model

The monthly distribution and magnitude of the natural flows derived from the Pitman model (Appendix Table F1 and F2) that were input to the RDRM were matched (as best as possible) to the output from the DRIFT model (see Appendix Table A6), as shown in Figure 3.10.

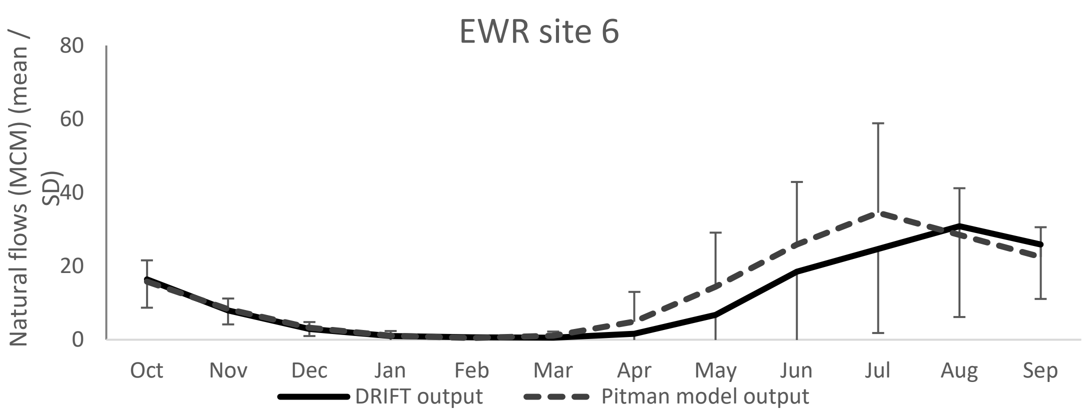


Figure 3.10 Natural flows output (mean with standard deviation (SD) error bars) from the Pitman model were matched to DRIFT output

In the hydrology model, the only parameter that can be changed is the maximum baseflow % point which is used to determine the wet and dry season maximum baseflow values. This parameter can vary between 5% and 20%, and different values for this parameter were applied in order to calibrate the RDRM hydrology to the DRIFT model. The value used for EWR site 6 was 20%. The RDRM identified February and July as the critical low and high flow months. A comparison of the total MAR and EWR (low flow and total) from DRIFT and RDRM models made in Table 3.7 shows that the values are comparable. Figure 3.11 shows the RDRM outputs of the flow duration curve for these two months against the DRIFT model outputs (data in Appendix Table A3).

Table 3.7 Comparison of total MAR and EWR values generated by DRIFT and RDRM for EWR site 6

EWR site 6	DRIFT	RDRM
Total MAR (± SD) MCM	137.86 ± 82.083	160.69 ± 59.96
Total EWR (B/C) MCM	60.331 (43.76 %MAR)	62.463 (38.9 %MAR)
Lowflow (B/C) MCM	25.331 (18.37 %MAR)	26.249 (16.3 %MAR)

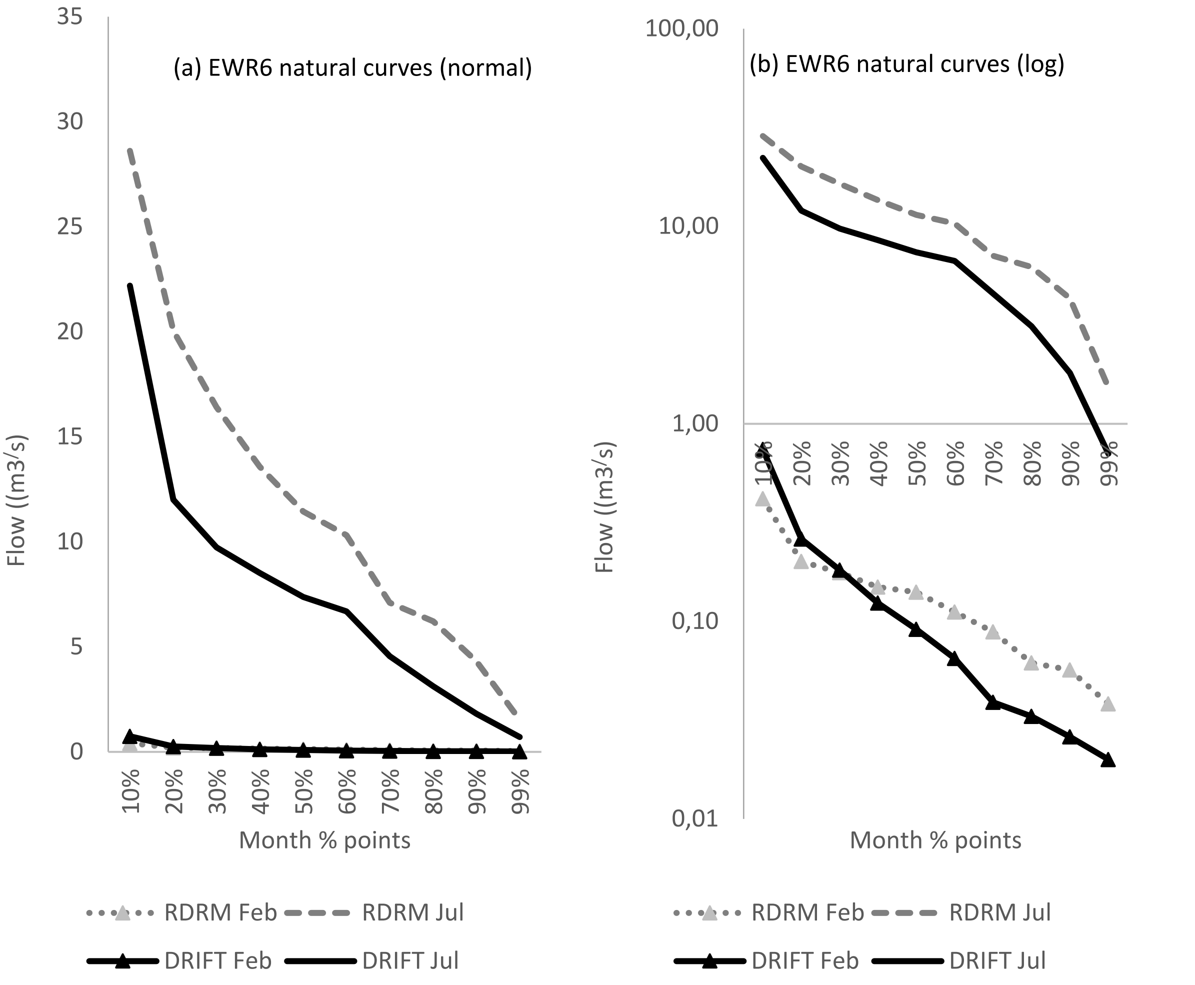


Figure 3.11 Comparison of flow for EWR6 natural duration curves for the two critical months generated by RDRM and DRIFT on (a) normal and (b) logarithmic y-axis

Hydraulics sub-model

The channel cross-section for input into the hydraulics sub-model of RDRM was derived from DWAF (2005b). Figure 3.12 shows a screen capture of the calibration of the hydraulic sub-model using this channel cross-section data.

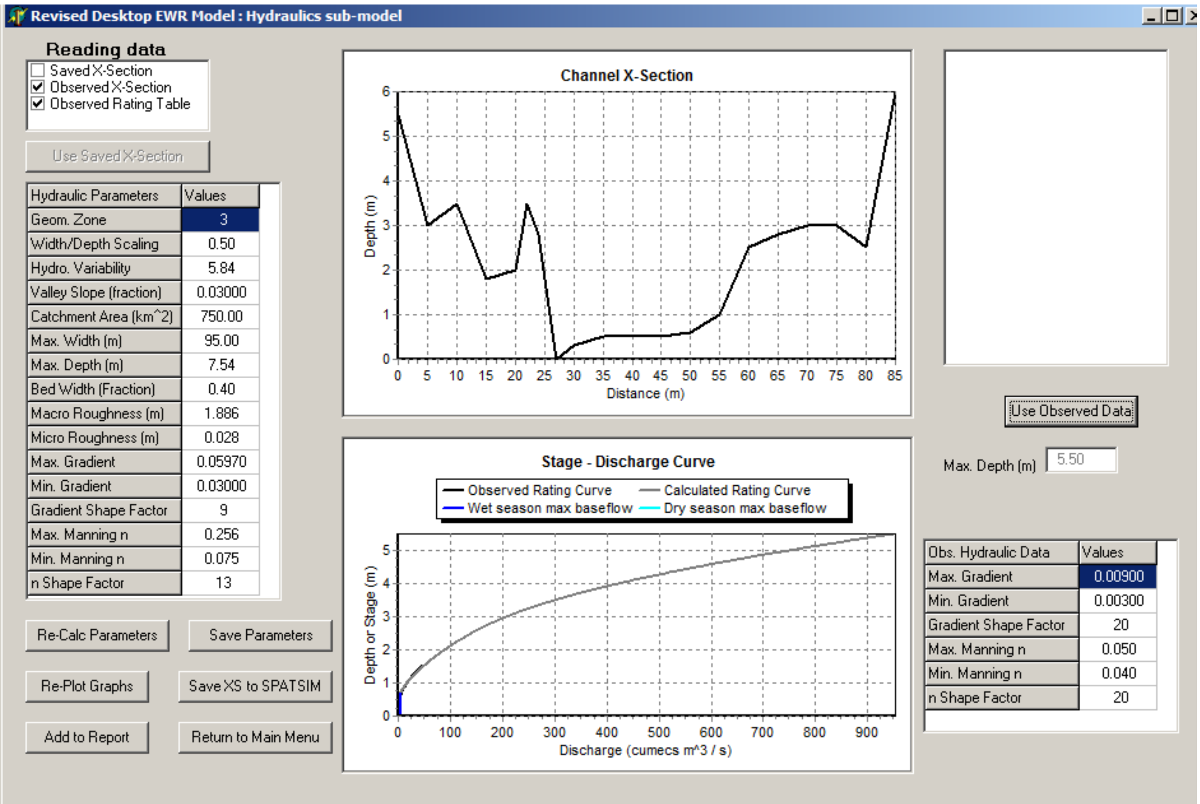


Figure 3.12 Screenshot of hydraulic sub-model calibration using observed channel cross-section data for EWR site 6

When the hydraulics sub-model is run, a text file of habitat percentages is created. For site 6, the results are plotted in Figure 3.13, which shows that the wetted width increases significantly with discharges above 1.4 m^3/s. Above this discharge value, the percent frequency of fast-deep (FD), fast-intermediate (FI) and fast-shallow (FS) habitats increase significantly.

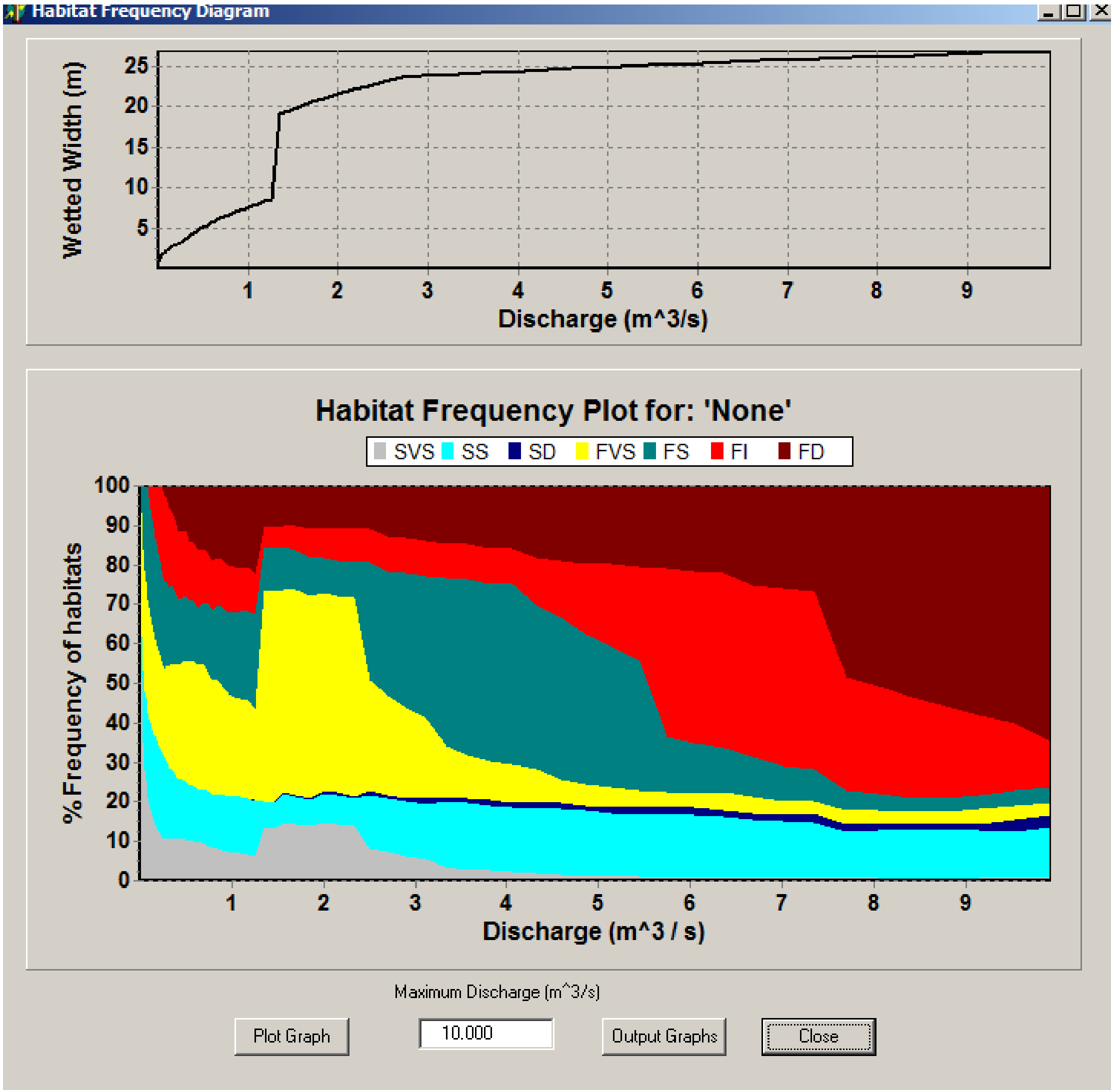
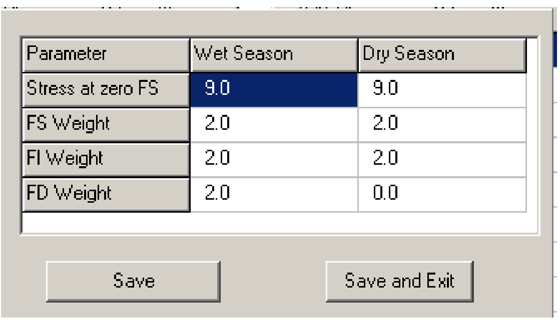


Figure 3.13 Habitat frequency plot generated for EWR site 6 by RDRM model

Ecology sub-model

Smax or the maximum stress was set at the default value of nine and the three fast habitats were weighted equally (Figure 3.14). In theory, these parameters can be reset based on Specialist feedback related to fish and macroinvertebrates.



Parameter	Wet Season	Dry Season
Stress at zero FS	9.0	9.0
FS Weight	2.0	2.0
FI Weight	2.0	2.0
FD Weight	2.0	0.0

Figure 3.14 Setting of maximum stress and the weighting of the three habitat types under the ecology sub-model. Note the zero for FD weight during dry season is set by the model because there are no FD habitats available.

Flood sub-model

The flood sub-model was calibrated using the data on required floods from DWA 2014 (Appendix Table A6) for annual floods (flood class 1, 2, 3, 4) and 1:2 and 1:5 year floods (Figure 3.15). Note that the RDRM only provides five classes of annual floods, together with 1 year in 2, and a 1 year in 5 floods, therefore 1 year in 10 and 1 year in 20 floods, which are calculated in DRIFT, are not included.

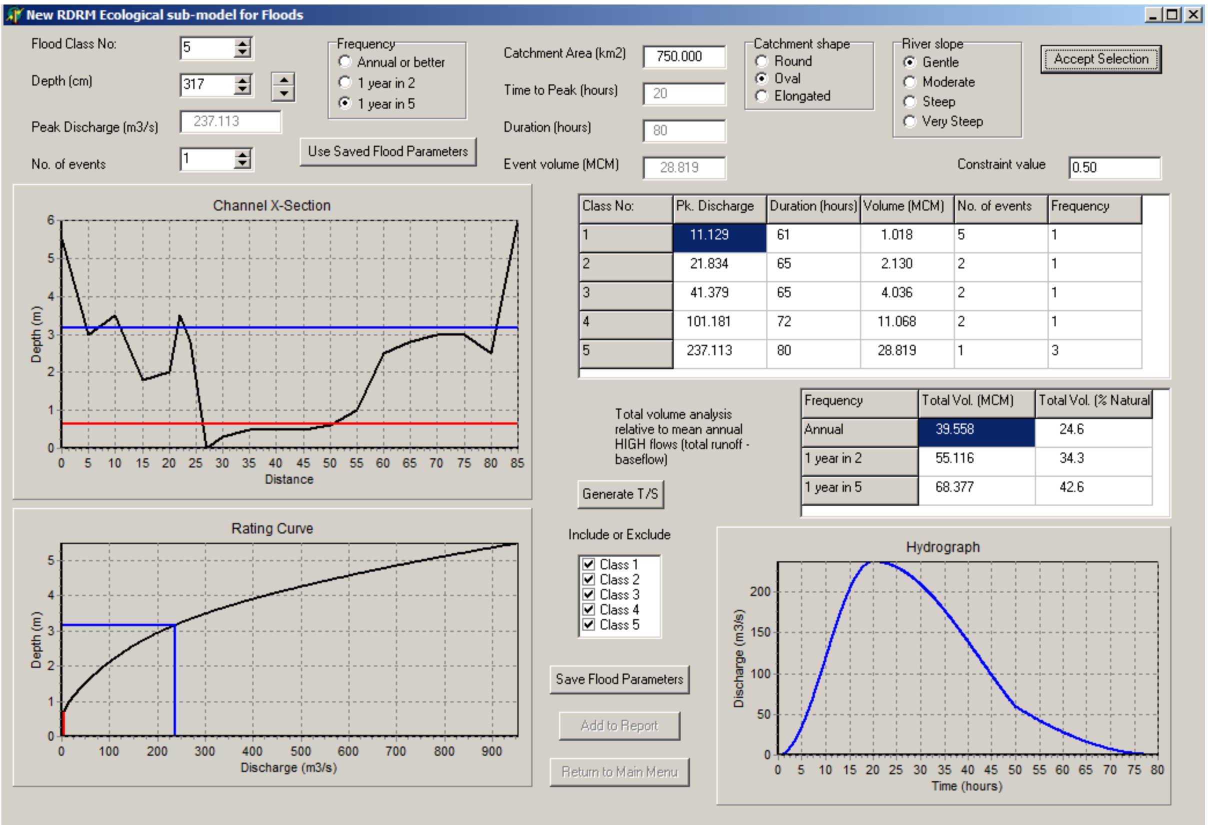


Figure 3.15 Calibration of the flood model to include the required floods from DRIFT model (DWA 2014) (data included in Appendix Table A6)

Figures 3.16 and 3.17 allow comparison of natural flows and total ecological Reserve and low flow assurance curves for EWR site 6 determined by RDRM versus the DRIFT model for the two critical months determined by RDRM. The RDRM flows are similar although not exactly the same as the DRIFT model output.

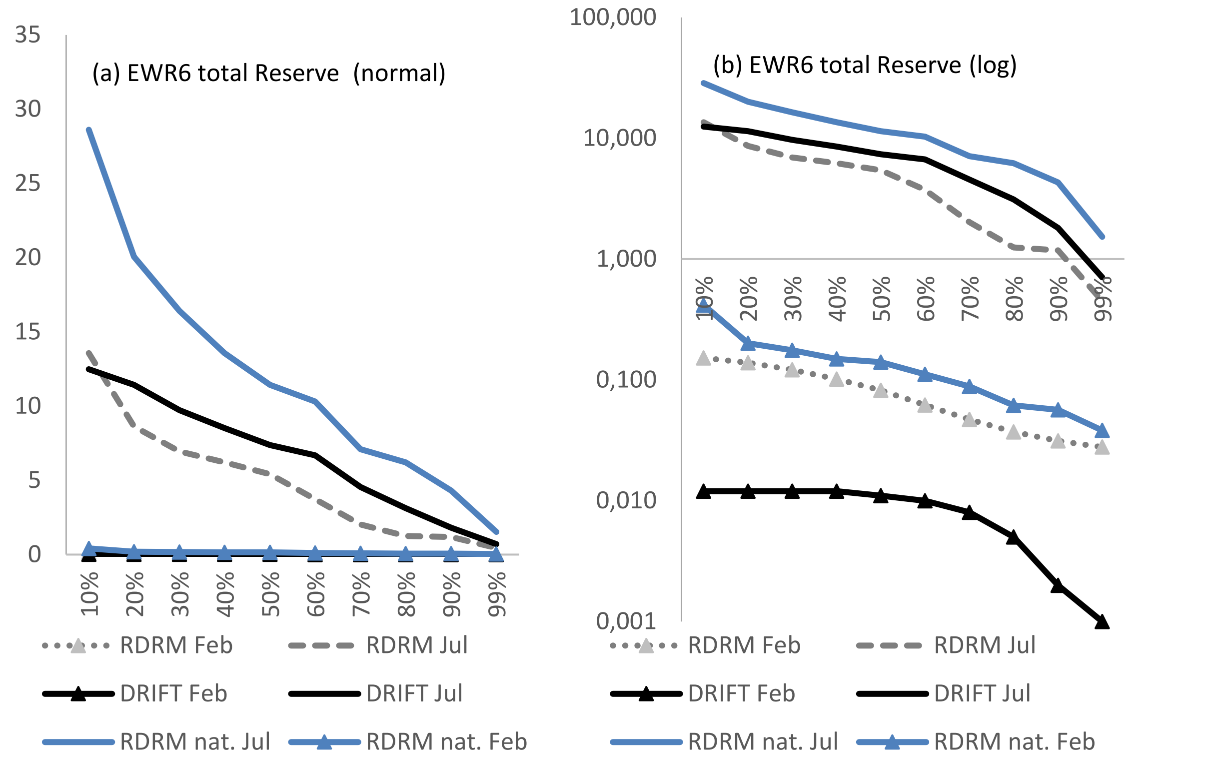


Figure 3.16 Comparison of natural flows (generated by RDRM) and total ecological Reserve ($m^3.s^{-1}$) for EWR site 6 determined by RDRM versus DRIFT model on (a) normal and (b) logarithmic y-axis

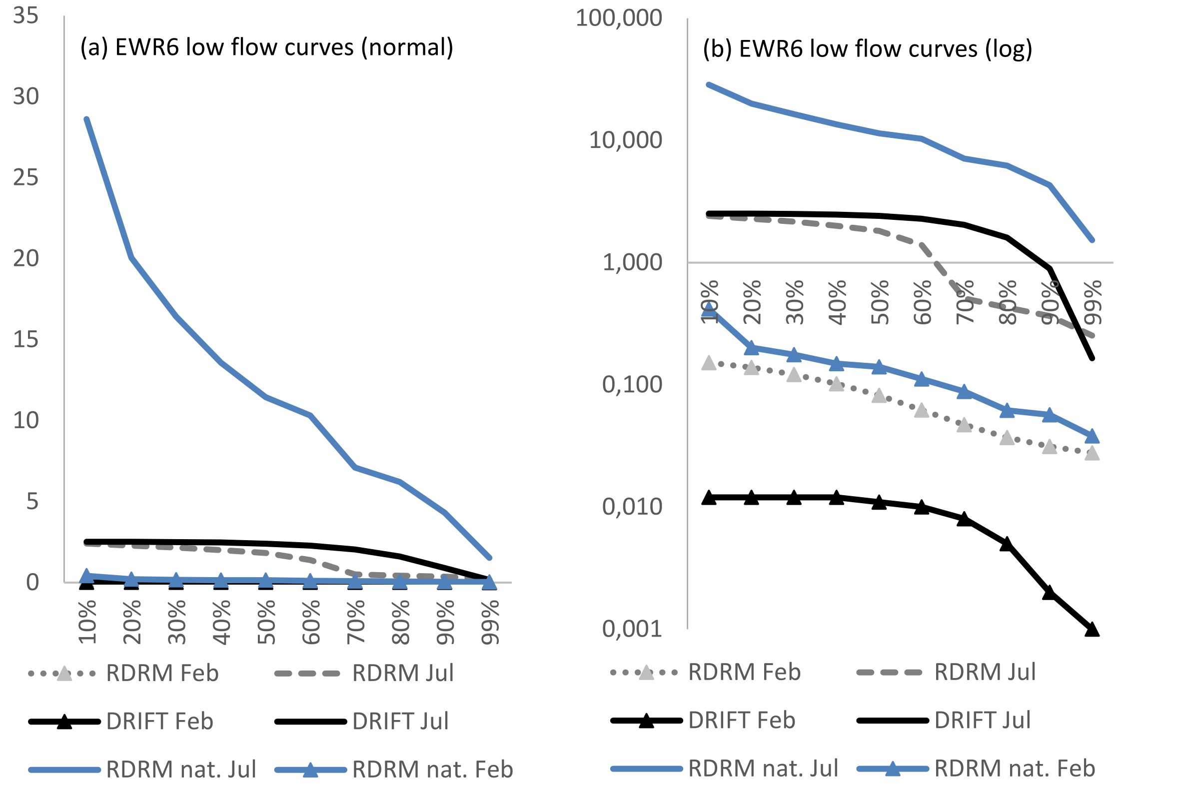


Figure 3.17 Comparison of natural flows (generated by RDRM) and low flow assurance curves ($m^3.s^{-1}$) for EWR site 6 determined by RDRM versus DRIFT model on (a) normal and (b) logarithmic y-axis

3.3.4 RDRM EWR Site 4

EWR site 4 has input flows from quaternary E24H (Figure 2.4).

Hydrology sub-model

The monthly distribution and magnitude of the natural flows derived from Pitman model (Appendix Table F3 and F4) that were input to the RDRM were matched (as best as possible) to those output from the DRIFT model (see Appendix Table A3), as shown in Figure 3.18.

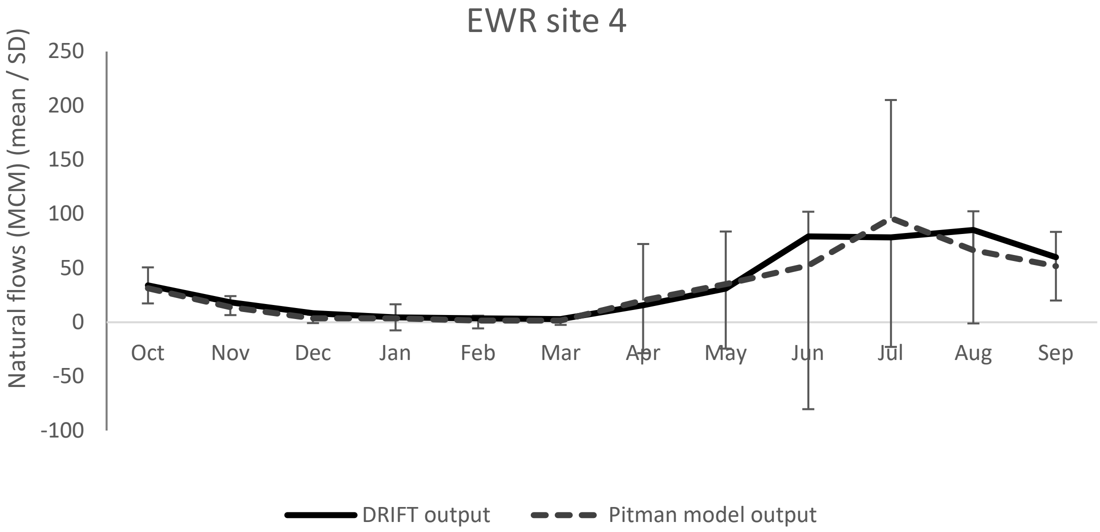


Figure 3.18 Natural flows output (mean with SD error bars) from Pitman model were matched to DRIFT output

The maximum baseflow % point was set to 10% and the RDRM identified March and July as critical low and high flow months. The RDRM outputs for these two months against the DRIFT model outputs are shown in Figure 3.19. A comparison of the total MAR and EWR (low flow and total) from DRIFT and RDRM models made in Table 3.8 shows that the values are comparable.

Table 3.8 Comparison of total MAR and EWR values generated by DRIFT and RDRM for EWR site 4

EWR site 4	DRIFT	RDRM
Total MAR (± SD) MCM	421.47 ± 337.32	378.18 ± 189.59
Total EWR (B) MCM	192.205 (45.60 %MAR)	163.666 (43.3 %MAR)
Lowflow (B) MCM	64.532 (15.31 %MAR)	65.334 (17.3 %MAR)

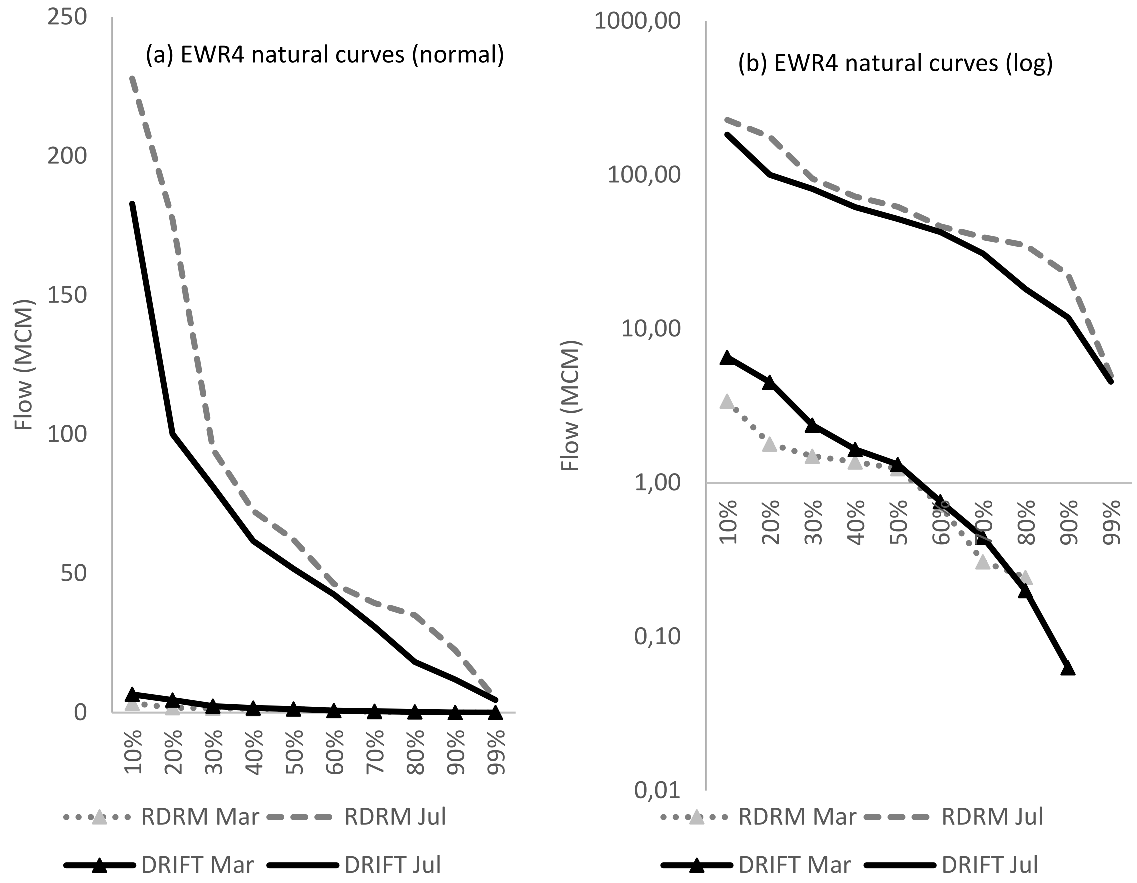


Figure 3.19 Comparison of flow for EWR4 natural duration curves for the two critical months generated by RDRM and DRIFT on (a) normal and (b) logarithmic y-axis (note that zero values cannot be displayed on a logarithmic scale)

Hydraulics sub-model

The channel cross-section for input into the hydraulics sub-model of RDRM was derived from DWAF (2005b). Figure 3.20 shows a screen capture of the calibration of the hydraulic sub-model using this channel cross-section data. The results of the hydraulic model are plotted in Figure 3.21, which shows a gradual increase in the wetted width against discharge.

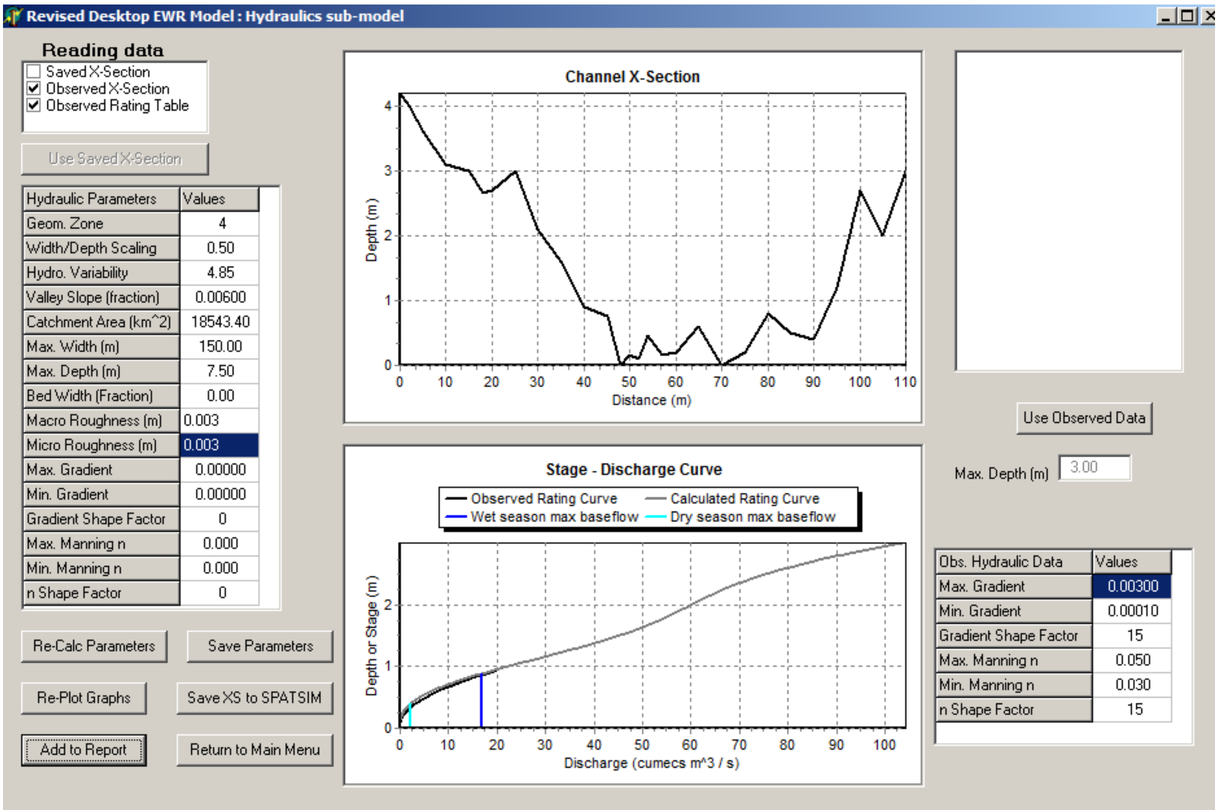


Figure 3.20 Screenshot of hydraulic sub-model calibration using observed channel cross-section data for EWR site 4

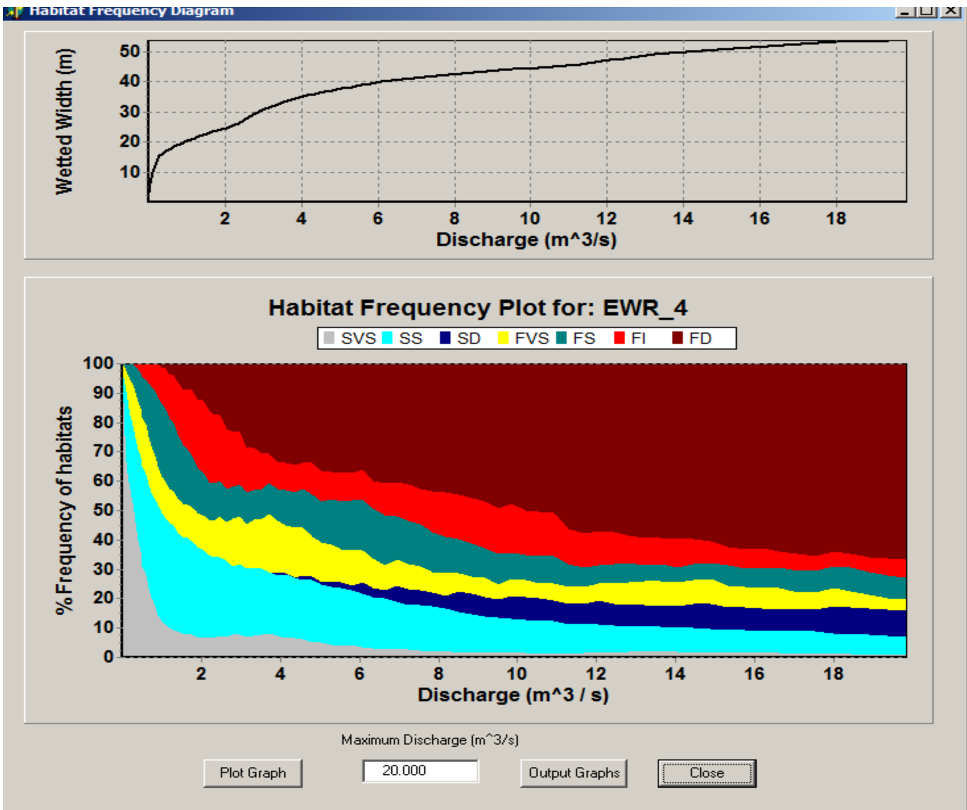


Figure 3.21 Habitat frequency plot generated for EWR site 4 by RDRM model

Ecology sub-model

Smax or the maximum stress was set at the default value of nine and the three fast habitats were weighted with FD weighting higher (Figure 3.22) because of the predominance of this habitat as shown in Figure 3.21). In theory, these parameters can be reset based on Specialist feedback related to fish and macroinvertebrates.

Parameter	Wet Season	Dry Season
Stress at zero FS	9.0	9.0
FS Weight	2.0	2.0
FI Weight	2.0	2.0
FD Weight	4.0	4.0

Save   Save and Exit

Figure 3.22 Setting of maximum stress and the weighting of the three habitat types under the ecology sub-model. FD weighting is higher than FS and FI because of greater prevalence of this habitat (see Figure 3.21)

Flood sub-model

Since there was no flood data available for EWR site 4, default floods were used (Figure 3.23).

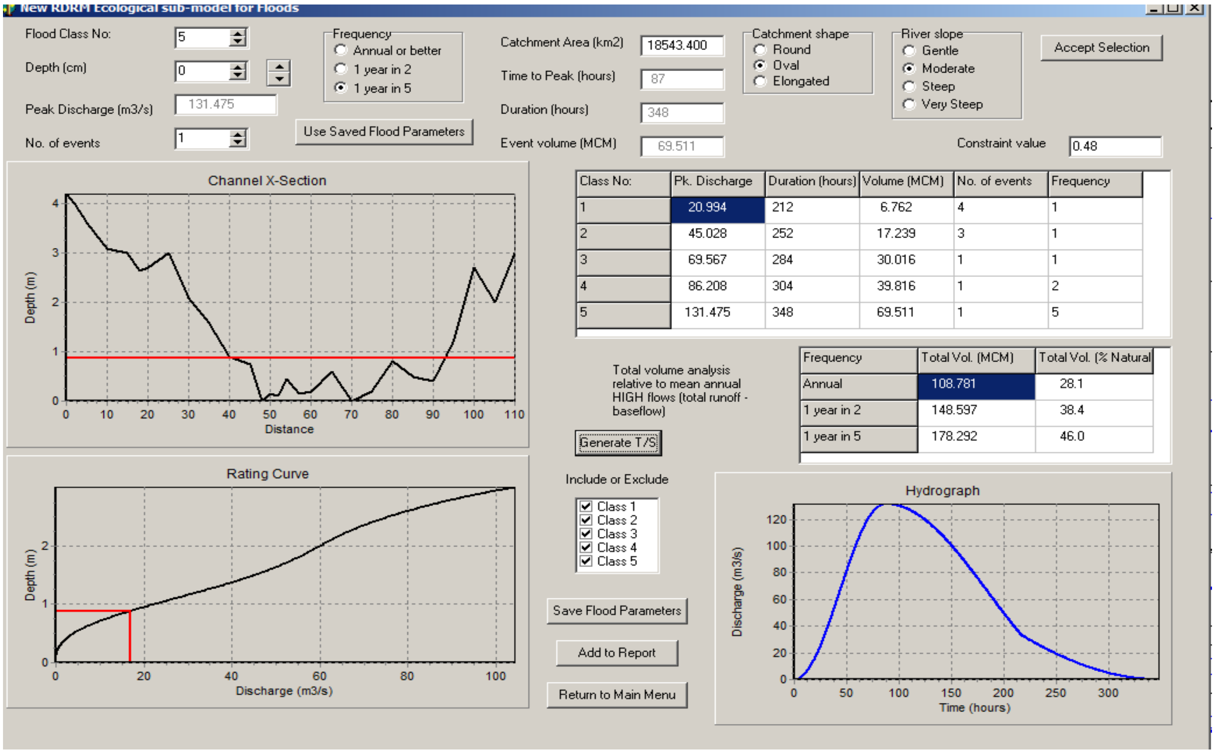


Figure 3.23 Default setting of floods for EWR site 4

Figures 3.24 and 3.25 allow comparison of natural flows and total ecological Reserve and low flow assurance curves for EWR site 4 determined by RDRM versus the DRIFT model for the two critical months determined by RDRM. The RDRM flows are similar although not exactly the same as the DRIFT model output.

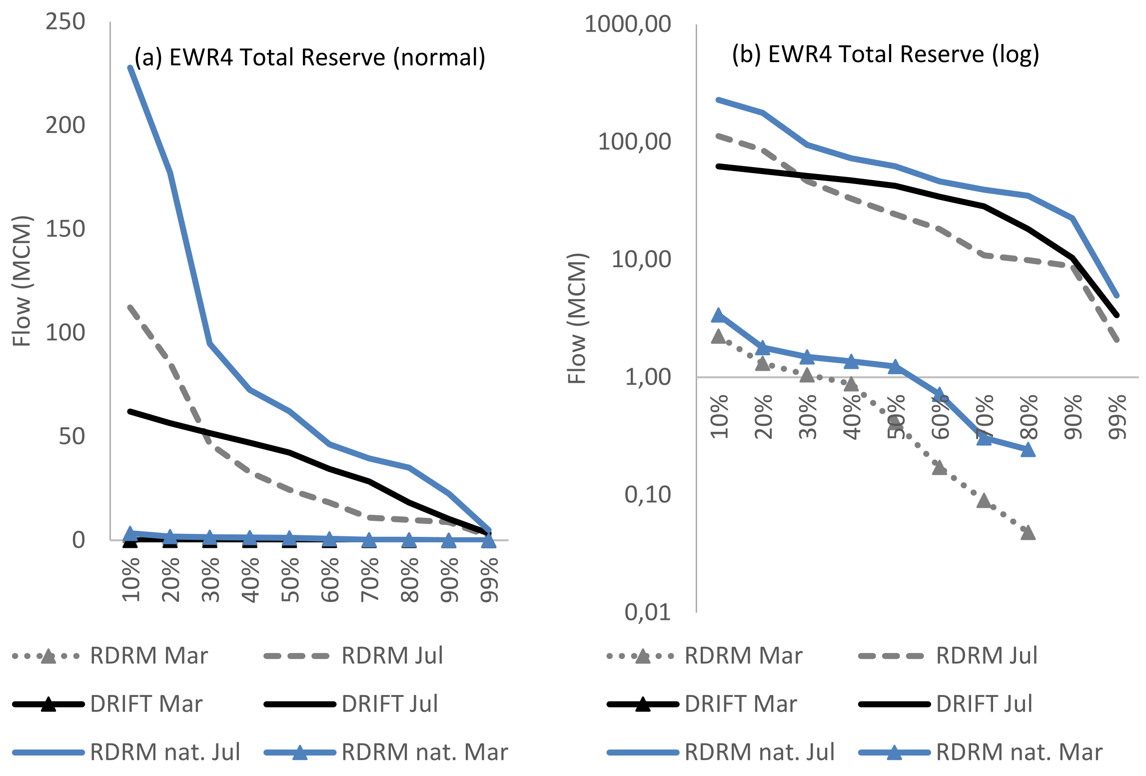


Figure 3.24 Comparison of natural flows (generated by RDRM) and total ecological Reserve flows assurance curves ($m^3.s^{-1}$) for EWR site 4 determined by RDRM versus DRIFT model on (a) normal and (b) logarithmic y-axis (note that zero values cannot be displayed on a log scale)

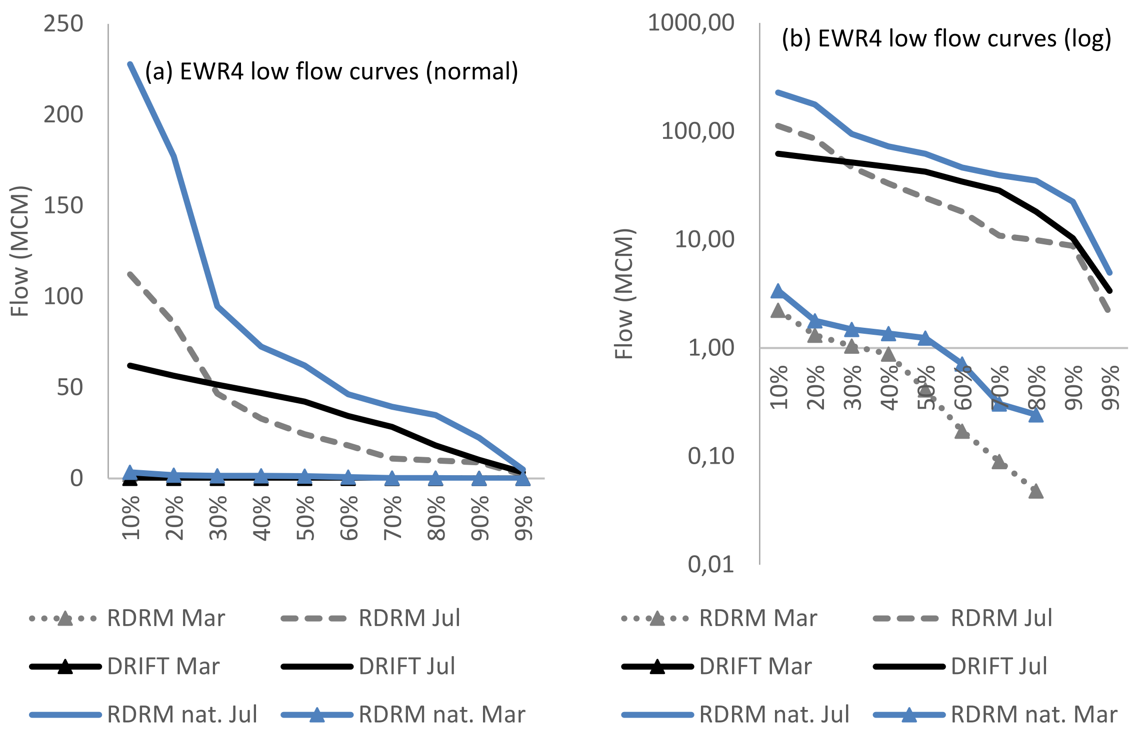


Figure 3.25 Comparison of natural flows (generated by RDRM) and low flow assurance curves ($m^3.s^{-1}$) for EWR site 4 determined by RDRM versus DRIFT model on (a) normal and (b) logarithmic y-axis (note that zero values cannot be displayed on a log scale)

3.3.5 RDRM EWR Site 5

EWR site 5 is the most downstream EWR site and receives input flows from quaternary E24L (Figure 2.4).

Hydrology sub-model

The monthly distribution and magnitude of the natural flows derived from Pitman model (Appendix Table F5 and F6) that were input to the RDRM were matched (as best as possible) to those output from the DRIFT model (see Appendix Table A5), as shown in Figure 3.26.

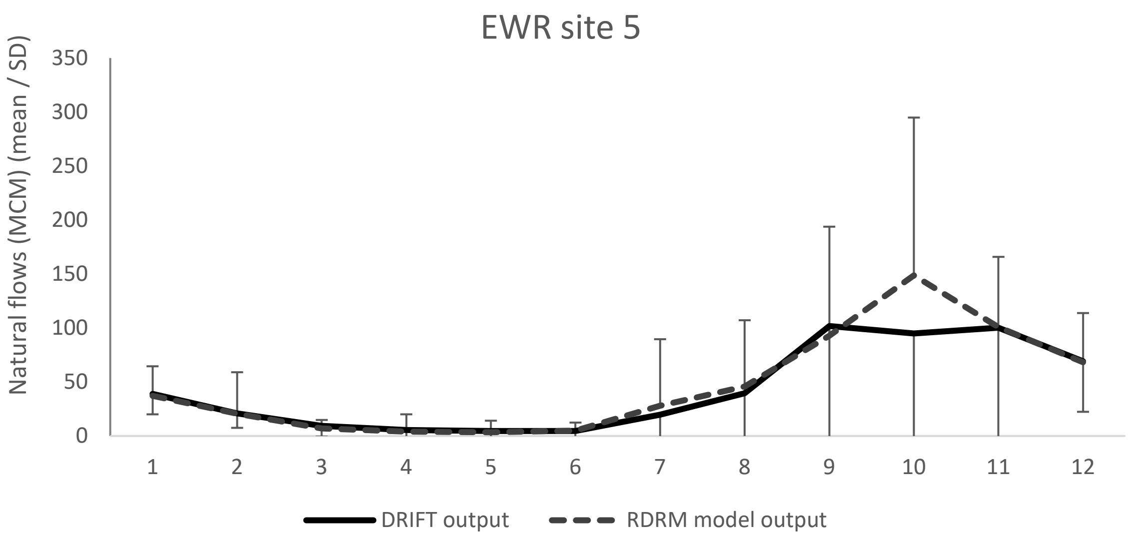


Figure 3.26 Natural flows output (mean with SD error bars) from Pitman model were matched to DRIFT output

The maximum baseflow % point was set to 10% and the RDRM identified January and July as critical low and high flow months. The RDRM outputs for these two months against the DRIFT model outputs are shown in Figure 3.27. A comparison of the total MAR and EWR (low flow and total) from DRIFT and RDRM models made in Table 3.9 shows that the values are comparable, although the low flow values in RDRM are significantly higher, although the %MAR value is similar.

Table 3.9 Comparison of total MAR and EWR values generated by DRIFT and RDRM for EWR site 5

EWR site 5	DRIFT	RDRM
Total MAR (± SD) MCM	509.62 ± 418.93	561.87 ± 310.79
Total EWR (B) MCM	232.41 (45.60 %MAR)	239.08 (42.06 %MAR)
Lowflow (B) MCM	78.029 (15.31 %MAR)	97.317 (17.3 %MAR)

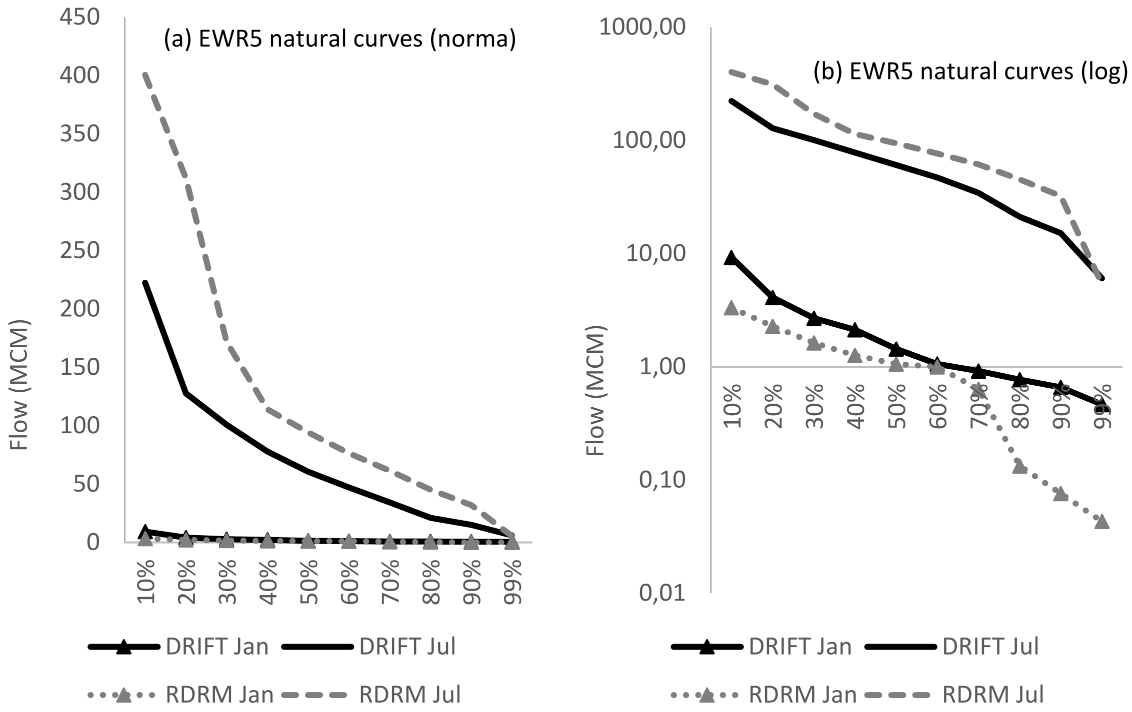


Figure 3.27 Comparison of flow for EWR5 natural duration curves for the two critical months generated by RDRM and DRIFT on (a) normal and (b) logarithmic y-axis

Hydraulics sub-model

The channel cross-section for input into the hydraulics sub-model of RDRM was derived from DWAF (2005b). Figure 3.28 shows a screen capture of the calibration of the hydraulic sub-model using this channel cross-section data. The results of the hydraulic model are plotted in Figure 3.29, which shows a gradual increase in the wetted width against discharge.

Ecology sub-model

Smax or the maximum stress was set at the default value of nine and the three fast habitats were weighted with FD weighting higher during the wet season (Figure 3.30) similar to EWR site 4 because of the predominance of this habitat as shown in Figure 3.29). These parameters can be reset based on Specialist feedback related to fish and macroinvertebrates.

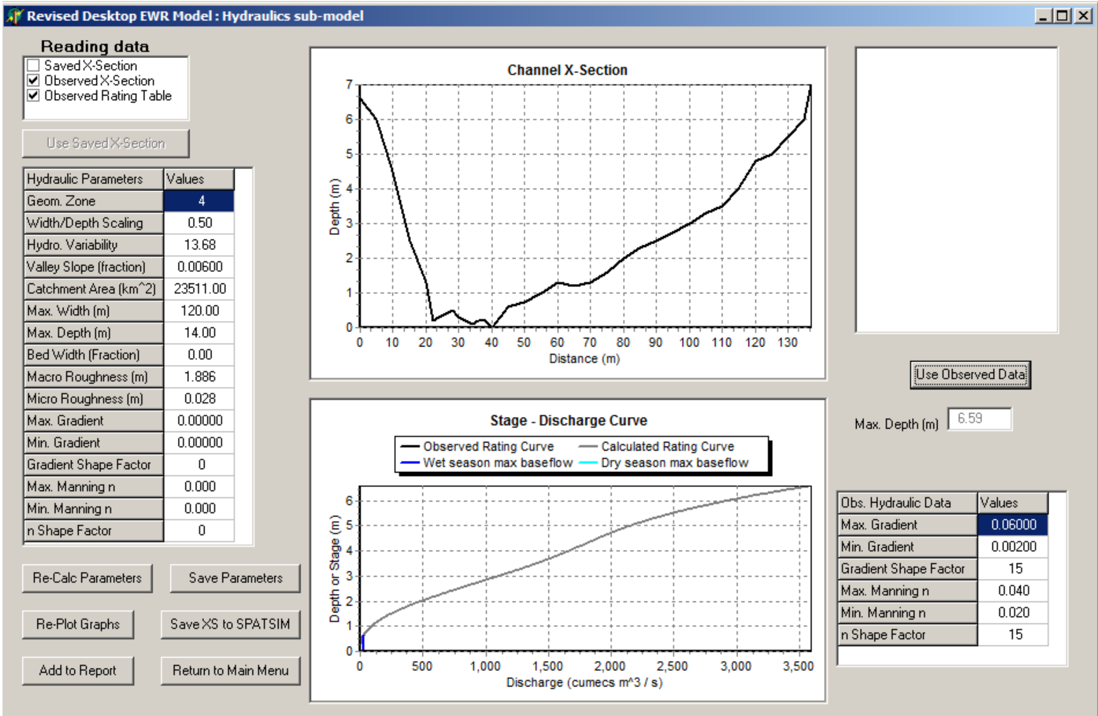


Figure 3.28 Screenshot of hydraulic sub-model calibration using observed channel cross-section data for EWR site 5

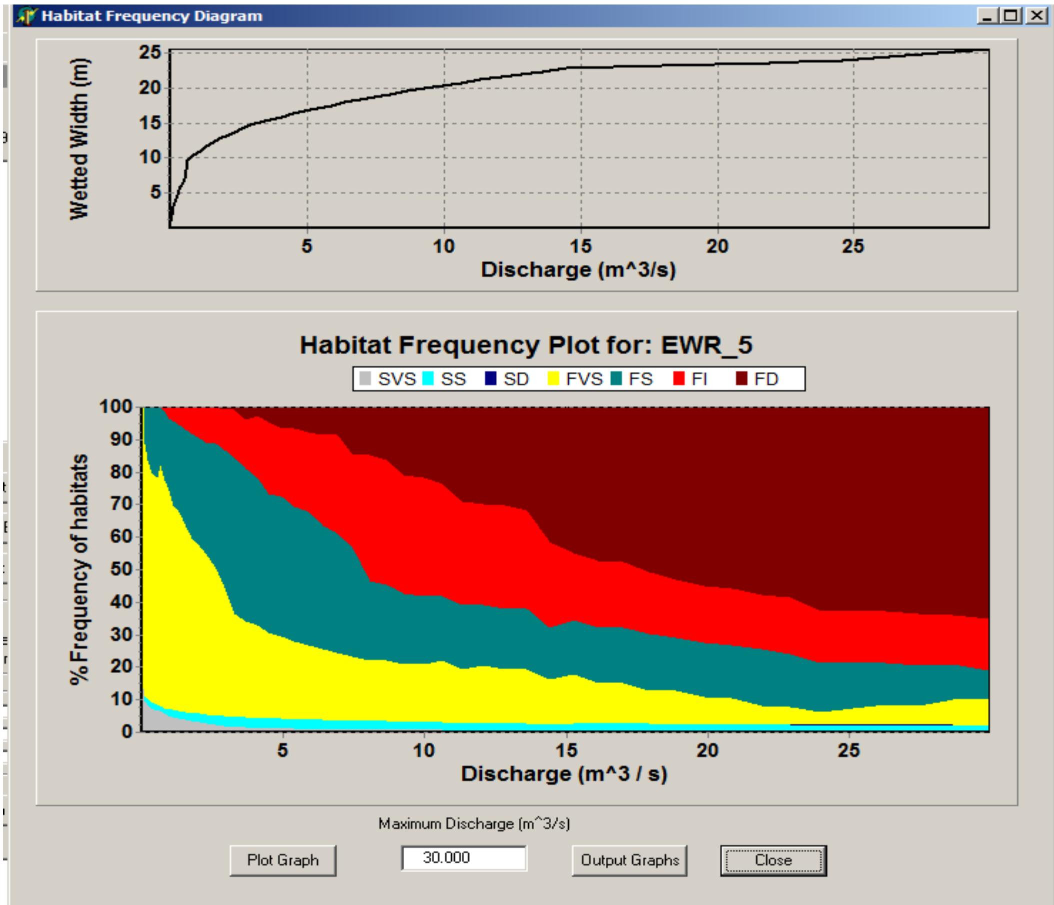


Figure 3.29 Habitat frequency plot generated for EWR site 5 by RDRM model

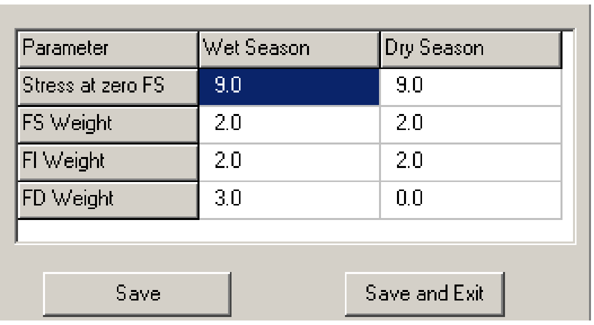


Figure 3.30 Setting of maximum stress and the weighting of the three habitat types under the ecology sub-model. Note the zero for FD weight during dry season is set by the model because there are no FD habitats available. The weighting for FD is higher than other two habitats because of the higher prevalence of this category as visible in Figure 3.29.

Flood sub-model

The flood sub-model was calibrated using the data on required floods from DWA 2014 (Appendix Table A5) for annual floods (flood class 1, 2, 3, 4) and 1:2 and 1:5 year floods (Figure 3.31). Note that the RDRM only provides five classes of floods so 1:10 and 1:20 year floods are not included.

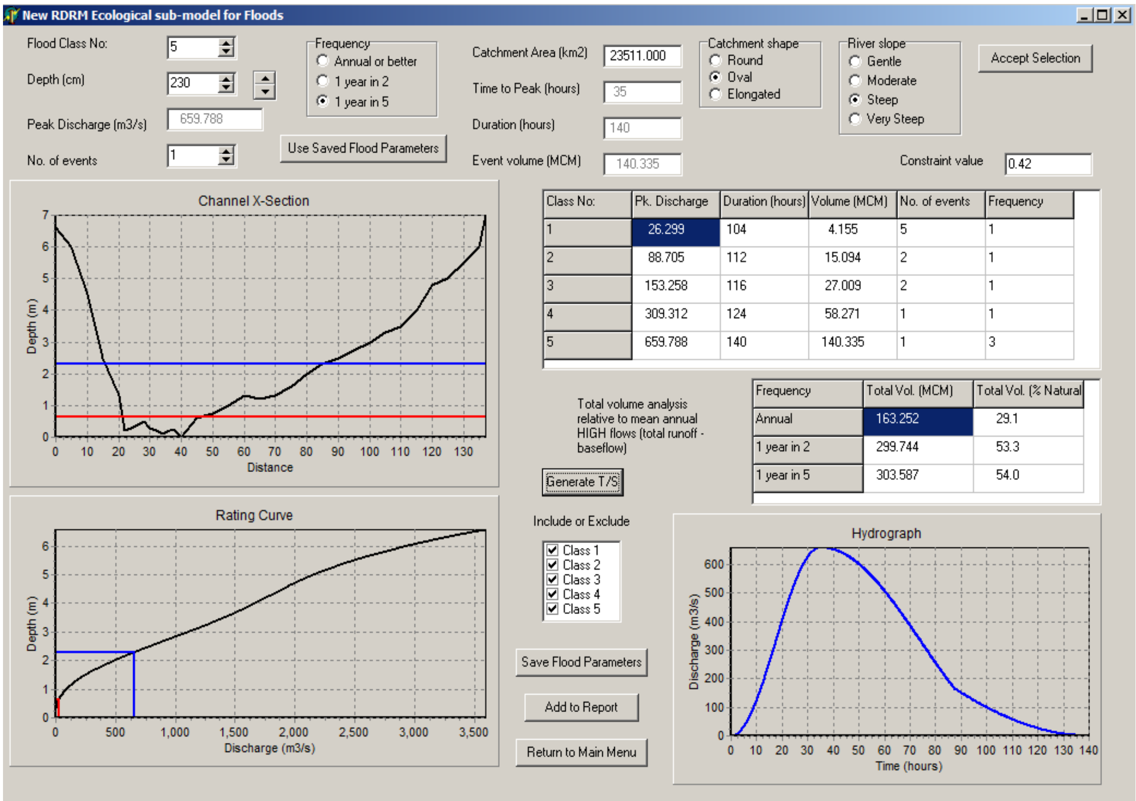


Figure 3.31 Calibration of the flood model to include the required floods from DRIFT model (DWA 2014) (data included in Appendix Table A5)

Figures 3.32 and 3.33 allow comparison of natural flows and total ecological Reserve and low flow assurance curves for EWR site 5 determined by RDRM versus the DRIFT model for the two critical months determined by RDRM. The RDRM flows are similar although not exactly the same to the DRIFT model output.

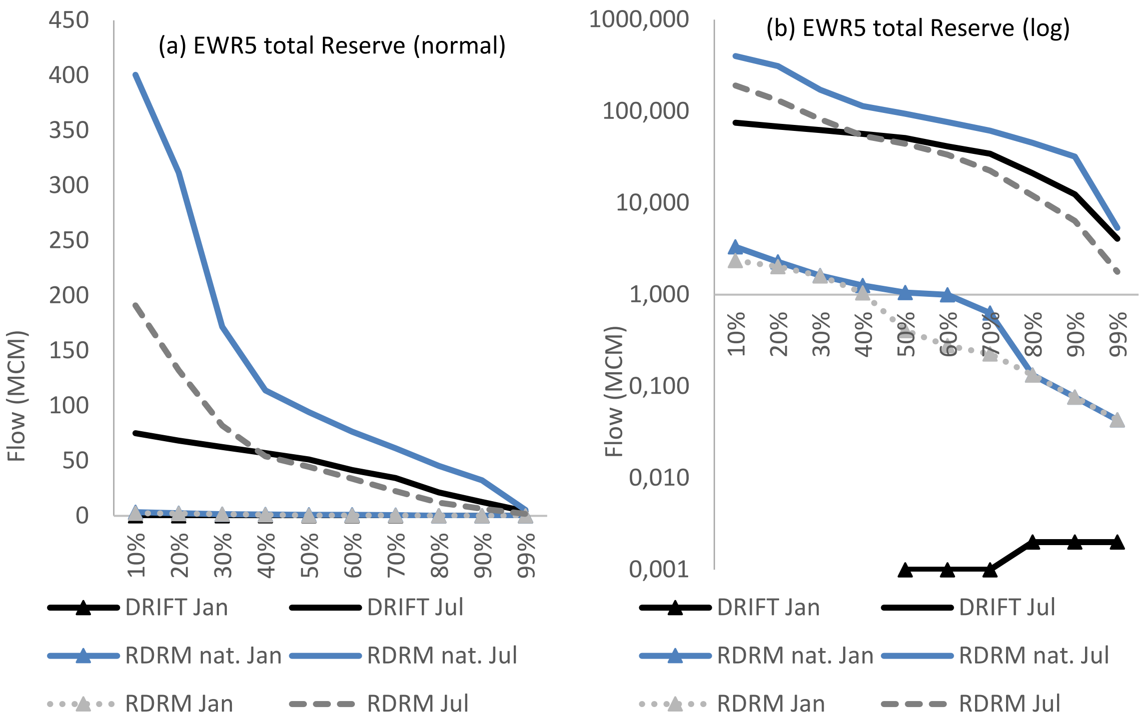


Figure 3.32 Comparison of natural flows (generated by RDRM) and total ecological Reserve ($m^3.s^{-1}$) for EWR site 5 determined by RDRM versus DRIFT model on (a) normal and (b) logarithmic y-axis (note that zero values cannot be displayed on a log scale)

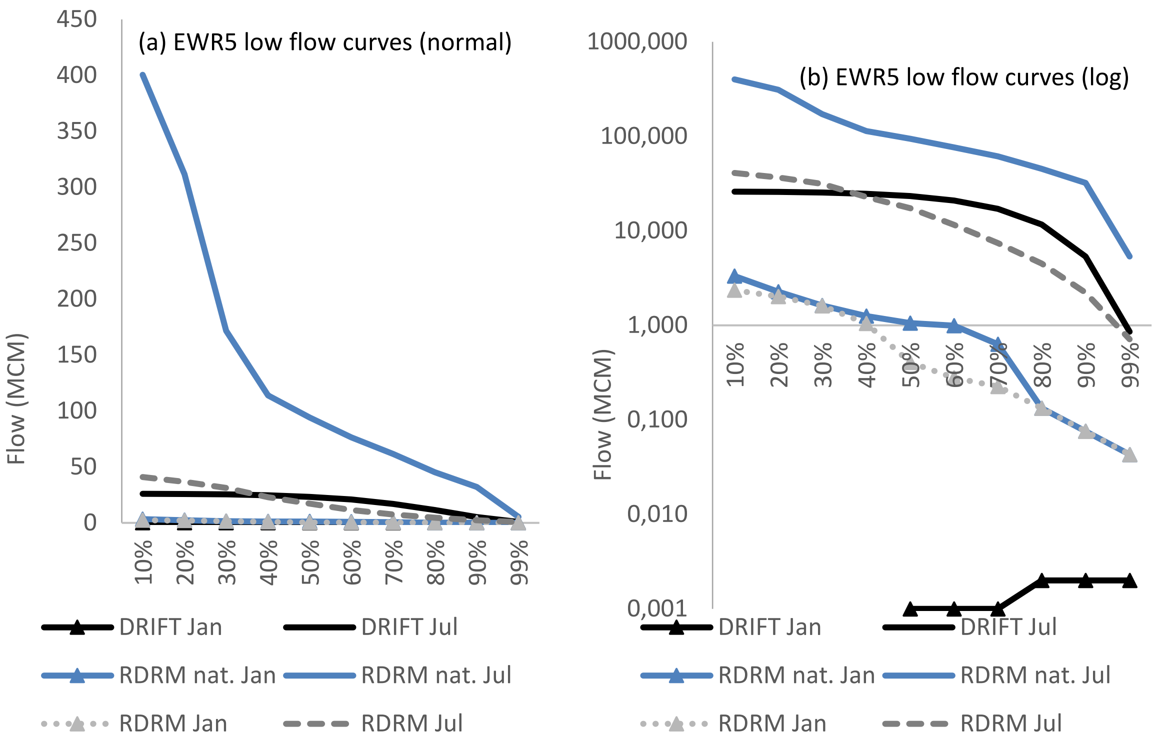


Figure 3.33 Comparison of natural flows (generated by RDRM) and low flow assurance curves ($m^3.s^{-1}$) for EWR site 5 determined by RDRM versus DRIFT model on (a) normal and (b) logarithmic y-axis (note that zero values cannot be displayed on a log scale)

Chapter 4 Climate Change Impacts of Increased Variability for Doring Catchment

4.1 Introduction and methodology

The following modelling framework was adopted for processing each RCP (2.6, 4.5, 6.0 and 8.5) for each Doring catchment EWR site. The future water quantity, water quality, and RDRM outputs were compared with minimum and maximum flow time series for the two extreme RCPs only (2.6 and 8.5).

The methodology and outputs are detailed in Sections 4.11 to 4.1.4 but a summary of the method is provided below and illustrated in Figure 4.1.

Obtaining and processing of future climate data (rainfall and evapotranspiration) (**Step 1)**. Since it was not possible to include all the rainfall time series in the model, a random selection of 500 rainfall time series for each RCP was conducted (**Step 2**). Spatsim hydrological model was run with 500 rainfall time series and the evaporation range (which was entered as an uncertainty parameter) to produce 100,000 flow (MAR) ensembles (**Step 3**). There were 200 parameter sets selected (each with a different value for evapotranspiration (ET) which fell within the range identified by downscaled climate data), and each parameter set was run with each of the 500 rainfall time series which resulted in 100 000 output flow ensembles. The 100,000 ensembles were sorted to obtain the minimum, maximum, median, 5th percentile and 95th percentile (**Step 4**).

The RDRM was first run with natural flows (**Step 5**) and present day hydrology (which includes anthropogenic impacts) and then later with future hydrology as scenarios (**Step 6**). The outputs generated are minimum and maximum future hydrology data which incorporate the impacts of climate change (**Step 7**). The outputs of the water quality (TDS) modelling (using future hydrology) show how the water quality (TDS conditions) will be changed under future climatic conditions (**Step 8**).

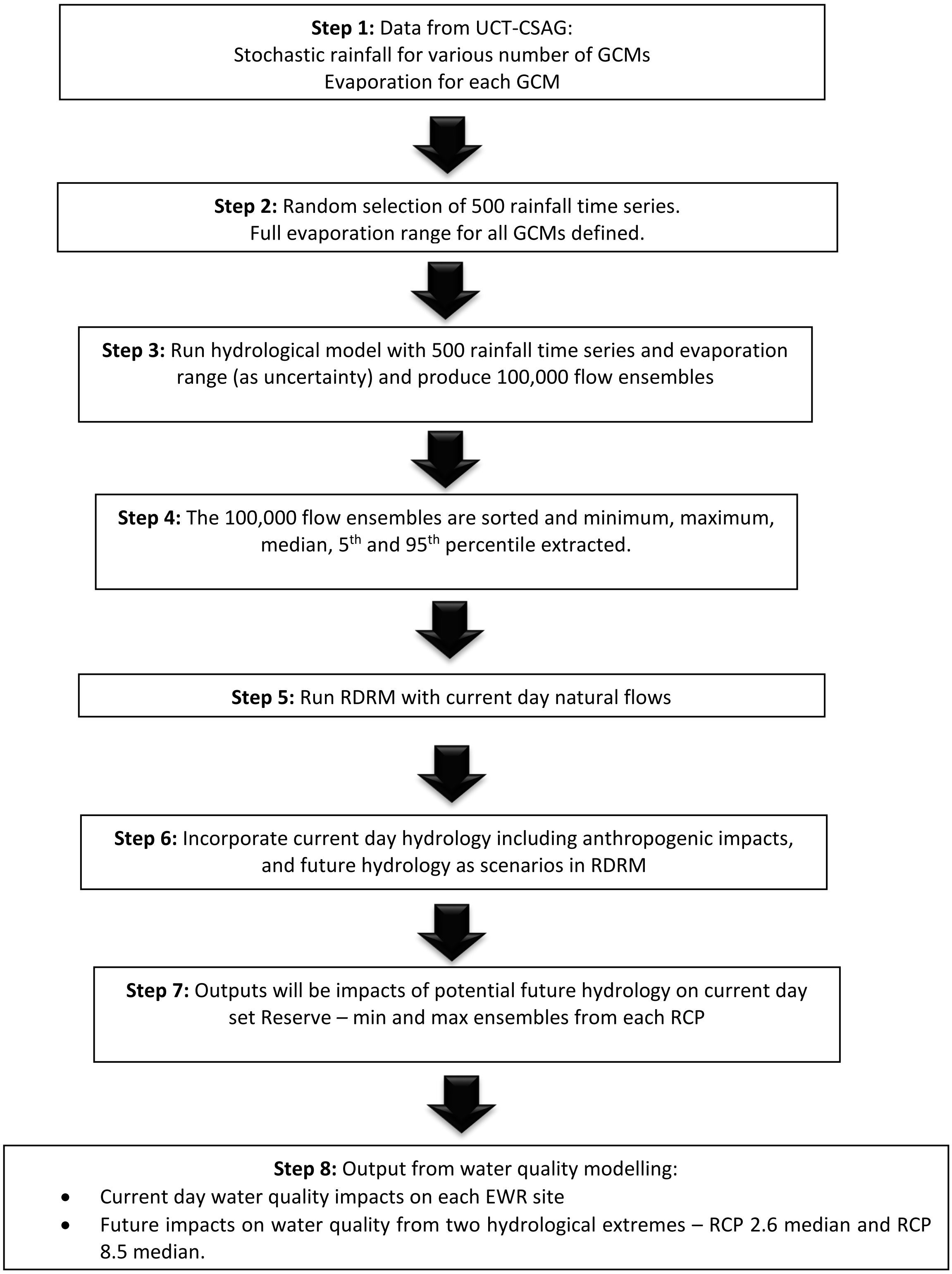


Figure 4.1 Framework adopted for water quantity and quality modelling under future climate (2041-2070)

4.1.1 Global Circulation Models (step 1)

Table 4.1 shows the number of GCMs and climate models for the four RCPs that were received from Dr Piotr Wolski (Senior Research Officer, Climate System Analysis Group, University of Cape Town) for each rainfall zone. The data was stochastically downscaled stationary rainfall time series for each catchment for the period of January 2041 to December 2070. The base data used for the statistical downscaling were rainfall from WR2012 for the period 1981-2010. The average monthly rainfall totals are fixed.

Table 4.1 The number of GCMs and total number of climate time series for the four RCPs obtained from Dr Wolski

RCP	Number of GCMs	Total number of climate time series
RCP 2.6	47	4,700
RCP 4.5	105	10,500
RCP 6.0	47	4,700
RCP 8.5	78	7,800

An example of the individual time series of future rainfall is shown in Figure 4.2 with each line representing a catchment. Figure 4.3 shows a summary of 10 generated time series for 46 GCMs for RCP2.6. The figure denotes that the mean annual rainfall is similar for the 10 generated time series corresponding to a particular GCM. Dr Wolski clarified that this is a consequence of fixing the average monthly rainfall totals. However, other attributes including maximum annual rainfall, or minimum annual rainfall, are not fixed and they vary independently from the mean annual precipitation. This, according to Dr Wolski, provides a more robust way of selecting a particular time series for simulations.

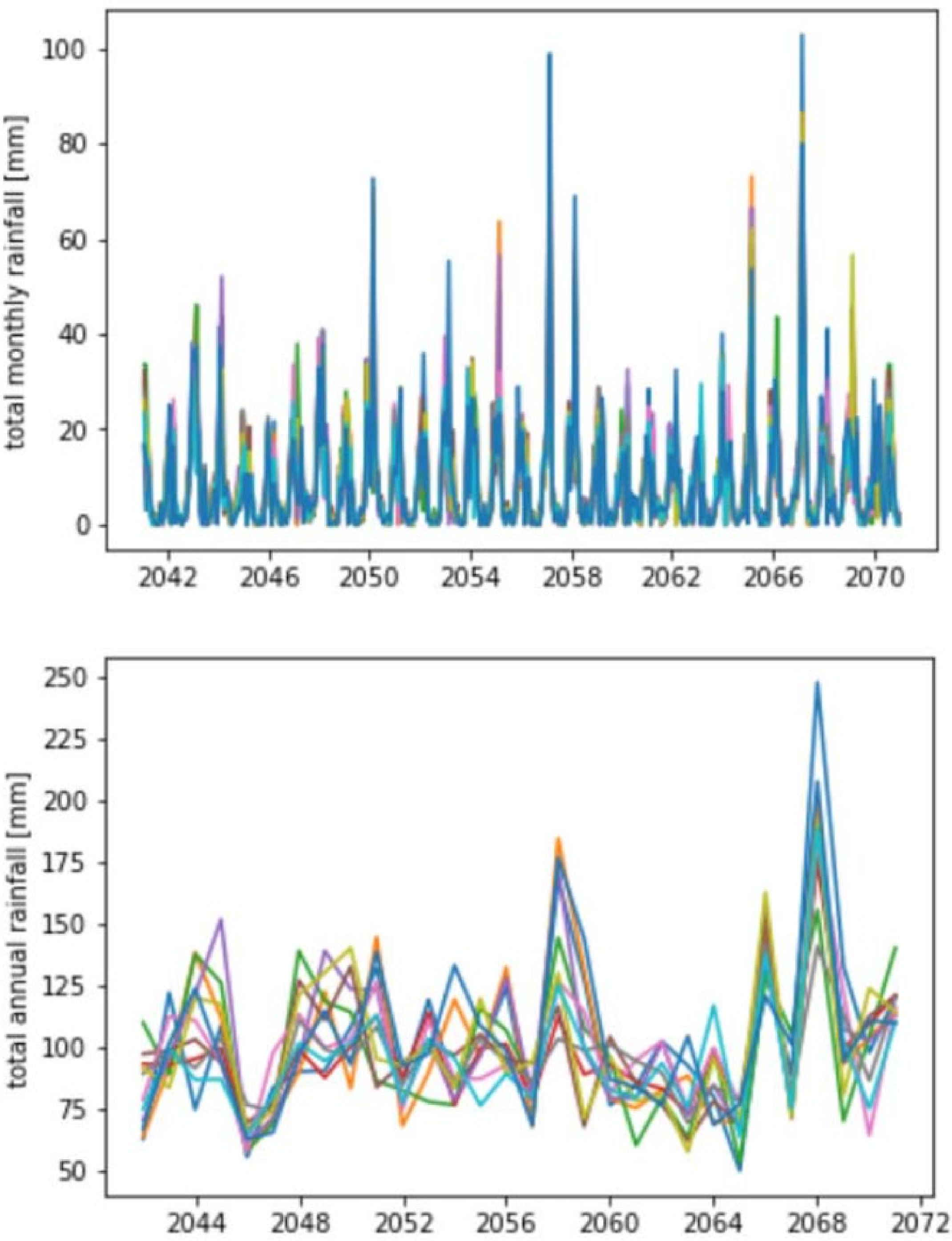


Figure 4.2 Example of future (2041-2070) rainfall time series for each catchment generated by Dr Wolski

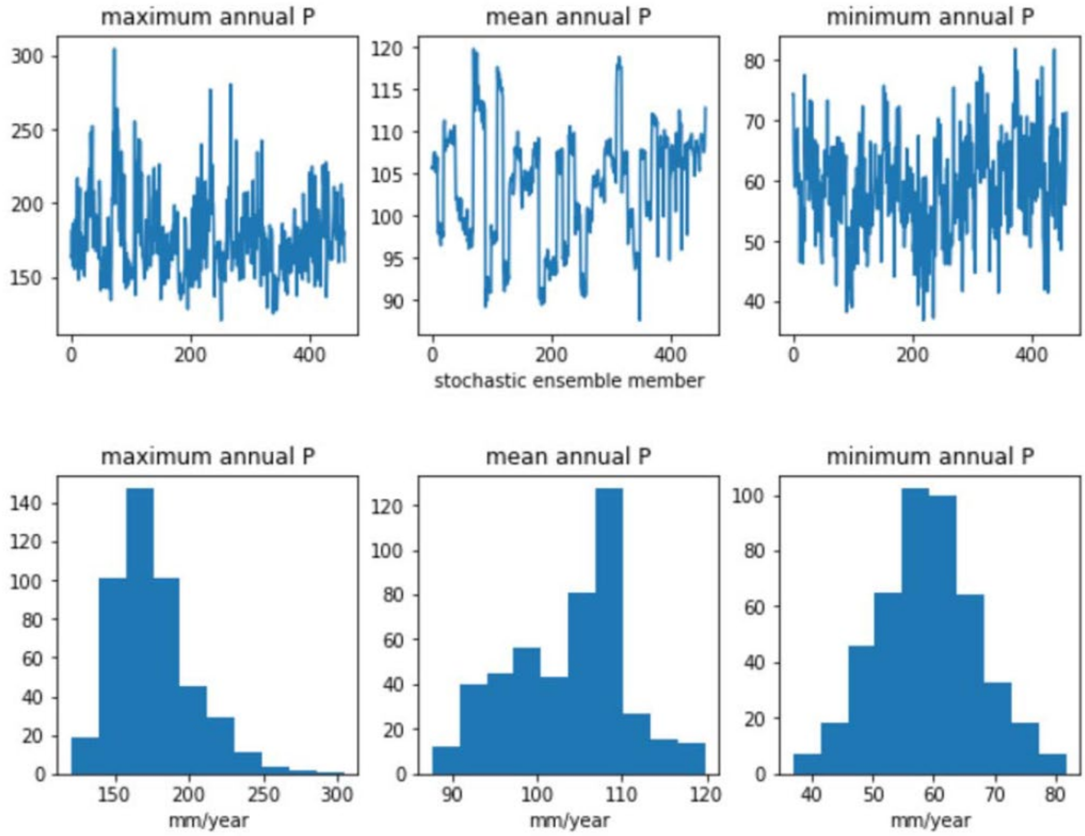


Figure 4.3 Example showing summary of 10 generated precipitation time series for 46 GCMs for RCP2.6

4.1.2 Selection of representative climate ensembles (step 2)

The Pitman model can accept a maximum of 500 rainfall ensembles (time series), and therefore we had to select 500 rainfall ensembles from the total provided for each RCP (4700 to 10 500 rainfall ensembles). These rainfall files are provided as % of MAP per quaternary, which were transformed into mm rainfall by multiplying them by present day MAP. A model was developed by the project team (random ensemble selector) which randomly selected 500 rainfall ensembles from the total list of ensembles. The range of 500 rainfall ensembles was analysed using a second model developed for the project called the ensemble sorter (shown in Figure 4.4 below). The ensemble sorter analyses and processes large amounts of ensembles and was used both for the rainfall and simulated flow. Statistics of the future rainfall relative to current are given in Tables 4.2 and 4.3, and shown in Figures 4.5 to 4.7. Although the visual interpretation of the rainfall does not seem to show a large difference between present day and future rainfall, Tables 4.2 and 4.3 indicate the differences are significant.

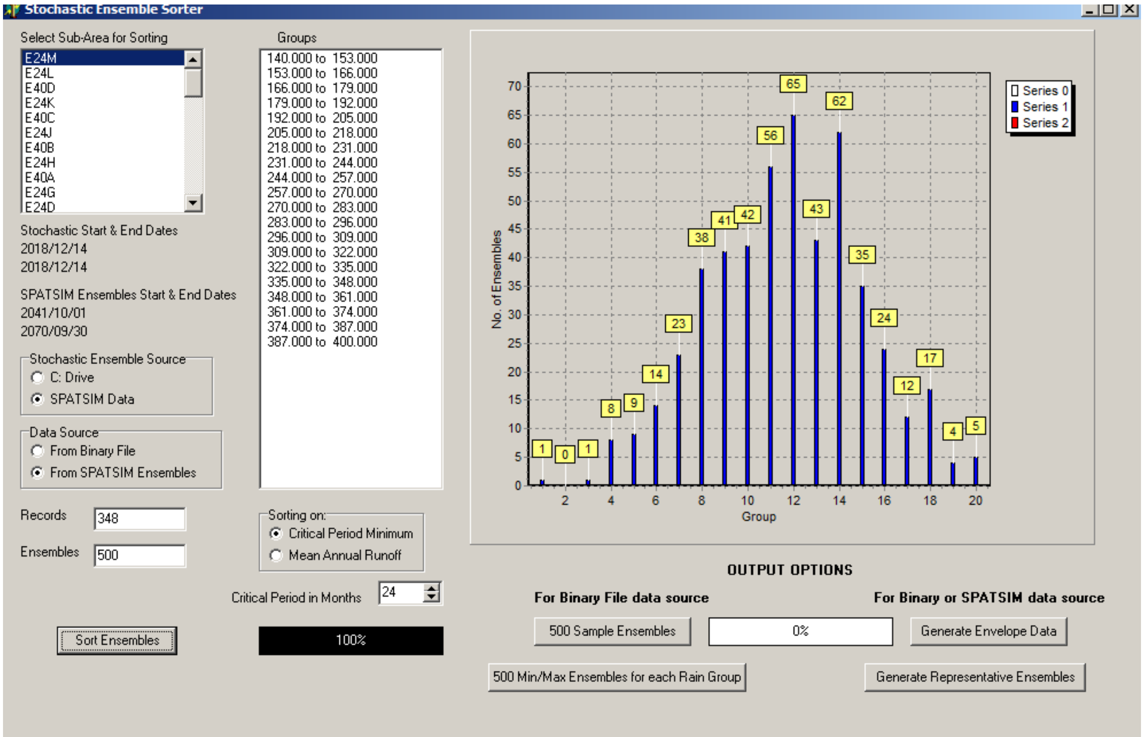


Figure 4.4 Random ensemble selector analysing the 500 rainfall ensembles selected for quaternary E24M for RCP 8.5

Table 4.2 Percent time zero monthly rainfall is received (%) under current climate versus that for the minimum and maximum ensembles under the four RCPs for the three quaternary catchments corresponding to the three EWR sites

Current	RCP ensembles	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
E21H (EWR site 6)					
3.43	Min ensemble zero rain	4.01	7.16	8.02	4.87
	Max ensemble zero rain	6.59	6.30	8.60	12.03
E24H (EWR site 4)					
15.19	Min ensemble zero rain	19.20	10.89	11.17	20.06
	Max ensemble zero rain	13.75	21.78	20.63	20.63
E24L (EWR site 5)					
7.43	Min ensemble zero rain	13.18	11.46	8.88	12.03
	Max ensemble zero rain	15.19	14.33	13.47	14.33

Table 4.3 Maximum monthly rainfall (mm) under current climate versus that for the minimum and maximum ensembles under the four RCPs for the three quaternary catchments corresponding to the three EWR sites

Current	RCP ensembles	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
E21H (EWR site 6)					
262.7	Min ensemble max rain	169.5	161.3	178.5	190.9
	Max ensemble max rain	331.6	291.7	256.1	256.5
E24H (EWR site 4)					
127.0	Min ensemble max rain	129.8	116.7	105.1	132.8
	Max ensemble max rain	331.2	163.4	213.8	141.2
E24L (EWR site 5)					
171.4	Min ensemble max rain	125.1	113.5	160.6	145.5
	Max ensemble max rain	310.5	231.6	221.7	209.5

Each GCM (Table 4.4) had an associated potential evapotranspiration value. This was incorporated into the Pitman model by varying the evapotranspiration parameter value in the Pitman model's uncertain framework, in accordance with the range reported by all the GCMs (this varied from RCP to RCP). The full range of evapotranspiration values used in the simulations is given in Table 4.4.

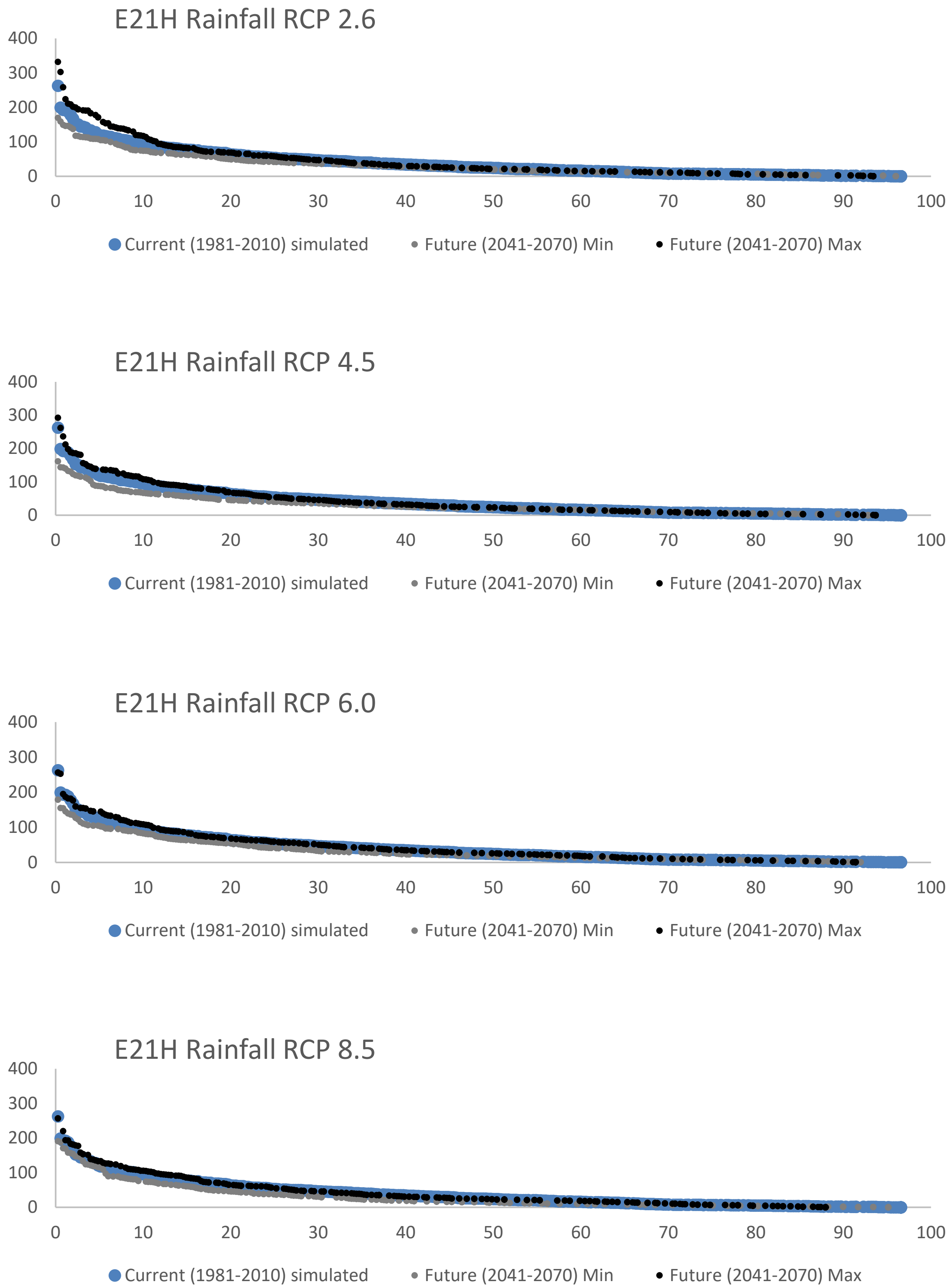


Figure 4.5 Uncertainty (min and max) in future rainfall relative to current simulated data for E21H (EWR site 6) under various RCPs

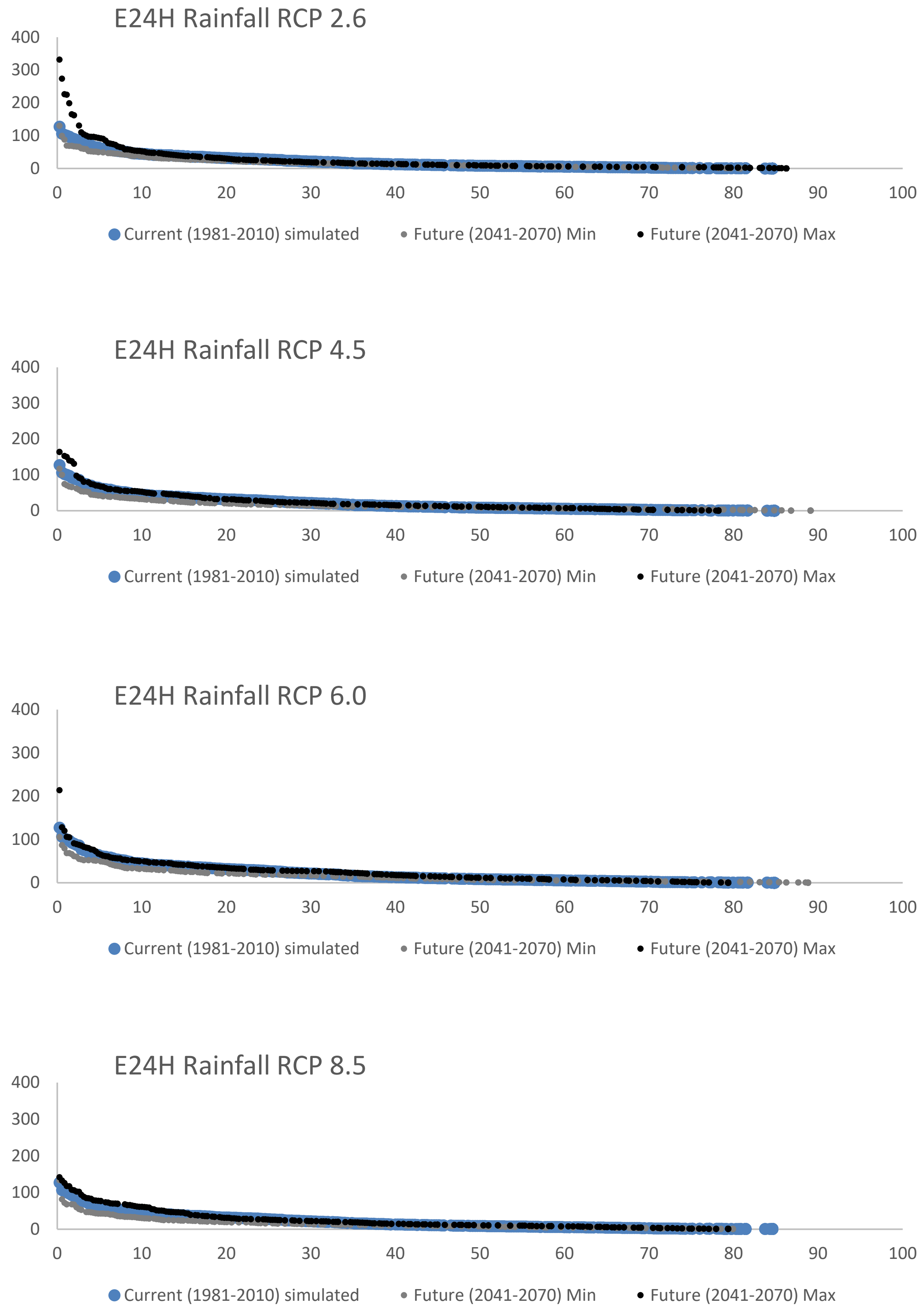
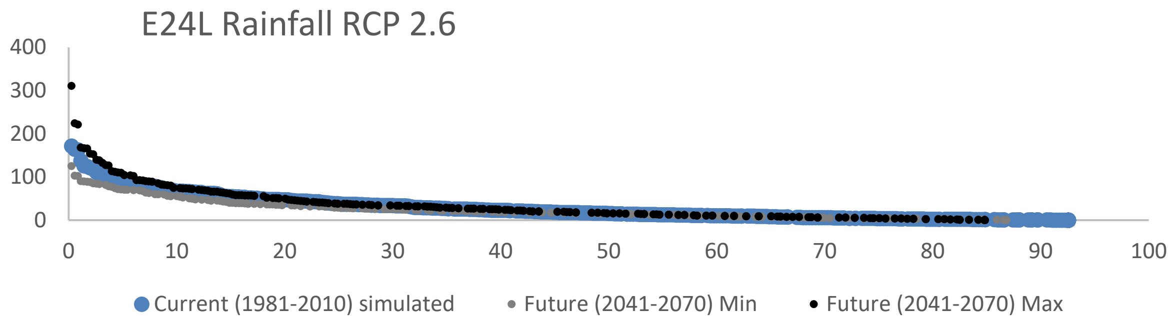
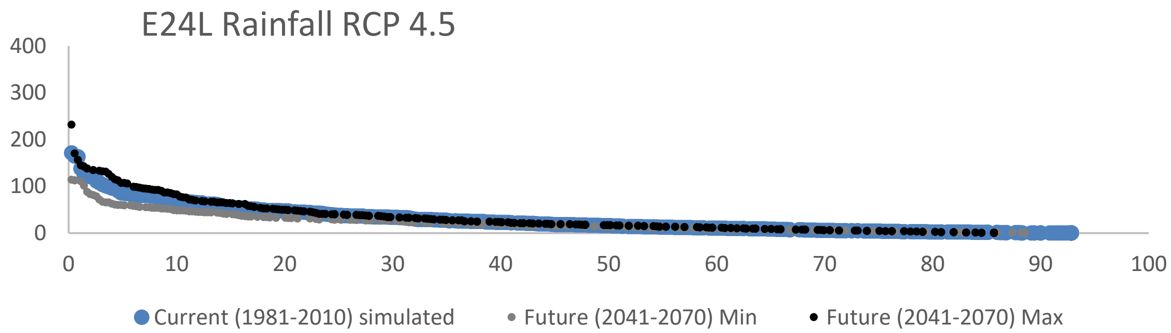
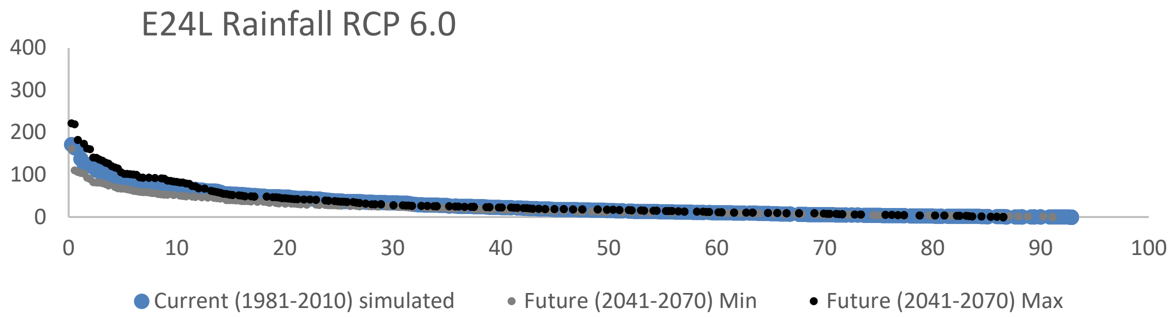


Figure 4.6 Uncertainty (min and max) in future rainfall relative to current simulated data for E24H (EWR site 4) under various RCPs







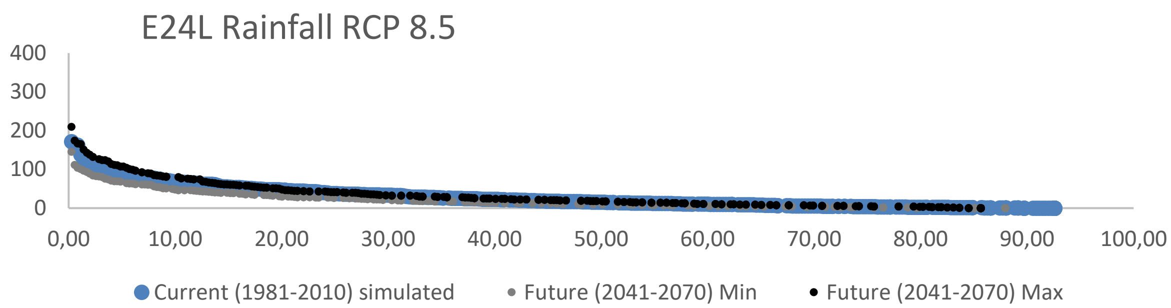


Figure 4.7 Uncertainty (min and max) in future rainfall relative to current simulated data for E24L (EWR site 5) under various RCPs

Table 4.4 Range of evapotranspiration for Doring study quaternaries for the four RCPs

Quat	MAE (mm)	RCP 2.6		RCP 4.5		RCP 6.0		RCP 8.5		All RCPs		All RCPs	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min % current	Max % current
E21A	1660	1655	1792	1665	1827	1672	1807	1691	1863	1655	1863	99.7%	112.2%
E21B	1670	1665	1803	1675	1838	1682	1818	1702	1874	1665	1874	99.7%	112.2%
E21C	1675	1670	1808	1680	1844	1687	1823	1707	1880	1670	1880	99.7%	112.2%
E21D	1665	1660	1798	1670	1833	1677	1812	1697	1869	1660	1869	99.7%	112.2%
E21E	1680	1677	1813	1686	1851	1694	1830	1718	1889	1677	1889	99.8%	112.4%
E21F	1690	1687	1824	1696	1862	1704	1841	1728	1900	1687	1900	99.8%	112.4%
E21G	1655	1652	1786	1661	1824	1669	1803	1692	1861	1652	1861	99.8%	112.4%
E21H	1670	1667	1802	1676	1840	1684	1819	1707	1878	1667	1878	99.8%	112.4%
E21J	1680	1677	1813	1686	1851	1694	1830	1718	1889	1677	1889	99.8%	112.4%
E21K	1680	1679	1811	1687	1852	1695	1828	1721	1888	1679	1888	99.9%	112.4%
E21L	1700	1697	1834	1706	1873	1714	1852	1738	1912	1697	1912	99.8%	112.4%
E22A	1920	1916	2072	1927	2116	1936	2091	1963	2159	1916	2159	99.8%	112.4%
E22B	1850	1846	1996	1857	2039	1865	2015	1891	2080	1846	2080	99.8%	112.4%
E22C	1690	1687	1824	1696	1862	1704	1841	1728	1900	1687	1900	99.8%	112.4%
E22D	1760	1756	1899	1766	1939	1775	1917	1799	1979	1756	1979	99.8%	112.4%
E22E	1725	1721	1861	1731	1901	1739	1879	1764	1940	1721	1940	99.8%	112.4%
E22F	1715	1711	1851	1721	1890	1729	1868	1753	1928	1711	1928	99.8%	112.4%
E22G	1730	1726	1867	1736	1906	1744	1884	1769	1945	1726	1945	99.8%	112.4%
E23A	1895	1892	2083	1904	2133	1914	2109	1950	2185	1892	2185	99.8%	115.3%
E23B	1870	1867	2055	1879	2105	1889	2081	1924	2156	1867	2156	99.8%	115.3%
E23C	1850	1847	2033	1858	2082	1869	2059	1904	2133	1847	2133	99.8%	115.3%
E23D	1850	1847	2033	1858	2082	1869	2059	1904	2133	1847	2133	99.8%	115.3%
E23E	1870	1867	2055	1879	2105	1889	2081	1924	2156	1867	2156	99.8%	115.3%
E23F	1835	1832	2017	1843	2065	1853	2042	1888	2116	1832	2116	99.8%	115.3%
E23G	1810	1806	1953	1816	1995	1825	1972	1850	2035	1806	2035	99.8%	112.4%
E23H	1820	1816	1964	1827	2006	1835	1982	1861	2047	1816	2047	99.8%	112.4%
E23J	1805	1801	1948	1811	1989	1820	1966	1845	2030	1801	2030	99.8%	112.4%
E23K	1800	1796	1942	1806	1984	1815	1961	1840	2024	1796	2024	99.8%	112.4%
E24A	1695	1694	1827	1702	1868	1710	1844	1737	1905	1694	1905	99.9%	112.4%
E24B	1725	1724	1859	1732	1901	1741	1877	1768	1939	1724	1939	99.9%	112.4%
E24C	1880	1880	2046	1891	2094	1900	2068	1935	2140	1880	2140	100.0%	113.8%
E24D	1845	1845	2008	1856	2055	1865	2030	1899	2101	1845	2101	100.0%	113.8%
E24E	1890	1889	2057	1901	2108	1910	2081	1945	2154	1889	2154	99.9%	114.0%
E24F	1895	1894	2063	1906	2114	1915	2086	1950	2159	1894	2159	99.9%	114.0%
E24G	1845	1844	1993	1854	2042	1863	2013	1895	2082	1844	2082	100.0%	112.8%
E24H	1795	1796	1937	1805	1982	1813	1956	1843	2022	1796	2022	100.0%	112.6%
E24J	1800	1801	1943	1810	1988	1818	1961	1848	2028	1801	2028	100.0%	112.6%
E24K	1860	1859	2010	1870	2059	1878	2029	1911	2099	1859	2099	100.0%	112.8%
E24L	1745	1743	1876	1752	1913	1761	1881	1784	1946	1743	1946	99.9%	111.5%
E24M	1760	1758	1892	1767	1929	1776	1897	1800	1963	1758	1963	99.9%	111.5%
E40A	1940	1939	2113	1952	2167	1961	2136	1998	2211	1939	2211	100.0%	114.0%
E40B	1945	1944	2118	1957	2172	1966	2142	2003	2217	1944	2217	100.0%	114.0%
E40C	1905	1905	2050	1914	2100	1924	2065	1955	2136	1905	2136	100.0%	112.2%
E40D	1850	1850	1991	1859	2040	1868	2005	1899	2075	1850	2075	100.0%	112.2%

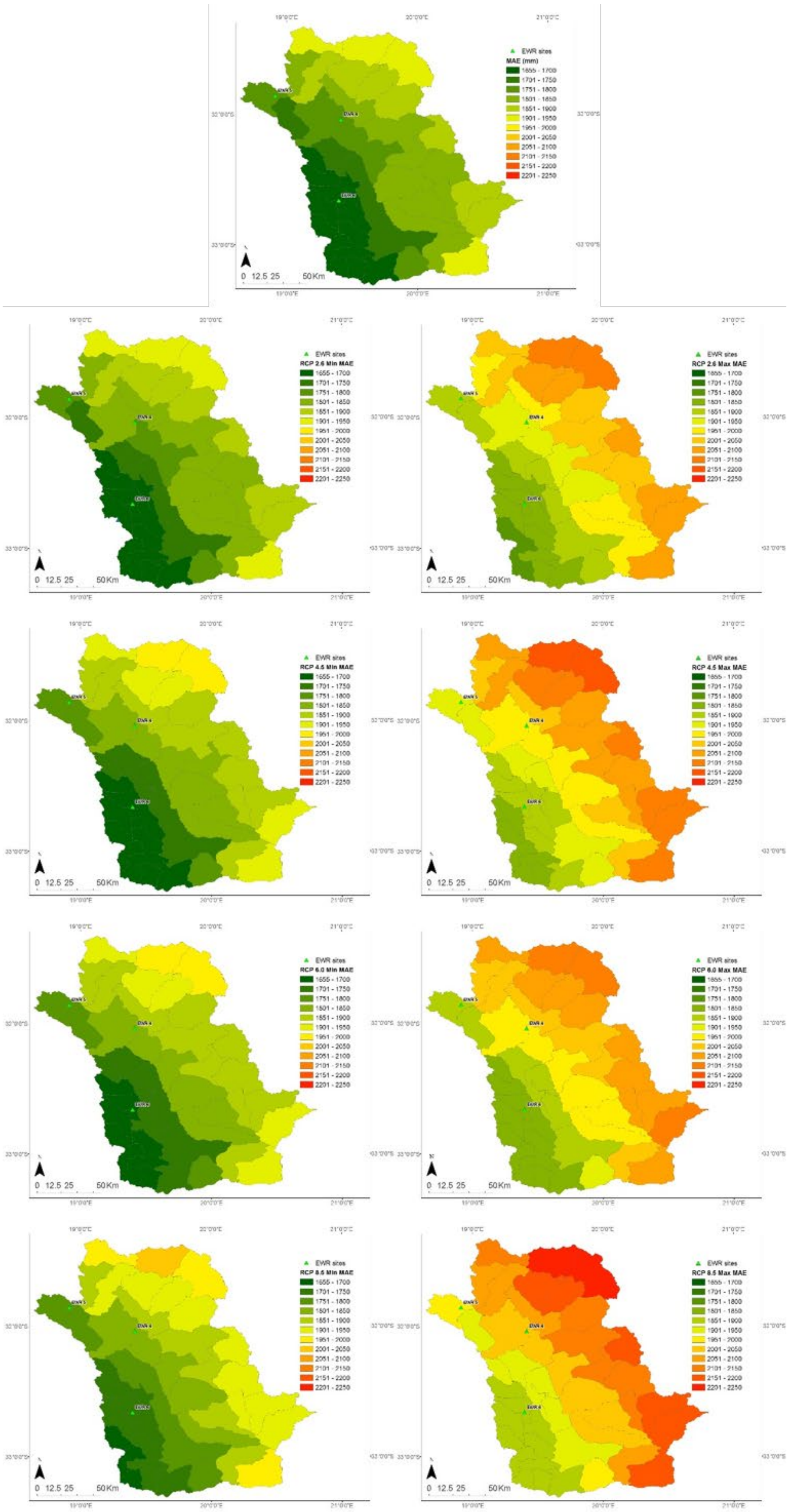


Figure 4.8 Range of uncertainty in the future MAE for the four RCPs relative to present day MAE (top figure) for the Doring River quaternaries.

4.1.3 Global options hydrological modelling with stochastic uncertainty (steps 3 and 4)

The Pitman model was run in an uncertain framework (see Figure 3.2 for details) which meant all 500 rainfall ensembles were used, together with the full range of possible values of evapotranspiration. For each EWR site and RCP, 200 values of evapotranspiration (falling within the range specified as detailed above), multiplied by each of the 500 rainfall ensembles resulted in an output of 100 000 flow time series (200 * 500 = 100 000). These were considered to be the potential range of flows under the uncertain future climate, and as expected there is a significantly wide band of uncertainty (Figure 4.8).

Lastly, the ensemble sorter interpreted and processed the 100 000 flow ensembles (Figures 4.9 and 4.10).

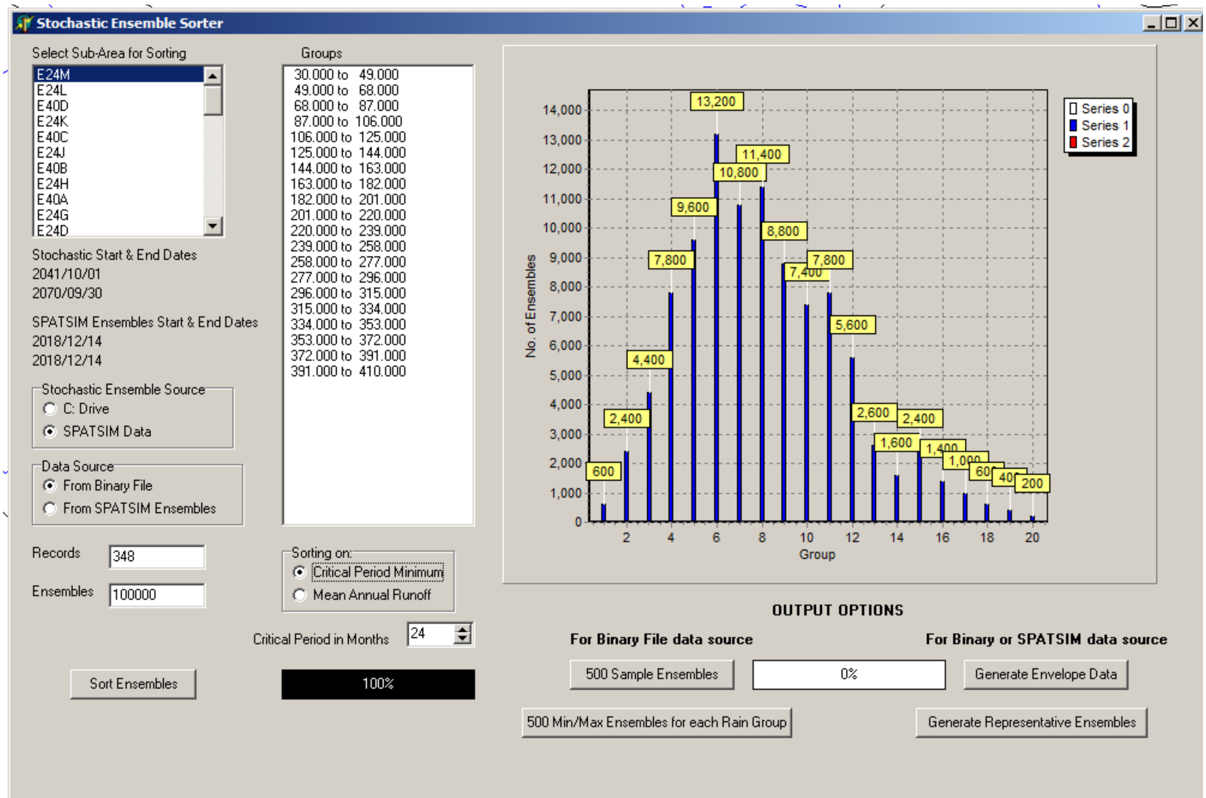


Figure 4.9 Analysis of 100 000 flow ensembles examining the critical period minimum for quaternary E24M

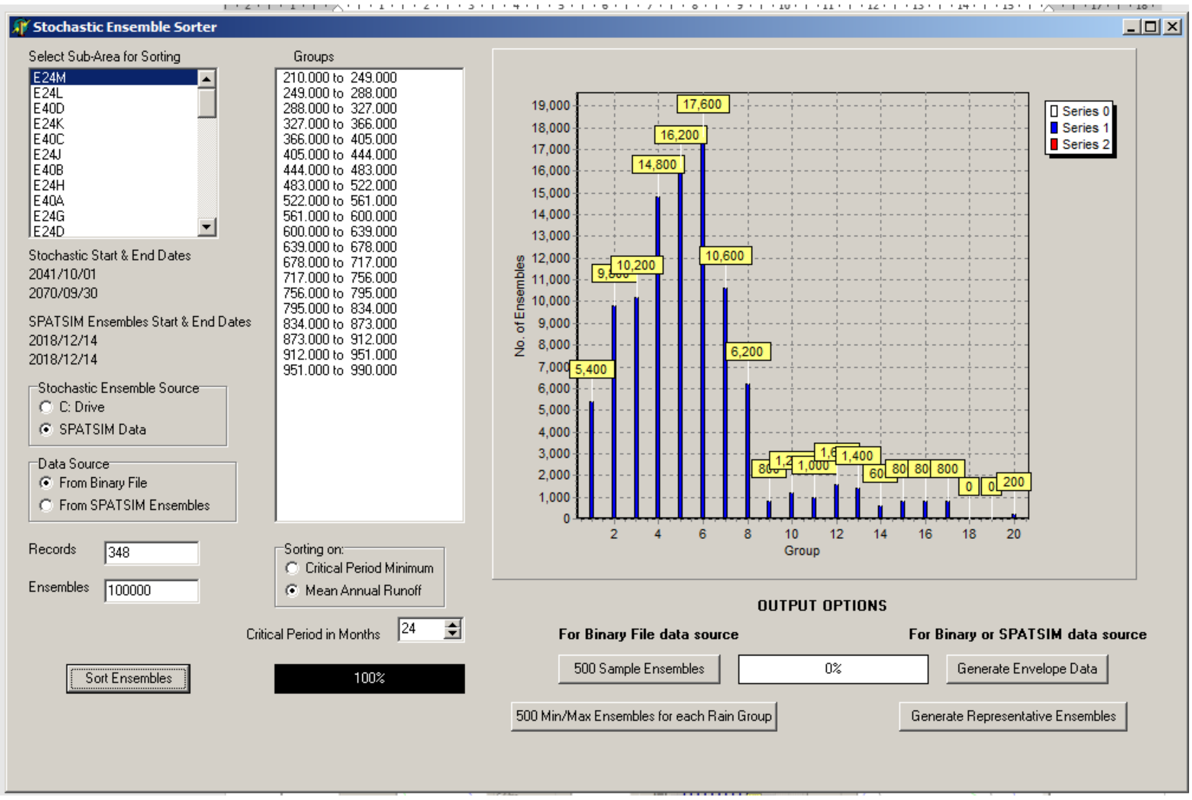


Figure 4.10 Analysis of 100 000 flow ensembles examining the MAR for quaternary E24M

4.1.4 Incorporating future hydrology into the RDRM model (steps 5 to 7)

The RDRM was first run with natural flows (**Step 5 – Section 3.3**) and the present day hydrology (which includes anthropogenic impacts) and then later with future hydrology as scenarios (**Step 6**). The outputs from the hydrological modelling and subsequent ensemble sorter, included min, max, 5th, 95th and median actual ensembles. The min and max time series of flow which represents the entire range of possible future flow ensembles were incorporated into the RDRM as scenario data which then allows a comparison of future flow with the impacts of climate change and the most recent ecological Reserve (or EWR) determination (**Step 7 – Section 4.2**).

4.2 Results

4.2.1 Future water quantity modelling outputs

Tables 4.5 and 4.6 compare the statistics for the natural and present day hydrology with the range of uncertainty under RCP 2.6 and 8.5 for the three catchments corresponding with the three EWR sites. The graphs showing minimum and maximum ensembles compared with present day and natural hydrology, are presented in Figures 4.11 to 4.13. These are actual simulated time series/ensembles of flow which are selected based on the average mean over the 29 years simulated flow.

Both climate scenarios result in increased time periods for zero flows in general, with RCP 8.5 being worse (Table 4.5). The range of uncertainty for the two RCPs straddles the present day percent zero flow time periods, in general. Note that since the minimum and maximum ensembles were selected based on the minimum and maximum values for the mean over the 29 years of modelled hydrology, the relationship between current climate versus RCP 2.6 or 8.5 scenarios is not always linear.

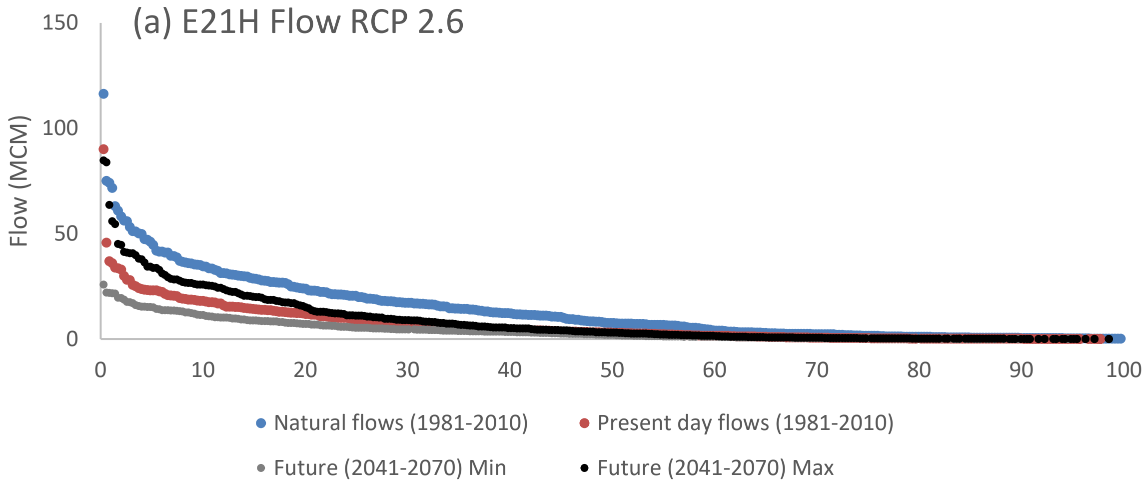
In terms of maximum monthly flow (Table 4.6), the range of uncertainty is large (particularly for RCP 2.6). The upstream catchment E21H is projected to have reduced maximum flows under both RCPs compared to both natural and present day. For the lower two quaternaries (E24H and E24L) the uncertainty range straddles both natural and present day maximum values.

Table 4.5 Percent time zero monthly flow (%) under current climate (natural and present day hydrology; 1981-2010) versus that for the minimum and maximum ensembles under RCP 2.6 and 8.5 (2041-2070) for the three quaternary catchments corresponding to the three EWR sites

Natural	Present Day	RCP ensembles	RCP 2.6	RCP 8.5
E21H (EWR site 6)				
0	2.29	Min ensemble zero flows	5.44	5.44
		Max ensemble zero flows	1.43	2.01
E24H (EWR site 4)				
0	6.88	Min ensemble zero flows	10.6	19.77
		Max ensemble zero flows	8.02	9.46
E24L (EWR site 5)				
0	18.91	Min ensemble zero flows	24.36	30.09
		Max ensemble zero flows	18.05	14.04

Table 4.6 Maximum monthly flow (MCM) under current climate (natural and present day hydrology; 1981-2010) versus that for the minimum and maximum ensembles under RCP 2.6 and 8.5 (2041-2070) for the three quaternary catchments corresponding to the three EWR sites

Natural	Present Day	RCP ensembles	RCP 2.6	RCP 8.5
E21H (EWR site 6)				
116.4	90.0	Min ensemble zero flows	25.8	36.0
		Max ensemble zero flows	84.7	71.7
E24H (EWR site 4)				
555.6	398.2	Min ensemble zero flows	299.4	329.7
		Max ensemble zero flows	2114.4	634.0
E24L (EWR site 5)				
582.0	404.8	Min ensemble zero flows	406.4	390.1
		Max ensemble zero flows	3173.0	777.2



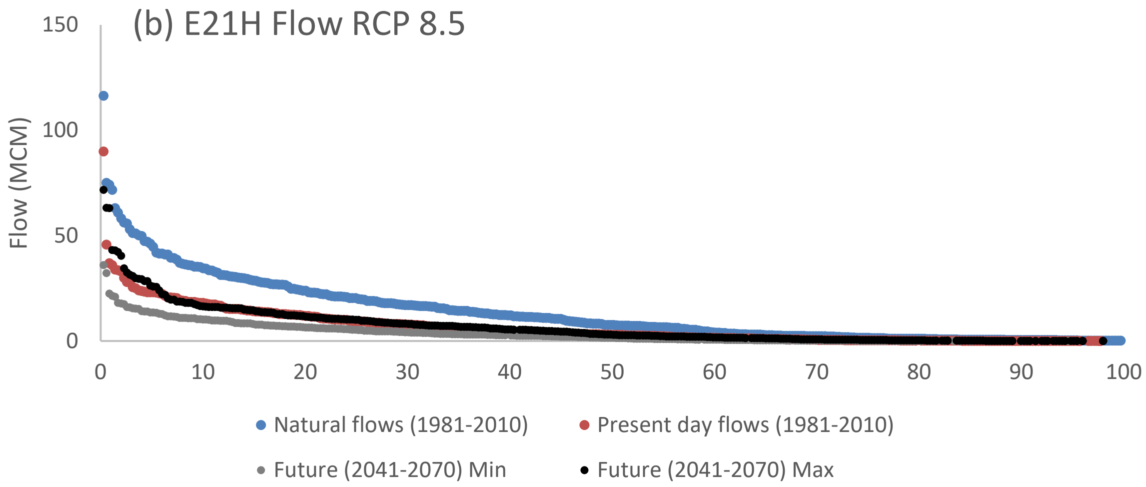


Figure 4.11 Uncertainty (minimum and maximum scenarios) in future flow (MCM) relative to natural and present day simulated data for E21H (EWR site 6) under RCPs (a) 2.6 and (b) 8.5

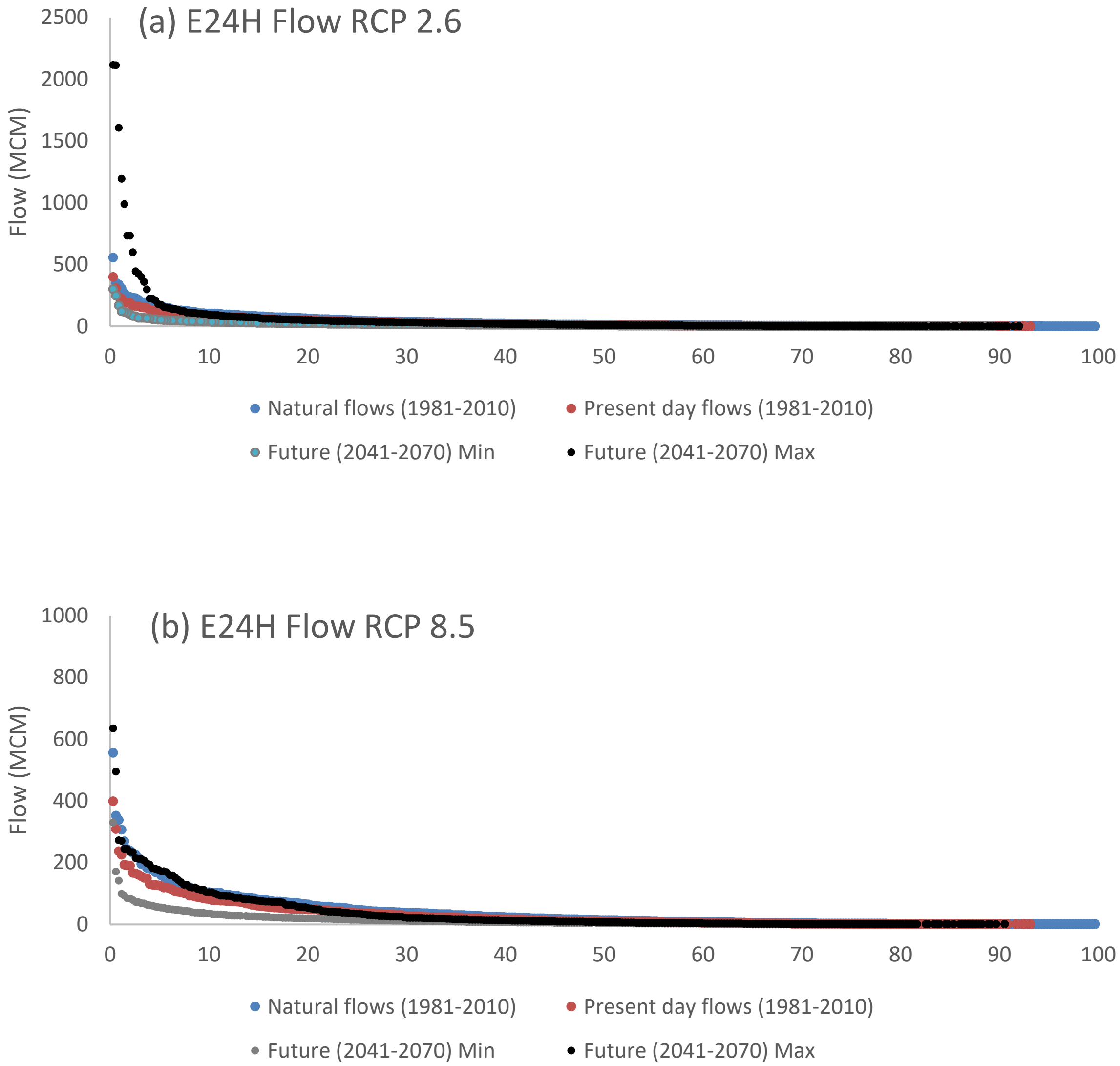
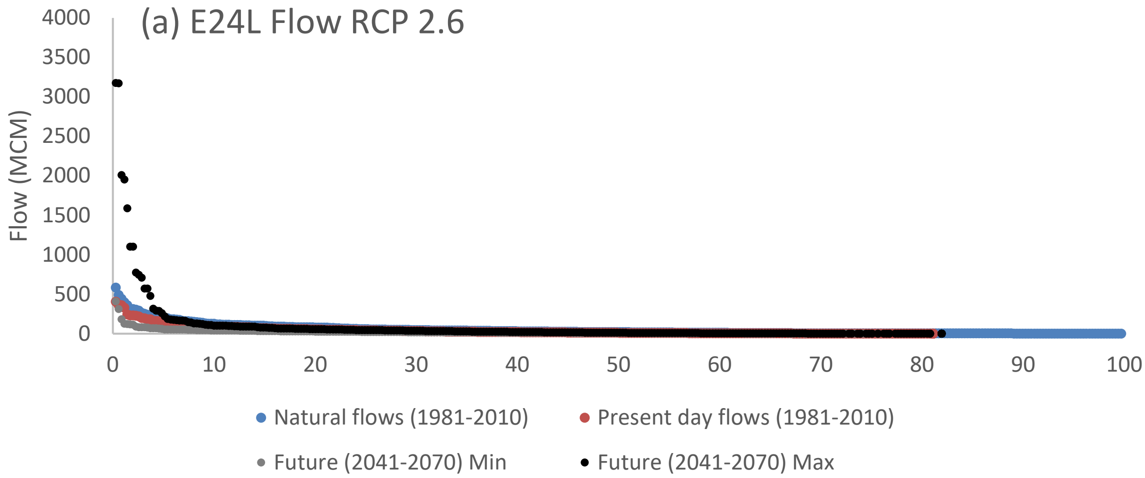


Figure 4.12 Uncertainty (minimum and maximum scenarios) in future flow (MCM) relative to natural and present day simulated data for E24H (EWR site 4) under RCPs (a) 2.6 and (b) 8.5



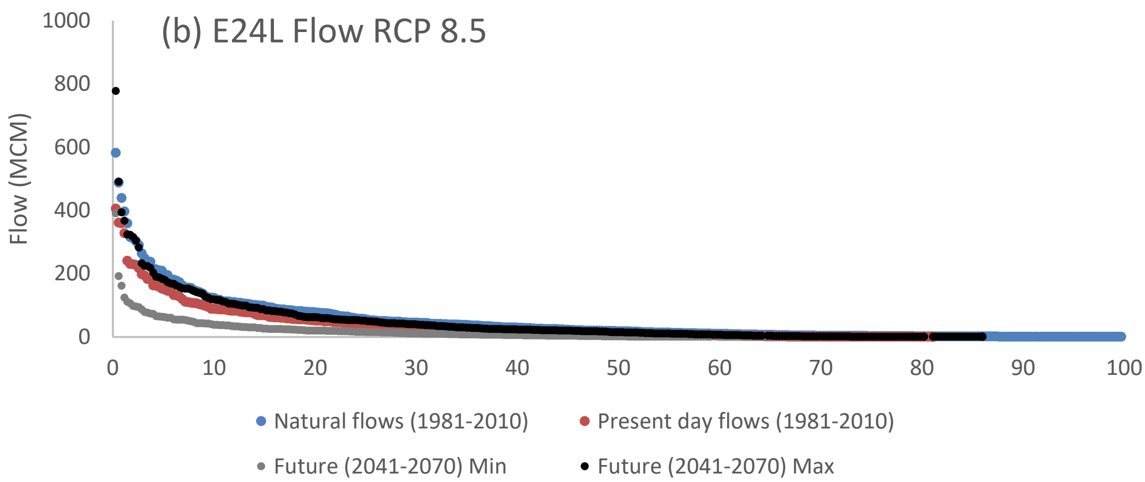


Figure 4.13 Uncertainty (minimum and maximum scenarios) in future flow (MCM) relative to natural and present day simulated data for E24L (EWR site 5) under RCPs (a) 2.6 and (b) 8.5

4.2.2 Future water quality modelling outputs

It was decided not to attempt to model the upper catchment under climate change as the calibration to observed data could not represent the spikes in TDS (Figure 3.5a). Maximum and minimum flows under climate change were processed in the same way as under the calibration, with the same baseflow separation parameters applied to derive flow fractions of surface water, interflow and groundwater flow. Figure 4.14a and Figure 4.14b show the time series of maximum and minimum TDS for the EWR4 site (E24H) and the lower Doring catchment (E24L), respectively for RCP 2.6 flows, with the lines indicating the band of uncertainty. Figure 4.15a and Figure 4.15b show the time series of maximum and minimum TDS under the RCP 8.5 climate change flows for the EWR4 site (E24H) and lower catchment (E24L), respectively, with the two lines indicating the band of uncertainty.

a)

b)

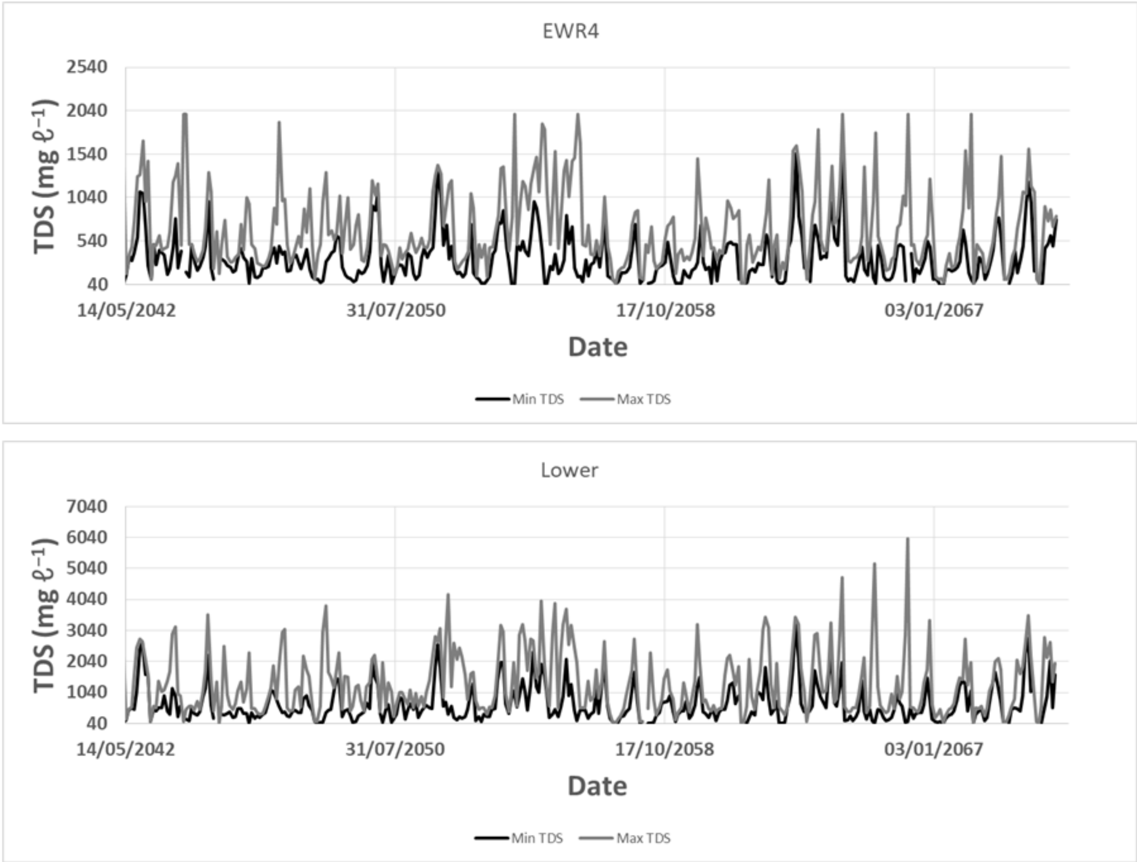
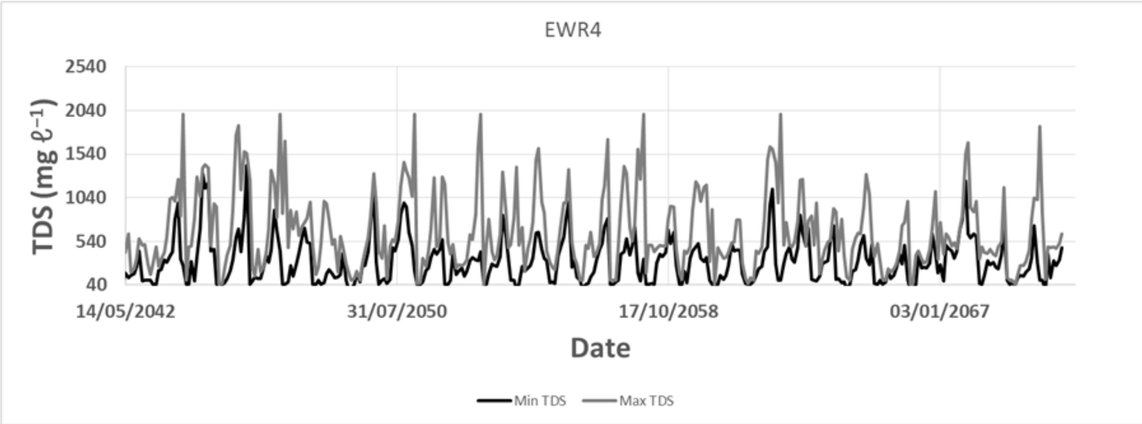


Figure 4.14 Minimum and maximum simulated TDS under climate change flows for RCP2.6. a) Middle Doring catchment (E24H/EWR4); b) Lower Doring catchment (E24L)

a)



b)

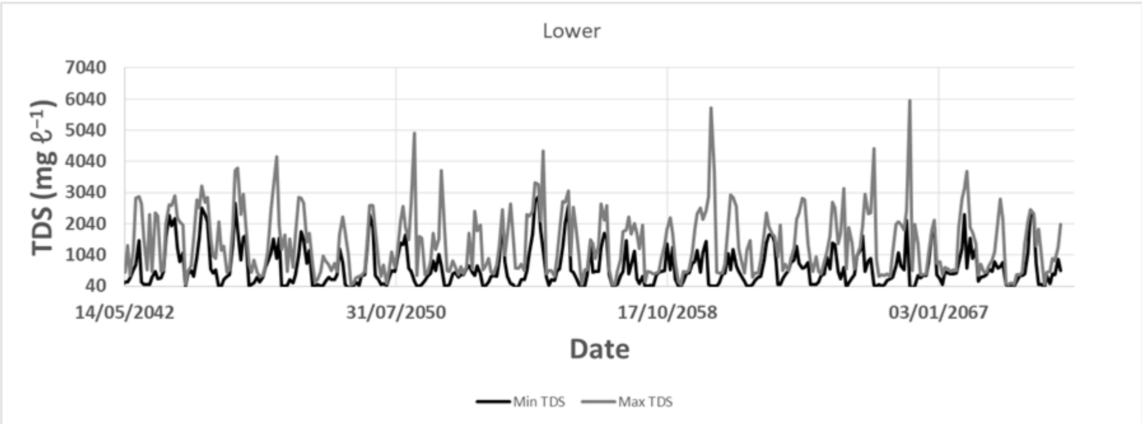


Figure 4.15 Minimum and maximum simulated TDS under climate change flows for RCP8.5. a) Middle Doring catchment (E24H/EWR4); b) Lower Doring catchment (E24L)

Figure 4.16 shows the frequency distributions of TDS under climate change compared to the current situation. Figure 4.16a shows that under RCP 2.6 at the EWR4 site (E24H), TDS will shift considerably upwards in relation to the current situation, with simulated maximum TDS under climate change being approximately double that under the current situation. The shift upwards is evident across the entire frequency distribution. Figure 4.16b shows that under climate change RCP 2.6 flows, TDS at the lower catchment (E24L) will shift considerably upwards compared to the current situation, with the maximum TDS being approximately three-fold that of the current situation. TDS seems to be shifted higher within the lower probabilities compared to the current distribution at this point. The frequency distribution of TDS under RCP 8.5 at EWR4 (Figure 4.16c) shows only slight differences to that under RCP 2.6. Similarly, the frequency distribution of TDS at E24L (Figure 4.16d) under RCP 8.5 is very similar to that under RCP 2.6.

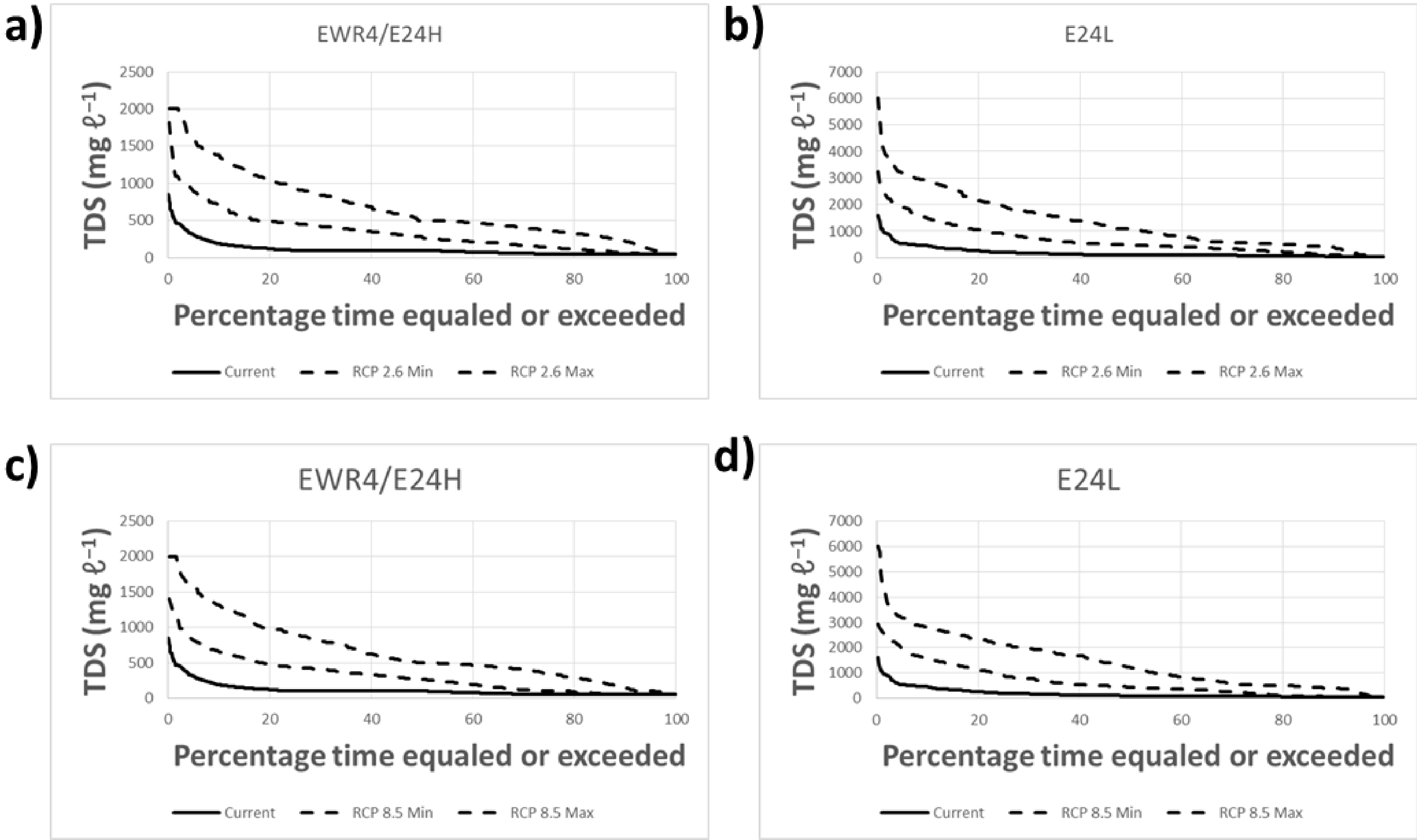


Figure 4.16 Frequency distributions of TDS under climate change (minimum and maximum indicating band of uncertainty) compared to the frequency distribution of the current situation. a) & b) RCP 2.6; c) & d) RCP 8.5

These estimates of TDS under climate change should be interpreted with some caution as the analysis suffered from several sources of uncertainty. Firstly, working at a monthly time step with TDS modelling is not ideal as water quality generally responds to events occurring at shorter time scales such as daily or sub-daily. In addition, the observed TDS data available were grab samples, which were not averaged to monthly values as there were too few data points available. These data points were compared directly to simulated monthly TDS during model calibration; therefore, there was a temporal discrepancy within the modelling exercise. In addition, the modelling analysis suffered from a general lack of observed TDS data. There were no observed TDS data available for the middle Doring catchment (EWR4/E24H); therefore, simulated TDS at this point had to be calibrated as part of the downstream calibration (E24L) for which there were some TDS data available.

The model simulations of TDS for the upper Doring catchment (E22H) were not able to capture the spikes in TDS in the observed data, which could perhaps be attributed to the temporal discrepancy between modelled and observed TDS data. The time series model simulations of TDS within the lower catchment did not match that of the observed data; however, the frequency distribution of simulated data in general matched that of the observed data well. The frequency distribution of simulated TDS appeared to be too high compared to that observed for the lowest frequencies, indicating that simulations of TDS under climate change flows would probably be unrealistically high at the lowest frequencies.

Further analysis could include further refinement of the TDS model to achieve an improved calibration. Other sources of data to reduce uncertainty in the calibration could be identified, such as observed borehole TDS data which could be used to validate groundwater TDS signatures.

4.2.3 Comparison of future versus current environmental flows

The outputs of the RDRM model for EWR site 6 are shown in Figures 4.17 a-d and 4.18 a-d with stress-frequency curves for the wet and dry seasons for ecological protection categories A-D relative to the climate change minimum and maximum ensembles for RCP 2.6 and RCP 8.5, respectively.

The band of uncertainty under RCP 2.6 overlaps the EWR site 6 B/C category during the wet season, although the range of uncertainty band exceeds the stresses under category D (Figure 4.17c). For this RCP, the dry season stresses are significantly beyond category D with stress values exceeding stress index of 7 majority of the time (Figure 4.17d). The results are similar for RCP 8.5 (Figure 4.18 c, d).

The results for EWR site 4 (ecological category B) show similar pattern with stress frequency curves exceeding the dry season stress index for both RCPs 2.6 and 8.5 with stress values above 7 or 8 for the dry season (Figure 4.19 and 4.20). The wet season band of uncertainty is smaller for RCP 2.6 versus RCP 8.5 (Figures 4.19 c versus 4.20c).

EWR site 5 (ecological category B) are similar to site 4 but the stress index values during the dry season are not as extreme throughout the season (Figure 4.21d and 4.22d).

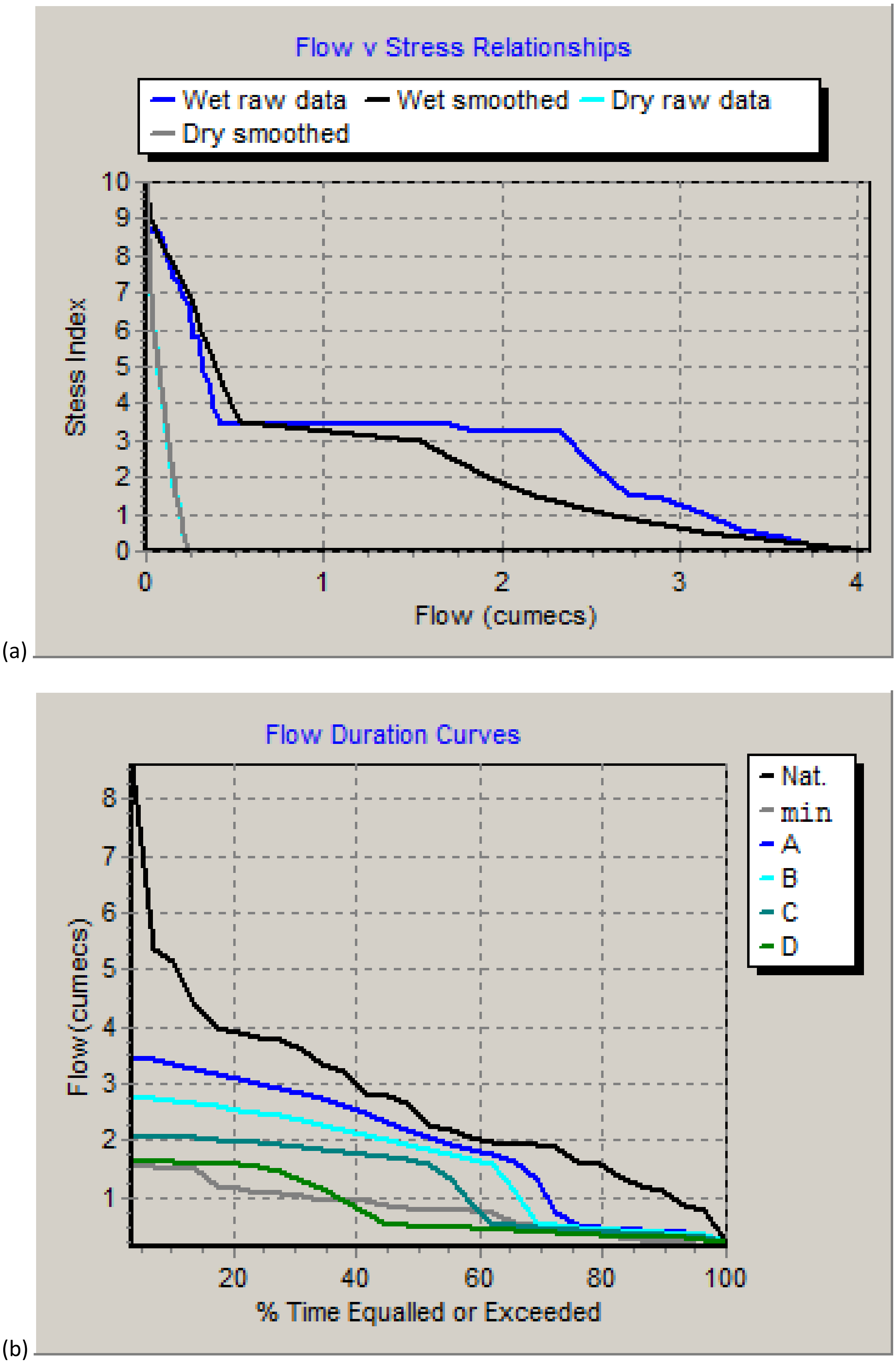
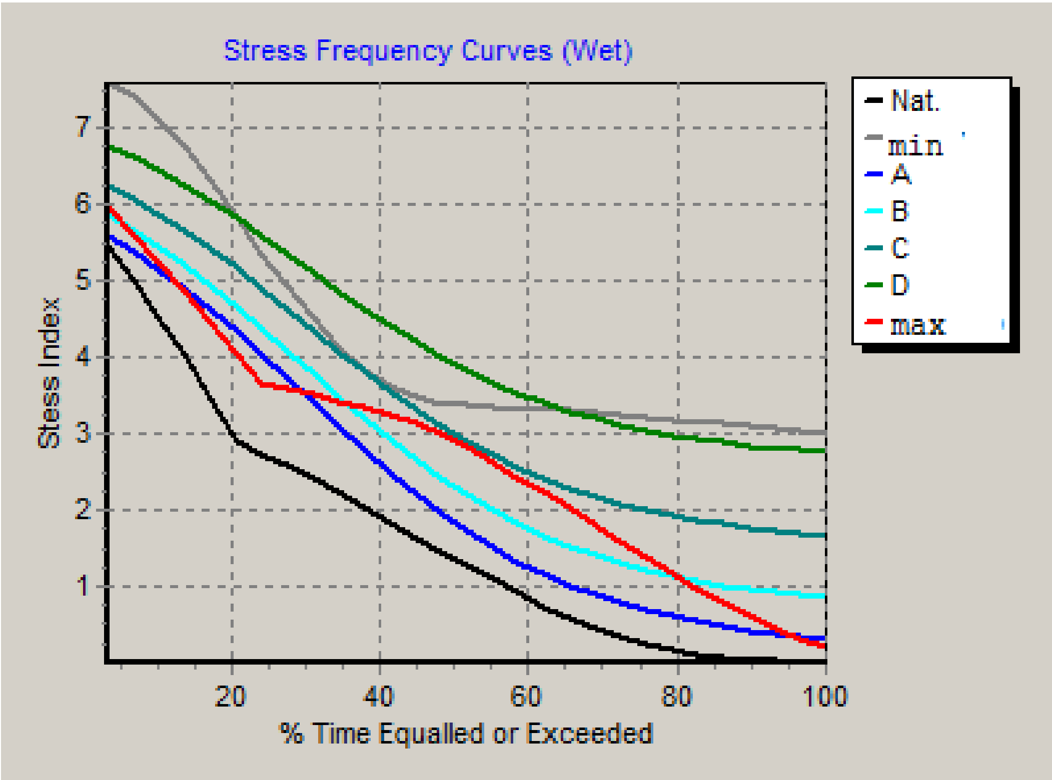


Figure 4.17 Outputs of the ecology sub-model with RCP 2.6 minimum and maximum ensembles for EWR site 6 (Ecological Category B/C [B under RSA 2018]) (a) flow versus stress relationships and (b) flow duration curves for natural, minimum ensemble and the four ecological categories

(c)



(d)

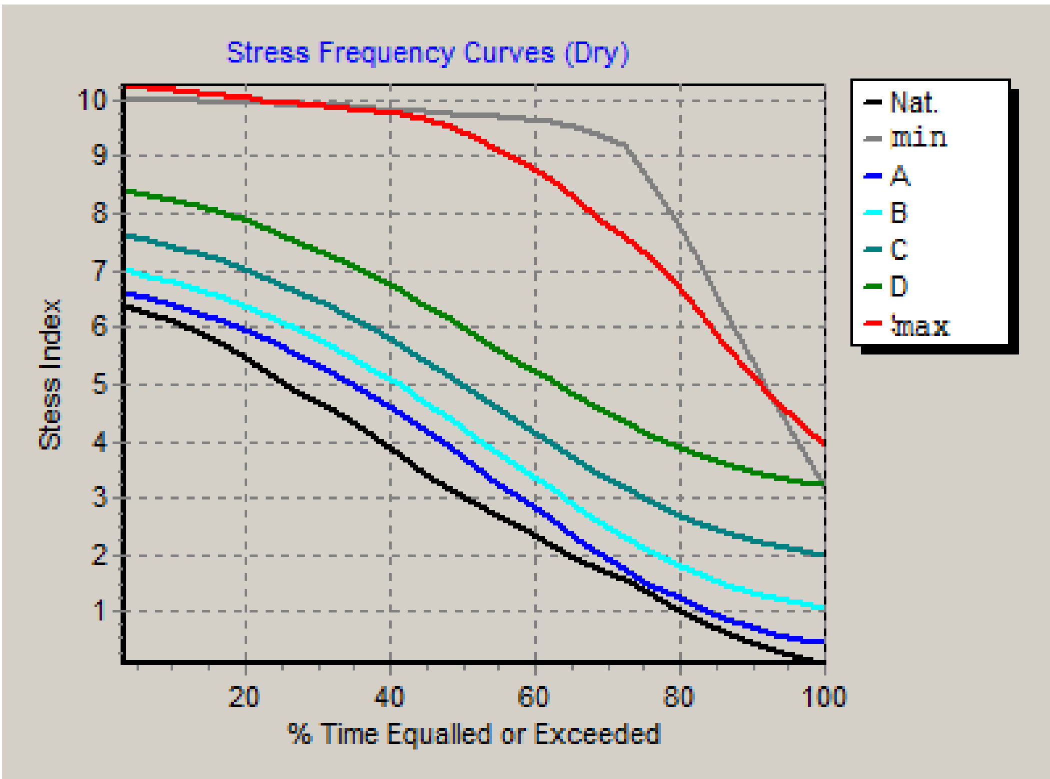
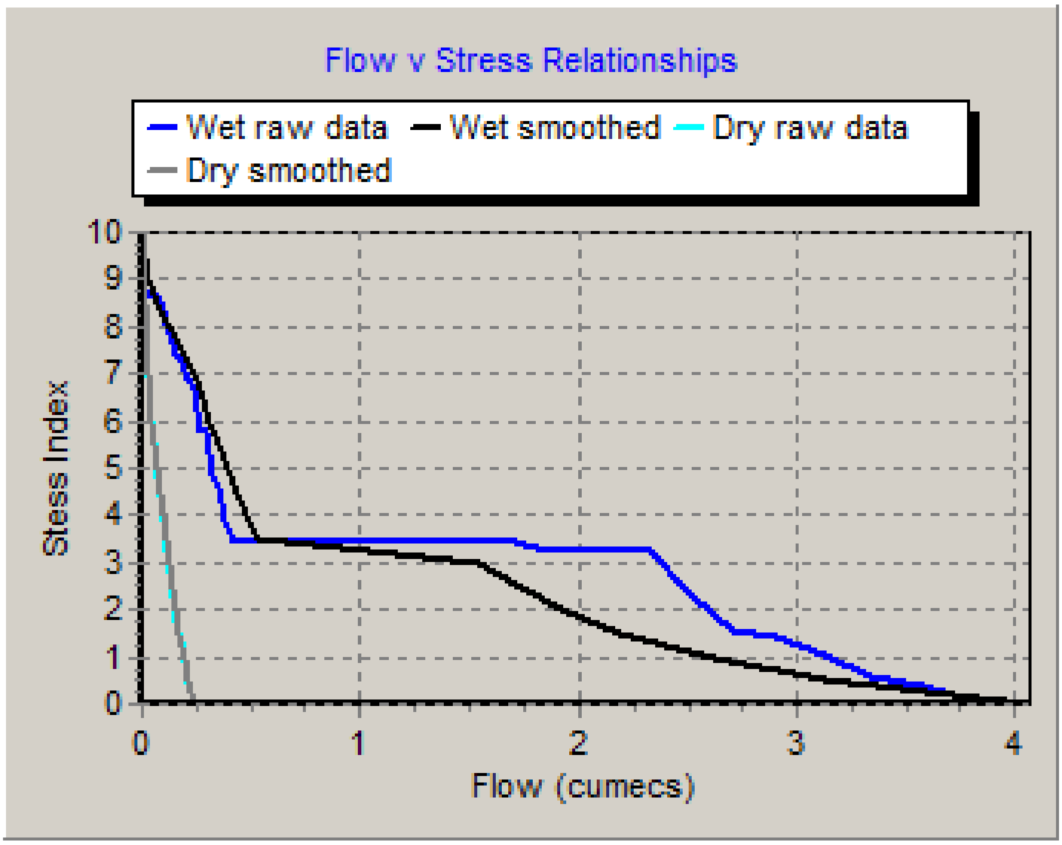


Figure 4.17 (cont) stress frequency curves for (c) wet and (d) dry seasons

(a)



(b)

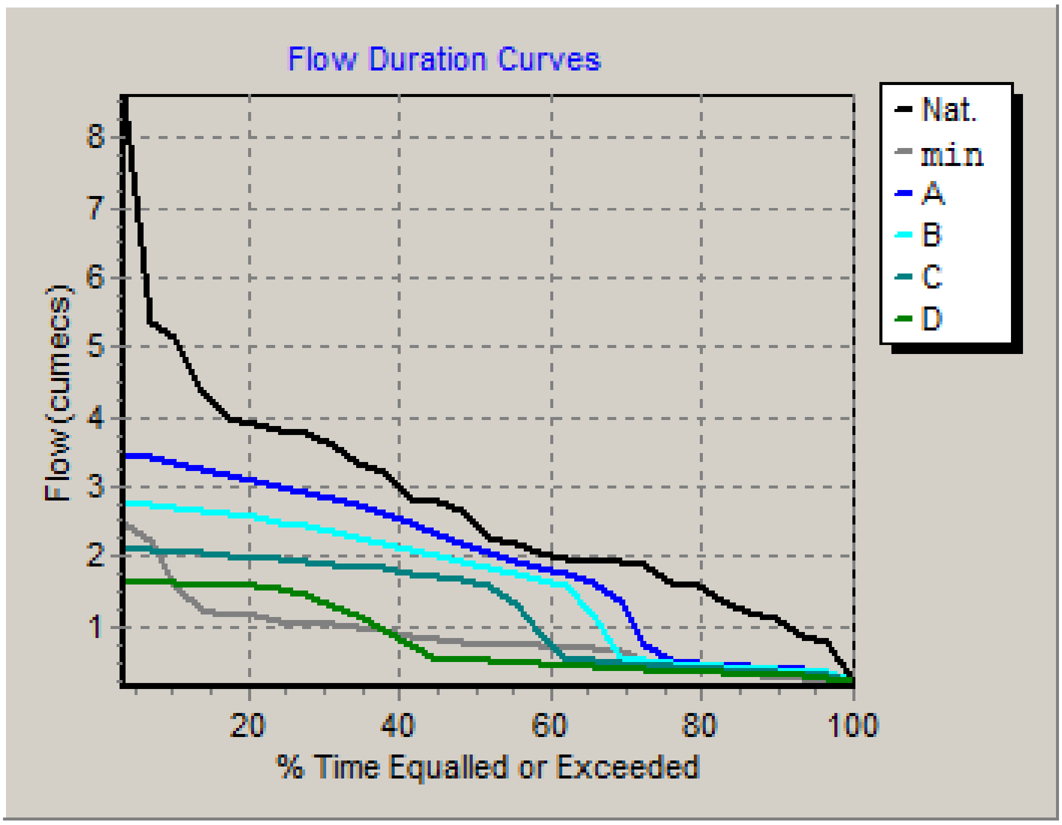
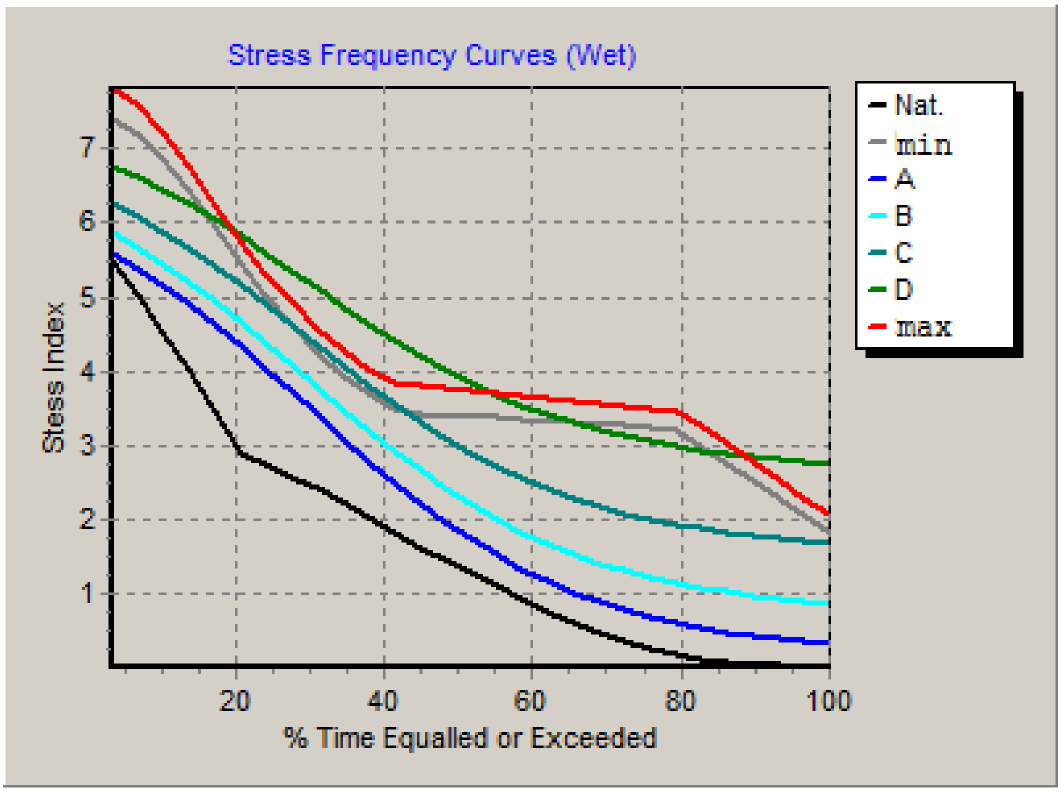
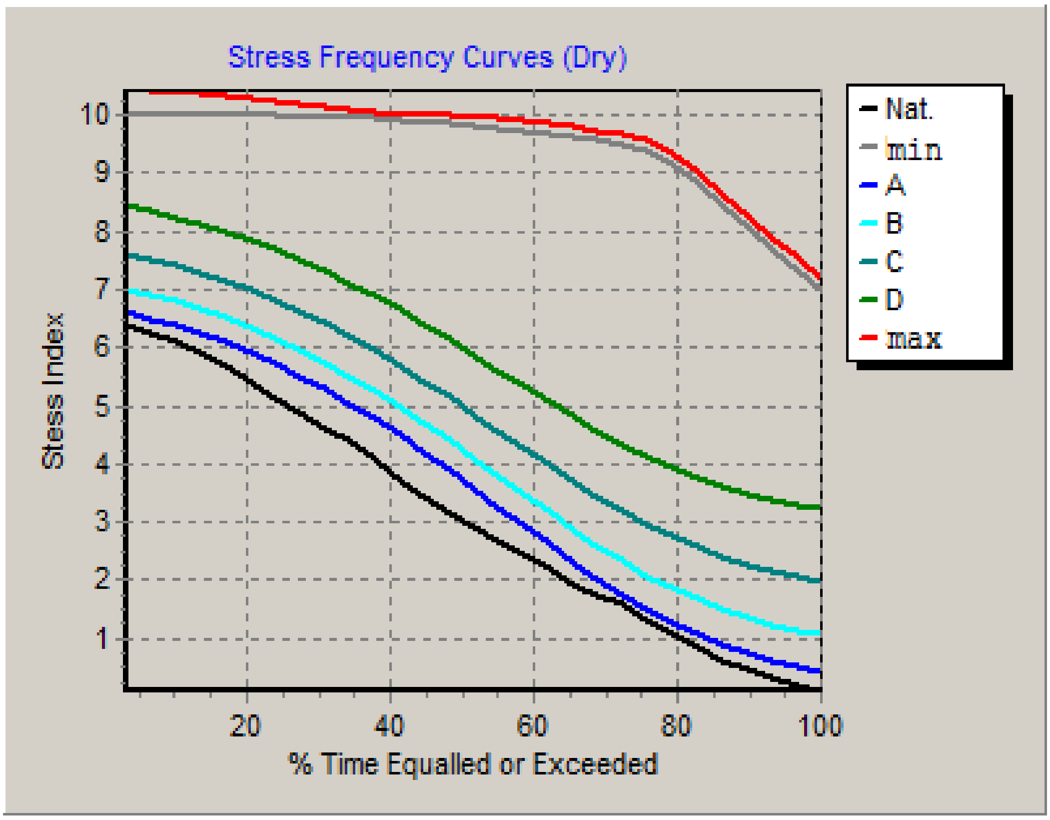


Figure 4.18 Output of the ecology sub-model with RCP 8.5 minimum and maximum ensembles for EWR site 6 (Ecological Category B/C [B under RSA 2018]) (a) flow versus stress relationships and (b) flow duration curves for natural, minimum ensemble and the four ecological categories.

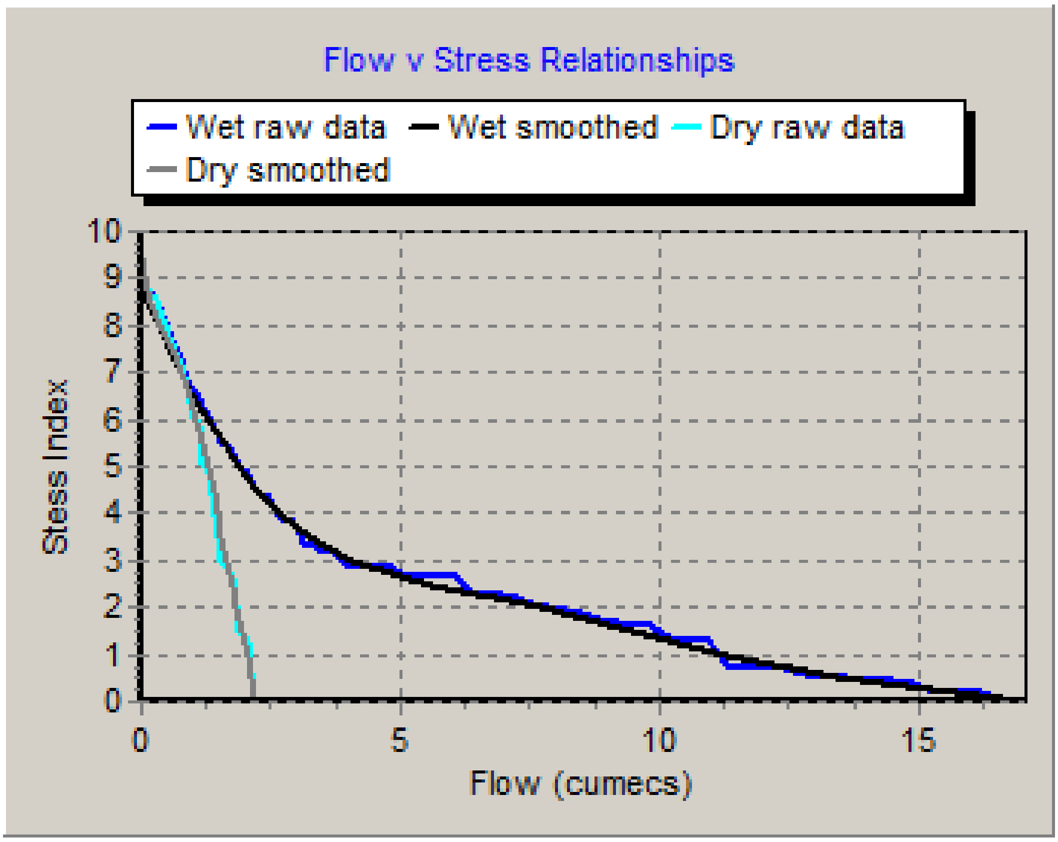


(c)

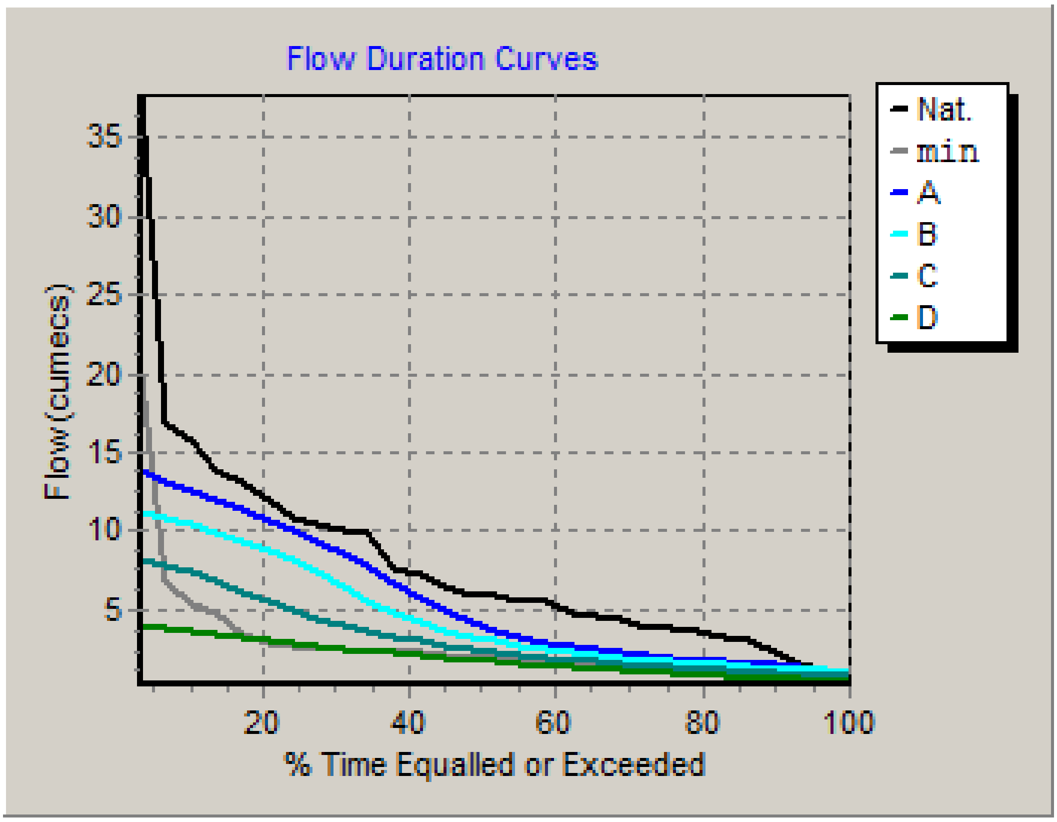


(d)

Figure 4.18 (cont) stress frequency curves for (c) wet and (d) dry seasons

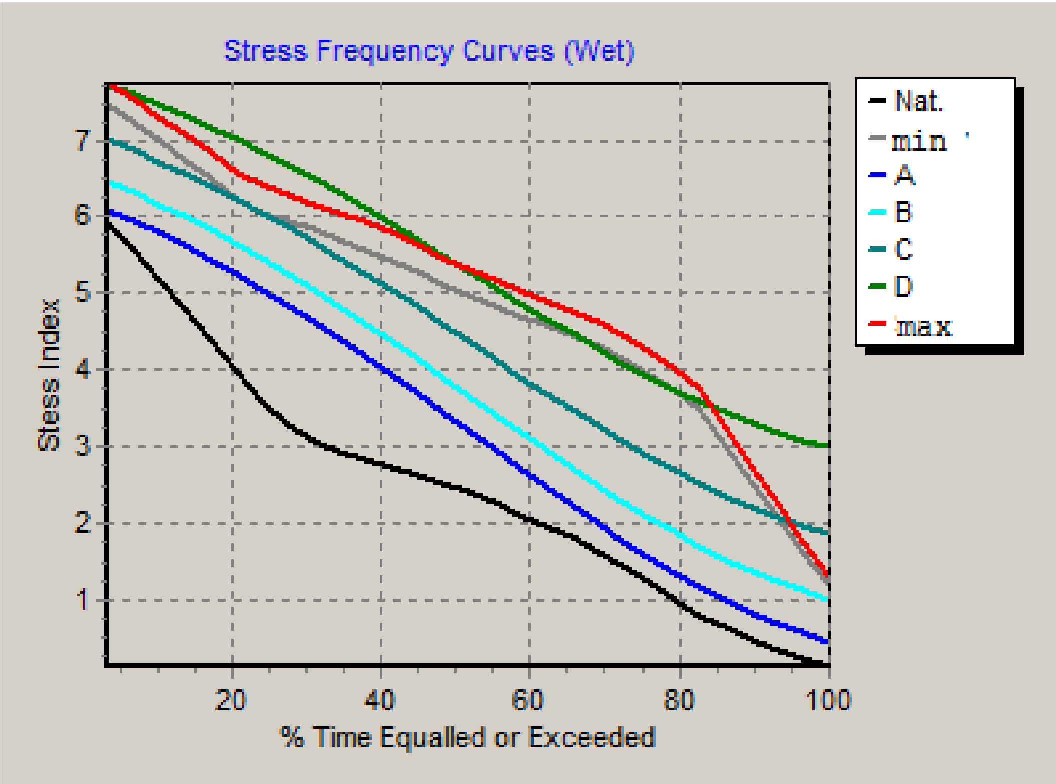


(a)



(b)

Figure 4.19 Output of the ecology sub-model with RCP 2.6 minimum and maximum ensembles for EWR site 4 (Ecological Category B) (a) flow versus stress relationships and (b) flow duration curves for natural, minimum ensemble and the four ecological categories



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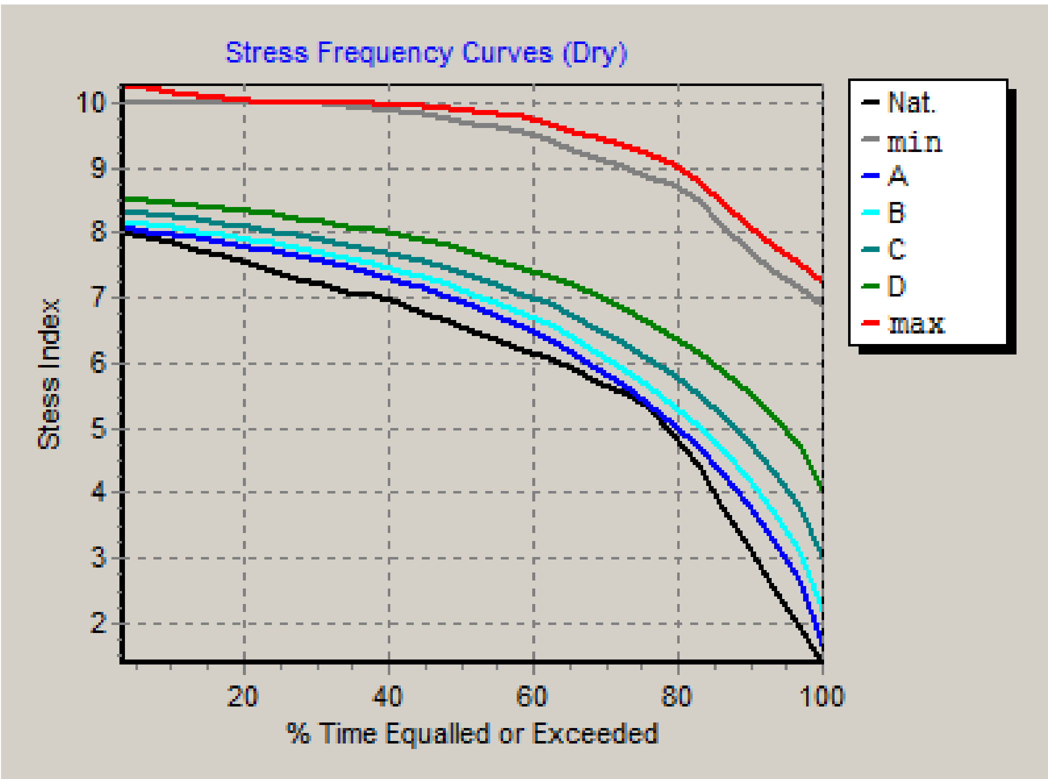
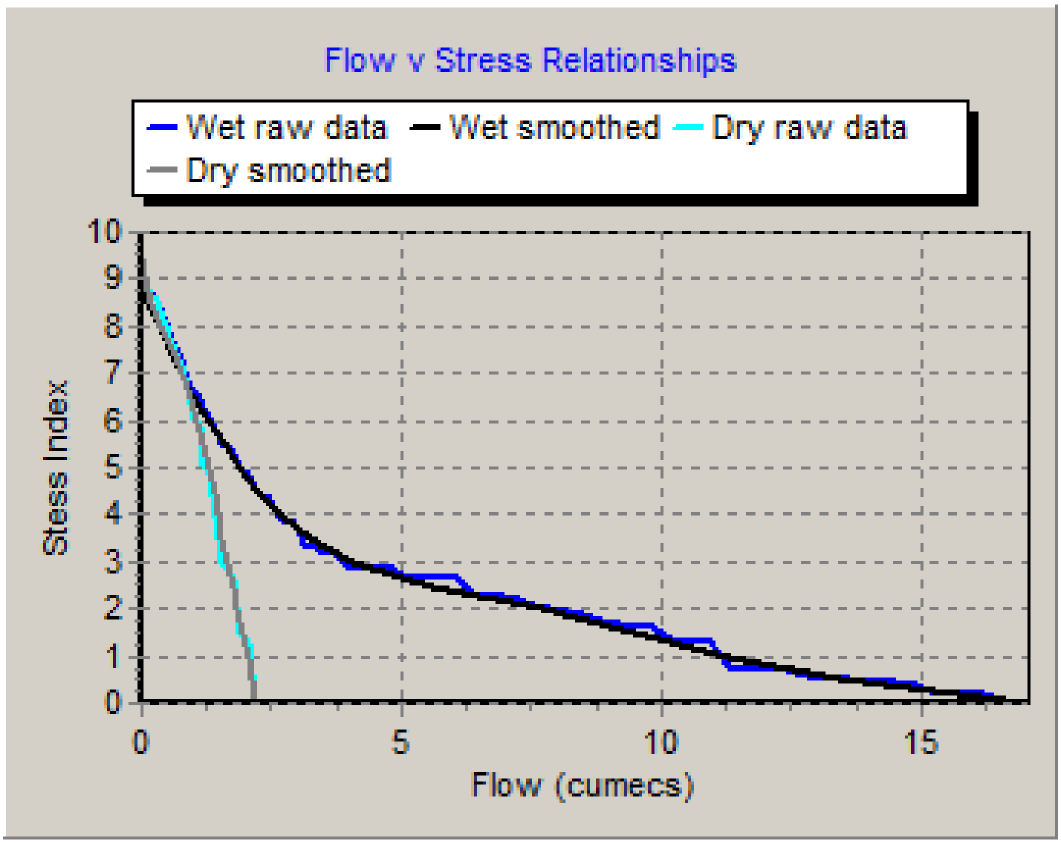


(d)

Figure 4.19 (cont) stress frequency curves for (c) wet and (d) dry seasons

(a)



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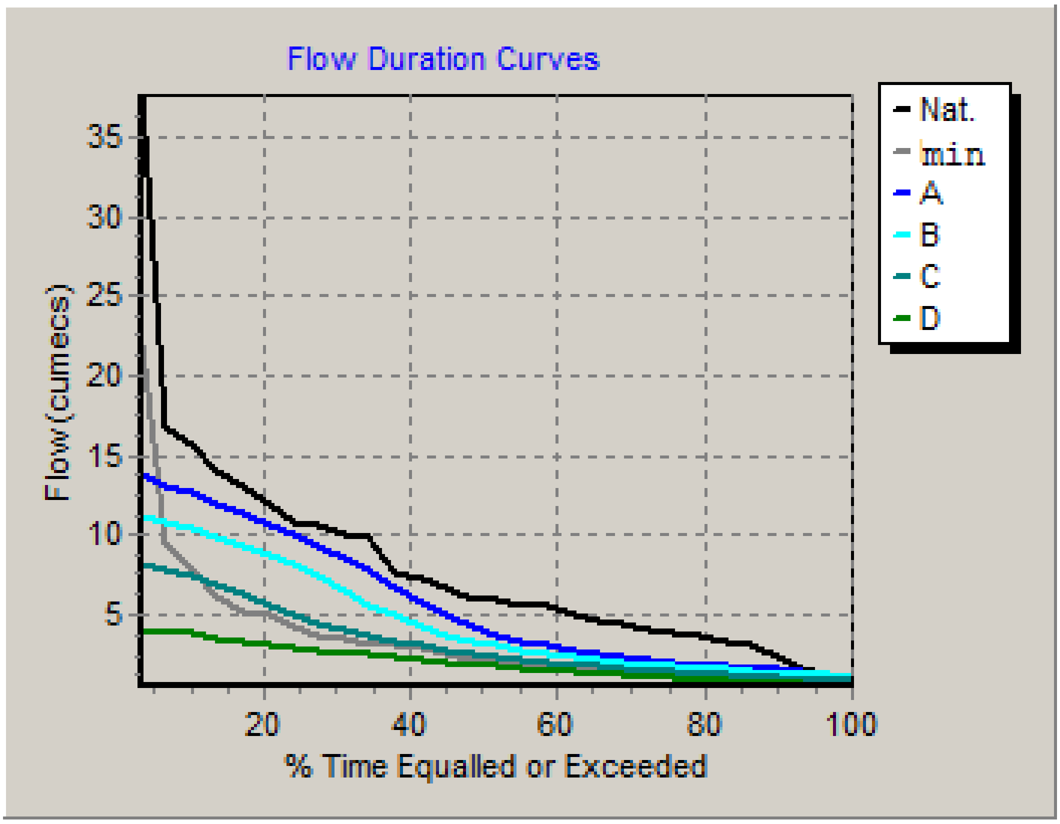
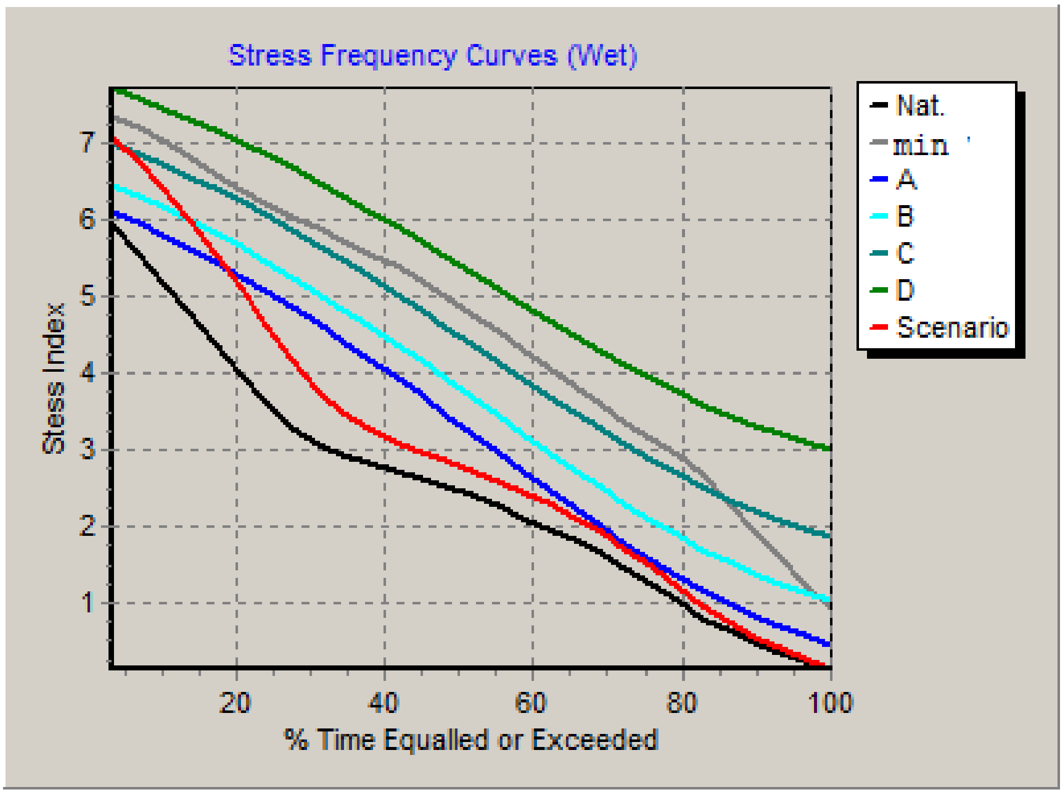


Figure 4.20 Output of the ecology sub-model with RCP 8.5 minimum and maximum ensembles for EWR site 4 (Ecological Category B) (a) flow versus stress relationships and (b) flow duration curves for natural, minimum ensemble and the four ecological categories



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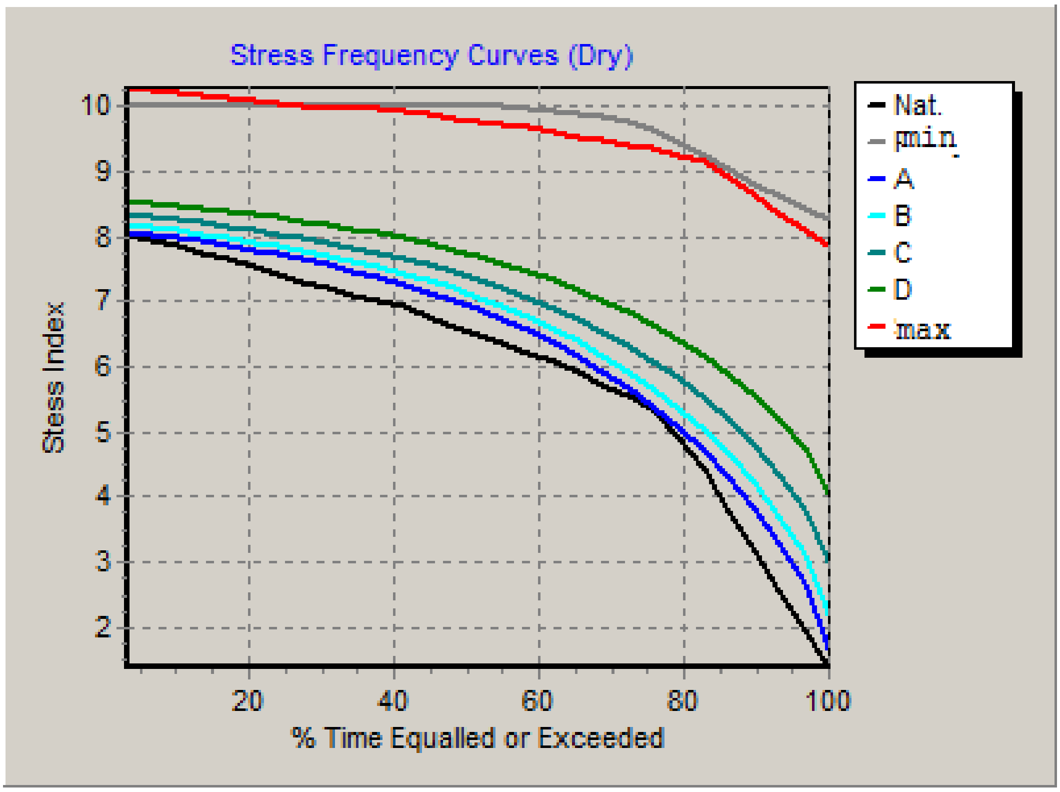
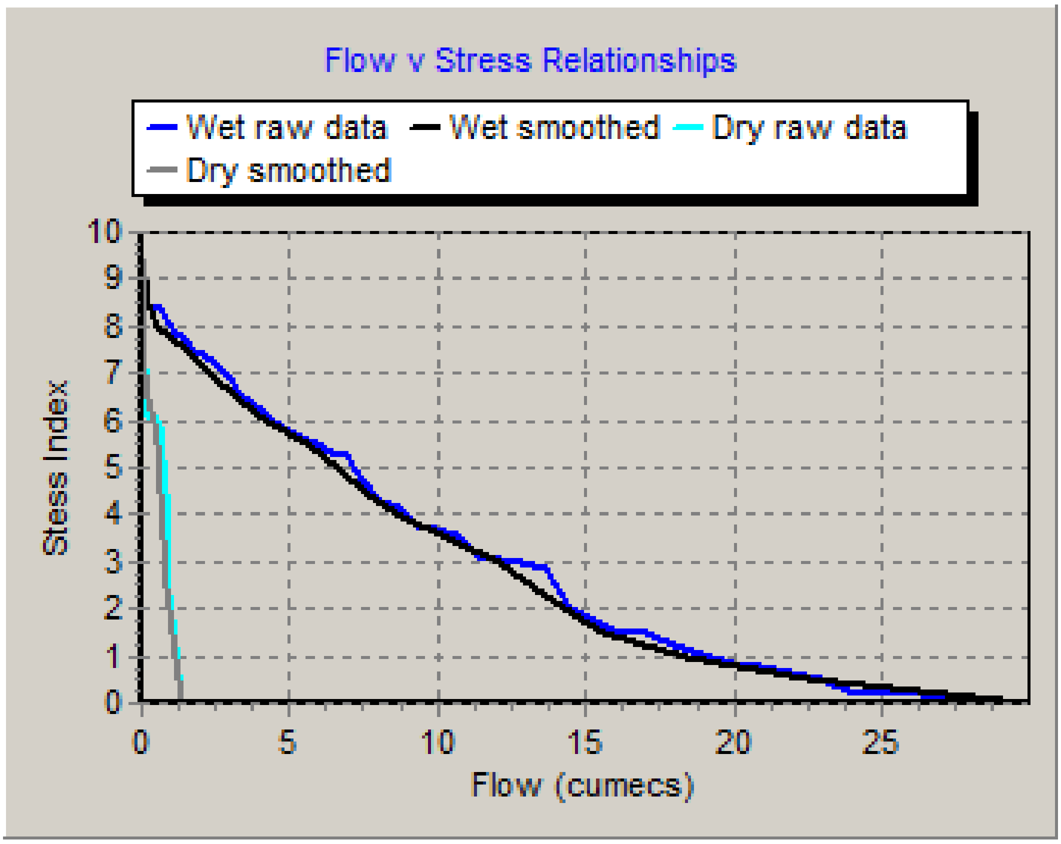
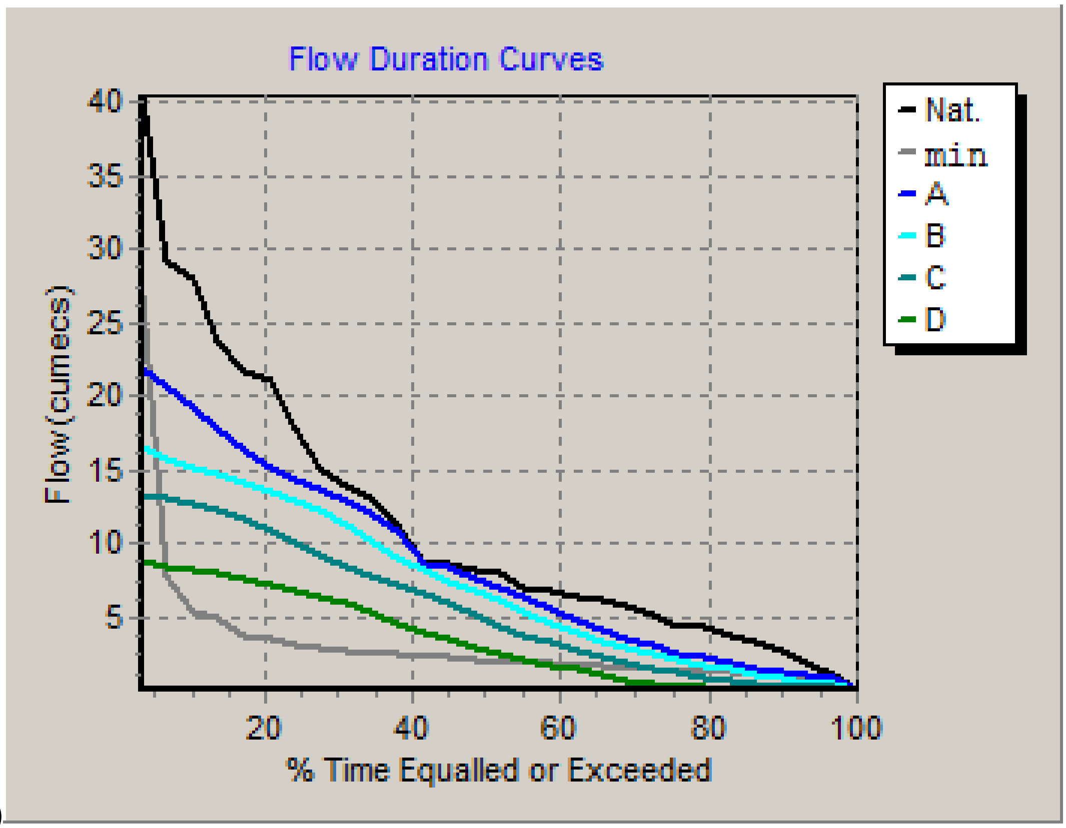


(d)

Figure 4.20 (cont) stress frequency curves for (c) wet and (d) dry seasons

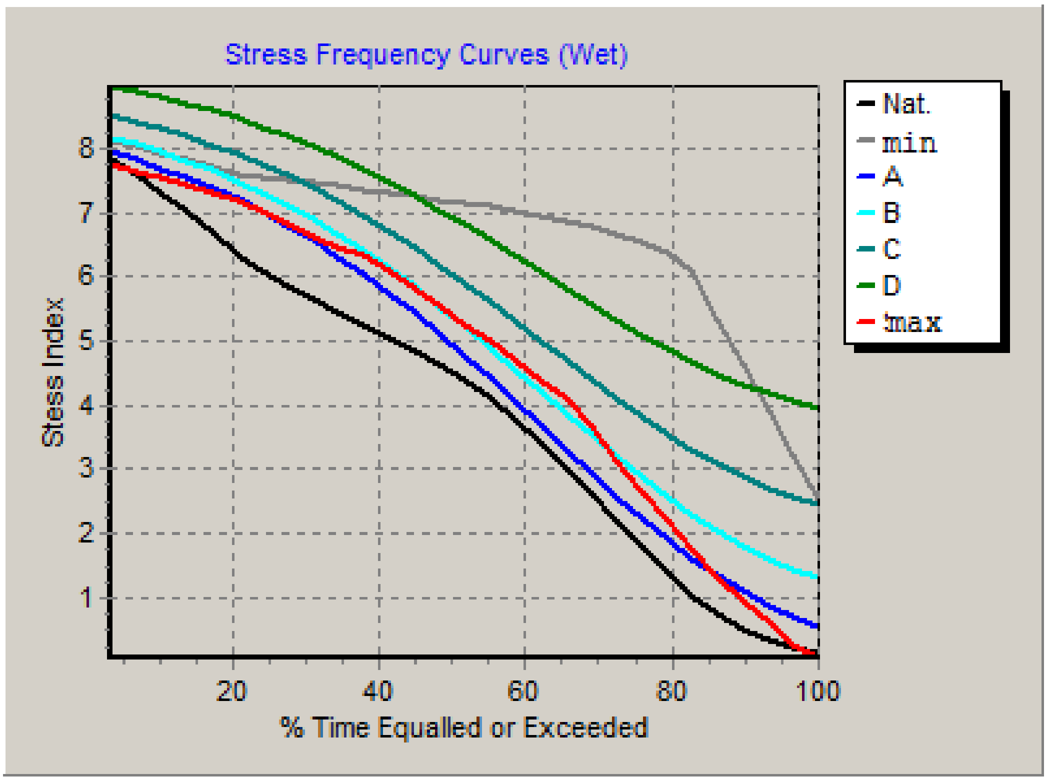


(a)



(b)

Figure 4.21 Output of the ecology sub-model with RCP 2.6 minimum and maximum ensembles for EWR site 5 (Ecological Category B) (a) flow versus stress relationships and (b) flow duration curves for natural, minimum ensemble and the four ecological categories



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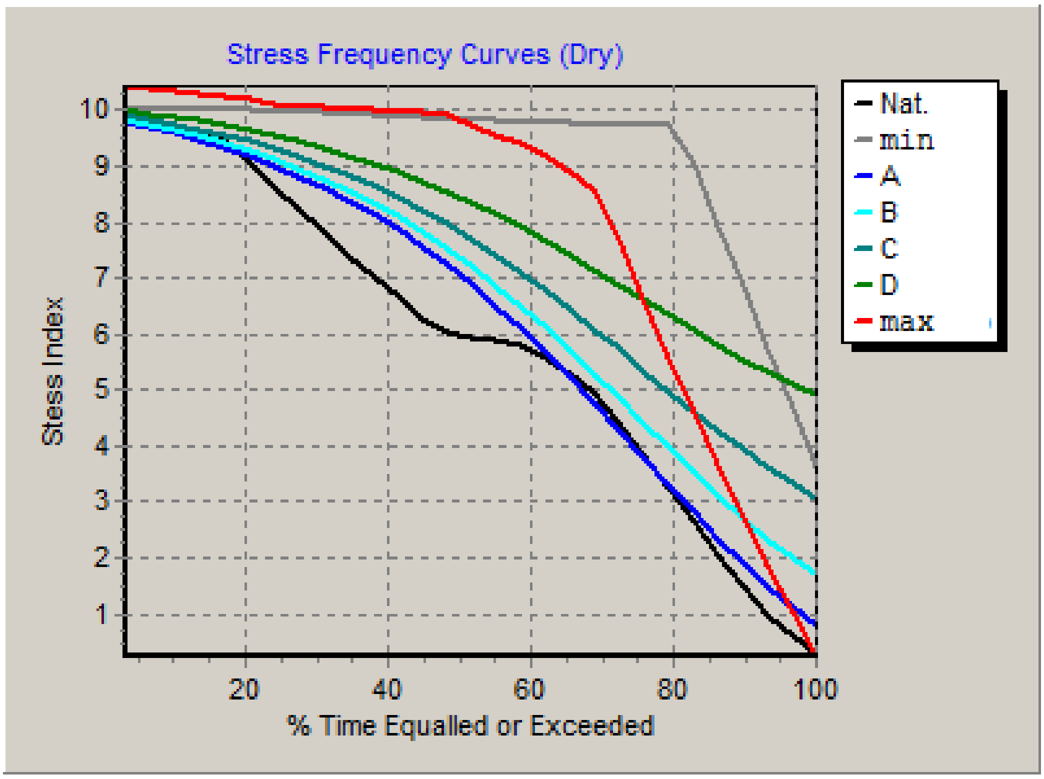
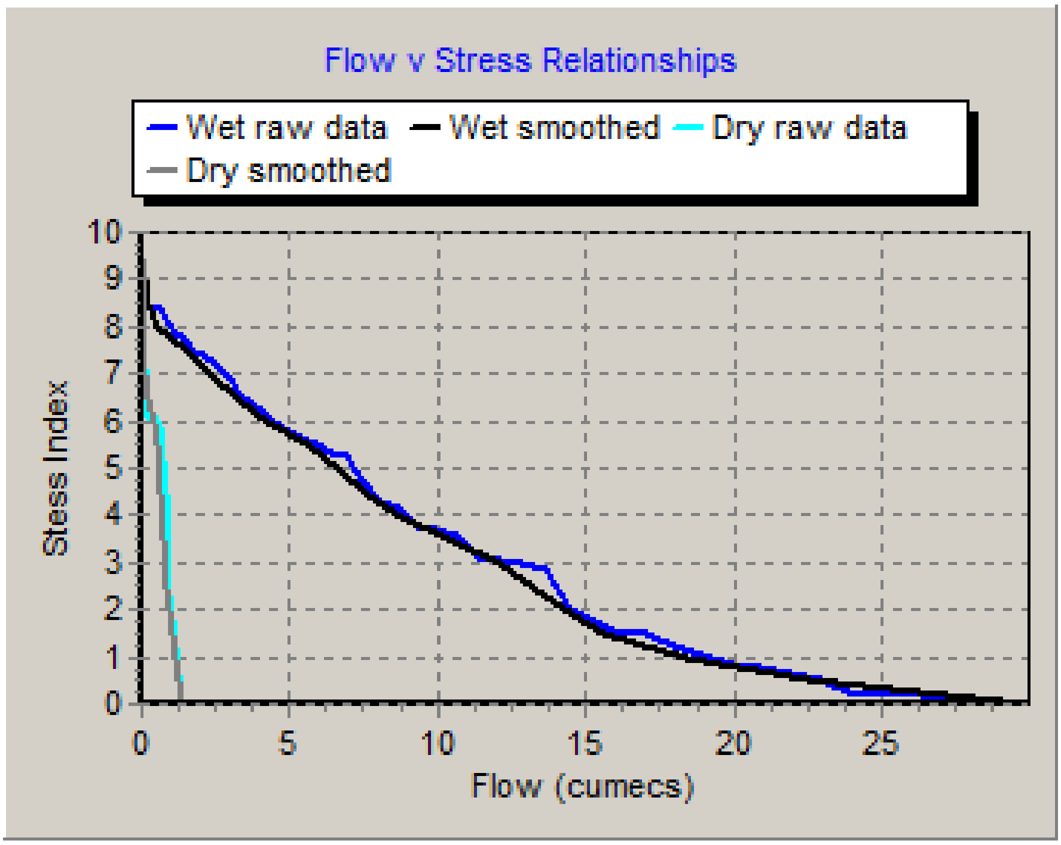
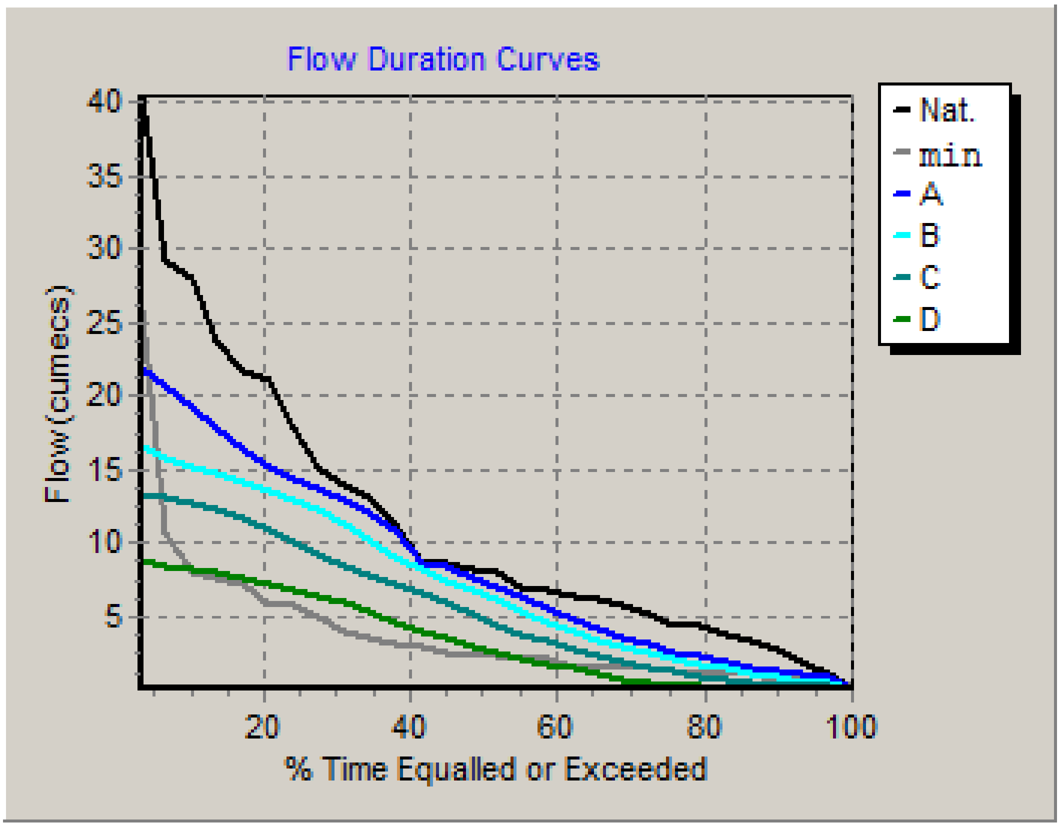


(d)

Figure 4.21 (cont) stress frequency curves for (c) wet and (d) dry seasons

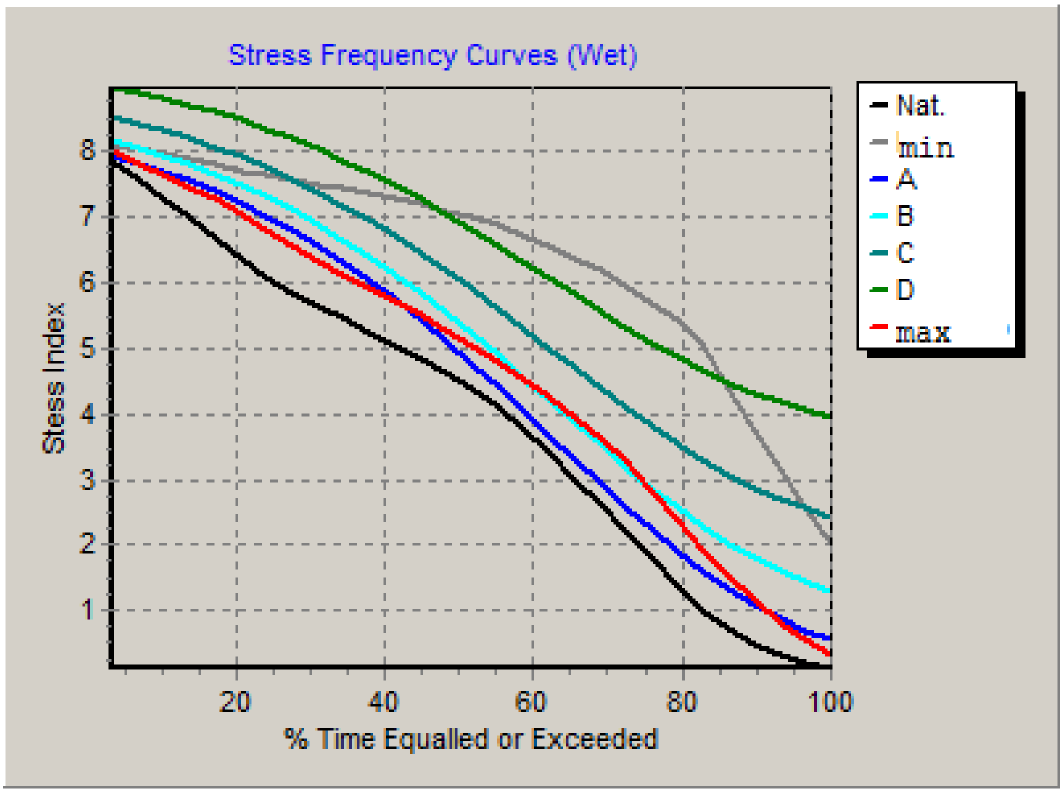


(a)



(b)

Figure 4.22 Output of the ecology sub-model with RCP 8.5 minimum and maximum ensembles for EWR site 5 (Ecological Category B) (a) flow versus stress relationships and (b) flow duration curves for natural, minimum ensemble and the four ecological categories



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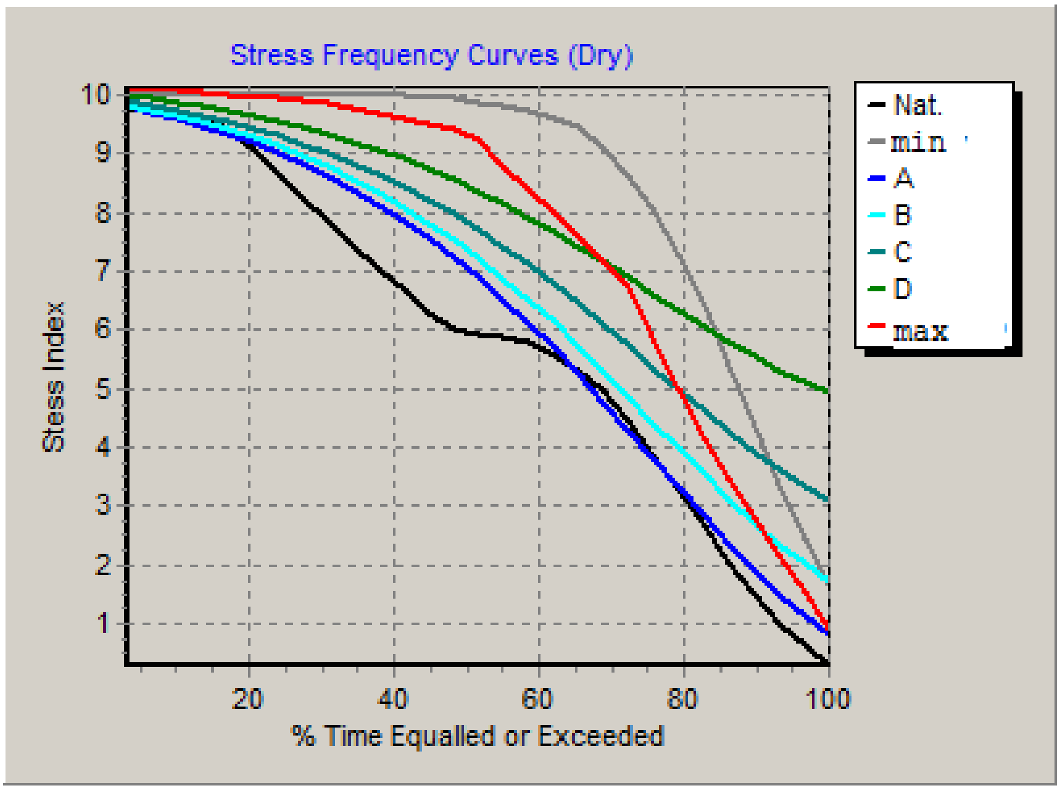

(d)

Figure 4.22 (cont) stress frequency curves for (c) wet and (d) dry seasons

Chapter 5 Specialist Reports on Impacts of Climate Change

5.1 Effects of climate change on water quality in the Doring River catchment

by Neil Griffin

5.1.1 Introduction

The Doring River lies in the Olifants-Doring catchment in the south-west of South Africa. It drains the Cederberg, Kouebokkeveld and Tankwa Karoo, before joining the Olifants River near Klawer in the Western Cape (RHP 2006). The 18,248 km^2 catchment is predominantly set in the Western Cape, though a small part, the Tankwa Karoo, lies in the Northern Cape.

The geology in the Olifants-Doring catchment is dominated by quartzitic and shale rocks of the Table Mountain Group, the Bokkeveld Group, and the Witzenberg Group. Vegetation types in the catchment include Sandstone Fynbos, Succulent Karoo and Tankwa Karoo (RHP 2006). Land uses in the catchment are largely agricultural, predominantly livestock (sheep and goats) farming and dryland agriculture. Population density is low, and the majority of the population are concentrated in the Kouebokkeveld in the upper catchment.

The catchment lies within a winter rainfall zone. The catchment is arid, with an annual rainfall of 220 mm set against evapotranspiration of 1814 mm (RHP 2006). The Groot River, a tributary of the Doring River, also receives 2.5 million $m^3.a^{-1}$ of water in the upper catchment from the Breede River Catchment (DWAF 2004a). The Doring River is ephemeral, with good winter flows, while in summer it is reduced to a chain of pools (DWA 2011). Flow in the catchment is bimodal, with different water quality signatures being found depending on the season (RHP 2006). During the winter, water draining from sandstone aquifers provides low salinity water to the catchment, while in the summer water draining from shale catchments is more saline and more turbid (RHP 2006, DWA 2011). This, combined with limited return flows, can limit the use of water in the lower Doring particularly in late summer (Belcher et al. 2011). The Oubaaskraal Dam on the Tankwa River provides water to 350 ha of land (RHP 2006). A further 350 ha is irrigated at the confluence of the Doring and Tankwa rivers (RHP 2006). Irrigation in the upper Kouebokkeveld, where deciduous fruit is produced, is extensive (DWAF 2005b).

5.1.2 Methodology

This assessment followed the steps for inclusion of water quality data in ecological Reserve assessments outlined in DWAF (2008). The assessment compares data from the start of the data record with high and low TDS levels from monitoring points EWR 4, EWR 5, and EWR 6 under modelled future rainfall scenarios in climate ensembles RCP2.6 and RCP 8.5.

TDS concentrations and loads were modelled using WQSAM as outlined in the Section 3.2 methods. Incremental flow for the upper, middle and lower Doring River catchments were separated into surface water, interflow and groundwater flow according to the simple statistical baseflow separation method of Hughes et al. (2003). Salinity data were the only data available for use in assessing the chemical water quality component of the ecological Reserve. This provided a minimal data set (c.f. DWAF 2006, DWAF 2008) for a water quality assessment, and as a result there cannot be high confidence ascribed to the results presented here. However, salinity is a major driver of water quality in the catchment (DWAF 2005a, DWA 2012). Of the other parameters used in the water quality ecological Reserve methodology, WQSAM can model temperature and nutrient levels in water. Water in the catchment is often oligotrophic, though elevated nutrient levels have caused recent concern (DWA 2012) and access to these modelled data would have added confidence to the outputs presented here.

The sites assessed were drawn from the previous ecological Reserve assessment (DWAF 2004c, 2006a). The EWR sites, together with selected data sources, are presented in Table 5.1.

Table 5.1 EWR sites and data sources used for assessment of TDS changes predicted under climate change. Sites are from DWAF (2004c).

Site	Name	Latitude	Longitude	Data
EWR 4	Doring at Biedou	S 32° 02.410	E 19° 24.896	Only 3 samples from site. Data is available from E2H002 stream gauge, approx. 70 km upstream in the Doring River. This dataset does not reflect summer saline input from the Tankwa and Wolf rivers (both unmonitored). Limited EWR 4 data show salinity was significantly impacted by these inputs, but this varied with time (the Tankwa River is ephemeral). Salinity (conductivity) at E2H002 is in an A category (using the default benchmark categories in DWAF (2008) for RC).This gives low confidence to the salinity assessment for EWR 4.
EWR 5	Doring at Oudrif	S 31° 51.446	E 18° 54.754	Only 13 samples from site. Used data from E2H003 stream gauge, approx. 20 km downstream on the Doring River. 27 samples from first three years of data record (from 1980). No clear potential impacts between EWR 5 and E2H003.
EWR 6	Groot at Mount Cedar	S 32° 39.552	E 19° 23.786	Only 3 samples from site. Used data from E2H007 stream gauge, approx. 20 km upstream in the Leeu River. 45 records from first three years of data record (from 1977). A potential impact between EWR 4 and E2H007 is input from Twee River, which flows though relatively small and localized area of irrigated agriculture.

WQSAM results express salinity levels as a mass concentration of salts in mg.l^{-1}, while DWAF (2008) standards are given as the proxy electrical conductivity in mS.m^{-1}. In order that a valid conversion between these units for the catchment was derived, the electrical conductivity from sites in the Doring River catchment was regressed against matching TDS concentrations (1428 records, $p<0.001$), and a conversion derived from the regression line's intercept and slope. All data were converted to a mass concentration. The default PES ratings per ecological category from DWAF (2008) is presented in Table 5.2, together with the appropriate rating values for TDS in the Doring River catchment.

Table 5.2 Present state rating values for salts from DWAF (2008) and TDS conversions for sites in the Doring River catchment.

Ecological categories	Electrical conductivity ($mS.m^{-1}$)	TDS ($mg.l^{-1}$)
A	≤ 30	≤ 164
B	30.1-≤ 55	164.1-≤ 313
C	55.1-≤ 85	313.1-≤ 491
D	≥ 85	≥ 491

Summary statistics were generated for all selected reference condition datasets, and PES standard rating values from DWAF (2008) were recalibrated where necessary to provide PES rating values for the various sites. 95th percentiles of maximum and minimum modelled TDS data under climate ensembles RCP 2.6 and RCP 8.5 were then compared with PES rating values to provide a PES for projected TDS conditions under climate change at three sites in the catchment.

5.1.3 Results and discussion

The modelled TDS category at each EWR site according to salinity under two climate change ensembles is presented in Table 5.3. This table also contains the current state at these points according to DWAF (2006b). It is clear from the presented data that the salinity under modelled climate scenarios is worse at EWR sites 4 and 5, and better at EWR site 6. This outcome was maintained regardless of the climate scenario assessed, and also of whether TDS maxima or minima under a particular climate change ensemble was assessed.

Despite a lack of change in TDS category with different climate change ensembles, and when one assesses maxima or minima, some differences are apparent. As the DWAF (2008) methodology uses 95th percentiles to categorize salts, these will be assessed here first. At EWR site 4, differences between the RCP 2.6 and RCP 8.5 ensembles are small, in particular with respect to maximum TDS from the two ensembles. However, the difference between minimum TDS under the two climate change scenarios was greater. The difference between TDS levels between minimum and maximum levels under either scenario was nearly a factor of two. At site EWR 5, salinities encountered were high than at EWR 4, and, the 95th percentile of maximum salinities encountered approximated one tenth the salinity of seawater. Differences between climate change ensemble results were minor. No differences between climate change scenarios and maximum and minimum TDS were found at EWR site 6.

The catchment has been identified as having bimodal flow patterns, with good quality water from sandstone aquifers in the winter, and saline and somewhat turbid water from shale aquifers in the summer (DWAF 2005a, RHP 2006). EWR 6, located in an area fed only by water from sandstone aquifers, would not be expected to show evidence of salinization. EWR 4 and 5 are both exposed to saline water from the Tankwa Karroo primarily via the Tankwa and the Wolf rivers, and signs of in particular summer salinization are apparent in datasets from the area. The results presented here suggest that a decrease in water quality state owing to salinization will be exacerbated under all climate change scenarios assessed.

Table 5.3 TDS under modelled future climate scenarios at EWR sites 4, 5, and 6 in the Doring River catchment.

Site	Ensemble	Max/min scenario	Count	Median ($mg.l^{-1}$)	95th %ile ($mg.l^{-1}$)	Category
EWR 4 PES water quality						B
EWR 4 Modelled Water Quality using TDS	RCP 2.6	Maximum	348	500	1576	D
		Minimum	337	283	891	D
	RCP 8.5	Maximum	348	503	1565	D
		Minimum	339	263	812	D
EWR 5 PES water quality						B
EWR 5 Modelled Water Quality using TDS	RCP 2.6	Maximum	347	1058	3220	D
		Minimum	340	481	1888	D
	RCP 8.5	Maximum	348	1222	3178	D
		Minimum	340	433	1940	D
EWR 6 PES water quality						A/B
EWR 6 Modelled Water Quality using TDS	RCP 2.6	Maximum	334	55	100	A
		Minimum	334	50	100	A
	RCP 8.5	Maximum	348	53	100	A
		Minimum	348	50	100	A

It is important to bear in mind that the site TDS category is based on assessment of the 95th percentile of the TDS dataset assessed. In this scenario where summer salinization occurs, if such salinization was evident during more than one twentieth of the data record, the 95th percentile of the data will represent summer salinity levels, and not the salinity levels present for the rest of year. The median salinities in this light offer more insight into year-round salinity at the sites. At EWR sites 4 and 5, median modelled salinities are consistently higher than RC salinities, suggesting an overall increase in salinity in the mid- and lower Doring River. Results from EWR 6 showed a slight increase in median levels, although the modelled results still had very low medians.

The modelled results from EWR 6 may seem rather unusual as medians and 95th percentiles are consistently similar or equal to 50 or 100. This is a function of the WQSAM modelling process in the upper catchment. A concentration of 50 mg.l^{-1} represents interflow, and 100 mg.l^{-1} represents groundwater TDS levels. The frequent occurrence of these in the EWR 6 modelled dataset indicates that the river in the upper catchment for the most part derives from input from interflow and baseflow. The low salinities encountered at this site attest to the quality of the groundwater in this part of the catchment.

This study has assessed the water quality component of the ecological Reserve in terms of salinity (TDS) alone, as this was the only water quality parameter that was modelled and hence that could be used for this report. The effects of climate change on TDS, as a conservative water quality variable, are more easily demonstrable compared to those on a non-conservative water quality variable as the instream dissolved salts are a function of rainfall-runoff, dilution, the relative contribution of baseflow to total flow and evaporation, which are processes that can be relatively easily linked to climate change projections. TDS is also a highly significant parameter in the current catchment, and models suggest that its influence on water quality is likely to increase under predicted climate change. However, assessment of the physicochemical component of the ecological Reserve would normally assess a range of other parameters including salts, temperature, pH, oxygen, nutrients and toxics. Increasing nutrient levels have been identified in this catchment in prior studies, and these may be significant under climate change. As only one parameter was assessed, confidence in this ecological Reserve assessment must remain low. In addition, while reasonable reference data were available for EWR sites 5 and 6, good reference data for EWR site 4 could not be located, and confidence in the EWR 4 assessment is therefore very low.

It has been noted that summer salinities lead farmers on the lower Doring to curtail irrigation owing to increased salt levels (Belcher et al. 2011). The increased salinities predicted under climate change will further limit water use in the mid- and lower catchment for irrigation. For example, a salinity of 500 mg.l^{-1}, which is approximately the median salinity at EWR 4 under RCP 2.6 and RCP 8.5 maximum levels, and slightly more than median salinity at EWR 5 under RCP 2.6 and RCP 8.5 minimum levels, would lead to minor crop losses and would require extra water for leaching of salts from soils (DWAF 1996b). Water of this salinity would have no significant adverse effects if supplied as drinking water to sheep, cows, horses, pigs or poultry (DWAF 1996c). If the salinity was doubled to 1000 mg.l^{-1}, yields of moderately salt-tolerant crops would be reduced and a larger leaching fraction would be required (DWAF 1996b). Livestock would exhibit a reluctance to drink, though no adverse effects would be predicted (DWAF 1996c). Finally, salinities of 3000 mg.l^{-1}, the worst predicted scenario at EWR 5, crop yield reductions of even salt tolerant crops would be greater, leaching fractions would be larger, and high frequency irrigation would be required, and livestock production would be decreased to some extent.

If salinity loads are high enough, this may impact on irrigated farming in the lower Olifants River as well, as saline stress in this catchment has already been identified as problem (DWA 2011). It has also been noted that bimodal low/high salinity flows found in the Doring River catchment contribute to unique habitats for nine indigenous fish species, seven of which are only found in this catchment (RHP 2006). The predicted increasing salinities are likely to impact negatively on all biota associated with the river. The Olifants River estuary, which is classified as a "desired protected area" by DWS (DWAF 2005b), may also be negatively affected by increasing saline input from the Doring River system.

5.1.4 Potential impacts of rising water temperature on water quality

Water temperature can act as a direct form of thermal stress on aquatic organisms, and many sensitive fish and macroinvertebrates are able to tolerate a relatively narrow range of water temperature (Dallas 2008). However, from a water quality perspective, it must also be considered that non-conservative water quality variables undergo changes in chemical form through various processes. These processes include uptake of nutrients by algae and macrophytes, decomposition, sedimentation and speciation (Chapra 1997). Water temperature is relevant in this respect as typically, the rate at which these processes occur is a function of water temperature (Chapra 1997), with the rates of the processes increasing with increasing water temperature. This is why water temperature must be considered within the potential impacts of climate change on water quality in addition to direct thermal stress. Climate change therefore has the potential to impact the levels of non-conservative water quality variables through both direct processes such as rainfall-runoff, dilution, evaporation and the relative contribution of baseflow to total flow, and through the indirect processes that occur instream that are regulated by water temperature.

5.1.5 Potential means of ameliorating impacts

Impacts consequent on predicted climate change that have been identified during this study relate to salinization of water in the mid- to lower Doring catchment. The extent of salinization that is predicted is severe and is far above natural or present day levels. This impact is not predicted for the upper catchment at EWR 6, where no amelioration will be required.

A common means of addressing salinity-related impacts is the release of less saline water to dilute the salinity of the system. The major upstream dam in this catchment that might be available for this is the Oubaaskraal Dam on the Tankwa River. No data were available on water quality in this dam, so the salinity of the water would need to be assessed prior to releases. An alternative source of water for dilution releases could be the smaller, but numerous, instream and off-channel dams in the Kouebokkeveld region. Alternatively, input of additional fresh water from the Breede River via the existing transfer scheme might be possible. Note that the use of freshwater, already a scarce resource, to dilute water quality issues, is not recommended.

As the salinity in flows from the Tankwa Karoo derive from groundwater (RHP 2006, DWA 2011), and annual peaks in salinity data are present in modelled data (Figure 4.14), it is presumed that salinity in modelled data derives from saline input from groundwater combined with evapotranspirative loss of water from the system. Another possible route to ameliorating higher salinities might therefore lie in reducing water loss through transpiration. Specifically, in reducing the use of water for irrigating crops. The irrigated land in the mid to lower catchment is limited, the majority of currently irrigated land lies in the Koubokkeveld. This option would require further study to determine its efficacy in reducing salinity levels downstream, and to weigh that against costs of reducing irrigation. This option may not need to be deployed in the mid- to lower catchment, as farmers currently stop irrigating when the river is saline (DWA 2011).

From the perspective of irrigated farming in the mid- to lower catchment, amelioration may be approached as discussed above by planting salt-tolerant crops and using more irrigation water to flush salts from the soil. This will have the effect of increasing groundwater salinity. In-stream salinity may also be increased by saline return flows from irrigated areas.

In summary, given that the increased salinities that are predicted are a function of natural processes and not, for example, caused by land use changes, there are few means of potentially reducing the impact of predicted salinity increases. Two options that seem more practical are dilution releases, and steps to reduce evapotranspirative water loss. However, in a water scarce region, neither of these will be uncontested by water users.

5.2 Effects of climate change on channel geomorphology in the Doring River

by Benjamin van der Waal

5.2.1 Introduction

The physiognomies of a river channel, such as size, shape and substrate, provide the template for biological, chemical and physical processes (Jaeger et al. 2017). The physical template is strongly shaped by hydrological and sediment regimes, such as sediment delivery to the channel and erosion and deposition along the channel (Jaeger et al. 2017). Intermittent and ephemeral rivers are extremely diverse in physical characteristics and support distinctive ecologies (Jaeger et al. 2017). Changes to the drivers and ultimately the physical characteristics of a river channel is likely under future climate change and anthropogenic flow manipulation.

Climate predictions for the Doring Catchment indicate that there will be in increase in months with no rainfall and no flow. Due to variability amongst the various future climate ensembles, rainfall and flow variability straddles the current rainfall and flow regime, with higher uncertainty and variability around the low frequency rainfall events. Similarly, the largest uncertainty and discharge variability is for low frequency flow events, which can either be greater or smaller compared to present events. All modelled flows fall below the natural flows, thus climate change is unlikely to result in flows that are greater than those under "pristine" conditions.

This section will assess likely future changes to these drivers and channel characteristics for the Doring River catchment in the Western Cape.

5.2.2 Effects of climate change on rainfall variability, rainfall intensity, vegetation cover and soil erosion

This section summarises some of the literature on effects of climate change on rainfall, vegetation cover and soil erosion.

Changes in rainfall regime changes the rainfall erosivity, vegetative cover and sediment transport (Xu 2003). Soil erosion is largely driven by the intensity of a storm and not by the number of rain days per year (Nearing et al. 2004). For the USA it is estimated that soil erosion rates will increase by 1.7% for every 1% change in annual rainfall (Nearing et al. 2004). The rainfall modelling for the Doring River suggest more days without rainfall, thus likely to increase rainfall intensity.

Shifts to a drier climate will reduce vegetation cover and increase soil erosion and sediment supply to the river channels (Xu 2003). Figure 5.1 shows the changes that are likely to occur on hill slopes that will decrease soil stability, vegetative cover and increase runoff intensity, all supporting soil erosion and sediment transport to the channel. This is further illustrated in Figure 5.2 where the spatial distribution of runoff and sediment generating areas increase with an increase in aridity. It is assumed that the opposite will happen if the climate becomes wetter and less variable.

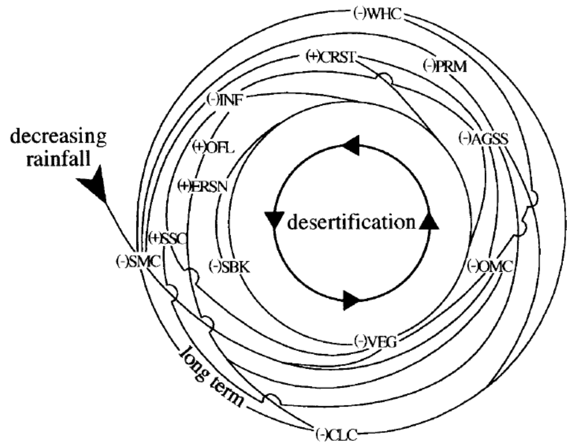

Figure 5.1 Interrelationships within ecogeomorphological system in response to decreasing rainfall as a result of climate change (from Lavee et al. (1998)). The lines connect between variables/processes that have direct relationships. AGSS = aggregate size

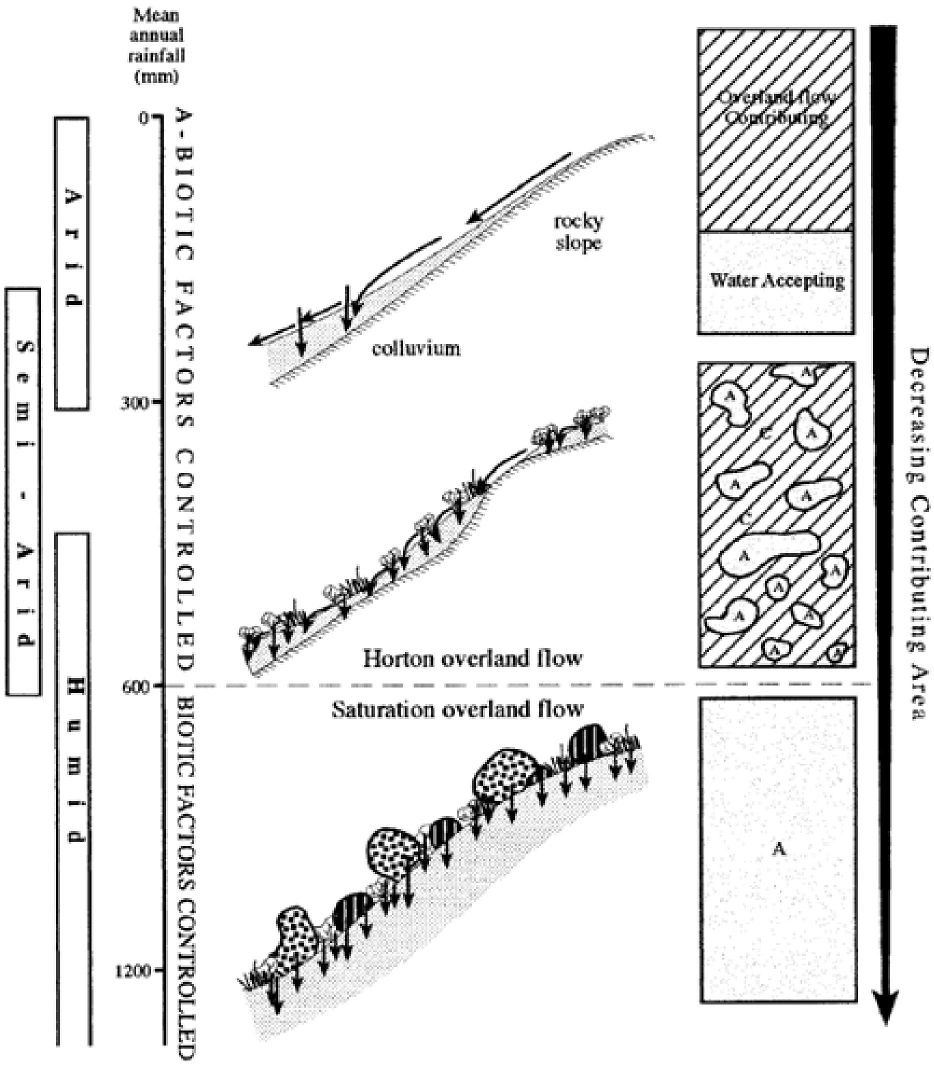

Figure 5.2 Changes to water and sediment contributing areas as aridity changes (from Lavee et al. 1998)

Sediment particle size tends to be more variable longitudinally in arid rivers, compared to the systematic fining of more humid rivers (Jaeger et al. 2017). Sediment flux is greater and more variable for drier systems, resulting in wider channels compared to wetter systems (Jaeger et al. 2017). Particle sorting decreases with increases in aridity due to increases in sediment supply (poor vegetation cover and high runoff), frequent scour and fill processes along the channel and floods are typically short-lived and do not support prolonged particle sorting and winnowing (Laronne et al. 1994). Furthermore, increases in climatic variability leads to increased weathering and supply of coarser material, thus particle size is likely to increase in channels (Peizhen et al. 2001).

Increases in sediment sully will lead to channel aggradation, with the possible loss of scour features such as pools and deep channels as these will be filled in. In contrast, decreases in sediment supply are likely to increase the bed particle size due to armouring, erode the bed and banks and floodplains (Wohl et al. 2015).

5.2.3 Effects of climate change on sediment transport and habitat template

Reductions in discharge will increase sedimentation as sediment entrainment is a function of stream power (Xu 2003). Increases in aridity increase flood magnitude variability, thus more large floods are expected in relation to small magnitude floods (Molnar 2001). This is translated to accelerated long-term (geological time) landscape incision that results in increased hill slope and channel erosion and sedimentation, despite reductions in discharge in rivers (Molnar 2001). Sediment transport is much higher in drier systems due to the lack of an armoured layer and the readily available supply of sediment (Reid and Laronne 1995). Bedload measurements show that all floods entrain bed load in dry systems, compared to more selective transport in wetter regions (more dependent on the flood magnitude) (Laronne et al. 1994).

River ecosystems are complex systems that cannot be explained by simple models. Increases in sediment delivery to the channel is likely to increase sediment deposition in the channel, leading to an increase in the magnitude and frequency of floodplain inundation/flood events, excluding the increase in discharge (Lane et al. 2007). Incorporating increases in discharge will exacerbate this trend. Increases in rainfall and flow variability is likely to increase flood magnitude and decrease flow duration. This will lead to less particle sorting and development of in-stream morphological features, such as benches, pools, sand bars, etc. Instead, sediment will be dumped as flows recede, leading to a wider more uniform channel bed with a straighter planform (Schumm 1969). A straighter river planform results in reduced hydraulic, geomorphological and aquatic diversity (Rhoads et al. 2003).

Pools are more sensitive to changes compared to riffles. Pools are likely to become shallower and narrower due to changes in flow (DWAF 2005b).

5.2.4 Expected changes to the Doring and Groot rivers (EWR 4 – 6)

Expected changes to drivers

Based on the climatic modelling the rainfall frequency is likely to become more variable, with increases in event intensity, and the annual volume possibly increasing or decreasing. Soil moisture regimes are likely to vary more, resulting in poorer vegetation cover and increased sediment availability. Due to poorer vegetation cover, runoff and sediment transport to the channel will be enhanced, leading to increased sediment supply to the channel for both extremes of the possible future climate ensembles.

The runoff modelling predicts an increase or decrease in event magnitude for large low frequency events (floods), thus high flow events and sediment transport events can be increased or decreased in magnitude based on the modelled future ensembles. It is assumed that for both extremes, event duration will be reduced as rainfall intensity increased.

Expected changes to habitat template

Previous modelling shows that only the large present day low-magnitude flows (0-10% frequency) are capable of entraining the median particle size, and that these flows are responsible for 95% of the bed sediment transport for EWR sites 4 to 6 (DWAF 2005b). Present day flows are lower, thus bedload transport is lower as compared to virgin conditions, resulting in the moderate PES scores of a C for geomorphology (DWAF 2005b). Modelling shows that the coarse fraction on the bed is only mobile during large floods (>10 year return interval), which are channel morphology reset events (DWAF

2005b). These results will apply to the changes in drivers as expected under the future climate predictions.

Table 5.4 Site summary with expected future PES scores

Site	Slope	Longitudinal zone	Reference description based on longitudinal zone (from Rowntree and Wadeson 1999)	PES (DWAF 2005b)	Future PES under increased high flows	Future PES under decreased high flows
EWR 4	0.006	Upper foothills	Moderately steep, cobble-bed or mixed bedrock cobble bed channel, with plain-bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain of sand, gravel or cobble often present.	C	C/D	D
EWR 5	0.006	Upper foothills	Moderately steep, cobble-bed or mixed bedrock cobble bed channel, with plain-bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow flood plain of sand, gravel or cobble often present.	C	C/D	D
EWR 6	0.03	Transitional	Moderately steep stream dominated by bedrock or boulder. Reach types include plain-bed, pool-rapid or pool riffle. Confined or semi-confined valley floor with limited flood plain development.	C	Low C	C/D

Increase in sediment supply and flow magnitude

There could be increased capacity to transport the larger sediment load, but due to the flashiness of the system it is likely to decrease habitat diversity due to infilling of pools and deeper channels, and poor sorting of materials to form sand bars, benches, etc. An increase in large flood frequency will result in more frequent resetting of the habitat template. These more frequent scour and fill disruptions will lead to a less stable river channel with more variable vegetation dynamics. These effects are likely to decrease the geomorphic diversity for EWR 4 and 5 to a C/D and EWR to a low D (Table 5.4). These changes to the geomorphological scores are relatively small due to the stable river planform (strong bedrock influence) and steep confined landscape setting, especially for the steeper, more confined EWR 6 (Table 5.4; Figure 5.3).

Increase in sediment supply with decreased flow magnitude

Reduced capacity to transport the increased sediment load will lead to a simpler plan form, poor habitat diversity and sediment accumulation. Wide shallow channels with poorly sorted sediment are likely. These effects are likely to decrease the geomorphic diversity for EWR sites 4 to 6, resulting in a D PES score for EWR 4 and 5 and a C/D for EWR 6 (Table 5.4). These changes to geomorphological scores are small due to the relatively stable river planform (due to bedrock influence) and steep confined landscape setting, especially for the steeper, more confined EWR 6 (Table 5.4; Figure 5.3).

(a)

(b)

(c)

Figure 5.3 Google Earth images for (a) EWR 4, (b) EWR 5 and (c) EWR 6 for February 2016

5.2.5 Impact amelioration

To reduce the production and transport of sediment to the channel and increase habitat diversity along the channel:

- Adjust grazing and browsing pressure to optimise vegetative cover.
- Reduce hillslope-channel connectivity where possible. This can be done by diverting storm runoff of livestock tracks and roads at regular intervals. This will promote sediment deposition and reduce the flashiness of flows.
- Restore degraded hillslopes, incised alluvial fans and incised wetlands.
- Manage alien vegetation which reduces vegetative cover, water availability and destabilises river banks.
- Maintain buffers of natural vegetation along the riparian zone.
- Manage sand mining activities to limit sensitive habitat disturbance.
- Limit grazing and trampling along river banks and bars by livestock.

5.3 Effects of climate change on riparian vegetation

by James MacKenzie

5.3.1 Introduction

The state of the rivers report for the Olifants, Doring and Sandveld rivers compiled in 2006 (River Health Programme) outlined that livestock farming (sheep and goats) was the predominant land use in the catchment, with small areas being used for dryland farming. At that time, only the upper reaches of the main rivers and their tributaries were still in a natural or good ecological state. The middle and lower reaches of many rivers were assessed as having poor ecological condition, the main culprit being alien plants (mainly *Nerium oleander* and *Prosopis glandulosa*) and fish infestations, as well as intensive agricultural development. In the same year an EWR study was conducted (DWAF 2006b) and showed that the Olifants River was markedly more utilized and impacted than the Doring River, and moreover that the PES was measurably worse (D and E vs B categories and B/C). One of the recommendations from that study was to maintain the ecological integrity of the better condition Doring River to ensure sustainable utilisation of the Olifants estuary, i.e. no dams in the Doring or Groot rivers. But how will such sound management plans be influenced by proposed climate changes in South Africa? The answer forms the crux of the current study.

5.3.2 Aim

Relying on the flow requirements determined by the EWR study of 2005/6 as an accepted flow regime to achieve desired ecological management objectives, the aim of this study is to assess what impact climate change may have on the riparian vegetation at three EWR sites in the Doring River system (EWR 4, EWR 5 and EWR 6). To this end two climate change scenarios (RCP 2.6 and RCP 8.5, both minimum and maximum variation) were assessed against natural and current hydrology at each site in relation to riparian vegetation requirements (as outlined in the EWR). The proposed response of riparian vegetation and its implications for ecological condition form the outputs of this sub-task.

5.3.3 Description of riparian vegetation in relation to EWR Sites

In general, about 75% of the Olifants / Doring WMA comprises Karoo and Karroid type vegetation, consisting of scrub, bushes and some grasses, all typically less than 1 m in height, and dwarf trees. Invasive alien plants cover an area of approximately 122 km^2, spread across the WMA. Much of the infested area is in riparian zones. *Acacias*, Pines, *Syringa*, *Eucalyptus* and *Prosopis* are among the top ten genera of invasive alien plants (Blackhurst et al. 2001). Broad-scale vegetation units as outlined by Mucina and Rutherford (2006, 2012 update) include Tanqua Karoo (within which EWR 4 occurs), Namaqualand Rivier (within which EWR 5 occurs) and Cederberg Sandstone Fynbos (within which EWR 6 occurs). Both Tanqua Karoo and Cederberg Sandstone Fynbos are terrestrial vegetation units which support hardy vegetation and do not directly apply to the finer-scale riparian sites which tend to support the inland azonal Tanqua Wash Riviere vegetation types. These are usually deeply incised valleys of often intermittent rivers that support a mix of succulent shrublands (species of the genera *Salsola* and *Lycium*) and *Vachellia* (*Acacia*) *karoo* gallery thickets. Namaqualand Riviere, on the other hand, comprises a complex of alluvial shrubland and tussock graminoids (including *Phragmites*) with tickets of *V. karoo* and *Tamarix usneoides* in places.

During the EWR study of 2005/6 (DWAF 2005b), Boucher comprehensively described and outlined the riparian vegetation communities at each EWR site. A summary of his work is included here for EWR 6, 4 and 5 for the sake of reference when assessing scenarios (Table 5.5, Table 5.6 and Table 5.7).

Table 5.5 EWR 6 – Mount Cedar, Groot River (PES = B/C; Veg = A/B)

Sub-zone within Riparian Zone	Notable Riparian Plant Indicators
Rooted aquatic zone	Both floating aquatics (*Azolla filiculoides*) and rooted aquatics (*Aponogeton distachyos*) were present in the pool.
Marginal fringe	None mentioned, but photographs indicate scattered *Salix mucronata* trees.
Wetbank	Dominated by 3.5-6 m high tree and tall shrub layer, mainly *Morella serrata* and *Salix mucronata*. A 2-3 m tall shrub stratum (*Freylinia lanceolata* and *Metrosideros angustifolia*) with reeds (*P. australis*), also formed dense patches with sedges (*C. textilis* and *Isolepis prolifer*) occurring in the open moist sandy patches.
Drybank	Dominated by 2-2.5 m tall shrubs (e.g.: *Diospyros glabra, Metrosideros angustifolia*) with a grass and restio understorey, mainly *Ischyrolepis subverticillata, Pennisetum macrourum* and *Willdenowia incurvata*. The right bank was dominated by up to 8 m tall *Brabejum stellatifolium* trees with 3 m tall *D. glabra, F. lanceolata* and *M. angustifolia*.
Back dynamic zone	Not mentioned.
Note:	
Pennisetum macrourum was common in the wetbank zone around the pool area. This indigenous species is likely to increase in abundance when other vegetation becomes stressed, such drying of the riparian wetbank zone.	

Table 5.6 EWR 4 – Upstream Biedouw River confluence, Doring River (PES = B/C; Veg = C)

Sub-zone within Riparian Zone	Notable Riparian Plant Indicators
Rooted aquatic zone	Supports some *Potamogeton pectinatus* in the pool sections.
Marginal fringe	Layer dominated by *Cyperus textilis* and *Juncus kraussii* or *J. longus*.
Wetbank	Either 2.5-4 m tall *Phragmites australis* reedbeds or 3-5 m tall *Vachellia karoo* trees with *C. textilis* and *J. kraussii* or *J. longus* lining the water's edge. The invasive shrub *Nerium oleander* is conspicuous and patchy.
Drybank	Generally consists of a 4-5 m tall tree layer, mainly *V. karoo*, with arid zone grasses and herbs interspersed in-between. *Nerium oleander* is conspicuous and patchy.
Back dynamic zone	Mainly succulent Karoo species, including shrubs (*Galenia africana, Montinia caryophyllacea* and *Searsia undulata*) and the spiny grass *Cladoraphis spinosa*.
Note:	
Infestations of *N. oleander* through the Drybank zone appeared to be related to episodic flood events as different cohorts of evenly sized individuals were present.	

Table 5.7 EWR 5 – Oudrif, Doring River (PES = B; Veg = B)

Sub-zone within Riparian Zone	Notable Riparian Plant Indicators
Rooted aquatic zone	No aquatic zone vegetation was observed in the transects, although *P. pectinatus* occurred in the upstream pool.
Marginal fringe	Bands of *C. textilis* where the reeds were absent or sparse. *Panicum repens*, rooted in the wetbank, formed runners that extend into the water during low flow.
Wetbank	*Phragmites australis* reedbeds, 2.5-4 m tall, occupied sections of the river in the wetbank zone forming islands. The grasses, *Cynodon dactylon* and *Ehrharta villosa*, formed mats in disturbed areas with deep sand.
Drybank	Dominated by 3.5 m tall *V. karroo* trees, and in parts was heavily invaded by 2-3 m tall *N. oleander* shrubs.
Back dynamic zone	Succulent Karoo plants, including the shrubs *Didelta spinosa* and *G. africana*, and the grasses *C. spinosa* and *Stipagrostis namaquensis.*
Note:	
The river is very dynamic in this reach and it flows between low cliffs that are overtopped on the left bank during large floods.	

5.3.4 The EWR in relation to riparian vegetation

The Doring River is currently a seasonally flowing river, although natural hydrology suggests that it may have been perennial, with a high variability in flow, and where in winter the river is constantly flowing and in summer the river flow infrequently and mainly consists of pools, many of which are perennial (DWAF 2011).

The integrated water requirements determined during the EWR study are shown in Tables 5.8, 5.9 and 5.10 for EWR sites 6, 4 and 5 respectively (taken directly from the EWR study of 2005/6; DWAF 2005b). It is important to note that these are integrated and contain vegetation requirements embedded within the overall requirements. This assessment assumes that the given flows, as shown, for each respective EWR site will maintain, or improve, the status of the riparian vegetation. In general, the base flow component is important for the survival of the different vegetation communities as well as the determination of species diversity. The wet season base flows (winter months) will service the growth, production, reproduction, density and vigour of aquatic and fringe communities as well as lower wetbank and to a lesser degree upper wetbank communities. These flows are also important for the survival of phreatophytic vegetation such as the trees and shrubs of the upper wetbank and drybank. The dry season base flows (summer months), or in the case of seasonal rivers, the duration of time experiencing zero flows, is important for the determination of species composition (e.g. the presence of sedges and grasses that can endure seasonal drying as opposed to those that require year-round wetness) as well as the perenniality of pools which importantly support aquatic vegetation and surrounding phreatophytes (increased periodicity of zero flows will reduce pool perenniality and have dramatic influence on surrounding vegetation).

Within-year floods (including the annual flood) are important as disturbances that promote both recruitment as well as increased species and habitat diversity. They contribute to overall heterogeneity within riparian zones and supply important biological cues for growth and reproduction of communities in all sub-zones, but importantly the upper wetbank and drybank sub-zones. Along the Doring River, they will also deliver sediment to pools and prevent encroachment of most woody species into the fringe and lower wetbank zones (excluding *Salix mucronata* but including aliens such as *Nerium oleander*). Less frequent and larger floods are important for recharging backwaters, where they exist, and activating and maintaining the woody communities, facilitating recruitment in these areas, but importantly also preventing encroachment of lower-level sub-zones by woody species, especially *Vachellia karoo*. They may also be important for the maintenance of pool depth, and in rare cases for the creation of new pools.

Flow requirements during [natural] drought conditions are particularly important as these ensure survival of refugia or core elements for recolonization and expansion in post drought conditions.

Table 5.8 Water quantity for REC (B/C) at EWR Site 6 on the Groot River at Mount Cedar, Western Cape (DWAF 2005b)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	VOL (MCM)	nMAR %
nMAR = 138 MCM. pdMAR = 104 MCM														
EWR Ecostatus Category = B/C.														
MAINTENANCE														
CAPPING FLOWS	Not set													
LOW FLOWS Q m^3s^{-1}	0.726	0.18	0.04	0.011	0.01	0.02	0.06	0.23	1.055	2.012	3.00	2.228	22	17
FLOOD Class 1[40]: 5.5 m^3s^{-1}	1					1		3				2	7x1	5
FLOOD Class 2: 11 m^3s^{-1}									2				2x2	3
FLOOD Class 3: 22 m^3s^{-1}									2				2x4	6
FLOOD Class 4: 44 m^3s^{-1}									2				2x11	16
Inter-annual floods	Estimated annual volume (1:5; 1;10 and 1:20 year floods)												16	12
MAINTENANCE TOTAL (Volume)	Annual[41]												**79**	**57**
	Long-term average[42]												**63**	**46**
DROUGHT														
LOW FLOWS m^3s^{-1}	0.04	0.01	0.001	0.001	0.001	0.001	0.001	0.01	0.04	0.15	0.42	0.54	3.2	2
FLOOD Peak m^3s^{-1}	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL FLOWS (MCM)	*2.699*	*2.085*	*0.725*	*0.296*	*0.127*	*0.261*	*0.764*	*5.756*	*8.713*	*13.148*	*17.681*	*11.168*	**63**	**46**

*Discrepancies relate to flood events occurring in some months and not in others.

40 Daily average peak.
41 Calculated as the volume of water required to meet the full requirements.
42 Calculated using the historical flow sequence, and only 'releasing' requirements in response to 'natural' cues

Table 5.9 Water quantity for REC (B) at EWR Site 4 on the Doring River upstream of the Biedou River (DWAF 2005b)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	VOL (MCM)	nMAR %
nMAR = 420 MCM. pdMAR =320 MCM														
EWR Ecostatus Category = B.														
MAINTENANCE														
CAPPING FLOWS	Not set	1 m^3s^{-1}	1 m^3s^{-1}	1 m^3s^{-1}	1 m^3s^{-1}	1 m^3s^{-1}	0 m^3s^{-1}	Not set					N/a	
LOW FLOWS Q m^3s^{-1}[30]	2.0	0.03	0	0	0	0	0.05	0.5	3.0	6.0	6.0	6.0	59.2	14
FLOOD Class 1[31]: 26 m^3s^{-1}	2	1				1		1				1	3.2x6	5
FLOOD Class 2: 52 m^3s^{-1}									1		1		11x2	5
FLOOD Class 3: 103 m^3s^{-1}									1		1		20.2x2	10
FLOOD Class 4: 209 m^3s^{-1}									1				45x1	11
FLOOD Class 5: 1:2 year													40	10
Inter-annual floods	Estimated annual volume (1:5; 1;10 and 1:20 year floods)												55	13
MAINTENANCE TOTAL (Volume)	Annual[32]												**277**	**66**
	Long-term average[33]												**199**	**47**
DROUGHT														
LOW FLOWS m^3s^{-1}	0.15	0.03	0	0	0	0	0	0.01	0.01	0.02	1.03	0.09	3.6	1
FLOOD Peak[34] m^3s^{-1}	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL FLOWS (MCM)	***6.75***	***3.88***	***1.26***	***6.28***	***1.96***	***0.91***	***13.19***	***25.22***	***39.32***	***39.05***	***36.71***	***24.74***	**199**	**47**

30 Figures rounded-off to the nearest one decimal place.
31 Daily average peak.
32 Calculated as the volume of water required to meet the full requirements.
33 Calculated using the historical flow sequence, and only 'releasing' requirements in response to 'natural' cues.
34 Daily average peak.

Table 5.10 Water quantity for REC (B) at EWR Site 5 on the Doring River at Ou Drif, Western Cape (DWAF 2005b)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	VOL (MCM)	nMAR %
N MAR = 511 MCM. pdMAR = 401 MCM														
EWR Ecostatus Category = B.														
MAINTENANCE														
CAPPING FLOWS	Not set	1 m^3s^{-1}	1 m^3s^{-1}	1 m^3s^{-1}	1 m^3s^{-1}	1 m^3s^{-1}	0 m^3s^{-1}	Not set					N/a	
LOW FLOWS Q m^3s^{-1}[35]	2.29	0.03	0	0	0	0	0.05	0.82	5.00	8.30	8.00	6.00	78	15
FLOOD Class 1[36]: 35.05 m^3s^{-1}	2	1				1		1				1	4x6	6
FLOOD Class 2: 70.11 m^3s^{-1}									1		1		15x2	6
FLOOD Class 3: 140.22 m^3s^{-1}									1		1		27x2	10
FLOOD Class 4: 280 m^3s^{-1}									1				59x1	12
Inter-annual floods	Estimated annual volume (1:5; 1;10 and 1:20 year floods)												65	13
MAINTENANCE TOTAL (Volume)	Annual[37]												**310**	**61**
	Long-term average[38]												**234.39**	**46**
DROUGHT														
LOW FLOWS m^3s^{-1}	0.03	0.03	0	0	0	0	0	0	0	0.06	0.19	0.18	15	3
FLOOD Peak[39] m^3s^{-1}	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL FLOWS (MCM)	*6.7*	*1.9*	*1.0*	*18.2*	*24.4*	*52.1*	*47.7*	*44.9*	*21.1*	*8.9*	*4.3*	*3.2*	**234.39**	**46**

[35] Figures rounded-off to the nearest one decimal place.
[36] Daily average peak
[37] Calculated as the volume of water required to meet the full requirements.
[38] Calculated using the historical flow sequence, and only 'releasing' requirements in response to 'natural' cues.
[39] Daily average peak

5.3.5 Scenarios

The scenarios presented for assessment at each EWR site include the EWR itself (also various categories), natural flows (no anthropogenic impacts), present day hydrology (which includes anthropogenic impacts) and future hydrology as scenarios of climate change (RCP 2.6 and RCP 8.5). Climate change scenarios are shown as minimum and maximum future hydrology for consideration of the high variability produced by climate change model outputs. Outputs from the RDRM included in this report are therefore:

- EWR site 6 ecological Reserve including comparison between minimum and maximum flow time series for RCP 2.6.
- EWR site 6 ecological Reserve including comparison between minimum and maximum flow time series for RCP 8.5.
- EWR site 5 ecological Reserve including comparison between minimum and maximum flow time series for RCP 2.6.
- EWR site 5 ecological Reserve including comparison between minimum and maximum flow time series for RCP 8.5.
- EWR site 4 ecological Reserve including comparison between minimum and maximum flow time series for RCP 2.6.
- EWR site 4 ecological Reserve including comparison between minimum and maximum flow time series for RCP 8.5.

The outputs generated are minimum and maximum future hydrology data which incorporate the impacts of climate change. Table 4.5 and Table 4.6 compare the statistics (zero flows and total flows respectively) for the natural and present day hydrology with the full range of uncertainty of climate change (RCP 2.6 and 8.5) for the three catchments corresponding with the three EWR sites. The graphs showing minimum and maximum ensembles compared with present day and natural hydrology are shown in Figure 4.11 to Figure 4.13.

Generally, both climate change scenarios result in increased periods of zero flow, but RCP 8.5 is worse than RCP 2.6, especially at EWR 4 and 5 (Table 4.5), although the range of uncertainty (shown as minimum and maximum) straddles the present day percent zero flow time periods for both RCPs. This makes an assessment of proposed responses to changes difficult because the modelled outputs of climate change have such high variability. Similar difficulties are evident in terms of maximum monthly flow (Table 4.6). The upstream catchment E21H (EWR 6) is projected to have reduced maximum flows compared to both natural and present day while for the lower catchments (E24H and E24L) the uncertainty range straddles both natural and present day maximum values.

5.3.6 Riparian vegetation responses to Scenarios

Given the minimum and maximum variation outputs of proposed climate change scenarios, what follows is a site by site assessment of what the response of riparian vegetation to climate change may be, and how that may affect the overall condition of the riparian zone. Two responses are proposed for each of the two scenarios (RCP 2.6 and RCP 8.5): one for the maximum potential outcome and one for the minimum potential outcome, albeit that in reality the integrated response will likely lie somewhere in-between these possibilities.

EWR site 6 (PES = B/C; Veg = A/B)

RCP 2.6 min

The percentage of time experiencing zero flows doubles from the present day value of 2.3% to 5.2% (where a value of 0% is indicated for natural flows), and the maximum monthly flow decreases from 90 MCM to 26 MCM (where a value of 116 MCM is indicated for natural flows). The flow duration chart shows that reduced flows occur across all percentiles but that the reduction relative to present day flows is higher at lower percentiles (higher flows). Hydrologically, this flow regime more or less equates that of a category C or D-river at greater than equal to 65th percentiles, is between a category C and D from the 40th to 65th percentiles, and is worse that a category D below the 38th percentile. Also, according to the RDRM flow duration curves the July maintenance (base) flow EWR requirement of 2.012 $m^3.s^{-1}$ does not occur during this scenario (neither a category D), while it is exceeded for about 40% of the time for the PES and REC categories (B/C).

Aquatic and marginal fringe vegetation are likely to be adversely affected by decreased flows and increased periods of zero flow. Smaller pools may dry up in the dry season in which case aquatic and pool edge vegetation will likely perish. The perenniality of larger pools may also be threatened and pool depth will be an important factor. *Aponogeton distachyos* may reduce in abundance or become absent from some pools. *Phragmites australis, Cyperus textilis* and *Isolepis prolifer* can all endure seasonal drying but the severity and duration will be critical for determining *in-situ* survival. Under this scenario these populations will likely have some die-off, especially along the edges furthest from the main channel / pool. Wetbank and fringe trees such as *Salix mucronata* and *Morella serrata* will likely have increased water stress in the dry season and reduced recruitment in the wet season while drybank phreatophytic species will likely benefit from reduced competition in the wetbank and reduced flooding disturbance, and encroach into the lower sub-zones of the riparian zone. All in all, the ecological status is expected to deviate from the reference condition more so than the present day and the ecological category is likely to deteriorate by a full category, i.e. B/C for vegetation. This in turn may reduce the overall PES of the site.

RCP 2.6 max

The percentage of time experiencing zero flows is reduced from the present day value of 2.3% to 1.4% (where a value of 0% is indicated for natural flows), and the maximum monthly flow decreases slightly from 90 MCM to 84.5 MCM (where a value of 116 MCM is indicated for natural flows). Even so, the flow duration chart shows that flows mostly occur between present day and natural flows for higher flows (during the wet season) and go below present day for lower flows (during the dry season).

The maximum range of scenario RCP 2.6's output presents similar stress in the dry season but the wet season (higher flows) tend more towards natural flows that the present day. Current or improved flooding will prevent the encroachment mentioned above but survival of aquatic and fringe vegetation in the dry season may still be threatened in small pools. The overall ecological category of riparian vegetation is not expected to change.

RCP 8.5 min

The percentage of time experiencing zero flows increases slightly from the present day value of 2.3% to 3.7% (where a value of 0% is indicated for natural flows), and the maximum monthly flow decreases from 90 MCM to 36.4 MCM (where a value of 116 MCM is indicated for natural flows). The flow duration chart shows that reduced flows occur across all percentiles but that the reduction relative to present day flows is higher at lower percentiles (higher flows). Hydrologically, this flow regime is similar to or slightly worse than a D category up to the 70th percentile and low flows (70th to 100th percentile) share similarity to categories B to D. Also, according to the RDRM flow duration curves the July maintenance (base) flow EWR requirement of 2.012 $m^3.s^{-1}$ occurs for less than 10% of the time, while for a category B/C (PES and REC) it occurs for about 50% of the time.

Riparian vegetation will likely respond similarly to the RCP 2.6 min scenario, or fare slightly better, since reductions in flow and increases in zero flow periods are less stringent. Nevertheless there remains a deviation from the present day condition and the ecological category is expected to deteriorate by half a category.

RCP 8.5 max

The percentage of time experiencing zero flows is reduced slightly from the present day value of 2.3% to 2.0% (where a value of 0% is indicated for natural flows), and the maximum monthly flow decreases slightly from 90 MCM to 72.2 MCM (where a value of 116 MCM is indicated for natural flows). Even so, the flow duration chart shows that flows mostly equate to present day flows or are slightly improved for higher flows (during the wet season), go below present day for lower flows (during the dry season).

Riparian vegetation is not expected to respond to this scenario and the ecological category will therefore remain the same.

EWR site 4 (PES = B/C; Veg = C)

RCP 2.6 min

The percentage of time experiencing zero flows increases slightly from the present day value of 6.9% to 8.0% (where a value of 0% is indicated for natural flows), and the maximum monthly flow decreases from 398 MCM to 308 MCM (where a value of 556 MCM is indicated for natural flows). The flow duration chart shows that reduced flows occur across all percentiles but that the reduction relative to present day flows is higher at lower percentiles (higher flows). Hydrologically, this flow regime more or less equates that of a category D-river at greater than equal to 15th percentiles, but has improved high flows at lower percentiles. Also, according to the RDRM flow duration curves the July maintenance (base) flow EWR requirement of 6.0 $m^3.s^{-1}$ is only exceeded for 10% of the time, while it is exceeded for about 30% of the time for the PES and REC categories (B/C).

Aquatic and marginal fringe vegetation are likely to be adversely affected by decreased flows, especially wet season base flows, and slightly increased periods of zero flow. Smaller pools may dry up in the dry season in which case aquatic and pool edge vegetation will likely perish. The perenniality of larger pools may also be threatened and pool depth will be an important factor. *Potomogeton pectinatus* may reduce in abundance or become absent from some pools as it requires permanent or near permanent pools to thrive. *Cyperus textilis* and *Juncus krausii* which occur in the fringe can endure seasonal drying but the severity and duration will be critical for determining *in-situ* survival, while *J. lomgus*, also in the fringe has a higher water demand and may be adversely affected. These three species, along with *P. australis*, also occur in the wetbank where their densities are likely to decrease, as well as vigour and likely some die-off at the upper edges of their distribution. Wetbank trees such as *V. karoo* and the alien *N. oleander* will likely increase due to reduced flooding disturbance and may even encroach towards the fringe. On the drybank these species will experience increased water stress in the dry season and reduced recruitment in the wet season but infrequent recruitment during rainfall events will slowly lead to increased densities. All in all, the ecological status is expected to deviate from the reference condition more so than the present day and the ecological category is likely to deteriorate by a at least half, if not a full category, i.e. C/D for vegetation at least. This in turn may reduce the overall PES of the site.

RCP 2.6 max

The percentage of time experiencing zero flows increased slightly from the present day value of 6.9% to 8.3% (where a value of 0% is indicated for natural flows), and the maximum monthly flow increases markedly from 398 MCM to 2117 MCM (which is more than the natural value of 556 MCM). The flow duration chart shows that flows mostly align with present day at greater than 10th percentile, but are notably more than present day as well as natural below the 6th percentile, i.e. infrequent flood are much larger than expected even under natural conditions.

The vegetation response to the low flow component will be similar to the response outlined above for the minimum variation but elevated infrequent floods will result in greater flooding disturbance when they do occur. There is likely to be scour at the site, which will include stripping of sediments and all vegetation components including damage to woody vegetation. This will include the alien species *N. oleander* which will be a benefit to the site. All in all, it is anticipated that general vegetation cover will reduce at the site and the ecological status will deteriorate by half a category, i.e. C/D for vegetation at least. This in turn may reduce the overall PES of the site.

RCP 8.5 min

The percentage of time experiencing zero flows increases from the present day value of 6.9% to 18.9% (where a value of 0% is indicated for natural flows), and the maximum monthly flow decreases from 398 MCM to 338.6 MCM (where a value of 556 MCM is indicated for natural flows). The flow duration chart shows that reduced flows occur across all percentiles but that the reduction relative to present day flows is higher at lower percentiles (higher flows). Hydrologically, this flow regime more or less equates that of a category C-river at >15th percentiles, but has improved high flows at lower percentiles. Also, according to the RDRM flow duration curves the July maintenance (base) flow EWR requirement of 6.0 $m^3.s^{-1}$ is exceeded for 20% of the time, while it is exceeded for about 30% of the time for the PES and REC categories (B/C).

This scenario is similar to the RCP 2.6 min, but with notably increased periods of zero flow. Aquatic and marginal fringe vegetation are likely to be adversely affected by decreased flows, especially wet season base flows, and increased periods of zero flow are likely to mimic drought responses. Smaller pools will likely dry up in the dry season in which case aquatic and pool edge vegetation will perish or diminish. The perenniality of larger pools may also be threatened and pool depth will be an important factor. *Potomogeton pectinatus* will likely reduce in abundance or become absent from some pools as it requires permanent or near permanent pools to thrive. *Cyperus textilis* and *Juncus krausii* which occur in the fringe can endure seasonal drying but the severity and duration will be critical for determining in-situ survival, while *J. lomgus*, also in the fringe has a higher water demand and may be adversely affected. These species are likely to encroach if available habitat exist or reduce in densities. These three species, along with *P. australis*, also occur in the wetbank where their densities are likely to decrease, as well as vigour and likely some die-off at the upper edges of their distribution. Wetbank trees such as *V. karoo* and the alien *N. oleander* will likely increase due to reduced flooding disturbance and may even encroach towards the fringe. On the drybank these species will experience increased water stress in the dry season and reduced recruitment in the wet season but infrequent recruitment during rainfall events will slowly lead to increased densities. All in all, the ecological status is expected to deviate from the reference condition more so than the present day and the ecological category is likely to deteriorate by a full category, i.e. D for vegetation. This in turn may reduce the overall PES of the site.

RCP 8.5 max

The percentage of time experiencing zero flows remains the same as the present day value of 6.9% (where a value of 0% is indicated for natural flows), and the maximum monthly flow increases from 398 MCM to 638 MCM (which is more than the natural value of 556 MCM). The flow duration chart shows that flows mostly align with present day at >20th percentiles, but are notably more than present day, and are aligned with or more than natural flows below the 20th percentile, i.e. infrequent flood are much larger than expected even under natural conditions.

The vegetation response to the low flow component will be similar to the response outlined above for the RCP 2.6 minimum variation but elevated infrequent floods will result in greater flooding disturbance when they do occur, although to a lesser degree than RCP 2.6 max. There is likely to be some scour at the site, which will include stripping of sediments and all vegetation components especially along the fringe and wetbank This will include the alien species *N. oleander* which will be a benefit to the site in these sub-zones. Phreatophytic trees in the upper wetbank and drybank are likely to benefit however and increase in density over time. All in all, it is anticipated that general vegetation cover will reduce at the site and the ecological status will deteriorate by half a category, i.e. C/D for vegetation. This in turn may reduce the overall PES of the site.

EWR site 5 (PES = B; Veg = B)

RCP 2.6 min

The percentage of time experiencing zero flows increases slightly from the present day value of 18.9% to 22.1% (where a value of 0% is indicated for natural flows), and the maximum monthly flow increases slightly from 404.8 MCM to 417.5 MCM (where a value of 582 MCM is indicated for natural flows). The flow duration chart shows that flows are generally aligned to present day or are less, particularly at lower percentiles (higher flows). Hence, even though maximum monthly flows show a slight increase, this increase is only realized at extreme low and high percentiles with generally less flows occurring at the site for the majority of the time. Hydrologically, this flow regime is worse than a category D river across most percentiles except at the extremes. Also, according to the RDRM flow duration curves the July maintenance (base) flow EWR requirement of 8.3 $m^3.s^{-1}$ is only exceeded for less than 10% of the time, while it is exceeded for about 35% of the time for the PES and REC categories (B).

Vegetation at the site already show signs of increased seasonality compared to upstream sites, e.g. mostly absent aquatic vegetation and hardier sedge species. The increase in zero flow periods together with elevated extreme low flows will likely result in mixed responses at the site. Overall the lower flows experience from about the 10th to 60th percentile will elevate water stress for vegetation in the fringe and wetbank, especially during the wet season. With reduced smaller floods and freshets it is likely that woody species, notably *V. karoo* and *N. oleander* (alien) will increase and encroach towards the channel. This overriding response should lead to a deterioration of the ecological status by a category, i.e. C for vegetation.

RCP 2.6 max

The percentage of time experiencing zero flows decreases slightly from the present day value of 18.9% to 17.5% (where a value of 0% is indicated for natural flows), and the maximum monthly flow increases significantly from 404.8 MCM to 3158 MCM (which is more than natural flows at 582 MCM). The flow duration chart shows that flows mostly align with present day or natural flows at percentiles higher than 10, but are notably more than present day as well as natural below the 10th percentile, i.e. infrequent floods are much larger than expected even under natural conditions.

The vegetation response to the low flow component will be similar to the response outlined above for the minimum variation but elevated infrequent floods will result in greater flooding disturbance when they do occur. There is likely to be scour at the site, which will include stripping of sediments and all vegetation components including damage to woody vegetation. This will include the alien species *N. oleander* which will be a benefit to the site. All in all, it is anticipated that general vegetation cover will reduce at the site and the ecological status will deteriorate by a category, i.e. C for vegetation. This in turn may reduce the overall PES of the site.

RCP 8.5 min

The percentage of time experiencing zero flows increases markedly from the present day value of 18.9% to 28.4% (where a value of 0% is indicated for natural flows), and the maximum monthly flow remains about the same as present day; 401 MCM and 404.8 MCM respectively (where a value of 582 MCM is indicated for natural flows). The flow duration chart however shows that flows are generally less than present day, particularly at the 50th percentile. Hence, even though maximum monthly flows show a slight increase, this increase is only realized at extreme low and high percentiles with generally less flows occurring at the site for the majority of the time. Hydrologically, this flow regime is worse than a category D river across most percentiles except at the extremes. Also, according to the RDRM flow duration curves the July maintenance (base) flow EWR requirement of 8.3 $m^3.s^{-1}$ is only exceeded for less than 10% of the time, while it is exceeded for about 35% of the time for the PES and REC categories (B).

Vegetation response is likely to be similar to that outlined for RCP 2.6 min: Vegetation at the site already show signs of increased seasonality compared to upstream sites, e.g. mostly absent aquatic vegetation and hardier sedge species. The increase in zero flow periods together with elevated extreme low flows will likely result in mixed responses at the site. Overall the lower flows experience from about the 10th to 60th percentiles will elevate water stress for vegetation in the fringe and wetbank, especially during the wet season. With reduced smaller floods and freshets it is likely that woody species, notably *V. karoo* and *N. oleander* (alien) will increase and encroach towards the channel. This overriding response should lead to a deterioration of the ecological status by a category, i.e. a C category for riparian vegetation.

RCP 8.5 max

The percentage of time experiencing zero flows decreases from the present day value of 18.9% to 12.9% (where a value of 0% is indicated for natural flows), and the maximum monthly flow doubles from 404.8 MCM to 820 MCM (which is more than natural flows at 582 MCM). The flow duration chart shows that flows mostly align with natural flows and only exceeds natural flows at extreme low percentiles.

The vegetation response will be similar to RCP 2.6 max but to a lesser degree: the low flow component will be similar to the response outlined above for the minimum variation but elevated infrequent floods will result in greater flooding disturbance when they do occur. There is likely to be scour at the site, which will include stripping of sediments and all vegetation components including damage to woody vegetation. This will include the alien species *N. oleander* which will be a benefit to the site. All in all, it is anticipated that general vegetation cover will reduce at the site and the ecological status will deteriorate by a half category, i.e. B/C for vegetation. This in turn may reduce the overall PES of the site.

5.3.7 Conclusion / Implications

Generally, both climate change scenarios result in increased periods of zero flow, but RCP 8.5 is worse than RCP 2.6, especially at EWR 4 and 5, although the range of uncertainty (shown as minimum and maximum) straddles the present day percent zero flow time periods for both RCPs. This makes an assessment of proposed responses to changes difficult because the modelled outputs of climate change have such high variability. Similar difficulties are evident in terms of maximum monthly flow. The upstream catchment E21H (EWR 6) is projected to have reduced maximum flows compared to both natural and present day while for the lower catchments (E24H and E24L) the uncertainty range straddles both natural and present day maximum values.

The climate change scenarios were assessed for riparian vegetation according to their minimum and maximum ranges of variation, but this is likely an unrealistic approach since the actual scenario experienced at the site is likely to oscillate between the full range. As such the responses that have been outlined can be seen as the most extreme and the actual outcome at sites will likely vary and be somewhere in-between. This makes it difficult to assess whether proposed climate change will favour or be detrimental to riparian vegetation since the range of results encompasses both possibilities in some cases.

Table 5.11 Summary of riparian vegetation ecological status (category) in response to climate change scenarios

Site	PES	REC	Veg PES	RCP 2.6		RCP 8.5	
				min	max	min	max
EWR 6	B/C	B/C	A/B	B/C	A/B	B	A/B
EWR 4	B/C	B/C	C	C/D	C/D	D	C/D
EWR 5	B	B	B	C	C	C	B/C

Table 5.11 outlines a summary of riparian vegetation ecological status (expressed as a category) in response to climate change scenarios at the extremes (minima and maxima) of their variation. EWR 6 remains in an A/B category at the maximum range of variation for both scenarios (RCP 2.6 and 8.5) but deteriorates slightly in response to the minimum range in variation, where RCP 2.6 min has the most adverse effect and reduces the ecological category to a B/C. In contrast, both climate change

scenarios (RCP 2.6 and RCP 8.5) have detrimental effects on sites farther downstream (EWR 4 and EWR 5) where the ecological category of riparian vegetation is predicted to deteriorate in all cases within the full range of variation. Also, overall it appears that scenario RCP 8.5 is better for riparian vegetation that scenario RCP 2.6.

5.4 Effects of climate change on aquatic macroinvertebrates

by Nelson Odume

5.4.1 Introduction

An ecological Reserve study was undertaken for the Doring River in 2005/6 for which flow requirements were determined to meet the ecological management objectives for the river (DWAF 2006a). The objective of the current study is to assess the potential impact of climate change on the ecological water requirements (EWR) of the Doring River. Two climate change scenarios (RCP 2.6 and RCP 8.5, under minimum and maximum flows respectively) indicative of potential future hydrology of the system have been modelled for EWR sites 4, 5 and 6 within the Doring system. The aim of this sub-task is to assess the climate change scenarios in relation to their potential impact on aquatic macroinvertebrates.

5.4.2 Climate change scenarios

The climate change scenarios are presented as future hydrology (RCP 2.6 and RCP 8.5) and are shown as minimum and maximum future hydrology incorporating the uncertainty produced under climate change predictions. The potential impact of the future hydrology is thus assessed in relation to macroinvertebrates.

5.4.3 Macroinvertebrates response to future hydrology (RCP 2.6 and RCP 8.5)

EWR site 6 (RCP 2.6 min)

The percentage of time experiencing zero flows for RCP 2.6 min more than doubles from the present day value of 2.3% to 5.2% and the maximum monthly flow decreases from 90 MCM to 26 MCM. The flow duration curve indicates reduced flows across all percentiles but that the reduction relative to present day flows is higher at lower percentiles (higher flows).

Macroinvertebrate instream habitats and water quality state are likely to be seriously affected by the decreased flow and the increased periods of zero flow. The reduced flow would impact on habitat diversity and quality. Significant loss of riffles/runs habitats would be observed, impacting seriously on macroinvertebrates that have a natural preference for riffles/runs and stones in current habitats. At EWR sites 6, key taxa that are likely to be most affected because of potential loss of riffles/runs habitats include Baetidae (*Baetis harrisoni*, *Pseudocloeon* sp.) Heptageniidae (*Afronurus barmardi*), Leptophlebiidae (*Euthralus elegans*), Hydropsychidae (*Cheumatopsyche afra*) and Athericidae. Further, the reduced flow and the extended periods of zero flow implies that smaller pools may dry out, also affecting invertebrate taxa that have an affinity for standing water associated with either stones or sediments. Key taxa that are likely to be negatively affected because of prolonged low flow and extended periods of zero flow include Caenidae (*Caenis* sp.1) and Ecnomidae (*Economus kimminsi*). With regard to marginal vegetation, these are likely to be without water for extended period of time and would potentially have negative effects on taxa with a strong preference for vegetation. Other impacts of the significant reduction in flow would include reduction in pool depth and loss of shallow water impacting on invertebrates such as *Cheumatopsyche afra, C. thomasetti* and *Ecnomus* spp. that are mostly affiliated with shallow waters. Temperature and electrical conductivity may increase while dissolved oxygen decreases, all of which will impact on the potential survival of sensitive invertebrate species such as *Afronuru barmardi*, *Baetis harrisoni* and Athericidae.

EWR site 6 (RCP 2.6 max)

The percentage of time experiencing zero flows is reduced from the present day value of 2.3% to 1.4%, and the maximum monthly flow decreases marginally from 90 MCM to 84.5 MCM. Flow during the dry season decreases compared to present day flow. RCP 2.6 Max presents scenarios for potential marginal flooding during the wet season, which is likely to support allochthonous input of organic matters as food sources for shredders, filter feeders and deposit feeders. Marginally increased flow during wet season may negatively impact on slow flow-loving invertebrates such as Coenagrionidae (*Enallagma*). The reduced flow during dry season may threaten habitat diversity particularly the stones in current, and dry out small pools and marginal vegetation, and impact the invertebrates that are associated with these habitats. Temperature and electrical conductivity would marginally increase, while dissolved oxygen decreases. The overall ecological condition on macroinvertebrate should not change.

EWR site 6 (RCP 8.5 min)

Under this scenario there is a slight increase in the percentage of time experiencing zero flows from the present day value of 2.3% to 3.72% and the maximum monthly flow decreases from 90 MCM to 36.4 MCM. The flow is more pronounced during higher flows compared to present day. Also, according to the RDRM flow duration curves the July maintenance (base) flow EWR requirement of 2.012 $m^3.s^{-1}$ occurs for less than 10% of the time, while for a category B/C (PES and REC) it occurs for about 50% of the time. The RCP 8.5 min ensemble present a similar condition as the RCP 2.6 although the condition presented by the latter for macroinvertebrate would appear to be more severe. Therefore, macroinvertebrate response for both RCP 2.6 min and RCP 8.5 min would be similar, but it is expected that small pools and riffles that would support macroinvertebrates should be in a slightly better condition under RCP 8.5 min compared to RCP 2.6 min.

EWR site 6 (RCP 8.5 max)

This scenario presents a marginal change from present day condition both in terms of percentage time zero flow is experienced and maximum monthly flow, with the flow duration indicating that predicted flow is mostly similar to present day flow. For these reasons, macroinvertebrates are expected to respond marginally, but not in ways that are significant.

EWR site 4 (RCP 2.6 min)

The percentage of time zero flows is experienced increases marginally from the present day value of 6.9% to 8.0%, but the maximum monthly flow decreases from 398 MCM to 308 MCM. The flow reduction occurs across all percentiles but reduction is more pronounced during higher flows compared to present day. The July maintenance (base) flow EWR requirement of 6.0 $m^3.s^{-1}$ is only exceeded for 10% of the time, while it is exceeded for about 30% of the time for the PES and REC categories (B/C).

With respect to macroinvertebrates, the reduction in flow throughout all season would have significant effects on macroinvertebrates with a preference for fast-medium velocity, and riffles/runs. Marginal vegetation may lose their contact with water during dry seasons, thus affecting macroinvertebrates with a preference for marginal vegetation. Deep pools may become shallower, although not for an extended period of time, but this may also alter the relative distribution of macroinvertebrates in relation to depth. With regard to alteration relating to velocity, riffles, and runs over cobbles, boulders and pebbles, reduced abundances can be experienced for macroinvertebrates such as Philopotamidae, Leptophlebiidae (*Euthraulu*), *Tricorythus discolour*, and *Baetis harrisoni*. Overall, this is likely to translate to a lower ecological category based on macroinvertebrates response.

EWR site 4 (RCP 2.6 max)

The percentage of time experiencing zero flows increased slightly from the present day value of 6.9% to 8.3%, and the maximum monthly flow increases markedly from 398 MCM to 2117 MCM. Below the 6^{th} percentile, the magnitude of floods is larger. With respect to macroinvertebrate response, the main disturbance would be associated with infrequent flooding. The infrequent flooding would lead to disturbance of riparian vegetation, dislodgement of attached macroinvertebrate taxa, and conversion of pools into riffles and runs during floods. All of these would have significant effects on macroinvertebrates taxa with a preference for aquatic vegetation and slow flowing waters. However, flooding would also lead to input of allochthonous materials that may favour shredders and filter feeders. Nevertheless, the infrequent flooding is expected to result in a further reduction in macroinvertebrate ecological category further.

EWR site 4 (RCP 8.5 min)

The percentage of time zero flow is experienced is expected to be more than double from the present day value of 6.9% to 18.9%, and the maximum monthly flow decreases from 398 MCM to 338.6 MCM. The flow duration chart shows that reduced flows occur across all percentiles but that the reduction relative to present day flows is higher at lower percentiles (higher flows). The July maintenance base flow EWR requirement of 6.0 $m^3.s^{-1}$ is exceeded for 20% of the time, while it is exceeded for about 30% of the time for the REC category (B/C).

The extended period of zero flow implies that small pools may dry up, and marginal vegetation may be out of the reach of water. Reduced flows may also impact on dissolved oxygen levels through reduction in turbulence, affecting macroinvertebrates that are sensitive to oxygen depletion. Slight increases in salinity may be experienced due to extended period of lower flows, also resulting in higher temperatures. Impacts on habitat diversity and quality (marginal vegetation, pools, riffles) and water quality (dissolved oxygen, temperature, and electrical conductivity) would likely have negative effects on macroinvertebrates taxa such as *Baetis* sp.1, *Caenis* sp.1, *Simulium* sp. *Paramerina* spp., *Ceriagrion* spp. and Gerridae. The overall effect on macroinvertebrates would be a reduced diversity due to a reduction in habitat quality and diversity, as well as effects on water physico-chemistry such as dissolved oxygen, temperature and electrical conductivity.

EWR site 4 (RCP 8.5 max)

The percentage of time experiencing zero flows remains the same as the present day value of 6.88% and the maximum monthly flow increases from 398 MCM to 638 MCM. The flow duration chart shows that flows mostly align with present day at >20^{th} percentile, but are notably more than present day, and are aligned with or more than natural flows below the 20th percentile. Infrequent flood is expected even under natural conditions. Macroinvertebrate responses are likely to follow a similar pattern as those outlined for RCP 2.6 max, although the infrequent floods are fewer for RCP 8.5 max as compared to RCP 2.6 max.

EWR site 5 (RCP 2.6 min)

The percentage of time experiencing zero flows increases slightly from the present day value of 18.9% to 22.1% and the maximum monthly flow increases slightly from 404.8 MCM to 417.5 MCM. The flow duration chart shows that flows are generally aligned to present day, particularly at lower percentiles. Hence, even though maximum monthly flows show a slight increase, this increase is only realized at extreme low and high percentiles with generally less flow at the site for the majority of the time. The July maintenance base flow EWR requirement of 8.3 $m^3.s^{-1}$ is only exceeded for less than 10% of the time, while it is exceeded for about 35% of the time for the REC category (B). The increase in zero flows compare to present day, and low flows experience at 10th to 60th percentiles, would have an impact on macroinvertebrates with a preference for marginal vegetation, particularly during the wet seasons, but this effects is likely to be mediated during period of smaller floods. Further, extended zero flow periods are also likely to impact on smaller pools, and reduce water currents and affect water turbulence and thus dissolved oxygen. All of these effects on habitats and water quality are likely to have negative effects on macroinvertebrate taxa such as Chironomidae (*Tanytarsus, Micropsecta*), Corbiculidae, Coenagrionidae (*Ceriagrion*), Chironomidae (*Thienemannimyia, Conchapelopia, Eukiefferiela*). However, it is likely that the overall ecological category for macroinvertebrates would not change from that for present day for the site.

EWR site 5 (RCP 2.6 max)

The percentage of time experiencing zero flows decreases slightly from the present day value of 18.9% to 17.5%, and the maximum monthly flow increases significantly from 404.8 MCM to 3158 MCM. Infrequent floods are predicted and are much larger than expected even under natural conditions.

Macroinvertebrate responses during low flow component would follow as similar pattern as those for RCP 2.6 min, but the infrequent floods predicted, when they do occur, are likely to cause serious impacts on habitat diversity and quality (aquatic, marginal vegetation, alteration of pools, i.e. pools becoming riffles/runs) and increased inputs of allochthonous materials likely to favour filter feeders such as Simuliidae. Simuliidae are also likely to be favoured during floods. The greatest effects would be on taxa with a preference for slow flowing /standing pool waters such as Annelidae, Caenidae, Coenagrionidae, Gomphidae and Veliidae. The overall effect of the infrequent floods is a likely deterioration of the macroinvertebrate-based ecological category.

EWR site 5 (RCP 8.5 min)

The percentage of time experiencing zero flows increases markedly from the present day value of 18.9% to 28.4%. No noticeable change is observed for the maximum monthly flow from present day value of 401 MCM and future predicted value of 404.8 MCM. The flow duration chart however shows that flows are generally lower than present day, particularly at the 50th percentile. Hence, even though maximum monthly flows show a slight increase, this increase is only realized at extreme low and high percentiles with generally less flow occurring at the site for the majority of the time. The July maintenance base flow EWR requirement of 8.3 $m^3.s^{-1}$ is only exceeded for less than 10% of the time, while it is exceeded for about 35% of the time for the REC category (B).

The extended period of zero flows compared to present day and generally low flows at the 50th percentile imply that small pools are likely to dry up, riffles/runs are likely to be affected, and reduced turbulence is also likely to reduce dissolved oxygen. The combined effects on macroinvertebrates are that the abundances of taxa such as Caenidae, Coenagrionidae, Gomphidae and Veliidae with a preference for standing/slow-flowing water are likely to reduce, as will that of oxygen-sensitive taxa such as Leptophlebiidae (*Euthralus* sp.), Tricorythidae (*Tricorythus* sp.) and Chironomidae (*Trissopelopia* sp). The implication is that the macroinvertebrate-based ecological category is likely to deteriorate further from present day condition.

EWR site 5 (RCP 8.5 max)

The percentage of time experiencing zero flows decreases from the present day value of 18.9% to 12.9%, and the maximum monthly flow doubles from 404.8 MCM to 820 MCM. The flow duration chart shows that flows mostly align with natural flows and only exceeds natural flows at extreme low percentiles. The infrequent floods are likely to present the main disturbance to macroinvertebrate assemblage structure. The main habitat disturbance would include alteration of marginal vegetation, pools becoming riffles/runs during floods, and input of allochthonous materials following wash-off from the catchment areas. Even though the population of filter feeders and taxa with a preference for fast-flowing water would likely increase, the overall impact on habitat quality and diversity would result in lower macroinvertebrate-based ecological categories.

5.4.4 Conclusion

Table 5.12 presents the likely effect of climate change under the scenarios assessed on the macroinvertebrate-based ecological categories.

Table 5.12 Likely effect of climate change on the macroinvertebrate-based ecological categories

		RCP 2.6		RCP 2.8	
Site	Invert PES	Min	Max	Min	Max
EWR 6	B	B/C	B	B/C	B/C
EWR 5	B/C	B/C	C	C	C/D
EWR 4	B/C	C/D	C/D	C	C

5.5 Effects of climate change on freshwater fish

by Bruce Paxton

5.5.1 Freshwater fishes of the Doring River

The Doring River is a hotspot of freshwater fish diversity in South Africa (Skelton et al. 1995; Impson 1999) and a catchment of national biogeographic importance. Endemism in this system is unusually high, with eight of the eleven described species, including six barbine cyprinids and two austroglanidid rock catfishes, endemic to the system itself (Table 5.12). The remaining three species (two cyprinids and galaxiid) have wider distribution ranges through the Cape Fold Ecoregion. Genetic studies by Swartz et al. (2004) identified two distinct lineages of the fiery redfin *Pseudobarbus phlegethon*. The Doring River lineage – *Pseudobarbus* sp. nov. "Doring" – is known from only two tributaries of the Doring system.

A substantial decline in the number of indigenous fish species in these rivers has been reported by ecologists, sports-fishermen and local farmers in the last fifty years (Jubb 1961; van Rensburg 1966; Scott 1982; Gore et al. 1991; Impson 1997). Six alien invasive fish species, including largemouth bass *Micropterus salmoides* and smallmouth bass *Micropterus dolomieu*, were introduced into the catchment for sport fishing in the 1930s and 1940s. The bluegill sunfish *Lepomis macrochirus* was later introduced as fodder for the angling species. These fish, in particular the bluegill sunfish, occur in high densities throughout the Doring River – especially the mainstem reaches – and prey on the juveniles of native species.

The decline of native fish populations is most attributable to the spread of the introduced fish species. However, intensification of agricultural activity in the upper reaches of the Doring River – notably the Kouebokkeveld – has reduced flows and aided the spread of invasive alien species which are better adapted to lentic conditions (Paxton et al. 2002). The three largest cyprinids – the Clanwilliam yellowfish *Labeobarbus seeberi* (Smith 1841), the sawfin *Pseudobarbus serra* (Peters 1864) and the Clanwilliam sandfish *Labeo seeberi* (Gilchrist and Thompson 1911) – are most endangered from habitat degradation and reduced flows in the upper, lower and middle reaches where they depend on adequate flows between October and December for migration and spawning.

5.5.2 Indicator species

In most instances, it is neither feasible nor necessary to assess the response of every fish species present in a river system to altered flows. Ecological guilds group species according to similar morphological, physiological, behavioural and life history adaptations rather than by taxonomic relatedness – the assumption being that species with similar adaptations will respond to environmental change and variability in similar ways (Leonard and Orth 1988; Aadland 1993; Welcomme et al. 2006; Baumgartner et al. 2013). Kleynhans et al. (2008) identifies three indicator guilds based on their requirement for flowing water during all (rheophilics) or part (semi-rheophilics) or no phases of their life cycle (limnophilics) (Table 5.13). Both rheophilic and semi-rheophilic groups are further subdivided into 'fast' and 'slow' groups depending on whether they require flows of greater or lower than 0.3 $m.s^{-1}$. Kleynhans et al. (2008) further classified guilds into (1) small (<15 cm), (2) intermediate (15-25 cm) and large (>25 cm) body sizes. This provides an indication of the absolute dimensions of the habitat required when considering the range of flow classes relevant to the species.

It also provides an indication of what range of depths might be required to provide fish passage between river reaches at certain times of the year.

Most rivers in the Cape Fold Ecoregion support a relatively low number of fish species compared to rivers elsewhere in the country. Furthermore, many of the potential indicator species (including rock catfish and redfin minnow) that may once have occurred at EWR Sites 4, 5 and 6 on the Doring River are now extinct from those sites. Only Clanwilliam sandfish, sawfin and yellowfish – all large semi-rheophilics – are still present and only these species are therefore considered here. These species are also the most flow-dependent species – and being larger and strongly migratory – they are likely to have the most stringent habitat and flow requirements.

5.5.3 Models for relating fish habitat requirements to flow

Models for assessing the responses of freshwater fishes to altered flow regimes can be broadly split into methods that focus on hydraulic habitat – which are based on instantaneous approximations of flow, depth and substratum (Bovee 1996; Milhous 1999; Fabris et al. 2017; Yao et al. 2018) – and conceptual hydrological models which focus on biologically relevant components of the hydrograph (Bunn and Arthington 2002; Arthington et al. 2013). The latter include the original version of the Desktop Reserve model (Hughes and Hannart 2003).

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Table 5.13 Native freshwater fish species occurring in the Doring River. The conservation status (IUCN Redlist status) is included for each species. Species names include the changes detailed in Skelton 2016. IUCN status: NA = not formally assessed, DD = Data Deficient, LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered and CR = Critically Endangered, AI = Alien Invasive. Reproduced and adapted from Ellender (2017).

Family & Common names	Species	Status	Distribution
Austroglanididae			
Spotted Rock Catfish	*Austroglanis barnardi*	EN	Olifants River system (endemic)
Clanwilliam rock catfish	*Austroglanis gilli*	VU	Olifants River system (endemic)
Cyprinidae			
Chubbyhead barb	*Enteromius anoplus*	LC	Widespread in South Africa
Large cyprinids			
Clanwilliam sandfish	*Labeo seeberi*	CR	Olifants River system (endemic)
Clanwilliam yellowfish	*Labeobarbus seeberi*	VU	Olifants River system (endemic)
Clanwilliam sawfin	*'Pseudobarbus' serra*	EN	Olifants River system (endemic)
Redfins			
Fiery redfin	*Pseudobarbus phlegethon*	EN	Olifants River system (endemic)
Fiery redfin*	*Pseudobarbus* sp. 'phlegethon Doring'	CR	Olifants River system (endemic)
Clanwilliam redfin	*'Pseudobarbus' calidus*	VU	Olifants River system (endemic)
Twee River redfin	*'Pseudobarbus' erubescens*	CR	Olifants River system (endemic)
Galaxiidae			
Cape galaxias	*Galaxias* sp. 'zebratus nebula'	NA	Widespread in Cape Fold Ecoregion
Anabantidae			
Cape kurper	*Sandelia capensis*	DD	Widespread in Cape Fold Ecoregion
Centrarchidae			
Bluegill sunfish	*Lepomis macrochirus*	AI	Introduced
Spotted bass	*Micropterus punctulatus*	AI	Introduced
Largemouth bass	*Micropterus salmoides*	AI	Introduced
Smallmouth bass	*Micropterus dolomieu*	AI	Introduced
Cichlidae			
Banded tilapia	*Tilapia sparrmanii*	AI	Introduced
Mozambique tilapia	*Oreochromis mossambicus*	AI	Introduced

Table 5.14 Indicator guilds (Hughes and Hannart 2003; Kleynhans et al. 2008).

Indicator guild	Description
Rheophilics (Small & Large)	Require flowing water during all phases of their life cycle Fast rheophilics: >0.3 $m.s^{-1}$ Slow rheophilics: <0.3 $m.s^{-1}$
Semi-rheophilics (Small & Large)	Require flowing water during certain phases of their life cycle Fast semi-rheophilics: >0.3 $m.s^{-1}$ Slow semi-rheophilics: <0.3 $m.s^{-1}$
Limnophilics (Small & Large)	No particular flow requirements during any phases of their life cycle. Water level may be required to provide cover features during certain phases of the life cycle

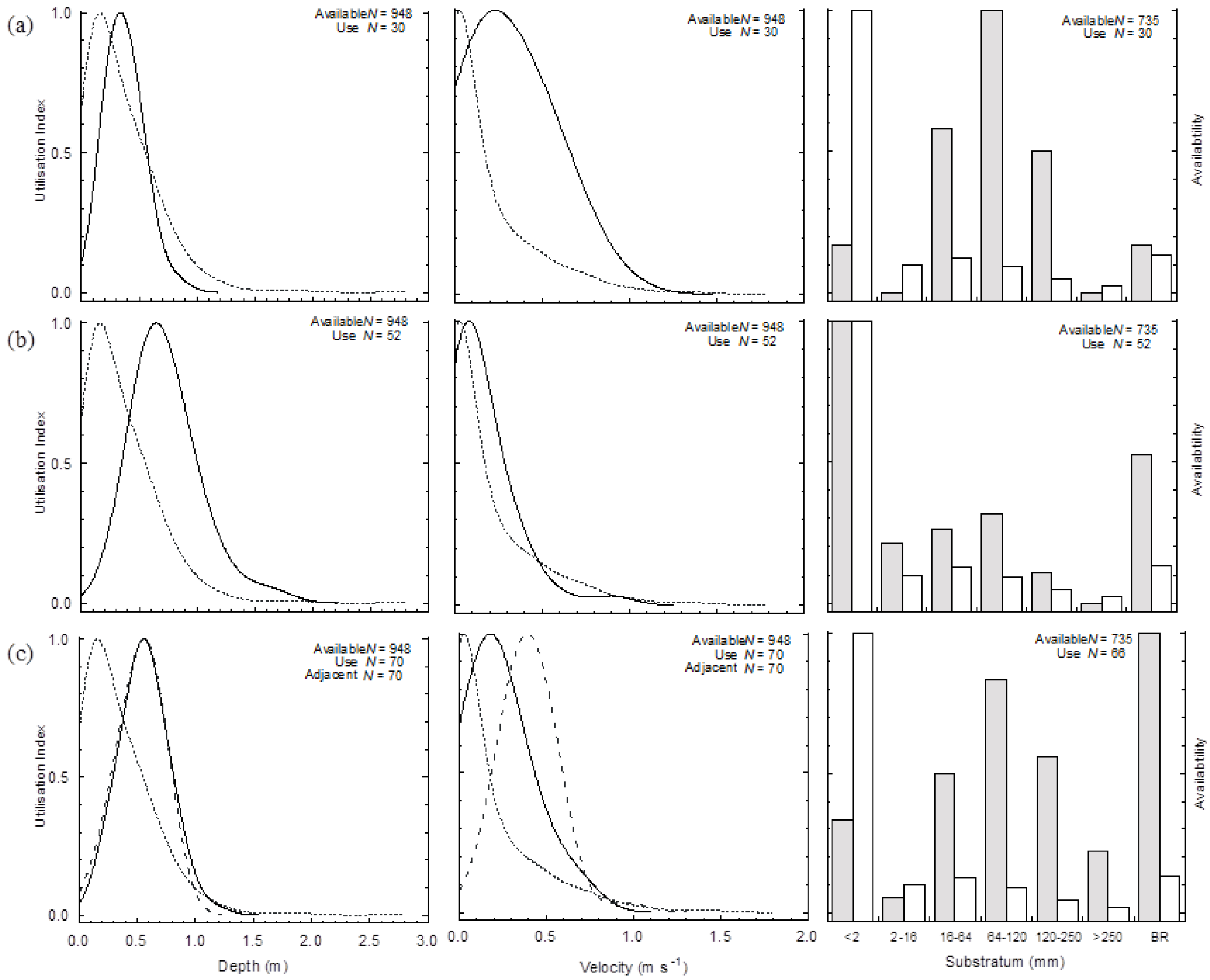

Figure 5.4 Habitat Suitability Criteria (HSC) derived for yellowfish. Kernel-smoothed density distributions of depth (m) and velocity (m s^{-1}) (broken lines = availability, solid lines = use, dashed lines = adjacent) and frequency distributions of substratum utilisation (open bars = availability, shaded bars = use) for (a) 75-150 mm total length (TL; (b) >150 mm TL; and (c) drift-feeding yellowfish (dashed lines indicate drift-feeding areas adjacent to holding positions) (Paxton and King 2009).

The most widely applied method for linking aquatic habitat to fish populations in the former group of models are habitat preference curves which represent the range of a species occurrence across a gradient of various abiotic variables. These habitat preference curves (or Habitat Suitability Criteria, HSC) (Bovee 1982; 1986) are univariate response curves which translate the hydraulic and geomorphological conditions in rivers into indices of habitat quality. They are used to make predictions with regard to how habitat quality and quantity will change under any given flow scenario when linked to a hydraulic model. Ecological response curves for juvenile, sub-adult/adult and drift-feeding Clanwilliam yellowfish (*Labeobarbus seeberi*) is provided in Figure 5.4 (Paxton and King 2009).

The RDRM incorporates hydraulic response curves in the form of 'Habitat' or 'Flow-Depth' classes (Kleynhans 1999; Jordanova et al. 2004) which represent hydraulic bands or 'envelopes' defining depth and velocity combinations deemed to be of importance to the biota (Oswood and Barber 1982). From an original four categories (Kleynhans 1999), these have been expanded to include seven classes (Table 5.14) (Kleynhans et al. 2008).

Table 5.15 Flow-Depth Classes for fish (Kleynhans et al. 2008)

Flow-Depth Class	Abbrev.	Velocity	Depth	Description
Slow Very Shallow	SVS	<0.3 $m.s^{-1}$	<0.1 m	Backwaters and slackwaters
Slow Shallow	SS	<0.3 $m.s^{-1}$	0.1-0.5 m	Backwaters and shallow pools
Slow Deep	SD	<0.3 $m.s^{-1}$	>0.5 m	Deep pools and backwaters
Fast Very Shallow	FVS	>0.3 $m.s^{-1}$	<0.1 m	Very shallow riffles and runs
Fast Shallow	FS	>0.3 $m.s^{-1}$	0.1-0.2 m	Shallow riffles and runs
Fast Intermediate	FI	>0.3 $m.s^{-1}$	0.2-0.3 m	Intermediate depth riffles and runs
Fast Deep	FD	>0.3 $m.s^{-1}$	>0.3 m	Deep riffles, runs and rapids

Flow-Depth Classes account for the availability of either maintenance flows which provide 'living space' for organisms or for flows that are sufficient for fish passage between river reaches. In addition, the timing of flows of certain magnitudes may trigger physiological or behavioural (e.g. migration) responses, continuity (flood interruption) which may cause fish strandings, the smoothness or flashiness of floods, rapidity of change, amplitude or duration. A change in the timing and duration of the flood may result in a more prolonged dry season with delayed spawning and a mismatch with other biological cues such as suitable temperatures or photoperiods. Together with Flow Classes, these considerations provide the conceptual basis of all deliberations regarding the response of fish populations in the Doring River to the range of scenarios assessed here.

Figure 5.5 shows a Depth-Velocity 'domain' for Clanwilliam yellowfish derived from the HSC shown in Figure 5.4. From this figure it is clear that different life stages of yellowfish use a wide range of hydraulic conditions for larval, juvenile and adult phases of their life cycle, as well as for different activities (growth and development, spawning and feeding). It would stand to reason therefore that optimal flow conditions in the river should support a diversity of these habitat classes.

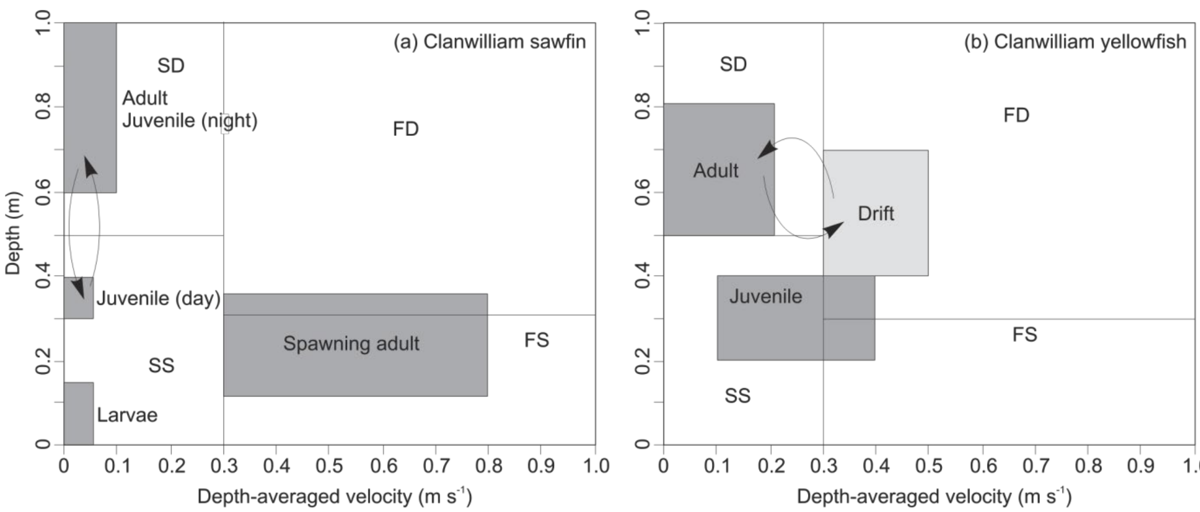

Figure 5.5 Depth-Velocity domains adapted for use in South Africa by Kleynhans (1999). The centroids represent >0.85 suitability ranges derived in Chapter 5. The arrows indicate movement between two types of habitat: in the case of (a) movement of juvenile sawfin between daytime and night-time habitat and (b) movement of foraging Clanwilliam yellowfish between hydraulic cover and drift-feeding zones (Paxton and King 2009).

5.5.4 Translating habitat models into EWRs: DRIFT vs RDRM

Both the DRIFT and RDRM methods use the habitat models in their various forms to translate the response of biotic indicators into EWRs. In both instances – the severity rating of the DRIFT and the stress level of the RDRM – the reliability of the predictions are subject to best available knowledge and will depend on well-established links between biotic-abiotic components, or the judgement of an expert. Any potential discrepancies in outcomes of the two methods therefore may depend not so much on their differences as on the interpretations of 'severity' and 'stress' ratings by users.

Where DRIFT differs is that it allows for a larger number of hydraulic, hydrological and geomorphological parameters to be generated and scored; for example: levels of floodplain inundation, dry season duration, flood frequency and percentage of fine sediment present in the riverbed. Indicators can be linked to one another so that a change in one triggers a change in another. The advantages of DRIFT therefore include its flexibility and what is perceived by many users as being a more intuitive approach to linking biotic indicators to abiotic drivers. DRIFT and HFSR rely on input from a large team of specialists whereas the RDRM is best suited for situations where knowledge and the availability of expertise may be limited, thereby making it a suitable desktop model.

5.5.5 Assessing the effects of climate change on freshwater fishes of the Doring River

Climate change is likely to have a significant effect on the hydrological regimes of rivers, freshwater-dependent ecosystems and the species that inhabit them, particularly in terms of the, quality, quantity and timing of water delivered to them (Aldous et al. 2011). The freshwater fishes of the Cape Fold Ecoregion are especially sensitive to what is predicted to become a hotter and dryer climate in the Western Cape under future climate change scenarios. A recent study showed that under these scenarios, indigenous fishes will suffer significant range restrictions from east to west and north to south and into increasingly higher-altitude habitats (Dallas et al. 2017). The predicted changes and reduced availability of surface waters will be exacerbated by higher demand for water for agricultural, domestic and industrial use. Rivers like the Doring River in the north of the region are particularly prone to reduced flows, longer dry seasons and more frequent drought years. These changes are likely to affect all species and life-stages present in the river, as well as affect the dynamics between indigenous and non-native species. A broad outline of some of the changes that can be expected is provided below.

Spawning growth and development – Clanwilliam yellowfish are non-guarding, open substratum, lithophilic spawners (Balon 1975; Cambray et al. 1997). They are repeat-spawners over several days and multiple-spawners throughout reproductive season (Cambray et al. 1997). Spawning takes place in high-velocity riffles (all 'Fast' depth classes; Table 5.15) over a cobble-boulder substratum between October and December when temperatures are 19°C and stable or rising. Similar spawning conditions are required by sawfin (Paxton and King 2009) and likely by sandfish as well. Yellowfish free embryos are photophobic and spend 9-10 days on the spawning beds before swim up occurs. Once they emerge they are carried out of high-flow riffle habitat and into backwaters and slackwaters where they would commence feeding and develop into larval fish (Cambray et al. 1997).

The absence particularly of sufficient Fast flow-depth habitat classes over the reproductive season (October to December) is likely to result in yellowfish skipping spawning (Paxton and King 2009), or if they do spawn, the growth and development of embryos may be compromised since velocities in the riffles are likely to be insufficient to provide oxygen to the eggs, or wash away metabolites. High egg mortality is likely to arise in these instances due to reduced rainfall and curtailed flows are likely to adversely affect recruitment. Reduced velocities in the riffles is also likely to affect invertebrate productivity and food availability in and adjacent to riffles and rapids for both adults and juveniles. Floods of sufficient magnitude and duration are also required to maintain the spawning habitat integrity, i.e. flush fines from cobble-bed riffles. A reduced frequency and magnitude of flooding is therefore likely to degrade spawning habitats.

Migration – permanent pools provide over-summering habitat for the indigenous fishes. Seasonal movement between winter, summer and spawning habitat is required. Migration cues may depend on temperature and/or flow-related migration cues for coordinating spawning aggregations (August). Of importance in these reaches is the maintenance of over-summering pools, as well as riffle depths and velocities over the spawning season (October, November and December) when fish are most active and migrating to spawning beds

Over-summering habitat – Under current day scenarios, the Doring River ceases flowing between December and June/July. Fish over-summer in deep pools over this period. During this time, the indigenous fishes are particularly susceptible to predation by bass and bluegill sunfish in the ever-shrinking pools. Also, these alien invasive fish species are less flow-dependent than the indigenous species and a prolonged dry season, or reduced flood intensity or frequency, would favour their proliferation. The climate scenarios examined in this study suggest an increase in the duration (% time) zero flows, with RCP 8.5 being higher than RCP 2.6. A prolonged period of zero-flow would also reduce survival in pools as a result of deteriorating water quality conditions, which, combined with higher temperatures would expose fish populations to significant stress.

Site-specific responses

Site 4: Doring – Biedouw Confluence – The Doring River mainstem downstream of the Bos River is an important reach for Clanwilliam sandfish populations. These populations are known to migrate up the Biedouw River, which confluences with the Doring River from the left bank at Site 4 in order to spawn. The Habitat Frequency Plots (Figure 3.21) generated by the RDRM for this site show that stress increases at a faster rate at discharges <4 $m^3.s^{-1}$ over the Wet Season which corresponds to a decline in the availability of FS, FI and FD habitat classes. Under future climate change scenarios, fish spawning and migration is likely to be compromised if the onset of the wet season is significantly prolonged accompanied by the loss of these habitat classes. As with all sites on the Doring River, it is the duration of the Dry Season, rather than flow volumes that are most likely to impact fish populations.

Site 5: Doring – Oudrif – related issues at Site 5 are likely depth of over-summering pools, sufficient riffle/rapid depth and velocities during the spawning season, and high flows which would limit bass and bluegill recruitment. The Habitat Frequency Plots (Figure 3.29) generated by the RDRM for this site show that Very Shallow habitats predominate and that Shallow habitats – which may permit movement between pools by large cyprinids – will become limiting at <0.06 $m^3.s^{-1}$. As with Site 4, these flows are likely to be available over the migration season (August), and only under extreme drought conditions – particularly if zero flow conditions extend well into the Wet Season – will they impact fish movement. The FSR curve shows a steady increase in the stress index (FSR curve, Figure 4.21 and Figure 4.22) between discharges of 0.5 and 15 $m^3.s^{-1}$ over the Wet Season at this site. This corresponds to a decline in the availability of Fast habitat classes over that same discharges over the same range.

Site 6: Doring – Groot River – Site 6 on the Groot River is a high conservation priority with significant populations of Clanwilliam yellowfish and sandfish present in the river downstream at De Mond. As with Sites 4 and 5, the priority flows here include sufficient 'Fast' habitat classes in riffles for spawning and passage at the end of the Wet Season, sufficient depths in over-summering pools, i.e. limiting the duration of the low flow period, and floods of sufficient magnitude and duration to maintain habitat quality. The RDRM predicts a sharp rate of increase in the stress index for discharges <0.5 $m^3.s^{-1}$.

5.5.6 Adaptive measures

Under present day conditions, flows in the Doring River are severely impacted by abstraction in the Kouebokkeveld region of the catchment in the upper reaches of the Groot River which flows in to the Doring River at De Mond. Under natural conditions, this region contributes as much as 40% of Doring River flows at the Olifants River confluence and 28% of the flows at the Olifants River mouth. It is also one of the most intensively farmed areas in the Olifants-Doring catchment, having the third highest registered surface water use (20.9%) (Belcher et al. 2011). Irrigation of primarily deciduous fruits for export and vegetables constitutes 98% of the water use in the area. There is an increasing demand for water for agricultural expansion to support emerging farmers and at the same time, to maintain profit margins among established commercial farmers. Current abstractions levels are unsustainable with a current estimated flows in the Riet River, for instance, estimated at being 10% of the historical MAR (Paxton et al. 2016).

Communicating the importance of judicious water resources management to landowners in the Kouebokkeveld is therefore essential if current unsustainable practices are to be halted or reversed. This is important if the ecological Reserve is to be implemented effectively and the impacts of future climate change are to be mitigated.

Incorporating the principles of Integrated Water Resource Management (IWRM), i.e. managing water and the land over which it flows in a way that accounts for its environmental, social and economic importance, is critical both for the sustainability of human societies in the catchment and freshwater ecosystems. This requires access to sufficient information about the availability and distribution of water, together with clear planning, cooperation and participation among individuals and institutions to ensure that it is managed and shared sustainably, equitably and efficiently among users. Currently, access to water in the Kouebokkeveld is highly contested and cooperation and sharing of water among farmers is limited.

In addition to agricultural practices such as improving irrigation efficiency and monitoring, practicing conservation tillage and planning for crop replacement, the following approaches to managing healthy catchment should be encouraged:

- Undertake catchment restoration by removing water-thirsty alien plants like wattle, gum and prosopis and implementing flood and erosion control and mitigation measures;
- Maintain river buffers zones and avoid degrading river courses and wetlands through ploughing or bulldozing for flood control or crop expansion;
- Develop a River Maintenance Plan to manage rivers, floodplains and wetlands on farms sharing the same catchment collectively and proactively;
- Commission a hydrological study to estimate how much water is available in the catchment and determine appropriate abstraction rates in accordance with the ecological Reserve;

- Identify and protect high-yield catchments and flow-regulating wetlands and rivers;
- Develop an integrated catchment management plan in association with the Irrigation Board or Water User Association that promotes a participatory, collaborative rather than competitive approach to water management.

Chapter 6 Conclusions and Recommendations

The specific aims of the project included:

1. Determine the impacts of climate change on the ecological Reserve as set for the Doring River.
2. Assess the resulting impacts of the increased variability.
3. Identify and evaluate the adaptive response options.

This report presents a methodology developed to analyse the potential impact of climate change on present day ecological Reserve determinations, using the outputs from the Doring River as a case study. The RDRM was set up using both natural and present-day hydrology, and then compared with projected future hydrology (an uncertainty range of possible hydrology) for four RCPs (2.6, 4.5, 6.0, and 8.5) for the Doring River (secondary catchments E21, E22, E23, E24 and E40).

Aim 1. Determine the impacts of climate change on the ecological Reserve as set for the Doring River

The future water quantity, water quality, and RDRM outputs were compared with minimum and maximum flow time series for the two extreme RCPs only (2.6 and 8.5). Both climate scenarios resulted in increased time periods for zero flows in general, with RCP 8.5 being worse. The upstream catchment E21H is projected to have reduced maximum flows under both RCPs compared to both natural and present day flow conditions. For the lower two quaternaries (E24H and E24L) the uncertainty range straddles both natural and present day maximum flow values. The uncertainty in water quantity and increased period of zero flows under RCP 2.6 and RCP 8.5 translate into uncertainty in the stress frequency curves, and indication that the river would deteriorate from a D ecological category, particularly during the dry season for all three EWR sites.

Note that the Site 6 gazetted category (B) is different than the EWR category listed in DWAF 2006a (B/C). This has implications for the comparisons presented in this report for evaluating the RDRM model outputs with DRIFT outputs using category B/C and with the specialist reports, and that the actual Reserve should be higher than that set for category B/C.

Aim 2. Assess the resulting impacts of the increased variability

Aim 3. Identify and evaluate the adaptive response options

These two aims were addressed by the specialists (Chapter 5) who were asked to assess the impacts on their specialist group and, in addition, identify some adaptive response options. Five specialist reports were obtained for this project: water quality (TDS), fish, macroinvertebrates, geomorphology and riparian vegetation.

It is important to note that, with the exception of the report on predicted TDS changes, these assessments are made in the light of modelled flow changes under climate change and as such do not formally consider modelled changes in water quality. Climate change scenarios which were considered include maximum and minimum flow changes under climate ensembles RCP 2.6 and RCP 8.5.

The Doring River lies in an arid region, and models indicate that it would become more arid under modelled climate change. In general, specialist reports highlight the negative impacts of climate change, although in some cases no change is predicted, and rarely, potential improvements indicated. In general, predicted changes involved a category decrease by one unit or less. An exception to this was salinity levels (TDS) at sites EWR 4 and EWR 5 in the mid-to lower Doring River, where the categorization was predicted to decrease by two categories.

EWR 6 lies at Mount Cedar on the Groot River in the Kouebokkeveld in the upper catchment of the Doring River. The site is downstream of the most heavily irrigated part of the Doring River catchment. Salinity is predicted to decrease at this point regardless of the climate change scenario. The geomorphology category should stay the same or decrease slightly depending on whether high flows increase of decrease. The riparian vegetation is predicted to be largely unchanged under high flow scenarios, or to degrade somewhat under low flow scenarios. Aquatic macroinvertebrate populations are predicted to degrade slightly, except under RCP 2.6 (maximum), when they do not change. Fish populations will be stressed by extension of the low flow period and suitable floods will be required to maintain habitat quality.

EWR 4 lies at Uitspankraal on the Doring River at the confluence with the Biedou River in the middle catchment of the Doring River. The region is arid, and the Doring River at this point has received saline inputs from the Tankwa Karroo, primarily via the Tankwa and Wolf rivers. Salinity at this point is predicted to increase significantly under all climate change scenarios. The geomorphology category is predicted to decrease, particularly under a scenario of decreased high flows. Riparian vegetation is predicted to degrade under all flow scenarios, but particularly RCP 8.5 (minimum). Aquatic macroinvertebrates communities are predicted to degrade somewhat, particularly under RCP 2.6 scenarios. Increased zero flow periods will stress fish populations as spawning and migration patterns are disturbed.

EWR 5 is at Oudrif on the Doring River, in the Lower Doring River catchment approximately 30 km upstream of the confluence with the Olifants River. Salinity at this point, which already limits irrigation in late summer, is predicted to increase significantly under all climate change scenarios making it the most saline EWR site in the catchment. Geomorphological state at this point is predicted to degrade somewhat under predicted climate change, with greater degradation anticipated should high flow events decrease. Riparian vegetation is anticipated to degrade by one category under all scenarios except under RCP 8.5 (maximum), where less degradation is predicted. Some degradation in macroinvertebrate community structure is predicted under all climate change scenarios except for RCP 2.6 (minimum). Fish populations will be impacted by extended low flow periods and a reduction in Fast habitats.

The predictions for water quality (salinity), geomorphology, and biotic change under climate change scenarios generally concur on a reduced ecological status regardless of the climate change scenario assessed. In general, predicted PES reductions range from a half to one full category when compared with the most recent PES per component. Exceptions to this rule include salinity levels at EWR 6, where an improvement was indicated, and a reduction of two full categories predicted for EWR 4 and EWR 5. It should be noted that these predictions are based on predicted flow and habitat quality and availability, and do not include consideration of greater silt transport predicted under all scenarios, and greater salinity predicted at EWR 4 and EWR 5. These may act to further impact on biotic responses.

Several specialists indicate that assessing the maximum and minimum modelled flow rates in effect only assesses the extremes, and that flow rates are likely to fall or fluctuate between these extremes. It is also noted that the difference between maximum and minimum flows is large and may straddle present day flow parameters. This contributes to uncertainty in identifying impacts of flow change. Other sources of uncertainty are identified in the text.

Specialists contributing to assessments of predicted biotic change under climate change indicated several predicted trends that may have a negative impact on biota. A common negative prediction related to extended periods of zero flow and potential lack of available and suitable pools during low or zero flow events. As the Doring River catchment has few in-stream dams there is little potential of releasing flow during dry periods to ameliorate this stress. The largest of these dams is the Oubaaskraal on the Tankwa River. The quality of water in this dam is not known, and it may be saline as the Tankwa River drains shales in the eastern catchment. Several specialists indicated that the demand for water in the upstream Kouebokkeveld parts of the catchment was significant and that the number of smaller off-channel dams was high. The potential of maintaining or supplementing flow in the lower Doring River (and potentially reducing salinity there) might therefore be addressed by managing water use in the Kouebokkeveld. Unfortunately, it was also noted that conflict between land users over water had been recorded, and that the potential for cooperative water management in this region was low. Another potential source of water to supplement flows might be via the transfer scheme from the Breede River catchment, but as this area is liable to be subject to the same or similar climatic changes as the Doring River catchment, availability of water from this source is liable to be curtailed.

A potential means of ameliorating reduced flow patterns could also relate to management of alien vegetation in the catchment. Water losses owing to alien plants have been found to be significant in South Africa (Le Maitre et al. 2016). The presence of *N. oleander* and other invasive species in the riparian zone of the Doring River has been established. In a similar light, the maintenance of buffer zones along rivers in the catchment may act to ameliorate impacts. Protection of high-yield sub-catchments will act to improve water availability in the catchment.

Amelioration of the impacts identified here will not be straightforward, and many of the proposed steps towards amelioration may be contested by other water users, particularly in the parts of the catchments where abstracted water, taken from surface or ground water, underlies economic activity. As climate change predictions indicate, the region will be under greater water stress in the future, a reduction in water availability will force further adaptive measures on the catchment's water users.

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Appendices

Appendix A Doring River EWR tables (DWAF 2006a, Appendix A)

Table A1: EWR 4 table

Desktop Version 2, Generated on 11/08/2006

Summary of Desktop (Version 2) estimate for Quaternary Catchment Area :

Total Runoff: Quaternaries E24J

Annual Flows (Mill. cu. m or index values):

MAR	421.47
S.Dev.	337.317
CV	0.8
Q75	2.373
Q75/MMF	0.068
BFI Index	0.307
CV(JJA+JFM) Index	2.619
Ecological Category	B
Total IFR	192.205 (45.60 %MAR)
Maint. Lowflow	64.532 (15.31 %MAR)
Drought Lowflow	3.705 (0.88 %MAR)
Maint. Highflow	127.673 (30.29 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type: W.Cape(dry)

Month	Natural flows			Modified flows (IFR)			
				Low flows		High flows	Total flows
	Mean	SD	CV	Maint.	Drought	Maint.	Maint.
Oct	34.175	16.766	0.491	5.542	0.416	6.622	12.164
Nov	18.27	11.662	0.638	0.08	0.08	3.311	3.391
Dec	8.261	9.028	1.093	0	0	0	0
Jan	4.567	12.061	2.641	0	0.001	0	0
Feb	3.547	9.217	2.599	0	0.001	0	0
Mar	2.914	5.358	1.839	0	0.001	0	0
Apr	15.736	44.293	2.815	0.134	0	3.311	3.445
May	31.026	55.377	1.785	1.386	0.028	0	1.386
Jun	79.408	159.675	2.011	8.045	0.027	11.381	19.426
Jul	78.429	101.188	1.29	16.627	0.055	20.899	37.526
Aug	85.205	86.278	1.013	16.627	2.854	32.28	48.907
Sep	59.931	39.858	0.665	16.091	0.241	49.869	65.96

EWR4 Rule Curves

Desktop Version 2, Generated on 11/08/2006

Summary of IFR rule curves (Desktop Version 2) for:

EWR Site 4:

Total Runoff: Quaternaries E24J

Regional Type: W.Cape (dry)

Ecological Category = B

Data are given in $m^3 * 10^6$ monthly flow volume

Month % Points										
	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	14.734	14.562	14.131	13.203	11.51	8.967	5.93	3.208	1.559	1.163
Nov	3.89	3.835	3.683	3.35	2.775	2.009	1.249	0.713	0.467	0.433
Dec	0	0	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001
Feb	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	0	0
Apr	3.959	3.913	3.799	3.433	2.131	1.648	1.218	0.766	0.459	0.031
May	1.79	1.773	1.734	1.653	1.5	1.25	0.899	0.501	0.172	0.039
Jun	23.407	23.194	22.713	21.717	19.862	16.806	12.492	7.525	3.279	1.304
Jul	62.071	56.511	51.618	47.052	42.306	34.347	28.407	18.153	10.313	3.369
Aug	89.155	78.323	69.141	60.826	46.023	39.495	30.279	19.669	10.598	6.38
Sep	123.436	82.889	65.366	59.34	49.24	43.823	37.429	22.715	10.546	5.636
Reserve Flows without High Flows										
Oct	7.162	7.078	6.865	6.406	5.57	4.313	2.813	1.468	0.653	0.458
Nov	0.104	0.104	0.103	0.101	0.097	0.091	0.086	0.083	0.081	0.081
Dec	0	0	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0.001	0.001	0.001	0.001	0.001	0.001
Feb	0	0	0	0	0	0	0	0	0	0
Mar	0	0	0	0	0	0	0	0	0	0
Apr	0.173	0.171	0.166	0.154	0.132	0.1	0.062	0.027	0.006	0.001
May	1.79	1.773	1.734	1.653	1.5	1.25	0.899	0.501	0.172	0.039
Jun	10.393	10.295	10.07	9.606	8.741	7.317	5.306	2.991	1.012	0.092
Jul	21.48	21.326	21.009	20.391	19.244	17.253	14.081	9.61	4.418	0.709
Aug	21.497	21.32	20.916	20.082	18.526	15.965	12.348	8.185	4.626	2.971
Sep	20.788	20.589	20.132	19.184	17.41	14.491	10.397	5.756	1.918	0.37
Natural Duration curves										
Oct	53.314	46.321	39.791	36.032	31.444	28.715	24.589	20.704	16.326	8.399
Nov	35.707	25.071	21.197	16.882	14.268	13.008	11.874	10.152	7.654	5.533
Dec	17.302	11.528	8.914	6.457	5.564	4.021	3.538	3.15	2.478	1.827
Jan	6.404	3.255	2.436	1.764	1.312	0.976	0.84	0.682	0.588	0.409
Feb	11.244	3.024	1.606	0.829	0.651	0.43	0.22	0.168	0.126	0.084
Mar	6.53	4.494	2.373	1.648	1.312	0.756	0.441	0.199	0.063	0
Apr	27.381	15.916	8.494	3.433	2.131	1.648	1.218	0.766	0.472	0.031
May	118.386	37.187	18.657	15.654	11.79	7.16	4.494	2.562	1.795	0.241
Jun	165.106	102.312	60.316	43.77	33.628	25.974	16.62	12.714	5.197	2.404
Jul	182.85	100.065	81.178	61.639	51.644	42.521	30.846	18.153	11.864	4.536
Aug	216.94	108.769	88.832	71.403	61.324	51.686	41.418	30.016	19.402	7.78
Sep	123.436	82.889	65.366	59.34	49.24	43.823	38.594	29.828	20.998	11.496

Table A2: EWR 5 table
Desktop Version 2, Generated on 11/08/2006
Summary of Desktop (Version 2) estimate for Quaternary Catchment Area :
Total Runoff: Quaternaries E24M
Annual Flows (Mill. cu. m or index values):

MAR	509.621
S.Dev.	418.927
CV	0.822
Q75	3.229
Q75/MMF	0.076
BFI Index	0.282
CV(JJA+JFM) Index	3.544
Ecological Category	B
Total IFR	232.405 (45.60 %MAR)
Maint. Lowflow	78.029 (15.31 %MAR)
Drought Lowflow	4.480 (0.88 %MAR)
Maint. Highflow	154.376 (30.29 %MAR)

Monthly Distributions (Mill. cu. m.)
Distribution Type: W.Cape(dry)

Month	Natural flows			Modified flows (IFR)			
				Low flows		High flows	Total flows
	Mean	SD	CV	Maint.	Drought	Maint.	Maint.
Oct	38.865	18.82	0.484	6.701	0.503	8.007	14.708
Nov	20.917	13.384	0.64	0.097	0.097	4.003	4.101
Dec	9.444	10.043	1.063	0	0	0	0
Jan	5.428	13.497	2.487	0	0.002	0	0
Feb	4.597	10.649	2.317	0	0.001	0	0
Mar	4.644	6.906	1.487	0	0.001	0	0
Apr	19.868	52.253	2.63	0.162	0	4.003	4.165
May	39.653	75.082	1.893	1.675	0.034	0	1.675
Jun	101.797	202.309	1.987	9.728	0.032	13.761	23.489
Jul	94.969	125.903	1.326	20.104	0.067	25.271	45.375
Aug	100.199	103.168	1.03	20.104	3.451	39.032	59.136
Sep	69.241	46.856	0.677	19.456	0.292	60.299	79.755

EWR5 Rule Curves

Desktop Version 2, Generated on 11/08/2006
Summary of IFR rule curves (Desktop Version 2) for:
EWR Site 5:
Total Runoff: Quaternaries E24M
Regional Type: W.Cape(dry)
Ecological Category = B

Data are given in $m^3 * 10^6$ monthly flow volume

Month % Points										
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%	99%
Oct	17.815	17.608	17.087	15.964	13.917	10.842	7.17	3.878	1.885	1.407
Nov	4.704	4.637	4.453	4.051	3.356	2.43	1.51	0.862	0.565	0.524
Dec	0	0	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0.001	0.001	0.001	0.002	0.002	0.002
Feb	0	0	0	0	0	0.001	0.001	0.001	0.001	0.001
Mar	0	0	0	0	0	0	0	0	0	0
Apr	4.787	4.732	4.593	4.295	2.592	2.052	1.426	1.08	0.555	0.043
May	2.165	2.144	2.097	1.998	1.814	1.511	1.087	0.606	0.207	0.047
Jun	28.302	28.046	27.463	26.26	24.016	20.321	15.104	9.099	3.965	1.577
Jul	75.053	68.33	62.414	56.893	51.155	41.53	34.344	21.146	12.47	4.073
Aug	107.802	94.705	83.602	73.548	55.649	47.755	36.612	23.783	12.815	7.714
Sep	147.604	93.874	77.393	65.243	59.681	51.073	43.016	27.466	12.751	6.815
Reserve flows without High Flows										
Oct	8.66	8.558	8.301	7.746	6.735	5.215	3.401	1.775	0.79	0.554
Nov	0.126	0.126	0.125	0.122	0.117	0.111	0.104	0.1	0.098	0.097
Dec	0	0	0	0	0	0	0	0	0	0
Jan	0	0	0	0	0.001	0.001	0.001	0.002	0.002	0.002
Feb	0	0	0	0	0	0.001	0.001	0.001	0.001	0.001
Mar	0	0	0	0	0	0	0	0	0	0
Apr	0.209	0.207	0.2	0.186	0.16	0.121	0.074	0.033	0.007	0.001
May	2.165	2.144	2.097	1.998	1.814	1.511	1.087	0.606	0.207	0.047
Jun	12.567	12.448	12.176	11.615	10.57	8.847	6.416	3.617	1.224	0.111
Jul	25.973	25.786	25.403	24.656	23.269	20.861	17.026	11.619	5.341	0.857
Aug	25.994	25.779	25.29	24.282	22.401	19.304	14.931	9.897	5.594	3.592
Sep	25.136	24.895	24.343	23.196	21.051	17.522	12.571	6.96	2.32	0.447
Natural Duration curves										
Oct	61.441	51.851	46.494	41.148	35.64	32.324	27.734	23.35	17.852	9.904
Nov	41.342	30.002	23.868	19.386	15.898	15.152	13.802	11.167	8.813	6.383
Dec	18.986	14.256	9.914	7.258	6.199	4.493	4.223	3.564	2.776	1.998
Jan	9.256	4.104	2.689	2.128	1.436	1.058	0.918	0.767	0.659	0.464
Feb	13.23	5	1.825	1.166	0.788	0.464	0.324	0.216	0.14	0.108
Mar	12.755	8.122	5.022	2.57	1.976	1.426	0.54	0.216	0.108	0
Apr	37.076	22.529	10.595	5.594	2.592	2.052	1.426	1.08	0.562	0.043
May	145.044	46.84	26.59	19.278	14.126	9.99	5.443	3.24	1.955	0.248
Jun	245.441	123.52	86.141	52.596	39.658	30.089	21.298	14.407	7.042	2.808
Jul	222.437	127.559	100.753	77.771	60.62	47.045	34.344	21.146	15.098	6.037
Aug	256.446	122.364	101.552	80.849	70.902	58.525	46.753	33.448	21.665	9.126
Sep	147.604	93.874	77.393	65.243	59.681	51.073	43.016	33.199	23.404	12.582

Table A3: EWR 6 table

Desktop Version 2, Generated on 11/08/2006

Summary of Desktop (Version 2) estimate for Quaternary Catchment Area :

Total Runoff: Quaternaries E24M

Annual Flows (Mill. cu. m or index values):

MAR	137.858
S.Dev.	82.083
CV	0.595
Q75	0.82
Q75/MMF	0.071
BFI Index	0.328
CV(JJA+JFM) Index	2.641
Ecological Category	B/C
Total IFR	60.331 (43.76 %MAR)
Maint. Lowflow	25.331 (18.37 %MAR)
Drought Lowflow	3.203 (2.32 %MAR)
Maint. Highflow	35.000 (25.39 %MAR)

Monthly Distributions (Mill. cu. m.)

Distribution Type: W.Cape(dry)

Month	Natural flows			Modified flows (IFR)			
				Low flows		High flows	Total flows
	Mean	SD	CV	Maint.	Drought	Maint.	Maint.
Oct	16.399	7.698	0.469	1.945	0.107	1	2.945
Nov	7.971	3.808	0.478	0.467	0.026	0	0.467
Dec	2.901	1.903	0.656	0.107	0.003	0	0.107
Jan	1.033	1.612	1.56	0.029	0.003	0	0.029
Feb	0.677	1.318	1.949	0.024	0.002	0	0.024
Mar	0.552	0.783	1.419	0.054	0.003	0	0.054
Apr	1.627	2.801	1.722	0.156	0.003	1	1.156
May	6.713	10.664	1.589	0.616	0.027	1	1.616
Jun	18.513	23.49	1.269	2.735	0.104	2	4.735
Jul	24.703	22.882	0.926	5.389	0.402	15	20.389
Aug	30.86	24.692	0.8	8.035	1.125	11	19.035
Sep	25.91	14.823	0.572	5.775	1.4	4	9.775

Rule Curves

Desktop Version 2, Generated on 11/08/2006

Summary of IFR rule curves (Desktop Version 2) for:

EWR Site 6:

Total Runoff: Quaternaries E21J

Regional Type: W.Cape(wet)

Ecological Category = B/C

Data are given in m^3/s mean monthly flow

Month % Points									
Month	10%	20%	30%	40%	50%	60%	70%	80%	90%
Oct	1.32	1.32	1.309	1.284	1.231	1.126	0.94	0.654	0.308
Nov	0.224	0.224	0.222	0.217	0.208	0.19	0.158	0.109	0.05
Dec	0.049	0.049	0.049	0.047	0.044	0.039	0.029	0.017	0.006
Jan	0.014	0.014	0.013	0.013	0.012	0.011	0.008	0.005	0.002
Feb	0.012	0.012	0.012	0.012	0.011	0.01	0.008	0.005	0.002
Mar	0.025	0.025	0.025	0.024	0.023	0.021	0.018	0.012	0.005
Apr	0.506	0.506	0.502	0.359	0.255	0.207	0.164	0.097	0.055
May	0.703	0.703	0.698	0.684	0.656	0.601	0.5	0.352	0.169
Jun	2.188	2.188	2.175	2.147	2.091	1.981	1.771	1.39	0.768
Jul	12.485	11.443	9.73	8.523	7.381	6.687	4.556	3.125	1.807
Aug	11.067	10.302	9.607	8.973	8.349	7.142	6.43	5.121	3.035
Sep	5.768	5.379	5.029	4.705	4.359	3.743	3.202	2.369	1.364
Reserve flows without High Flows									
Oct	0.902	0.902	0.894	0.877	0.84	0.768	0.639	0.44	0.2
Nov	0.224	0.224	0.222	0.217	0.208	0.19	0.158	0.109	0.05
Dec	0.049	0.049	0.049	0.047	0.044	0.039	0.029	0.017	0.006
Jan	0.014	0.014	0.013	0.013	0.012	0.011	0.008	0.005	0.002
Feb	0.012	0.012	0.012	0.012	0.011	0.01	0.008	0.005	0.002
Mar	0.025	0.025	0.025	0.024	0.023	0.021	0.018	0.012	0.005
Apr	0.075	0.075	0.074	0.072	0.069	0.063	0.052	0.035	0.015
May	0.286	0.286	0.283	0.278	0.266	0.243	0.201	0.138	0.061
Jun	1.321	1.321	1.313	1.296	1.261	1.193	1.063	0.827	0.443
Jul	2.52	2.52	2.505	2.473	2.409	2.283	2.043	1.607	0.895
Aug	3.759	3.759	3.737	3.692	3.602	3.425	3.086	2.472	1.469
Sep	2.771	2.771	2.751	2.706	2.611	2.423	2.089	1.575	0.954
Natural Duration curves									
Oct	10.224	8.134	7.087	6.08	5.539	5.15	4.556	3.897	3.173
Nov	5.231	4.367	3.528	2.999	2.725	2.463	2.299	1.94	1.466
Dec	2.09	1.483	1.207	1.007	0.842	0.748	0.689	0.624	0.436
Jan	0.718	0.447	0.324	0.265	0.218	0.177	0.153	0.135	0.112
Feb	0.743	0.261	0.182	0.124	0.091	0.065	0.039	0.033	0.026
Mar	0.524	0.377	0.206	0.177	0.088	0.053	0.047	0.029	0.012
Apr	1.557	0.791	0.602	0.359	0.255	0.207	0.164	0.097	0.055
May	8.811	2.755	2.201	1.519	1.16	0.824	0.5	0.424	0.23
Jun	18.533	8.473	6.478	5.65	4.732	3.57	2.585	1.484	0.906
Jul	22.196	12.008	9.73	8.523	7.381	6.687	4.556	3.125	1.807
Aug	23.756	15.716	13.867	11.478	9.359	7.846	6.457	5.121	3.408
Sep	19.494	13.217	11.793	9.61	8.704	7.682	6.271	5.565	4.014

Table A4. Water quantity RQOs for rivers in priority RUs – relevant data only available for EWR sites 5 and 6 (Table 8.2: DWA 2014; DWS 2016; Government Gazette No. 39943)

EWR Site	Mainstem / Cumulative Ecological Category	Averae tributary / Incremental Ecological Category	Month with lowest flow	Mean of month with lowest flow (m^3/s)	Instantaneous drought absolute minimum (m^3/s)	% nMAR	Floods in addition to Desktop Model	Implications of flood RQOs
Site 4 (E24J)	B	B	-	-	-	-	-	-
Site 5 (E24M)	B	B	February	0	0	48.5	>80% of natural floods for July, August and September	No in-channel dams
Site 6 (E21J)	B	B	February	0.010	0.001	48.1	>80% of natural floods for July, August and September	No in-channel dams

Table A5. Summary of the hydrology requirements for E24M (derived from Table 16.2; DWA 2014) used for EWR site 5

Flood type	Daily average peak (m^3/s)	Duration (days)	Volume (MCM)	Number requested	Months
Intra-annual Class (i.e. each flood has a return period of 1:1)					
Class 1	35.05	2	4	6	September-June
Class 2	70.11	4	15	2	June-September
Class 3	140.22	5	27	2	June-September
Class 4	280.43	6	59	1	June-September
Inter-annual Class (return period given below)					
1:2	311.59	7	136.88	Absent	Not applicable
1:5	535.57	8	140.46	Present	Not stipulated
1:10	1057.7	8	234.56	Present	Not stipulated
1:20	1396.4	8	284.65	Present	Not stipulated

Mean flow in November and April: 0.03 m^3/s
Even in extreme drought, November and April flow should not drop below: 0.03 m^3/s

Table A6. Summary of the hydrology requirements for E21J (derived from Table 19.2; DWA 2014) used for EWR site 6

Flood type	Daily average peak (m^3/s)	Duration (days)	Volume (MCM)	Number requested	Months
Intra-annual Class (i.e. each flood has a return period of 1:1)					
Class 1	5.51	3	1	7[1]	September-June
Class 2	11.02	5	2	2	June-September
Class 3	22.03	5	4	2	June-September
Class 4	44.06	7	11	2	June-September
Inter-annual Class (return period given below)					
1:2	48.96	-	15.5	Present	Not stipulated
1:5	66.26	-	29.5	Present	Not stipulated
1:10	77.89	-	33.7	Present	Not stipulated
1:20	162.55	-	43.2	Present	Not stipulated

Mean flow in driest month (February): 0.06 m^3/s (E21J), 0.1 m^3/s (E21L)
Even in extreme drought flow should not drop below: 0.001 m^3/s (E21J), 0.002 m^3/s (E21L)

Table A7. Geomorphological RQOs and TPCs at EWR 5 (derived from Table 16.4; DWA 2014). * = exotic species.

Component	Values: Cross-section A	Values: Cross-section B	TPCs
Dry season bed material composition (mm)			
D_{16}	0.4	8	>20% increase or decrease
D_{50}	18	45	>20% increase or decrease
D_{84}	30	180	>30% increase or decrease
Channel geometry			
Dry season water surface slope (m/m)	0.00006	0.05	>5% increase or decrease
Active channel width(m)	34	60	>5% increase or decrease
Bankfull width (m)	38	82	>5% increase or decrease
Key habitats			
Aquatic vegetation in and out of current	-	Present all year (this habitat is threatened by livestock)	None available
Stones-in-current, including riffle and run	-	All winter, spring and early summer	None available

Table A8. Geomorphological RQOs and TPCs at EWR 6 (derived from Table 19.4; DWA 2014). * = exotic species

Component	Values: Cross-section A	Values: Cross-section B	TPCs
Dry season bed material composition (mm)			
D_{16}	13	38	>20% increase or decrease
D_{50}	64	80	>20% increase or decrease
D_{84}	360	120	>30% increase or decrease
Channel geometry			
Dry season water surface slope (m/m)	0.004	0.0001	>5% increase or decrease
Active channel width(m)	38	67	>5% increase or decrease
Bankfull width (m)	44	74	>5% increase or decrease
Key habitats			
Aquatic vegetation in and out of current	present throughout the year	present throughout the year	None available
Stones-in-current, including riffle and run	should be present and available for habitation by invertebrates	-	None available

Appendix B Doring River water quality EcoSpecs (adapted from DWAF 2006b)

Table B1: EWR 4 – Doring River: EcoSpecs relating to physico-chemical data (PES and REC)

DATA AND SITE DETAIL		
WQ Data Station used	E1H002Q01 (Doring River at Aspoort) and E2H003QO1 (Doring River at Melkboom).	
Data Period	Aspoort. Continuous 1982-3 and 1989-2003. Melkboom. Continuous when flowing since 1984.	
Data Trends	Aspoort =None. Melkboom = Slight upward trends in nitrates and phosphorus.	
Data Peaks	Aspoort = October to March, late winter minima. Melkboom = summer minima, winter maxima.	
Data Limitations	No data for water temperature, dissolved oxygen, turbidity or chlorophyll-a.	
Identified point source(s) impacts within or upstream of reach	None.	
Data support Flow-Concentration Modeling	No.	
Present Ecological State category	B (Water Quality)	
Confidence (Overall Assessment)	Medium	
ECOLOGICAL RESERVE SPECIFICATION		
Target Ecostatus =B		
Constituent	Value	Detail
Salts[1, 2]		
$MgSO_4$ (mg ℓ^{-1})	<23	
Na_2SO_4 (mg ℓ^{-1})	<33	
$MgCl_2$ (mg ℓ^{-1})	<30	
$CaCl_2$ (mg ℓ^{-1})	<57	
NaCl (mg ℓ^{-1})	<191	
Water temperature (°C)	Adult fish: maximum daily mean = 40°C (all year). Spawning: Minimum = 19 °C, ideal = 25-28 °C (November to January).	
pH	6.5- 8.5	
Electrical Conductivity (mS m^{-1})	<20	Maxima: Adult Fish = 500 mS m^{-1} (year-round); Juveniles = 170-280 mS m^{-1} (October to February)
Dissolved oxygen (DO) (mg ℓ^{-1})	>6.0	
Toxics[3]		
Ammonia as NH_3 (mg ℓ^{-1})	<0.007	
Nutrients		
Nitrates as N (mg ℓ^{-1})	<0.020	
Phosphorus as PO_4-P (mg ℓ^{-1})	<0.020	

1 The data for salts, either individually or as Total Dissolved Solids, are not supported by the salinity-modelling component that was anticipated to become available from the WODRIS project (Brown et al. 2002).
2 There are no locally-relevant data available for salts or salinity tolerances of aquatic invertebrates.
3 Specific data characterizing effluents from identified wastewater treatment plants not yet received from RQIS.

Table B2: EWR 5 – Doring River: EcoSpecs relating to physico-chemical data (PES and REC)

DATA AND SITE DETAIL		
WQ Data Station used		E2H003QO1 (Doring River at Melkboom).
Data Period		Continuous when flowing since 1984.
Data Trends		Slight upward trends in nitrates and phosphorus.
Data Peaks		Summer minima, winter maxima.
Data Limitations		No data for water temperature, dissolved oxygen, turbidity or chlorophyll-a.
Identified point source(s) impacts within or upstream of reach		None.
Data support Flow-Concentration Modeling		No.
Present Ecological State category		B (Water Quality)
Confidence (Overall Assessment)		Medium
ECOLOGICAL RESERVE SPECIFICATION		
Target Ecostatus =B		
Constituent	Value	Detail
Salts[1, 2]		
$MgSO_4$ ($mg\ \ell^{-1}$)	<23	
$Na2SO_4$ ($mg\ \ell^{-1}$)	<33	
$MgCl_2$ ($mg\ \ell^{-1}$)	<30	
$CaCl_2$ ($mg\ \ell^{-1}$)	<57	
NaCl ($mg\ \ell^{-1}$)	<191	
Water temperature (°C)	Adult fish: maximum daily mean = 40°C (all year). Spawning: Minimum = 19 °C, ideal = 25-28 °C (November to January).	
pH	6.5-8.5	
Electrical Conductivity ($mS\ m^{-1}$)	<50	Maxima: Adult Fish = 500 $mS\ m^{-1}$ (year-round); Juveniles = 170-280 $mS\ m^{-1}$ (October to February)
Dissolved oxygen (DO) ($mg\ \ell^{-1}$)	>6.0	
Toxics[3]		
Ammonia as NH_3 ($mg\ \ell^{-1}$)	<0.007	
Nutrients		
Nitrates as N ($mg\ \ell^{-1}$)	<0.020	
Phosphorus as PO_4-P ($mg\ \ell^{-1}$)	<0.020	

1 The data for salts, either individually or as Total Dissolved Solids, are not supported by the salinity-modeling component that was anticipated to become available from the WODRIS project.
2 There are no locally-relevant data available for salts or salinity tolerances of aquatic invertebrates.
3 Specific data characterizing effluents from identified wastewater treatment plants not yet received from RQIS.

Table B3: EWR 6 – Doring River: EcoSpecs relating to physico-chemical data (PES and REC)

DATA AND SITE DETAIL		
WQ Data Station used	E2H007QO1 (Leeuw River) (upper Groot).	
Data Period	Complete from 1979-2003 with short gaps.	
Data Trends	Upward trend in nitrates from 1997.	
Data Peaks	Maxima during early to mid-winter, summer minima.	
Data Limitations	No data for water temperature, dissolved oxygen, turbidity or chlorophyll-a.	
Identified point source(s) impacts within or upstream of reach	None.	
Data support Flow-Concentration Modeling	No.	
Present Ecological State category	A/B (Water Quality)	
Confidence (Overall Assessment)	Medium	
ECOLOGICAL RESERVE SPECIFICATION		
Target Ecostatus =B/C		
Constituent	Value	Detail
Salts[1,2]		
$MgSO_4$ (mg ℓ$^{-1}$)	<23	
$Na2SO_4$ (mg ℓ$^{-1}$)	<33	
$MgCl_2$ (mg ℓ$^{-1}$)	<30	
$CaCl_2$ (mg ℓ$^{-1}$)	<57	
NaCl (mg ℓ$^{-1}$)	<191	
Water temperature (°C)	Adult fish: maximum daily mean = 40°C (all year). Spawning: Minimum = 19 °C, ideal = 25-28 °C (November to January).	
pH	6.0-8.5	
Electrical Conductivity (mS m^{-1})	<15	Maxima: Adult Fish = 500 mS m^{-1} (year-round); Juveniles = 170-280 mS m^{-1} (October to February)
Dissolved oxygen (DO) (mg ℓ$^{-1}$)	>6.0	
Toxics[3]		
Ammonia as NH_3 (mg ℓ$^{-1}$)	<0.007	
Nutrients		
Nitrates as N (mg ℓ$^{-1}$)	<0.050	
Phosphorus as PO_4-P (mg ℓ$^{-1}$)	<0.020	

1 The data for salts, either individually or as Total Dissolved Solids, are not supported by the salinity-modeling component that was anticipated to become available from the WODRIS project.
2 There are no locally-relevant data available for salts or salinity tolerances of aquatic invertebrates.
3 Specific data characterizing effluents from identified wastewater treatment plants not yet received from RQIS.

Appendix C Doring River fish EcoSpecs (DWAF 2006b)

Table C1: EWR4 Doring River: EcoSpecs relating to fish

Descriptors	Most recent PES (No. of Individuals)			EcoSpecs for REC (No. of Individuals)		
Species	Fyke net	Seine	Electrofish	Fyke net	Seine	Electrofish
Clanwilliam yellowfish (adult)	1-3	-	-	3-5	-	-
Clanwilliam sandfish (adult)	10-20	-	-	-	>0	>0
Smallmouth bass (all sizes)	10-20	20-30	20-30	20-30	-	-
Bluegill sunfish (all sizes)	20-30	100-200	20-30	-	>0	>0

The dash (-) means that the sampling method was not applicable to the species under discussion.

Table C2: EWR5 Doring River: EcoSpecs relating to fish

Descriptors	Most recent PES (No. of Individuals)			EcoSpecs for REC (No. of Individuals)		
Species	Fyke net	Seine	Electrofish	Fyke net	Seine	Electrofish
Clanwilliam yellowfish (adult)	1-3	-	-	3-5	-	-
Clanwilliam yellowfish (juvenile/larval)	-	-	-	-	>0	>0
Clanwilliam sawfin (adult)	1-5	-	-	3-5	-	-
Clanwilliam sawfin (juvenile/larval)	-	-	-	-	>0	>0
Clanwilliam sandfish (adult)	5-10	-	-	20-30	-	-
Clanwilliam sandfish (juvenile/larval)	-	-	-	-	>0	>0
Smallmouth bass (all sizes)	10-20	20-30	20-30	<10	<10	<10
Bluegill sunfish (all sizes)	20-30	100-200	20-30	<20	<10	<10

The dash (-) means that the sampling method was not applicable to the species under discussion.

Table C3: EWR6 Doring River: EcoSpecs relating to fish

Descriptors	Most recent PES (No. of Individuals)			EcoSpecs for REC (No. of Individuals)		
Species	Fyke net	Seine	Electrofish	Fyke net	Seine	Electrofish
Clanwilliam yellowfish (adult)	1-3	-	-	3-5	-	-
Clanwilliam yellowfish (juvenile/larval)	-	-	-	-	>0	>0
Clanwilliam sawfin (adult)	1-3	-	-	3-5	-	-
Clanwilliam sawfin juvenile/larval)	-	-	-	-	>0	>0
Smallmouth bass (all sizes)	10-20	20-30	5-10	>30	>50	>30
Bluegill sunfish (all sizes)	20-30	20-30	5-10	>30	>50	>30

The dash (-) means that the sampling method was not applicable to the species under discussion.

Appendix D Doring River macroinvertebrate EcoSpecs (DWAF 2006b)

Doring EWR4

EWR Site 4 is on the Doring River and is situated upstream of the Biedouw River confluence.

The extension of no-flow conditions during the dry season low-flow period due to abstraction upstream appears to have a significant impact on the invertebrate assemblages. PES in summer (B/C, based on SASS scores) is lower than in winter, when a number of flow-sensitive species have been recorded, at least in some years.

The following EcoSpecs are suggested targets if an extension of summer low flows is achieved through regulating abstraction:

- SASS Scores should be maintained near a Category B, i.e. SASS5 >125; ASPT should be >6. The fact that the river does cease to flow in summer means that summer ASPTs would be lower than suggested by Dallas (2002) for this class of river.
- At least two of the following taxa should be present:
  - Trichoptera:
    - Ecnomidae
    - Philopotamidae (winter)
    - Hydropsychidae
    - Hydroptilidae.
- The following taxa should be present in stones in current / out of current until mid- summer at least:
  - Ephemeroptera: Leptophlebiidae – present 80% of the time (cumulative for the site).
  - Diptera: Simuliidae – present in 50% of stones-in-current samples.
- The presence of Blephariceridae in spring/early summer would be a response to the extension of summer low flows.
- The following habitat/biotopes should be present and available for habitation by invertebrates:
  - Aquatic vegetation out of current, as well as submerged aquatic vegetation throughout the year (this is threatened by habitat degradation by livestock).
  - Stones-in-current, including fast flowing riffles, at least through spring and early summer.

Doring EWR5

The EcoSpecs for this site are the same as at Site 4, with the exception that Blephariceridae are not expected to frequent this site. In this regard the presence of Notonemouridae through winter to early summer would be a response to the extension of summer low flows.

Doring EWR6

The SASS scores at this site during the summer survey indicate a diverse physical environment (SASS score >200), but some water quality impairment (ASPT = 7).

Possible flow modification over and above the present level of abstraction would threaten the present state of the river.

The following EcoSpecs are suggested:

- SASS Scores should be within a Category B or higher, specifically, i.e. SASS5 >170; ASPT should be >7.5.
- The following taxa should be present:
  - Trichoptera: at least three families of cased caddis present overall at site, with at least two of the following families:
    - Ecnomidae
    - Leptoceridae
    - Philopotamidae
    - Sericostomatidae
  - Ephemeroptera:

    - Leptophlebiidae – present in 90% of samples (cumulative for the site, taken over time).
    - Heptageniidae – present in 80% of samples (cumulative for the site, taken over time).
  - Megaloptera:
    - Corydalidae – present in 40% of samples (cumulative for the site, taken over time).
  - At least 3 families of Coleoptera should be present.
- Blephariceridae and Notonemouridae should remain present in low numbers until at least early summer (November / December) in most years.
- The following habitat/biotopes should be present and available for habitation by invertebrates:
  - Stones-in-current, including fast-flowing, turbulent riffle and run.

Appendix E Doring River riparian vegetation EcoSpecs (DWAF 2006b)

Table E1: EWR4 and EWR5 Doring River: EcoSpecs relating to riparian vegetation

Lateral River Zone	Species	Normal condition	Reaction (Above or below normal)	Cause	Solution
Aquatic Zone	*Azolla filiculoides* *	Not present as this is an exotic species	Increase	Water levels and flow speeds constant as in dry season	Control density by introducing variability in flow
		Not present as this is an exotic species	Decrease	Biological control or adverse environmental conditions	None required.
Lower Wet Bank	*Paspalum urvillei**	Low leaf density around edges of waterways during dry season	Increase extending into Tree-shrub and Back Dynamic Zones	Natural vegetation stressed. Possible increase in moisture during dry season	Investigate causal factors, e.g. leaking canals or unnatural drying out of substrate.
Lower Wet Bank	*Cyperus textilis*	Spread between LD and Lower Wet Bank with concentration in Upper WetBank	Narrow banding	Water levels and flow speeds constant	Control density by introducing variability in flow. Increase grazing pressure.
Lower Dynamic and Wet Bank	*Phragmites australis*	Narrow banding in Wet Bank only	Increase extending into Tree-shrub and Back Dynamic Zones	A. Fire burnt Tree-Shrub Zone. Invasion greater with stock grazing. Reed is pioneer. B. Increased salinity in environment.	Keep disturbance to minimum so that balance can restore itself
Tree-shrub, Back Dynamic	*Acacia karoo*	Lining parts of rivers and streams exposed to annual winter high flows	Decrease of mature trees (dead branches becoming common). Many seedlings in Lower Dynamic and Wet Bank Zones.	Vegetation under stress such as reduced flows. Vegetation being disturbed.	Vegetation under stress such as reduced flows. Vegetation being disturbed.
All zones	*Acacia longifolia**, *Acacia mearnsii**, *Acacia melanoxylon**, *Eucalyptus camaldulensis**	Not present as exotic invader	Increase	Vegetation under stress such as reduced flows. Vegetation being disturbed.	Allow indigenous vegetation to reinstate natural cover. Remove disturbance. Reinstate natural flow regimes. Control exotics mechanically, chemically and biologically.

Alien species marked with *

Table E2. Riparian RQOs and TPCs at EWR 5 (derived from Table 16.5; DWA 2014). * = exotic species.

Component	Species	RQO	TPCs
Aquatic Zone	*Azolla filiculoides**	None present.	Present
Lower Wet Bank	*Paspalum urvillei**	Low leaf density around edges of waterways during dry season.	None available
Lower Wet Bank	*Cyperus textilis*	Spread between LD and Lower Wet Bank with concentration in Upper Wet Bank	None available
Lower Dynamic and Wet Bank	*Phragmites australis*	Only a narrow banding should be present in Wet Bank.	None available
Tree-shrub, Back Dynamic	*Acacia karoo*		None available
All Zones	*Nerium oleander*	Present but not dominant	Any increase
	Acacia longifolia, A. mearnsii*, A. melanoxylon*, Eucalyptus camaldulensis**	Not present.	Present

Table E3: EWR6 Doring River: EcoSpecs relating to riparian vegetation

Lateral River Zone	Species	Normal condition	Reaction	Cause	Solution
Aquatic Zone	*Azolla filiculoides* *	Not present, as this is an exotic species.	Increase.	Water levels and flow speeds constant as in dry season.	Control density by introducing variability in flow.
		Not present, as this is an exotic species.	Decrease.	Biological control or adverse environmental conditions.	None required.
Lower Wet Bank	*Paspalum urvillei**	Low leaf density around edges of waterways during dry season.	Increase extending into Tree-shrub and Back Dynamic Zones.	Natural vegetation stressed. Possible increase in moisture during dry season.	Investigate causal factors, e.g. leaking canals or unnatural drying out of substrate.
Lower Dynamic and Wet Bank	*Phragmites australis*	Narrow banding in Wet Bank only	Increase extending into Tree-shrub and Back Dynamic Zones.	A. Fire burnt Tree-Shrub Zone. Invasion greater with stock grazing. Reed is pioneer. B. Increased salinity in environment.	Keep disturbance to minimum so that balance can restore itself.
Wet Bank	*Salix mucronata*	Lining parts of rivers and streams exposed to annual winter high flows.	Decrease.	Natural increase in trees or unnatural increase in tall exotics.	If abnormal increase in trees (non *Salix*) consider reason for their increase and remedy if necessary (e.g. control exotics to reduce biomass density)
Tree-shrub, Back Dynamic	*Brabejum stellatifolium*	Lining parts of rivers and streams exposed to annual winter high flows.	Decrease of mature trees (dead branches becoming common). Many seedlings in Lower Dynamic and Wet Bank Zones.	Vegetation under stress such as reduced flows. Vegetation being disturbed.	Vegetation under stress such as reduced flows. Vegetation being disturbed.
All zones	*Acacia longifolia**, *Acacia mearnsii**, *Acacia melanoxylon**, *Eucalyptus camaldulensis**	Not present as exotic invader.	Increase.	Vegetation under stress such as reduced flows. Vegetation being disturbed.	Allow indigenous vegetation to reinstate natural cover. Remove disturbance. Reinstate natural flow regimes. Control exotics mechanically, chemically and biologically.

Alien species marked with *

Table E4. Riparian RQOs and TPCs at EWR 6 (derived from Table 19.5; DWA 2014). * = exotic species.

Component	Species	RQO	TPCs
Aquatic Zone	*Azolla filiculoides**	None present.	Present
Lower Wet Bank	*Paspalum urvillei**	Low leaf density around edges of waterways during dry season.	None available
Lower Dynamic and Wet Bank	*Phragmites australis*	narrow banding in Wet Bank only	None available
Wet Bank	*Salix mucronata*	Lining parts of rivers and streams exposed to annual winter high flows	None available
Tree-shrub, Back Dynamic	*Brabejum stellatifolium*	Present lining parts of rivers and streams exposed to annual winter high flows	None available
All Zones	*Nerium oleander*	Present but not dominant	Any increase
	Acacia longifolia, A. mearnsii*, A. melanoxylon*, Eucalyptus camaldulensis**	Not present.	Present

Appendix F RDRM output files

Table F1. RDRM output for Doring EWR site 6 with RCP 2.6 data.

Revised Desktop Model outputs for site: 'EWR_6'

HYDROLOGY DATA SUMMARY

Natural Flows:					RCP 2.6 min flows:				
Area (km^2)	MAR (m^3 * 10^6)	Ann.SD	Q75	Ann. CV	Area (km^2)	MAR (m^3 * 10^6)	Ann.SD	Q75	Ann. CV
0.00	160.69	59.96	1.47	0.37	0.00	48.31	15.06	0.27	0.31

% Zero flows =   0.0   % Zero flows =   5.2
Baseflow Parameters: A = 0.970, B = 0.42Baseflow Parameters: A = 0.970, B = 0.420
BFI = 0.30 : Hydro Index =   5.8   BFI = 0.27 : Hydro Index = 9.9

MONTH	MEAN (m^3 * 10^6)	SD	CV	MONTH	MEAN (m^3 * 10^6)	SD	CV
Oct	15.79	5.79	0.37	Oct	4.22	3.37	0.80
Nov	8.29	2.91	0.35	Nov	2.28	1.91	0.84
Dec	3.27	1.53	0.47	Dec	0.78	0.65	0.83
Jan	1.10	1.27	1.16	Jan	0.19	0.29	1.53
Feb	0.46	0.56	1.21	Feb	0.12	0.32	2.71
Mar	1.09	1.13	1.03	Mar	0.54	1.05	1.95
Apr	4.88	8.12	1.66	Apr	2.46	4.46	1.81
May	14.43	14.68	1.02	May	4.58	4.68	1.02
Jun	25.87	17.02	0.66	Jun	6.55	4.28	0.65
Jul	34.51	24.34	0.71	Jul	10.16	6.44	0.63
Aug	28.53	12.66	0.44	Aug	10.13	5.89	0.58
Sep	22.48	8.11	0.36	Sep	6.32	3.36	0.53

Critical months: WET : Jul, DRY : Feb
Using 20th percentile of FDC of separated baseflows
Max. baseflows (m^3/s): WET :   3.977, DRY :   0.217

HYDRAULICS DATA SUMMARY

Catchment Area (km^2)	750.00
Geomorph. Zone	3
Valley Slope (Fraction)	0.0300
Width/Depth scaling	0.50
Max. Channel width (m)	95.00
Max. Channel Depth (m)	5.50

Observed Channel XS used
Observed Rating Curve used
(Gradients and Roughness n values calibrated)

Max. Gradient	0.00900
Min. Gradient	0.00300
Gradient Shape Factor	20
Max. Mannings n	0.050
Min. Mannings n	0.040

n Shape Factor 20

Habitat Type definitions used:

Fast:	>	0.3 m/s
Shallow:	>	0.1 m
Intermediate:	>	0.2 m
Deep (fast):	>	0.3 m
Deep (slow):	>	0.5 m

FLOW - STRESSOR RESPONSE DATA SUMMARY

Table of Stress weightings

Season	Wet	Dry
Stress at 0 FS:	9	9
FS Weight:	2	2
FI Weight:	2	2
FD Weight:	2	0

Table of flows ($m^3/2$) v stress index

Stress	Wet Season Flow	Dry Season Flow
0.0	4.067	0.237
0.5	3.132	0.213
1.0	2.618	0.191
1.5	2.187	0.170
2.0	1.923	0.152
2.5	1.746	0.135
3.0	1.544	0.121
3.5	0.540	0.108
4.0	0.477	0.096
4.5	0.432	0.084
5.0	0.388	0.071
5.5	0.351	0.059
6.0	0.312	0.049
6.5	0.283	0.040
7.0	0.241	0.033
7.5	0.178	0.027
8.0	0.127	0.022
8.5	0.076	0.017
9.0	0.023	0.012
9.5	0.010	0.007
10.0	0.000	0.000

Table of default/altered SHIFT factors for the Stress Frequency Curves

Category	High SHIFT		Low SHIFT	
	Default	Altered	Default	Altered
Wet season				
A	5.596	5.596	0.278	0.278
A/B	5.727	5.727	0.551	0.551
B	5.859	5.859	0.823	0.823
B/C	6.055	6.055	1.232	1.232
C	6.252	6.252	1.642	1.642
C/D	6.515	6.515	2.187	2.187

D	6.778	6.778	2.732	2.732
Dry season				
A	6.606	6.606	0.409	0.409
A/B	6.808	6.808	0.719	0.719
B	7.011	7.011	1.029	1.029
B/C	7.315	7.315	1.495	1.495
C	7.619	7.619	1.960	1.960
C/D	8.024	8.024	2.581	2.581
D	8.429	8.429	3.201	3.201

Perenniality Rules
Non-Perennial Allowed

Alignment of maximum stress to Present Day stress
Not Aligned

HIGH FLOW REQUIREMENT SUMMARY

Bankfull channel discharge (m^3/s) = 953.120
Flood event requirements

Class	Frequency	Peak(m^3/s)	Duration(hours)	N. Events	Volume(MCM)
1	Annual	11.129	61	5	1.018
2	Annual	21.834	65	2	2.130
3	Annual	41.379	65	2	4.036
4	1:2 year	101.181	72	2	11.068
5	1:5 year	237.113	80	1	28.819

Flood requirements have been constrained to a maximum of 0.46 of natural high flows

Events excluded from the time series of high flow requirements:
No Events excluded.

FINAL RESERVE SUMMARY DETAILS

EWR Flows are NOT constrained to be below Natural or Present Day Flows

Long term mean flow requirements (Mill. m^3 and %MAR)

Category	Low Flows		Total Flows	
	Mill. m^3	%MAR	Mill. m^3	%MAR
A	34.683	21.6	76.369	47.5
A/B	32.040	19.9	71.996	44.8
B	29.528	18.4	67.577	42.1
B/C	26.249	16.3	62.463	38.9
C	23.441	14.6	57.629	35.9
C/D	20.043	12.5	52.209	32.5
D	16.348	10.2	46.483	28.9

FLOW DURATION and RESERVE ASSURANCE TABLES

Columns are FDC precentage points:

	10	20	30	40	50	60	70	80	90	99
Natural Total flow duration curve (mill. m^3)										
Oct	27.334	19.292	16.725	14.354	14.042	12.864	12.322	12.028	11.260	10.643
Nov	12.590	9.673	8.733	8.225	7.163	6.974	6.657	6.581	6.184	5.677
Dec	6.578	3.903	3.547	2.909	2.614	2.455	2.371	2.294	2.200	2.022
Jan	2.330	1.337	1.006	0.759	0.685	0.639	0.600	0.556	0.477	0.452
Feb	1.081	0.521	0.457	0.386	0.364	0.289	0.229	0.160	0.147	0.099
Mar	3.177	1.490	1.179	0.976	0.809	0.602	0.475	0.335	0.173	0.097
Apr	11.947	6.588	3.645	3.125	2.519	1.790	1.411	1.088	1.014	0.605
May	39.711	28.336	17.257	10.882	8.865	7.473	5.289	4.213	2.420	1.422
Jun	52.321	36.826	31.609	28.364	23.312	20.359	16.956	13.475	7.203	2.506
Jul	74.170	51.978	42.542	35.177	29.646	26.730	18.395	16.117	11.195	3.962
Aug	47.921	39.770	36.143	30.242	26.974	24.767	21.430	16.893	14.344	9.612
Sep	33.620	29.250	24.469	22.187	21.017	19.463	17.903	17.417	13.817	12.006
Natural Baseflow flow duration curve (mill. m^3)										
Oct	9.556	8.006	7.090	6.677	6.304	5.829	5.280	4.439	3.991	3.214
Nov	6.894	6.539	5.908	5.634	5.471	4.908	4.509	3.869	3.264	2.591
Dec	4.672	3.903	3.547	2.909	2.614	2.455	2.329	2.196	2.110	1.976
Jan	2.330	1.337	1.006	0.759	0.685	0.639	0.600	0.556	0.477	0.452
Feb	1.081	0.521	0.457	0.386	0.364	0.289	0.229	0.160	0.147	0.099
Mar	1.109	0.697	0.665	0.537	0.439	0.351	0.316	0.274	0.161	0.097
Apr	3.853	1.563	1.157	0.872	0.801	0.649	0.577	0.403	0.349	0.272
May	7.421	5.423	3.864	2.214	2.030	1.684	1.368	1.075	0.646	0.450
Jun	9.724	7.623	6.753	6.466	5.105	4.366	3.594	2.764	1.543	0.666
Jul	13.813	10.506	9.766	7.984	6.641	5.415	5.094	4.122	2.942	1.013
Aug	10.519	9.895	9.189	7.798	6.902	5.999	5.585	4.938	3.971	2.387
Sep	9.532	8.971	7.843	7.495	6.761	6.280	5.394	4.888	4.012	3.240
Category Low Flow Assurance curves (mill. m^3)										
A Category										
Oct	6.346	6.346	6.147	5.637	5.226	4.723	4.003	3.063	2.810	2.806

Nov	5.031	5.031	4.983	4.671	4.345	3.904	3.100	2.233	2.212	2.193
Dec	3.210	3.210	3.140	2.718	2.293	2.019	1.764	1.549	1.548	1.547
Jan	1.234	1.172	0.993	0.776	0.613	0.530	0.484	0.447	0.417	0.415
Feb	0.503	0.458	0.395	0.328	0.267	0.214	0.164	0.129	0.107	0.089
Mar	0.635	0.629	0.596	0.500	0.388	0.306	0.252	0.212	0.155	0.109
Apr	1.678	1.494	1.109	0.827	0.655	0.543	0.444	0.359	0.287	0.257
May	4.329	4.329	3.632	2.520	1.735	1.403	1.109	0.819	0.580	0.457
Jun	6.008	6.008	5.601	5.029	4.286	3.452	2.614	1.588	0.972	0.687
Jul	8.970	8.306	7.681	6.767	5.680	4.836	3.124	1.256	1.057	0.685
Aug	7.377	7.377	7.255	6.562	5.774	5.031	4.157	3.146	2.561	2.284
Sep	6.564	6.564	6.464	5.964	5.486	4.907	4.086	3.092	2.670	2.668
A/B Category										
Oct	5.789	5.789	5.646	5.199	4.854	4.408	3.662	2.820	2.752	2.744
Nov	4.638	4.638	4.597	4.322	4.045	3.647	2.804	2.214	2.178	2.145
Dec	2.978	2.978	2.915	2.532	2.144	1.886	1.630	1.553	1.539	1.528
Jan	1.142	1.091	0.927	0.727	0.575	0.495	0.448	0.414	0.404	0.403
Feb	0.470	0.428	0.370	0.308	0.251	0.199	0.151	0.119	0.099	0.087
Mar	0.593	0.587	0.558	0.469	0.364	0.286	0.233	0.195	0.144	0.104
Apr	1.545	1.387	1.036	0.775	0.614	0.507	0.411	0.331	0.268	0.246
May	3.976	3.976	3.362	2.345	1.624	1.312	1.022	0.750	0.543	0.439
Jun	5.479	5.479	5.150	4.641	3.984	3.229	2.382	1.416	0.918	0.659
Jul	7.965	7.567	6.978	6.188	5.346	4.618	2.219	1.214	1.024	0.677
Aug	6.734	6.734	6.631	6.036	5.364	4.694	3.800	2.855	2.421	2.208
Sep	6.009	6.009	5.924	5.488	5.089	4.581	3.742	2.814	2.605	2.603
B Category										
Oct	5.305	5.305	5.191	4.805	4.513	4.087	3.276	2.655	2.639	2.625
Nov	4.276	4.276	4.243	4.004	3.763	3.377	2.438	2.072	2.060	2.050
Dec	2.763	2.763	2.707	2.358	2.001	1.750	1.487	1.474	1.472	1.470
Jan	1.061	1.016	0.866	0.681	0.538	0.461	0.412	0.388	0.388	0.388
Feb	0.438	0.399	0.346	0.290	0.236	0.183	0.138	0.109	0.091	0.081
Mar	0.553	0.548	0.521	0.439	0.342	0.266	0.214	0.180	0.134	0.097
Apr	1.431	1.289	0.966	0.725	0.575	0.472	0.377	0.304	0.249	0.231
May	3.664	3.664	3.112	2.184	1.518	1.220	0.929	0.682	0.507	0.418
Jun	5.021	5.021	4.739	4.291	3.706	2.997	2.097	1.232	0.867	0.630

Jul	7.221	6.863	6.372	5.705	5.058	4.386	1.455	1.173	0.994	0.669
Aug	6.152	6.152	6.066	5.560	4.987	4.354	3.397	2.562	2.277	2.100
Sep	5.505	5.505	5.434	5.062	4.728	4.250	3.352	2.550	2.495	2.488
B/C Category										
Oct	4.690	4.690	4.606	4.317	4.071	3.608	2.760	2.473	2.462	2.451
Nov	3.804	3.804	3.781	3.600	3.383	2.956	2.032	1.943	1.928	1.915
Dec	2.475	2.475	2.429	2.128	1.802	1.543	1.414	1.405	1.395	1.386
Jan	0.949	0.914	0.782	0.616	0.485	0.410	0.366	0.366	0.366	0.365
Feb	0.394	0.360	0.314	0.264	0.213	0.161	0.122	0.096	0.081	0.072
Mar	0.498	0.494	0.471	0.398	0.309	0.237	0.189	0.159	0.119	0.088
Apr	1.276	1.156	0.872	0.657	0.519	0.420	0.331	0.268	0.222	0.209
May	3.250	3.250	2.780	1.969	1.370	1.082	0.799	0.598	0.458	0.390
Jun	4.423	4.423	4.208	3.855	3.336	2.624	1.695	1.048	0.797	0.590
Jul	6.252	5.941	5.621	5.185	4.716	3.611	1.323	1.112	0.950	0.656
Aug	5.410	5.410	5.350	4.983	4.504	3.852	2.866	2.242	2.078	1.954
Sep	4.860	4.860	4.810	4.544	4.267	3.756	2.827	2.328	2.324	2.320
C Category										
Oct	4.229	4.229	4.159	3.908	3.639	3.036	2.334	2.298	2.292	2.287
Nov	3.427	3.427	3.408	3.239	2.981	2.372	1.816	1.805	1.795	1.786
Dec	2.234	2.234	2.193	1.920	1.602	1.339	1.319	1.314	1.309	1.305
Jan	0.852	0.824	0.706	0.557	0.434	0.359	0.346	0.345	0.345	0.345
Feb	0.355	0.325	0.285	0.240	0.189	0.141	0.107	0.085	0.072	0.063
Mar	0.449	0.446	0.426	0.360	0.277	0.209	0.165	0.141	0.106	0.080
Apr	1.143	1.041	0.788	0.594	0.465	0.368	0.288	0.237	0.198	0.190
May	2.919	2.919	2.510	1.780	1.224	0.929	0.679	0.533	0.414	0.365
Jun	3.966	3.966	3.797	3.483	2.963	2.133	1.318	0.957	0.732	0.552
Jul	5.527	5.345	5.097	4.810	4.342	1.996	1.239	1.052	0.904	0.645
Aug	4.876	4.876	4.829	4.511	4.031	3.247	2.374	2.025	1.896	1.817
Sep	4.383	4.383	4.344	4.118	3.820	3.160	2.338	2.164	2.163	2.162
C/D Category										
Oct	3.714	3.714	3.644	3.339	2.889	2.237	2.095	2.092	2.089	2.087
Nov	2.985	2.985	2.958	2.721	2.272	1.644	1.635	1.633	1.631	1.629
Dec	1.953	1.953	1.914	1.648	1.306	1.223	1.219	1.215	1.211	1.207

Jan	0.743	0.719	0.616	0.482	0.367	0.320	0.320	0.320	0.320	0.320
Feb	0.309	0.284	0.250	0.207	0.158	0.117	0.090	0.072	0.060	0.053
Mar	0.392	0.389	0.372	0.312	0.235	0.174	0.139	0.119	0.091	0.070
Apr	0.998	0.909	0.688	0.513	0.391	0.302	0.240	0.201	0.170	0.166
May	2.566	2.566	2.204	1.541	1.009	0.728	0.558	0.458	0.361	0.335
Jun	3.489	3.489	3.323	2.970	2.316	1.454	1.028	0.850	0.654	0.507
Jul	4.891	4.777	4.593	4.287	2.612	1.326	1.145	0.981	0.842	0.633
Aug	4.303	4.303	4.252	3.869	3.193	2.377	1.926	1.769	1.677	1.650
Sep	3.857	3.857	3.813	3.526	3.030	2.317	1.993	1.985	1.977	1.970

D Category

Oct	3.125	3.125	2.920	2.329	1.960	1.950	1.940	1.930	1.920	1.911
Nov	2.462	2.462	2.397	1.959	1.519	1.507	1.503	1.499	1.495	1.492
Dec	1.661	1.661	1.611	1.308	1.130	1.128	1.126	1.124	1.122	1.120
Jan	0.648	0.625	0.531	0.406	0.313	0.306	0.304	0.302	0.300	0.298
Feb	0.269	0.248	0.216	0.173	0.130	0.098	0.075	0.060	0.050	0.044
Mar	0.340	0.338	0.321	0.264	0.194	0.144	0.116	0.100	0.077	0.062
Apr	0.873	0.791	0.592	0.431	0.320	0.249	0.201	0.169	0.146	0.145
May	2.230	2.230	1.879	1.251	0.781	0.587	0.474	0.391	0.315	0.309
Jun	2.969	2.969	2.683	2.098	1.458	1.081	0.910	0.754	0.583	0.466
Jul	4.338	4.216	3.615	2.188	1.360	1.207	1.054	0.912	0.793	0.618
Aug	3.585	3.585	3.399	2.707	1.993	1.766	1.666	1.542	1.503	1.503
Sep	3.184	3.184	3.024	2.387	1.838	1.820	1.815	1.810	1.805	1.800

Category Total Flow Assurance curves (mill. m^3)

A Category

Oct	10.585	9.494	9.295	7.767	7.356	6.853	6.133	5.193	4.846	2.806
Nov	6.160	6.049	6.001	5.689	5.363	4.922	3.812	2.233	2.212	2.193
Dec	3.210	3.210	3.140	2.718	2.293	2.019	1.764	1.549	1.548	1.547
Jan	1.234	1.172	0.993	0.776	0.613	0.530	0.484	0.447	0.417	0.415
Feb	0.503	0.458	0.395	0.328	0.267	0.214	0.164	0.129	0.107	0.089
Mar	0.736	0.629	0.596	0.500	0.388	0.306	0.252	0.212	0.155	0.109
Apr	4.100	2.512	2.127	1.845	0.655	0.543	0.444	0.359	0.287	0.257
May	17.535	12.657	7.668	4.650	3.865	3.512	2.127	0.819	0.580	0.457
Jun	23.593	19.131	16.669	12.422	9.849	8.099	6.650	3.718	3.008	0.982

Jul	37.890	24.020	20.785	17.835	16.748	14.037	8.178	6.106	4.528	1.303
Aug	19.574	18.445	18.323	17.488	15.101	12.178	9.211	7.182	6.597	4.709
Sep	17.632	15.108	12.870	11.425	10.096	8.943	8.122	6.240	5.716	4.798
A/B Category										
Oct	10.028	8.937	8.794	7.329	6.984	6.538	5.792	4.931	3.668	2.744
Nov	5.767	5.656	5.615	5.340	5.063	4.665	2.804	2.214	2.178	2.145
Dec	2.978	2.978	2.915	2.532	2.144	1.886	1.630	1.553	1.539	1.528
Jan	1.142	1.091	0.927	0.727	0.575	0.495	0.448	0.414	0.404	0.403
Feb	0.470	0.428	0.370	0.308	0.251	0.199	0.151	0.119	0.099	0.087
Mar	0.694	0.587	0.558	0.469	0.364	0.286	0.233	0.195	0.144	0.104
Apr	3.967	2.405	2.054	1.793	0.614	0.507	0.411	0.331	0.268	0.246
May	15.044	10.215	7.398	4.882	3.754	3.404	2.040	1.388	0.543	0.439
Jun	23.064	18.602	14.285	11.158	9.038	7.265	6.418	3.546	2.951	0.954
Jul	36.886	24.035	19.370	17.256	16.127	13.123	6.968	5.159	3.867	1.268
Aug	19.838	18.006	17.699	16.092	14.182	11.377	8.548	6.891	6.134	4.338
Sep	17.077	13.915	11.283	10.542	9.699	8.617	7.511	5.758	4.735	4.733
B Category										
Oct	9.544	7.435	7.321	6.935	6.643	6.217	5.378	4.340	3.556	2.625
Nov	5.406	5.294	5.261	5.022	4.781	3.988	2.438	2.072	2.060	2.050
Dec	2.763	2.763	2.707	2.358	2.001	1.750	1.487	1.474	1.472	1.470
Jan	1.061	1.016	0.866	0.681	0.538	0.461	0.412	0.388	0.388	0.388
Feb	0.438	0.399	0.346	0.290	0.236	0.183	0.138	0.109	0.091	0.081
Mar	0.553	0.548	0.521	0.439	0.342	0.266	0.214	0.180	0.134	0.097
Apr	3.769	2.307	1.984	1.743	0.575	0.472	0.377	0.304	0.249	0.231
May	14.567	9.716	7.148	4.314	3.648	3.256	1.947	1.541	0.507	0.418
Jun	22.704	18.143	13.253	10.363	8.760	7.033	6.133	3.362	2.732	0.925
Jul	36.142	23.300	18.763	16.773	15.118	11.069	5.582	4.321	3.124	1.259
Aug	19.256	17.220	17.134	14.469	12.077	10.426	7.433	6.598	5.335	4.230
Sep	16.573	13.070	10.488	9.150	8.764	7.931	6.500	4.680	4.625	4.618
B/C Category										
Oct	9.046	6.820	6.736	6.447	6.201	5.738	4.791	3.491	3.480	2.451
Nov	4.934	4.822	4.799	4.618	3.820	2.956	2.032	1.943	1.928	1.915
Dec	2.475	2.475	2.429	2.128	1.802	1.543	1.414	1.405	1.395	1.386

Jan	0.949	0.914	0.782	0.616	0.485	0.410	0.366	0.366	0.366	0.365
Feb	0.394	0.360	0.314	0.264	0.213	0.161	0.122	0.096	0.081	0.072
Mar	0.498	0.494	0.471	0.398	0.309	0.237	0.189	0.159	0.119	0.088
Apr	3.614	2.174	1.890	0.657	0.519	0.420	0.331	0.268	0.222	0.209
May	14.067	7.693	6.816	4.099	3.500	2.711	1.817	1.160	0.458	0.390
Jun	21.893	16.731	11.669	9.927	7.881	6.660	5.568	3.178	1.815	0.885
Jul	35.173	22.348	18.012	16.092	14.056	9.683	5.238	3.242	3.071	1.165
Aug	18.514	16.478	16.160	12.909	10.576	9.569	6.902	6.100	4.208	3.294
Sep	15.801	12.350	9.151	8.580	8.303	6.904	5.975	4.458	4.454	3.633

C Category

Oct	8.585	6.562	6.289	6.038	5.722	4.812	3.352	3.316	3.125	2.287
Nov	4.556	4.445	4.426	4.241	3.273	2.372	1.816	1.805	1.795	1.786
Dec	2.234	2.234	2.193	1.920	1.602	1.339	1.319	1.314	1.309	1.305
Jan	0.852	0.824	0.706	0.557	0.434	0.359	0.346	0.345	0.345	0.345
Feb	0.355	0.325	0.285	0.240	0.189	0.141	0.107	0.085	0.072	0.063
Mar	0.449	0.446	0.426	0.360	0.277	0.209	0.165	0.141	0.106	0.080
Apr	3.481	2.059	1.806	0.594	0.465	0.368	0.288	0.237	0.198	0.190
May	13.650	8.176	6.546	3.910	2.798	1.947	1.697	0.533	0.414	0.365
Jun	20.203	16.275	11.258	8.945	6.999	6.169	4.161	3.087	1.728	0.552
Jul	34.346	21.721	17.488	15.183	11.526	7.050	4.794	3.182	1.922	0.940
Aug	17.980	15.944	15.254	12.092	9.995	7.946	6.410	4.155	4.009	3.011
Sep	15.324	10.443	9.398	8.154	7.394	6.215	4.468	4.294	4.190	3.180

C/D Category

Oct	7.954	5.844	5.774	5.469	4.925	3.255	3.113	3.110	2.913	2.087
Nov	4.114	4.003	3.976	2.721	2.272	1.644	1.635	1.633	1.631	1.629
Dec	1.953	1.953	1.914	1.648	1.306	1.223	1.219	1.215	1.211	1.207
Jan	0.743	0.719	0.616	0.482	0.367	0.320	0.320	0.320	0.320	0.320
Feb	0.309	0.284	0.250	0.207	0.158	0.117	0.090	0.072	0.060	0.053
Mar	0.392	0.389	0.372	0.312	0.235	0.174	0.139	0.119	0.091	0.070
Apr	2.420	1.927	1.589	0.513	0.391	0.302	0.240	0.201	0.170	0.166
May	13.211	7.620	6.240	3.671	2.583	1.746	1.532	0.458	0.361	0.335
Jun	18.810	14.964	10.784	7.491	6.352	5.135	3.158	2.923	0.654	0.507
Jul	33.710	21.121	16.984	13.750	9.749	5.303	3.275	3.093	1.845	0.802
Aug	16.491	15.371	14.292	10.348	7.738	6.413	5.390	3.880	2.695	2.299

Sep	14.047	8.911	7.849	6.674	6.137	5.358	4.123	3.946	2.995	2.878

D Category

Oct	7.365	5.255	5.050	4.459	3.996	2.968	2.958	1.930	1.920	1.911
Nov	3.591	3.480	3.084	1.959	1.519	1.507	1.503	1.499	1.495	1.492
Dec	1.661	1.661	1.611	1.308	1.130	1.128	1.126	1.124	1.122	1.120
Jan	0.648	0.625	0.531	0.406	0.313	0.306	0.304	0.302	0.300	0.298
Feb	0.269	0.248	0.216	0.173	0.130	0.098	0.075	0.060	0.050	0.044
Mar	0.340	0.338	0.321	0.264	0.194	0.144	0.116	0.100	0.077	0.062
Apr	2.294	1.809	0.898	0.431	0.320	0.249	0.201	0.169	0.146	0.145
May	12.789	6.524	5.915	3.381	1.799	1.605	1.347	0.391	0.315	0.309
Jun	16.575	13.237	10.145	6.186	5.494	4.229	3.040	1.772	0.583	0.466
Jul	33.157	19.715	16.007	11.300	5.905	4.661	3.184	1.930	1.431	0.618
Aug	15.773	14.653	12.878	8.987	6.538	5.802	4.266	3.168	2.256	1.503
Sep	13.807	9.256	7.099	6.176	4.986	3.950	3.857	2.828	2.405	1.800

Table F2: RDRM output for Doring EWR site 6 with RCP 8.5 data.

Revised Desktop Model outputs for site: 'EWR_6'

HYDROLOGY DATA SUMMARY

Natural Flows:					RCP 8.5 min flows:				
Area	MAR	Ann.SD	Q75	Ann.	Area	MAR	Ann.SD	Q75	Ann.
(km^2)	(m^3 * 10^6)			CV	(km^2)	(m^3 * 106)			CV
0.00	160.69	59.96	1.47	0.37	0.00	44.45	21.45	0.10	0.48

% Zero flows = 0.0 % Zero flows = 3.7

Baseflow Parameters: A = 0.970, B = 0.42Baseflow Parameters: A = 0.970, B = 0.420

BFI = 0.30 : Hydro Index = 5.8 BFI = 0.27 : Hydro Index = 8.5

MONTH	MEAN	SD	CV	MONTH	MEAN	SD	CV
	(m^3 * 10^6)				(m^3 * 10^6)		
Oct	15.79	5.79	0.37	Oct	3.93	2.99	0.76
Nov	8.29	2.91	0.35	Nov	1.74	1.69	0.97
Dec	3.27	1.53	0.47	Dec	0.68	0.74	1.09
Jan	1.10	1.27	1.16	Jan	0.18	0.25	1.41
Feb	0.46	0.56	1.21	Feb	0.02	0.04	1.88
Mar	1.09	1.13	1.03	Mar	0.48	0.88	1.82
Apr	4.88	8.12	1.66	Apr	2.46	4.98	2.02
May	14.43	14.68	1.02	May	3.94	5.71	1.45
Jun	25.87	17.02	0.66	Jun	6.71	4.25	0.63
Jul	34.51	24.34	0.71	Jul	11.12	8.01	0.72
Aug	28.53	12.66	0.44	Aug	7.79	4.53	0.58
Sep	22.48	8.11	0.36	Sep	5.40	3.29	0.61

Critical months: WET : Jul, DRY : Feb
Using 10th percentile of FDC of separated baseflows
Max. baseflows (m^3/s): WET : 3.977, DRY : 0.217

HYDRAULICS DATA SUMMARY

Catchment Area (km^2)	750.00
Geomorph. Zone	3
Valley Slope (Fraction)	0.0300
Width/Depth scaling	0.50
Max. Channel width (m)	95.00
Max. Channel Depth (m)	5.50

Observed Channel XS used
Observed Rating Curve used
(Gradients and Roughness n values calibrated)

Max. Gradient	0.00900
Min. Gradient	0.00300
Gradient Shape Factor	20
Max. Mannings n	0.050
Min. Mannings n	0.040
n Shape Factor	20

Habitat Type definitions used:

Fast:	>	0.3 m/s
Shallow:	>	0.1 m
Intermediate:	>	0.2 m
Deep (fast):	>	0.3 m
Deep (slow):	>	0.5 m

FLOW - STRESSOR RESPONSE DATA SUMMARY

Table of Stress weightings

Season	Wet	Dry
Stress at 0 FS:	9	9
FS Weight:	2	2
FI Weight:	2	2
FD Weight:	2	0

Stress	Flow	Flow
0.0	4.067	0.237
0.5	3.132	0.213
1.0	2.618	0.191
1.5	2.187	0.170
2.0	1.923	0.152
2.5	1.746	0.135
3.0	1.544	0.121
3.5	0.540	0.108
4.0	0.477	0.096
4.5	0.432	0.084
5.0	0.388	0.071
5.5	0.351	0.059
6.0	0.312	0.049
6.5	0.283	0.040
7.0	0.241	0.033
7.5	0.178	0.027
8.0	0.127	0.022
8.5	0.076	0.017
9.0	0.023	0.012
9.5	0.010	0.007
10.0	0.000	0.000

Table of default/altered SHIFT factors for the Stress Frequency Curves

Category	High SHIFT		Low SHIFT	
	Default	Altered	Default	Altered
Wet season				
A	5.596	5.596	0.278	0.278
A/B	5.727	5.727	0.551	0.551
B	5.859	5.859	0.823	0.823
B/C	6.055	6.055	1.232	1.232
C	6.252	6.252	1.642	1.642
C/D	6.515	6.515	2.187	2.187
D	6.778	6.778	2.732	2.732
Dry season				
A	6.606	6.606	0.409	0.409

A/B	6.808	6.808	0.719	0.719
B	7.011	7.011	1.029	1.029
B/C	7.315	7.315	1.495	1.495
C	7.619	7.619	1.960	1.960
C/D	8.024	8.024	2.581	2.581
D	8.429	8.429	3.201	3.201

Perenniality Rules
Non-Perennial Allowed

Alignment of maximum stress to Present Day stress
Not Aligned

HIGH FLOW REQUIREMENT SUMMARY

Bankfull channel discharge (m^3/s) = 953.120

Flood event requirements

Class	Frequency	Peak(m^3/s)	Duration(hours)	N. Events	Volume(MCM)
1	Annual	11.129	61	5	1.018
2	Annual	21.834	65	2	2.130
3	Annual	41.379	65	2	4.036
4	1:2 year	101.181	72	2	11.068
5	1:5 year	237.113	80	1	28.819

Flood requirements have been constrained to a maximum of 0.46 of natural high flows

Events excluded from the time series of high flow requirements:
No Events excluded.

FINAL RESERVE SUMMARY DETAILS

EWR Flows are NOT constrained to be below Natural or Present Day Flows

Long term mean flow requirements (Mill. m^3 and %MAR)

Category	Low Flows		Total Flows	
	Mill. m^3	%MAR	Mill. m^3	%MAR
A	34.683	21.6	76.369	47.5
A/B	32.040	19.9	71.996	44.8
B	29.528	18.4	67.577	42.1
B/C	26.249	16.3	62.463	38.9
C	23.441	14.6	57.629	35.9
C/D	20.043	12.5	52.209	32.5
D	16.348	10.2	46.483	28.9

FLOW DURATION and RESERVE ASSURANCE TABLES

Columns are FDC precentage points:

Natural Total flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	27.334	19.292	16.725	14.354	14.042	12.864	12.322	12.028	11.260	10.643
Nov	12.590	9.673	8.733	8.225	7.163	6.974	6.657	6.581	6.184	5.677
Dec	6.578	3.903	3.547	2.909	2.614	2.455	2.371	2.294	2.200	2.022
Jan	2.330	1.337	1.006	0.759	0.685	0.639	0.600	0.556	0.477	0.452
Feb	1.081	0.521	0.457	0.386	0.364	0.289	0.229	0.160	0.147	0.099
Mar	3.177	1.490	1.179	0.976	0.809	0.602	0.475	0.335	0.173	0.097
Apr	11.947	6.588	3.645	3.125	2.519	1.790	1.411	1.088	1.014	0.605
May	39.711	28.336	17.257	10.882	8.865	7.473	5.289	4.213	2.420	1.422
Jun	52.321	36.826	31.609	28.364	23.312	20.359	16.956	13.475	7.203	2.506
Jul	74.170	51.978	42.542	35.177	29.646	26.730	18.395	16.117	11.195	3.962
Aug	47.921	39.770	36.143	30.242	26.974	24.767	21.430	16.893	14.344	9.612
Sep	33.620	29.250	24.469	22.187	21.017	19.463	17.903	17.417	13.817	12.006

Natural Baseflow flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	9.556	8.006	7.090	6.677	6.304	5.829	5.280	4.439	3.991	3.214
Nov	6.894	6.539	5.908	5.634	5.471	4.908	4.509	3.869	3.264	2.591
Dec	4.672	3.903	3.547	2.909	2.614	2.455	2.329	2.196	2.110	1.976
Jan	2.330	1.337	1.006	0.759	0.685	0.639	0.600	0.556	0.477	0.452
Feb	1.081	0.521	0.457	0.386	0.364	0.289	0.229	0.160	0.147	0.099
Mar	1.109	0.697	0.665	0.537	0.439	0.351	0.316	0.274	0.161	0.097
Apr	3.853	1.563	1.157	0.872	0.801	0.649	0.577	0.403	0.349	0.272
May	7.421	5.423	3.864	2.214	2.030	1.684	1.368	1.075	0.646	0.450
Jun	9.724	7.623	6.753	6.466	5.105	4.366	3.594	2.764	1.543	0.666
Jul	13.813	10.506	9.766	7.984	6.641	5.415	5.094	4.122	2.942	1.013
Aug	10.519	9.895	9.189	7.798	6.902	5.999	5.585	4.938	3.971	2.387
Sep	9.532	8.971	7.843	7.495	6.761	6.280	5.394	4.888	4.012	3.240

Category Low Flow Assurance curves (mill. m^3)

A Category

Oct	6.346	6.346	6.147	5.637	5.226	4.723	4.003	3.063	2.810	2.806
Nov	5.031	5.031	4.983	4.671	4.345	3.904	3.100	2.233	2.212	2.193
Dec	3.210	3.210	3.140	2.718	2.293	2.019	1.764	1.549	1.548	1.547
Jan	1.234	1.172	0.993	0.776	0.613	0.530	0.484	0.447	0.417	0.415
Feb	0.503	0.458	0.395	0.328	0.267	0.214	0.164	0.129	0.107	0.089
Mar	0.635	0.629	0.596	0.500	0.388	0.306	0.252	0.212	0.155	0.109
Apr	1.678	1.494	1.109	0.827	0.655	0.543	0.444	0.359	0.287	0.257
May	4.329	4.329	3.632	2.520	1.735	1.403	1.109	0.819	0.580	0.457
Jun	6.008	6.008	5.601	5.029	4.286	3.452	2.614	1.588	0.972	0.687
Jul	8.970	8.306	7.681	6.767	5.680	4.836	3.124	1.256	1.057	0.685
Aug	7.377	7.377	7.255	6.562	5.774	5.031	4.157	3.146	2.561	2.284
Sep	6.564	6.564	6.464	5.964	5.486	4.907	4.086	3.092	2.670	2.668

A/B Category

Oct	5.789	5.789	5.646	5.199	4.854	4.408	3.662	2.820	2.752	2.744
Nov	4.638	4.638	4.597	4.322	4.045	3.647	2.804	2.214	2.178	2.145
Dec	2.978	2.978	2.915	2.532	2.144	1.886	1.630	1.553	1.539	1.528
Jan	1.142	1.091	0.927	0.727	0.575	0.495	0.448	0.414	0.404	0.403
Feb	0.470	0.428	0.370	0.308	0.251	0.199	0.151	0.119	0.099	0.087
Mar	0.593	0.587	0.558	0.469	0.364	0.286	0.233	0.195	0.144	0.104
Apr	1.545	1.387	1.036	0.775	0.614	0.507	0.411	0.331	0.268	0.246
May	3.976	3.976	3.362	2.345	1.624	1.312	1.022	0.750	0.543	0.439
Jun	5.479	5.479	5.150	4.641	3.984	3.229	2.382	1.416	0.918	0.659
Jul	7.965	7.567	6.978	6.188	5.346	4.618	2.219	1.214	1.024	0.677
Aug	6.734	6.734	6.631	6.036	5.364	4.694	3.800	2.855	2.421	2.208
Sep	6.009	6.009	5.924	5.488	5.089	4.581	3.742	2.814	2.605	2.603

B Category

Oct	5.305	5.305	5.191	4.805	4.513	4.087	3.276	2.655	2.639	2.625
Nov	4.276	4.276	4.243	4.004	3.763	3.377	2.438	2.072	2.060	2.050
Dec	2.763	2.763	2.707	2.358	2.001	1.750	1.487	1.474	1.472	1.470
Jan	1.061	1.016	0.866	0.681	0.538	0.461	0.412	0.388	0.388	0.388
Feb	0.438	0.399	0.346	0.290	0.236	0.183	0.138	0.109	0.091	0.081
Mar	0.553	0.548	0.521	0.439	0.342	0.266	0.214	0.180	0.134	0.097
Apr	1.431	1.289	0.966	0.725	0.575	0.472	0.377	0.304	0.249	0.231
May	3.664	3.664	3.112	2.184	1.518	1.220	0.929	0.682	0.507	0.418

Jun	5.021	5.021	4.739	4.291	3.706	2.997	2.097	1.232	0.867	0.630
Jul	7.221	6.863	6.372	5.705	5.058	4.386	1.455	1.173	0.994	0.669
Aug	6.152	6.152	6.066	5.560	4.987	4.354	3.397	2.562	2.277	2.100
Sep	5.505	5.505	5.434	5.062	4.728	4.250	3.352	2.550	2.495	2.488
B/C Category										
Oct	4.690	4.690	4.606	4.317	4.071	3.608	2.760	2.473	2.462	2.451
Nov	3.804	3.804	3.781	3.600	3.383	2.956	2.032	1.943	1.928	1.915
Dec	2.475	2.475	2.429	2.128	1.802	1.543	1.414	1.405	1.395	1.386
Jan	0.949	0.914	0.782	0.616	0.485	0.410	0.366	0.366	0.366	0.365
Feb	0.394	0.360	0.314	0.264	0.213	0.161	0.122	0.096	0.081	0.072
Mar	0.498	0.494	0.471	0.398	0.309	0.237	0.189	0.159	0.119	0.088
Apr	1.276	1.156	0.872	0.657	0.519	0.420	0.331	0.268	0.222	0.209
May	3.250	3.250	2.780	1.969	1.370	1.082	0.799	0.598	0.458	0.390
Jun	4.423	4.423	4.208	3.855	3.336	2.624	1.695	1.048	0.797	0.590
Jul	6.252	5.941	5.621	5.185	4.716	3.611	1.323	1.112	0.950	0.656
Aug	5.410	5.410	5.350	4.983	4.504	3.852	2.866	2.242	2.078	1.954
Sep	4.860	4.860	4.810	4.544	4.267	3.756	2.827	2.328	2.324	2.320
C Category										
Oct	4.229	4.229	4.159	3.908	3.639	3.036	2.334	2.298	2.292	2.287
Nov	3.427	3.427	3.408	3.239	2.981	2.372	1.816	1.805	1.795	1.786
Dec	2.234	2.234	2.193	1.920	1.602	1.339	1.319	1.314	1.309	1.305
Jan	0.852	0.824	0.706	0.557	0.434	0.359	0.346	0.345	0.345	0.345
Feb	0.355	0.325	0.285	0.240	0.189	0.141	0.107	0.085	0.072	0.063
Mar	0.449	0.446	0.426	0.360	0.277	0.209	0.165	0.141	0.106	0.080
Apr	1.143	1.041	0.788	0.594	0.465	0.368	0.288	0.237	0.198	0.190
May	2.919	2.919	2.510	1.780	1.224	0.929	0.679	0.533	0.414	0.365
Jun	3.966	3.966	3.797	3.483	2.963	2.133	1.318	0.957	0.732	0.552
Jul	5.527	5.345	5.097	4.810	4.342	1.996	1.239	1.052	0.904	0.645
Aug	4.876	4.876	4.829	4.511	4.031	3.247	2.374	2.025	1.896	1.817
Sep	4.383	4.383	4.344	4.118	3.820	3.160	2.338	2.164	2.163	2.162
C/D Category										
Oct	3.714	3.714	3.644	3.339	2.889	2.237	2.095	2.092	2.089	2.087
Nov	2.985	2.985	2.958	2.721	2.272	1.644	1.635	1.633	1.631	1.629

Dec	1.953	1.953	1.914	1.648	1.306	1.223	1.219	1.215	1.211	1.207
Jan	0.743	0.719	0.616	0.482	0.367	0.320	0.320	0.320	0.320	0.320
Feb	0.309	0.284	0.250	0.207	0.158	0.117	0.090	0.072	0.060	0.053
Mar	0.392	0.389	0.372	0.312	0.235	0.174	0.139	0.119	0.091	0.070
Apr	0.998	0.909	0.688	0.513	0.391	0.302	0.240	0.201	0.170	0.166
May	2.566	2.566	2.204	1.541	1.009	0.728	0.558	0.458	0.361	0.335
Jun	3.489	3.489	3.323	2.970	2.316	1.454	1.028	0.850	0.654	0.507
Jul	4.891	4.777	4.593	4.287	2.612	1.326	1.145	0.981	0.842	0.633
Aug	4.303	4.303	4.252	3.869	3.193	2.377	1.926	1.769	1.677	1.650
Sep	3.857	3.857	3.813	3.526	3.030	2.317	1.993	1.985	1.977	1.970

D Category

Oct	3.125	3.125	2.920	2.329	1.960	1.950	1.940	1.930	1.920	1.911
Nov	2.462	2.462	2.397	1.959	1.519	1.507	1.503	1.499	1.495	1.492
Dec	1.661	1.661	1.611	1.308	1.130	1.128	1.126	1.124	1.122	1.120
Jan	0.648	0.625	0.531	0.406	0.313	0.306	0.304	0.302	0.300	0.298
Feb	0.269	0.248	0.216	0.173	0.130	0.098	0.075	0.060	0.050	0.044
Mar	0.340	0.338	0.321	0.264	0.194	0.144	0.116	0.100	0.077	0.062
Apr	0.873	0.791	0.592	0.431	0.320	0.249	0.201	0.169	0.146	0.145
May	2.230	2.230	1.879	1.251	0.781	0.587	0.474	0.391	0.315	0.309
Jun	2.969	2.969	2.683	2.098	1.458	1.081	0.910	0.754	0.583	0.466
Jul	4.338	4.216	3.615	2.188	1.360	1.207	1.054	0.912	0.793	0.618
Aug	3.585	3.585	3.399	2.707	1.993	1.766	1.666	1.542	1.503	1.503
Sep	3.184	3.184	3.024	2.387	1.838	1.820	1.815	1.810	1.805	1.800

Category Total Flow Assurance curves (mill. m^3)

A Category

Oct	10.585	9.494	9.295	7.767	7.356	6.853	6.133	5.193	4.846	2.806
Nov	6.160	6.049	6.001	5.689	5.363	4.922	3.812	2.233	2.212	2.193
Dec	3.210	3.210	3.140	2.718	2.293	2.019	1.764	1.549	1.548	1.547
Jan	1.234	1.172	0.993	0.776	0.613	0.530	0.484	0.447	0.417	0.415
Feb	0.503	0.458	0.395	0.328	0.267	0.214	0.164	0.129	0.107	0.089
Mar	0.736	0.629	0.596	0.500	0.388	0.306	0.252	0.212	0.155	0.109
Apr	4.100	2.512	2.127	1.845	0.655	0.543	0.444	0.359	0.287	0.257
May	17.535	12.657	7.668	4.650	3.865	3.512	2.127	0.819	0.580	0.457

Jun	23.593	19.131	16.669	12.422	9.849	8.099	6.650	3.718	3.008	0.982
Jul	37.890	24.020	20.785	17.835	16.748	14.037	8.178	6.106	4.528	1.303
Aug	19.574	18.445	18.323	17.488	15.101	12.178	9.211	7.182	6.597	4.709
Sep	17.632	15.108	12.870	11.425	10.096	8.943	8.122	6.240	5.716	4.798
A/B Category										
Oct	10.028	8.937	8.794	7.329	6.984	6.538	5.792	4.931	3.668	2.744
Nov	5.767	5.656	5.615	5.340	5.063	4.665	2.804	2.214	2.178	2.145
Dec	2.978	2.978	2.915	2.532	2.144	1.886	1.630	1.553	1.539	1.528
Jan	1.142	1.091	0.927	0.727	0.575	0.495	0.448	0.414	0.404	0.403
Feb	0.470	0.428	0.370	0.308	0.251	0.199	0.151	0.119	0.099	0.087
Mar	0.694	0.587	0.558	0.469	0.364	0.286	0.233	0.195	0.144	0.104
Apr	3.967	2.405	2.054	1.793	0.614	0.507	0.411	0.331	0.268	0.246
May	15.044	10.215	7.398	4.882	3.754	3.404	2.040	1.388	0.543	0.439
Jun	23.064	18.602	14.285	11.158	9.038	7.265	6.418	3.546	2.951	0.954
Jul	36.886	24.035	19.370	17.256	16.127	13.123	6.968	5.159	3.867	1.268
Aug	19.838	18.006	17.699	16.092	14.182	11.377	8.548	6.891	6.134	4.338
Sep	17.077	13.915	11.283	10.542	9.699	8.617	7.511	5.758	4.735	4.733
B Category										
Oct	9.544	7.435	7.321	6.935	6.643	6.217	5.378	4.340	3.556	2.625
Nov	5.406	5.294	5.261	5.022	4.781	3.988	2.438	2.072	2.060	2.050
Dec	2.763	2.763	2.707	2.358	2.001	1.750	1.487	1.474	1.472	1.470
Jan	1.061	1.016	0.866	0.681	0.538	0.461	0.412	0.388	0.388	0.388
Feb	0.438	0.399	0.346	0.290	0.236	0.183	0.138	0.109	0.091	0.081
Mar	0.553	0.548	0.521	0.439	0.342	0.266	0.214	0.180	0.134	0.097
Apr	3.769	2.307	1.984	1.743	0.575	0.472	0.377	0.304	0.249	0.231
May	14.567	9.716	7.148	4.314	3.648	3.256	1.947	1.541	0.507	0.418
Jun	22.704	18.143	13.253	10.363	8.760	7.033	6.133	3.362	2.732	0.925
Jul	36.142	23.300	18.763	16.773	15.118	11.069	5.582	4.321	3.124	1.259
Aug	19.256	17.220	17.134	14.469	12.077	10.426	7.433	6.598	5.335	4.230
Sep	16.573	13.070	10.488	9.150	8.764	7.931	6.500	4.680	4.625	4.618
B/C Category										
Oct	9.046	6.820	6.736	6.447	6.201	5.738	4.791	3.491	3.480	2.451
Nov	4.934	4.822	4.799	4.618	3.820	2.956	2.032	1.943	1.928	1.915

Dec	2.475	2.475	2.429	2.128	1.802	1.543	1.414	1.405	1.395	1.386
Jan	0.949	0.914	0.782	0.616	0.485	0.410	0.366	0.366	0.366	0.365
Feb	0.394	0.360	0.314	0.264	0.213	0.161	0.122	0.096	0.081	0.072
Mar	0.498	0.494	0.471	0.398	0.309	0.237	0.189	0.159	0.119	0.088
Apr	3.614	2.174	1.890	0.657	0.519	0.420	0.331	0.268	0.222	0.209
May	14.067	7.693	6.816	4.099	3.500	2.711	1.817	1.160	0.458	0.390
Jun	21.893	16.731	11.669	9.927	7.881	6.660	5.568	3.178	1.815	0.885
Jul	35.173	22.348	18.012	16.092	14.056	9.683	5.238	3.242	3.071	1.165
Aug	18.514	16.478	16.160	12.909	10.576	9.569	6.902	6.100	4.208	3.294
Sep	15.801	12.350	9.151	8.580	8.303	6.904	5.975	4.458	4.454	3.633

C Category

Oct	8.585	6.562	6.289	6.038	5.722	4.812	3.352	3.316	3.125	2.287
Nov	4.556	4.445	4.426	4.241	3.273	2.372	1.816	1.805	1.795	1.786
Dec	2.234	2.234	2.193	1.920	1.602	1.339	1.319	1.314	1.309	1.305
Jan	0.852	0.824	0.706	0.557	0.434	0.359	0.346	0.345	0.345	0.345
Feb	0.355	0.325	0.285	0.240	0.189	0.141	0.107	0.085	0.072	0.063
Mar	0.449	0.446	0.426	0.360	0.277	0.209	0.165	0.141	0.106	0.080
Apr	3.481	2.059	1.806	0.594	0.465	0.368	0.288	0.237	0.198	0.190
May	13.650	8.176	6.546	3.910	2.798	1.947	1.697	0.533	0.414	0.365
Jun	20.203	16.275	11.258	8.945	6.999	6.169	4.161	3.087	1.728	0.552
Jul	34.346	21.721	17.488	15.183	11.526	7.050	4.794	3.182	1.922	0.940
Aug	17.980	15.944	15.254	12.092	9.995	7.946	6.410	4.155	4.009	3.011
Sep	15.324	10.443	9.398	8.154	7.394	6.215	4.468	4.294	4.190	3.180

C/D Category

Oct	7.954	5.844	5.774	5.469	4.925	3.255	3.113	3.110	2.913	2.087
Nov	4.114	4.003	3.976	2.721	2.272	1.644	1.635	1.633	1.631	1.629
Dec	1.953	1.953	1.914	1.648	1.306	1.223	1.219	1.215	1.211	1.207
Jan	0.743	0.719	0.616	0.482	0.367	0.320	0.320	0.320	0.320	0.320
Feb	0.309	0.284	0.250	0.207	0.158	0.117	0.090	0.072	0.060	0.053
Mar	0.392	0.389	0.372	0.312	0.235	0.174	0.139	0.119	0.091	0.070
Apr	2.420	1.927	1.589	0.513	0.391	0.302	0.240	0.201	0.170	0.166
May	13.211	7.620	6.240	3.671	2.583	1.746	1.532	0.458	0.361	0.335
Jun	18.810	14.964	10.784	7.491	6.352	5.135	3.158	2.923	0.654	0.507
Jul	33.710	21.121	16.984	13.750	9.749	5.303	3.275	3.093	1.845	0.802

Aug	16.491	15.371	14.292	10.348	7.738	6.413	5.390	3.880	2.695	2.299
Sep	14.047	8.911	7.849	6.674	6.137	5.358	4.123	3.946	2.995	2.878

D Category

Oct	7.365	5.255	5.050	4.459	3.996	2.968	2.958	1.930	1.920	1.911
Nov	3.591	3.480	3.084	1.959	1.519	1.507	1.503	1.499	1.495	1.492
Dec	1.661	1.661	1.611	1.308	1.130	1.128	1.126	1.124	1.122	1.120
Jan	0.648	0.625	0.531	0.406	0.313	0.306	0.304	0.302	0.300	0.298
Feb	0.269	0.248	0.216	0.173	0.130	0.098	0.075	0.060	0.050	0.044
Mar	0.340	0.338	0.321	0.264	0.194	0.144	0.116	0.100	0.077	0.062
Apr	2.294	1.809	0.898	0.431	0.320	0.249	0.201	0.169	0.146	0.145
May	12.789	6.524	5.915	3.381	1.799	1.605	1.347	0.391	0.315	0.309
Jun	16.575	13.237	10.145	6.186	5.494	4.229	3.040	1.772	0.583	0.466
Jul	33.157	19.715	16.007	11.300	5.905	4.661	3.184	1.930	1.431	0.618
Aug	15.773	14.653	12.878	8.987	6.538	5.802	4.266	3.168	2.256	1.503
Sep	13.807	9.256	7.099	6.176	4.986	3.950	3.857	2.828	2.405	1.800

Table F3: RDRM output for Doring EWR site 4 with RCP 2.6 data.

Revised Desktop Model outputs for site: EWR_4

HYDROLOGY DATA SUMMARY

Natural Flows:					RCP 2.6 min Flows:				
Area	MAR	Ann.SD	Q75	Ann.	Area	MAR	Ann.SD	Q75	Ann.
(km^2)	(m^3 * 10^6)			CV	(km^2)	(m^3 * 10^6)			CV
0.00	387.23	193.19	4.03	0.50	0.00	192.02	139.62	0.94	0.73

% Zero flows =   0.0   % Zero flows =   8.0

Baseflow Parameters: A = 0.970, B = 0.42Baseflow Parameters: A = 0.970, B = 0.420

BFI = 0.32 : Hydro Index =   4.9   BFI = 0.26 : Hydro Index = 14.8

MONTH	MEAN	SD	CV	MONTH	MEAN	SD	CV
	(m^3 * 10^6)				(m^3 * 10^6)		
Oct	29.78	16.24	0.55	Oct	18.29	13.92	0.76
Nov	15.57	10.31	0.66	Nov	8.96	8.68	0.97
Dec	7.48	4.45	0.60	Dec	3.21	4.77	1.48
Jan	4.02	3.28	0.81	Jan	0.85	1.21	1.43
Feb	2.72	1.51	0.56	Feb	0.75	2.20	2.92
Mar	3.58	3.16	0.88	Mar	2.80	11.20	4.00
Apr	10.40	16.79	1.61	Apr	7.78	14.10	1.81
May	32.94	42.34	1.29	May	12.51	12.58	1.01
Jun	59.91	51.91	0.87	Jun	19.07	12.02	0.63
Jul	98.86	106.92	1.08	Jul	37.43	55.65	1.49
Aug	70.12	37.16	0.53	Aug	49.12	55.13	1.12
Sep	51.84	32.27	0.62	Sep	31.25	26.64	0.85

Critical months: WET : Jul, DRY : Feb

Using 10th percentile of FDC of separated baseflows

Max. baseflows (m^3/s): WET :   16.850, DRY :   2.085

HYDRAULICS DATA SUMMARY

Catchment Area (km^2)	18543.40
Geomorph. Zone	4
Valley Slope (Fraction)	0.0060
Width/Depth scaling	0.50
Max. Channel width (m)	150.00
Max. Channel Depth (m)	3.00

Observed Channel XS used

Observed Rating Curve used

(Gradients and Roughness n values calibrated)

Max. Gradient	0.00300
Min. Gradient	0.00010
Gradient Shape Factor	15
Max. Mannings n	0.050
Min. Mannings n	0.030
n Shape Factor	15

Habitat Type definitions used:

Fast:	>	0.3 m/s
Shallow:	>	0.1 m
Intermediate:	>	0.2 m
Deep (fast):	>	0.3 m
Deep (slow):	>	0.5 m

FLOW - STRESSOR RESPONSE DATA SUMMARY

Table of Stress weightings

Season	Wet	Dry
Stress at 0 FS:	9	9
FS Weight:	2	2
FI Weight:	2	2
FD Weight:	4	4

Table of flows ($m^3/2$) v stress index

Stress	Wet Season Flow	Dry Season Flow
0.0	17.081	2.187
0.5	13.450	2.122
1.0	11.299	2.040
1.5	9.458	1.937
2.0	7.724	1.852
2.5	5.572	1.763
3.0	4.073	1.634
3.5	3.218	1.545
4.0	2.659	1.475
4.5	2.236	1.391
5.0	1.868	1.285
5.5	1.561	1.163
6.0	1.278	1.045
6.5	1.016	0.915
7.0	0.765	0.762
7.5	0.542	0.570
8.0	0.340	0.369
8.5	0.123	0.150
9.0	0.049	0.053
9.5	0.020	0.022
10.0	0.000	0.000

Table of default/altered SHIFT factors for the Stress Frequency Curves

Category	High SHIFT		Low SHIFT	
	Default	Altered	Default	Altered
Wet season				
A	6.103	6.103	0.420	0.420
A/B	6.283	6.283	0.702	0.702
B	6.464	6.464	0.985	0.985
B/C	6.734	6.734	1.408	1.408
C	7.004	7.004	1.832	1.832
C/D	7.365	7.365	2.397	2.397
D	7.725	7.725	2.961	2.961

Dry season

A	8.081	8.081	1.651	1.651
A/B	8.132	8.132	1.914	1.914
B	8.184	8.184	2.176	2.176
B/C	8.260	8.260	2.570	2.570
C	8.337	8.337	2.964	2.964
C/D	8.440	8.440	3.490	3.490
D	8.542	8.542	4.015	4.015

Perenniality Rules
Non-Perennial Allowed

Alignment of maximum stress to Present Day stress
Not Aligned

HIGH FLOW REQUIREMENT SUMMARY

Bankfull channel discharge (m^3/s) = 104.273

Flood event requirements

Class	Frequency	Peak(m^3/s)	Duration(hours)	N. Events	Volume(MCM)
1	Annual	20.994	212	4	6.762
2	Annual	45.028	252	3	17.239
3	Annual	69.567	284	1	30.016
4	1:2 year	86.208	304	1	39.816
5	1:5 year	131.475	348	1	69.511

Flood requirements have been constrained to a maximum of 0.48 of natural high flows

Events excluded from the time series of high flow requirements:
No Events excluded.

FINAL RESERVE SUMMARY DETAILS

EWR Flows are NOT constrained to be below Natural or Present Day Flows

Long term mean flow requirements (Mill. m^3 and %MAR)

Category	Low Flows		Total Flows	
	Mill. m^3	%MAR	Mill. m^3	%MAR
A	98.668	25.5	205.215	53.0
A/B	92.338	23.8	192.245	49.6
B	86.224	22.3	182.370	47.1
B/C	77.442	20.0	167.594	43.3
C	68.930	17.8	154.512	39.9
C/D	58.903	15.2	139.629	36.1
D	50.724	13.1	126.666	32.7

FLOW DURATION and RESERVE ASSURANCE TABLES

Columns are FDC precentage points:

Natural Total flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	59.140	41.501	31.622	27.492	25.389	22.910	21.834	17.242	15.084	12.066
Nov	20.992	18.487	17.963	14.702	13.067	12.745	11.733	10.376	8.288	5.936
Dec	14.361	10.559	7.542	7.252	6.429	6.107	5.406	4.502	3.484	2.593
Jan	6.024	5.078	4.369	3.902	3.408	3.064	2.630	2.030	1.503	1.225
Feb	5.306	3.651	3.053	2.881	2.408	2.142	1.829	1.715	1.142	0.842
Mar	7.556	4.421	3.718	2.966	2.826	2.762	2.433	1.769	0.916	0.750
Apr	23.774	12.443	8.266	6.844	5.301	3.736	3.084	2.786	2.610	2.342
May	93.283	56.646	39.422	24.014	14.329	11.575	10.350	6.504	3.970	2.878
Jun	158.553	88.126	79.568	57.909	46.898	34.199	27.406	22.281	10.220	4.617
Jul	227.524	158.641	128.465	76.086	62.163	53.866	39.197	34.477	24.470	5.411
Aug	124.084	106.068	94.861	71.385	66.507	64.266	52.843	35.090	27.919	12.233
Sep	108.256	79.053	52.697	48.485	42.192	39.276	35.923	28.392	21.399	16.960

Natural Baseflow flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	25.438	21.450	17.966	16.130	15.727	13.705	11.765	8.667	7.293	4.516
Nov	17.808	15.582	13.837	13.361	12.852	10.746	9.843	7.776	6.186	3.657
Dec	13.102	10.292	7.542	7.252	6.429	6.107	5.406	4.502	3.484	2.593
Jan	6.024	5.078	4.369	3.902	3.408	3.064	2.630	2.030	1.503	1.225
Feb	5.028	3.490	3.053	2.881	2.408	2.142	1.829	1.715	1.142	0.842
Mar	4.533	3.107	2.955	2.789	2.671	2.395	1.930	1.546	0.916	0.750
Apr	8.590	4.762	3.825	3.101	2.948	2.815	2.547	1.973	1.572	1.276
May	18.357	12.596	9.968	6.762	4.569	4.121	3.743	3.274	2.017	1.381
Jun	30.511	19.876	17.066	14.222	11.147	8.942	8.381	5.718	2.795	2.486
Jul	42.487	32.660	27.419	19.801	15.752	14.132	11.277	9.493	5.817	2.687
Aug	31.784	26.800	23.242	21.389	19.188	15.567	13.935	11.736	9.015	3.683
Sep	30.605	26.037	20.960	18.301	16.977	15.620	11.037	10.003	7.530	5.117

Category Low Flow Assurance curves (mill. m^3)

A Category

Oct	19.625	19.243	16.689	13.784	11.337	9.043	7.315	5.728	4.933	4.804
Nov	15.168	14.068	12.517	10.864	9.080	7.190	5.679	4.697	4.143	3.885
Dec	11.557	9.718	7.890	6.433	5.463	4.663	3.945	3.277	2.834	2.683
Jan	7.448	5.332	4.382	3.673	3.030	2.575	2.125	1.714	1.416	1.293
Feb	3.859	3.152	2.734	2.348	1.988	1.660	1.378	1.148	0.963	0.760
Mar	4.576	3.243	2.717	2.468	2.233	2.004	1.614	1.223	0.937	0.816
Apr	7.864	5.295	3.817	3.029	2.511	2.262	1.956	1.615	1.367	1.275
May	16.863	12.781	9.629	6.881	4.685	3.487	2.867	2.377	1.910	1.551
Jun	21.566	19.181	15.128	12.037	8.867	6.449	4.985	3.883	2.823	2.395
Jul	33.890	28.963	23.398	16.347	10.552	7.706	6.040	4.840	3.969	2.687
Aug	24.121	23.851	21.090	17.893	15.018	12.069	9.525	7.881	6.492	5.085
Sep	22.076	21.757	18.611	15.291	12.743	10.438	7.831	5.983	5.806	5.381
A/B Category										
Oct	18.562	18.088	15.553	12.533	10.194	8.328	6.852	5.388	4.728	4.658
Nov	14.545	13.437	11.862	10.034	8.261	6.634	5.309	4.411	3.926	3.765
Dec	11.187	9.437	7.663	6.143	5.161	4.413	3.733	3.102	2.697	2.606
Jan	7.258	5.237	4.313	3.562	2.910	2.462	2.023	1.630	1.353	1.259
Feb	3.764	3.152	2.682	2.279	1.919	1.586	1.310	1.087	0.908	0.760
Mar	4.417	3.092	2.571	2.304	2.096	1.911	1.537	1.162	0.892	0.793
Apr	7.653	5.196	3.765	2.946	2.419	2.164	1.862	1.537	1.307	1.242
May	16.184	12.303	9.297	6.565	4.442	3.317	2.722	2.254	1.818	1.505
Jun	20.368	18.010	14.177	11.031	8.067	5.996	4.682	3.655	2.682	2.330
Jul	30.691	26.301	20.942	13.955	9.420	7.092	5.609	4.514	3.684	2.676
Aug	22.522	22.089	19.391	16.335	13.859	11.308	8.976	7.432	6.142	4.892
Sep	20.736	20.221	17.165	13.812	11.579	9.773	7.362	5.639	5.530	5.215
B Category										
Oct	17.610	16.958	14.404	11.365	9.236	7.702	6.409	5.042	4.436	4.406
Nov	13.944	12.801	11.184	9.255	7.571	6.150	4.956	4.122	3.682	3.563
Dec	10.825	9.135	7.399	5.847	4.881	4.173	3.523	2.920	2.538	2.468
Jan	7.067	5.125	4.218	3.439	2.789	2.346	1.918	1.539	1.274	1.187
Feb	3.688	3.120	2.611	2.204	1.844	1.511	1.242	1.026	0.850	0.712
Mar	4.264	2.943	2.417	2.143	1.971	1.820	1.459	1.097	0.840	0.752
Apr	7.446	5.083	3.690	2.852	2.323	2.064	1.766	1.451	1.230	1.169
May	15.534	11.811	8.920	6.234	4.214	3.150	2.577	2.126	1.710	1.416

Jun	19.239	16.870	13.202	10.081	7.390	5.594	4.391	3.431	2.535	2.243
Jul	27.891	23.740	18.075	11.945	8.489	6.560	5.202	4.192	3.400	2.601
Aug	21.080	20.384	17.667	14.818	12.842	10.614	8.441	6.979	5.762	4.612
Sep	19.500	18.736	15.710	12.420	10.579	9.167	6.906	5.280	5.193	4.932
B/C Category										
Oct	16.187	15.237	12.651	9.852	8.088	6.883	5.782	4.540	4.031	4.015
Nov	13.026	11.789	10.111	8.228	6.721	5.510	4.459	3.704	3.310	3.236
Dec	10.251	8.610	6.923	5.418	4.495	3.827	3.213	2.648	2.293	2.249
Jan	6.754	4.908	4.020	3.244	2.606	2.171	1.761	1.402	1.150	1.068
Feb	3.576	2.989	2.492	2.086	1.722	1.398	1.139	0.934	0.760	0.629
Mar	4.024	2.708	2.172	1.922	1.801	1.682	1.341	1.000	0.760	0.684
Apr	7.110	4.868	3.526	2.699	2.175	1.911	1.621	1.321	1.109	1.050
May	14.542	10.996	8.255	5.744	3.895	2.903	2.359	1.932	1.542	1.273
Jun	17.569	15.131	11.682	8.817	6.553	5.052	3.978	3.105	2.307	2.101
Jul	23.872	19.790	14.024	9.801	7.399	5.831	4.648	3.738	3.002	2.461
Aug	19.025	17.836	15.052	12.782	11.550	9.651	7.667	6.311	5.184	4.166
Sep	17.691	16.519	13.526	10.616	9.356	8.329	6.254	4.749	4.665	4.473
C Category										
Oct	14.688	13.459	11.019	8.664	7.173	6.157	5.181	4.036	3.494	3.472
Nov	12.038	10.731	9.089	7.389	6.022	4.938	3.987	3.287	2.904	2.805
Dec	9.605	8.033	6.419	5.018	4.130	3.488	2.905	2.368	2.018	1.944
Jan	6.389	4.660	3.793	3.044	2.419	1.992	1.601	1.260	1.018	0.931
Feb	3.451	2.845	2.369	1.964	1.592	1.282	1.036	0.839	0.671	0.547
Mar	3.755	2.464	1.939	1.736	1.646	1.543	1.221	0.899	0.671	0.594
Apr	6.720	4.624	3.333	2.538	2.021	1.754	1.474	1.188	0.981	0.916
May	13.460	10.115	7.566	5.297	3.591	2.657	2.141	1.735	1.365	1.110
Jun	15.823	13.335	10.253	7.812	5.870	4.556	3.575	2.768	2.028	1.806
Jul	19.834	15.186	11.027	8.294	6.527	5.180	4.139	3.297	2.609	2.097
Aug	16.901	15.239	12.663	11.165	10.441	8.747	6.913	5.641	4.571	3.624
Sep	15.808	14.242	11.508	9.220	8.352	7.543	5.622	4.209	4.088	3.882
C/D Category										
Oct	12.838	11.365	9.358	7.452	6.156	5.280	4.423	3.387	2.808	2.782
Nov	10.830	9.448	7.983	6.478	5.215	4.240	3.394	2.751	2.378	2.254

Dec	8.824	7.289	5.809	4.516	3.658	3.045	2.500	1.997	1.657	1.561
Jan	5.967	4.325	3.490	2.770	2.162	1.751	1.386	1.069	0.841	0.753
Feb	3.256	2.655	2.194	1.787	1.418	1.126	0.898	0.706	0.551	0.437
Mar	3.455	2.175	1.689	1.528	1.451	1.356	1.059	0.763	0.554	0.479
Apr	6.262	4.288	3.073	2.314	1.807	1.542	1.276	1.007	0.810	0.740
May	12.102	8.991	6.770	4.757	3.193	2.330	1.850	1.470	1.129	0.898
Jun	13.571	11.129	8.777	6.771	5.087	3.937	3.062	2.330	1.668	1.445
Jul	13.891	10.891	8.602	6.885	5.532	4.418	3.505	2.741	2.104	1.659
Aug	14.247	12.232	10.329	9.530	9.117	7.597	5.937	4.757	3.766	2.926
Sep	13.453	11.588	9.514	7.835	7.211	6.547	4.815	3.507	3.332	3.125

D Category

Oct	11.446	9.844	8.129	6.450	5.253	4.470	3.697	2.761	2.185	2.160
Nov	9.855	8.419	7.081	5.674	4.479	3.595	2.833	2.237	1.881	1.752
Dec	8.149	6.623	5.246	4.017	3.187	2.609	2.100	1.631	1.314	1.213
Jan	5.579	3.986	3.181	2.481	1.894	1.507	1.168	0.876	0.671	0.591
Feb	3.030	2.459	2.002	1.584	1.238	0.969	0.750	0.573	0.432	0.347
Mar	3.207	1.944	1.488	1.340	1.260	1.167	0.894	0.626	0.440	0.373
Apr	5.846	3.950	2.805	2.074	1.584	1.327	1.075	0.825	0.646	0.581
May	11.001	8.060	6.080	4.233	2.791	2.002	1.558	1.205	0.900	0.704
Jun	11.917	9.542	7.667	5.894	4.375	3.353	2.565	1.902	1.318	1.106
Jul	10.066	8.462	7.048	5.790	4.673	3.728	2.908	2.206	1.646	1.248
Aug	12.360	10.197	8.725	8.191	7.869	6.489	4.979	3.886	2.992	2.280
Sep	11.759	9.766	8.119	6.729	6.183	5.595	4.039	2.849	2.623	2.431

Category Total Flow Assurance curves (mill. m^3)

A Category

Oct	28.043	26.005	23.451	18.674	13.098	9.043	7.315	5.728	4.933	4.804
Nov	15.168	14.068	12.517	10.864	9.080	7.190	5.679	4.697	4.143	3.885
Dec	11.557	9.718	7.890	6.433	5.463	4.663	3.945	3.277	2.834	2.683
Jan	7.448	5.332	4.382	3.673	3.030	2.575	2.125	1.714	1.416	1.293
Feb	3.859	3.152	2.734	2.348	1.988	1.660	1.378	1.148	0.963	0.760
Mar	4.576	3.243	2.717	2.468	2.233	2.004	1.614	1.223	0.937	0.816
Apr	15.673	5.295	3.817	3.029	2.511	2.262	1.956	1.615	1.367	1.275
May	52.470	30.020	24.478	13.311	8.784	3.487	2.867	2.377	1.910	1.551

Jun	85.514	51.147	40.766	29.276	26.106	17.268	11.747	10.559	2.823	2.395
Jul	116.925	92.498	66.239	43.826	33.552	24.945	20.032	11.602	10.731	3.801
Aug	68.664	62.041	50.698	41.894	36.621	29.308	26.492	17.769	13.254	7.046
Sep	56.784	46.897	35.589	29.279	24.197	17.200	14.593	12.745	12.534	6.973
A/B Category										
Oct	26.372	24.850	21.557	14.335	10.194	8.328	6.852	5.388	4.728	4.658
Nov	14.545	13.437	11.862	10.034	8.261	6.634	5.309	4.411	3.926	3.765
Dec	11.187	9.437	7.663	6.143	5.161	4.413	3.733	3.102	2.697	2.606
Jan	7.258	5.237	4.313	3.562	2.910	2.462	2.023	1.630	1.353	1.259
Feb	3.764	3.152	2.682	2.279	1.919	1.586	1.310	1.087	0.908	0.760
Mar	4.417	3.092	2.571	2.304	2.096	1.911	1.537	1.162	0.892	0.793
Apr	15.463	5.196	3.765	2.946	2.419	2.164	1.862	1.537	1.307	1.242
May	49.748	29.542	18.748	12.685	4.442	3.317	2.722	2.254	1.818	1.505
Jun	75.508	49.976	39.198	28.270	24.649	16.240	11.444	10.148	2.682	2.330
Jul	113.726	82.278	63.783	40.570	28.925	23.142	16.628	11.276	10.345	3.604
Aug	67.065	59.016	43.901	39.339	34.536	28.547	25.443	14.194	12.904	8.469
Sep	55.444	39.952	30.904	27.336	18.341	16.535	14.124	12.349	10.971	6.553
B Category										
Oct	25.420	23.720	20.467	11.365	9.236	7.702	6.409	5.042	4.436	4.406
Nov	13.944	12.801	11.184	9.255	7.571	6.150	4.956	4.122	3.682	3.563
Dec	10.825	9.135	7.399	5.847	4.881	4.173	3.523	2.920	2.538	2.468
Jan	7.067	5.125	4.218	3.439	2.789	2.346	1.918	1.539	1.274	1.187
Feb	3.688	3.120	2.611	2.204	1.844	1.511	1.242	1.026	0.850	0.712
Mar	4.264	2.943	2.417	2.143	1.971	1.820	1.459	1.097	0.840	0.752
Apr	14.721	5.083	3.690	2.852	2.323	2.064	1.766	1.451	1.230	1.169
May	41.567	29.050	17.661	12.353	4.214	3.150	2.577	2.126	1.710	1.416
Jun	73.702	48.238	32.470	27.320	21.139	12.356	11.153	9.314	2.535	2.243
Jul	110.926	79.717	60.917	33.638	25.728	22.475	11.964	10.954	9.909	3.344
Aug	64.788	56.819	41.434	36.573	30.443	27.853	23.957	13.741	12.500	5.996
Sep	54.197	38.467	29.234	25.944	17.341	15.929	13.668	12.042	9.990	6.016
B/C Category										
Oct	23.996	21.999	18.032	13.706	8.088	6.883	5.782	4.540	4.031	4.015
Nov	13.026	11.789	10.111	8.228	6.721	5.510	4.459	3.704	3.310	3.236

Dec	10.251	8.610	6.923	5.418	4.495	3.827	3.213	2.648	2.293	2.249
Jan	6.754	4.908	4.020	3.244	2.606	2.171	1.761	1.402	1.150	1.068
Feb	3.576	2.989	2.492	2.086	1.722	1.398	1.139	0.934	0.760	0.629
Mar	4.024	2.708	2.172	1.922	1.801	1.682	1.341	1.000	0.760	0.684
Apr	13.610	4.868	3.526	2.699	2.175	1.911	1.621	1.321	1.109	1.050
May	40.300	28.235	15.017	11.863	3.895	2.903	2.359	1.932	1.542	1.273
Jun	70.992	45.296	30.950	25.689	16.696	11.814	10.422	3.105	2.307	2.101
Jul	106.907	73.807	56.865	27.040	24.638	19.397	11.410	10.440	8.332	2.461
Aug	61.148	52.774	37.728	30.021	28.789	26.890	20.534	13.073	10.735	5.227
Sep	52.300	36.251	27.050	17.378	16.118	15.091	13.016	10.910	7.924	4.473
C Category										
Oct	22.498	20.221	16.160	8.664	7.173	6.157	5.181	4.036	3.494	3.472
Nov	12.038	10.731	9.089	7.389	6.022	4.938	3.987	3.287	2.904	2.805
Dec	9.605	8.033	6.419	5.018	4.130	3.488	2.905	2.368	2.018	1.944
Jan	6.389	4.660	3.793	3.044	2.419	1.992	1.601	1.260	1.018	0.931
Feb	3.451	2.845	2.369	1.964	1.592	1.282	1.036	0.839	0.671	0.547
Mar	3.755	2.464	1.939	1.736	1.646	1.543	1.221	0.899	0.671	0.594
Apr	12.444	4.624	3.333	2.538	2.021	1.754	1.474	1.188	0.981	0.916
May	34.715	27.354	14.328	11.416	3.591	2.657	2.141	1.735	1.365	1.110
Jun	63.524	43.594	30.853	24.171	16.048	11.318	8.784	2.768	2.028	1.806
Jul	102.869	69.175	53.868	25.533	23.453	16.923	10.901	9.667	2.609	2.097
Aug	59.024	46.617	35.339	28.404	27.680	22.271	16.009	11.476	6.856	3.624
Sep	46.943	39.300	25.032	17.828	15.114	14.305	11.876	6.935	4.088	3.882
C/D Category										
Oct	20.647	18.127	15.398	7.452	6.156	5.280	4.423	3.387	2.808	2.782
Nov	10.830	9.448	7.983	6.478	5.215	4.240	3.394	2.751	2.378	2.254
Dec	8.824	7.289	5.809	4.516	3.658	3.045	2.500	1.997	1.657	1.561
Jan	5.967	4.325	3.490	2.770	2.162	1.751	1.386	1.069	0.841	0.753
Feb	3.256	2.655	2.194	1.787	1.418	1.126	0.898	0.706	0.551	0.437
Mar	3.455	2.175	1.689	1.528	1.451	1.356	1.059	0.763	0.554	0.479
Apr	7.986	4.288	3.073	2.314	1.807	1.542	1.276	1.007	0.810	0.740
May	31.295	19.895	13.532	10.677	5.121	2.330	1.850	1.470	1.129	0.898
Jun	60.052	39.681	28.045	22.074	11.849	10.699	6.958	2.330	1.668	1.445
Jul	96.926	64.366	51.444	25.985	20.725	11.180	10.267	7.808	2.104	1.659

Aug	56.369	43.378	32.740	26.769	26.329	19.947	12.699	9.916	6.968	2.926
Sep	43.630	34.667	22.957	14.597	13.973	13.309	8.210	3.507	3.332	3.125

D Category

Oct	19.241	16.606	9.819	6.450	5.253	4.470	3.697	2.761	2.185	2.160
Nov	9.855	8.419	7.081	5.674	4.479	3.595	2.833	2.237	1.881	1.752
Dec	8.149	6.623	5.246	4.017	3.187	2.609	2.100	1.631	1.314	1.213
Jan	5.579	3.986	3.181	2.481	1.894	1.507	1.168	0.876	0.671	0.591
Feb	3.030	2.459	2.002	1.584	1.238	0.969	0.750	0.573	0.432	0.347
Mar	3.207	1.944	1.488	1.340	1.260	1.167	0.894	0.626	0.440	0.373
Apr	7.566	3.950	2.805	2.074	1.584	1.327	1.075	0.825	0.646	0.581
May	30.194	19.739	12.790	9.239	4.609	2.002	1.558	1.205	0.900	0.704
Jun	53.758	37.891	26.935	19.633	11.137	9.447	2.565	1.902	1.318	1.106
Jul	93.101	61.938	49.764	24.026	14.816	10.490	8.118	5.409	1.646	1.248
Aug	54.483	35.551	27.425	25.430	23.715	13.251	11.613	3.886	2.992	2.280
Sep	41.936	32.005	20.723	13.491	12.945	11.794	4.039	2.849	2.623	2.431

Table F4: RDRM output for Doring EWR site 4 with RCP 8.5 data.

Revised Desktop Model outputs for site: EWR_4

HYDROLOGY DATA SUMMARY

Natural Flows:					RCP 8.5 min Flows:				
Area (km^2)	MAR (m^3 * 10^6)	Ann.SD	Q75	Ann. CV	Area (km^2)	MAR (m^3 * 10^6)	Ann.SD	Q75	Ann. CV
0.00	387.23	193.19	4.03	0.50	0.00	163.47	115.14	0.11	0.70

% Zero flows = 0.0 % Zero flows = 19.0

Baseflow Parameters: A = 0.970, B = 0.42Baseflow Parameters: A = 0.970, B = 0.420

BFI = 0.32 : Hydro Index = 4.9 BFI = 0.26 : Hydro Index = 16.0

MONTH	MEAN (m^3 * 10^6)	SD	CV	MONTH	MEAN (m^3 * 10^6)	SD	CV
Oct	29.78	16.24	0.55	Oct	10.41	6.10	0.59
Nov	15.57	10.31	0.66	Nov	3.63	3.44	0.95
Dec	7.48	4.45	0.60	Dec	5.77	13.88	2.40
Jan	4.02	3.28	0.81	Jan	1.83	5.52	3.02
Feb	2.72	1.51	0.56	Feb	0.12	0.29	2.40
Mar	3.58	3.16	0.88	Mar	0.29	1.07	3.68
Apr	10.40	16.79	1.61	Apr	1.46	3.21	2.20
May	32.94	42.34	1.29	May	10.31	18.71	1.82
Jun	59.91	51.91	0.87	Jun	22.88	22.36	0.98
Jul	98.86	106.92	1.08	Jul	47.93	64.51	1.35
Aug	70.12	37.16	0.53	Aug	36.87	35.31	0.96
Sep	51.84	32.27	0.62	Sep	21.98	13.96	0.64

Critical months: WET : Jul, DRY : Feb

Using 10th percentile of FDC of separated baseflows

Max. baseflows (m^3/s): WET : 16.850, DRY : 2.085

HYDRAULICS DATA SUMMARY

Catchment Area (km^2)	18543.40
Geomorph. Zone	4
Valley Slope (Fraction)	0.0060
Width/Depth scaling	0.50
Max. Channel width (m)	150.00
Max. Channel Depth (m)	3.00

Observed Channel XS used

Observed Rating Curve used

(Gradients and Roughness n values calibrated)

Max. Gradient	0.00300
Min. Gradient	0.00010
Gradient Shape Factor	15
Max. Mannings n	0.050
Min. Mannings n	0.030
n Shape Factor	15

Habitat Type definitions used:

Fast:	>	0.3 m/s
Shallow:	>	0.1 m
Intermediate:	>	0.2 m
Deep (fast):	>	0.3 m
Deep (slow):	>	0.5 m

FLOW - STRESSOR RESPONSE DATA SUMMARY

Table of Stress weightings

Season	Wet	Dry
Stress at 0 FS:	9	9
FS Weight:	2	2
FI Weight:	2	2
FD Weight:	4	4

Table of flows ($m^3/2$) v stress index

Stress	Wet Season Flow	Dry Season Flow
0.0	17.081	2.187
0.5	13.450	2.122
1.0	11.299	2.040
1.5	9.458	1.937
2.0	7.724	1.852
2.5	5.572	1.763
3.0	4.073	1.634
3.5	3.218	1.545
4.0	2.659	1.475
4.5	2.236	1.391
5.0	1.868	1.285
5.5	1.561	1.163
6.0	1.278	1.045
6.5	1.016	0.915
7.0	0.765	0.762
7.5	0.542	0.570
8.0	0.340	0.369
8.5	0.123	0.150
9.0	0.049	0.053
9.5	0.020	0.022
10.0	0.000	0.000

Table of default/altered SHIFT factors for the Stress Frequency Curves

Category	High SHIFT		Low SHIFT	
	Default	Altered	Default	Altered
Wet season				
A	6.103	6.103	0.420	0.420
A/B	6.283	6.283	0.702	0.702
B	6.464	6.464	0.985	0.985
B/C	6.734	6.734	1.408	1.408
C	7.004	7.004	1.832	1.832
C/D	7.365	7.365	2.397	2.397
D	7.725	7.725	2.961	2.961

Dry season

A	8.081	8.081	1.651	1.651
A/B	8.132	8.132	1.914	1.914
B	8.184	8.184	2.176	2.176
B/C	8.260	8.260	2.570	2.570
C	8.337	8.337	2.964	2.964
C/D	8.440	8.440	3.490	3.490
D	8.542	8.542	4.015	4.015

Perenniality Rules
Non-Perennial Allowed

Alignment of maximum stress to Present Day stress
Not Aligned

HIGH FLOW REQUIREMENT SUMMARY

Bankfull channel discharge (m^3/s) = 104.273

Flood event requirements

Class	Frequency	Peak(m^3/s)	Duration(hours)	N. Events	Volume(MCM)
1	Annual	20.994	212	4	6.762
2	Annual	45.028	252	3	17.239
3	Annual	69.567	284	1	30.016
4	1:2 year	86.208	304	1	39.816
5	1:5 year	131.475	348	1	69.511

Flood requirements have been constrained to a maximum of 0.48 of natural high flows

Events excluded from the time series of high flow requirements:
No Events excluded.

FINAL RESERVE SUMMARY DETAILS

EWR Flows are NOT constrained to be below Natural or Present Day Flows

Long term mean flow requirements (Mill. m^3 and %MAR)

Category	Low Flows		Total Flows	
	Mill. m^3	%MAR	Mill. m^3	%MAR
A	98.668	25.5	98.668	25.5
A/B	92.338	23.8	92.338	23.8
B	86.224	22.3	86.224	22.3
B/C	77.442	20.0	77.442	20.0
C	68.930	17.8	68.930	17.8
C/D	58.903	15.2	58.903	15.2
D	50.724	13.1	50.724	13.1

FLOW DURATION and RESERVE ASSURANCE TABLES

Columns are FDC precentage points:

Natural Total flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	59.140	41.501	31.622	27.492	25.389	22.910	21.834	17.242	15.084	12.066
Nov	20.992	18.487	17.963	14.702	13.067	12.745	11.733	10.376	8.288	5.936
Dec	14.361	10.559	7.542	7.252	6.429	6.107	5.406	4.502	3.484	2.593
Jan	6.024	5.078	4.369	3.902	3.408	3.064	2.630	2.030	1.503	1.225
Feb	5.306	3.651	3.053	2.881	2.408	2.142	1.829	1.715	1.142	0.842
Mar	7.556	4.421	3.718	2.966	2.826	2.762	2.433	1.769	0.916	0.750
Apr	23.774	12.443	8.266	6.844	5.301	3.736	3.084	2.786	2.610	2.342
May	93.283	56.646	39.422	24.014	14.329	11.575	10.350	6.504	3.970	2.878
Jun	158.553	88.126	79.568	57.909	46.898	34.199	27.406	22.281	10.220	4.617
Jul	227.524	158.641	128.465	76.086	62.163	53.866	39.197	34.477	24.470	5.411
Aug	124.084	106.068	94.861	71.385	66.507	64.266	52.843	35.090	27.919	12.233
Sep	108.256	79.053	52.697	48.485	42.192	39.276	35.923	28.392	21.399	16.960

Natural Baseflow flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	25.438	21.450	17.966	16.130	15.727	13.705	11.765	8.667	7.293	4.516
Nov	17.808	15.582	13.837	13.361	12.852	10.746	9.843	7.776	6.186	3.657
Dec	13.102	10.292	7.542	7.252	6.429	6.107	5.406	4.502	3.484	2.593
Jan	6.024	5.078	4.369	3.902	3.408	3.064	2.630	2.030	1.503	1.225
Feb	5.028	3.490	3.053	2.881	2.408	2.142	1.829	1.715	1.142	0.842
Mar	4.533	3.107	2.955	2.789	2.671	2.395	1.930	1.546	0.916	0.750
Apr	8.590	4.762	3.825	3.101	2.948	2.815	2.547	1.973	1.572	1.276
May	18.357	12.596	9.968	6.762	4.569	4.121	3.743	3.274	2.017	1.381
Jun	30.511	19.876	17.066	14.222	11.147	8.942	8.381	5.718	2.795	2.486
Jul	42.487	32.660	27.419	19.801	15.752	14.132	11.277	9.493	5.817	2.687
Aug	31.784	26.800	23.242	21.389	19.188	15.567	13.935	11.736	9.015	3.683
Sep	30.605	26.037	20.960	18.301	16.977	15.620	11.037	10.003	7.530	5.117

Category Low Flow Assurance curves (mill. m^3)

A Category

Oct	19.625	19.243	16.689	13.784	11.337	9.043	7.315	5.728	4.933	4.804
Nov	15.168	14.068	12.517	10.864	9.080	7.190	5.679	4.697	4.143	3.885
Dec	11.557	9.718	7.890	6.433	5.463	4.663	3.945	3.277	2.834	2.683
Jan	7.448	5.332	4.382	3.673	3.030	2.575	2.125	1.714	1.416	1.293
Feb	3.859	3.152	2.734	2.348	1.988	1.660	1.378	1.148	0.963	0.760
Mar	4.576	3.243	2.717	2.468	2.233	2.004	1.614	1.223	0.937	0.816
Apr	7.864	5.295	3.817	3.029	2.511	2.262	1.956	1.615	1.367	1.275
May	16.863	12.781	9.629	6.881	4.685	3.487	2.867	2.377	1.910	1.551
Jun	21.566	19.181	15.128	12.037	8.867	6.449	4.985	3.883	2.823	2.395
Jul	33.890	28.963	23.398	16.347	10.552	7.706	6.040	4.840	3.969	2.687
Aug	24.121	23.851	21.090	17.893	15.018	12.069	9.525	7.881	6.492	5.085
Sep	22.076	21.757	18.611	15.291	12.743	10.438	7.831	5.983	5.806	5.381
A/B Category										
Oct	18.562	18.088	15.553	12.533	10.194	8.328	6.852	5.388	4.728	4.658
Nov	14.545	13.437	11.862	10.034	8.261	6.634	5.309	4.411	3.926	3.765
Dec	11.187	9.437	7.663	6.143	5.161	4.413	3.733	3.102	2.697	2.606
Jan	7.258	5.237	4.313	3.562	2.910	2.462	2.023	1.630	1.353	1.259
Feb	3.764	3.152	2.682	2.279	1.919	1.586	1.310	1.087	0.908	0.760
Mar	4.417	3.092	2.571	2.304	2.096	1.911	1.537	1.162	0.892	0.793
Apr	7.653	5.196	3.765	2.946	2.419	2.164	1.862	1.537	1.307	1.242
May	16.184	12.303	9.297	6.565	4.442	3.317	2.722	2.254	1.818	1.505
Jun	20.368	18.010	14.177	11.031	8.067	5.996	4.682	3.655	2.682	2.330
Jul	30.691	26.301	20.942	13.955	9.420	7.092	5.609	4.514	3.684	2.676
Aug	22.522	22.089	19.391	16.335	13.859	11.308	8.976	7.432	6.142	4.892
Sep	20.736	20.221	17.165	13.812	11.579	9.773	7.362	5.639	5.530	5.215
B Category										
Oct	17.610	16.958	14.404	11.365	9.236	7.702	6.409	5.042	4.436	4.406
Nov	13.944	12.801	11.184	9.255	7.571	6.150	4.956	4.122	3.682	3.563
Dec	10.825	9.135	7.399	5.847	4.881	4.173	3.523	2.920	2.538	2.468
Jan	7.067	5.125	4.218	3.439	2.789	2.346	1.918	1.539	1.274	1.187
Feb	3.688	3.120	2.611	2.204	1.844	1.511	1.242	1.026	0.850	0.712
Mar	4.264	2.943	2.417	2.143	1.971	1.820	1.459	1.097	0.840	0.752
Apr	7.446	5.083	3.690	2.852	2.323	2.064	1.766	1.451	1.230	1.169
May	15.534	11.811	8.920	6.234	4.214	3.150	2.577	2.126	1.710	1.416

Jun	19.239	16.870	13.202	10.081	7.390	5.594	4.391	3.431	2.535	2.243
Jul	27.891	23.740	18.075	11.945	8.489	6.560	5.202	4.192	3.400	2.601
Aug	21.080	20.384	17.667	14.818	12.842	10.614	8.441	6.979	5.762	4.612
Sep	19.500	18.736	15.710	12.420	10.579	9.167	6.906	5.280	5.193	4.932

B/C Category

Oct	16.187	15.237	12.651	9.852	8.088	6.883	5.782	4.540	4.031	4.015
Nov	13.026	11.789	10.111	8.228	6.721	5.510	4.459	3.704	3.310	3.236
Dec	10.251	8.610	6.923	5.418	4.495	3.827	3.213	2.648	2.293	2.249
Jan	6.754	4.908	4.020	3.244	2.606	2.171	1.761	1.402	1.150	1.068
Feb	3.576	2.989	2.492	2.086	1.722	1.398	1.139	0.934	0.760	0.629
Mar	4.024	2.708	2.172	1.922	1.801	1.682	1.341	1.000	0.760	0.684
Apr	7.110	4.868	3.526	2.699	2.175	1.911	1.621	1.321	1.109	1.050
May	14.542	10.996	8.255	5.744	3.895	2.903	2.359	1.932	1.542	1.273
Jun	17.569	15.131	11.682	8.817	6.553	5.052	3.978	3.105	2.307	2.101
Jul	23.872	19.790	14.024	9.801	7.399	5.831	4.648	3.738	3.002	2.461
Aug	19.025	17.836	15.052	12.782	11.550	9.651	7.667	6.311	5.184	4.166
Sep	17.691	16.519	13.526	10.616	9.356	8.329	6.254	4.749	4.665	4.473

C Category

Oct	14.688	13.459	11.019	8.664	7.173	6.157	5.181	4.036	3.494	3.472
Nov	12.038	10.731	9.089	7.389	6.022	4.938	3.987	3.287	2.904	2.805
Dec	9.605	8.033	6.419	5.018	4.130	3.488	2.905	2.368	2.018	1.944
Jan	6.389	4.660	3.793	3.044	2.419	1.992	1.601	1.260	1.018	0.931
Feb	3.451	2.845	2.369	1.964	1.592	1.282	1.036	0.839	0.671	0.547
Mar	3.755	2.464	1.939	1.736	1.646	1.543	1.221	0.899	0.671	0.594
Apr	6.720	4.624	3.333	2.538	2.021	1.754	1.474	1.188	0.981	0.916
May	13.460	10.115	7.566	5.297	3.591	2.657	2.141	1.735	1.365	1.110
Jun	15.823	13.335	10.253	7.812	5.870	4.556	3.575	2.768	2.028	1.806
Jul	19.834	15.186	11.027	8.294	6.527	5.180	4.139	3.297	2.609	2.097
Aug	16.901	15.239	12.663	11.165	10.441	8.747	6.913	5.641	4.571	3.624
Sep	15.808	14.242	11.508	9.220	8.352	7.543	5.622	4.209	4.088	3.882

C/D Category

Oct	12.838	11.365	9.358	7.452	6.156	5.280	4.423	3.387	2.808	2.782
Nov	10.830	9.448	7.983	6.478	5.215	4.240	3.394	2.751	2.378	2.254

Dec	8.824	7.289	5.809	4.516	3.658	3.045	2.500	1.997	1.657	1.561
Jan	5.967	4.325	3.490	2.770	2.162	1.751	1.386	1.069	0.841	0.753
Feb	3.256	2.655	2.194	1.787	1.418	1.126	0.898	0.706	0.551	0.437
Mar	3.455	2.175	1.689	1.528	1.451	1.356	1.059	0.763	0.554	0.479
Apr	6.262	4.288	3.073	2.314	1.807	1.542	1.276	1.007	0.810	0.740
May	12.102	8.991	6.770	4.757	3.193	2.330	1.850	1.470	1.129	0.898
Jun	13.571	11.129	8.777	6.771	5.087	3.937	3.062	2.330	1.668	1.445
Jul	13.891	10.891	8.602	6.885	5.532	4.418	3.505	2.741	2.104	1.659
Aug	14.247	12.232	10.329	9.530	9.117	7.597	5.937	4.757	3.766	2.926
Sep	13.453	11.588	9.514	7.835	7.211	6.547	4.815	3.507	3.332	3.125

D Category

Oct	11.446	9.844	8.129	6.450	5.253	4.470	3.697	2.761	2.185	2.160
Nov	9.855	8.419	7.081	5.674	4.479	3.595	2.833	2.237	1.881	1.752
Dec	8.149	6.623	5.246	4.017	3.187	2.609	2.100	1.631	1.314	1.213
Jan	5.579	3.986	3.181	2.481	1.894	1.507	1.168	0.876	0.671	0.591
Feb	3.030	2.459	2.002	1.584	1.238	0.969	0.750	0.573	0.432	0.347
Mar	3.207	1.944	1.488	1.340	1.260	1.167	0.894	0.626	0.440	0.373
Apr	5.846	3.950	2.805	2.074	1.584	1.327	1.075	0.825	0.646	0.581
May	11.001	8.060	6.080	4.233	2.791	2.002	1.558	1.205	0.900	0.704
Jun	11.917	9.542	7.667	5.894	4.375	3.353	2.565	1.902	1.318	1.106
Jul	10.066	8.462	7.048	5.790	4.673	3.728	2.908	2.206	1.646	1.248
Aug	12.360	10.197	8.725	8.191	7.869	6.489	4.979	3.886	2.992	2.280
Sep	11.759	9.766	8.119	6.729	6.183	5.595	4.039	2.849	2.623	2.431

Category Total Flow Assurance curves (mill. m^3)

A Category

Oct	19.625	19.243	16.689	13.784	11.337	9.043	7.315	5.728	4.933	4.804
Nov	15.168	14.068	12.517	10.864	9.080	7.190	5.679	4.697	4.143	3.885
Dec	11.557	9.718	7.890	6.433	5.463	4.663	3.945	3.277	2.834	2.683
Jan	7.448	5.332	4.382	3.673	3.030	2.575	2.125	1.714	1.416	1.293
Feb	3.859	3.152	2.734	2.348	1.988	1.660	1.378	1.148	0.963	0.760
Mar	4.576	3.243	2.717	2.468	2.233	2.004	1.614	1.223	0.937	0.816
Apr	7.864	5.295	3.817	3.029	2.511	2.262	1.956	1.615	1.367	1.275
May	16.863	12.781	9.629	6.881	4.685	3.487	2.867	2.377	1.910	1.551

Jun	21.566	19.181	15.128	12.037	8.867	6.449	4.985	3.883	2.823	2.395
Jul	33.890	28.963	23.398	16.347	10.552	7.706	6.040	4.840	3.969	2.687
Aug	24.121	23.851	21.090	17.893	15.018	12.069	9.525	7.881	6.492	5.085
Sep	22.076	21.757	18.611	15.291	12.743	10.438	7.831	5.983	5.806	5.381
A/B Category										
Oct	18.562	18.088	15.553	12.533	10.194	8.328	6.852	5.388	4.728	4.658
Nov	14.545	13.437	11.862	10.034	8.261	6.634	5.309	4.411	3.926	3.765
Dec	11.187	9.437	7.663	6.143	5.161	4.413	3.733	3.102	2.697	2.606
Jan	7.258	5.237	4.313	3.562	2.910	2.462	2.023	1.630	1.353	1.259
Feb	3.764	3.152	2.682	2.279	1.919	1.586	1.310	1.087	0.908	0.760
Mar	4.417	3.092	2.571	2.304	2.096	1.911	1.537	1.162	0.892	0.793
Apr	7.653	5.196	3.765	2.946	2.419	2.164	1.862	1.537	1.307	1.242
May	16.184	12.303	9.297	6.565	4.442	3.317	2.722	2.254	1.818	1.505
Jun	20.368	18.010	14.177	11.031	8.067	5.996	4.682	3.655	2.682	2.330
Jul	30.691	26.301	20.942	13.955	9.420	7.092	5.609	4.514	3.684	2.676
Aug	22.522	22.089	19.391	16.335	13.859	11.308	8.976	7.432	6.142	4.892
Sep	20.736	20.221	17.165	13.812	11.579	9.773	7.362	5.639	5.530	5.215
B Category										
Oct	17.610	16.958	14.404	11.365	9.236	7.702	6.409	5.042	4.436	4.406
Nov	13.944	12.801	11.184	9.255	7.571	6.150	4.956	4.122	3.682	3.563
Dec	10.825	9.135	7.399	5.847	4.881	4.173	3.523	2.920	2.538	2.468
Jan	7.067	5.125	4.218	3.439	2.789	2.346	1.918	1.539	1.274	1.187
Feb	3.688	3.120	2.611	2.204	1.844	1.511	1.242	1.026	0.850	0.712
Mar	4.264	2.943	2.417	2.143	1.971	1.820	1.459	1.097	0.840	0.752
Apr	7.446	5.083	3.690	2.852	2.323	2.064	1.766	1.451	1.230	1.169
May	15.534	11.811	8.920	6.234	4.214	3.150	2.577	2.126	1.710	1.416
Jun	19.239	16.870	13.202	10.081	7.390	5.594	4.391	3.431	2.535	2.243
Jul	27.891	23.740	18.075	11.945	8.489	6.560	5.202	4.192	3.400	2.601
Aug	21.080	20.384	17.667	14.818	12.842	10.614	8.441	6.979	5.762	4.612
Sep	19.500	18.736	15.710	12.420	10.579	9.167	6.906	5.280	5.193	4.932
B/C Category										
Oct	16.187	15.237	12.651	9.852	8.088	6.883	5.782	4.540	4.031	4.015
Nov	13.026	11.789	10.111	8.228	6.721	5.510	4.459	3.704	3.310	3.236

Dec	10.251	8.610	6.923	5.418	4.495	3.827	3.213	2.648	2.293	2.249
Jan	6.754	4.908	4.020	3.244	2.606	2.171	1.761	1.402	1.150	1.068
Feb	3.576	2.989	2.492	2.086	1.722	1.398	1.139	0.934	0.760	0.629
Mar	4.024	2.708	2.172	1.922	1.801	1.682	1.341	1.000	0.760	0.684
Apr	7.110	4.868	3.526	2.699	2.175	1.911	1.621	1.321	1.109	1.050
May	14.542	10.996	8.255	5.744	3.895	2.903	2.359	1.932	1.542	1.273
Jun	17.569	15.131	11.682	8.817	6.553	5.052	3.978	3.105	2.307	2.101
Jul	23.872	19.790	14.024	9.801	7.399	5.831	4.648	3.738	3.002	2.461
Aug	19.025	17.836	15.052	12.782	11.550	9.651	7.667	6.311	5.184	4.166
Sep	17.691	16.519	13.526	10.616	9.356	8.329	6.254	4.749	4.665	4.473
C Category										
Oct	14.688	13.459	11.019	8.664	7.173	6.157	5.181	4.036	3.494	3.472
Nov	12.038	10.731	9.089	7.389	6.022	4.938	3.987	3.287	2.904	2.805
Dec	9.605	8.033	6.419	5.018	4.130	3.488	2.905	2.368	2.018	1.944
Jan	6.389	4.660	3.793	3.044	2.419	1.992	1.601	1.260	1.018	0.931
Feb	3.451	2.845	2.369	1.964	1.592	1.282	1.036	0.839	0.671	0.547
Mar	3.755	2.464	1.939	1.736	1.646	1.543	1.221	0.899	0.671	0.594
Apr	6.720	4.624	3.333	2.538	2.021	1.754	1.474	1.188	0.981	0.916
May	13.460	10.115	7.566	5.297	3.591	2.657	2.141	1.735	1.365	1.110
Jun	15.823	13.335	10.253	7.812	5.870	4.556	3.575	2.768	2.028	1.806
Jul	19.834	15.186	11.027	8.294	6.527	5.180	4.139	3.297	2.609	2.097
Aug	16.901	15.239	12.663	11.165	10.441	8.747	6.913	5.641	4.571	3.624
Sep	15.808	14.242	11.508	9.220	8.352	7.543	5.622	4.209	4.088	3.882
C/D Category										
Oct	12.838	11.365	9.358	7.452	6.156	5.280	4.423	3.387	2.808	2.782
Nov	10.830	9.448	7.983	6.478	5.215	4.240	3.394	2.751	2.378	2.254
Dec	8.824	7.289	5.809	4.516	3.658	3.045	2.500	1.997	1.657	1.561
Jan	5.967	4.325	3.490	2.770	2.162	1.751	1.386	1.069	0.841	0.753
Feb	3.256	2.655	2.194	1.787	1.418	1.126	0.898	0.706	0.551	0.437
Mar	3.455	2.175	1.689	1.528	1.451	1.356	1.059	0.763	0.554	0.479
Apr	6.262	4.288	3.073	2.314	1.807	1.542	1.276	1.007	0.810	0.740
May	12.102	8.991	6.770	4.757	3.193	2.330	1.850	1.470	1.129	0.898
Jun	13.571	11.129	8.777	6.771	5.087	3.937	3.062	2.330	1.668	1.445
Jul	13.891	10.891	8.602	6.885	5.532	4.418	3.505	2.741	2.104	1.659

Aug	14.247	12.232	10.329	9.530	9.117	7.597	5.937	4.757	3.766	2.926
Sep	13.453	11.588	9.514	7.835	7.211	6.547	4.815	3.507	3.332	3.125
D Category										
Oct	11.446	9.844	8.129	6.450	5.253	4.470	3.697	2.761	2.185	2.160
Nov	9.855	8.419	7.081	5.674	4.479	3.595	2.833	2.237	1.881	1.752
Dec	8.149	6.623	5.246	4.017	3.187	2.609	2.100	1.631	1.314	1.213
Jan	5.579	3.986	3.181	2.481	1.894	1.507	1.168	0.876	0.671	0.591
Feb	3.030	2.459	2.002	1.584	1.238	0.969	0.750	0.573	0.432	0.347
Mar	3.207	1.944	1.488	1.340	1.260	1.167	0.894	0.626	0.440	0.373
Apr	5.846	3.950	2.805	2.074	1.584	1.327	1.075	0.825	0.646	0.581
May	11.001	8.060	6.080	4.233	2.791	2.002	1.558	1.205	0.900	0.704
Jun	11.917	9.542	7.667	5.894	4.375	3.353	2.565	1.902	1.318	1.106
Jul	10.066	8.462	7.048	5.790	4.673	3.728	2.908	2.206	1.646	1.248
Aug	12.360	10.197	8.725	8.191	7.869	6.489	4.979	3.886	2.992	2.280
Sep	11.759	9.766	8.119	6.729	6.183	5.595	4.039	2.849	2.623	2.431

Table F5. RDRM output for Doring EWR site 5 with RCP 2.6 data.

Revised Desktop Model outputs for site: EWR_5

HYDROLOGY DATA SUMMARY

Natural Flows:					RCP 2.6 min Flows:				
Area	MAR	Ann.SD	Q75	Ann.	Area	MAR	Ann.SD	Q75	Ann.
(km^2)	($m^3 * 10^6$)			CV	(km^2)	($m^3 * 10^6$)			CV
0.00	561.87	310.79	2.79	0.55	0.00	207.07	171.26	0.05	0.83

% Zero flows = 0.0 % Zero flows = 22.1

Baseflow Parameters: A = 0.970, B = 0.42Baseflow Parameters: A = 0.970, B = 0.420

BFI = 0.27 : Hydro Index = 13.7 BFI = 0.25 : Hydro Index = 20.4

MONTH	MEAN	SD	CV	MONTH	MEAN	SD	CV
	(m^3 * 10^6)				(m^3 * 10^6)		
Oct	37.12	27.42	0.74	Oct	18.69	16.46	0.88
Nov	20.68	38.36	1.85	Nov	8.84	10.38	1.17
Dec	7.10	7.74	1.09	Dec	2.50	6.53	2.61
Jan	4.14	15.92	3.85	Jan	0.34	1.31	3.85
Feb	3.46	10.70	3.09	Feb	0.75	2.95	3.92
Mar	4.83	7.58	1.57	Mar	3.75	14.82	3.95
Apr	27.87	61.74	2.22	Apr	9.55	18.31	1.92
May	45.72	61.45	1.34	May	13.56	16.17	1.19
Jun	92.93	100.89	1.09	Jun	20.28	13.62	0.67
Jul	148.72	146.15	0.98	Jul	43.62	75.31	1.73
Aug	101.01	64.87	0.64	Aug	53.46	65.96	1.23
Sep	68.29	45.55	0.67	Sep	31.74	28.29	0.89

Critical months: WET : Jul, DRY : Jan

Using 10th percentile of FDC of separated baseflows

Max. baseflows (m^3/s): WET : 29.191, DRY : 1.279

HYDRAULICS DATA SUMMARY

Catchment Area (km^2)	23511.00
Geomorph. Zone	4
Valley Slope (Fraction)	0.0060
Width/Depth scaling	0.50
Max. Channel width (m)	120.00
Max. Channel Depth (m)	6.59

Observed Channel XS used

Observed Rating Curve used

(Gradients and Roughness n values calibrated)

Max. Gradient	0.06000
Min. Gradient	0.00200
Gradient Shape Factor	15
Max. Mannings n	0.040
Min. Mannings n	0.020
n Shape Factor	15

Habitat Type definitions used:

Fast:	>	0.3 m/s
Shallow:	>	0.1 m
Intermediate:	>	0.2 m
Deep (fast):	>	0.3 m
Deep (slow):	>	0.5 m

FLOW - STRESSOR RESPONSE DATA SUMMARY

Table of Stress weightings

Season	Wet	Dry
Stress at 0 FS:	9	9
FS Weight:	2	2
FI Weight:	2	2
FD Weight:	3	0

Table of flows ($m^3/2$) v stress index

Stress	Wet Season Flow	Dry Season Flow
0.0	29.929	1.328
0.5	22.457	1.225
1.0	18.405	1.122
1.5	15.538	1.019
2.0	14.229	0.923
2.5	13.195	0.851
3.0	12.109	0.798
3.5	10.309	0.751
4.0	8.613	0.704
4.5	7.554	0.654
5.0	6.614	0.596
5.5	5.547	0.521
6.0	4.180	0.392
6.5	3.164	0.208
7.0	2.273	0.151
7.5	1.410	0.120
8.0	0.479	0.101
8.5	0.178	0.088
9.0	0.092	0.074
9.5	0.041	0.047
10.0	0.000	0.000

Table of default/altered SHIFT factors for the Stress Frequency Curves

Category	High SHIFT		Low SHIFT	
	Default	Altered	Default	Altered
Wet season				
A	7.938	7.938	0.510	0.510
A/B	8.052	8.052	0.888	0.888
B	8.166	8.166	1.266	1.266
B/C	8.337	8.337	1.833	1.833
C	8.508	8.508	2.400	2.400
C/D	8.736	8.736	3.156	3.156
D	8.964	8.964	3.912	3.912
Dry season				
A	9.806	9.806	0.738	0.738

A/B	9.828	9.828	1.199	1.199
B	9.849	9.849	1.661	1.661
B/C	9.882	9.882	2.353	2.353
C	9.914	9.914	3.046	3.046
C/D	9.957	9.957	3.969	3.969
D	10.000	10.000	4.892	4.892

Perenniality Rules
Non-Perennial Allowed

Alignment of maximum stress to Present Day stress
Not Aligned

FLOW - STRESSOR RESPONSE DATA SUMMARY
Table of Stress weightings

Season	Wet	Dry
Stress at 0 FS:	9	9
FS Weight:	2	2
FI Weight:	2	2
FD Weight:	3	0

Table of flows ($m^3/2$) v stress index

Stress	Wet Season Flow	Dry Season Flow
0.0	29.929	1.328
0.5	22.457	1.225
1.0	18.405	1.122
1.5	15.538	1.019
2.0	14.229	0.923
2.5	13.195	0.851
3.0	12.109	0.798
3.5	10.309	0.751
4.0	8.613	0.704
4.5	7.554	0.654
5.0	6.614	0.596
5.5	5.547	0.521
6.0	4.180	0.392
6.5	3.164	0.208
7.0	2.273	0.151
7.5	1.410	0.120
8.0	0.479	0.101
8.5	0.178	0.088
9.0	0.092	0.074
9.5	0.041	0.047
10.0	0.000	0.000

Table of default/altered SHIFT factors for the Stress Frequency Curves

Category	High SHIFT		Low SHIFT	
	Default	Altered	Default	Altered
Wet season				
A	7.938	7.938	0.510	0.510
A/B	8.052	8.052	0.888	0.888
B	8.166	8.166	1.266	1.266
B/C	8.337	8.337	1.833	1.833
C	8.508	8.508	2.400	2.400

C/D	8.736	8.736	3.156	3.156
D	8.964	8.964	3.912	3.912
Dry season				
A	9.806	9.806	0.738	0.738
A/B	9.828	9.828	1.199	1.199
B	9.849	9.849	1.661	1.661
B/C	9.882	9.882	2.353	2.353
C	9.914	9.914	3.046	3.046
C/D	9.957	9.957	3.969	3.969
D	10.000	10.000	4.892	4.892

Perenniality Rules
Non-Perennial Allowed

Alignment of maximum stress to Present Day stress
Not Aligned

HIGH FLOW REQUIREMENT SUMMARY
Bankfull channel discharge (m^3/s) = 3592.809

Flood event requirements

Class	Frequency	Peak(m^3/s)	Duration(hours)	N. Events	Volume(MCM)
1	Annual	26.299	104	5	4.155
2	Annual	88.705	112	2	15.094
3	Annual	153.258	116	2	27.009
4	1:2 year	309.312	124	1	58.271
5	1:5 year	659.788	140	1	140.335

Flood requirements have been constrained to a maximum of 0.42 of natural high flows

Events excluded from the time series of high flow requirements:
No Events excluded.

FINAL RESERVE SUMMARY DETAILS

EWR Flows are NOT constrained to be below Natural or Present Day Flows

Long term mean flow requirements (Mill. m^3 and %MAR)

Category	Low Flows		Total Flows	
	Mill. m^3	%MAR	Mill. m^3	%MAR
A	112.806	20.1	269.548	48.0
A/B	104.817	18.7	253.338	45.1
B	97.317	17.3	239.080	42.6
B/C	86.994	15.5	224.410	39.9
C	76.620	13.6	206.170	36.7
C/D	62.255	11.1	187.280	33.3
D	47.629	8.5	165.440	29.4

FLOW DURATION and RESERVE ASSURANCE TABLES

Columns are FDC precentage points:

Natural Total flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	84.658	50.073	39.688	32.216	29.353	25.287	21.012	19.022	18.114	15.541
Nov	25.362	20.442	15.896	13.355	11.503	10.354	9.502	9.240	7.558	7.160
Dec	25.875	11.406	5.373	4.476	3.977	3.403	3.219	2.924	2.149	1.325
Jan	3.322	2.275	1.621	1.258	1.056	0.995	0.632	0.133	0.076	0.043
Feb	12.766	1.568	0.928	0.730	0.203	0.092	0.066	0.048	0.036	0.012
Mar	20.007	8.353	4.911	2.123	1.407	0.862	0.522	0.100	0.060	0.020
Apr	124.199	34.441	15.714	8.881	5.764	3.332	2.632	1.622	1.206	0.529
May	157.259	89.301	42.492	33.155	21.187	16.441	10.832	5.956	3.583	1.981
Jun	237.402	132.079	106.528	78.134	60.395	49.497	39.730	30.142	15.671	3.991
Jul	400.505	311.698	171.670	113.908	94.243	76.344	61.449	45.282	32.167	5.355
Aug	189.186	148.338	119.815	101.530	83.996	79.269	73.617	45.236	37.356	15.564
Sep	127.904	111.468	80.745	64.197	50.733	45.502	43.669	37.495	27.549	20.974

Natural Baseflow flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	33.256	26.732	20.893	19.557	18.292	16.448	13.963	9.813	8.096	5.091
Nov	21.484	14.983	13.719	12.138	10.754	9.744	9.060	7.499	6.724	3.814
Dec	14.068	9.281	4.727	4.331	3.936	3.403	3.219	2.924	2.149	1.325
Jan	3.322	2.250	1.621	1.258	1.056	0.995	0.632	0.133	0.076	0.043
Feb	4.177	1.425	0.928	0.730	0.132	0.077	0.063	0.048	0.036	0.012
Mar	4.626	3.046	1.243	0.982	0.515	0.348	0.219	0.100	0.042	0.017
Apr	21.469	6.980	3.997	2.298	1.787	1.236	0.991	0.710	0.394	0.171
May	27.248	18.800	10.456	6.645	4.650	3.626	2.822	2.052	1.137	0.448
Jun	41.400	29.370	20.790	17.566	15.675	10.173	8.940	6.378	3.857	0.848
Jul	75.247	56.653	38.350	25.848	22.062	17.822	14.937	11.275	7.000	1.163
Aug	49.219	36.065	32.843	28.928	24.206	18.538	16.882	13.709	10.113	3.629
Sep	36.558	32.591	28.069	26.419	23.483	16.519	14.708	11.749	8.076	6.058

Category Low Flow Assurance curves (mill. m^3)

A Category

Oct	23.162	23.162	20.465	18.250	15.664	12.562	9.350	6.678	5.371	4.956
Nov	17.200	14.485	12.090	10.918	8.408	5.971	4.933	4.695	4.099	3.506
Dec	8.252	8.252	5.728	3.935	2.809	2.194	2.190	2.187	2.043	1.539
Jan	2.752	2.131	1.621	1.258	0.494	0.303	0.238	0.133	0.076	0.043
Feb	3.019	1.992	0.833	0.552	0.254	0.056	0.034	0.029	0.024	0.015
Mar	3.263	2.701	1.547	0.906	0.558	0.258	0.137	0.094	0.052	0.023
Apr	12.129	8.245	4.258	2.547	1.328	0.644	0.561	0.547	0.469	0.275
May	15.753	15.687	10.998	7.075	3.986	1.994	1.470	1.453	1.182	0.673
Jun	30.390	24.989	20.043	16.106	12.351	7.917	5.012	4.189	3.021	1.581
Jul	52.152	41.490	35.416	25.543	19.799	14.360	9.116	5.867	3.488	1.000
Aug	32.128	32.128	28.601	25.679	19.576	12.765	9.631	9.360	7.939	5.180
Sep	26.444	26.444	24.298	22.409	18.007	12.462	9.257	7.774	6.864	5.803

A/B Category

Oct	21.647	21.647	19.602	17.439	14.689	11.554	8.506	6.079	4.930	4.713
Nov	15.529	13.563	11.658	10.465	7.814	5.483	4.561	4.363	3.767	3.264
Dec	7.788	7.788	5.544	3.793	2.590	2.197	2.171	2.144	1.991	1.487
Jan	2.530	2.106	1.621	1.180	0.446	0.290	0.232	0.133	0.076	0.043
Feb	2.722	1.849	0.799	0.531	0.240	0.052	0.031	0.028	0.023	0.015
Mar	2.963	2.542	1.495	0.867	0.520	0.237	0.128	0.090	0.050	0.022
Apr	10.947	7.685	4.138	2.472	1.220	0.594	0.548	0.540	0.468	0.274
May	14.699	14.699	10.618	6.832	3.691	1.830	1.433	1.422	1.167	0.662
Jun	27.124	23.164	19.170	15.420	11.596	7.326	4.648	3.932	2.849	1.473
Jul	45.708	38.828	33.645	24.490	18.598	12.967	8.228	5.194	2.851	0.829
Aug	29.677	29.677	27.070	24.233	18.154	11.769	9.013	8.884	7.566	4.913
Sep	24.568	24.568	23.055	21.057	16.567	11.414	8.534	7.330	6.559	5.559

B Category

Oct	20.301	20.301	18.618	16.410	13.578	10.552	7.691	5.496	4.525	4.516
Nov	14.148	12.713	11.115	9.869	7.142	5.013	4.204	4.038	3.438	3.070
Dec	7.342	7.342	5.305	3.593	2.342	2.093	2.086	2.079	1.942	1.444
Jan	2.351	2.023	1.605	1.049	0.405	0.278	0.225	0.133	0.076	0.043
Feb	2.475	1.722	0.761	0.501	0.221	0.047	0.029	0.026	0.022	0.014
Mar	2.710	2.386	1.425	0.816	0.475	0.216	0.119	0.086	0.049	0.021
Apr	9.966	7.178	3.972	2.358	1.095	0.548	0.535	0.533	0.466	0.273
May	13.815	13.815	10.155	6.491	3.349	1.678	1.398	1.392	1.153	0.653

Jun	24.551	21.643	18.216	14.536	10.724	6.748	4.297	3.681	2.678	1.371
Jul	40.963	36.790	31.330	22.815	17.350	11.610	7.411	4.520	2.215	0.713
Aug	27.640	27.640	25.439	22.444	16.539	10.807	8.473	8.420	7.199	4.667
Sep	22.931	22.931	21.698	19.459	14.994	10.398	7.838	6.897	6.264	5.344
B/C Category										
Oct	18.558	18.558	16.895	14.526	11.830	9.085	6.495	4.605	4.009	3.989
Nov	12.710	11.622	10.113	8.685	6.103	4.388	3.680	3.540	2.910	2.634
Dec	6.751	6.751	4.865	3.150	2.089	2.024	2.008	1.992	1.851	1.336
Jan	2.151	1.885	1.521	0.742	0.354	0.262	0.215	0.133	0.076	0.036
Feb	2.221	1.571	0.692	0.440	0.185	0.042	0.026	0.024	0.020	0.013
Mar	2.441	2.188	1.304	0.716	0.405	0.190	0.106	0.080	0.046	0.019
Apr	8.957	6.578	3.659	2.094	0.905	0.538	0.531	0.525	0.459	0.260
May	12.687	12.687	9.309	5.741	2.812	1.511	1.353	1.344	1.126	0.627
Jun	22.006	19.772	16.550	12.863	9.347	5.930	3.786	3.313	2.428	1.227
Jul	37.299	33.889	27.081	20.378	15.340	9.811	6.205	3.489	1.300	0.630
Aug	25.080	25.080	22.688	19.260	14.101	9.535	7.765	7.726	6.626	4.232
Sep	20.866	20.866	19.491	16.940	12.883	9.059	6.839	6.234	5.749	4.826
C Category										
Oct	16.708	16.708	14.778	12.292	10.037	7.665	5.374	3.706	3.319	3.317
Nov	11.588	10.492	8.822	7.193	5.085	3.803	3.190	3.060	2.443	2.156
Dec	6.132	6.132	4.284	2.553	1.931	1.915	1.900	1.885	1.749	1.183
Jan	1.989	1.734	1.298	0.521	0.318	0.249	0.205	0.133	0.076	0.027
Feb	2.036	1.434	0.608	0.366	0.152	0.036	0.023	0.022	0.018	0.011
Mar	2.238	2.000	1.158	0.598	0.338	0.166	0.095	0.075	0.044	0.017
Apr	8.206	6.005	3.235	1.710	0.722	0.511	0.510	0.510	0.447	0.236
May	11.498	11.498	8.188	4.707	2.285	1.382	1.305	1.290	1.089	0.573
Jun	20.058	17.843	14.495	10.851	7.943	5.129	3.309	2.947	2.198	1.083
Jul	34.210	29.917	23.119	18.277	12.980	8.245	5.022	2.398	0.967	0.516
Aug	22.510	22.510	19.745	16.231	11.938	8.329	7.028	7.018	6.064	3.700
Sep	18.775	18.775	17.075	14.541	11.088	7.795	5.899	5.553	5.209	4.142
C/D Category										
Oct	13.849	13.849	11.682	9.431	7.854	5.899	3.969	2.575	2.354	2.327
Nov	9.930	8.764	6.862	5.325	4.000	3.084	2.560	2.429	1.870	1.474

Dec	5.176	5.176	3.355	1.814	1.668	1.666	1.664	1.663	1.528	0.909
Jan	1.766	1.483	0.836	0.389	0.281	0.231	0.188	0.131	0.065	0.016
Feb	1.776	1.238	0.484	0.276	0.119	0.030	0.019	0.019	0.016	0.009
Mar	1.950	1.727	0.944	0.453	0.266	0.136	0.080	0.067	0.040	0.013
Apr	7.113	5.119	2.524	1.192	0.562	0.480	0.476	0.473	0.405	0.186
May	9.619	9.619	6.404	3.375	1.789	1.219	1.192	1.185	0.983	0.459
Jun	17.045	14.789	11.464	8.310	6.277	4.112	2.685	2.428	1.841	0.847
Jul	28.335	23.593	19.543	15.228	9.986	6.335	3.431	1.173	0.562	0.380
Aug	18.630	18.630	16.010	13.070	9.629	6.825	6.014	5.971	5.141	2.830
Sep	15.591	15.591	13.740	11.591	8.933	6.234	4.728	4.581	4.333	3.050

D Category

Oct	10.643	10.643	8.475	6.944	5.942	4.321	2.634	1.568	1.392	1.327
Nov	7.856	6.687	4.755	3.842	3.152	2.433	1.928	1.809	1.326	0.844
Dec	3.937	3.937	2.269	1.345	1.335	1.332	1.329	1.326	1.169	0.586
Jan	1.476	1.028	0.463	0.316	0.253	0.212	0.163	0.108	0.046	0.004
Feb	1.445	1.002	0.353	0.202	0.093	0.024	0.015	0.015	0.012	0.006
Mar	1.568	1.346	0.673	0.334	0.210	0.109	0.065	0.056	0.033	0.008
Apr	5.711	3.965	1.660	0.788	0.472	0.392	0.392	0.391	0.318	0.121
May	7.474	7.363	4.417	2.356	1.464	1.037	1.005	0.993	0.776	0.311
Jun	13.386	11.449	8.374	6.153	4.856	3.200	2.036	1.856	1.396	0.575
Jul	22.187	19.612	16.262	11.498	7.577	4.486	1.770	0.704	0.382	0.273
Aug	14.642	14.642	12.392	10.241	7.618	5.438	4.752	4.704	3.906	1.847
Sep	12.128	12.128	10.346	8.878	6.985	4.795	3.472	3.432	3.210	1.874

Category Total Flow Assurance curves (mill. m^3)

A Category

Oct	42.827	29.505	24.620	22.405	19.819	16.717	13.172	6.678	5.371	4.956
Nov	21.355	14.485	12.090	10.918	8.408	5.971	4.933	4.695	4.099	3.506
Dec	8.252	8.252	5.728	3.935	2.809	2.194	2.190	2.187	2.043	1.539
Jan	2.752	2.131	1.621	1.258	0.494	0.303	0.238	0.133	0.076	0.043
Feb	7.174	1.992	0.833	0.552	0.254	0.056	0.034	0.029	0.024	0.015
Mar	7.418	2.701	1.547	0.906	0.558	0.258	0.137	0.094	0.052	0.023
Apr	41.777	16.555	8.413	2.547	1.328	0.644	0.561	0.547	0.469	0.275
May	74.628	32.443	26.092	11.230	8.141	4.487	1.470	1.453	1.182	0.673

Jun	120.656	75.341	47.052	43.115	29.523	23.011	13.322	8.344	6.107	1.581
Jul	202.307	136.987	88.191	63.576	48.686	41.369	31.852	20.961	13.327	2.205
Aug	90.263	79.938	59.765	52.688	46.585	38.332	24.725	23.508	15.834	6.385
Sep	66.597	50.569	39.392	37.503	32.261	24.621	17.567	11.929	11.019	7.008
A/B Category										
Oct	37.156	27.990	23.757	21.594	18.844	15.709	11.415	6.079	4.930	4.713
Nov	19.684	13.563	11.658	10.465	7.814	5.483	4.561	4.363	3.767	3.264
Dec	7.788	7.788	5.544	3.793	2.590	2.197	2.171	2.144	1.991	1.487
Jan	2.530	2.106	1.621	1.180	0.446	0.290	0.232	0.133	0.076	0.043
Feb	6.674	1.849	0.799	0.531	0.240	0.052	0.031	0.028	0.023	0.015
Mar	7.118	2.542	1.495	0.867	0.520	0.237	0.128	0.090	0.050	0.022
Apr	40.395	15.995	5.385	2.472	1.220	0.594	0.548	0.540	0.468	0.274
May	69.142	31.455	25.270	10.987	7.846	4.323	1.433	1.422	1.167	0.662
Jun	106.242	62.242	46.179	39.305	26.690	21.423	15.866	8.087	4.518	1.473
Jul	195.863	134.325	84.253	53.161	45.607	39.976	23.322	19.998	11.254	2.034
Aug	87.813	76.828	54.079	51.242	42.904	29.356	24.107	20.510	11.721	6.015
Sep	67.087	48.693	38.149	36.023	26.954	19.724	12.689	11.485	10.714	5.559
B Category										
Oct	35.810	26.644	22.773	20.565	17.733	14.682	7.691	5.496	4.525	4.516
Nov	18.303	12.713	11.115	9.869	7.142	5.013	4.204	4.038	3.438	3.070
Dec	7.342	7.342	5.305	3.593	2.342	2.093	2.086	2.079	1.942	1.444
Jan	2.351	2.023	1.605	1.049	0.405	0.278	0.225	0.133	0.076	0.043
Feb	2.891	1.722	0.761	0.501	0.221	0.047	0.029	0.026	0.022	0.014
Mar	6.865	2.386	1.425	0.816	0.475	0.216	0.119	0.086	0.049	0.021
Apr	39.215	11.333	3.972	2.358	1.095	0.548	0.535	0.533	0.466	0.273
May	66.547	37.296	24.174	10.646	7.504	1.678	1.398	1.392	1.153	0.653
Jun	99.929	59.890	45.225	36.889	25.818	20.878	11.360	7.836	4.735	1.371
Jul	191.117	132.287	81.845	53.979	44.359	33.738	22.505	11.999	6.370	1.776
Aug	85.776	64.316	52.448	49.453	37.399	28.394	23.312	17.524	11.354	8.030
Sep	51.865	47.056	36.792	33.166	23.304	18.708	11.993	11.052	10.419	5.344
B/C Category										
Oct	33.652	24.901	21.050	18.681	15.985	10.966	6.495	4.605	4.009	3.989
Nov	16.865	11.622	10.113	8.685	6.103	4.388	3.680	3.540	2.910	2.634

Dec	6.751	6.751	4.865	3.150	2.089	2.024	2.008	1.992	1.851	1.336
Jan	2.151	1.885	1.521	0.742	0.354	0.262	0.215	0.133	0.076	0.036
Feb	2.637	1.571	0.692	0.440	0.185	0.042	0.026	0.024	0.020	0.013
Mar	6.596	2.188	1.304	0.716	0.405	0.190	0.106	0.080	0.046	0.019
Apr	38.006	10.733	3.659	2.094	0.905	0.538	0.531	0.525	0.459	0.260
May	57.780	35.469	22.144	9.896	6.967	1.511	1.353	1.344	1.126	0.627
Jun	95.849	58.019	43.559	35.938	24.441	14.240	10.849	7.468	2.428	1.227
Jul	187.453	129.386	76.350	47.387	40.886	29.060	21.299	10.968	5.455	1.427
Aug	83.215	61.755	49.697	45.187	33.350	24.629	22.070	16.019	10.781	7.056
Sep	53.539	44.991	34.585	29.860	21.193	17.058	10.994	10.389	9.904	5.896
C Category										
Oct	31.802	26.375	18.933	16.447	12.115	7.665	5.374	3.706	3.319	3.317
Nov	15.743	10.492	8.822	7.193	5.085	3.803	3.190	3.060	2.443	2.156
Dec	6.132	6.132	4.284	2.553	1.931	1.915	1.900	1.885	1.749	1.183
Jan	1.989	1.734	1.298	0.521	0.318	0.249	0.205	0.133	0.076	0.027
Feb	2.036	1.434	0.608	0.366	0.152	0.036	0.023	0.022	0.018	0.011
Mar	6.393	2.000	1.158	0.598	0.338	0.166	0.095	0.075	0.044	0.017
Apr	37.056	10.160	3.235	1.710	0.722	0.511	0.510	0.510	0.447	0.236
May	49.113	30.757	16.567	8.862	2.285	1.382	1.305	1.290	1.089	0.573
Jun	86.391	51.500	41.504	33.204	22.676	13.439	10.297	7.102	2.198	1.083
Jul	184.364	125.414	72.388	45.286	36.109	23.339	19.998	6.553	5.069	1.047
Aug	80.646	51.181	46.754	38.584	27.032	23.423	18.247	14.497	10.219	4.688
Sep	51.449	42.900	32.169	22.851	19.398	11.950	10.054	9.708	8.590	4.884
C/D Category										
Oct	28.943	22.990	15.837	13.586	11.196	5.899	3.969	2.575	2.354	2.327
Nov	14.085	8.764	6.862	5.325	4.000	3.084	2.560	2.429	1.870	1.474
Dec	5.176	5.176	3.355	1.814	1.668	1.666	1.664	1.663	1.528	0.909
Jan	1.766	1.483	0.836	0.389	0.281	0.231	0.188	0.131	0.065	0.016
Feb	2.153	1.238	0.484	0.276	0.119	0.030	0.019	0.019	0.016	0.009
Mar	5.717	1.727	0.944	0.453	0.266	0.136	0.080	0.067	0.040	0.013
Apr	35.763	8.970	2.524	1.192	0.562	0.480	0.476	0.473	0.405	0.186
May	43.494	25.755	14.714	7.530	3.569	1.219	1.192	1.185	0.983	0.459
Jun	74.605	48.446	38.473	30.663	20.130	12.422	6.840	6.400	1.841	0.847
Jul	178.489	119.090	67.565	42.237	29.235	21.135	15.702	5.328	4.504	0.380

Aug	76.765	46.470	43.019	32.930	24.723	20.170	17.005	10.126	8.930	2.830
Sep	48.264	36.392	28.834	19.901	13.088	10.389	8.883	7.357	4.333	3.050
D Category										
Oct	25.737	16.460	12.630	11.099	5.942	4.321	2.634	1.568	1.392	1.327
Nov	12.011	6.687	4.755	3.842	3.152	2.433	1.928	1.809	1.326	0.844
Dec	3.937	3.937	2.269	1.345	1.335	1.332	1.329	1.326	1.169	0.586
Jan	1.476	1.028	0.463	0.316	0.253	0.212	0.163	0.108	0.046	0.004
Feb	1.445	1.002	0.353	0.202	0.093	0.024	0.015	0.015	0.012	0.006
Mar	1.984	1.346	0.673	0.334	0.210	0.109	0.065	0.056	0.033	0.008
Apr	34.161	4.796	1.660	0.788	0.472	0.392	0.392	0.391	0.318	0.121
May	38.251	22.457	11.947	6.511	1.464	1.037	1.005	0.993	0.776	0.311
Jun	70.945	45.106	35.383	27.065	13.166	9.848	6.191	1.856	1.396	0.575
Jul	172.342	115.109	56.983	38.507	24.748	18.708	7.903	4.642	2.469	0.273
Aug	72.778	41.651	39.401	29.109	22.712	15.526	12.576	8.859	5.601	1.847
Sep	44.801	32.208	25.440	17.188	11.140	8.950	7.627	3.432	3.210	1.874

Table F6. RDRM output for Doring EWR site 5 with RCP 8.5 data.

Revised Desktop Model outputs for site: EWR_5

HYDROLOGY DATA SUMMARY

Natural Flows:					RCP 8.5 min Flows:				
Area (km^2)	MAR (m^3 * 10^6)	Ann.SD	Q75	Ann. CV	Area (km^2)	MAR (m^3 * 10^6)	Ann.SD	Q75	Ann. CV
0.00	61.87	310.79	2.79	0.55	0.00	175.56	131.38	0.00	0.75

% Zero flows = 0.0 % Zero flows = 28.4

Baseflow Parameters: A = 0.970, B = 0.42Baseflow Parameters: A = 0.970, B = 0.420

BFI = 0.27 : Hydro Index = 13.7 BFI = 0.25 : Hydro Index = 19.3

MONTH	MEAN (m^3 * 10^6)	SD	CV	MONTH	MEAN (m^3 * 10^6)	SD	CV
Oct	37.12	27.42	0.74	Oct	9.62	6.31	0.66
Nov	20.68	38.36	1.85	Nov	2.79	4.44	1.59
Dec	7.10	7.74	1.09	Dec	6.39	18.81	2.94
Jan	4.14	15.92	3.85	Jan	1.98	7.30	3.69
Feb	3.46	10.70	3.09	Feb	0.04	0.08	2.26
Mar	4.83	7.58	1.57	Mar	0.35	1.68	4.85
Apr	27.87	61.74	2.22	Apr	1.41	4.32	3.07
May	45.72	61.45	1.34	May	9.58	23.13	2.41
Jun	92.93	100.89	1.09	Jun	25.45	29.97	1.18
Jul	148.72	146.15	0.98	Jul	55.96	76.92	1.37
Aug	101.01	64.87	0.64	Aug	39.52	39.28	0.99
Sep	68.29	45.55	0.67	Sep	22.48	14.59	0.65

Critical months: WET : Jul, DRY : Jan

Using 10th percentile of FDC of separated baseflows

Max. baseflows (m^3/s): WET : 29.191, DRY : 1.279

HYDRAULICS DATA SUMMARY

Catchment Area (km^2) 23511.00

Geomorph. Zone 4

Valley Slope (Fraction) 0.0060

Width/Depth scaling 0.50

Max. Channel width (m) 120.00

Max. Channel Depth (m) 6.59

Observed Channel XS used

Observed Rating Curve used

(Gradients and Roughness n values calibrated)

Max. Gradient 0.06000

Min. Gradient 0.00200

Gradient Shape Factor 15

Max. Mannings n 0.040

Min. Mannings n 0.020

n Shape Factor 15

Habitat Type definitions used:

Fast: > 0.3 m/s

Shallow: > 0.1 m

Intermediate: > 0.2 m

Deep (fast): > 0.3 m
Deep (slow): > 0.5 m

FLOW - STRESSOR RESPONSE DATA SUMMARY

Table of Stress weightings

Season	Wet	Dry
Stress at 0 FS:	9	9
FS Weight:	2	2
FI Weight:	2	2
FD Weight:	3	0

Table of flows ($m^3/2$) v stress index

Stress	Wet Season Flow	Dry Season Flow
0.0	29.929	1.328
0.5	22.457	1.225
1.0	18.405	1.122
1.5	15.538	1.019
2.0	14.229	0.923
2.5	13.195	0.851
3.0	12.109	0.798
3.5	10.309	0.751
4.0	8.613	0.704
4.5	7.554	0.654
5.0	6.614	0.596
5.5	5.547	0.521
6.0	4.180	0.392
6.5	3.164	0.208
7.0	2.273	0.151
7.5	1.410	0.120
8.0	0.479	0.101
8.5	0.178	0.088
9.0	0.092	0.074
9.5	0.041	0.047
10.0	0.000	0.000

Table of default/altered SHIFT factors for the Stress Frequency Curves

Category	High SHIFT		Low SHIFT	
	Default	Altered	Default	Altered
Wet season				
A	7.938	7.938	0.510	0.510
A/B	8.052	8.052	0.888	0.888
B	8.166	8.166	1.266	1.266
B/C	8.337	8.337	1.833	1.833
C	8.508	8.508	2.400	2.400
C/D	8.736	8.736	3.156	3.156
D	8.964	8.964	3.912	3.912
Dry season				
A	9.806	9.806	0.738	0.738
A/B	9.828	9.828	1.199	1.199
B	9.849	9.849	1.661	1.661
B/C	9.882	9.882	2.353	2.353
C	9.914	9.914	3.046	3.046
C/D	9.957	9.957	3.969	3.969
D	10.000	10.000	4.892	4.892

Perenniality Rules
Non-Perennial Allowed

Alignment of maximum stress to Present Day stress
Not Aligned
Table of default/altered SHIFT factors for the Stress Frequency Curves

Category	High SHIFT		Low SHIFT	
	Default	Altered	Default	Altered
Wet season				
A	7.938	7.938	0.510	0.510
A/B	8.052	8.052	0.888	0.888
B	8.166	8.166	1.266	1.266
B/C	8.337	8.337	1.833	1.833
C	8.508	8.508	2.400	2.400
C/D	8.736	8.736	3.156	3.156
D	8.964	8.964	3.912	3.912
Dry season				
A	9.806	9.806	0.738	0.738
A/B	9.828	9.828	1.199	1.199
B	9.849	9.849	1.661	1.661
B/C	9.882	9.882	2.353	2.353
C	9.914	9.914	3.046	3.046
C/D	9.957	9.957	3.969	3.969
D	10.000	10.000	4.892	4.892

HIGH FLOW REQUIREMENT SUMMARY
Bankfull channel discharge (m^3/s) = 3592.809

Flood event requirements

Class	Frequency	Peak(m^3/s)	Duration(hours)	N. Events	Volume(MCM)
1	Annual	25.139	104	5	3.972
2	Annual	88.705	112	2	15.094
3	Annual	153.258	116	2	27.009
4	1:2 year	309.312	124	1	58.271
5	1:5 year	659.788	140	1	140.335

Flood requirements have been constrained to a maximum of 0.42 of natural high flows

Events excluded from the time series of high flow requirements:
No Events excluded.

FINAL RESERVE SUMMARY DETAILS
EWR Flows are NOT constrained to be below Natural or Present Day Flows

Long term mean flow requirements (Mill. m^3 and %MAR)

Category	Low Flows		Total Flows	
	Mill. m^3	%MAR	Mill. m^3	%MAR
A	112.806	20.1	268.696	47.8
A/B	104.817	18.7	252.455	44.9
B	97.317	17.3	239.340	42.6
B/C	86.994	15.5	223.568	39.8
C	76.620	13.6	207.803	37.0
C/D	62.255	11.1	186.616	33.2
D	47.629	8.5	165.136	29.4

FLOW DURATION and RESERVE ASSURANCE TABLES

Columns are FDC precentage points:

Natural Total flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	84.658	50.073	39.688	32.216	29.353	25.287	21.012	19.022	18.114	15.541
Nov	25.362	20.442	15.896	13.355	11.503	10.354	9.502	9.240	7.558	7.160
Dec	25.875	11.406	5.373	4.476	3.977	3.403	3.219	2.924	2.149	1.325
Jan	3.322	2.275	1.621	1.258	1.056	0.995	0.632	0.133	0.076	0.043
Feb	12.766	1.568	0.928	0.730	0.203	0.092	0.066	0.048	0.036	0.012
Mar	20.007	8.353	4.911	2.123	1.407	0.862	0.522	0.100	0.060	0.020
Apr	124.199	34.441	15.714	8.881	5.764	3.332	2.632	1.622	1.206	0.529
May	157.259	89.301	42.492	33.155	21.187	16.441	10.832	5.956	3.583	1.981
Jun	237.402	132.079	106.528	78.134	60.395	49.497	39.730	30.142	15.671	3.991
Jul	400.505	311.698	171.670	113.908	94.243	76.344	61.449	45.282	32.167	5.355
Aug	189.186	148.338	119.815	101.530	83.996	79.269	73.617	45.236	37.356	15.564
Sep	127.904	111.468	80.745	64.197	50.733	45.502	43.669	37.495	27.549	20.974

Natural Baseflow flow duration curve (mill. m^3)

	10	20	30	40	50	60	70	80	90	99
Oct	33.256	26.732	20.893	19.557	18.292	16.448	13.963	9.813	8.096	5.091
Nov	21.484	14.983	13.719	12.138	10.754	9.744	9.060	7.499	6.724	3.814
Dec	14.068	9.281	4.727	4.331	3.936	3.403	3.219	2.924	2.149	1.325
Jan	3.322	2.250	1.621	1.258	1.056	0.995	0.632	0.133	0.076	0.043
Feb	4.177	1.425	0.928	0.730	0.132	0.077	0.063	0.048	0.036	0.012
Mar	4.626	3.046	1.243	0.982	0.515	0.348	0.219	0.100	0.042	0.017
Apr	21.469	6.980	3.997	2.298	1.787	1.236	0.991	0.710	0.394	0.171
May	27.248	18.800	10.456	6.645	4.650	3.626	2.822	2.052	1.137	0.448
Jun	41.400	29.370	20.790	17.566	15.675	10.173	8.940	6.378	3.857	0.848
Jul	75.247	56.653	38.350	25.848	22.062	17.822	14.937	11.275	7.000	1.163
Aug	49.219	36.065	32.843	28.928	24.206	18.538	16.882	13.709	10.113	3.629
Sep	36.558	32.591	28.069	26.419	23.483	16.519	14.708	11.749	8.076	6.058

Category Low Flow Assurance curves (mill. m^3)

A Category

Oct	23.162	23.162	20.465	18.250	15.664	12.562	9.350	6.678	5.371	4.956
Nov	17.200	14.485	12.090	10.918	8.408	5.971	4.933	4.695	4.099	3.506
Dec	8.252	8.252	5.728	3.935	2.809	2.194	2.190	2.187	2.043	1.539
Jan	2.752	2.131	1.621	1.258	0.494	0.303	0.238	0.133	0.076	0.043
Feb	3.019	1.992	0.833	0.552	0.254	0.056	0.034	0.029	0.024	0.015
Mar	3.263	2.701	1.547	0.906	0.558	0.258	0.137	0.094	0.052	0.023
Apr	12.129	8.245	4.258	2.547	1.328	0.644	0.561	0.547	0.469	0.275
May	15.753	15.687	10.998	7.075	3.986	1.994	1.470	1.453	1.182	0.673
Jun	30.390	24.989	20.043	16.106	12.351	7.917	5.012	4.189	3.021	1.581
Jul	52.152	41.490	35.416	25.543	19.799	14.360	9.116	5.867	3.488	1.000
Aug	32.128	32.128	28.601	25.679	19.576	12.765	9.631	9.360	7.939	5.180
Sep	26.444	26.444	24.298	22.409	18.007	12.462	9.257	7.774	6.864	5.803

A/B Category

Oct	21.647	21.647	19.602	17.439	14.689	11.554	8.506	6.079	4.930	4.713
Nov	15.529	13.563	11.658	10.465	7.814	5.483	4.561	4.363	3.767	3.264
Dec	7.788	7.788	5.544	3.793	2.590	2.197	2.171	2.144	1.991	1.487
Jan	2.530	2.106	1.621	1.180	0.446	0.290	0.232	0.133	0.076	0.043
Feb	2.722	1.849	0.799	0.531	0.240	0.052	0.031	0.028	0.023	0.015
Mar	2.963	2.542	1.495	0.867	0.520	0.237	0.128	0.090	0.050	0.022
Apr	10.947	7.685	4.138	2.472	1.220	0.594	0.548	0.540	0.468	0.274
May	14.699	14.699	10.618	6.832	3.691	1.830	1.433	1.422	1.167	0.662
Jun	27.124	23.164	19.170	15.420	11.596	7.326	4.648	3.932	2.849	1.473
Jul	45.708	38.828	33.645	24.490	18.598	12.967	8.228	5.194	2.851	0.829
Aug	29.677	29.677	27.070	24.233	18.154	11.769	9.013	8.884	7.566	4.913
Sep	24.568	24.568	23.055	21.057	16.567	11.414	8.534	7.330	6.559	5.559

B Category

Oct	20.301	20.301	18.618	16.410	13.578	10.552	7.691	5.496	4.525	4.516
Nov	14.148	12.713	11.115	9.869	7.142	5.013	4.204	4.038	3.438	3.070
Dec	7.342	7.342	5.305	3.593	2.342	2.093	2.086	2.079	1.942	1.444
Jan	2.351	2.023	1.605	1.049	0.405	0.278	0.225	0.133	0.076	0.043
Feb	2.475	1.722	0.761	0.501	0.221	0.047	0.029	0.026	0.022	0.014
Mar	2.710	2.386	1.425	0.816	0.475	0.216	0.119	0.086	0.049	0.021
Apr	9.966	7.178	3.972	2.358	1.095	0.548	0.535	0.533	0.466	0.273
May	13.815	13.815	10.155	6.491	3.349	1.678	1.398	1.392	1.153	0.653

Jun	24.551	21.643	18.216	14.536	10.724	6.748	4.297	3.681	2.678	1.371
Jul	40.963	36.790	31.330	22.815	17.350	11.610	7.411	4.520	2.215	0.713
Aug	27.640	27.640	25.439	22.444	16.539	10.807	8.473	8.420	7.199	4.667
Sep	22.931	22.931	21.698	19.459	14.994	10.398	7.838	6.897	6.264	5.344

B/C Category

Oct	18.558	18.558	16.895	14.526	11.830	9.085	6.495	4.605	4.009	3.989
Nov	12.710	11.622	10.113	8.685	6.103	4.388	3.680	3.540	2.910	2.634
Dec	6.751	6.751	4.865	3.150	2.089	2.024	2.008	1.992	1.851	1.336
Jan	2.151	1.885	1.521	0.742	0.354	0.262	0.215	0.133	0.076	0.036
Feb	2.221	1.571	0.692	0.440	0.185	0.042	0.026	0.024	0.020	0.013
Mar	2.441	2.188	1.304	0.716	0.405	0.190	0.106	0.080	0.046	0.019
Apr	8.957	6.578	3.659	2.094	0.905	0.538	0.531	0.525	0.459	0.260
May	12.687	12.687	9.309	5.741	2.812	1.511	1.353	1.344	1.126	0.627
Jun	22.006	19.772	16.550	12.863	9.347	5.930	3.786	3.313	2.428	1.227
Jul	37.299	33.889	27.081	20.378	15.340	9.811	6.205	3.489	1.300	0.630
Aug	25.080	25.080	22.688	19.260	14.101	9.535	7.765	7.726	6.626	4.232
Sep	20.866	20.866	19.491	16.940	12.883	9.059	6.839	6.234	5.749	4.826

C Category

Oct	16.708	16.708	14.778	12.292	10.037	7.665	5.374	3.706	3.319	3.317
Nov	11.588	10.492	8.822	7.193	5.085	3.803	3.190	3.060	2.443	2.156
Dec	6.132	6.132	4.284	2.553	1.931	1.915	1.900	1.885	1.749	1.183
Jan	1.989	1.734	1.298	0.521	0.318	0.249	0.205	0.133	0.076	0.027
Feb	2.036	1.434	0.608	0.366	0.152	0.036	0.023	0.022	0.018	0.011
Mar	2.238	2.000	1.158	0.598	0.338	0.166	0.095	0.075	0.044	0.017
Apr	8.206	6.005	3.235	1.710	0.722	0.511	0.510	0.510	0.447	0.236
May	11.498	11.498	8.188	4.707	2.285	1.382	1.305	1.290	1.089	0.573
Jun	20.058	17.843	14.495	10.851	7.943	5.129	3.309	2.947	2.198	1.083
Jul	34.210	29.917	23.119	18.277	12.980	8.245	5.022	2.398	0.967	0.516
Aug	22.510	22.510	19.745	16.231	11.938	8.329	7.028	7.018	6.064	3.700
Sep	18.775	18.775	17.075	14.541	11.088	7.795	5.899	5.553	5.209	4.142

C/D Category

Oct	13.849	13.849	11.682	9.431	7.854	5.899	3.969	2.575	2.354	2.327
Nov	9.930	8.764	6.862	5.325	4.000	3.084	2.560	2.429	1.870	1.474

Dec	5.176	5.176	3.355	1.814	1.668	1.666	1.664	1.663	1.528	0.909
Jan	1.766	1.483	0.836	0.389	0.281	0.231	0.188	0.131	0.065	0.016
Feb	1.776	1.238	0.484	0.276	0.119	0.030	0.019	0.019	0.016	0.009
Mar	1.950	1.727	0.944	0.453	0.266	0.136	0.080	0.067	0.040	0.013
Apr	7.113	5.119	2.524	1.192	0.562	0.480	0.476	0.473	0.405	0.186
May	9.619	9.619	6.404	3.375	1.789	1.219	1.192	1.185	0.983	0.459
Jun	17.045	14.789	11.464	8.310	6.277	4.112	2.685	2.428	1.841	0.847
Jul	28.335	23.593	19.543	15.228	9.986	6.335	3.431	1.173	0.562	0.380
Aug	18.630	18.630	16.010	13.070	9.629	6.825	6.014	5.971	5.141	2.830
Sep	15.591	15.591	13.740	11.591	8.933	6.234	4.728	4.581	4.333	3.050

D Category

Oct	10.643	10.643	8.475	6.944	5.942	4.321	2.634	1.568	1.392	1.327
Nov	7.856	6.687	4.755	3.842	3.152	2.433	1.928	1.809	1.326	0.844
Dec	3.937	3.937	2.269	1.345	1.335	1.332	1.329	1.326	1.169	0.586
Jan	1.476	1.028	0.463	0.316	0.253	0.212	0.163	0.108	0.046	0.004
Feb	1.445	1.002	0.353	0.202	0.093	0.024	0.015	0.015	0.012	0.006
Mar	1.568	1.346	0.673	0.334	0.210	0.109	0.065	0.056	0.033	0.008
Apr	5.711	3.965	1.660	0.788	0.472	0.392	0.392	0.391	0.318	0.121
May	7.474	7.363	4.417	2.356	1.464	1.037	1.005	0.993	0.776	0.311
Jun	13.386	11.449	8.374	6.153	4.856	3.200	2.036	1.856	1.396	0.575
Jul	22.187	19.612	16.262	11.498	7.577	4.486	1.770	0.704	0.382	0.273
Aug	14.642	14.642	12.392	10.241	7.618	5.438	4.752	4.704	3.906	1.847
Sep	12.128	12.128	10.346	8.878	6.985	4.795	3.472	3.432	3.210	1.874

Category Total Flow Assurance curves (mill. m^3)

A Category

Oct	42.626	29.359	24.437	22.222	19.636	16.534	13.044	6.678	5.371	4.956
Nov	21.172	14.485	12.090	10.918	8.408	5.971	4.933	4.695	4.099	3.506
Dec	8.252	8.252	5.728	3.935	2.809	2.194	2.190	2.187	2.043	1.539
Jan	2.752	2.131	1.621	1.258	0.494	0.303	0.238	0.133	0.076	0.043
Feb	6.991	1.992	0.833	0.552	0.254	0.056	0.034	0.029	0.024	0.015
Mar	7.235	2.701	1.547	0.906	0.558	0.258	0.137	0.094	0.052	0.023
Apr	41.777	16.189	8.230	2.547	1.328	0.644	0.561	0.547	0.469	0.275
May	74.628	32.370	26.092	11.047	7.958	4.377	1.470	1.453	1.182	0.673

Jun	120.437	75.231	47.052	43.115	29.431	23.011	12.956	8.161	6.107	1.581
Jul	201.941	136.145	88.081	63.356	48.686	41.369	31.852	20.961	13.290	2.152
Aug	90.226	79.791	59.582	52.688	46.585	38.186	24.725	23.398	15.486	6.332
Sep	66.084	50.276	39.392	37.503	32.261	24.378	17.201	11.746	10.836	6.955
A/B Category										
Oct	37.138	27.843	23.574	21.411	18.661	15.526	11.287	6.079	4.930	4.713
Nov	19.501	13.563	11.658	10.465	7.814	5.483	4.561	4.363	3.767	3.264
Dec	7.788	7.788	5.544	3.793	2.590	2.197	2.171	2.144	1.991	1.487
Jan	2.530	2.106	1.621	1.180	0.446	0.290	0.232	0.133	0.076	0.043
Feb	6.655	1.849	0.799	0.531	0.240	0.052	0.031	0.028	0.023	0.015
Mar	6.935	2.542	1.495	0.867	0.520	0.237	0.128	0.090	0.050	0.022
Apr	40.395	15.629	8.110	2.472	1.220	0.594	0.548	0.540	0.468	0.274
May	69.142	31.382	25.270	10.804	7.663	4.214	1.433	1.422	1.167	0.662
Jun	105.401	61.986	46.179	39.305	26.690	21.423	15.372	7.904	4.518	1.473
Jul	195.497	133.483	84.143	53.088	45.607	39.976	23.322	19.998	11.217	1.981
Aug	87.776	76.681	54.079	51.242	42.721	29.247	24.107	20.006	11.538	6.015
Sep	67.068	48.400	38.149	36.023	26.497	19.358	12.506	11.302	10.531	5.559
B Category										
Oct	35.792	26.497	22.590	20.382	17.550	14.524	7.691	5.496	4.525	4.516
Nov	18.120	12.713	11.115	9.869	7.142	5.013	4.204	4.038	3.438	3.070
Dec	7.342	7.342	5.305	3.593	2.342	2.093	2.086	2.079	1.942	1.444
Jan	2.351	2.023	1.605	1.049	0.405	0.278	0.225	0.133	0.076	0.043
Feb	2.872	1.722	0.761	0.501	0.221	0.047	0.029	0.026	0.022	0.014
Mar	6.682	2.386	1.425	0.816	0.475	0.216	0.119	0.086	0.049	0.021
Apr	39.215	11.945	3.972	2.358	1.095	0.548	0.535	0.533	0.466	0.273
May	66.547	37.003	24.174	10.463	7.321	1.678	1.398	1.392	1.153	0.653
Jun	99.504	60.465	45.225	36.935	26.215	20.878	8.269	7.653	4.735	1.371
Jul	190.751	131.445	81.223	51.413	44.359	33.665	22.505	16.294	6.187	1.776
Aug	85.739	64.023	52.448	49.453	37.307	28.284	23.312	18.281	11.171	7.977
Sep	51.847	46.763	36.792	33.166	24.924	18.342	11.810	10.869	10.236	5.344
B/C Category										
Oct	33.652	24.754	20.867	18.498	15.802	10.966	6.495	4.605	4.009	3.989
Nov	16.682	11.622	10.113	8.685	6.103	4.388	3.680	3.540	2.910	2.634

Dec	6.751	6.751	4.865	3.150	2.089	2.024	2.008	1.992	1.851	1.336
Jan	2.151	1.885	1.521	0.742	0.354	0.262	0.215	0.133	0.076	0.036
Feb	2.619	1.571	0.692	0.440	0.185	0.042	0.026	0.024	0.020	0.013
Mar	6.413	2.188	1.304	0.716	0.405	0.190	0.106	0.080	0.046	0.019
Apr	38.006	10.550	3.659	2.094	0.905	0.538	0.531	0.525	0.459	0.260
May	57.121	35.396	22.144	9.713	6.784	1.511	1.353	1.344	1.126	0.627
Jun	95.830	57.800	43.559	35.938	24.441	13.874	10.538	7.285	2.428	1.227
Jul	187.087	128.544	75.782	47.387	40.886	28.877	21.299	10.638	5.272	1.427
Aug	83.178	61.463	49.697	45.187	33.167	24.629	21.905	15.670	10.598	7.003
Sep	53.356	44.698	34.585	29.823	20.827	16.838	10.811	10.206	9.721	5.896
C Category										
Oct	31.802	22.905	18.750	16.264	13.484	7.665	5.374	3.706	3.319	3.317
Nov	15.560	10.492	8.822	7.193	5.085	3.803	3.190	3.060	2.443	2.156
Dec	6.132	6.132	4.284	2.553	1.931	1.915	1.900	1.885	1.749	1.183
Jan	1.989	1.734	1.298	0.521	0.318	0.249	0.205	0.133	0.076	0.027
Feb	2.433	1.434	0.608	0.366	0.152	0.036	0.023	0.022	0.018	0.011
Mar	6.210	2.000	1.158	0.598	0.338	0.166	0.095	0.075	0.044	0.017
Apr	37.056	9.977	3.235	1.710	0.722	0.511	0.510	0.510	0.447	0.236
May	48.783	30.757	16.567	8.679	3.818	1.382	1.305	1.290	1.089	0.573
Jun	86.373	52.638	41.504	33.095	22.676	13.073	10.062	6.919	2.198	1.083
Jul	183.998	124.572	71.820	45.286	37.789	23.339	19.998	9.212	4.904	1.047
Aug	80.609	58.893	46.754	38.474	27.032	23.423	17.753	14.167	10.036	5.767
Sep	51.266	42.608	32.169	24.198	19.032	13.661	9.871	9.525	8.467	4.142
C/D Category										
Oct	28.943	22.587	15.654	13.403	11.104	5.899	3.969	2.575	2.354	2.327
Nov	13.902	8.764	6.862	5.325	4.000	3.084	2.560	2.429	1.870	1.474
Dec	5.176	5.176	3.355	1.814	1.668	1.666	1.664	1.663	1.528	0.909
Jan	1.766	1.483	0.836	0.389	0.281	0.231	0.188	0.131	0.065	0.016
Feb	2.153	1.238	0.484	0.276	0.119	0.030	0.019	0.019	0.016	0.009
Mar	5.699	1.727	0.944	0.453	0.266	0.136	0.080	0.067	0.040	0.013
Apr	35.763	8.933	2.524	1.192	0.562	0.480	0.476	0.473	0.405	0.186
May	43.329	25.755	14.348	7.347	1.789	1.219	1.192	1.185	0.983	0.459
Jun	74.588	48.153	38.473	30.553	20.130	12.056	6.657	6.254	1.841	0.847
Jul	178.123	118.248	67.052	42.237	27.066	21.135	15.592	5.145	4.339	0.380

Aug	76.729	47.173	43.019	32.930	24.723	20.040	16.738	9.943	8.907	2.830
Sep	48.081	36.245	28.834	19.535	12.905	10.206	8.700	7.357	4.333	3.050
D Category										
Oct	25.737	16.204	12.447	10.916	5.942	4.321	2.634	1.568	1.392	1.327
Nov	11.828	6.687	4.755	3.842	3.152	2.433	1.928	1.809	1.326	0.844
Dec	3.937	3.937	2.269	1.345	1.335	1.332	1.329	1.326	1.169	0.586
Jan	1.476	1.028	0.463	0.316	0.253	0.212	0.163	0.108	0.046	0.004
Feb	1.445	1.002	0.353	0.202	0.093	0.024	0.015	0.015	0.012	0.006
Mar	4.052	1.346	0.673	0.334	0.210	0.109	0.065	0.056	0.033	0.008
Apr	34.161	4.760	1.660	0.788	0.472	0.392	0.392	0.391	0.318	0.121
May	38.251	22.457	9.356	6.328	1.464	1.037	1.005	0.993	0.776	0.311
Jun	70.927	44.813	35.383	26.955	13.537	9.555	6.008	1.856	1.396	0.575
Jul	171.976	114.267	56.379	38.507	24.657	18.708	7.848	4.547	2.469	0.273
Aug	72.741	41.651	39.401	29.109	22.712	15.380	12.387	8.676	5.601	1.847
Sep	44.618	31.988	25.440	16.822	12.186	8.767	7.444	3.432	3.210	1.874