A Conceptual Framework for Using Historical Information When Monitoring Resource Quality Objectives

"The use of long-term, large-scale data combined with historical ecological data to support Reserve implementation"

Report to the

Water Research Commission

by

KARL REINECKE, ROZWI MAGOBA, CATE BROWN AND ALISON JOUBERT

Project Leader: M.K. Reinecke

WRC Report No.2345/1/18

February 2018

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031
orders@wrc.org.za or download from www.wrc.org.za

ISBN 978-0-6392-0034-7

Printed in the Republic of South Africa

Executive summary

In South Africa, river catchment activities are governed by the National Water Act (NWA; Act 36 of 1998), the National Environmental Management Act (NEMA; Act 107 of 1998) and the Conservation of Agricultural Resources Act (CARA; Act 43 of 1983). The departments responsible for implementing these Act share the responsibility for managing and monitoring river condition and each monitors river ecosystems in some way. The focus of this study, however, was the NWA and the monitoring activities of the Chief Directorate: (CD: Water Ecosystems) at the Department of Water and Sanitation (DWS). The attention of the DWS has recently shifted from Reserve determination and classification to full-scale implementation, which has increased the need to defend the Ecological Reserve and to show that it is working. There are inherent difficulties in predicting and monitoring the relationship between flow and ecosystem condition, not least because flow is not the only variable responsible for dictating ecosystem condition. It stands to reason, therefore, that interpretation of monitored changes in rivers and their relationship to flow should be contextualised within an understanding of other potential impacts on the river ecosystem, some of which may be the result of historical and current activities in the catchment.

Taking the time to understand and analyse past activities in our river catchments and how these have affected the ecological condition of the rivers that drain them is an investment in better managing our inland aquatic ecosystems, and is vital for implementing and monitoring Resource Quality Objectives (RQOs). It is particularly important given the shortage of budget, skills and access to robust data sets needed to ensure comprehensive and scientifically defendable monitoring, and reporting of successes and failures. It would be naïve to presume that implementation of the Ecological Reserve and its efficacy in meeting the agreed RQOs will not at some point be challenged in a court of law, and so it is imperative that ***all*** available data are used to support monitoring, reporting and the conclusions drawn.

The intended main sources of data on whether or not the Ecological Reserve is being correctly implemented in a catchment, and its efficacy in sustaining the RQOs for that catchment, are the River Ecostatus Monitoring Programme (REMP) and the RQO monitoring programmes (DWS 2013). For the most part, these programmes centre on sites established in Reserve determination studies, and use the hydrological and ecological information from those studies as benchmarks for ongoing monitoring. While this pragmatic approach is understandable, it is important to recognise that the data collection and analyses done for the Reserve determination studies are not aimed at providing historical "reference" baselines for ongoing monitoring. This is particular relevant for REMP indices, which depend on a robust definition of reference conditions. The premise of this study is that contextualising the outcomes of Reserve studies in a broader historical and catchment-based perspective will lead to more robust and defensible definitions of baseline/reference conditions and a better understanding of the reasons for any deviations from reference conditions, and in so doing provide a better basis for interpreting monitoring data.

The two main objectives of this project were:

- to gather and evaluate historical information at various scales for the Berg River to see if this information could be used to contextualise the outputs of the REMP, and thus support and strengthen the evaluation of ecological condition and the identification of the drivers of that condition;
- to use the insights gained to develop a framework for the collation and evaluation of similar data in other catchments with a view to providing a catchment-centred context within which REMP data can be assessed.

Following the collation and evaluation of historical information and evaluation of the fluctuations in river ecosystem condition, a catchment-centred framework to assess monitoring data was developed.

The study provided important insights into the sorts of historical data and information that are available for a catchment, which of those can be readily accessed, and the effort required to process different kinds of data. One of the main, and most obvious, advantages of historical data is that they assist with quantifying baseline conditions that preceed a significant portion of "modern" impacts when they extend back to before these impacts occurred. This is important because many of the Reserve and REMP assessments are based on deviation from some reference condition, usually natural (Kleynhans and Louw 2007), and when there is no reference condition, a surrogate is used.

The five project aims were:

1. To review the quality, nature and scale of historical riverine data in the Western Cape and on this basis select data sets and the river catchment for this study.
2. To use a variety of sources of data to establish a conceptual framework for temporal change in the nature and/or condition of river ecosystems at a catchment scale.
3. To identify the main drivers of historical change and, if possible, isolate flow-driven changes for the selected river basin.
4. To augment the basin-level data with site-specific information in the selected river basin, set in the context of the basin-specific drivers of historical change.
5. To provide a framework of long-term changes in the selected river basin against which future monitoring of potential impacts associated with changes in water availability can be compared.

The five project aims were completed successfully. The Berg River Catchment was selected for the study. A conceptual framework was established by comparing a variety of data from published papers, the Berg River Reserve studies, the River Health Programme and the REMP, which are summarised in Section 2. Drivers of change over time were identified in the Berg River Catchment, some of which were flow-related, and summarised in Section 3. The use of catchment-scale and site-specific data were compared at different spatial and temporal scales in Section 4, and developed into a framework for other catchments in Section 5.

The Berg River is approximately 285 km in length from source to sea, with a catchment of approximately 9 000 km^2. It rises in the Drankenstein and Franschhoek mountains, south of Franschhoek, about 6 km upstream of the Berg River Dam, and flows north past the towns of Paarl, Wellington, Hermon and Gouda before turning west past Piketberg and Hopefield to the Atlantic Ocean on the West Coast at Velddrif. The main tributaries are the Dwars, Franschhoek, Wemmershoek, Hugos, Krom, Kompanjies, Doring, Klein Berg, Sandspruit, Twenty-fours, Moorreesburg and Sout rivers.

Data collected at four (river) Reserve sites (IFR 1/96, IFR 3/96, IFR 4 and IFR 5), six Berg River Monitoring Programme sites (BRBM 1 – 6) and 34 REMP sites in the catchment were collated and compared (see Section 2).

Historical data relevant to understanding the influence of the flow regime on the ecosystem functioning of the Berg River were collated and collected under four key themes (Section 3):

- landuse;
- rainfall and hydrology;
- channel structure and riparian vegetation;
- aquatic macroinvertebrates.

The spatial and temporal spread of historical data for landuse, rainfall, hydrology, channel and riparian morphology, and historical faunal surveys, relative to data collected for REMP, is illustrated in Section 5. The indices completed as part of the REMP are:

- Geomorphological Assessment Index (GAI, Rowntree *et al.* 2013);
- Physico-chemical Assessment Index (PAI, Scherman 2008);
- Fish Response Assessment Index (FRAI, Kleynhans 2008);
- Macroinvertebrate Response and Assessment Index (MIRAI, Thirion *et al.* 2008);
- Vegetation Response and Assessment Index (VEGRAI, Kleynhans *et al.* 2007);
- Index of Habitat Integrity (Kleynhans *et al.* 2008).

The potential use of historical data to inform the calculation of the indices required for REMP, and/or their analysis and interpretation is illustrated in Figure 5.2.

This study demonstrated the value gained by investing in the collation and analysis of historical data in a simple, cost-effective manner, and how this may be used to augment Reserve and monitoring data to provide a more robust definition of reference conditions for REMP indices and the interpretation of RQO monitoring data, and to provide a quantitative basis for what are otherwise highly subjective assessments. Information was gathered from a variety of sources and then tested to see if it was useful in interpreting change in the Berg River. The study also yielded valuable lessons in making the most of data with irregular coverage, in patching data to ensure that it could be analysed, in combining data from different temporal and spatial scales, and in applying scales broader than those routinely considered in Reserve determinations or monitoring studies to augment the assessments required. There was more information available without charge than originally envisaged and so, with hindsight, the main investment was the time taken to collate and analyse it all. Furthermore, the insights gained greatly increased our understanding of the functioning of the Berg River ecosystem and the factors at play in its continuing management.

It is recommended that the historical data available for every catchment in the country be assessed and made available to DWS for use in their monitoring activities. Not only is the information vital for interpreting and augmenting data already incorporated into Reserve, REMP and RQO studies, but the nature and content of such assessments makes them ideal for exposing DWS staff to a relatively straightforward range of procedures and skills that will improve their understanding of the nature and timing of human impacts on rivers, how river ecosystems respond to changes in their catchments and the historical context in which they should be managed.

Acknowledgements

We extend our gratitude to:

- Mr Bonani Madikizela for overseeing the project and chairing the Reference Group committee meetings, and for his understanding with respect to changes that were necessary where the PhD thesis was concerned;
- Ms Gerda Kruger, for her role in facilitating communication between Southern Waters and the WRC;
- Staff at the Department of Mapping and Surveys for assistance in selecting and copying topographical maps;
- Ms Uhone Magoba for her assistance with digitising the landuse maps;
- Mr Ian Wilson for assistance with QGIS;
- Mr Gerald Howard for assistance with patching hydrological records;
- Dr Moses Cho for introducing Ms Magoba to remote sensing;
- Mrs Liesl Phigeland who picked and sorted the macroinvertebrate samples;
- Dr Denise Schael who did the macroinvertebrate identifications;
- Dr Helen Dallas for provision of, and assistance with understanding the historical macroinvertebrate data;
- our colleagues in Southern Waters for their support;
- the Reference Group for their input and review:
    - Professor Jenny Day; Freshwater Research Centre
    - Dr Mike Silberbauer; DWS:RQS
    - Professor Karen Esler; Department of Conservation Ecology and Entomology, University of Stellenbosch
    - Dr Kas Hamman; Private
    - Dr Helen Dallas; Freshwater Research Centre
    - Dr Andrew Gordon; Regional Western Cape DWS office.

Special thanks to Ms Magoba's non-Southern Waters PhD supervisors, Prof. Karen Esler and Prof. Dominic Mazvimavi, for their inputs throughout the project.

Table of contents

List of figures

List of tables

Acronyms

ASPT	Average Score per Taxon
BRBM	Berg River Basin Monitoring
CARA	Conservation of Agricultural Resources Act
CSIR	Council for Scientific and Industrial Research
DRIFT	Downstream Response to Imposed Flow Transformation
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
FRAI	Fish Response and Assessment Index
GAI	Geomorphological Assessment Index
GIS	Geographical Information System
IBT	Inter-basin Transfer
IFR	Instream Flow Requirements
IHI	Index of Habitat Integrity
LFH	Lower foothills
LL	Lowlands
MAR	Mean Annual Runoff
MCM	Million Cubic Metres
MIRAI	Macroinvertebrate Response Assessment Index
NEMA	National Environmental Management Act
NFEPA	National Freshwater Ecosystem Priority Areas
NWA	National Water Act
PAI	Physico-chemical Assessment Index
REMP	River Ecostatus Monitoring Programme
RHP	River Health Programme
RQO	Resource Quality Objectives
SANBI	South African National Biodiversity Institute
SASS	South African Scoring System
SAWS	South African Weather Service
UFH	Upper foothills
VEGRAI	Vegetation Response Assessment Index
WRC	Water Research Commission

1 Introduction

1.1 Background

In South Africa, river catchment activities are (mainly) governed by the National Water Act (NWA; Act 36 of 1998), the National Environmental Management Act (NEMA; Act 107 of 1998) and the Conservation of Agricultural Resources Act (CARA; Act 43 of 1983). Each of these Acts includes clauses written to protect the integrity of the country's rivers so that they can continue to support the livelihoods of South Africans for generations to come. The departments that oversee these regulations[1] share the responsibility of managing and monitoring river conditions, and each monitors river ecosystems in some way. The focus of this study, however, is the NWA and the monitoring activities of the Chief Directorate: (CD: Water Ecosystems) at the Department of Water and Sanitation (DWS).

The NWA makes provision for the "Reserve", which is defined as the quantity and quality of water required to satisfy basic human needs by securing a basic water supply as prescribed under the Water Services Act (Act 108 of 1997), for people who are, or who will in the reasonably near future, be relying upon, taking water from, or supplied from the relevant water resources; and water to protect aquatic ecosystems in order to ensure ecologically sustainable development and use of the relevant water resources (the so-called "Ecological Reserve").

The Ecological Reserve stipulates the pattern and volume of a river's flow regime in order to facilitate its maintenance in some prescribed resource quality. Resource quality is defined as the quality or all aspects of the water resource, including:

- the quality, pattern, timing, water level and assurance of instream flow;
- the water quality, including the physical, chemical and biological characteristics of the water;
- the character and condition of the instream and riparian habitat;
- the characteristics, condition and distribution of the aquatic biota.

The NWA (1998) also makes provision for the classification of water resources based on their ecological condition and the requirements of users, and the setting of Resource Quality Objectives (RQOs), which encompass target conditions for physical, chemical and biological characteristics and the Ecological Reserve intended to meet them. The RQOs are set at ecological reserve sites, and monitored to determine whether they are being met. Since the early 1990s, the DWS has funded and managed studies throughout South Africa to provide the information necessary for classification and for setting of the RQOs for the country's rivers. The basic scientific information is now available for most major rivers in the country, and

[1] The NWA and the DWS; NEMA and the Department of Environmental Affairs and Development Planning; CARA and the Department of Agriculture, Forestry and Fisheries.

classification has either been completed or is underway in six out of nine Water Management Areas (WMAs), with the remainder to follow shortly. During this same period, the River Eco-Status Monitoring Programme (REMP) was developed and rolled out nationally. The REMP was borne of the old River Health Programme(RHP) and the REMP Database (http://www.dwa.gov.za/iwqs/rhp/default.aspx) includes data that have been collected since the early 1990s.

Neither the RHP nor the RHEP were designed specifically with the Reserve process in mind. Nonetheless, within the constraints inherent in rolling out a national programme with limited budgets and skilled personnel, the data that underlie the Ecological Reserve determinations and classification, combined with those that are generated by the REMP provide a useful basis against which to evaluate both the implementation of the Reserve and the efficacy of the underlying flow recommendations. However, as the focus of the DWS shifts from Reserve determination and classification to full-scale implementation, it is expected that there will be increased pressure to defend the Ecological Reserve and to show that it is working. This is likely to highlight the inherent difficulties of predicting and monitoring the relationships between flow and ecosystem condition, not least because flow is not the only variable responsible for dictating ecosystem condition (Davies *et al.* 2015). It stands to reason, therefore, that interpretation of monitored changes in rivers and their relationship to flow should be contextualised across the entire river catchment in order to understand as full a suite as possible of potential impacts on the river ecosystem. This is the central tenant of Integrated Water Resource Management (DWAF, 2004), which "*promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*" GWP (2000).

Historical information about a river's catchment can provide the context required to interpret REMP and RQO monitoring data. It can be used to identify and document past and current pressures on the system, establish the historical context for the aquatic ecosystems, enhance understanding of how these responded to past pressures, and; ensure that ongoing monitoring data are interpreted within an understanding of past pressures on the system. The RHP State of the Basin (DWAF 2004) reports already acknowledged the importance of historical context, and routinely included a section on past (and future) development. This study builds on that and proposes a possible framework for a more systematic, but pragmatic, consideration of historical data in RQO monitoring and evaluation, based on lessons learnt in the Berg River Catchment.

1.2 Project aims

The five project aims were:

1. To review the quality, nature and scale of historical riverine data in the Western Cape and on this basis select data sets and the river catchment[2] for this study.
2. To use a variety of sources of data to establish a conceptual framework of temporal change in the nature and/or condition of river ecosystems at a catchment scale.
3. To identify the main drivers of historical change and, if possible, isolate flow-driven changes for the selected river basin.
4. To augment the catchment-level data with site-specific information in the selected river catchment, set in the context of the catchment-specific drivers of historical change.
5. To provide a framework of long-term changes in the selected river catchment against which future monitoring of potential impacts associated with changes in water availability can be compared.

The five project aims were encompassed by two main objectives.

The first was to gather and evaluate historical information[3] at various scales for the Berg River to see if this information could be used to contextualise the outputs of Reserve-related monitoring activities, such as the REMP, and thus support and strengthen the evaluation of ecological condition and the identification of the drivers of that condition. This was tackled as part of a PhD study that collated relevant available historical information for the Berg River, and used this to evaluate fluctuations in the condition of the river ecosystem and the possible reasons for major shifts in condition. The main findings from this study are summarised in Section 3.

The second was to use the insights gained to develop a framework for the collation and evaluation of similar data, as and when available, in other catchments with a view to improving the spatial and temporal context within which Reserve-related data are evaluated. The second objective is addressed in this report, which used the Reserve-related and historical data to develop a framework to provide a catchment-centred context within which data collected as part of Reserve-related monitoring can be assessed. Method statements for the collation of the historical data are also provided.

[2] The contract uses the term basin, but the reference group suggested changing this to catchment throughout the document.

[3] The invertebrate data and some of the contextual maps collated in this study are housed in the Freshwater Biodiversity Information System at the Freshwater Research Centre (www.frcsa.org.za). The maps and the hydrological data are available from Southern Waters Ecological Research and Consulting cc (www.southernwaters.co.za).

1.3 Report outline

The five project aims were completed successfully. The Berg River Catchment was selected for the study with approval from the members of the Reference Group. A conceptual framework was established by comparing a variety of data from published papers, the Berg River Reserve studies, the River Health Programme and the River Ecostatus Monitoring Programme (REMP), which are summarised in Section 2. Drivers of change over time were identified in the Berg River Catchment, some of which were flow-related, and are summarised in Section 3. The use of catchment-scale and site-specific data were compared at different spatial and temporal scales with a view to highlighting the value added by the historical analysis in Section 4. The data, and the experience gained in compiling them, were used to develop a framework, along with method statements, for the inclusion of historical data in the interpretation of Reserve-related monitoring data (Section 5). Section 6 concludes the report and makes recommendations for further work.

2 Reserve-related data for the Berg River

2.1 Introduction

In South Africa, water resources were initially managed for water provision alone without consideration of the ecological and environmental processes that support them (Palmer 1999). In the last two or so decades, management has progressed to include consideration of the ecosystems underpinning the water resources and the use of biophysical data in an integrated approach that seeks to explain how physical drivers of river condition, such as water and sediment flows, geomorphology and riparian vegetation, influence the biological responses of macroinvertebrates, fish, birds, herpetofauna and mammals (DWAF 1998). In practical terms, this has taken the form of setting (and increasingly implementing) an Ecological Reserve to meet a targeted condition for every significant water resource in the country; and monitoring the ecological condition of these water resources to ensure that the targeted conditions are met (DWS 2013). An Ecological Reserve refers to the quantity and quality of water set aside to provide for human basic needs and the needs of the aquatic ecosystem (NWA 1998).

There is an “8-step” process for determining the Ecological Reserve, which covers the activities from initiation of a study to implementation and monitoring of the Ecological Reserve. The nature and number of the steps varies over time but, in general, the steps are (DWS 2015):

1. Initiate a study, delineate study area and finalise methods to be used.
2. Delineate resource units and Reserve sites.
3. Determine reference and baseline condition, which is usually the condition at the time of the study, known as Present Ecological Status (PES).
4. Collate flow, biological, hydraulic and water quality data for each Reserve site, and use this to make recommendations on the volume and timing of water flows needed to maintain PES and ecological categories on either side of that, where relevant.
5. Use the information developed in Step 4 above to evaluate a series of development/operational scenarios in terms of their ecological consequences.
6. Decide on the ecological category that will be used to set the Ecological Reserve. In earlier studies this category was decided by DWS, and more recently it has been the outcome of a classification process.
7. Set the RQOs[4] for the selected ecological category.
8. Implement the Ecological Reserve flows and any other mitigation measures, and design and implement a programme to monitor the RQOs.

As part of monitoring the efficacy of the Ecological Reserve, data on flow, water quality, aquatic macroinvertebrates, riparian vegetation and other indicators are routinely collected at river sites by DWS personnel under the auspices of the REMP. These data are used in a number

[4] Note: The RQOs include the hydrological specifications of the Ecological Reserve.

of management processes, including monitoring the ecological condition of rivers and direct implementation of the Ecological Reserve.

Thus, in the Berg River Catchment, the bulk of the Reserve-related monitoring data for the rivers were generated in rough accordance with these eight steps as part of four projects: two Ecological Reserve determination studies, the first of which dealt with the upper reaches of the river (DWAF 1996) and the second with the lower reaches (DWAF, 2002); the Berg River Basin Monitoring programme (BRBM; Ractliffe *et al.* 2007), and; the REMP. An impressive array of biophysical data was collated in the first three projects, which has been augmented through ongoing REMP activities. The BRBM, in particular, generated invaluable baseline data, including some historical data that were used to inform qualitative descriptions of channel change, but it is worth noting that such tailored baseline monitoring programmes are rare in South Africa.

2.1.1 Ecological sites on the Berg River

The first Ecological Reserve study (DWAF 1996) established two sites in the upper parts of the catchment, IFR 1/96 and IFR 3/96 (Figure 2.1) and the second (DWAF 2002) established two sites (IFR 4 and IFR 5) in the lower parts of the catchment.

Figure 2.1 The location of Ecological Reserve, BRBM and REMP sites, and DWS gauging weirs, in the Berg River Catchment

The BRBM data were collected at six sites: four at the Ecological Reserve sites (BRBM 2, 4 5 and 6); BRBM 1 upstream of the Berg River Dam, and; BRBM 3 upstream of Paarl.

The REMP data are collected at the six BRBM sites and at 28 other locations, mainly in the tributaries (shown as purple dots in Figure 2.1).

2.2 Data from the Ecological Reserve studies

The two Reserve determination studies were completed in 1996 and 2002. Both used the Building Block Methodology (King *et al*. 2008). Thus, the data collected were designed to provide input to the Building Block Methodology. Despite this, pragmatic considerations related mainly to available budget and expertise mean that these data now provide the bulk of the baseline data for setting and monitoring of the RQOs. The result is that information for setting non-hydrological RQOs in rivers[5] is patchy and spatially and temporally uneven, which has implications for the detail of the RQOs; particularly in cases where additional field work and data analysis are not possible[6]. The most relevant of the data are summarised here to illustrate their nature and detail.

2.2.1 IFR sites 1/96 and 3/96 (DWAF 1996)

The following data were compiled for the 1996 Reserve study (IFR sites 1/96 and 3/96; DWAF 1996).

Hydrology:

- modelled naturalised monthly flows at G1H004 (from 1928-1993) and G1H036 (1928-1988, Figure 2.1, which excluded any water resource developments or water use after 1978;
- modelled "present day" monthly flows at G1H004 (1928-1988) and G1H036 (1928-1988), which incorporated water resource developments or water use up to and including 1990;
- seasonal distribution of simulated monthly naturalised and present day flows;
- flood frequency curves based on annual maxima.

Hydraulics:

- surveyed cross-sectional profiles at IFR 1/96 and IFR 3/96;
- stage-discharge rating curves for each cross-sectional profile valid for 1996.

Water quality:

[5] And probably estuaries, groundwater and wetlands.

[6] Note: Ecological Reserve and REMP data are likely to be available for most catchments in the country, but specific monitoring programmes, such as the BRBM, are less common.

- a summary of available water chemistry data up to 1990.

Riparian vegetation:
- species list for Berg River riparian vegetation;
- an assessment of the condition of the indigenous riparian vegetation along the length of the river, assessed by means of a helicopter survey in September 1995.

Fish:
- fish species known to inhabit the Berg River, including: *Barbus andrewi* (witvis), *Sandelia capensis* (Cape kurper) and *Galaxias zebratus* (Cape galaxias).

Macroinvertebrates:
- an assessment of the status of the invertebrate communities in 1991 and a description of changes noted between 1951 and 1991 (these two data sets are the same as those listed under historical data in Section 3.5);
- an assessment of the invertebrate communities present in 1994 and 1995 using the South African Scoring System (SASS4; Box 1). The parameters provided were:
  - presence/absence of families;
  - total score;
  - average score per taxon.

Box 1 The South African Scoring System

The South African Scoring System, versions 4 and 5 (e.g. Dickens and Graham 2002) uses the presence of macroinvertebrates to indicate "river health" based on the presence or absence of 90 different macroinvertebrate families. Different macroinvertebrates have different sensitivities to water quality conditions and are given a rating score from 1–15, whereby a rating of 1 indicates the members of the family are tolerant of poor water quality and a score of 15 indicates the family is highly sensitive to poor water quality. Macroinvertebrates are useful for biomonitoring because they are easy to collect and identify and are relatively sedentary so help with identifying point sources of pollution.

2.2.2 IFR 4 and IFR 5

The following were compiled for the 2002 Reserve study (IFR 4 and IFR 5; DWAF, 2002):

Hydrology:
- modelled naturalised monthly flows at G1H013 and G1H031 (Figure 2.1) all from 1928 to 1988, which excluded any water resource developments or water use after 1978;

- modelled “present day” monthly flows at G1H013 and G1H031 from 1928 to 1988, which incorporated water resource developments or water use up to and including 1990;
- seasonal distribution of simulated monthly naturalised and present day flows;
- flood frequency curves based on annual maxima.

Hydraulics:

- surveyed cross-sectional profiles;
- stage-discharge rating curves for each cross-sectional profile valid for 2002.

Geomorphology:

- list of structural features of bed and banks.

Water quality:

- average concentrations of inorganic salts, nutrients, physical variables and toxicity at G1H013Q01 (IFR 4) and G1H031Q01 (IFR 5) for 1996 to 2001 and for 1996 to 2001;
- tables of mean and median values for the available water chemistry data.

Riparian vegetation:

- an assessment of the condition of the indigenous riparian vegetation species and their vertical and longitudinal zonation pattern in November 2001;
- a description of the naturalised and present day condition of the riparian vegetation, with lists of species expected and found.

Fish:

- a list of indigenous and introduced fish species known to inhabit the Berg River at IFR 4 and IFR 5;
- a list of fish species recorded.

Macroinvertebrates:

- an assessment of the invertebrate communities present in 2001 using the SASS5 (Box 1). The parameters provided were:
  - presence/absence of families;
  - total score;
  - average score per taxon;
- a comparison of invertebrate communities in 1995 and 2001.

2.3 Data collected for the BRBM (Ractliffe 2007)

BRBM data were collected from six sites (Figure 2.1) and built on the Reserve data collections. The following information and data were collected/collated at each BRBM site.

Hydrology and rainfall:

- simulated naturalised monthly data at G1H004, G1H020, G1H036, G1H013 from 2002 to 2005 (Figure 2.1);
- present day monthly data at G1H004, G1H020, G1H036, G1H013 from 2002 to 2005;
- recorded daily average flow data at G1H004, G1H036 and G1H013 from 2002 to 2005;
- peak magnitude, volume and number of floods recorded at G1H004, G1H036 and G1H013 from 2002 to 2005.

Hydraulics and channel morphology:

- aerial photographs from the 1930s to 1998 and older versions of the 1:50 000 topographical maps dating back to the 1940s were used to inform a qualitative assessment of historical changes in river width, planform and sand deposition over a 100-metre length;
- a topographic survey recording bed elevation at 1-metre intervals in the river channel along the 100 m length of each site during summer;
- three surveyed channel cross-sections at each site, recording channel depth and width (e.g. Figure 2.2);
- mean flow velocity (m/s) and depth of flow (m) along each cross-section;
- width, depth and length (cm) of cobbles and boulders at BRBM 1, 2 and 3;
- the proportion of sand and gravel from sand bars at each cross-section at each site;
- hand-drawn maps showing type and proportion of biotopes at two different discharges for summer low and winter high flows.

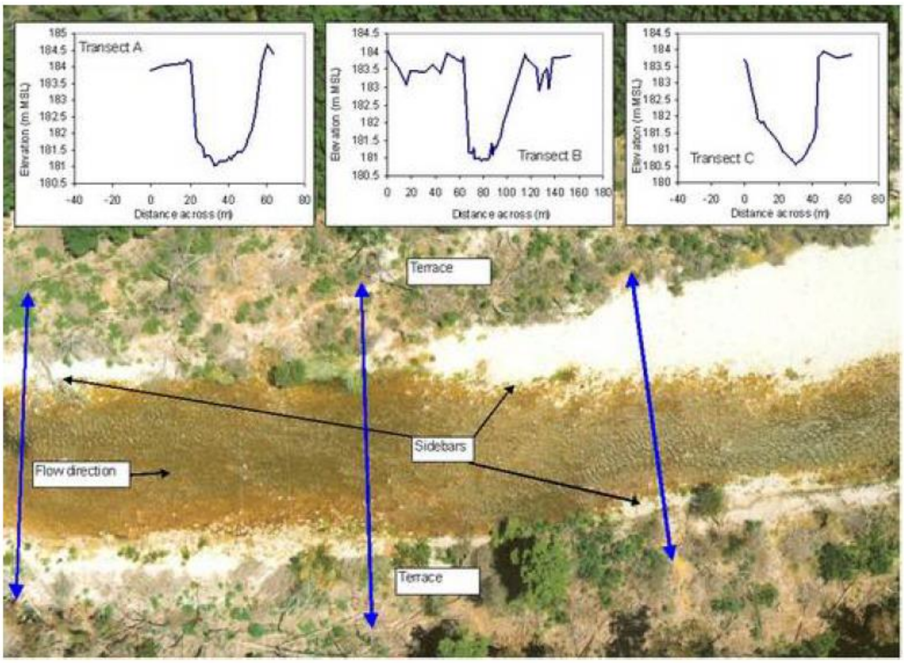


Figure 2.2 An aerial photograph of the channel at BRBM 2 (IFR 1/96; taken in 2003) and the location and shape of three channel cross-sections (Ractliffe 2007)

Water quality:

- historical data gleaned from earlier studies: Harrison and Elsworth (1958), Fourie and Steer (1971), Fourie and Gorgens (1978), Hall and Gorgens (1978), Bath (1989), Bath (1993 a and b), Dallas (1992), Dyke and Howard (1993), Brown (1993), Dallas *et al.* (1994), Day and Dallas (1996), Dallas *et al.* (1998), Snaddon (1998) and Snaddon and Davies (2000); (all cited by Ractliffe *et al. 2007);*
- DWS long-term monthly monitoring data for 1965 to 2003 from G1H004, G1H020, G1H036, G1H013 for pH, nitrate+nitrite nitrogen (NO3+NO2-N); ammonia nitrogen (NH4-N); Kjeldahl nitrogen, chloride, sulphate, fluoride, total alkalinity, sodium, potassium, magnesium, calcium; silica, sulphate, orthophosphate phosphorus, total phosphorus and electrical conductivity;
- seasonal quarterly measurements of pH, electrical conductivity, dissolved oxygen and temperature with hand-held instruments:
  - Autumn – March, April, May
  - Winter – June, July, August
  - Spring – September, October, November
  - Summer – December, January, February;
- quarterly total suspended solids, nitrate+nitrite nitrogen, Kjedahl nitrogen, total phosphorous and ortho-phosporous, Cholorphyll-a and Escherichia coli concentration, analysed at a certified laboratory;
- total phosphorous concentrations in sediment at BRBM sites 3-6;
- temperature readings every 30 minutes, upstream and downstream of the Berg River Dam;
- conductivity readings every 12 minutes, upstream and downstream of the Berg River Dam.

Riparian vegetation:

- percentage cover of dominant tree, shrub, herb and groundcover species along the three cross-sections, recorded once during summer in 2003, 2004 and 2005;
- a presence/absence list of all species present along each cross-section.

Algae:

- seasonal algal biomass at BRBM 1, 2, 5, and 6 collected from marginal vegetation, benthic stones and sediments in 2003, 2004 and 2005 (seasons same as for water quality);
- seasonal algal species composition and abundance (# cells/ml) at BRBM 1, 2, 5, and 6 found on marginal vegetation and benthic stones and in sediments.

Aquatic macroinvertebrates:

- historical data from earlier studies: Harrison and Elsworth (1958), Scott (1958), Coetzer (1978), Dallas and Day (1992), Dallas (1997), Snaddon (1998) and Snaddon and Davies (2000); (all cited by Ractliffe *et al.*, *2007);*
- seasonal Total SASS scores and Average Score per Taxon (ASPT) using the SASS 5 method in 2003, 2004 and 2005 (seasons same as for water quality);
- the abundance of families, or nearest taxon, in the biotopes sampled, reduced to percentages of the total recorded per sample.

Fish:

- historical species composition, abundance (number of individuals per sample) and size (mm) from earlier studies Rall (2003), Impson (unpublished), Woodford (2002) and Sieberhagen (2000); (all cited by Ractliffe *et al.*, 2007);
- species composition, abundance (number of individuals per sample) and size (mm) assessed along the 100-metre site length in summer 2003, 2004 and 2005.

2.4 Data collected for the River Ecostatus Monitoring Programme (DWS 2017 unpublished internal report)

REMP data are collected at 34 sites in the Berg River Catchment. See Figure 2.1 and Table 2.1 (Kleynhans and Louw 2007). Data collection involves subjective assessment of six indices:

- Geomorphological Assessment Index (GAI, Rowntree *et al.* 2013);
- Physico-chemical Assessment Index (PAI, Scherman 2008);
- Fish Response Assessment Index (FRAI, Kleynhans 2008);
- Macroinvertebrate Response and Assessment Index (MIRAI, Thirion *et al.* 2008);
- Vegetation Response and Assessment Index (VEGRAI, Kleynhans *et al.* 2007);
- Index of Habitat Integrity (Kleynhans *et al.* 2008).

Table 2.1 REMP sites in the Berg River Catchment. The location of the four Berg River Reserve sites are in bold

Site code	River	Latitude	Longitude	Site description
G1BERG-BRBM1	Berg	-33.956231	19.0726	U/s Theewaterskloof water transfer tunnel
G1BERG-BRBM2	**Berg**	**-33.899747**	**19.052842**	**100 m d/s of Berg River Dam IFR 1/96**
G1BERG-BR45R	Berg	-33.877069	19.032694	Berg River d/s of R45 Road bridge
G1BERG-CECIL	Berg	-33.762861	18.973764	Cecila's Drift, u/s Paarl
G1BERG-DALJO	Berg	-33.731493	18.973128	Daljasophat in Paarl; d/s sewage works
G1BERG-HERMO	**Berg**	**-33.43333**	**18.95556**	**D/s Hermon road bridge IFR 3/96**
G1BERG-ZONQU	Berg	-33.342046	18.978926	At low-flow bridge at Zonquasdrif
G1BERG-DRIEH	**Berg**	**-33.130605**	**18.862983**	**D/s of Drie Heuwels weir IFR 4**
G1BERG-BRBM6	**Berg**	**-32.998013**	**18.780423**	**Die Brug at IFR 5 d/s Misverstand Dam**
G1BOES-BANGH	Boesmans	-32.772499	18.651031	Above Banghoek
G1BOES-KAPTE	Boesmans	-32.7743	18.58187	At Kapteinskloof, d/s of roadbridge
G1DRAK-WEMME	Drakenstein	-33.80775	19.077	U/s Wemmershoek Dam
G1DWAR-GWEIR	Dwars	-33.94733	18.9688	U/s of gauging weir; Zevenrivieren
G1DWAR-KYLEM	Dwars	-33.91242	18.94392	D/s of bridge at Kylemore
G1DWAR-RHODE	Dwars	-33.866366	18.984944	D/s of roadbridge near Rhodes fruit farms
G1FRAN-LAPRO	Franschoek	-33.895414	19.08981	On winefarm "La Provence"
G1HUGO-DEKKE	Hugos	-33.735033	19.040427	At Dekkersvlei
G1HUGO-PAARL	Hugos	-33.721247	18.992625	In Paarl; at Abbatoir Street
G1KLEI-GWEIR	Klein Berg	-33.31563	19.07628	At DWS gauging weir
G1KLEI-R44BR	Klein Berg	-33.21857	18.97433	U/s R44 bridge
G1KLEI-TWEEJ	Klein Berg	-33.275258	19.104522	Bridge to Tweejongengezelen
G1KROM-ABIBT	Krom	-33.616813	19.087441	U/s Intercatchment Transfer
G1KROM-BEIBT	Krom	-33.625417	19.0818	D/s Intercatchment Transfer; at Doolhof wine farm
G1KROM-GROEN	Krom	-33.627367	19.025571	Leliefontein-Groenfontein old bridge
G1LEEU-BRIDG	Leeu	-33.31138	19.11177	D/s of bridge
G1MAAT-GWEIR	Maatjies	-33.047554	18.831302	D/s of Maatjies river gauging weir

Site code	River	Latitude	Longitude	Site description
G1OLIF-ABRID	Olifants	-33.83748	19.111	U/s of Wemmershoek Dam
G1PLAT-GOEDV	Platkloof	-32.864981	18.678336	At Goedverwacht
G1SOUT-HAZEK	Sout	-33.010892	18.363332	D/s of roadbridge to farm "Hazekraal"
G1TWEN-AWEIR	Twenty four	-33.13502	19.06253	U/s weir
G1TWEN-BWEIR	Twenty four	-33.140216	19.055275	D/s of weir
G1TWEN-HALMA	Twenty four	-33.151633	18.980194	U/s of roadbridge at Halfmanshof; R44 road
G1WATE-WATER	Watervals	-33.353849	19.109594	In Waterval Nature Reserve; above weir
G1WEMM-WEMME	Wemmershoek	-33.85348	19.040547	U/s of roadbridge

Source: Kleynhans and Louw, 2007

The ecoclassification manuals (Kleynhans and Louw 2007) describe the tasks undertaken and provide MS Excel-based rule models to calculate the scores for these indices relative to hypothetical reference conditions from A to F, where A represents close to natural and F is a critically modified condition. By and large, the methods are qualitative and subjective, and rank how flow-related and non-flow-related impacts ae expected to change conditions from natural. None of the methods explicitly state the period that defines “natural conditions” or the scale at which impacts are to be assessed. However, based on experience, different practitioners collect data in different ways to derive and calculate flow-linked relationships that are then used to score and rank the identified impacts that change the outcomes of the models.

The methods were derived using data and flow-linked relationships from the results of Ecological Reserve studies but do not take account of specific Reserve requirements at a site when scoring conditions. Rather, the focus is on whether ecological conditions have changed from natural and/or from previous sampling times, and whether the reasons for change are perceived as being flow-related or not. It is possible that a seventh index, the Hydrological Assessment Index (HAI *in prep*), will incorporate quantitative comparisons between measured discharge and the Ecological Reserve hydrology, but this is not yet available.

The Geomorphological Assessment Index (GAI) is an assessment of changes in connectivity between a river and hillslopes of the surrounding catchment; sediment supply and features of the river channel and floodplain; and channel stability. There is no internal database of natural conditions expected so a combination of maps, aerial images and data collected in the field is used to construct a hypothetical reference condition and to calculate the GAI score. These include:

- a qualitative assessment of the flow conditions at the time of a site visit;
- consideration of changes in MAR and flood frequency (if available);
- site photographs, plan view sketches and surveyed channel cross-sections;
- an evaluation of changes in channel width and depth;
- a description of the dominant bed material in sediment size classes;
- a qualitative assessment of channel and bank morphology (habitat) such as presence of benches, floodplain and terraces, and steps, cascades, pools, riffles, rapids, backwaters, bars, secondary channels and islands.

The Physico-chemical Assessment Index (PAI) is an assessment of how measured water quality parameters, collected during the site visit or downloaded from the DWS water quality database (http://www.dwa.gov.za/iwqs/wms/data/000key.asp), differ from the concentrations recommended for a reference condition, which is programmed into the PAI database. The main variables used to calculate the PAI score are:

- inorganic salts (sodium Na, calcium Ca, magnesium Mg, chlorine Cl, sulphate SO_4);
- nutrients (phosphate PO_4 and total inorganic nitrogen TIN);
- dissolved oxygen;
- pH;
- turbidity;
- temperature;
- toxic substances.

The Fish Response Assessment Index (FRAI) is an assessment during a site visit of changes in habitat conditions for fish based on a qualitative assessment of flow velocity and depth and how this differs to that expected in an unregulated, naturally shaped and vegetated river channel. It also compares the frequency of occurrence of exotic and indigenous fish species collected from the site to an internal database of those expected in order to calculate the FRAI score using:

- the extent of flow-depth classes for a river reach (slow-deep, slow-shallow, fast-deep and fast-shallow);
- the frequency of occurrence of fish species recorded versus those expected to occur.

The Macroinvertebrate Response Assessment Index (MIRAI) is an assessment of changes in flow, habitat and water quality conditions that affect aquatic invertebrates. It also compares the frequency of occurrence of macroinvertebrate families to a reference condition generated by the practitioner and calculates the MIRAI score using:

- a qualitative assessment of river dimensions, sediment type and habitat types present;
- measured basic water quality parameters, such as pH, conductivity and oxygen concentration;
- the frequency of occurrence of macroinvertebrate families present versus those expected to occur.

The Vegetation Response Assessment Index (VEGRAI) is an assessment of changes in the cover and species composition of the riparian vegetation. There is no internal database of indigenous or exotic species expected to occur so all and any records available are used to construct a hypothetical reference condition and to calculate the VEGRAI score using:

- site photographs, a plan view sketch and a surveyed channel cross-section;
- a species list of plants present and their location in the channel or on the bank;
- an account of the extent of exotic plant species present.

The Index of Habitat Integrity (IHI) is an overall assessment of river condition based on the scores calculated for each component above and for different river types according to:

- whether the river is perennial or non-perennial and whether the site is situated high up or lower down the river's longitudinal profile, using either the National Freshwater Ecosystem Protection Areas (NFEPA) or national South African National Biodiversity nstitute (SANBI) Geographical Information System (GIS) covers database;
- a qualitative measure of whether the channel width and depth has changed from natural, based on a site visit or the GAI assessment;
- a qualitative assessment of natural, degraded, cultivated and urban landuse from notes made during a site visit or viewed in Google Earth®;
- an assessment of changes in base flow and floods from an analysis of the flow record if possible, or a qualitative assessment based on secondary information, such as the presence of marginal vegetation indicating that dry season flows are sustained perennially, or the absence of well-sorted channel bed substrata indicating that floods are being held back or interrupted, and so on.

The REMP data are written up in unpublished DWS reports (DWS, 2017) and are incorporated into the published "State of the Rivers Reports" (DWAF 2004), which summarise the ecological condition scores per component for rivers across the country. The REMP data can also be accessed for use in other studies via the REMP website (http://www.dwa.gov.za/iwqs/rhp/naehmp.aspx).

2.5 Summary

The data collated for Ecological Reserve studies were not specifically designed for monitoring. Rather, the data were analysed with the goal of predicting the consequences of future flow scenarios on a river ecosystem based on an assessment of how these future flow scenarios differ to a "current day" and a "baseline" scenario. Flow scenarios in Reserve studies are generally modelled data, *viz.* not *observed* measured values, and so are not helpful for monitoring.

BRBM information was specifically collected to describe baseline conditions prior to operation of the Berg River Dam but it was also intended for use in setting targets for monitoring. To assist this, the team undertook some historical analyses of hydrological, water quality and macroinvertebrate data and made other qualitative assessments of historical changes in riparian vegetation, fish and landuse. These are all helpful to contextualise current day conditions but they are difficult to compare with one another over time. It is easier to document historical changes if the changes can be quantified and if the methods to do this are clearly stated and easy to follow. This facilitates the collection of comparable data sets over time that can be added to a historical time series.

The REMP monitoring protocol relies heavily on subjective assessments of change, and while these are useful for a general index they are not useful for quantifying whether the observed change is real or not or for testing its legitimacy.

Some of these challenges can be met by a more quantitative analysis of historical information, if this is possible. Historical data do not necessarily exclude recently acquired data nor the quantitative analyses done in other studies; all these data, when put together against a time line, add enormous value. In Section 3 the relevance of analysing historical data to feed into the REMP monitoring is addressed.

3 Historical data collated for the Berg River

In this study, historical data for the Berg River were collated and analysed as part of the activities undertaken by Ms Rozwi Magoba for her PhD studies. These described historical changes in the Berg River Catchment, and assessed their relative influence on the flow regime and ecosystem functioning of the Berg River. This section summarises the main aspects of the dissertation and summarises all the components that were used to inform the framework.

The dissertation focused on collation and assessment of historical information in four key areas (Figure 3.1):

1. landuse;
2. rainfall and hydrology;
3. channel structure and riparian vegetation;
4. aquatic macroinvertebrates.

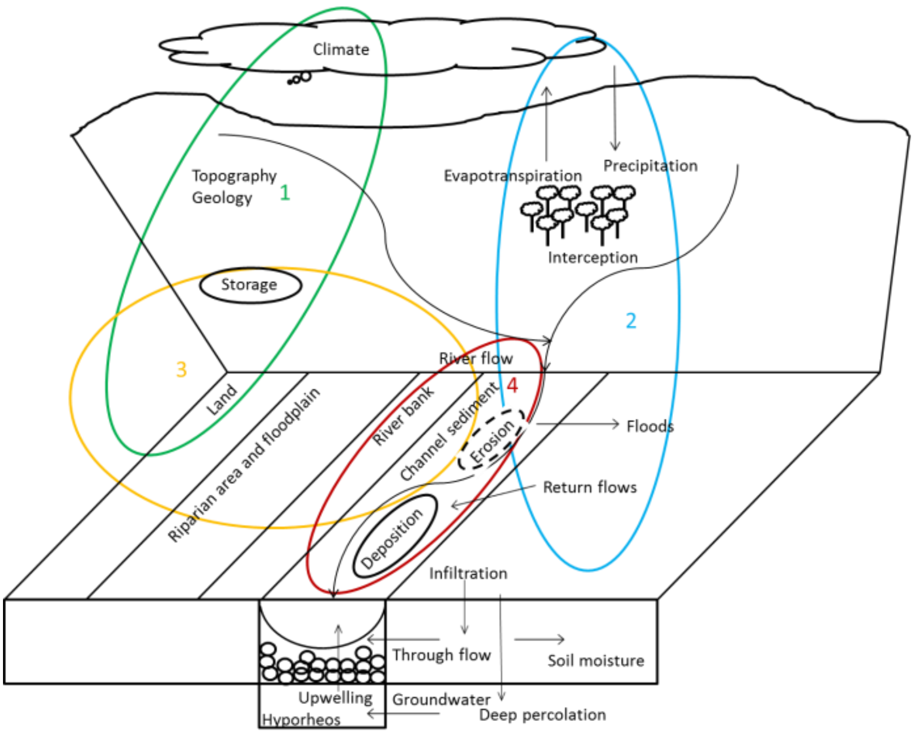


Figure 3.1 The four focus areas for the PhD thesis. 1 = landuse; 2 = rainfall and hydrology; 3 = channel structure and riparian vegetation; 4 = aquatic invertebrates.

The central hypothesis was that all activities in the catchment contribute either directly or indirectly to a river's ecological condition, as defined broadly by physical, biological and chemical attributes (Naiman *et al.* 2005). The cumulative result of the many impacts may lead to changes in the basic structure and function of the river ecosystem resulting in a reduced ability to perform ecological functions (van Meter *et al.* 2016). With this in mind, understanding the natural and historical fluctuations within river ecosystems is essential to provide a context in which data generated by monitoring programmes are assessed. There is a growing awareness of the value of incorporating these large-scale and less obvious causes of change into judgements made with respect to river condition and so this study sought to enhance our current understanding of the natural and historical fluctuations within river ecosystems and their drivers at a river basin scale, through the use of long-term data sets of historic impacts and ecosystem condition. The main aim of the study was to document, analyse and assess large-scale biophysical data that were readily available to help inform monitoring of rivers.

The approach was to build a database of different information layers, such as topography, landuse type, urban development and agricultural areas, hydrology and macroinvertebrates, each representing particular periods in the history of the catchment from as early as possible with various time-layers from *c*. 1900 to 2014.

The methods, results and lessons learnt for each of these are addressed in Sections 3.2, 3.3, 3.4 and 3.5, respectively.

3.1 Study area

The study area was the Berg River Catchment in the Western Cape Province, South Africa (Figure 3.2).

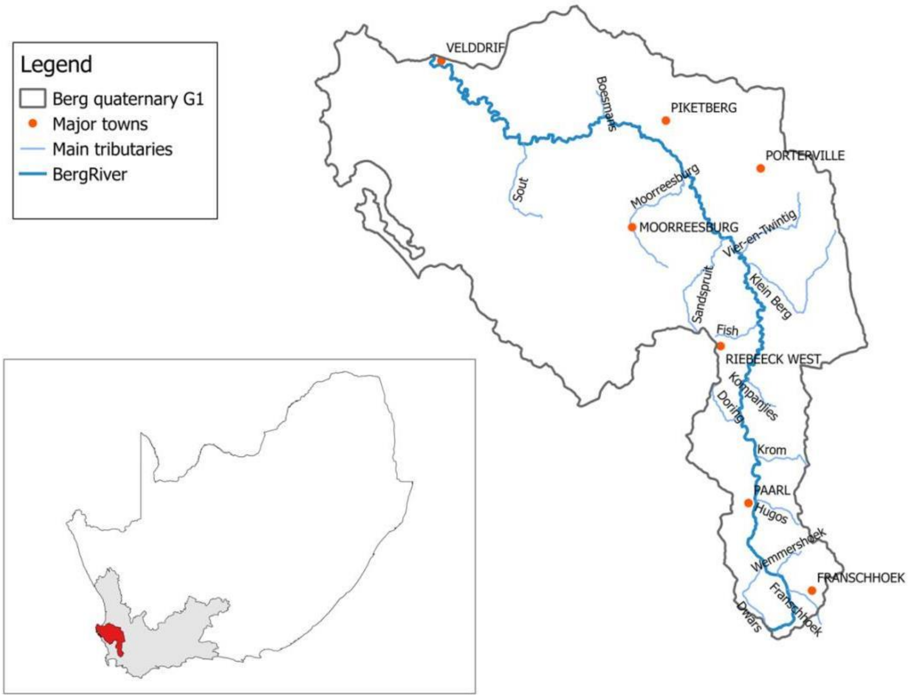


Figure 3.2 The Berg River and its main towns and tributaries. Insert: map of South Africa with the Western Cape Province (grey) and Berg River Catchment G1 (red)

The Berg River is ~285 km long from source to sea, with a catchment of ~9 000 km^2 (Ractliffe *et al.* 2007). It rises in the Drankenstein and Franschhoek mountains, south of Franschhoek, ~6 km upstream of the Berg River Dam, and flows north past the towns of Paarl, Wellington, Hermon and Gouda before turning west past Piketberg and Hopefield to the Atlantic Ocean on the West Coast at Velddrif. The main tributaries are the Dwars, Franschhoek, Wemmershoek, Hugos, Krom, Kompanjies, Doring, Klein Berg, Sandspruit, Twenty-fours, Moorreesburg, Boesmans and Sout rivers.

3.2 Landuse

The current monitoring activities of the REMP do not overtly consider the condition of the surrounding river basin. However, since river condition is, at least in part, driven by large-scale processes of water and sediment transported through the river catchment (Ward *et al.* 2001) it is necessary to integrate and reconcile site-specific monitoring data with large-scale catchment processes in a meaningful way. Thus, one of the main aims of the study was to document, analyse and assess large-scale biophysical data that were readily available to help inform monitoring of rivers, with a view to introducing environmental history as an important part of management of the water resources of South Africa (after Foster *et al.* 2003). The intention was to demonstrate that consideration of natural and historical fluctuations within river ecosystems is essential to understanding data generated by monitoring programmes in order to assess whether changes in river condition may be taking place unnaturally.

With this in mind, the objective of this section was to document large-scale landuse changes in the Berg River Catchment over space and through time, analysing whether changes have taken place and if so, describing what these changes were. The central assumption was that all activities in the river catchment contribute either directly or indirectly to a river's ecological condition, as defined broadly by physical, biological and chemical attributes (Naiman *et al.* 2005).

Humans drive change across river catchments as agricultural settlements expand to increase production of food and produce for the enlarging and expanding development in urban areas as population growth and economic development increases (Tockner *et al.* 2010). Food production in agricultural areas has intensified driven by the need for higher yields and multiple crop types (Alexandratos 1999). The Berg River is relatively small compared to other rivers in the Western Cape and has experienced an increase in population that is heavily dependent on agricultural production, which comes with high consumption of water resources. For these reasons, an analysis of historical changes across the catchment of the Berg River was expected to show that:

- Changes in landuse were progressive.
- The rate of change in landuse has accelerated over time.

3.2.1 Methods

Data on changes in landuse were digitised from historical 1:50 000 maps obtained from the local Department of Surveys and Mapping in Cape Town (http://www.dla.gov.za/contact-us/national-geo-spatial-information/37-national-geo-spatial-planning-cape-townmap-sales). Maps that covered the entire catchment were collated for four periods, since these were the only four periods for which full basin coverage was available; 1955–1965, 1976–1985, 1996–2005 and 2006–2015. In other years there were either maps missing for large portions of the catchment, or the maps were not georeferenced, and so could not be analysed in GIS. Landuse was categorised into 13 classes and grouped into four categories: agricultural lands, urban areas, buildings outside of urban areas (rural buildings), and water bodies (Table 3.1).

Table 3.1 Landuse categories and descriptions of classes

Category	Landuse class	Description	Data type
Agricultural lands	Dryland farming	Agricultural land used for ploughing mainly wheat and cash crops	Area (km^2)
	Orchards and vineyards	Irrigated land used for orchards and vineyards	
	Plantations (forestry)	Includes stands of pine, black wattle and Eucalypts in the Berg catchment	
Urban areas	Towns	The spatial extent of the built-up and paved areas of main towns	Area (km^2)
	Townships	The spatial extent of the built-up and paved areas of townships	
	Towns	The number of the built-up and paved areas of main towns	Point data (counts)
Buildings outside of urban areas	Farms	Rural residential settlements, farm houses, small farm villages and estates	Point data (counts)
	Industrial buildings	Rural factories, lime and salt-works, and abattoirs	
	Townships	Informal residential settlements and villages smaller than towns	
Water bodies	Dams	Water bodies with a wall on at least one side	Point data (counts)
	Non-perennial water	Water bodies with no wall that are empty during some part of the year	
	Perennial water	Water bodies with no wall that have water all year	
	Dry pans	Stand-alone areas without walls or water	

Polygons of the extent of agricultural lands and urban areas were digitised in QGIS, and the water bodies (including farm dams) and rural buildings were counted. These data were summarised per landuse class for each time period and compared between periods and between sub-catchments (Figure 3.3).

3.2.2 Results

The Berg River Catchment was already extensively cultivated by 1955/60 (Figure 3.3).

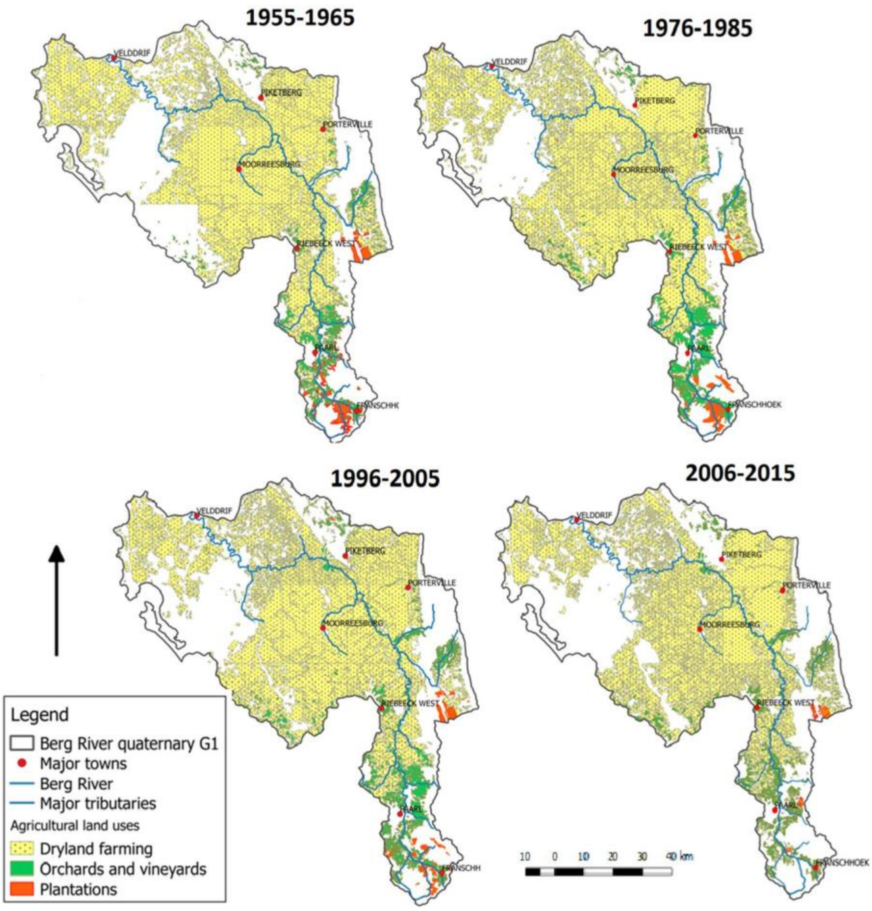


Figure 3.3 Changes in landuse of the Berg River Catchment over time, digitised from 1:50 000 topographic maps

Dryland crop production covered ~73% of the catchment, followed by orchards and vineyards (~6%), and forestry plantations (~2%; Figure 3.4).

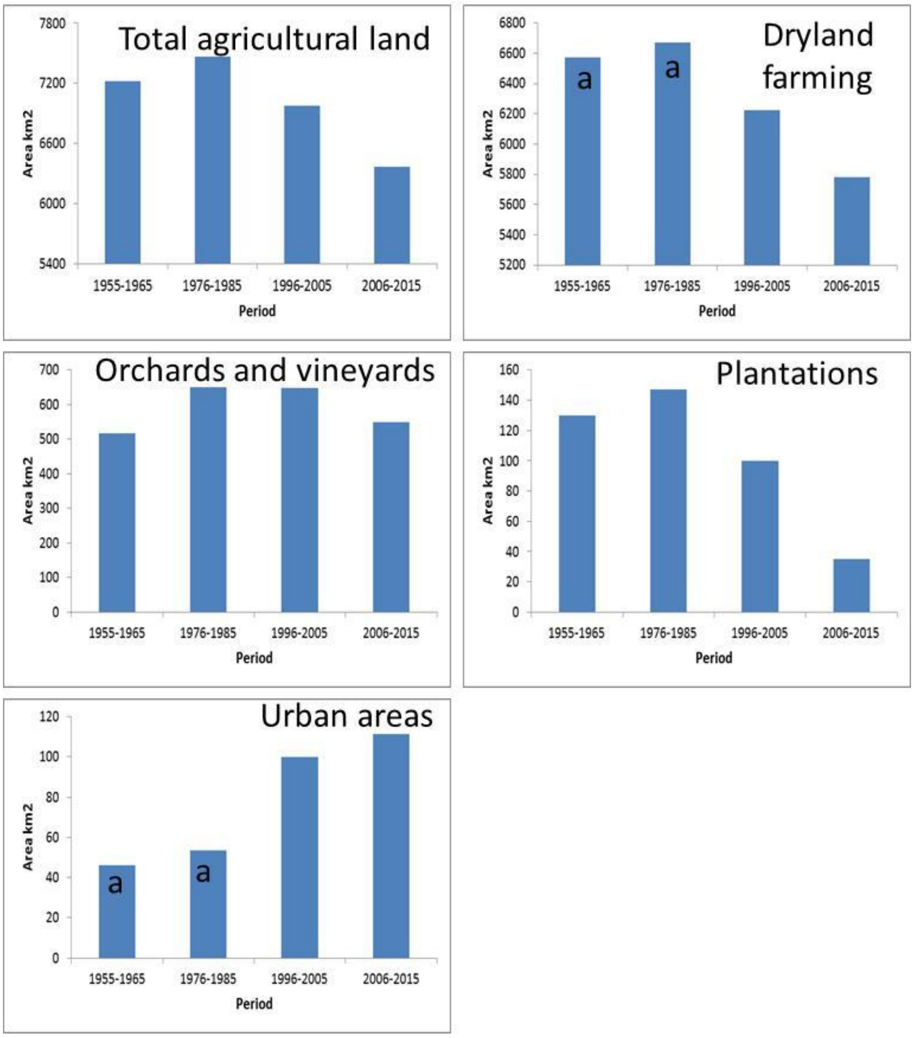


Figure 3.4 The total area of agricultural land, dryland farming, orchards and vineyards, plantations and urban areas over the Berg River Catchment over time. The "a" means the two periods are not different from one another (p < 5%; ANOVA of least squares means)

Landuse differed between the sub-catchments (Table 3.2). The bulk of the dryland crop production was in the lower foothills, lowlands and estuary, and most of the orchards, vineyards and plantations were in the upper foothills of the Berg River and in the Klein Berg catchment near Tulbagh. Between 1955/60 and 2006/15, the extent of agricultural land in the catchment declined as dryland crops were converted to orchards and vineyards, leaving large tracts of land fallow. Over the same period, the area under plantations declined by 33%, urban areas doubled in size, and dry land farming declined to half of what is was in 1976–1985 (Figure 3.4).

Table 3.2 Differences in landuse over time. Highlighted rows indicate differences between the period 1955–1965 and the period 2006–2015 ($p < 0.05$)

Sub-catchment	Landuse class	Difference 1955–1965 to 2006–2015	
		Area (km^2)	Percentage of 1955-1965 area
Upper foothills (km^2)	Dryland farming	0.48	0.01
	Orchards and vineyards	-4.88	-0.05
	Plantations	-1.30	-0.01
	Total agricultural land	-5.70	-0.06
	Towns	0.11	0.001
	Townships	1.17	0.01
	Total urban area	1.28	0.01
	Undeveloped land	4.42	0.05
Lower foothills (km^2)	Dryland farming	-147.61	-1.65
	Orchards and vineyards	-16.92	-0.19
	Plantations	-32.12	-0.36
	Total agricultural land	-196.65	-2.20
	Towns	26.86	0.30
	Townships	3.65	0.04
	Total urban area	30.50	0.34
	Undeveloped land	166.14	1.85
Lowlands (km^2)	Dryland farming	-434.60	-4.85
	Orchards and vineyards	52.09	0.58
	Plantations	-61.45	-0.69
	Total agricultural land	-443.90	-4.96
	Towns	-12.92	-0.14
	Townships	5.73	0.06
	Total urban area	-7.19	-0.08
	Undeveloped land	451.08	5.04
Estuary(km^2)	Dryland farming	-208.75	-2.33
	Orchards and vineyards	1.35	0.02
	Plantations	0.00	0.00
	Total agricultural land	-207.40	-2.32
	Towns	28.49	0.32
	Townships	12.00	0.13
	Total urban area	40.49	0.45
	Undeveloped land	166.91	1.86
TOTAL	Agricultural land	-853.64	-9.53
	Dryland farming	-790.48	-8.8
	Orchards and vineyards	31.64	0.35
	Plantations	-94.87	-1.05
	Urban area	65.10	0.73
	Undeveloped land	788.54	8.80

As the extent of urban areas increased, the number of rural buildings decreased, possibly as people moved off farms and to the urban areas (Figure 3.5). Over the same period, the number of farm dams doubled in the lower foothills and tripled in the lowlands, presumably in response to the increased need for irrigation water for the orchards and vineyards that replaced the dryland farming (Figure 3.5).

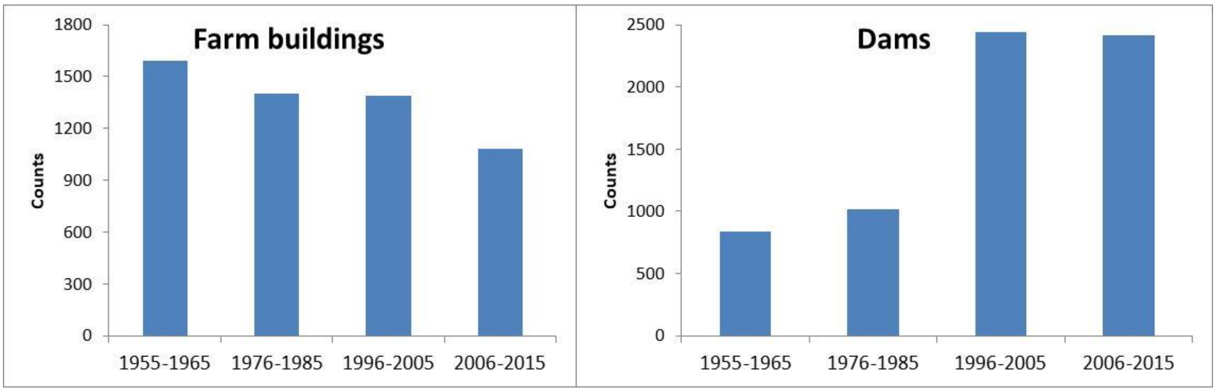


Figure 3.5 Total number of farm buildings (left) and farm dams (right) across the catchment

The rate of change in landuse was shown to accelerate over time in both positive and negative directions (Table 3.3). From the 1960s to the present, agricultural land was lost at an accelerated value largely due to reductions in the extent of dryland farming. This was complemented by an accelerated increase in total urban area, comprising towns and townships, and an accelerated increase in the extent of undeveloped land. There was also an accelerated increase in the number of buildings from the 1960s to the 1990s, mostly driven by an increase in the number of townships, and an accelerated increase in the number of man-made water bodies, largely farm dams.

Table 3.3 Rates of change in landuse across the Berg River Catchment over time

Landuse classes	**Rate of change between periods (km^2/year)**		
	1955–1965 to 1976–1985	1976–1985 to 1996–2005	1996–2005 to 2006–2015
Dryland farming	4.85	-22.20	-29.55
Orchards and vineyards	6.64	-0.13	-6.5
Plantation	0.87	-2.36	-4.34
Total agricultural	**12.36**	**-24.69**	**-40.46**
Towns	0.15	1.82	0.19
Townships	0.20	0.48	0.57
Total urban area	**0.36**	**2.31**	**0.76**
Undeveloped land	-12.72	22.38	39.69
Count			
Farms	-9.60	-0.55	-20.2
Industrial buildings	-0.05	-0.05	0.46
Towns	0.15	0.00	0.66
Townships	-0.90	5.40	16.73
Total buildings	**-10.40**	**4.80**	**-2.33**
Dams	8.95	71.20	-1.4
Dry pans	-3.85	-2.15	0
Non-perennial pans	1.70	10.00	-0.2
Perennial pans	1.45	0.30	-0.06
Total water bodies	**8.25**	**79.35**	**-1.66**

3.2.3 Conclusion

Contrary to expectations, changes in landuse were not progressive throughout the study period. Conversion of natural vegetation and/or cultivated area to urban was the only progressive change in landuse; and urban areas increased by ± 1%. This relatively small increase in the coverage of urban areas in the catchment belies two important factors: (1) the (negative) influence that urban areas in the catchment tend to exert on downstream ecosystems, mainly in terms of water usage and water pollution; and (2) the negative influence of increased urban areas outside of the catchment, for instance Greater Cape Town and Stellenbosch, which draw some of their water supplies from the basin's rivers.

The other major landuse types in the basin, cultivation and plantations, declined by ±10% over the study period; and undeveloped land, which includes land recovering from cultivation or plantations, increased by almost the same amount (8%).

The increase in undeveloped land is fairly recent, with most clearing of woody vegetation having taken place since the start of the Working for Water (WfW) programme, which is tasked with clearing exotic woody forests to reduce water lost via transpiration (Albhaisi *et al.*, 2013). A subsequent goal of the programme is to improve the ecological condition of rivers and the river catchment overall, with the expectation that this will also increase flow in rivers to buffer that required by the Ecological Reserve prescribed by the National Water Act (Act 36 of 1998). Losses of plantations were also due to forest fires near Franschhoek (Garcia-Ruiz 2003, Currie *et al.* 2009, Albhaisi *et al.* 2013). There have been few or no attempts to actively re-vegetate the Berg River Catchment. In most cases forest removal creates "undeveloped land", which may or may not recover naturally (Currie *et al.*, 2009). The bulk of this recovering land is in the upper foothills, upstream of the newly constructed Berg River Dam. This means that any benefits that may have accrued to the river ecosystem from having a portion of its basin return to a more natural condition are offset by the barrier effect and flow regulation of the Berg River Dam.

The decline in cultivated area also does not imply an automatic improvement in ecological condition. This, in part, is also influenced by the recent reduction in the number of farms due to the reduced profitability of farming and general scarcity of water country wide. However, despite the decline in acreage under cultivation, production remains relatively constant, indicating a shift towards intensified agriculture, changes in irrigation techniques, improved fertilisers, more efficient mechanisation and the use of drought- and pathogen-resistant genetically modified seeds (du Plessis, 2004), none of which bode particularly well for the rivers in the catchment.

The increase in the purchase of agricultural lands (farms) for alternative uses may have contributed to the decreased area of land under cultivation/irrigation. More farms within the middle and lower reaches of the basin have been bought by lifestyle farmers who are more focused on a country life style than agricultural production (Reed and Kleynhans, 2009). For instance, lifestyle farmers will not necessarily plant the same number of hectares as a commercial farmer.

While the increases in undeveloped land should be deemed to have had a positive influence on the functioning of the river ecosystems in the basin, the positive influence will have been offset by development in other areas, chiefly increased water abstraction and regulation and the construction of the Berg River Dam.

3.2.4 Lessons learnt

The landuse data analysis yielded extremely useful and, at times, unexpected information on catchment-wide changes, which was helpful in interpreting changes in the hydrological flow regime (see Section 3.3) and channel changes (see Section 3.4) in particular.

The effort required to access these data in the Berg River was considerable. The 9 000 km^2 of the Berg River Catchment comprises 25 1:50 000 maps that were digitised for four periods. Digitising took ~15 months to complete. Much effort was spent clipping and cropping polygon edges between adjacent landuse types to avoid/reduce errors in the area calculations. Furthermore, because the catchment was already heavily cultivated by the time of the earliest maps, *c.* 1940, the subsequent changes in agriculture were relatively small. The team accessed aerial photographs that predated the maps (*c*. 1940), but these proved exceptionally challenging to work with and were eventually not used for any quantitative analysis. The difficulties were linked to the fact that: the images were not georeferenced; the photographic flight crisscrossed the landscape with considerable overlap, which meant there were literally hundreds of individual images, with only very rudimentary, hand-drawn lines on maps to aid their orientation; and the images themselves were unclear, so it was difficult to distinguish crop type or riparian vegetation. All of this meant that processing time was even longer than for the maps, and in the end unacceptably so for a project of the sort undertaken here.

In summary, the lessons learnt were:

- In many catchments, formal maps do not extend back far enough in time to capture periods when agricultural activities were small or non-existent, and older maps needed to be scanned and georeferenced.
- Historical, non-georeferenced, monochromatic aerial photographs were available for earlier periods but these proved extremely difficult to use.
- Digitising information from the maps is time consuming, and should be kept to a minimum. On the upside though it only needs to be done once for each catchment, and yields information that is either difficult or costly to derive in another manner. The data from this project are available from Southern Waters Ecological Research and Consulting cc (www.southernwaters.co.za).
- The periods for which maps were available were patchy and it was difficult to choose periods where there was complete coverage of the catchment. The resultant information was clumpy and difficult to pare down to smaller sub-catchments.
- Maps and aerial photographs were readily available from the 1970s.

3.3 Rainfall and hydrology

The flow regime is the pattern and timing of high and low flows in a river. Each river's flow regime is different, depending on the characteristics of its catchment and the local climate; although regional trends do emerge (McMahon 198, Poff *et al.* 1997, Ractcliffe 2009). The flow regime is regarded as the driver of river character because, to a large extent, it determines the nature of the river channel, sediments, water quality and the life these support (Poff and Ward 1989, Poff *et al.* 1997, Bunn and Arthington 2002; Figure 3.6). The different "parts" of the flow regime, including its variability, together contribute to the overall maintenance of the river, and all can be considered important (King *et al.* 2003).

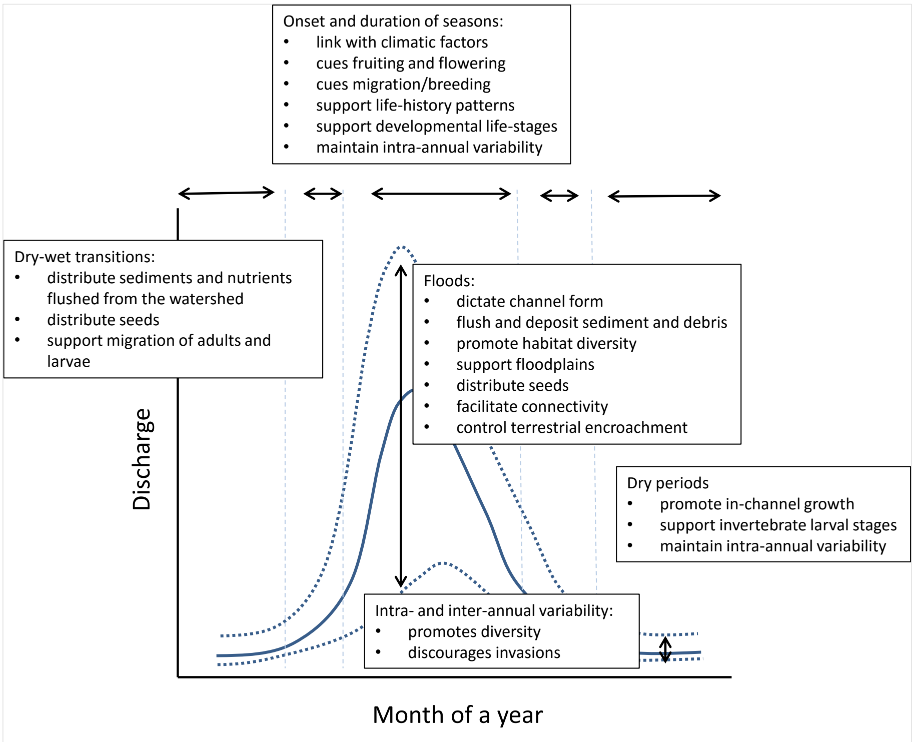


Figure 3.6 The importance of different parts of the flow regime (after Poff *et al.* 1997; Bunn and Arthington 2002)

Water resource developments and landuse changes affect rivers' flow regimes, water chemistry and sediment and temperature regimes and, as a knock-on effect, their fauna and flora (Poff *et al.* 1997, Bunn and Arthington 2002, King *et al.* 2003). These changes also affect the people living near to and/or dependent on rivers.

There are numerous methods employed worldwide to distinguish ecologically relevant aspects of the flow regime in a flow record. Possibly the most used are Indicators of Hydrologic Alteration (IHA, Richter *et al.* 1996), developed by The Nature Conservancy, and Downstream

Response to Imposed Flow Transformation (DRIFT), developed by Southern Waters (King *et al.* 2003, Brown *et al.* 2013). IHA recognises that hydrological data it is not always presented in ways that have ecological meaning, but it can be used to characterise the flow regime of a river in a biologically relevant way and compares this to the human-induced changes in the flow regime caused by dams, landuse changes, diversions and similar. DRIFT is an interactive, scenario-based approach for setting project, basin or regional environmental flows (E-Flows), which includes a hydrological analysis module that characterises and summarises long-term daily flow hydrological time series in terms of the parts of the flow regime recognised in Figure 3.6.

The overarching aim of this section was to identify changes in the Berg River flow regime over time and to identify, if and where possible, the cause(s) thereof. It was expected that:

- Landuse and water resource developments in the Berg River Catchment have affected the volume and distribution of flows in the Berg River.
- The effects of landuse change on the flow regime could be isolated from changes due to large impoundments and water resource schemes (e.g., the Theewaterskloof-Berg Scheme, the Berg River Dam, Voëlvlei Dam and Misverstand Dam).

3.3.1 Water resource developments in the Berg River Catchment

Several water resource development schemes have been implemented over the years that have altered the flows in the Berg River. Early water management schemes included engineering interventions at the river mouth and diversions and weirs for water supply. For example, as early as 1852, a transfer of water from the Witte River via a furrow to the Kromme River was implemented ("Gawie se Water"), and the damming of Voëlvlei first began some decades later (DWAF 2004).

From 1950 onwards various large-scale engineering works and dams were developed, which became part of the Western Cape Water Supply System (WCWSS; DWS, 2014; Table 3.4). In the 1950s, Wemmershoek Dam, 58 million cubic metres (MCM), and the seasonal wetland storage scheme at Voëlvlei, were built (Figure 3.7). The capacity of the off-channel Voëlvlei Dam was increased in 1971 (158 MCM) and a few years later Misverstand Dam was built to supply water to farmers and various West Coast urban settlements. In the late 1970s, the Theewaterskloof Dam and its associated transfer tunnels were constructed to link the Riviersonderend catchment with that of the Berg and the Eerste rivers. From November 1980, the Theewaterskloof-Berg River Water Scheme started to supplement dry season flows in the Berg River Catchment (Snaddon and Davies 1998) and at one point, 27% of water was transferred into the catchment from the Breede River (www.fewlbnexus.uct.ac.za, accessed 17 January 2017).

Table 3.4 Major water resource developments in the Berg River Catchment

Impoundment	Date established	Capacity (MCM)	Sub-basin
Theewaterskloof-Berg River Scheme	1979	n/a	Upper foothills
Berg River Dam	2007	127 000	Upper foothills
Wemmershoek Dam	1957	58 644	Lower foothills
Voëlvlei	1953; 1971 increased	158 600	Lowlands
Misverstand	1977	6 400	Lowlands

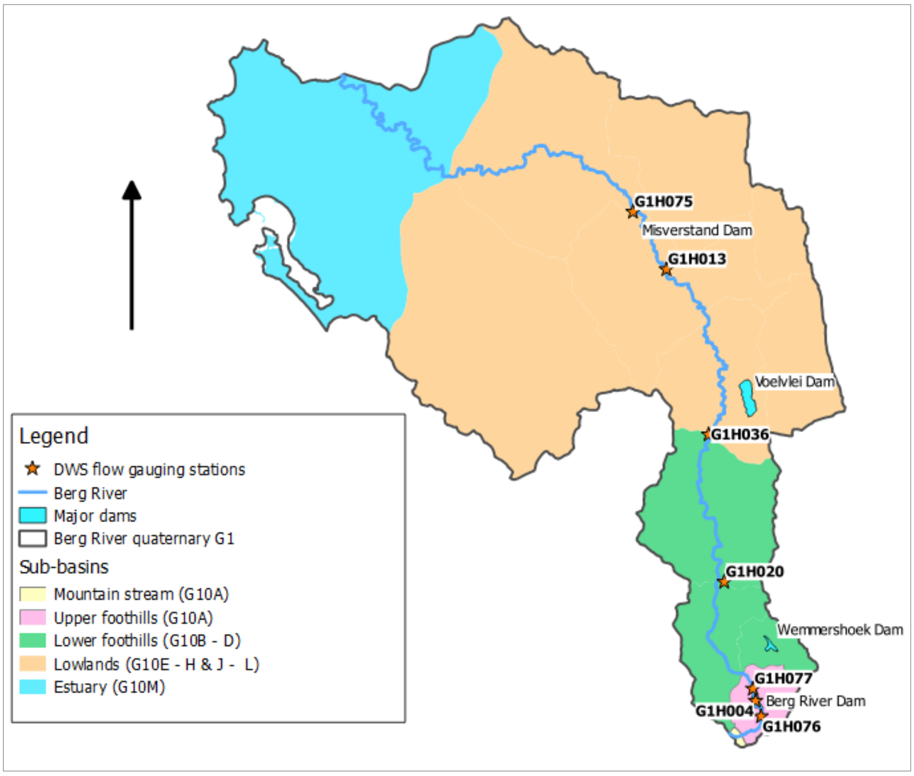


Figure 3.7 Location of DWS flow gauges on the main Berg River that were patched for use in the study

The transfers from the Breede River ceased in *c*. 2007 with the completion of the most recent major water resource development in the catchment, the Berg River Dam and Supplement Scheme (127 MCM; Table 3.4). The transfers result in a complex system to pump water around the Berg catchment and also between adjacent basins. There are also hundreds of smaller impoundments or farm dams (see Section 3.2.2, Figure 3.5) each of which has a small individual impact on flow in the Berg River, although their cumulative impacts could be substantial (e.g. Mantel *et al.* 2010).

3.3.2 Methods

Flow records were constructed from five gauges on the main Berg River (Table 3.5). The location of these gauges is shown in Figure 3.7. Raw data were downloaded from the Department of Water and Sanitation website (http://www.dwaf.gov.za/hydrology/). Note that gauges G1H004, G1H076 and G1H077 form a set. G1H004 was discontinued in 2007 when it was flooded by the Berg River Dam. In 2008, it was replaced by G1H076 (upstream of the full supply level of the Berg River Dam) and G1H077 (downstream of the Berg River Dam). Data from G1H077 were thus added to those from G1H004 in order to analyse a full period from 1949 to 2016 (and referred to as G1H004-77). Data from G1H076 were not used in any analyses since all the Ecological Reserve sites are located downstream of the Berg River Dam.

Table 3.5 Hydrological gauges on the main Berg River with hydrological records sufficiently long enough for use in the analysis of ecologically relevant flow indicators

Number	Reserve site	Location	Upstream area (km^2)	Coordinates S	Coordinates E	Start date	End date
G1H004	IFR 1/96	Bergriviershoek	70	33.92722	19.06083	1949-04-01	2007-05-17
G1H077		Downstream Berg River Dam	83	33.90494	19.05478	2008-05-28	2016-08-31
G1H020		Daljosafat	628	33.70778	18.99111	1966-03-01	2016-12-31
G1H036	IFR 3/96	Vleesbank	1311	33.43500	18.95639	1979-01-01	2013-04-05
G1H013	IFR 4	Drie Heuwels	2936	33.13083	18.86278	1964-12-01	2016-12-31

Gaps in the flow records were patched using either rainfall data or flows from a nearby gauge.

Rainfall data were acquired from the South African Weather Service (SAWS) for three weather stations (Table 3.6). Rainfall data were used to patch some of the flow data and also used in some of the "double mass" plots to determine if changes in flow were linked with changes in rainfall. Gaps in the rainfall data were not patched. For flow-rain relationships, rainfall at Paarl was used for all gauges because this was the longest record and the pattern of rain was similar to the other rainfall stations.

Table 3.6 Rainfall gauges used to patch gaps in the flow records.

Station number	Location	Coordinates S	Coordinates E	Period	Years
SAWS Paarl 1	Paarl (00 21823 0)	-33.721	18.972	1900-2015	115
SAWS Paarl 2	Paarl-TNK (00 21824 2)	-33.733	18.967	1978-1993	15
SAWS Paarl 3	Paarl- (00 21825 4)	-33.75	18.967	1938-1998	60

SAWS = South African Weather Service

Three methods were used for patching the daily hydrological records, depending on the size of the gap and the availability of a reference flow gauge from which to estimate monthly volumes and distributions of daily flow. In brief, the three methods used were:

- Method 1: (for data gaps of less than a month; reference flow gauge available). The volume and distribution of flow in the gauge with missing data were estimated by comparison with those from the gauge used for patching, based on the relative sizes of their Mean Annual Runoff (MAR).

- Method 2: (for data gaps of more than a month; reference flow gauge available). The missing volume was estimated using regressions developed for the gauge with missing data, and either another flow gauge, or a rainfall gauge (or an average of the two estimates).
- Method 3: (for data gaps of more than a month; reference flow gauge not available). The missing volume was estimated using a regression relationship with rainfall, and apportioned using an "average" distribution of flow for wet or dry months for that flow gauge.

The type of gap (a couple of days to months) determined the method of patching to be used; therefore more than one method could be used on one gauge. An example of how gauge G1H004 was patched using different flow gauges and rainfall for all three methods is given below. A WRC project on patching hydrology provides further guidance (Herold *et al.* 2016).

Table 3.7 Flow gauges that were used for patching missing data

Zone	Gauge with missing data	Gauges used for patching
Upper foothills	G1H004 and G1H004-77	G1H003, G1H020 and SAWS Paarl 1
Lower foothills	G1H020	G1H004, G1H036 and SAWS Paarl 1
	G1H036	G1H020, G1H004 and SAWS Paarl 1
Lowlands	G1H013	G1H003, G1H020 and SAWS Paarl 1
	G1H075	G1H013

Example: G1H004 (inundated by Berg River Dam, replaced by G1H004-77)

Missing data were patched using other flow gauges and rainfall. Before a nearby flow or rainfall gauge could be regarded as suitable for patching, regressions were used to test for relationships between the two. In some cases, different regression relationships were used for different periods. For G1H004-77, appropriate reference flow gauges were G1H003 and G1H020 and rainfall from SAWS Paarl 1 (Figure 3.8 to Figure 3.10).

For Methods 1 and 2, there were numerous gaps between February 1951 and January 1960. G1H003 was used for the earlier period (up until March 1966), based on the relationships in Figure 3.8, after which G1H020 was used for patching where possible (based on the relationships in Figure 3.9).

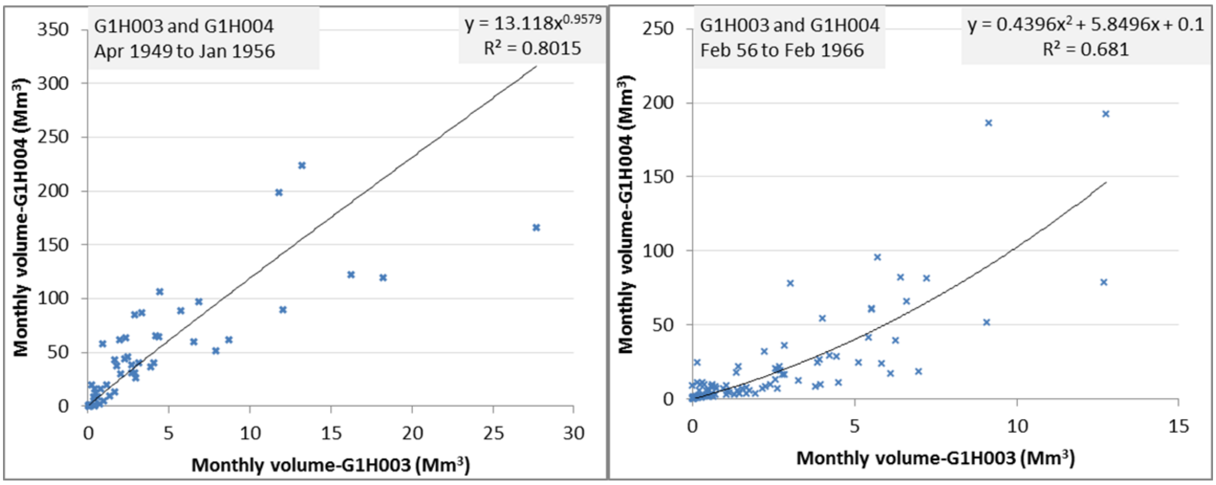


Figure 3.8 The relationship between flow at G1H004 and G1H003 for patching Method 1 or 2, for the period April 1949 to January 1956 (left) and for the period February 1956 to February 1966 (right)

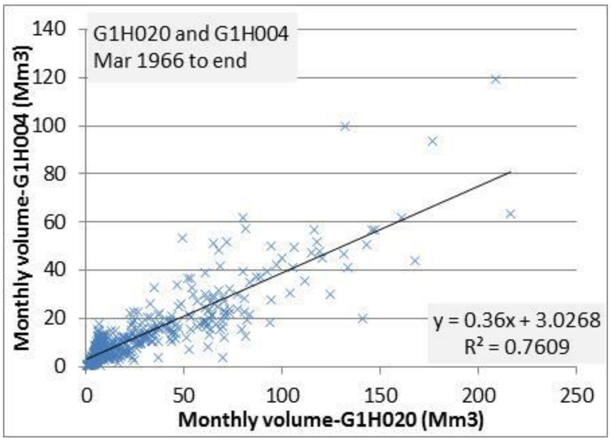


Figure 3.9 The relationship between flow at G1H004 and G1H020 for patching Method 1 or 2, for the period March 1966 to the end of G1H004's flow record (30 April 2007)

Relationships with rain gauge SAWS Paarl 1 [0021823 0] were used for periods with longer gaps: June 1952 to May 1954 (762 days missing), January 1957 and March 1959 (full month missing). For periods when patching Method 3 was used (June 1952 to May 1954; January 1957; March 1959), the relationship $y = 0.5837\ x + 0.5$ was used. This relationship was from the data from April 1949 to May 1955 (Figure 3.10, left), but the equation was also used for January 1957 and March 1959. When a relationship was fitted for the period April 1949 to December 1959 (i.e. extending the end of the regression from 1955 to 1959), the R^2 was much lower (Figure 3.10, right), and the relationship was not used. Only the relationship on the left was applied. After 1959 the relationship was even weaker (not shown).

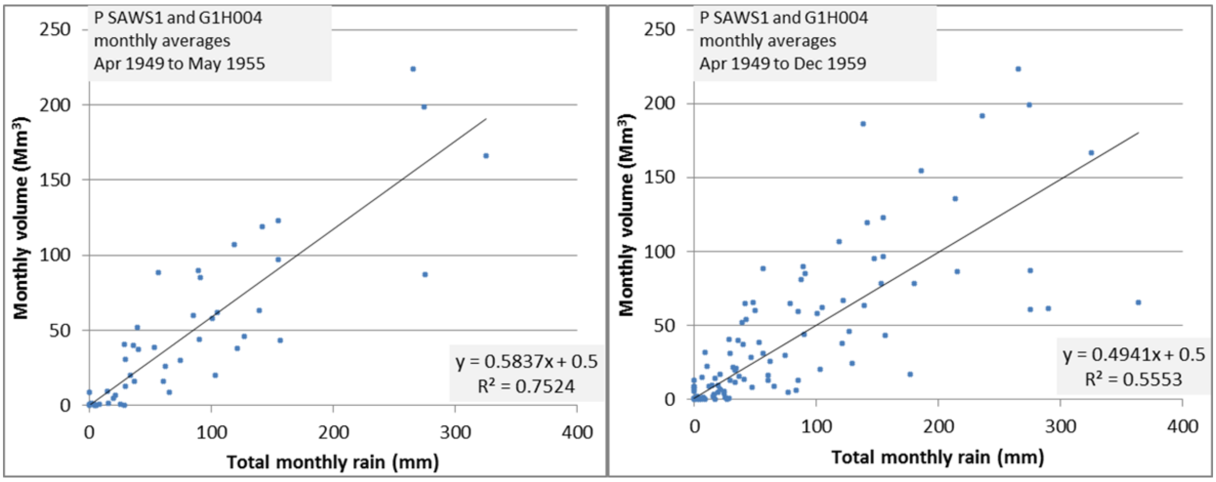


Figure 3.10 Relationship between rainfall and flow at G1H004 for patching Method 3 for the period 1949 to 1955 (left). The relationship extended to December 1959 (right).

The extensive data gap from 1 June 1952 to 31 May 1954 was patched using Method 3: Rainfall was used to estimate monthly volume and an "average" shape applied to distribute it. The daily volume for the period from 1951 to 1954, which includes this gap together with the data patched using Method 3, is shown in Figure 3.11.

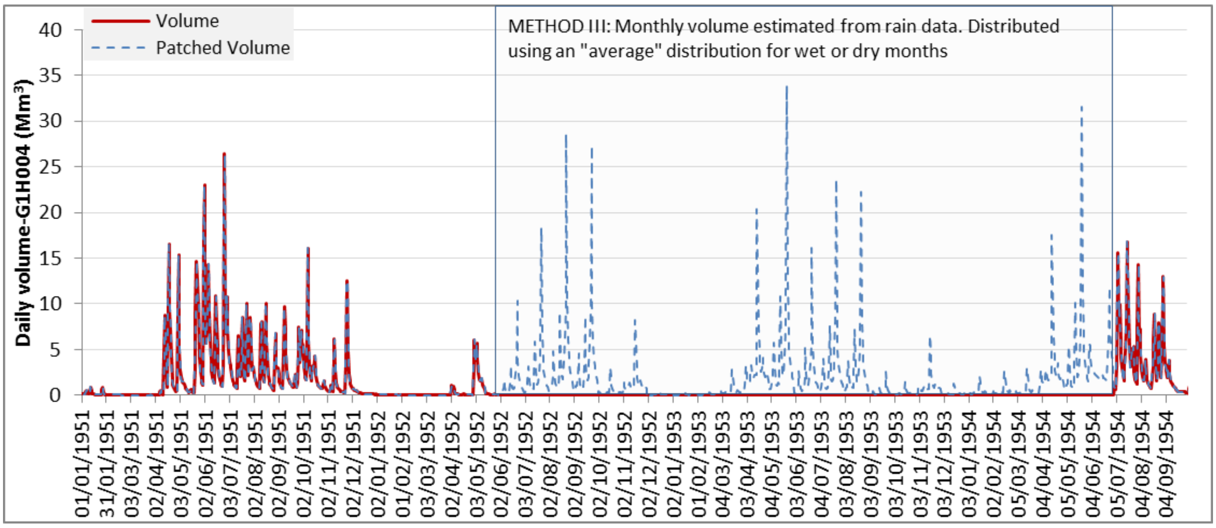


Figure 3.11 Daily hydrograph for G1H004 showing an extended data gap from 1 June 1952 to 31 May 1954 which was patched using Method 3

After data sets were patched, the daily flow time series was imported into the DRIFT software. In DRIFT, a set of ecologically relevant flow indicators (after King *et al.* 2003, Brown *et al.* 2013; Table 3.8) was calculated for each gauge. Note that in DRIFT, indicators are calculated according to four seasons: the dry season (d) the wet or flood season (w or f), the transition season between dry and wet seasons (T1), and the transition season after the wet season (T2).

DRIFT characterises flow in terms of the:

- pattern of flow: the timing (onset) and duration of wet, dry and transitional seasons;
- magnitude of flows: minimum dry season flow, maximum flood season flow, and average flows for each season;
- high flows: For "flashy" flow regimes, such as those characteristic of the Western Cape rivers, higher flows or peak events are allocated to one of eight flood classes and frequencies calculated:
    - Four intra-annual floods (Class 1, Class 2, Class 3, and Class 4)
    - Four inter-annual floods with return periods of 2 (Class 5), 5 (Class 6), 10 (Class 7) and 20 (Class 8) years.

Table 3.8 Examples of the ecologically relevant flow indicators calculated in this study

Flow indicator	Code	Units
Mean annual runoff	MAR	MCM
Dry season onset	Do	Calendar week
Dry season duration	Dd	Days
Dry season minimum flow (taken from 5-day running average)	Dq	m^3/s
Dry season average daily volume	Ddv	MCM
Flood season onset	Fo	Calendar week
Flood season peak (taken from 5-day running average)	Fq	m^3/s
Flood season average daily volume	Fdv	MCM
Flood season volume	Fv	MCM
Flood season duration (days)	Fd	Days
Number of intra-annual floods (Class 1, Class 2, Class 3, and Class 4) in the wet season[1]	C1w, C2w, C3w, C4w	Number per annum
Number of inter-annual floods with a return periods of 2, 5, 10 and 20 years	C5, C6, C7, C8	Number per annum

1. Note that the numbers of these floods are also calculated for the Dry, T1 and T2 seasons

The Berg River flow regime is "flashy" (James and King 2010), so flood events were separated from the daily average flow record using tools provided in the DRIFT Decision Support System (Brown *et al.* 2013). In this DRIFT module, flood events are selected manually, by marking the beginning and end of each event. The software separates all the marked high flows from the low flows and then categorises the floods according to eight size classes for inter- and intra-annual floods. In order to do this, the DRIFT software calculates the 1:2 year flood size (as well as the other inter-annual floods), and then calculates the size of the Class 4 (C4) flood (the largest intra-annual flood) by halving the 1:2 year flood (as halving the magnitude of an event results, in general terms, in a significant change in the sediment-moving power of the flood (Brown *et al.* 2013). The C3 flood size is calculated by halving the size of the C4 flood, and so on, down to C1.

DRIFT flow indicators were only analysed for the Berg River mainstem gauges with more than 10 years of flow data. These were: G1H004 (together with G1H077) in the upper foothills, G1H020 and G1H036 in the lower foothills, and G1H013 in the lowlands. These were analysed for changes over time and then compared with landuse and other changes in the catchment to identify possible reasons for these changes. Since the results are somewhat repetitive, the results from the analysis of G1H036, at IFR site 3 Hermon, are provided in this report as illustrative examples. The same results for the other gauges are not shown but the findings from the results using the other gauges are also described in the conclusions made.

"Double mass" plots are used to identify changes in the relationship between two sets of data over time. A double mass plot shows the cumulative values of one variable versus the cumulative values of another (e.g. daily, monthly, or annual flows). The cumulative data from the two sets of data were plotted against each other. If the relationship remained constant, or the gauge remains accurate, the points would plot in a straight line. If the relationship changed the slope of the line changes (although small deviations above and below the line are expected). Changes in the slope (i.e. inflection points) of the double mass curve indicate a change in relationship between variables; changes may be due to local conditions, measuring techniques or instrumentation at one location that are not experienced at the other (Searcy and Hardison, 1960).

The timing of temporal changes in DRIFT flow indicators were identified using double mass plots to identify inflection points showing changes in the relationships between MAR and various DRIFT indicators, and between MAR and rainfall. In this study, inflections points could indicate:

- a change in landuse affecting flow at a particular flow gauge;
- a change in water resource developments affecting flow; or
- that one or other gauge had (i) changed function; or (ii) had an error.

Time series graphs were created showing the years of change in DRIFT flow indicators identified using the double mass plots, the (three-year) dry season average flow, time periods during which large changes in landuse occurred and the number of farm dams changed (from Section 3.2.2).

These data were generated for the flow records from the five hydrological gauging stations situated in the vicinity of the four Ecological Reserve river sites on the Berg River (Table 3.5) and are available from Southern Waters Eological Research and Consulting cc (www.southernwaters.co.za). Since these results are somewhat repetitive an example of the analytical results for one of the gauging stations, G1H036 situated at Hermon at the Ecological Reserve study site IFR 3/96, is given in the results that follow.

3.3.3 Results

The estimated 2017 MAR and the naturalised and historical MARs (Ractliffe 2009) from the five hydrological gauges are provided in Table 3.9.

Table 3.9 Naturalised and historical MAR (Ractliffe 2009) and historical MAR from this study. Units in MCM

Gauge number	Berg River Reserve Site	Ractliffe (2009)		This study
		Naturalised MAR	Historical MAR for 1980–2004	Historical MAR (patched data)
		MCM/annum		
G1H004		135	162	149
G1H004-77	IFR 1/96	n/a	n/a	142
G1H020		413	303	334
G1H036	IFR 3/96	521	391	339
G1H013	IFR 4	817	572	548

3.3.3.1 Time series plots

Examples of these time series plots for data recorded at G1H036 are given in MAR = Mean Annual Runoff, Do = dry season onset, Dd = dry season duration, Dq = dry season average discharge, Fo = flood season onset, Fq = flood season average discharge, Fv = flood volume, Fd = flood season duration, Ddv = dry season daily average volume, Fdv = flood season daily average volume, C1-C5 = the number of class 1-5 floods.

Significant (Sign.) trends are indicated at $p < 0.05$. Units are given in Table 3.8

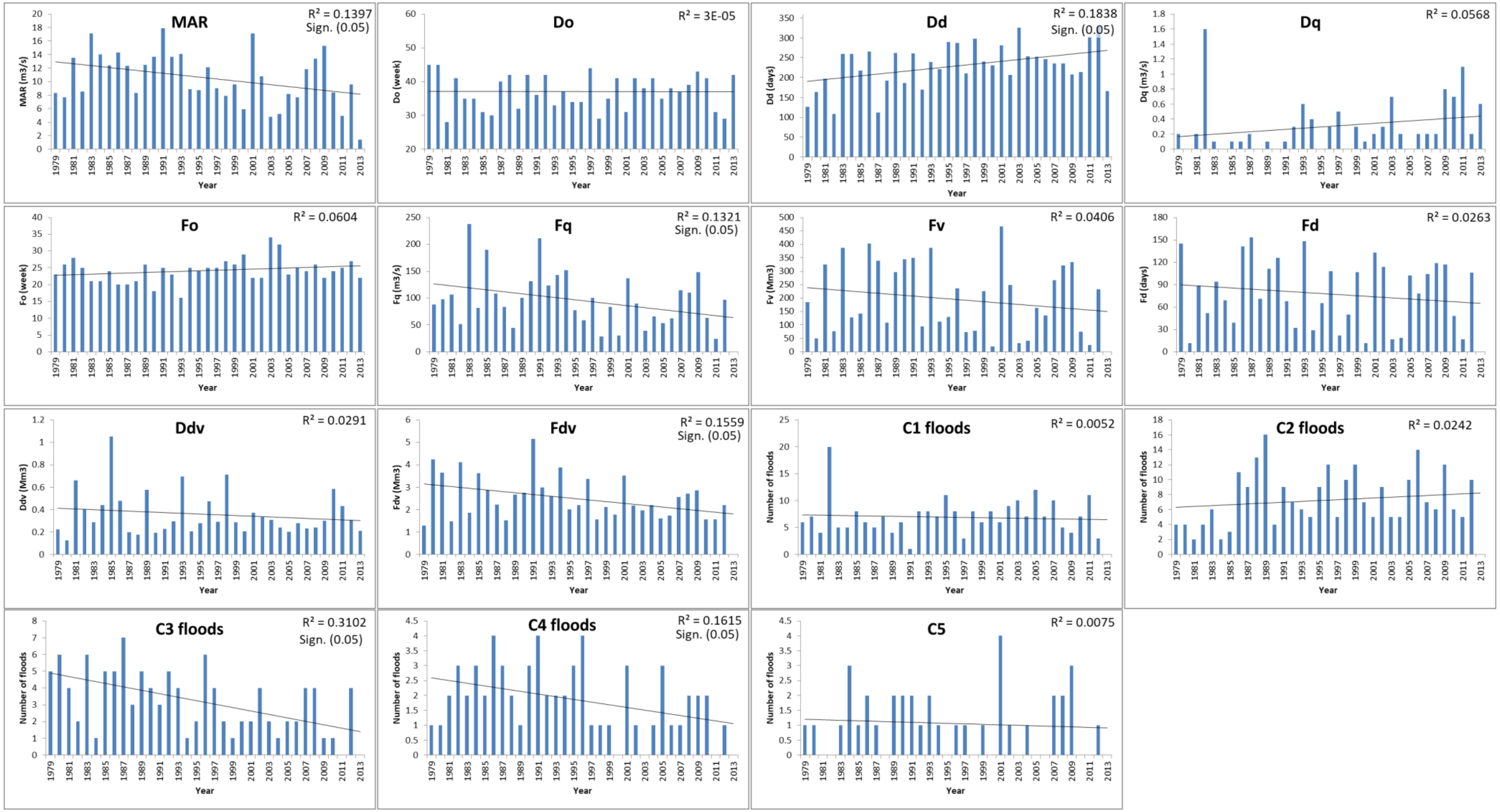
Figure 3.12. In general, the changes were more marked at the gauges downstream, and most marked at G1H036; and the trends were towards increased dry season flows and decreased wet season flows. For example, it is clear that discharge in the dry season increased and the number of Class 3 floods decreased through Paarl at G1H020 due to the release of water from, and the capturing of floods by, the Berg River Dam to meet the irrigation demand downstream. These effects are also shown by the reduction in daily flood volume recorded downstream of the Berg River Dam at G1H0044_7 (IFR 1/96) and at Hermon at G1H036 (IFR 3/96), and a decrease in numbers of Class 3 and 4 floods, downstream of the Berg River Dam, and Class 5 floods at Hermon. These irrigation releases also lengthen the duration of the dry season recorded at Misverstand Dam at G1H013 (IFR 4).

3.3.3.2 Double mass plots

Two main types of double mass plot were used:

- Double mass plots of cumulative MAR against cumulative rain. Inflection points in these would indicate changes in the relationship between rainfall and flow, which could be due to changes in landuse or water resource developments.
- Double mass plots of cumulative MAR against cumulative values for DRIFT indicators. Inflection points in these indicate changes in the relationship between MAR and other ecologically relevant characteristics of the flow regime. These might arise if flow were

stored in an impoundment in the wet season and released in the dry season, but could also result from landuse changes.



MAR = Mean Annual Runoff, Do = dry season onset, Dd = dry season duration, Dq = dry season average discharge, Fo = flood season onset, Fq = flood season average discharge, Fv = flood volume, Fd = flood season duration, Ddv = dry season daily average volume, Fdv = flood season daily average volume, C1-C5 = the number of class 1-5 floods.

Significant (Sign.) trends are indicated at $p < 0.05$. Units are given in Table 3.8

Figure 3.12 Changes in the DRIFT flow indicators calculated from the data from G1H036

For MAR-DRIFT indicator plots, six DRIFT indicators were used: dry season onset (Do), dry season duration (Dd), dry season five-day average volume (Ddv), wet season onset (Fo), wet season duration (Fd) and wet season average daily volume (Fdv), as these were considered the more robust indicators. Examples of these double mass plots for data recorded at G1H036 are given in Figure 3.13.

Using this example, inflection points are clearly evident in onset of the dry season (Do), duration of the dry season (Dd), onset of the flood season (Fo), the number of Class 1 floods (C1), the number of Class 2 floods (C2) and the number of Class 5 floods (C5), suggesting changes in the timing of flows independent of changes in MAR.

These plots are also useful to identify the *timing* of the changes identified in the trends analysis. For instance, an inflection point occurs in most of the 1982/1983 years, after the inter-basin transfers into the Berg River were initiated from Theewaterskloof Dam, and others around 1990/1991, when there was a large increase in the number of farm dams.

3.3.3.3 t-tests

Table 3.10 provides the averages for the flow indicators at G1H036 for the different periods assessed, and indicates where these were different from one another ($p < 0.1$). While there were some significant changes in individual indicators for the other periods, the main differences were higher dry and lower wet season flows from 1979–1982 to 1983–1987 and from 1988–1992 to 1993–2006 (Table 3.10).

Changes in the timing of flow and rainfall were compared with changes in landuse graphically by plotting the 3-year dry season average daily volume (brown), rainfall (blue), extent of agricultural land (red) and number of farm dams (blue) at G1H036 (Figure 3.14).

Dry season average daily volume at G1H036 fluctuated over the duration of the record, increasing after inter-basin transfers (IBT) began from Theewaterskloof, decreasing again in the early 2000s in response to drier conditions, increasing again after flow releases began from the Berg River Dam, before decreasing again in response to severe water shortages resulting from the drought in 2016/17 (Figure 3.14).

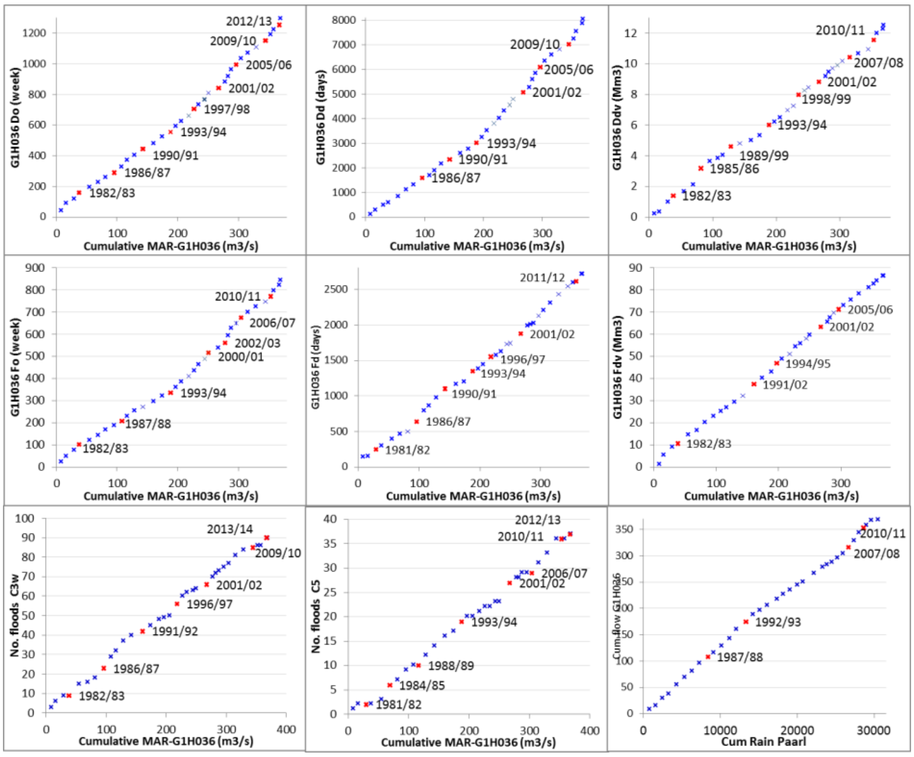


Figure 3.13 **Double mass plots of mean annual runoff (MAR) at G1H036 MAR vs. dry season onset (Do), dry season duration (Dd), daily average volume in the dry season (Ddv), flood season onset (Fo), flood season duration (Fd), daily average volume in the flood season (Fdv), the number of Class 2 (C2) and 3 (C3) floods in the wet season, and the flow-rain relationship. Red crosses indicate inflection points along the line of data being compared (blue crosses). Units are given in Table 3.8.**

Table 3.10 **Averages of flow indicators at G1H036 in different periods. Highlighted values show where values are significantly different from the *following* period ($p < 0.1$). Units are given in Table 3.8.**

	1979–1982	1983–1987	1988–1992	1993–2006	2007–2013
MAR	9.50	14.02	13.22	9.28	9.26
Do	39.75	34.20	38.80	36.50	37.43
Dd	149.00	222.40	214.20	255.79	241.57
Dq	0.50	0.10	0.10	0.27	0.54c
Ddv	0.35	0.49	0.29	0.35	0.33
Fo	25.50	21.20	22.60	25.36	24.29
Fq	86.00	140.40	122.04	80.14	79.66
Fv	159.50	279.40	239.00	168.21	179.00
Fd	74.50	99.20	81.60	71.71	73.00
T1dv	0.84	2.82	1.61	1.31	1.01
Fdv	2.66	2.93	3.01	2.34	1.92
C1w	3.50	1.60	2.20	3.07	2.43
C2w	2.50	4.20	5.20	6.50	5.86
C3w	2.25	4.00	3.20	2.29	1.86
C4w	1.25	2.20	2.00	1.36	0.86
C5	0.50	1.60	1.40	0.86	1.14
Rain	830.23	1014.58	981.42	905.32	659.17

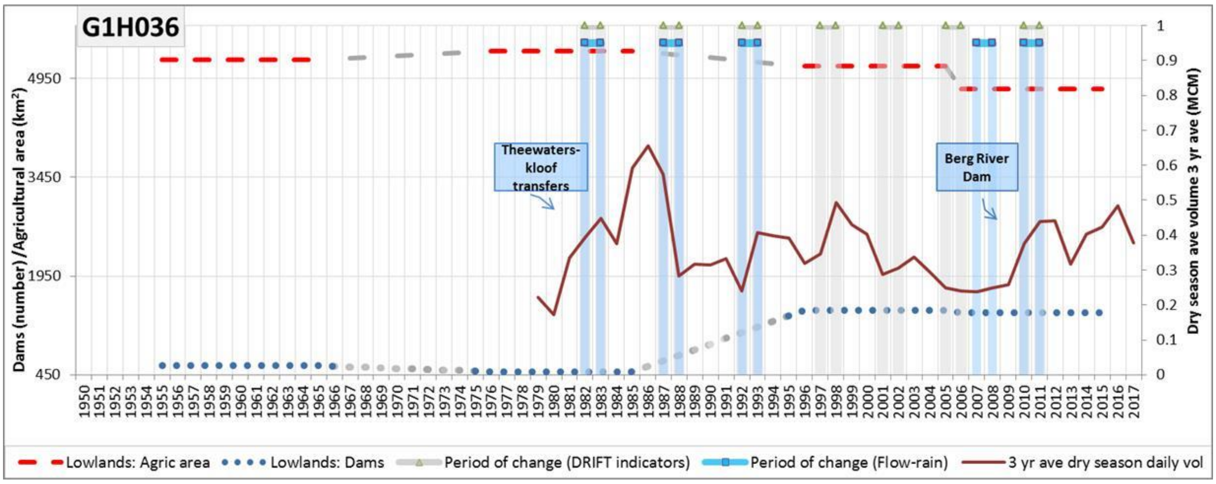


Figure 3.14 Three-year dry season average daily volume (brown), rainfall (blue), extent of agricultural land (red) and number of farm dams (blue) at G1H036

The effects of the Theewaterskloof-Berg River Scheme could not be tested at G1H036 as the data record starts in 1979, one year before the start of the transfers. Comparing flow indicators six years before and after the Berg River Dam closed (in 2007) showed that the dry season minimum discharge (Dq) doubled when there were no differences in MAR or rainfall (Table 3.11).

Table 3.11 Averages of DRIFT indicators before and after the Theewaterskloof-Berg Scheme and the Berg River Dam at G1H036. Highlighted values are different (p< 0.1). Units are described in Table 3.8

	Berg River Dam	
	Before	**After**
	2002-2007	2008-2013
MAR	8.08	8.83
Do	38.33	37.50
Dd	253.50	242.50
Dq	0.27	0.60
Fo	26.67	24.33
Fq	70.85	73.83
Fv	148.00	164.50
Fd	72.33	67.83
Ddv	0.27	0.35
T1dv	1.28	0.94
Fdv	2.04	1.81
C1w	3.67	2.33
C2w	6.33	5.83
C3w	2.50	1.50
C4w	1.17	0.83
C5	0.67	1.00
Rain	733.93	656.07

3.3.4 Conclusion

The hydrology of the Berg River has changed over the last 200 years, but reliable records of instream flow are only available for the last 50 years. The fluctuations in flow early in the records are more closely correlated with rainfall than those later in the record, which tend to be delinked from rainfall, and thus are likely attributable to anthropogenic impacts related to, for instance, landuse and water resource developments. Linking changes in flow to landuse was complicated because the periods used for landuse were slightly different from those identified hydrologically and because each flow gauge had a different record length. This meant that it was difficult to distinguish the direct effects of modified flow regimes from impacts associated with landuse change that often accompany water resource development. Despite this, changes in the recorded flows can be attributed to farms dams, given that in all sub-catchments the number of small dams increased over time, with the highest increase shown around the mid 90s, rather than changes in vegetation or urbanisation since the area under cultivation has reduced while the area of fallow and “natural” vegetation has increased. This seems counterintuitive but probably relates to the trend in the purchase of agricultural lands for lifestyle farms and the use of more water to maintain and run farms where aesthetics are the most important feature, and the changes in crop type described in Section 3.2.2.

The hydrological records clearly show changes to the pattern and volume of flows in the Berg River due to the Theewaterskloof-Berg Scheme and the Berg River Dam. These included an increase in discharge and daily volume in the dry season, delayed onset of the flood season, a decrease in discharge and daily volume in the wet season and a reduction in the number of intra-annual floods. The changes are in line with the release of irrigation flows in the summer dry season, and the attenuation and storage of wet season, winter flows. These changes are noticeable down the whole length of the Berg River as a result of the effects of distance, attenuation and contributions from incremental catchments, but also because of the manipulation of flows for irrigation supply.

3.3.5 Lessons learnt

The daily river flows that are measured at the gauging stations are different from the modelled natural and “present day” flow records used in Reserve, Classification and RQO projects, which do not include any trends and are often at a monthly time-step. The hydrological analysis for the Berg River data demonstrated the value of using observed daily flow records. The measured data, and the trends that they indicate, are essential for understanding changes in the flow regime that have taken place over time as a result of activities in a catchment, such as the indirect effects of landuse, or the direct effects of abstractions and releases, or influences beyond the catchment, such as climate change. They are also required for estimating whether the flow regime associated with the Ecological Reserve at a particular site is being met or not (see Section 4.1).

Importantly, many of the historical hydrological changes in the Berg River were delinked from MAR, and involved changes in timing of flows but no change in MAR; others involved increases in MAR as a result of IBTs.

In summary, the lessons learnt were:

- The observed daily flow records had extensive gaps that needed to be patched. This exercise was time consuming and technically difficult but was necessary before the analysis of trends and changes could be undertaken.
- Rainfall and tributary hydrological records were essential for patching the mainstem time series.
- Once patched, the measured data, and the trends that they indicate, were essential for understanding changes in the flow regime that have taken place over time as a result of activities in the Berg River, although establishing cause and effect was difficult.
- Calculation of ecologically relevant summary statistics enhanced understanding of the volumetric and temporal changes that have taken place, and allowed for comparison between conditions in the river and predictions made during Reserve studies.
- Time series plots were useful for identifying general trends but double mass plots and t-tests were needed for determining the timing of changes, the significance of the changes and the possible reason for the change.
- The historical landuse and development data gathered and assessed were useful for inferring and understanding cause and effect; although this was complicated by the non-alignment of the dates for which different sorts of information were available.

3.4 Channel structure and riparian vegetation

The natural variability of factors that control channel morphology, such as a river's prevailing discharge and sediment load (Leopold and Wolman 1960, Beck and Basson 2003), means that a river channel is never completely stable but rather continually strives to reach a balance between the amount of sediment supplied to the system and the capacity of the system to transport that sediment (Mueller and Pitlick 2005). This occurs through subtle changes in cross-sectional area, channel slope and pattern to uphold an optimal transport of the flow and sediments supplied from the incremental catchment upstream. River reaches are considered to be in equilibrium when this balance is achieved. In the equilibrium condition river characteristics, such as discharge, sediment supply, channel width and depth, are mutually interdependent, meaning that a change in any one parameter requires a response in one or more of the others. In reality, however, once a river reaches this equilibrium state, major changes in channel planform tend to occur only in response to significant events, such as a large flood or a major disruption in the flow and sediment regime, such as when a dam is constructed upstream, or as a result of direct interventions, such as bulldozing of its banks or bed, and/or removal of the riparian vegetation (Beck and Basson 2003). Apart from the latter, a river's response to changes in flow and sediment tends to be some form of incision, channel widening or channel narrowing (Schumm 1963). Structural change can be the result of a more straightened course imposed on the river through landuse and channel management activities, or a channel response to other adjustment processes such as narrowing and widening.

Although river channels and their riparian vegetation occupy a relatively small area in the landscape, they provide irreplaceable ecosystem functions and services (Gregory *et al.* 1991, Naiman and Decamps 1997, Merritt and Wohl 2002). Healthy riparian areas help to maintain channel form by binding soils and strengthening rivers banks (Thorne 1990). The presence of trees and shrubs reduces flow velocity leading to deposition of fine sediments and seeds in these areas (King *et al.* 2003), which helps to create sandbanks and bars. Riparian vegetation also protects river banks and channel beds by buffering against sediments, fertilisers, pesticides and other matter draining into the river from the surrounding catchment (Dosskey *et al.* 2010). The removal of, or a change in, riparian vegetation can expose the channel and riparian area to erosion; this could initiate changes in channel structure and shape (Davies-Colley *et al.* 2009).

Channel changes can be quantified by measuring a set of channel characteristics, such as width and depth, before and after changes took place (Gregory 2006). Historical images and maps are important in the study of channel change since they contain precise information on the position and characteristics of river courses at particular moments in time (David *et al.* 2016). However, methods currently in use are limited by a series of challenges that must be overcome to avoid scaling errors (Hooke and Redmond 1989). The most common problems are: (i) the information is from an overhead perspective, (ii) images and maps usually lack coordinates, and (iii) scales and coverage often vary between one section of a river and another, and also between the years when taken (David *et al.* 2016). Despite the many associated problems, historical information continues to be of use when reconstructing changes in a river's structure and shape (Gurnell *et al.* 1994, Leys and Werritty 1999, Galster *et al.* 2008, Clerici *et al.* 2015, Lauer *et al.* 2017).

This objective of this study was to identify and assess historical changes in the structure and shape of the Berg River channel, the nature and extent of the riparian area and the floodplain. Since changes in landuse and flow were different in different parts of the catchment, Berg River reaches in different sub-catchments were expected to have undergone different historical paths of change. It was also expected that the nature and extent of the features of the tributaries would differ from one another and also differ from those of the Berg River since the flow regime of, and surrounding landuse along, each tributary differed. Therefore, a secondary objective was to link the observed changes with changes in landuse (Section 3.2) and or flow (Section 3.3). It was expected that:

- In general, the changes that occur in river planform as a result of development will tend towards narrower systems with less habitat diversity.
- Different land-uses affect the riparian area and river channel structure in different ways.

3.4.1 Methods

The original intention was to resurvey historical cross-sections so that historical and more recent channel shapes could be compared, but this was not possible because the old benchmarks could not be located. Considerable effort was spent in the field trying to locate the benchmarks set during the Reserve studies (DWAF 1996, DWAF 2002) and/or the cross-section used for the Berg River Baseline Monitoring report (BRBM; Ractliffe *et al.* 2007) using a GPS. These historical cross-sections comprised a set of 130 pins, and of these only 12 were found. It takes 3 survey pins to accurately align a theodolite along a line-of-sight and there was only one survey pin found at any one of the cross-sections so these could not be relocated.

Thus, a different approach was adopted, which used historical aerial photographs and aerial images captured from GoogleEarthPro©[7]. This was also not without its challenges since most flight plans along which aerial photographs were taken in the Berg River Catchment only covered a portion of the catchment at one time, and the resolution of many of the aerial photographs viewed was too poor to enable distinguishing features of the channel, riparian and floodplain areas.

Ten reaches were assessed. These were five 6-km reaches along the main stem of the Berg River and five 2-km reaches up the length of adjacent tributaries, from their junction with the Berg River (Table 3.12, Figure 3.15).

Aerial photographs dating back to 1938 were obtained from the local Department of Surveys and Mapping in Cape Town (http://www.dla.gov.za/contact-us/national-geo-spatial-information/37-national-geo-spatial-planning-cape-townmap-sales). The periods assessed were dictated by the availability of imagery for the full suite of reaches. This was relatively simple for 2003 onwards as GoogleEarthPro© imagery provides a full coverage of the catchment.

Table 3.12 Location of study reaches where detailed data on channel shape were collected along the Berg River

Sub-basin	Study reaches	Reach coordinates		Time period assessed		
		Upstream end	Downstream end			
Upper foothills	Berg River downstream of the Berg River Dam (IFR 1/96)	-33.901640°; 19.053351°	-33.877784°; 19.033890°	1938	2004	2017
	Associated tributary: Franschhoek River	-33.890726°; 19.078846°	-33.881875°; 19.044107°	1938	2003	2017
Lower foothills	Berg River between the Wemmershoek and Dwars rivers	-33.841622°; 18.987581°	33.876636°; 19.025552°.	1938	2003	2017
	Associated tributary: Dwars River	-33.864403°;	-33.848988°;	1938	2003	2017

[7] GoogleEarthPro© uses images from many sources, including satellite data and South African NGI aerial photography. If you zoom in to an area, copyright information and sources appear in the bottom centre of each image, e.g. Image (c) 2017 DigitalGlobe (c) AfriGIS (Pty) Ltd. (c) 2017 Google, etc. Imagery Date: m/d/y (USA format). Pers. Comm. Dr Mike Silberbauer (November 2017).

Sub-basin	Study reaches	Reach coordinates		Time period assessed		
		Upstream end	Downstream end			
		18.985792°	18.993653°			
	Berg River upstream of the Hermon road bridge (IFR 3/96)	-33.476677°; 18.938518°	-33.435000°; 18.956239°	1938	2009	2017
	Associated tributary: Doring River	-33.548111°; 18.907751°	-33.541475°; 18.926492°	1938	2009	2017
Lowlands	Berg River upstream of the Twenty-fours River junction (IFR 4)	-33.191918°; 18.934408°	-33.159081°; 18.899872°	1938	2006	2017
	Associated tributary: Twenty-fours River	-33.156382°; 18.972718°	-33.191749°; 18.935737°	1938	2006	2017
	Berg River downstream of Misverstand Dam (IFR 5)	-33.014354°; 18.784943°	-32.972712°; 18.752218°	1938	2006	2017
	Associated tributary: Mooreesbergspruit River	-33.048239°; 18.789970°	-33.032967°; 18.789610°	1938	2006	2017

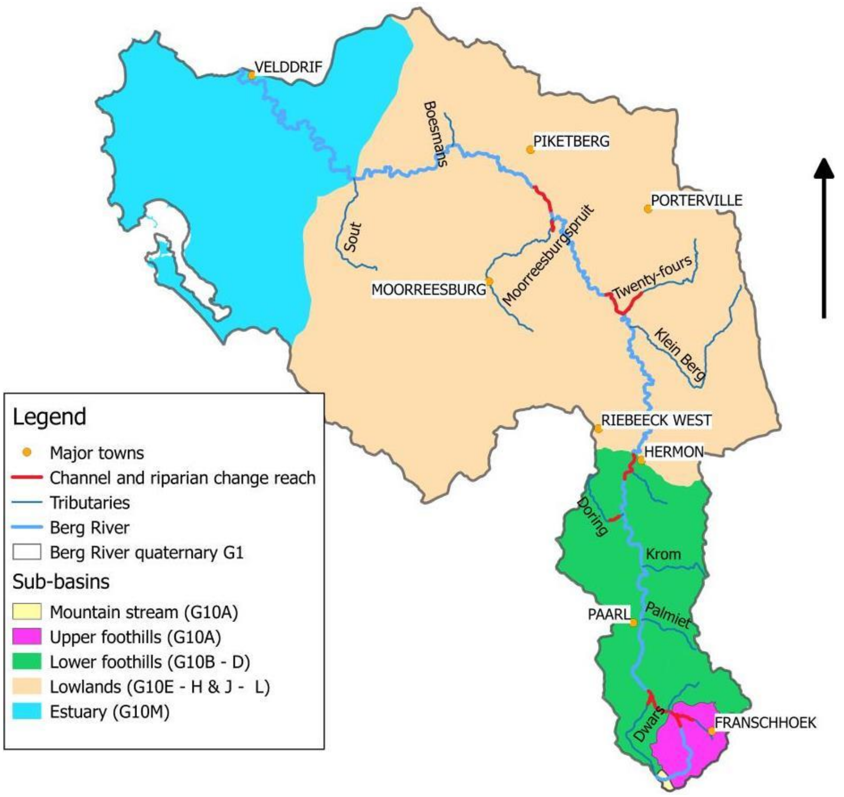


Figure 3.15 The location of the study reaches (red) where data on channel shape were collected along the Berg River and key tributaries in different sub-basins

Prior to this, there were approximately 19 aerial surveys of the Western Cape. Of these, only one (1938) covered the Berg River macro-channel entirely, and a survey in 1978 covered at least 50% of the macro-channel. Three periods were assessed for each site (*viz*: 1938 (aerial images); 2003, 2006 or 2009[8] (GoogleEarthPro©) and 2015 (GoogleEarthPro©). Aerial images covering the five sites were also available for 1978 but the resolution was too poor for mapping riverine features so they could not be used.

Since the aerial photographs were not georeferenced, and to georeference them was not feasible within the time and budget constraints of the project, a method was developed to align and scale the aerial photographs and the GoogleEarthPro© images manually in Power Point, assisted by using recognisable features of the landscape common to and clearly visible in all the images used in the time series. Temane *et al.* (2014) showed that expert knowledge and rapid characterisation of catchments in this way was useful to assess siltation risks and to analyse controlling factors at a larger scale with minimum costs and acceptable accuracy. The method used was:

- measure key areas and lengths for one period in GoogleEarthPro© to establish a scale bar;
- overlay aerial images from all periods onto GoogleEarthPro© images and scale these using easily recognisable features in the landscape, such as roads, bridges and buildings;
- trace features for all periods using Microsoft Power Point and exporting as *.jpeg shapes;
- copy *.jpeg shapes of traced features into Excel and write a script to produce the relative areas and lengths of all the traced features for each time period relative to each other, at each site;
- calculate actual areas and lengths using the proportional differences between time periods and the measured values obtained from GoogleEarthPro©.

The following river features were measured:

- the length of the thalweg[9] and a straight line along the valley length over which the thalweg was measured;
- the area of sand bars in the channel;
- a combination of the river channel and riparian area, and;
- the area of the floodplain.

The following river features were estimated as proportions visually by eye:

- a description of the channel form, from straight, through meandering to braided, with or without riffle/pool sequences (Leopold and Wolman 1960);
- estimates of the extent that grasses, shrubs and trees comprise different proportions of the riparian area;
- estimates of continuity of the riparian area (González del Tánago & de Jalón 2006) in three categories:

---

[8] 2006 and 2009 were chosen to replace 2003 if the resolution of the 2003 data was too poor to discriminate river features.

[9] Thalweg is the point of lowest elevation in the river channel and the length along which flow moves through the channel, most obvious at low flow conditions.

- Extensive, > 75% cover.
- Moderate, 25–75% cover.
- Insignificant, < 25% cover.

Any relevant literature, in this case the Ecological Reserve studies (DWAF 1996, DWAF 2002) and the Berg River Monitoring Programme reports (Ractliffe *et al.* 2007), was used to distinguish tree species from one another at the sites and, in particular, to distinguish indigenous from exotic trees (see summaries in Sections 2.3 and 2.4).

3.4.2 Results

Different sorts of changes were evident in changes to the channel and riparian area, the floodplain, sand bars and channel sinuosity at different sites on the Berg River and tributaries (Table 3.13). For example, the channel and riparian area decreased at all sites from 1938 to 2017 and these reductions were more severe on the Berg River when compared with the tributaries. There were few noticeable changes in the sinuosity of the river at any of the sites. At the scale of measurement, floodplains, if present, were not distinguishable on the narrow tributaries and decreased in in area and number over time on the Berg River with the exception being at IFR 1/96, downstream of the Berg River Dam. The river here, prior to construction of the dam, comprised a wide and braided river channel that changed to a single thread channel with a floodplain by 2017, after the dam became operational in 2007. The number of sand bars also increased here, downstream of the Berg River Dam, as the braided channel aggraded, disconnecting from the river.

At IFR 3/96, Hermon, the channel and riparian area reduced over time and the floodplain was lost between 2003 and 2017, along with the few sand bars historically present.

At IFR 4, upstream of Misverstand Dam, the channel and riparian area reduced over time but was present to a greater extent in 2017, when compared to all the other sites, and sand bars appeared for the first time by 2017.

IFR 5, downstream of Misverstand Dam, showed a small reduction in channel and riparian area but the greatest reduction in sand bars, due to trapping of sediment in the reservoir.

The sub-catchments responded differently as different driving forces were evident at different reaches. The upper foothills (IFR 1/96) demonstrated a loss of channel braiding and an increase in the area of floodplain and sand bars (Figure 3.16).

Conversely, the lower foothills sites, the Berg River between the Wemmershoek and Dwars rivers and IFR 3/96, Hermon, experienced reductions and a loss of floodplains and sand bars respectively. In the lowlands, IFR 4 and 5, there was no floodplain at any time but there was a reduction in the area of sand bars, both upstream and downstream of the reservoir (Figure 3.17).

One other notable change was a reduction in the number of Twenty-fours River channels as the floodplain was cultivated (Figure 3.18).

Different sorts of changes were evident on the tributaries (Table 3.14). There were no floodplains on the Franschhoek, Dwars or Doring rivers. Floodplains were only present on the Twenty-fours River and here they decreased over time. Sandbars were only present in the Twenty-fours and Mooreesburgspruit rivers, but there were no trends. There was no trend in how sinuosity changed but the channel and riparian area decreased at four of the tributaries while at the Mooreesburgspruit River there was a slight increase. Channel braiding was evident in the Doring River and was stable over time whereas the braiding decreased in the Twenty-fours River. The proportion of trees and shrubs decreased as these were replaced by grasses and reeds at four of the tributaries, but not at the Mooresburgspruit River, where trees and shrubs took over from grasses and reeds.

3.4.3 Conclusion

Given the extensive land use changes that had already taken place by 1938 (Section 3.2), it is likely that the planform and riparian vegetation of rivers in the Berg River Catchment were already changed from their natural state by then. Nonetheless, the changes in channel form, habitat diversity and riparian vegetation between then and now (2017) have been extensive. In general, as expected, these changes tend towards narrower systems with less habitat diversity and less protection from the surrounding activities; there was a progressive decline in channel braiding and loss of woody riparian vegetation, and for the most part sandbars and riparian floodplains present in 1938 were lost by 2003. There are some obvious exceptions to this. Changes in the Berg River downstream of the Berg River Dam followed the expected trends between 1938 and 2003, but these were dramatically reversed by 2017. This reversal was the result of extensive investment in rehabilitation of this reach of river following removal of the surrounding plantation forestry and construction of the Berg River Dam. Following restoration, braiding and sinuosity increased and the area covered by the channel and its riparian vegetation increased, although the trees and shrubs failed to recover. Another exception was the Moorreesburgspruit River, which, although single thread over all periods, became slightly more sinuous, sandbanks came and went between periods and the riparian vegetation community shifted from one dominated by reeds and grasses to one dominated by trees and shrubs. The reasons for the Moorreesburgspruit's deviation from the more common trends were not immediately clear.

Table 3.13 Changes in the areal extent of the river channel and riparian area, floodplain and sandbars, measured in km², and river channel sinuosity at five Berg River reaches and five associated tributaries

Reach #		**1**			**2**			**3**			**4**			**5**		
Aspect	**Units**	**Berg River @ Franschhoek (IFR 1/96)**			**Berg River @ Dwars**			**Berg River @ Hermon (IFR3/96)**			**Berg River @ Twenty-fours (IFR 4)**			**Berg River @ Misverstand (IFR 5)**		
		1938	**2003**	**2017**	**1938**	**2003**	**2017**	**1938**	**2003**	**2017**	**1938**	**2006**	**2017**	**1938**	**2006**	**2017**
Sinuosity	Index	1.61	1.25	1.51	1.78	1.59	1.54	1.95	2.09	1.87	1.29	1.30	1.29	1.32	1.35	1.42
Channel and riparian area	km²	1.12	0.73	0.37	0.77	1.04	0.26	1.05	0.86	0.79	2.18	1.69	1.34	0.84	0.77	0.60
Sand bars	km²	0.14	0.14	0.28	0.09	0.07	0.05	0.09	0	0	0.09	01	0.02	0.09	0.03	0.01
Floodplain	km²	0	1.14	1.47	1.21	0.17	0.26	0.31	0.30	0	0	0	0	0	0	0
Braiding	%	90	20	60	50	10	15	50	5	5	5	0	0	90	40	20
Riparian continuity	%	>75	>75	>75	25-75	25-75	<25	25-75	>75	25-75	25-75	25-75	25-75	25-75	25-75	25-75
Trees and shrubs	%	50	40	20	50	65	5	5	90	10	40	70	70	5	30	40
Reeds and grasses	%	50	60	80	50	35	95	95	10	90	60	30	30	95	70	60

Table 3.14 Changes in the percentage of channel braiding, riparian continuity, the proportion of trees, shrubs, reeds and grasses, estimated by eye at five Berg River reaches and five associated tributaries

Reach #	**Units**	**1a**			**2a**			**3a**			**4a**			**5a**		
Aspect		**Franschhoek River**			**Dwars River**			**Doring River**			**Twenty-fours River**			**Moorreesbergspruit**		
		1938	**2003**	**2017**	**1938**	**2003**	**2017**	**1938**	**2003**	**2017**	**1938**	**2006**	**2017**	**1938**	**2006**	**2017**
Sinuosity	Index	1.42	1.33	1.38	1.77	1.69	1.67	1.46	1.42	1.66	1.34	1.13	1.20	1.49	1.65	1.58
Channel and riparian area	km²	0.14	0.07	0.10	0.29	0.25	0.14	0.40	0.35	0.29	1.83	0.80	0.93	0.06	0.06	0.09
Sand bars	km²	0	0	0	0	0	0	0	0	0	0	0.01	0.01	0.01	0	0.01
Floodplain	km²	0	0	0	0	0	0	0	0	0	1.63	0.71	0.81	0	0	0
Braiding	%	0	0	0	20	20	20	0	0	0	85	30	20	0	0	0
Riparian continuity	%	>75	>75	>75	>75	>75	25-75	25-75	25-75	25-75	25-75	25-75	25-75	25-75	25-75	25-75
Trees and shrubs	%	80	60	60	90	90	70	70	50	60	60	40	30	20	20	60
Reeds and grasses	%	20	40	40	10	10	30	30	50	40	40	60	70	80	80	40

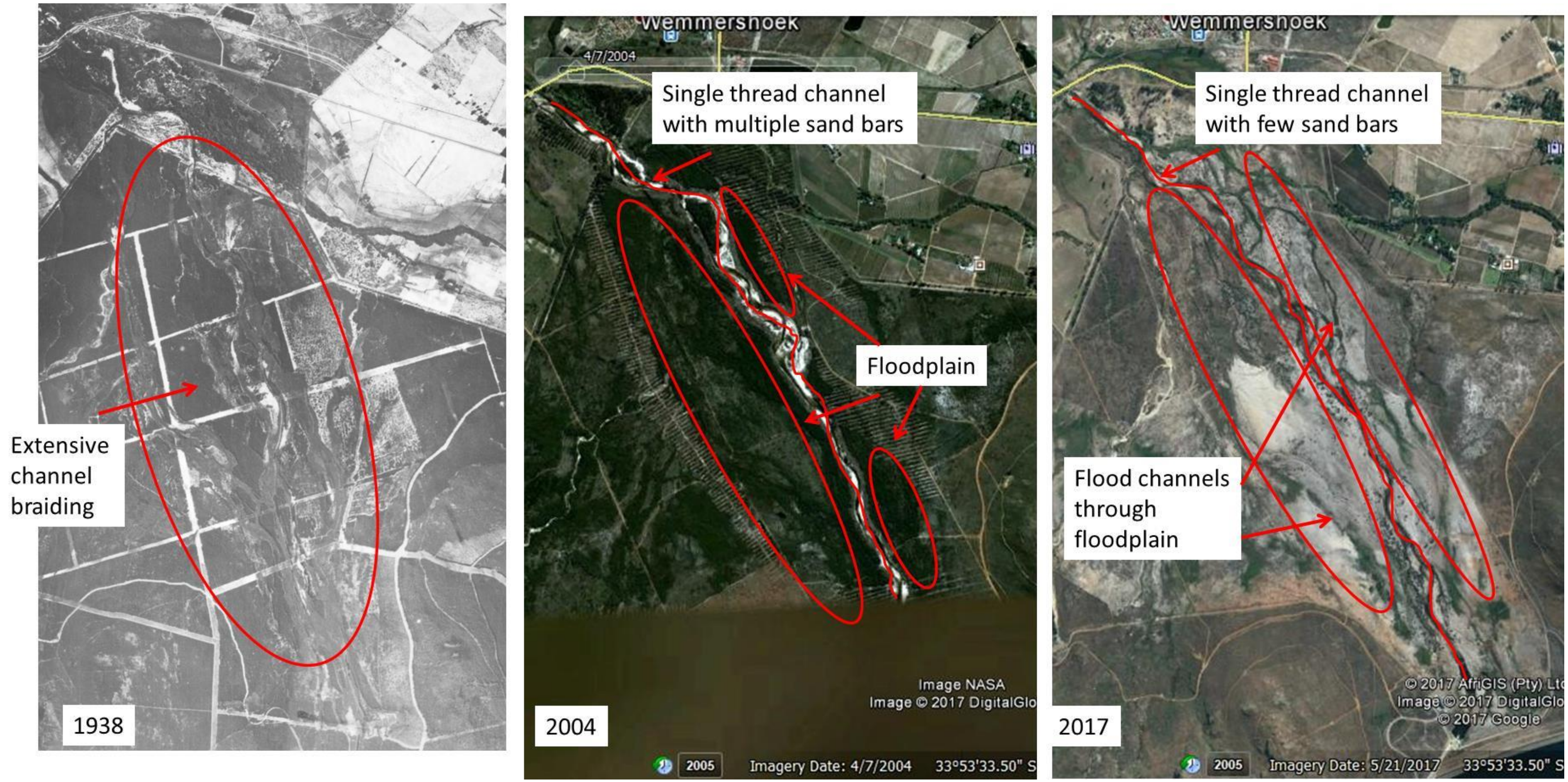


Figure 3.16 Changes in channel form, the area of sand bars, floodplain, and channel and riparian area at IFR 1/96 on the Berg River downstream of the Berg River Dam in the upper foothills

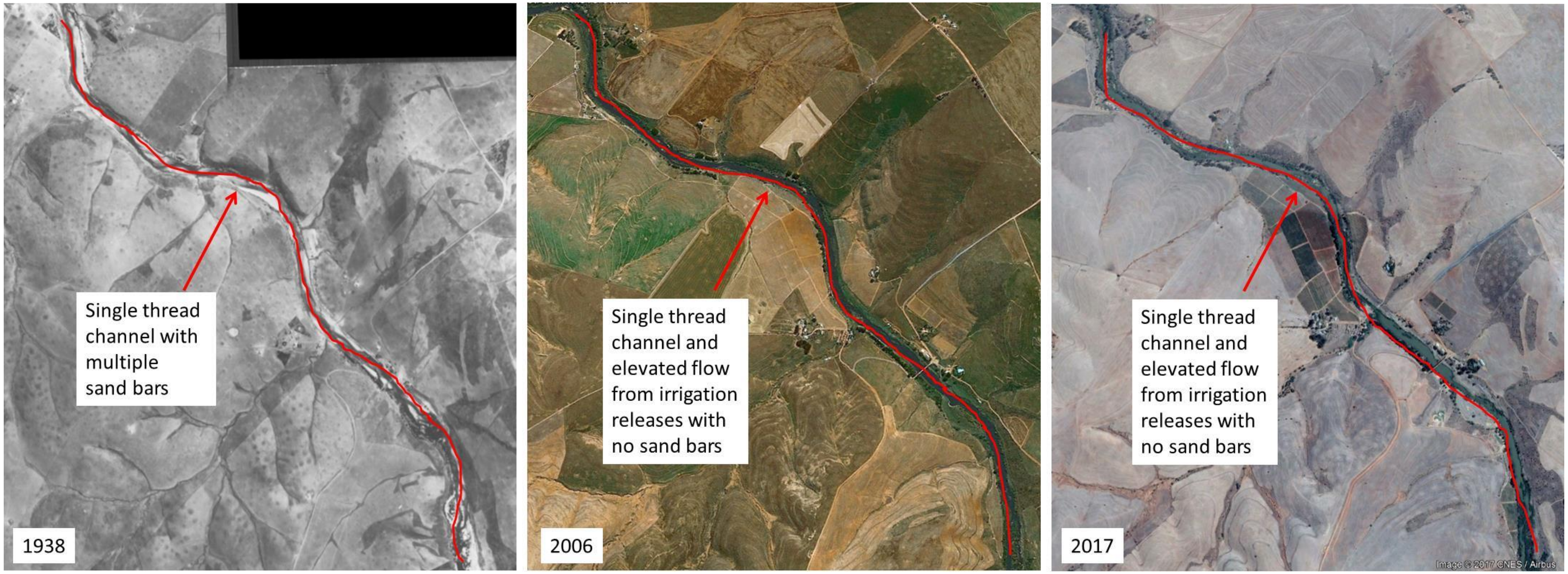


Figure 3.17 Changes in channel form, the area of sand bars, floodplain, and channel and riparian area on the Berg River at IFR 5, downstream of Wemmershoek Dam in the lowlands

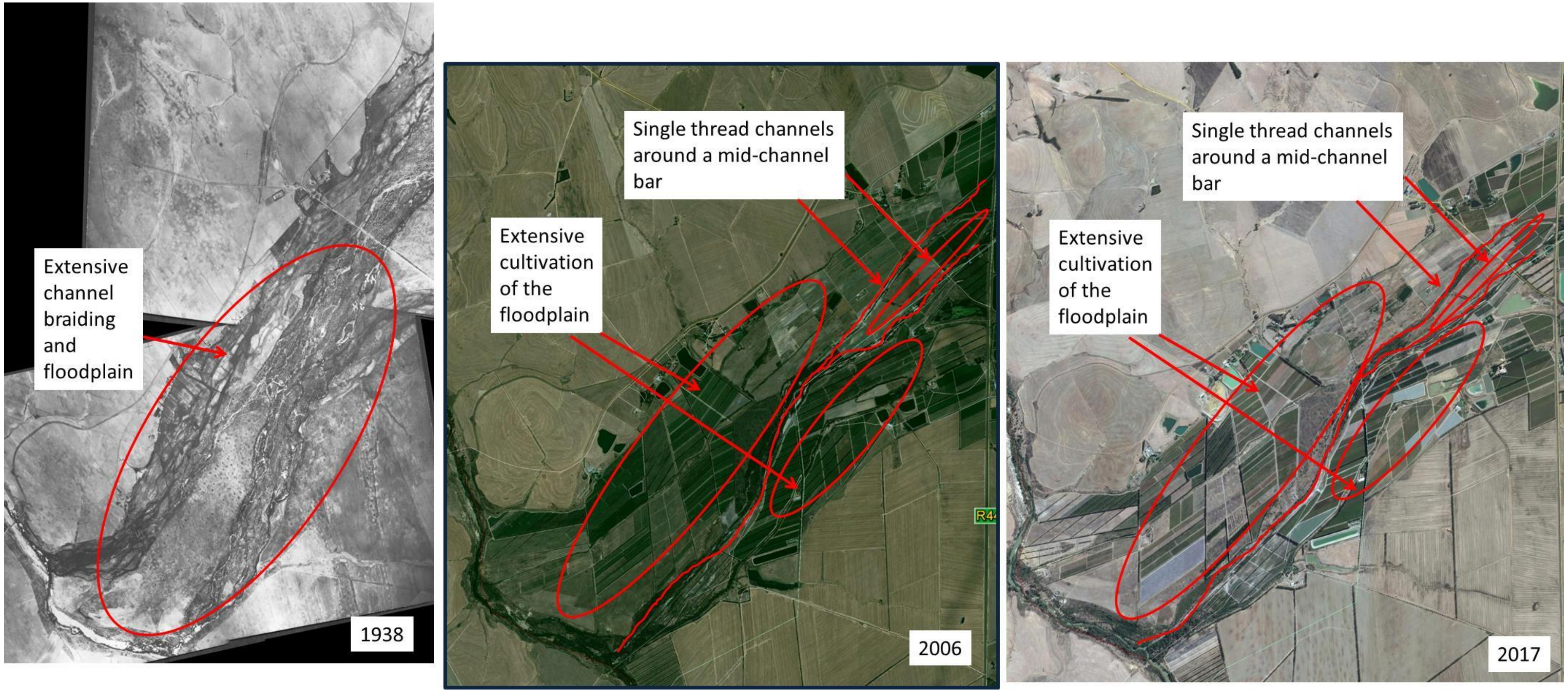


Figure 3.18 Changes in channel form, the area of sand bars, floodplain, and channel and riparian area on the Twenty-fours River in the lower foothills

In several cases, the change in the composition of the riparian vegetation appeared to be linked to invasion of the riparian areas by woody exotics, such as *Eucaluptus* spp *and Acacia* spp. The WfW programme was launched in 1995 to clear exotic woody trees from our river catchments and is currently being managed by the Department of Environmental Affairs. Some other changes may have been caused by the WfW clearing teams. Chief among these is that the invasion by woody exotic plants, and its subsequent clearing, has also reduced the number of indigenous trees and shrubs and the channel and riparian area. In other words, although the removal of the exotic vegetation undoubtedly has benefits for water supply and ecosystem functions, the results of this study suggest that removal of the alien vegetation reduced the buffer zone around the rivers in the Berg River Catchment, which is known to have negative knock-on effects on habitat quality (Richardson *et al.* 2007).

It was not possible to link the effects of different landuse directly to specific changes on the Berg River nor the tributaries. Partly this was because the changes were similar at all sites, and partly because in the Berg River differences in landuse are more than likely masked by differences in position in the catchment, as forestry and viticulture tends to occur in the upper reaches and wheat farming in the lower reaches (Section 3.2). Some tributaries did however change far more than others and the tributaries responded in different ways to what was shown on the Berg River.

Channel planform and riparian vegetation are particularly sensitive to development and serve as good indicators of environmental change (Naiman *et al.* 2005). However, it is not always easy to record and analyse these changes. In this study, attempts to rely on previously surveyed cross-sections were unsuccessful as benchmarks could not be located despite considerable efforts in the field. With a better understanding of the extent of change in channel planform gained from analysis of historical aerial photographs, it is unsurprising that the survey pins could not be found. It was, however, possible to track changes in channel morphology and riparian zone vegetation from historical aerial images. Although it is recognised that the use of aerial images is not without its problems, the results presented clearly show that the channels of both the Berg River and its tributaries have become narrower and less diverse as a result of development in the basin. They also show that with a concerted effort it is possible to reverse some of the more immediate changes, e.g. downstream of the Berg River Dam at IFR 1/96, which would undoubtedly have knock-on benefits for biodiversity, but also for water management and supply, throughout the basin.

3.4.4 Lessons learnt

The evaluation of channel structure and riparian vegetation yielded some valuable insights, despite the fact that only a fairly rudimentary analysis was possible. For instance, when channels narrow but the flow and the incidence of floods remains the same, the channel bed and banks, and the biota present, experience higher shear stress. The increased channel velocities scour into the channel bed picking up and transporting sediment downstream. Viewing historical images allows us to witness these sorts of changes from natural habitat conditions further back into the past than by other means since most biological data records start after the 1950s. Hydrological data records generally extend further back than records of most other kinds of data but none reach far back enough in time to represent natural conditions truly. Without these data, research into trends of change navigates blindly with no empirical evidence to support separating out natural fluctuations from change due to unnatural perturbations. For most parts of the country, Google Earth® images are available from the early 2000s and in some parts there are data as far back as the late 1980s.

In summary, the lessons learnt were:

- Evaluation of channel structure and riparian vegetation was only possible at the reach scale because the images were time consuming to prepare and analyse.
- Selection of the location and length of each study reach is important to maximise focus on locations of interest and reduce scaling errors between image comparisons.
- Historical, non-georeferenced, monochromatic aerial photographs for the target reaches were available for 1938 and 1977, but the resolution of the 1977 photographs was too poor for them to be of use in the assessment.
- For some catchments (or locations within catchments), GoogleEarthPro© goes back as far as the early 1980s in some parts of the country but the resolution is only sufficiently fine for mapping river features from the early 2000s. For the Berg River, the Google Earth® images with reasonable resolution were only available from 2000.
- Comparison of channel shape and features between old non-georeferenced images and more recent images can be done in a fairly simple and inexpensive way using a combination of GoogleEarthPro©, MS Power Point and MS Excel.

3.5 Aquatic macroinvertebrates

Aquatic biomonitoring programmes have been implemented all over the world and biomonitoring programmes have been developed to survey the overall state of aquatic ecosystems in order to keep track of ecosystem change (Roux *et al.* 1999). Programmes based on macroinvertebrates have been successfully used in biological monitoring of rivers around the world (Ollis *et al.* 2006). Aquatic macroinvertebrate communities are widely used since they are visible to the naked eye, highly diverse, well studied, easy to identify, have a rapid life cycle, their ecology and life history is relatively well understood, are abundant and common with a wide distribution, are generally sedentary and are easy to collect (Dallas and Day 1993, Chutter 1995).

According to Ollis *et al.* (2006), early hydrobiological studies on macroinvertebrate communities of South African major rivers laid the foundations for river biomonitoring in South Africa (e.g. Harrison & Elsworth 1958, Oliff 1960). In South Africa, SASS 5 (Dickens & Graham 2002) is widely used for monitoring water quality and extent of aquatic habitat. In SASS 5, scores are assigned to taxa based on their susceptibility or resistance to pollution or poor water quality; lower scores are assigned to taxa that are resistant and higher scores to those susceptible to pollution.

The history of an ecosystem's structure and functioning is recognised as being important for understanding how present conditions came about (Turner 2005), how ecosystems function, and defining reference conditions (Newson 2008), and is a crucial approach to ecologically sound management (Bis *et al.* 2000, Rhemtulla and Mladenoff 2007). There are, however, very few detailed long-term data sets in existence with which to examine large-scale temporal changes in the community composition of freshwater systems (Lancaster *et al.* 1996, Ractliffe *et al.* 2007), particularly in Africa.

The Berg River is exceptional among South African rivers in that it has detailed records of macroinvertebrate community structure collected at intervals from as far back as the 1950s (Ractliffe *et al.* 2007); these data provide an invaluable record of past conditions. In the 1950s, the Berg River was considered a relatively unpolluted river (Harrison & Elsworth 1958). It also was largely unregulated, with only two off-channel impoundments: Voëlvlei and Wemmershoek dams (Harrison & Elsworth 1958). The first detailed survey of the macroinvertebrates in the system was done in 1951 by Harrison and Elsworth (1958), who visited 13 sites along the length of the river, collecting macroinvertebrate and water samples. Forty years later (in 1991), Dallas and Day repeated the Harrison and Elsworth survey, at the same sites and using a purposefully similar approach to enable comparison. There have been three subsequent surveys (Coetzer 1978, Dallas 1997, Ractliffe *et al.* 2007) of the macroinvertebrates along the Berg River. These were augmented in this study with a survey undertaken in November 2015 at the same Berg River sites following similar approaches to data collection and processing (Harrison & Elsworth 1958; Ractliffe *et al.* 2007).

This section presents these historical and more recent data for macroinvertebrate communities of the Berg River and evaluates the changes over time. It was expected that:

- Macroinvertebrate assemblages in the Berg River have changed over time, with more tolerant taxa becoming more dominant.
- These changes are linked more closely with changes in habitat and water quality than changes in flow.

3.5.1 Methods

Between 1958 and 2017, five surveys collected detailed data on macroinvertebrate communities along the full length of the Berg River from 13 roughly comparable sites, the locations of which are given in Table 3.15 and illustrated in Figure 3.19.

Table 3.15 Location of sites and their codes in the different studies, *bolded are dates when data were collected

Sub-catchment	Harrison and Elsworth (1958) *1951–1953	Dallas and Day (1992) *1991	Dallas (1997) *1993 & 1994	Ractliffe *et al.* (2007) *2003, 2004 & 2005	This study *2015	Location	
						Longitude	Latitude
Upper foothills	II (1)	UBG	UBG		Site 1	19.069278	33.974537
	IIIA (3)	ABT	ABT	BRBM 1	Site 2	19.072068	33.956846
	IIIA (5)	JFB	JFB	BRBM 2	Site 3	19.034340	33.877884
Lower foothills	IIIB (9)	SMD	SMD		Site 4	18.968959	33.828032
	IIIB (10)	CDR	CDR		Site 5	18.973905	33.763512
	IIIB (11)	DJT	DJT		Site 6	18.974109	33.707663
	IIIB (12)	LLB	LLB		Site 7	18.976529	33.629653
	IV (13)	HRB	HRB	BRBM 4	Site 8	18.955967	3.4347128
Lowlands	IV 14)	GOU	GOU		Site 9	18.952915	33.256299
	IV (16)	BRD	BRD	BRBM 5	Site 10	18.860092	33.133934
	IV (18)	PKB	PKB	BRBM 6	Site 11	18.749170	32.973109
	IV (19)	SNT	SNT		Site 12	18.353600	32.535500
Estuary	V (21)	KFN	KFN		Site 13	18.200000	32.540000

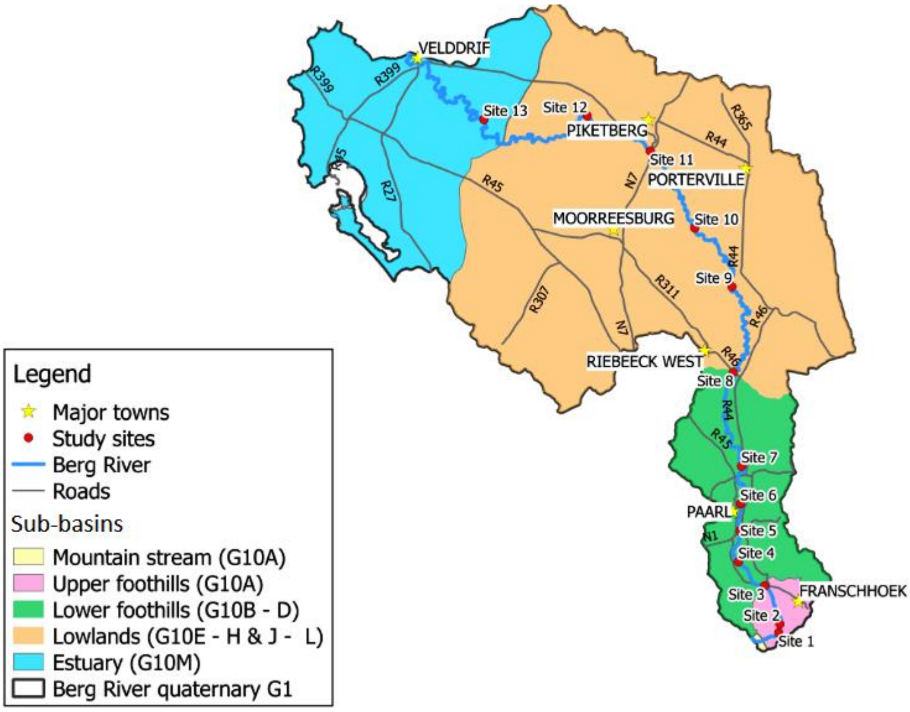


Figure 3.19 The location of the 13 sites in the different sub-basins

Two different methods were used to collect samples in the historical studies. Harrison and Elsworth (1958) used hand nets and square bottomed samples with a mesh size of 780-µm while Dallas and Day (1992) gathered macroinvertebrates from marginal vegetation using sweep nets and used square-framed benthic box samplers, both with 250-µm mesh, to gather organisms from stones in current, or gravel sand and mud biotopes. At each site, two stone in current samples were collected, bottled and preserved in formalin for later laboratory identification to species level, where possible. The number of individuals of each species was recorded and the percentage composition of each species per sample was calculated. Dallas (1997) and Ractliffe *et al.* (2007) followed the SASS 4 (Chutter 1995) and SASS 5 (Dickens and Graham 2002) sampling protocol respectively, using hand-held nets of 250 µm and 950 µm[10] respectively, identifying organisms to family level only and calculating SASS specific scores according to the organisms sensitivity to poor water quality. The historical data were collected at different frequencies, either monthly or seasonally, but only the spring season samples were used in the analyses for this study as this is when samples were collected in 2015.

In this study, macroinvertebrates were sampled in the spring of 2015, using a box sampler for benthic samples and a hand net for marginal vegetation, comparable to the method of collection used in the 1958 and 1992 studies, despite differences in mesh size already mentioned, and also following the SASS protocol as done for the 1997 and 2007 study. It is worth noting that the data written up by Harrison (1958) comprised data from repeat samples collected between 1951 and 1953 and that it was not possible to separate the data out into seasons nor years. The other historical studies also collected repeat samples, seasonally and monthly, but only the spring sample collected in each case was used for comparison to the once-off sample collected in the spring of 2015 during this study.

Two replicate box samples were collected and one SASS sample was collected. All the samples were preserved in the field in 70% alcohol. They were transferred to a laboratory where they were picked and separated into family groups that were identified down to species, or nearest taxonomic resolution as possible, and counted.

The two invertebrate data sets analysed were:

- The benthic box samples and the marginal vegetation sweep samples collected in 1951, 1991 and 2015, identified down to species level, where possible.
- The SASS samples collected in 1993, 2003, 2004, 2005 and 2015, identified down to family level with the three habitats combined and reported as presence or absence.

A range of multivariate statistics (Primer, Clarke and Worley, 2006) was used to discern similarity and dissimilarity between samples over time. For each data set the same analyses were performed:

- An Anosim (Analysis of Similarity, akin to a univariate Analysis of Variance (Anova)) test of differences between:

[10] Differences in mesh size affect the abundance and the instar stage that macroinvertebrates may be collected; smaller mesh sizes capture more and smaller macroinvertebrates. This does affect the ability to compare data from historical studies and so interpreting comparable data must be done with this in mind.

- Sample years
- Sub-catchment
- Cluster analyses of Bray-Curtis similarity for all samples
- Simper analyses of sample groups from the Cluster analysis between:
  - Sample years
  - Sub-catchment.

The Cluster analyses indicate the extent to which the type and abundance of taxa making up the communities sampled are similar to one another and the Simper analyses identify the taxa that are similar (similarity) and different (dissimilarity) between the groups.

Standard SASS-type calculations were made of total SASS Score (SASS score), average score per taxon (ASPT) and the number of taxa for each site. A graph of total SASS score versus ASPT was plotted, following the guidelines of Dallas (2007) in order to determine the ecological condition of the macroinvertebrate communities for each time period at all SASS sites. Sites compared were located in the upper and lower foothills and the lowlands. The five ecological categories and category boundaries for a combination of the upland and lowland sites for the South Western Cape are shown in Table 3.16.

Table 3.16 Ecological categories for interpreting SASS data, adopted from Dallas (2007), South Western Coastal Belt

Ecological category	Description	Boundary values for categories	
		SASS score	ASPT
A	Unmodified natural	110	6.1
B	Largely natural with few modifications	70	4.8
C	Moderately modified	53	4.4
D	Largely modified	38	3.9
E/F	Critically or extremely modified	<38	<3.9

The taxonomy of aquatic macroinvertebrates has changed since the 1950s and the extent to which the authors distinguished different groups from one another has differed, so the historical data sets had to be adjusted to account for this. This was mainly a problem for the box samples collected in 1951 and 1991 where chironomids, simulids, anisoptera, zygoptera and trichoptera were not separated down into lower taxa as done in 2015. Therefore, to enable comparison, the taxonomic groups in the data were reduced down so that time periods had the same taxonomic groups. For example, there were many more species of chironomids in the 2015 data set and no chironomid species reported in the 1951 and 1991 data, so the lowest common taxon was the family Chironomidae and all chironomid species in the 2015 dataset were reduced to one entry at family level.

The chironomids of the Berg River were studied in detail by Scott (1958) and again by Coetzer (1978), but the sites at which the samples were collected and the methods of data collection and sample processing used were not directly comparable to the rest of the historical data.

Scott's study (1958) was a taxonomic investigation with varying levels of effort expended at different sites, and also involved hatching chironomid larvae out, identifying the adults down to species, as well as sampling out-of-channel aquatic habitats (side channels and standing backwaters) at different times of the year. Coetzer (1978) on the other hand only sampled a sub-set of the total number of habitats and at slightly different locations along the river. For these reasons, these data were not included in the analyses.

The SASS samples were less of a problem despite the SASS methods having changed from 1997 to 2015. Only minor adjustments were necessary. However, it is important to note that the 1993 SASS samples were taken using the SASS 2 approach where all habitats are combined into one sample and organisms and abundances are scored as presence/absence, which differs to the SASS 5 approach followed in 2015 that scores the habitats separately from one another and also combined but also where abundances of organisms are ranked. For this reason, the analysis of the SASS data was made for combined samples of presence/absence data only.

It is unlikely that species level data will be available from routine monitoring since most invertebrate monitoring takes place at family level, using the SASS protocol.

3.5.2 Results

3.5.2.1 Benthic box samples and marginal vegetation sweep samples identified down to species

The Cluster analysis shows the relationship, based on the Bray-Curtis similarity, between all samples of macroinvertebrates collected at all sites from stone (s) and vegetation (v) biotopes in the Berg River in 1951, 1991 and 2015 (Figure 3.20):

- There were eight groups, some of which were separated by year or sample type, and others that were mixed.
- Group 1 comprised vegetation samples collected in 2015 from the lowland sites 9, 12 and 13.
- Group 2 comprised a mixed bag of samples from both biotopes and predominantly collected during 1991 (14 out of 17 samples) but also contained two lowland samples from site 11, one collected in 1951 and the other in 2015, and also an upper foothill sample collected from site 1 in 2015.
- Group 3 comprised four vegetation samples collected in 1991, one at the upper foothill site 3, two at the lower foothills sites 7 and 8, and one at the lowland site 9.
- Group 4 comprised stone samples collected in the upper foothills from sites 1, 2 and 3 in 1951, site 1 in 1991 and site 2 in 2015, along with two lower foothill sites 5 and 7 in 1951.
- Group 5 comprised vegetation samples from the upper foothill sites 1, 2, and 3 and the lower foothills sites 4 and 5 from 1951, along with the upper foothill sample site 1 in 1991.

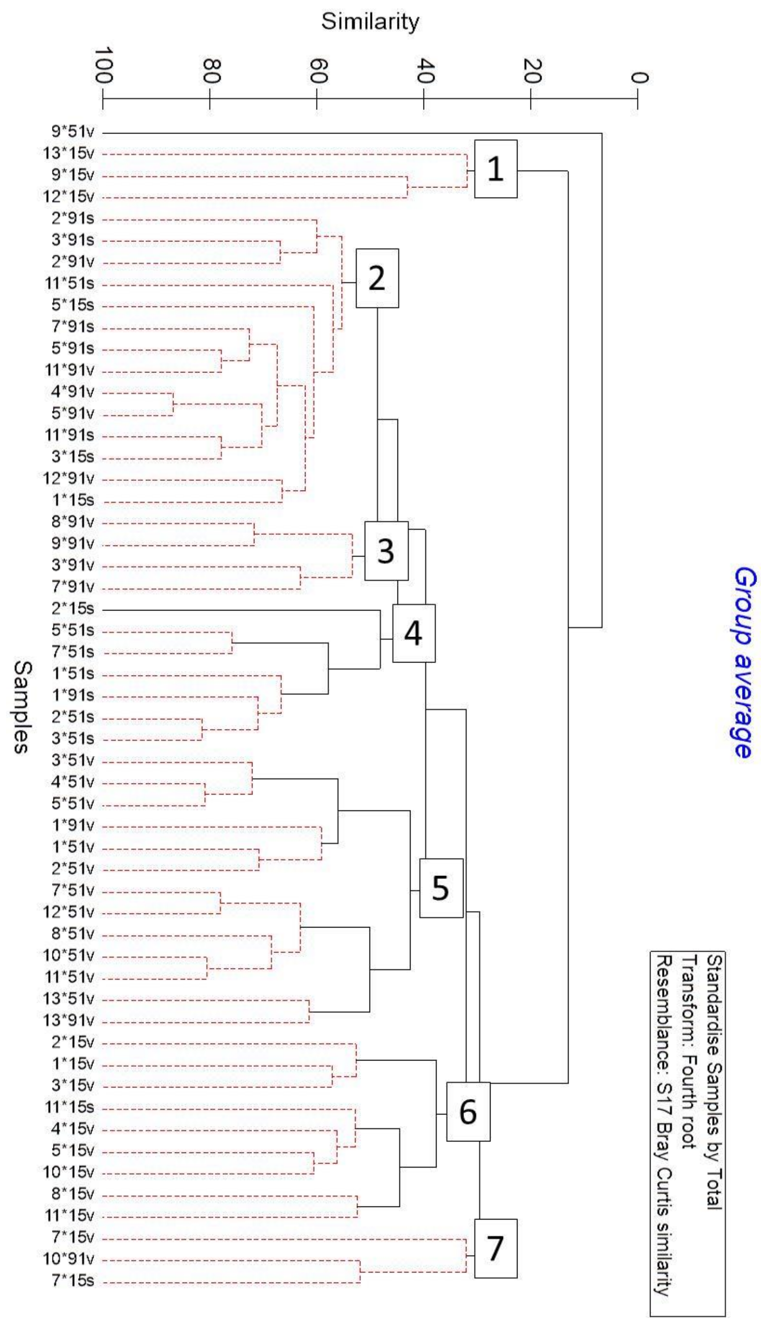


Figure 3.20 CLUSTER analysis aquatic macroinvertebrate assemblages from stone (s) and vegetation (v) habitats from sites along the Berg River, collected in 1951, 1991 and 2015. Sample codes 9*15v = site 9, 2015, vegetation

- Group 6 also comprised vegetation samples from the lower foothill sites 7 and 8 and the lowland sites 10, 11, 12 and 13, all from 1951, along with the lowland site 13 from 1991.
- Group 7 comprised vegetation samples from 2015 from the upper foothill sites 1, 2, 3, the lower foothill sites, 4, 5 and 8, and the lowland sites 10, 11 and 12, along with one stone sample collected from the lowland site 11 also in 2015.

- Group 8 comprised both the vegetation and stone sample collected from the lower foothills at site 7 in 2015 and a vegetation sample collected from site 10 in 1991.

The communities of invertebrates were different in different years ($R = 0.334$ $p < 0.1\%$). A Simper similarity analysis showed that the differences over time were because the 1951 communities had a higher proportion of simulids and baetids, whereas the 1991 and 2017 communities were dominated by chironomids (Table 3.17).

Table 3.17 Results of the Simper analysis showing macroinvertebrates responsible for similarity between samples collected over time.

		Group 1951				
Average similarity	**43.33%**					
Order	**Family**	**Species**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**
Ephemeroptera	Baetidae	*Baetis sp.*	1.91	10.1	1.93	23.31
Ephemeroptera	Baetidae	*Pseudocloen vinosum*	1.81	8.78	1.3	20.25
Diptera	Chironomidae	Chironomidae sp.	1.5	8.2	2.1	18.93
Diptera	Simulidae	Simulidae sp.	1.24	5.16	1.06	11.91
Trichoptera		Trichoptera sp.	0.78	2.8	0.79	6.46
Tubificida	Naididae	*Nais sp.*	0.62	1.77	0.6	4.09
Plecoptera	Notonemouridae	*Aphanicerca spp.*	0.46	0.76	0.38	1.75
Ephemeroptera	Baetidae	*Centroptilim excisum*	0.39	0.67	0.32	1.56
Diptera	Dixidae	*Dixa sp.*	0.34	0.61	0.32	1.41
Gastropoda	Ancylidae	*Ferrissia sp.*	0.33	0.52	0.26	1.19
		Group 1991				
Average similarity	**51.55%**					
Order	**Family**	**Species**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**
Diptera	Chironomidae	Chironomidae sp.	2.62	20.87	3.47	40.48
Ephemeroptera	Baetidae	*Baetis sp.*	1.78	11.97	2.5	23.21
Diptera	Simulidae	Simulidae sp.	1.42	8.35	1.41	16.2
Trichoptera		Trichoptera sp.	0.7	3.27	0.91	6.35
Tubificida	Naididae	*Nais sp.*	0.52	1.55	0.47	3
Odonata: Zygoptera		Zygoptera sp.	0.37	0.82	0.39	1.58
		Group 2015				
Average similarity	**33.07%**					
Order	**Family**	**Species**	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**
Diptera	Chironomidae	Chironomidae sp.	1.89	10.73	1.56	32.44
Trichoptera		Trichoptera sp.	1.46	5.84	1.08	17.66
Diptera	Simulidae	Simulidae sp.	1.08	3.57	0.76	10.8
Ephemeroptera	Baetidae	*Baetis sp.*	1.09	3.15	0.58	9.53
Ephemeroptera	Baetidae	*Pseudocloeon sp.*	0.84	1.62	0.51	4.91
Odonata: Zygoptera		Zygoptera sp.	0.74	1.53	0.51	4.62
Hemiptera	Mesoveliidae	*Mesovelia vittigera*	0.61	1.11	0.46	3.37
Ephemeroptera	Baetidae	*Pseudopannota sp.*	0.47	0.66	0.32	2.01
Ephemeroptera	Baetidae	*Cheleocloeon excisum*	0.4	0.51	0.31	1.54
Gastropoda	Physidae	*Physa acuta*	0.4	0.51	0.32	1.53
Odonata: Anisoptera		Anisoptera sp.	0.35	0.5	0.32	1.52
Ephemeroptera	Caenidae	*Caenis sp.*	0.42	0.5	0.32	1.51

Av.Abund = average abundance, Av.Sim = average similarity, Sim/SD = similarity/standard deviation, Contrib% = % contribution made to group similarity

This indicates a decrease in water quality since chironomids are more common in polluted water. Other groups also pointed to declines in habitat and water quality, for instance, plecopterans, which are sensitive to pollution and prefer clean stony beds, were only represented in 1951; caenids, which prefer slower flowing areas often associated with a sandy bottomed channel, and mesovelids, which live in slow-flowing areas with marginal vegetation, were only represented in 2015.

There were no differences between the macroinvertebrates collected at the upper and lower foothill sites, but there were differences between those collected from the upper foothill and the lowland sites ($R = 0.333$, $p < 0.57$; Table 3.18). A Simper analysis showed that these differences were largely due to the exclusive presence of the ephemerellids *Lithogloea harrisoni* and *Lestagella pennicillata* and the leptophlebids *Aprionyx peterseni* and *Castanophlebia calida,* a helodid beetle and the stone fly *Aphanicerca* spp., in the upper foothills, all of which are more sensitive to pollution than the other six organisms found only in the lower foothills; the bugs *Micronecta* sp., *Apassus* sp. and *Gerris swakopnesis,* the mayflies *Caenis* sp. and *Pseudocloeon* sp., and the snail *Ferrissia,* all of which are more tolerant of pollution.

Table 3.18 Results of the Simper analysis showing macroinvertebrates responsible for dissimilarity between samples collected in different sub-catchments

Average dissimilarity	**69.41%**		**Upper foothills**	**Lowlands**			
Order	**Family**	**Species**	**Av.Abund**	**Av.Abund**	**Av.Diss**	**Diss/SD**	**Contrib%**
Diptera	Simulidae	Simulidae sp.	1.49	0.84	3.65	1.31	5.26
Coleptera	Elmidae	Elmidae sp.	0.69	0.13	2.32	1.03	3.34
Hemiptera	Mesoveliidae	*Mesovelia vittigera*	0.07	0.41	1.34	0.59	1.92
Ephemeroptera	Baetidae	*Centroptilim excisum*	0.04	0.29	1.11	0.53	1.6
Gastropoda	Physidae	*Physa acuta*	0.06	0.32	0.98	0.63	1.41
Ephemeroptera	Telaganodidae	*Lithogloea harrisoni*	0.55	0	1.96	0.87	2.82
Ephemeroptera	Telaganodidae	*Lestagella pennicillata*	0.43	0	1.36	0.54	1.95
Ephemeroptera	Leptophlebidae	*Aprionyx peterseni*	0.44	0	1.46	0.67	2.1
Ephemeroptera	Leptophlebida	*Castanophlebia calida*	0.38	0	1.19	0.55	1.71
Plecoptera	Notonemouridae	*Aphanicerca spp.*	0.51	0	1.65	0.77	2.38
Coleoptera	Helodidae	Helodidae sp.	0.38	0	1.26	0.66	1.81
Hemiptera	Corixidae	*Micronecta sp.*	0	0.52	1.76	0.56	2.54
Hemiptera	Belostomatidae	*Appasus sp.*	0	0.37	1.04	0.54	1.5
Hemiptera	Gerridae	*Gerris swakopensis*	0	0.32	0.88	0.56	1.27
Ephemeroptera	Baetidae	*Pseudocloeon sp.*	0	0.54	1.55	0.65	2.23
Ephemeroptera	Caenidae	*Caenis sp.*	0	0.28	0.79	0.58	1.13
Gastropoda	Ancylidae	*Ferrissia sp.*	0	0.29	1.13	0.53	1.63

Av.Abund = average abundance, Av.Diss = average dissimilarity, Diss/SD = dissimilarity/standard deviation, Contrib% = % contribution made to group dissimilarity

3.5.2.2 SASS samples identified down to family level

A Cluster analysis based on combined SASS biotopes at family level showed two main divisions of sites 2 and 3 in the upper foothills for all years (group 3) separating from sites 8 in the lower foothills and 10 and 11 in the lowlands (Figure 3.21). Groups 1 and 4 are small groups of mixed years and sites.

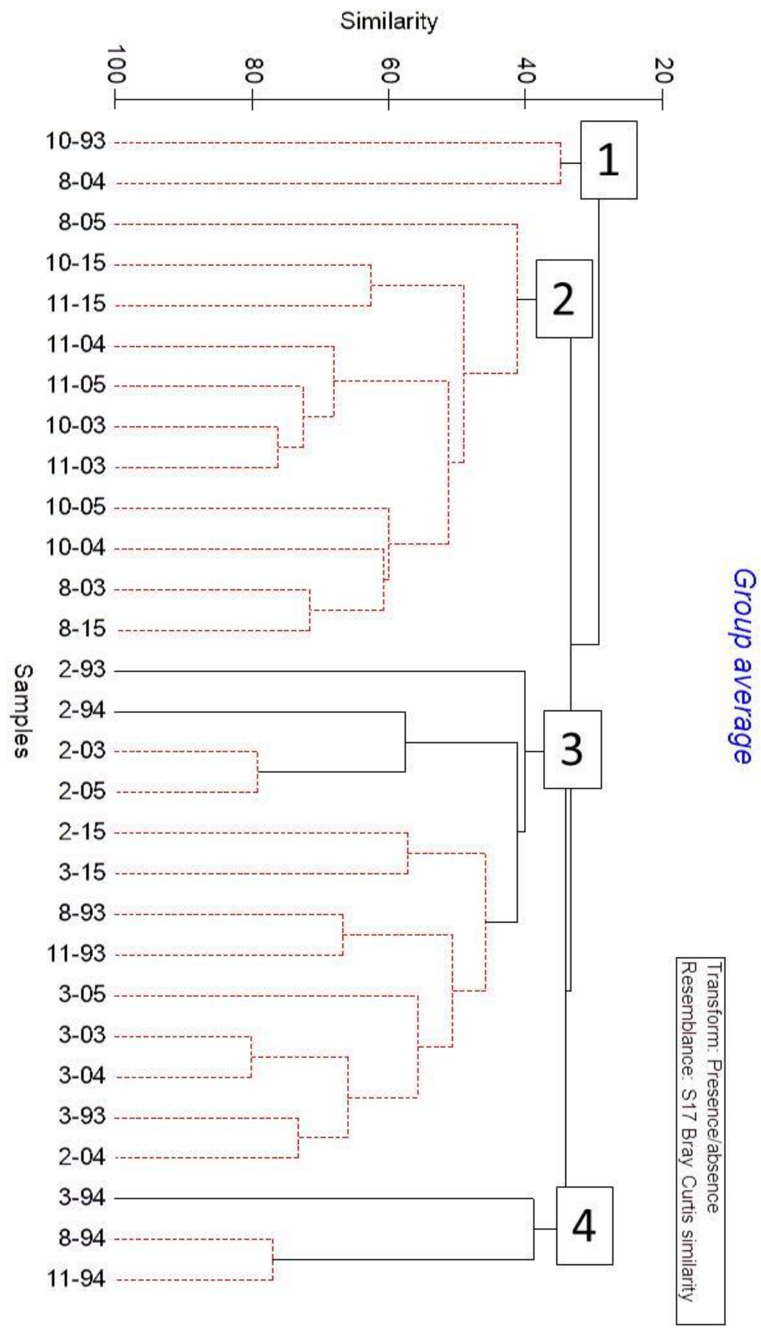


Figure 3.21 CLUSTER analysis of aquatic macroinvertebrate assemblages from stone and vegetation habitats along the Berg River, collected in 1993, 1994, 2003, 2004, 2005 and 2015. Sample codes: 2 = site 2, 03 = 2003

The communities of invertebrates were not different between 2003, 2004, 2005 and 2015 in any combination but these collectively were different to those in 1993 and 1994 ($R = 0.215$, $p < 0.2\%$) and the invertebrates of the upper foothills were different to both those in the lower foothills ($R = 0.409$, $p < 0.3\%$) and lowlands ($R = 0.267$, $p < 0.3\%$). A Simper dissimilarity analysis revealed aeshnids and potamonautids were only recorded in 1993 (Table 3.19) and there were more Lymnaeids and Oligochaets post 1990, which are usually associated with slow flows, fine sediments and detritus, and there was an increase in the abundance and dominance of beetles and bugs, normally associated with aquatic and marginal vegetation in pools of slow-flowing rivers, such as hydraenids, gerrids, dyticids, gyrinids, velids, notonectids and naucorids.

Table 3.19 Results of the Simper analysis showing macroinvertebrate families responsible for dissimilarity between samples collected using the SASS methods over time

	Year	Present in…					
		1993	**1994**	**2003**	**2004**	**2005**	**2015**
Compared with…	1993		Baetidae	Ancylidae Lymnaeidae Oligochaeta Hydropsychidae Hydroptilidae Baetidae Hydraenidae		Gerridae Lymnaeidae Dytiscidae Baetidae	Naucoridae Baetidae Notonectidae Hydropsychidae
	1994	Baetidae Aeshnidae Potamonautidae* Libellulidae			Oligochaeta Veliidae Dytiscidae	Gerridae Gyrinidae* Libellulidae Dytiscidae* Veliidae Lymnaeidae Oligochaeta	Oligochaeta Naucoridae* Gyrinidae* Notonectidae* Veliidae Hydropsychidae
	2003	Baetidae					
	2004						
	2005	Gomphidae Aeshnidae Potamonautidae					
	2015	Aeshnidae Potamonautidae					

These changes in fauna reflect the changes in flow already described (Section 3.3); trends of increased dry season flows and decreased wet season flows that would result in a shift from a rocky to a sandy channel bed. The scale at which channel habitats were mapped (Section 3.4) is at too coarse a scale to be useful to describe changes in habitat for macroinvertebrates but it is postulated that the combination of reduced flows and the clearing of woody exotic trees (see Section 3.4) has allowed marginal and aquatic vegetation to establish to a greater extent than previously occurred.

In general, low Total SASS scores reflect impairment of habitat availability, and low ASPT indicates that a greater proportion of the taxa present are tolerant of poor water or habitat quality.

The Total SASS scores and the ASPT were both higher in the upper foothills (sites 1 to 3) when compared to the lower foothills (sites 4 to 8) and lowlands (sites 9 to 13, Table 3.20). In the upper foothills, the samples collected in 2003/4/5 had higher scores than those collected in 1993/4, both of which were on average twice as high as the scores for the 2015 samples.

This means conditions for macroinvertebrates have worsened since the construction of the Berg River Dam and since the pine plantations were removed from the upper foothills.

Table 3.20 Average Score per Taxon (ASPT) and Total SASS score at each site and time period

Sub - catchment	Sites	Total SASS score						Total ASPT					
		1993	1994	2003	2004	2005	2015	1993	1994	2003	2004	2005	2015
Upper foothills	Site 1	144	111				35	9.0	8.5				5.0
	Site 2	77	133	163	146	151	84	8.5	10.2	7.7	6.9	6.8	6.0
	Site 3	131	62	170	165	79	71	6.5	6.8	6.8	6.6	5.6	5.0
Lower foothills	Site 4						55						4.5
	Site 5	36	56				59	4.5	5.6				4.5
	Site 6	22	21				27	4.4	3.0				3.8
	Site 7	59	64				30	4.5	4.2				5.0
	Site 8	76	32	65	69	54	67	5.0	4.5	4.6	4.90	4.5	4.1
Lowlands	Site 9	30	33				30	3.3	3.6				4.2
	Site 10	42		110	58	75	73	4.6		5.0	4.0	4.6	4.2
	Site 11	67	37	104	66	107	50	5.1	4.6	5.2	4.4	5.6	3.5
	Site 12	47					28	4.7					3.5
	Site 13	5					3	2.5					3.0

The scores at the lower foothill sites remained comparatively poor from 1993–2015 with the lowest score being recorded at Daljasofaat, downstream of Paarl, where the river is canalised.

The lowland sites had better scores in 2003 but otherwise scored relatively poorly, but were on average still better than the lower foothill sites.

When looking at the number of taxa collected at all the sites that were sampled in every period (sites 2, 3, 8, 10 and 11), it was clear that there was a higher diversity of organisms collected from 2003 to 2005, when compared to the 1990s and 2015 samples at each site (Figure 3.22). The number of taxa was different at all sites and periods with the 1993/94 period having lower diversity overall. The highest diversity was recorded for samples that were taken from 2003–2005. Across all three periods, Site 8 at Hermon particularly had the lowest number of taxa (Figure 3.22).

Sites located in the upper foothills remained unmodified (category A) during the historical periods, but in 2015 the condition changed to largely natural with few modifications (category B, Table 3.21). Sites in the lower foothills and lowlands were generally classified as either largely natural with few modifications (category B) or moderately modified (category C). In 2015, sites were generally classified into lower ecological categories when compared to other previous years; Site 11 in particular moved from a category B in 2005 to a category D (largely modified). In 2003 all sites were in a better ecological condition (categories A and B).

Change is evident over time. For instance, at Site 8 at Hermon (IFR 3/96), the condition of the macroinvertebrates in 1993 was “largely natural state” (category B) and by 1994 the site condition had dropped to a moderately modified state (category C). In 2003 the site condition improved to an unmodified natural (category A) but then deteriorated to a category B in 2004, which thereafter dropped to a category C in both 2005 and 2015. According to the 2015 data, none of the sites' ecological condition had improved from before; sites had either remained within the same ecological category (sites 3, 8 and 10) or deteriorated (sites 2 and 11).

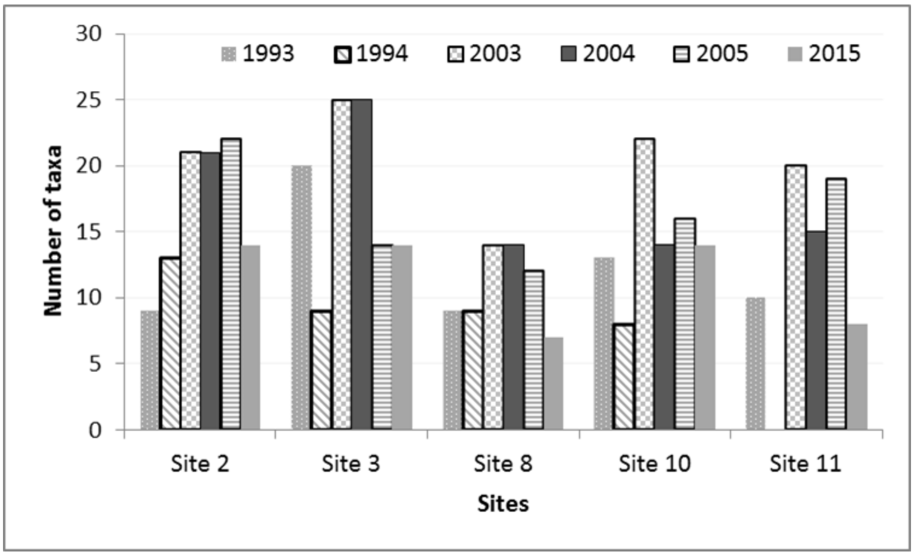


Figure 3.22 Change in the number of taxa over time

Table 3.21 Ecological category/ condition of sites over time (after Dallas, 2007)

Sub-catchment		1993	1994	2003	2004	2005	2015
Upper foothills	Site 2	A	A	A	A	A	B
	Site 3	A	A	A	A	B	B
Lower foothills	Site 8	B	C	A	B	C	C
Lowlands	Site 10	C	-	B	C	B	B
	Site 11	B	C	B	C	B	D

3.5.3 Conclusion

In the 1950s, the Berg River was considered relatively unpolluted and unregulated (Harrison & Elsworth, 1958), with the only major impoundments being Voëlvlei and Wemmershoek dams (Harrison and Elsworth 1958), neither of which was situated on the main stem. There is little doubt that this has changed over time.

Two main factors suggest that the differences between the periods when box data were collected may not be solely a result of variations in taxonomic identification. The first is that these differences extend as far as family level, and the second is that the SASS scores and ASPT (collected using different methods – SASS 4 and SASS 5 – and at different times) support the notion that the health of the ecosystem has declined significantly over the last 20 years (1993–2015).

There is little doubt that conditions in the Berg River have changed since the 1950s when flow was less regulated and conditions relatively unpolluted (Harrison & Elsworth 1958). Despite some "noise" created by species level data (Lenat and Resh, 2000) we can conclude that real differences extend as far as family level, and that the SASS scores and ASPT support the notion that the health of the ecosystem has declined significantly over the last 20 years (1993–2015). In order for that change to have happened, there must have been a substantial change in either water quality or habitat quality, or both.

3.5.4 Lessons learnt

Species level data, which is time-consuming and expensive to collect, may be susceptible to changes in species recognition parameters over time. If, for any particular faunal, or floral, taxonomic group, these name changes are well documented and readily available, it means that any historical datasets will require "updating" to new species names, which is difficult, if not impossible, without access to the original samples. The results of the species level and Family level analyses echoed one another despite there being variation based on the extent to which life history information is available for the taxa described.

Data collected using the SASS protocol should be augmented with some consideration of abundance of the various families; ranked abundance does not affect the sample collection process or duration (Dallas 2002). The most recent version of SASS, i.e. SASS 5, incorporates ranked estimates of abundance, but does not use these in Total Score or ASPT, and in most cases the abundance data are not reported outside of the raw data (which are rarely available to follow-up researchers), although the REMP database does make provision for the inclusion of these data. It was not possible to test the usefulness of this here as abundance data were not collected in the historical SASS sampling.

In summary, the lessons learnt were:

- If species level data are to be used, the financial support for training in taxonomy and sample curation will need to be considerably higher than at present.
- Discontinuity between teams undertaking sampling is likely to lead to researcher-driven differences in communities that are difficult to separate out from degradation-driven differences in community structure.
- The sensitivity of SASS scores could be enhanced through the inclusion of abundance, as noted by Brown (1997).

4 Assessment of value added by historical data in interpretation of RQO monitoring data

The study provided important insights into the sorts of historical data and information that are available for a catchment (Table 4.1), which of those can be readily accessed, and the effort required to process different kinds of data. Table 4.2 highlights the sorts of data that are routinely collected in Reserve and REMP studies, those collected as part of the BRMP (which as its name suggests provides the basis for RQO monitoring in the Berg River Catchment) and the sorts of historical data collated in this project.

This section summarises these insights and discusses the potential value added by using the historical data that were accessed for the Berg River to interpret RQO monitoring data.

Table 4.1 Potential contribution of historical data to Reserve-related assessments

	Historical data	**Landuse**	**Rainfall, Hydrology**	**Channel structure**	**Riparian vegetation**	**Aquatic fauna**
Reserve and BRBM programme	**REMP assessments**					
Hydrology	HAI		✓			
Riparian vegetation	VEGRAI			✓	✓	
Geomorphology	GAI	✓		✓	✓	
Water quality	PAI	✓	✓			
Fish	FRAI					
Macroinvertebrates	MRAI					✓
Overall ecological condition	IHI	✓				✓

REMP = River Ecostatus Monitoring Programme; BRBM = Berg River Monitoring Programme

One of the main, and most obvious, advantages of historical data is that they assist with quantifying baseline conditions that exclude a significant portion of "modern" impacts because they often extend back to before these occurred. This is important because many of the Reserve and REMP assessments are based on deviation from some reference condition, usually natural (Kleynhans and Louw 2007) and when they do not, then a surrogate is used. For instance, PAI is based on the difference between measured water quality and water quality parameters recommended. Although useful in many situations, these surrogate parameters will fail in others, such as in the Doring River in the Western Cape, which is naturally saline from spring until first winter flush. An analysis of the historical water quality would allow replacement of these broad surrogates with values that better reflect the geological and hydrological characteristics of the catchment. Many of the other REMP indices require comparison against lists of species that are "*expected to occur*" for which catchment-specific calibration can ONLY be achieved with some understanding of the natural history of the catchment.

Table 4.2 Data collected in Reserve, Berg River Monitoring Programme (BRMP) and River Ecostatus Monitoring Programme (REMP) and the complementary historical data collated in this project

Aspect	Reserve and BRMP		REMP data collected		Historical	
	Scale	Scale	Data collected	Data collected	Scale	Data collected
Landuse	Site/ reach	None	Site	Landuse at time of study, from a site visit or Google Earth® IHI score	Catchment	Catchment-wide cover of 1:50 000 topographic maps for type and extent of landuse at four periods: 1955–1965, 1976–1985, 1996–2005, 2006–2015
Hydrology and rainfall	Site	Naturalised daily time series at G1H004, G1H020, G1H036, G1H013 "Present day" daily time series at G1H004, G1H020, G1H036, G1H013 Target flows Flood peaks and recurrence intervals at G1H004, G1H020, G1H036, G1H013	N/A	Intended to be HAI but index not yet developed/available	Site	Recorded daily discharge at four stations for: 58 years @ G1H004 48 years @ G1H0120 34 years @ G1H036 50 years @ G1H013 Recorded daily rainfall at three stations for: 115 years @ SAWS Paarl 1 15 years at SAWS Paarl 2 60 years at SAWS Paarl 3
Water quality	Site	Historical data from 1950–2000 (pH, conductivity, total dissolved solids, nutrients) DWS gauge data for inorganic salts, nutrients, pH, conductivity, temperature, dissolved oxygen and toxicity Quarterly pH, conductivity, temperature, dissolved oxygen, total suspended solids (TSS), nitrate+nitrite nitrogen, Kjedahl	Site	DWS long-term data for inorganic salts, nutrients, pH, conductivity, temperature and dissolved oxygen and toxicity pH, conductivity, temperature and dissolved oxygen on a site visit PAI score	N/A	Not done because assessed in the Reserve studies (section 2.2) and again in detail in the BRMP (Day 2007, summarised in section 4.2).

Aspect	Reserve and BRMP		REMP data collected		Historical	
	Scale	**Scale**	**Data collected**	**Data collected**	**Scale**	**Data collected**
		nitrogen, total phosphorous and ortho-phosporous, Cholorphyll-a and *Escherichia coli* Temperature (30 mins) and conductivity (12 mins) at Site 1 and 2				
Hydraulics/ channel shape	Site and reach	Historical aerial images and 1:50 000 topographic maps from 1940–1998 Three cross-sections of channel width and depth at each site 100-m length longitudinal survey of channel and bank heights at 1-m intervals Mean flow velocity (m/s) and depth along the cross-section Stage-discharge relationships	N/A	See geomorphology	N/A	Benchmarks for cross-sections no longer exist, so not possible to resurvey historical cross-sections
Geomorphology	Site and reach	Channel width and depth Width, depth and length of boulders and cobbles (cm) at sites 1, 2 and 3 Proportion of sand and gravel in sand bars at each cross-section	Site	Site photographs, plan view sketches, dominant bed material size classes GAI score	Reach	River channel form (sinuosity) in 1938, 2003 and 2017 Extent of sand bars and floodplain in 1938, 2003 and 2017
Riparian vegetation	Site and reach	Seasonal algal biomass, species composition and abundance at sites 1, 2, 5, and 6 from marginal vegetation, benthic stones and sediments Percentage cover of dominant tree,	Site	Site photographs, plan view sketch and notes on plant distribution Species list of plant species present.	Reach	Extent and continuity of riparian zone in 1938, 2003 and 2017 Proportion of trees, shrubs and grasses in 1938, 2003 and 2017

Aspect	Reserve and BRMP		REMP data collected		Historical	
	Scale	Scale	Data collected	Data collected	Scale	Data collected
		shrub, herb and groundcover species on each cross-section Species lists of plants present and their position on the cross-section		VEGRAI score		
Aquatic fauna	Site and reach	Historical invertebrate data from 1950–2000 Biotope map at a low (summer) and high (winter) discharge Seasonal SASS scores and ASPT Abundance of invertebrate families or nearest taxon per biotope Historical fish species Species list of fish, number of individuals and size (mm)	Reach	pH, conductivity, temperature and dissolved oxygen on a site visit Site photographs, sketch map of aquatic habitat (biotopes) Family list of aquatic macroinvertebrates per biotope MIRAI score Extent of flow-depth classes for fish Frequency of occurrence of fish species FRAI score	Catchment	Invertebrate community structure at 1958, 1992, 2003, 2004, 2005 and 2015 List of organisms at different taxonomic levels (Order, Family, Genus, Species) responsible for similarity and differences between time periods

4.1 Landuse

Reserve projects typically consider landuse broadly as an inference for impacts at Reserve sites and to contribute as a component to the calculations of a habitat integrity score. This involves ranking the importance of different types of landuse at the site in the Department's Index of Habitat Integrity (IHI) module (see Section 2.4). This takes account of current day landuse in the REMP and over time, following successive follow-up investigations, and the subsequent record of IHI, recorded over time, will produce a timeline of changes in IHI from the starting point. The changes in landuse are ranked and not quantified in this exercise. This differs to what was achieved by looking back in time and mapping historical landuse.

Mapping historical landuse over time:

- quantified the type and extent of changes and when these took place in the catchment;
- provided insight into the consequences of these changes, for example:
    - a switch from dryland farming to irrigated crops requires increased water supply that necessitates increased abstraction from rivers and storage in farms dams;
    - the expansion of urban areas leads to an increase in the release of treated and untreated sewage effluent into rivers;
    - gentrification converts working farms to lifestyle estates that require water for landscaped gardens, golf courses and recreational dams;
- provided a context to understand changes in the "naturalised" flow record that pre-dates the observed flows.

The mapping exercise was time consuming as it involved working with old analogue maps, but the historical assessment of landuse only needs to be done once per catchment and so the level of effort should be viewed in that light. Updates of change going forward which will be recorded using electronic and georeferenced maps will be faster to add to the time series. The broad changes in landuse across the catchment over time were useful to understand the river's flow regime and also informed possible cause and effect for changes in river channel shape, habitats and aquatic fauna.

4.1.1 Rainfall and hydrology

Reserve projects model "present day" and naturalised flow using the best available hydrological data and/ or rainfall to describe relationships between the flow regime and the river ecosystem (Table 4.2). These modelled data exclude anthropogenic trends affecting changes in water supply and demand, and are not useful in determining whether or not the Reserve is being met, nor to understand historical trends in hydrology. The patching and analysis of the hydrological record was time consuming and technically difficult but provided invaluable insight into the history of changes in flow prior to and after the Reserve was set 20 years ago. Once the historical flow regime had been patched and the methods for doing so established, updating the flow regime going forward and the use of these data to retrospectively check whether the Reserve maintenance flows are being met is fundamental to the entire monitoring programme.

In summary, patching the historical daily discharge:

- Meant the observed daily flow record could be analysed and compared to observed rainfall records to discriminate whether changes in flow were taking place in response to a dry period or whether they were due to abstractions, which:
    - provided temporal changes in flow on an hourly, seasonal and annual basis that informed when changes in flow took place and how long these persisted;
    - facilitated the analysis of ecologically relevant flow indicators for the length, duration and magnitude of flow in the wet and dry season and the occurrence and number of intra- and inter-annual floods.
- Contextualised the relative wetness or dryness of sample years.
- Allowed for comparisons between actual hydrological records with the hydrological requirements for the Ecological Reserve.

Comparing actual flow in the river with the hydrological requirements for the Ecological Reserve is essential for answering the question "Is the Ecological Reserve being implemented correctly and achieving the desired results?" An example of this comparison for G1H036, near IFR Site 3/96, is shown in Figure 4.1 and Figure 4.2. Figure 4.1 shows both wetter and drier years and Figure 4.2 shows an average year. Both indicate that, for the most part, the Reserve requirements at IFR3/96 were met. Figure 4.3 shows the same but for a dry year, and it is clear to see that in dry years the issue with the Reserve at IFR 3/96 is not that low flows are too low but that they are too high. Furthermore, the flood flows were not met in the year shown.

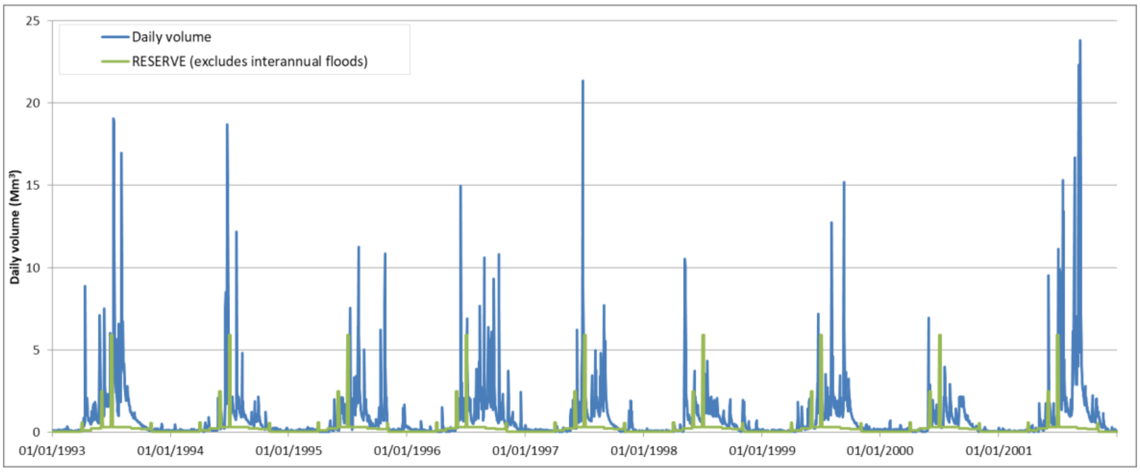


Figure 4.1 Daily volume for G1H036 (patched) showing a fairly typical sequence of wetter and drier years, together with Reserve requirements

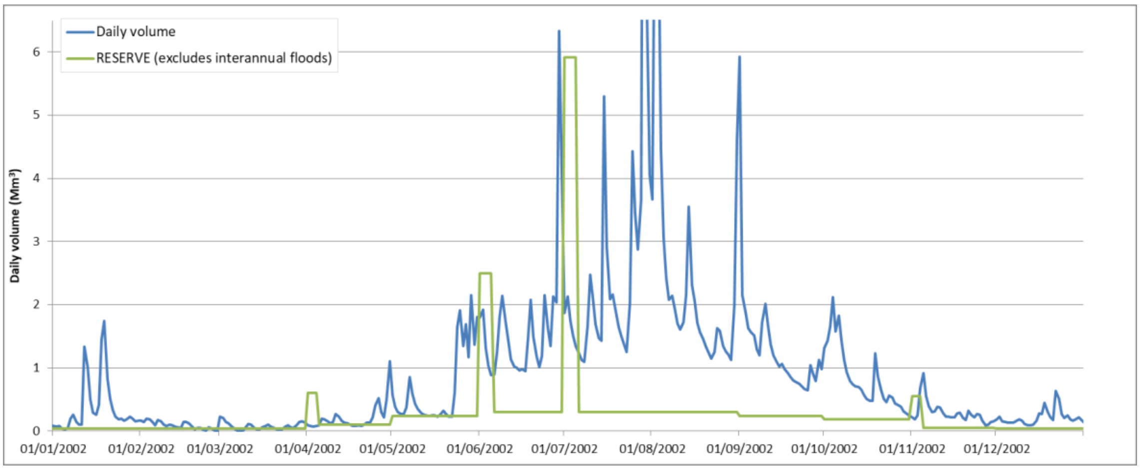


Figure 4.2 Daily volume for G1H036 (patched) for a year with an average annual volume, together with Reserve requirements

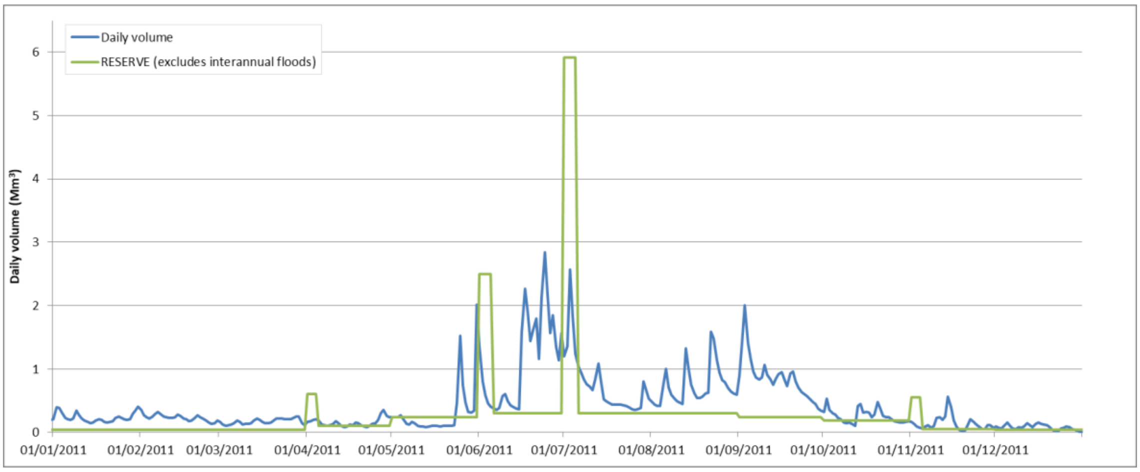


Figure 4.3 Daily volume for G1H036 (patched) for a year with a below-average annual volume (2011), together with Reserve requirements

Table 4.3 illustrates a simple way to display the historical data to contextualise the wetness or dryness of a particular year relative to other years in the record, which is valuable in evaluating the effects of climate change.

Table 4.3 Annual volume for G1H036 (patched). Red is driest, then orange and green. Median value is yellow, 372.6 MCM

	Annual volume (MCM)	Rank order (1= driest, 34=wettest)
1979	263.2	10
1980	243.6	6
1981	426.8	25
1982	267.3	12
1983	539.2	33

	Annual volume (MCM)	Rank order (1= driest, 34=wettest)
1984	441.5	28
1985	389.9	22
1986	451.3	30
1987	386.3	21
1988	262.3	9
1989	395.1	23
1990	433.4	26
1991	565.8	34
1992	434.5	27
1993	445.2	29
1994	280.5	14
1995	274.9	13
1996	382.1	20
1997	284.1	15
1998	249.9	7
1999	303.6	17
2000	185.1	4
2001	539.0	32
2002	339.6	18
2003	150.5	1
2004	165.9	3
2005	259.1	8
2006	242.8	5
2007	372.6	19
2008	423.2	24
2009	481.9	31
2010	266.2	11
2011	154.5	2
2012	302.9	16

4.2 Water quality

Collation and assessment of historical water quality data holds similar benefits to those outlined for the assessment of historical hydrological data. Since the BRBM included a comprehensive assessment of historical water quality records for the Berg River, these were not reassessed in this study (Table 4.2). The main findings from the BRBM assessment are given below, taken from Day (2007).

There are no records of natural water quality in the Berg River prior to development. The upper foothills were considered to be naturally acidic with a low nutrient status and there was an increase in the conductivity down the length of the river, especially after some of the drier saline tributaries flow into the lower foothills and lowlands during winter. Before 1960, the upper foothills were generally in a near natural state but conductivity and total dissolved solids increased downstream. There was an increase in urban and agricultural runoff around Franschhoek and Pniel and there was an increase in the pollution from larger towns such as Paarl and Wellington and also an increase in abstraction from the tributaries. From 1960–1980, the upper foothills remained unimpacted while the lower foothills and lowlands continued to receive increased organic loads from waste water treatment works at Paarl and Wellington and also higher conductivity water from Voëlvlei Dam in the summer months. The lowlands also revealed elevated pollutant levels due to fertilisers and increased abstraction of water from the river. From 1980–2004, the inter-basin transfer of water from Theewaterskloof Dam changed the character of the upper foothills by increasing the conductivity, pH and suspended solids concentration in the summer months. Further, increases in conductivity continued especially near Voëlvlei as did discharge of waste water treatment effluent from Paarl and Wellington and there was now also an increase in the concentrations of phosphorous from agricultural runoff in the lower foothills and lowlands.

4.3 Channel structure and riparian vegetation

Reserve projects record and describe a number of channel features at each site using a combination of surveyed cross-sections, channel maps, aerial images and site photographs (Table 4.2). Sites are selected taking cognisance of the reach in which they are located and how this relates to the diversity of reaches catchment-wide using a desktop approach, but the data collected are site specific (Table 4.2). This information is used to calculate a reference and present day score for the geomorphological condition and how this is likely to change in response to flow.

Mapping historical features of the river channel:

- described changes at a reach scale, providing insight into how parts of the river respond differently from one another and from the tributaries;
- quantified these changes numerically and visually over time providing evidence for changes only previously described, such as:
    - the change from a braided channel to one with a floodplain below the Berg River Dam (Figure 3.16);
    - the loss of multiple river channels at the Twenty-fours River (Figure 3.17);
    - the reduction in sand bars downstream of Misverstand Dam (Figure 3.18).

Reserve projects describe the plant species and communities present, taking cognisance of the location of each species in the channel and on the banks. This site-specific information is used to calculate a reference and present day score for the condition of the riparian vegetation (Table 4.2).

Mapping historical features of the riparian vegetation:

- described changes at a reach scale, providing insight into how parts of the river have changed over time in response to natural and human-induced impacts;
- quantified these changes numerically and visually over time providing evidence for changes only previously described qualitatively, such as:
    - changes in channel and riparian area and floodplains along the Berg River;
    - changes from a woody riparian zone in 1938 to a riparian zone comprised of grasses and shrubs following removal of the plantations (see Section 2) below the Berg River Dam by 2003;

- the invasion of the riparian area by woody exotics at Hermon by 2009 and subsequent clearing of the trees by 2017.

The collation and analysis of channel changes was relatively straightforward, does not require GIS programmes or skills, and was well worth the effort to understand past river conditions. Since many changes pre-date the hydrological records it is worth sourcing the oldest aerial photographs available and including these in the analysis, but later analysis using Google Earth® was much simpler. The time line of changes can also be updated from time to time, using future Google Earth® images.

4.3.1 Aquatic macroinvertebrates (and other fauna)

Reserve projects record and describe the presence and abundance of aquatic habitat available to macroinvertebrates and fish at each site using a combination of site photographs and qualified statements. This site-specific information is used to calculate a reference and present day score for the condition of the aquatic fauna and how this is likely to change in response to flow. No data on fish were interrogated in this project and the comments made below pertain to macroinvertebrates only, since work on other aquatic fauna, such as fish, reptiles, birds and mammals, are also worked through at species level.

The comparison of historical records of macroinvertebrate species:

- required adjustments to the data to account for differences in the methods of collection, the methods of analysis and taxonomic name changes;
- revealed little gain for the effort and expense incurred to work at a species level, mainly because the life history information is difficult to obtain or not available, which limits interpretation;
- at a family level were easy to compare with other data since most were collected using the SASS method and there was much more life history data available to create flow-linked guilds to aid interpretation.

The historical datasets of invertebrates from the Berg River provided an invaluable opportunity to investigate changes at a species level over time and are unlikely to be available at most other rivers. Family level data, however, are routinely collected through the REMP and almost every freshwater ecological study conducted nationally. These data were collated into the Rivers database (http://www.dwa.gov.za/iwqs/rhp/naehmp.aspx) up to 2015. There is currently a project underway to incorporate the data from the old BioBase with the Rivers database, which will take the historical family level data back to the early 1990s (Dallas *et al.* 2011), and will be available to inform monitoring efforts in catchments around the country in a newly established Freshwater Biodiversity Information System housed at the Freshwater Research Centre (www.frcsa.org.za).

5 Proposed framework for contextualising RQO monitoring data

Biological patterns, such as those in habitat availability or quality and/or macroinvertebrate communities, are generated by processes acting over temporal and spatial scales. Thus, meaningful interpretations of monitoring data should be underpinned by consideration of the influence of factors at a wider spatial scale and over a longer period than is possible in routine REMP monitoring (e.g. Thompson *et al.* 2001). Such information and data are used to support interpretation of site-specific biological monitoring and to help establish cause and effect relationships.

The requisite to consider these factors is not new, and many (but not all) reports and presentations using REMP data have taken due consideration of the spatial and temporal context. The purpose of the framework proposed here is to encourage more widespread and systematic incorporation and coordination of large-scale, long-term data into monitoring and interpreting implementation of the Ecological Reserve via the RQOs, and to provide method statements for collating and analysing historical data for landuse, rainfall, hydrology, channel change and historical faunal surveys.

The spatial and temporal spread of historical data for landuse, rainfall, hydrology, channel change and riparian vegetation, and historical faunal surveys, relative to data collected as part of REMP field surveys, is illustrated in Figure 5.1. Currently, the REMP is the only ecological monitoring taking place in the Berg River Catchment, and RQOs have as yet not been gazetted. Thus, the REMP is used as a reference in Figure 5.1; however, the principles illustrated should apply equally for other monitoring data. REMP monitoring surveys take place over a period of days or weeks and focus in on study sites across the catchment (Table 2.1). By comparison, the analysis of historical data in this study focused on study sites when looking at riverine biota, extended outward to the channel reach when considering changes in channel form, riparian vegetation and the floodplain, and extended out to the geozone and catchment, when considering hydrology, rainfall and landuse. Similarly, the analysis of historical data extended the temporal view back *c* 80 years compared to the within-year sampling events of the REMP.

The potential use of these data to inform the calculation of the indices required for REMP, and/or their analysis and interpretation, is illustrated in Figure 5.2. Gauge data (hydrology and rainfall) can feed directly into the Hydrological Assessment Index. Gauge data can also feed into the physico-chemical assessment. Channel shape and riparian vegetation can feed directly into the geomorphological and riparian vegetation assessments and historical faunal surveys directly into the assessments for fish and macroinvertebrates. Rainfall is useful to interpret changes seen in the hydrology while landuse is useful to interpret changes seen in geomorphology, riparian vegetation and water quality.

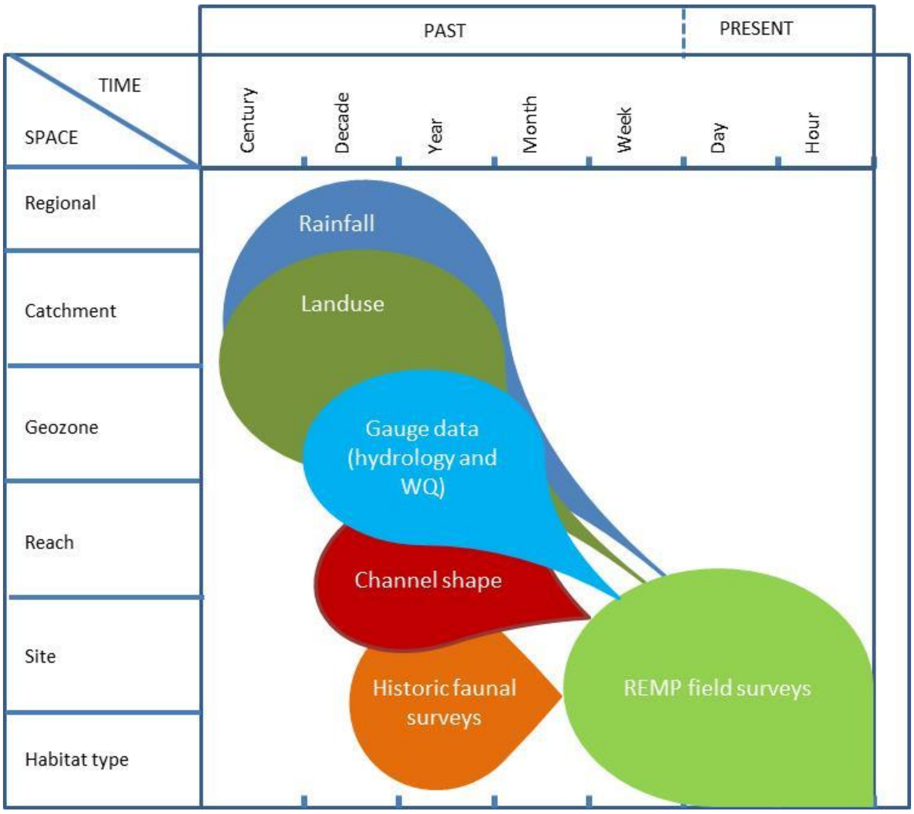


Figure 5.1 Temporal and spatial resolution for different types of data

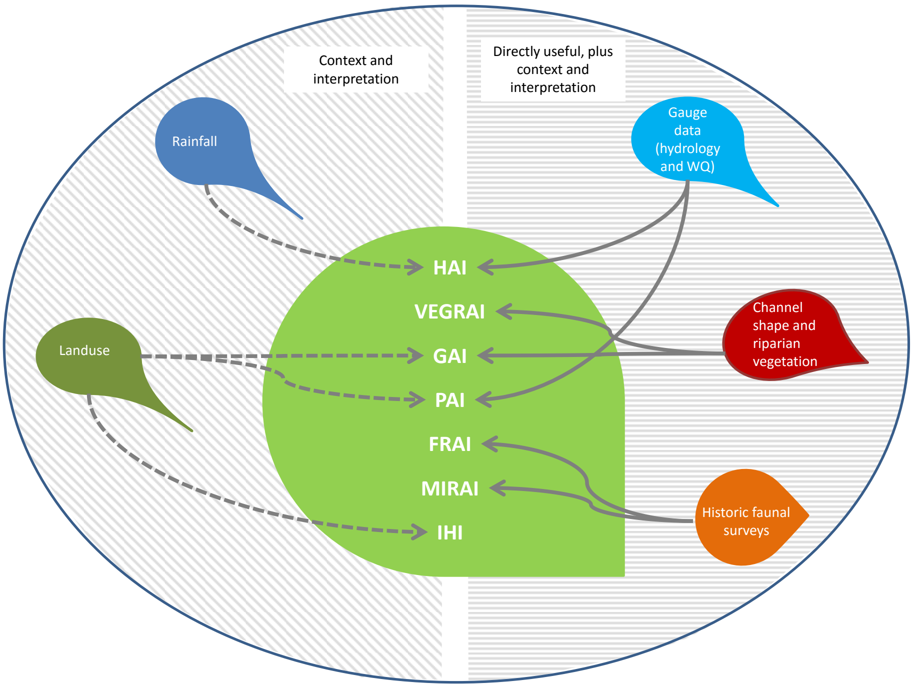


Figure 5.2 The potential use of historical data to inform the calculation of River Ecostatus Monitoring Programme indices, and/or their analysis and interpretation

Collecting and collating historical data can be time consuming but the resultant information is an invaluable contribution to understanding a catchment and interpreting monitoring outcomes, and the process only needs to be undertaken once. This section provides method statements for collation and analysis of the sorts of data that were available for the Berg River (Table 5.1), which included:

- 1:50 000 topographical maps and aerial images from the local Department of Surveys and Mapping;
- daily rainfall data from the SAWS;
- daily discharge data from the DWS Hydrological Services website;
- community data from past (historical) biological surveys.

Table 5.1 Timeline of data available for the Berg River Catchment

	1900	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010	2017
Topographic maps													
Aerial images													
Daily rainfall													
Discharge data													
Biological surveys													

Method statements are provided for the collation and assessment of data on landuse (Table 5.2); rainfall and hydrology (Table 5.3); channel change and riparian vegetation (Table 5.4); and macroinvertebrates (Table 5.5).

The method statements provided here are unlikely to cover all eventualities, as it is likely that the sets of data that are available for another catchment will differ either slightly or significantly from that available for the Berg River Catchment. Thus, the principles, approach and method statements outlined should be viewed as examples of pragmatic and cost-efficient use of these sorts of data that may need to be adapted to other sorts of data sets.

The macroinvertebrate method statement (Table 5.5) deals only with FAMILY level identifications. This is based on the outcome of the assessment of the Berg River macroinvertebrate data sets in Ms Magoba's PhD, which concluded that the expense and complications involved in the use of data at a lower taxonomic level were not justified.

Table 5.2 Collation and assessment of historical data on landuse: Method statement

Method	Data collection/collation	Equipment	Data processing	Data format	Data analysis
Collation and assessment of data on catchment landuse	Work with staff at Department of Surveys and Mapping to identify historical topographic maps that cover the entire river catchment For these periods, obtain the historical topographic maps in electronic format from the Department (there is no charge if you supply the DVD/flash drives) Copy the data files into a folder maps and launch the *.tif images in GIS	Flash drive (~64 GB); computer with MS Excel; a GIS Package (QGIS freeware was used in the Berg River Catchment)	Create a QGIS project file for the river catchment and load the following covers: DWS quaternary shapefile 1:500 000 rivers Dams and water bodies DWS gauging stations Towns and roads Identify suitable categories of landuse Create a shapefile for each category landuse (Table 3.1) and capture: Polygons for areas Points for single features Use the built-in scripts (these vary between GIS packages) to calculate areas of polygons and count points Generate maps of landuse and summary tables of areas and counts	GIS shapefiles; MS Excel spreadsheets comprising areas of polygon features (km^2), counts of point data (nominal)	Test for differences in areas and counts between periods Create summary bar graphs of pertinent changes Create summary tables of results shown to be different

Table 5.3 Collation and assessment of hydrological data: Method statement

Method	Data collection/collation	Equipment	Data processing	Data format	Data analysis
Collation and assessment of hydrological data	Go to www.dwa.gov.za to find gauging weirs in the river Access daily hydrological discharge data for identified gauges by selecting the gauge number and daily average flow m^3/s Download the entire record Provide the coordinates for the location of gauging weirs identified above to the South African Weather Service and they will provide rainfall data from nearby rain gauges. (A fee is payable for access to these data)	Computer with MS Excel; flow analysis software (DRIFT was used here)	Patch the hydrological data (see Section 3.3.2 and Herold *et al.* 2016) For gaps of less than one month, patch using data from a nearby reference gauge based on relative MAR For gaps longer than one month, patch using regression coefficients Calculate time series of ecologically relevant summary statistics (DRIFT was used here) Follow steps described in the user manual for flow analysis software (e.g., for DRIFT this is available on www.DRIFT-EFlows.co.za)	DRIFT project file; summary statistics for flow indicators, MS Excel spreadsheets, discharge (m^3/s) time series, rainfall (mm) time series	Export statistics for ecologically meaningful flow indicators from DRIFT Plot double mass plots of MAR against rainfall and selected DRIFT flow indicators Calculate t-tests to determine when changes in flow, rainfall and DRIFT indicators took place Compare time periods with the timing of changes in landuse or water resource developments

Table 5.4 Collation and assessment of channel change and riparian vegetation data: Method statement

Method	Data collection/collation	Equipment	Data processing	Data format	Data analysis
Collation and assessment of channel change and riparian vegetation data	Go to Department of Surveys and Mapping with blank DVDs and ask to see the flight plans for aerial images across the river catchment Select images that correspond to the periods selected (Table 5.1) and the location of sites Copy the data files into a folder *aerial images* Download the program **Image Composite Editor** from www.microsoft.com/en-us/download/ Open the images from each site and select *new panorama* to load and stitch the images together Open Google Earth Pro® and capture recent images for the same sites, saved as *.jpeg Load the stitched historical and Google Earth Pro® images into MS Power Point per time period and site	Flash drive (~64 GB); computer with MS Excel and Google Earth®	Select a rigid and permanent feature on the image, such as a road, or a bridge, and mark it out on each image Use the dimensions and orientation of this feature to size the images to the same scale and direction as one another Capture a line along the thalweg and polygons of the alluvial bars, riparian area and floodplain from each historical image Select one of the Google Earth® images and open the slide show alongside a view of the site in Google Earth® Capture the thalweg line and polygons and record the distance in m and the area in m^2 Measure a straight line along the distance of the thalweg and record the distance in m	MS Power Point files, MS Excel spreadsheets, lengths of channel (m^2), area of polygon features (km^2)	Calculate the relative length of lines and the proportional area of polygons for each site in MS Excel Use the ratio of proportions between years per site to calculate ACTUAL lengths and areas using those measured for one of the recent images in Google Earth® Calculate sinuosity; divide the thalweg length by the straight line length Tabulate lengths and areas for comparison

Table 5.5 Collation and assessment of data from macroinvertebrate surveys: Method statement

Method	Data collection/collation	Equipment	Data processing	Data format	Data analysis
Collation and assessment of data from macro-invertebrate surveys	Source and collate community data from historical surveys, and organise the data into sample columns and row list of taxa For current data, the samples are collected using the SASS 5 procedures – so if SASS 5 assessments are being done for REMP it is only necessary to collect samples for processing To collect the samples, drain water from sample through sieve, and empty tray contents into a sample jar, preserve with 96% ethanol diluted with river water to a 70% solution Mark sample clearly and store sample out of the sun, in a dark cupboard, until processed	Data collection: Hand-held 1-mm mesh net; sampling tray, forceps, SASS 5 identification guide, 1-mm mesh sieve, 96% chemical grade ethanol, 500 ml sample jars, plastic vegetable bags, masking tape, alcohol proof marking pen, pencil, white paper Data processing: Dissecting microscope, tray, 5-ml sample storage tubes Data analysis: computer with MS Excel; statistical analysis package (Primer was used here, Clarke and Worley 2006)	New samples: Sieve the sample to remove debris and stones Float organisms in distilled water and separate into family groups Enter data into spreadsheets in format used for SASS 5 historical data All data: Cross-check family names to ensure that any changes have been captured and families are correctly named Format data into Primer project files according to instructions in Primer manual	MS Excel spreadsheets; counts of families, SASS scores; PRIMER project files, graphs and tables of community abundance, similarity and dissimilarity	Calculate total SASS 5 score and ASPT per biotope Use Dallas (2007) to calculate a condition score Load the spreadsheet of family abundance per site per year into Primer and enter factor codes. For each site: Run an Anosim test for differences between years Create Cluster graphs of similarity between years Run Simper analysis to determine the organisms responsible for similarity and dissimilarity between years

5.1 Other potentially useful historical data

Ecological research and monitoring is entering a new era of integration and collaboration as we meet the challenge of understanding the great complexity of biological systems (Thompson *et al.* 2001). As part of this, maximising information across a variety of disciplines, made possible by new methods, technologies, and funding opportunities, is proving central to providing the information needed to manage and protect these systems in the face of major stresses and major ecological questions.

The history of an ecosystem's structure and functioning is vital for understanding how present conditions came about (Turner 2005), how ecosystems function, and for defining reference conditions (Newson 2008). As such, collating and analysing the past is crucial to ecologically-sound management (Bis *et al.* 2000; Rhemtulla and Mladenoff 2007). The distribution of organisms at large and small scales is influenced by natural and anthropogenic histories (Turner et al 1989). The historical data presented here are those that were available for use in the Berg River Catchment, and as mentioned, the nature and format of these data may differ from catchment to catchment. Historical data gathered from pollen cores, tree rings, old land survey records, written accounts of early travellers, cadastral maps, aerial photographs and oral interviews (Rhemtulla and Mladenoff 2001) have all been used to uncover ecosystem drivers (Rhemtulla and Mladenoff 2007). Today, these are augmented by the high-resolution, freely available images on Google Earth® over large geographic regions which provide current and historical views of landuse, and offer an inexpensive means of assessing character, composition and patterns in rivers (Johnson and Host 2010). Increasingly, Google Earth® images are augmented by the analysis of other satellite images such as Spot 5 and RapidEye imagery, both readily available at a resolution of 5-m now, considerably better than the 30-m resolution of the old Landsat imagery. It is also important to remember that spectral resolution is important for detecting differences in land cover and vegetation type.

6 Conclusions and recommendations

Taking the time to understand and analyse past activities in our river catchments and how these have affected the ecological conditions of the rivers that drain them is an investment that should be made to better manage our inland aquatic ecosystems. It is especially important as the focus of the DWS shifts from setting Reserves to implementing and monitoring RQOs, and in light of the shortage of budget, skills and access to robust data sets needed to ensure comprehensive and scientifically defendable monitoring and reporting of successes and failures. It would be naïve to presume that implementation of the Ecological Reserve and its efficacy in meeting the agreed RQOs will not at some point be challenged in a court of law, which means that it would be sensible to maximise the use of ***all*** available data to support monitoring, reporting and the conclusions drawn in that regard.

The main sources of data on whether or not the Ecological Reserve is being correctly implemented in a catchment, and its efficacy in sustaining the RQOs for that catchment, are intended to be the REMP and the RQO monitoring programmes (DWS 2013). For the most part, these focus on sites established in Reserve determination studies, and use the hydrological and ecological information developed in those studies as benchmarks for ongoing monitoring. While this pragmatic approach is understandable, it is important to recognise that the data collection and analyses done for the Reserve determination studies were not necessarily aimed at providing historical baselines for ongoing monitoring. This is particularly so for the REMP indices, which are assessed according to change from “reference” conditions, and therefore depend on a robust definition of reference conditions. As such, the premise upon which this study was based is that data from the Reserve studies will benefit from being contextualised within a broader historical and catchment-based perspective, particularly with regards to the description of more robust and defensible definitions of baseline/reference conditions on which to base monitoring.

This study demonstrated the value gained by investing in the collation and analysis of historical data in a simple, cost-effective manner and how this may be used to augment Reserve and monitoring data to provide a more robust definition of reference conditions for REMP indices and the interpretation of RQO monitoring data, and to provide a quantitative basis for what are otherwise highly subjective assessments. Information was gathered from wherever it could be found and then tested to see if it was useful in interpreting change in the Berg River. The study provided valuable lessons in making the most of data with irregular coverage, in patching data to ensure that it could be analysed, in combining data from different temporal and spatial scales, and in applying scales broader than those routinely considered in Reserve determinations or monitoring studies to augment the assessments required. There was more information available without charge than originally envisaged and so, with hindsight, the main investment was the time taken to collate and analyse it all. Furthermore, the insights gained greatly increased our understanding of the functioning of the Berg River ecosystem and the factors at play in its continuing management.

6.1 Recommendations

The recommendations from this study are that assessments of the available historical data should be done for every catchment in the country, and made available to DWS for use in interpreting their monitoring data and guiding their management of the rivers. Not only is the information vital for interpreting and augmenting data already incorporated into Reserve, REMP and RQO studies, but the nature and content of such assessments make them ideal for postgraduate study. They are relatively straightforward but necessitate a range of procedures and skills, and would provide postgraduate students with a deep understanding of the nature and timing of human impacts on rivers, how the river ecosystems respond and the historical context in which they should be managed, which would be invaluable in their ensuing careers.

The invertebrate data and some of the contextual maps generated in this project are housed in the Freshwater Biodiversity Information System, managed by the Freshwater Research Centre (www.frcsa.org.za).

7 References

Albhaisi M, Brendonck L and Batelaan O. 2013. Predicted impacts of land use change on groundwater recharge of the upper Berg catchment, South Africa. ISSN 1816-7950 (On-line) *Water SA* Vol. 39 (2)

Alexandratos N. 1999. World food and agriculture: outlook for the medium and longterm. Proceedings of the National Academy of Sciences of the United States of America. National Academy of Sciences.

Allan JD. 1995. *Stream ecology: structure and function of running waters*. Chapman and Hall, London

Bath A. 1989. Phosphorous transport in the Berg River, Western Cape. Unpublished PhD thesis, University of Cape Town.

Bath A. 1993. Western Cape System Analysis. Water quality. Volume 1: general. Ninham Shand report to DWAF. DWAF Report No. PG000/00/2891.

Beck JS and Basson GR. 2003. The hydraulics of the impacts of dam development on the river morphology. WRC Report No. 1102/1/03. ISBN No. 1-77005-044-2. Water Research Commission, South Africa.

Bis B, Zdanowicz A and Zalewski M. 2000. Effects of catchment properties on hydrochemistry, habitat complexity and invertebrate community structure in a lowland river. *Hydrobiologia* Vol 149: 369–387

Brown CA. 1992. Initial surveys in the investigation to determine effects of trout farm effluent on riverine biotas in the south-western Cape. Final interim report to the Department of Water Affairs and Forestry, Pretoria, and Cape Nature Conservation, Cape Town. Freshwater Research Unit, University of Cape Town, South Africa.

Bunn SE and Arthington AH 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Flow Regimes and Aquatic Biodiversity. *Environmental Management* Vol. 30 (4) 492–507

CARA. 1983. Conservation of Agricultural Resources Act No. 43 of 1983. Government of the Republic of South Africa.

Clarke KR and Gorley RN. 2006. Primer V6: user manual/tutorial. Plymouth, Uk, Primer-E.

Clarke KR and Warwick RM. 2006. *Change in marine communities: an approach to statistical analysis and interpretation*, 2nd ed. Primer-E, Plymouth, UK.

Chutter FM. 1995. The role of aquatic organisms in the management of river basins for sustainable utilisation. *Water Science and Technology* 32 (5&6): 283–291

Chutter FM. 1998. Research on the rapid biological assessment of water quality impacts in streams and rivers. WRC Report No 422/1/98. Water Research Commission, Pretoria, South Africa.

Clerici A, Perego S, Chelli A and Tellini C. 2015. Morphological changes of the floodplain reach of the Taro River (Northern Italy) in the last two centuries. *Journal of Hydrology* 527: 1106–1122

Coetzer A. 1978. The invertebrate fauna and biotic index value of water quality of the Great Berg River, Western Cape. *J. Limnol. Soc. Afr.* 4 (1)1–7.

Dallas HF and Day JA. 1993. The effect of water quality variables on riverine ecosystems: a review. WRC Report No. TT 61/93. Water Research Commission, Pretoria, South Africa.

Dallas HF and Reynolds E. 1994. The effects of water quality variables on riverine biotas. WRC report No 351/1/94. Water Research Commission, Pretoria, South Africa.

Dallas HF. 1997. A preliminary evaluation of aspects of SASS (South African Scoring System) for the rapid bioassessment of water quality in rivers, with particular reference to the incorporation of SASS into a national biomonitoring programme. *South African Journal of Science* 23 (1) 79–94.

David M, Carozza JM, Valette P, Llubes M, Py V, Grparu T. 2016. The fluvial dynamics of the middle Garonne river documented by combining historical maps, stratigraphy and geophysics approaches on the Grenade-Ondes study site. *Geomorphologie relief processus environment* 21 (1) 21–44.

Davies-Colley RJ, Meleason MA, Hall RMJ, Rutherford JC. 2009. Modelling the time course of shade, temperature and wood recovery in streams with riparian forest restoration. *New Zealand Journal of Marine and Freshwater Research* 43 673–688.

Day E. 2007. Water Chemistry. In: Ractliffe, SG (ed) Berg River Baseline Monitoring Programme Final Report Volume 2. Report to the Department of Water Affairs and Forestry. Project No. 2002/069

Department of surveys and mapping website http://www.dla.gov.za/contact-us/national-geo-spatial-information/37-national-geo-spatial-planning-cape-townmap-sales

Dickens CWS and Graham PM. 2002. The South African Scoring System (SASS) Version 5 Rapid bioassessment method for rivers. *African Journal of Science* Vol 27: 1–10.

Dorava JM, Montgomery DR, Palcsak BB, Fitzpatrick FA. 2001. *Geomorphic processes and riverine habitat*. American Geophysical Union. John Wiley and Sons, Inc. USA. 253 pp.

Dosskey MG, Vidon P, Gurwick NP, Allan CJ, Duval TP, Lowrance R. 2010. The role of riparian vegetation in protecting and improving chemical water quality in streams. *Journal of the American Water Resources Association* 46 261–277

DWAF 1996. Summary of proceedings and assessment of original Skuifraam IFR workshop of 1992/1993 and proposed process for the 1996 workshop. Internal document prepared by Southern Waters for the Department of Water Affairs and Forestry.

DWAF 2002. Voelvlei intermediate reserve determination (lower Berg River). Volume 1: background and synthesis. Prepared for the Department of Water Affairs and Forestry by Southern Waters.

DWAF 2004. State of the Rivers Report – the Berg River System 2004. River Health Programme publication series of the Department of Water Affairs and Forestry. ISBN No 0-620-32075-3

DWS 2013. National Water Resource Strategy. Water for an equitable and sustainable future. Department of Water and Sanitation publication series.

DWS 2014. Support to the Continuation of the Water Reconciliation Strategy for the Western Cape Water Supply System: Status Report October 2014. Prepared by Umvoto Africa (Pty) Ltd in association with WorleyParsons on behalf of the Directorate : National Water Resource Planning. Department of Water and Sanitation, South Africa.

DWS 2015. Reserve determination studies for the selected surface water, groundwater, estuaries and wetlands in the Gouritz Water Management Area. Project technical report 10. River RDM report – intermediate assessment. Department of Water and Sanitation report No. RDM/WMA16/00/CON/1-13.

DWS hydrology website http://www.dwaf.gov.za/hydrology/

DWS RHP website (http://www.dwa.gov.za/iwqs/rhp/default.aspx).

DWS WMS database website http://www.dwa.gov.za/iwqs/wms/data/000key.asp

DRIFT www.DRIFT-EFlows.co.za

Dyke G and Howard G. 1993. Western Cape System Analysis. Hydrosalinity modelling of the Berg River basin. Ninham Shand Report for DWAF. DWAF report no. PG000/00/3392.

Foster D, Swanson F, Aber J, Burke I, Brokaw N, Tilman D and Knapp A. 2003. The importance of land-use legacies to ecology and conservation. *Bioscience* Vol 53 (1) 77–88

Fourie JM and Steer AG. 1971. A survey of water quality of the Great Berg River (1963 to 1970). Report, National Institute of Water Research, CSIR, to the Provincial Administration of the Cape of Good Hope.

Galster JC, Pazzaglia FJ and Germanoski D. 2008. Measuring the impact of urbanization on channel widths using historical aerial photographs and modern surveys. J*. Am. Water Resour. Assoc.* 44: 948–960

Garcia-Ruiz IM, Lasanta T, Ruiz-Flano P, Ortigosa L, White SI and Marti C. 1996. Land-use changes and sustainable development in mountain areas: a case study in the Spanish Pyrenees. *Landscape Ecology* Vol. 1 (5) 267–277

Grau HR, Aide TM, Zimmerman JK, Thomlinson JR, Helmer E and Zou X. 2003. The ecological consequences of socioeconomic and land-use changes in postagriculture Puerto Rico. *BioScience* Vol. 53 (12) 1159–1168

Gregory KJ. 2006. The human role in changing river channels. *Geomorphology* Vol. 79: 172–191

Gurnell AM, Downward SR and Jones R. 1994. Channel planform change on the River Dee meanders, 1876-1992. *Regulated rivers: research & management* Vol. 9: 187–204

Hall GC and Gorgens AHM. 1978. Studies of mineralisation in South African rivers. South African National Scientific Programmes Report No 26, CSIR. Pretoria.

HAI in prep

Harald S. 1975. Tropical rivers as expressions of their terrestrial environments. Chapter 19 Tropical Ecological Systems Volume 11 of the series Ecological Studies p 275–288.

Harrison AC and Elsworth JF. 1958. Hydrobiological studies on the Great Berg River, Western Cape province. Part 1. General description, chemical studies and main features of the flora and fauna. *Trans. Roy. Soc. South Africa.* Vol 25 (3) 125–226.

Image composite editor www.microsoft.com/en-us/download/

James CS and King JM. 2010. Ecohydraulics for South African Rivers A Review and Guide in South African Handbook on Environmental River Hydraulics. WRC Project No. K5/1767, Water Research Commision, South Africa.

King JM, Brown C, Sabet H. 2003. A scenario-based holistic approach to environmental flow assessments for rivers. *River Research and Applications* 19: 619–639.

Kleynhans CJ and Louw MD. 2007. River ecoclassification manual for ecostatus determination (Version 2). Module A. Ecoclassification and ecostatus determination. WRC Report No TT 377-08, Water Research Commission, South Africa.

Kleynhans CJ, Mackenzie J, Louw MD. 2007. River ecoclassification manual for ecostatus determination (Version 2). Module F. Riparian Vegetation Response Assessment Index. WRC Report No. TT 377-08, Water Research Commission, South Africa.

Kleynhans CJ. 2008. River ecoclassification manual for ecostatus determination (Version 2). Module D: Volume 1. Fish Response Assessment Index (FRAI). WRC Report No TT 377-08, Water Research Commission, Pretoria, South Africa.

Kleynhans CJ, Louw, MD, Graham M. 2008. River ecoclassification manual for ecostatus determination (Version 2). Module G. Index of Habitat Integrity. Section 1: technical manual. WRC Report No TT 377-08, Water Research Commission, Pretoria, South Africa.

Lancaster J, Real M, Juggins S, Monteith DT, Flower RJ and Beaumont WRC. 1996. Monitoring temporal changes in the biology of acid waters. *Freshwater Biology* Vol 36: 179–201

Lenat DR, Resh VH. 2000. Taxonomy and stream ecology – the benefits of genus and species level identifications. *Freshwater Science* 20 (2) 287–298

Leopold LB and Wolman MG. 1960. River meanders. *Bull Geol Soc Am* Vol. 71 (6) 769–794

Leys KF and Werritty A. 1999. River channel planform change: software for historical analysis. *Geomorphology* Vol. 29: 107–120

Mantel SK, Hughes DA and Muller NWJ. 2010. Ecological impacts of small dams on South African rivers Part 1: Drivers of change – water quantity and quality. ISSN 1816-7950 *Water SA* Vol. 36 (3) April 2010.

Merritt DM and Wohl EE. 2002. Processes governing hydrochory along Rivers: Hydraulics, hydrology, and dispersal phenology: *Ecological applications* Vol. 12 (4) 1071–1087.

Mueller ER and Pitlick J. 2005. Morphologically based model of bed load transport capacity in a headwater stream. *Journal of Geophysical Research* Vol 110:1–14.

Naiman RJ and Decamps H. 1997.The ecology of interfaces: Riparian zones. Annual reviews. *Ecol. Syst.* 28: 621–58

Naiman RJ, Decamps H and McClain ME. 2005. Riparia. Ecology, conservation and management of streamside communities. Elsevier Academic Press, MA, USA

NWA. 1998. National Water Act No. 36, Government Gazette No. 19182, 26 August 1998. The Republic of South Africa.

NEMA. 1998. National Environmental Management Act. No. 107, Government Gazette No. 19519, The Republic of South Africa.

Oliff WD. 1960. Hydrobiological studies on the Tugela River system. Part 1: the main Tugela River. *Hydrobiologia* 14: 281–385

Ollis DJ, Dallas HF, Esler KJ and Boucher C. 2006. Bioassessment of the ecological integrity of river ecosystems using aquatic macroinvertebrates: an overview with a focus on South Africa. *African Journal of Aquatic Science* Vol. 31 (2) 205–227

Petts GE. 1994. Rivers: dynamic components of catchment ecosystems, in Calow P and Petts GE (Eds). *The River Handbook. Hydrological and Ecological Principles,* Vol. 2. Blackwell Scientific Publications, Oxford. 3–22

Poff LN and Ward JV. 1989. Implications of streamflow variability and predictability for lotic community structure: A regional analysis of streamflow patterns. *Can. J. Fisheries & Aquat Sci* Vol. 46 (10) 1805–1818

Poff LN, Allan JD, Bain BM, Karr JR, Prestegaard KL, Richter BD, Sparks ER and Stromberg CJ. 1997.The natural flow regime. A paradigm for river conservation and restoration. *Bio Science* Vol. 47 (11) 769–784.

Ractliffe SG. 2007. Berg River Baseline Monitoring Programme Final report - VOLUME 1: Introduction to the Berg River Catchment; Groundwater and Hydrology DWAF Report No. P WMA 19/G10/00/1707

Ractliffe SG. 2009. The hydrological characteristics of the Berg River. *Transactions of the Royal Society of South Africa* Vol. 64 (2) 96–118.

Reed LL and Kleynhans TE. 2009. Agricultural land purchases for alternative uses – evidence from two farming areas in the Western Cape Province, South Africa. *Agrekon* Vol 48(3)

REMP manual website http://www.dwa.gov.za/iwqs/rhp/naehmp.aspx

REMP http://www.dwa.gov.za/iwqs/rhp/default.aspx

Rhemtulla JM and Mladenoff DJ. 2007. Why history matters in landscape ecology. *Landscape Ecology* 22: 1-3.

Richardson DM, Holmes PM, Esler KJ, Galatowitsch SM, Stromberg JC, Kirkman PS, Pysek P and Hobbs RJ. 2007. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. *Diversity and Distributions* Vol.13: 126–139.

Richter BD, Baumgartner JV, Powell J, Braun DP. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10 (4) 1163–1174.

Richter BD, Mathews R, Harrison D and Wigington R. 2003. Ecologically sustainable water management: Managing river flows for ecological integrity. *Ecological Applications* Vol. 13 (1) 206–224.

Roux DJ, Kempster PL, Kleynhans CJ, Van Vliet HR and Du Preez HH. 1999. Integrating stressor and response monitoring into a resource-based water quality assessment framework. *Environmental Management* 23 (1) 15–30

Rowntree KM, Kelly L, Rountree M. 2013. River ecoclassification: manual for ecostatus determination (version 2). Module B: Geomorphology Driver Assessment Index (GAI). WRC Report No TT 551/13. Water Research Commission, Pretoria, South Africa.

SANBI GIS. www.sanbi.org.za

Scherman P. 2008. Methods for determining the water quality component of the ecological reserve for rivers. Prepared for the Department of Water Affairs by Scherman Colloty and Associates.

Schumm SA. 1963. Sinuosity of alluvial rivers on the Great Plains: *Geol. Soc. America Bulletin* Vol 74: 1089–1100.

Searcy JK and Hardison CH. 1960. Double-mass curves. Manual of hydrology: Part 1. General surface-water techniques. Methods and practices of the Geological Survey.

Sieberhagen A. 2000. Distribution, abundance and conservation of indigenous freshwater fish species of the Berg River, Western Cape Province, South Africa. Unpublished BSc (Hons) thesis, University of Stellenbosch. 11p.

Snaddon CD and Davis BR. 1998. A preliminary assessment of the effects of a small South African Inter-Basin Water Transfer on discharge and invertebrate community structure. *Regulated Rivers Research and Management* 14: 421–441.

Snaddon CD and Davies BR. 2000. An assessment of the ecological effects of inter-basin water transfer schemes (IBTs) in dryland environments. WRC Report TT 665/1/00. Water Research Commission, Pretoria, South Africa.

Thirion C. 2007. River ecoclassification manual for ecostatus determination (Version 2). Module E. Macroinvertebrates Response Assessment Index (MIRAI). WRC Report No TT 377-08. Water Research Commission, Pretoria, South Africa.

Thompson JN, Reichman OJ, Morin PJ, Polis GA, Power ME, Sterner RW, Couch CA, Gough, L, Holt R, Hooper DU *et al*. 2001. Frontiers of Ecology: As ecological research enters a new era of collaboration, integration, and technological sophistication, four frontiers seem paramount for understanding how biological and physical processes interact over multiple spatial and temporal scales to shape the earth's biodiversity. *BioScience* Vol. 51 (1) 15–24

Thorne CR. 1990. Effects of vegetation on riverbank erosion and stability. *Vegetation and Erosion: Processes and Environments* JB Thornes (Ed.) Chichester: John Wiley and Sons, pp. 125–144.

Tockner K, Pusch M, Borchardt D and Lorang MS. 2010. Multiple stressors in coupled river floodplain ecosystems. *Freshwater Biology* Vol. 55 (1) 135–151

Turner MG, O'Neill VR, Gardner RH and Milne BT. 1989. Effects of changing spatial scale on the analysis of landscape pattern. *Landscape Ecology* Vol. 3 (3/4) 153–162

Turner MG. 2005. Landscape ecology: What is the state of the science? *Annu. Rev. Ecol. Evol. Syst* (5) Vol. 36: 319–44

Van Meter K, Thompson SE, Basu NB. 2016. Human impacts on stream hydrology and water quality. *Stream Ecosystems in a Changing Environment* DOI/10.1016/B978-0-12-405890-3.00011-7.

Ward JV, Tockner K, Uehlinger U and Malard F. 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. *Regulated Rivers: Research & Management* Vol. 17: 311–323

www.fewlbnexus.uct.ac.za