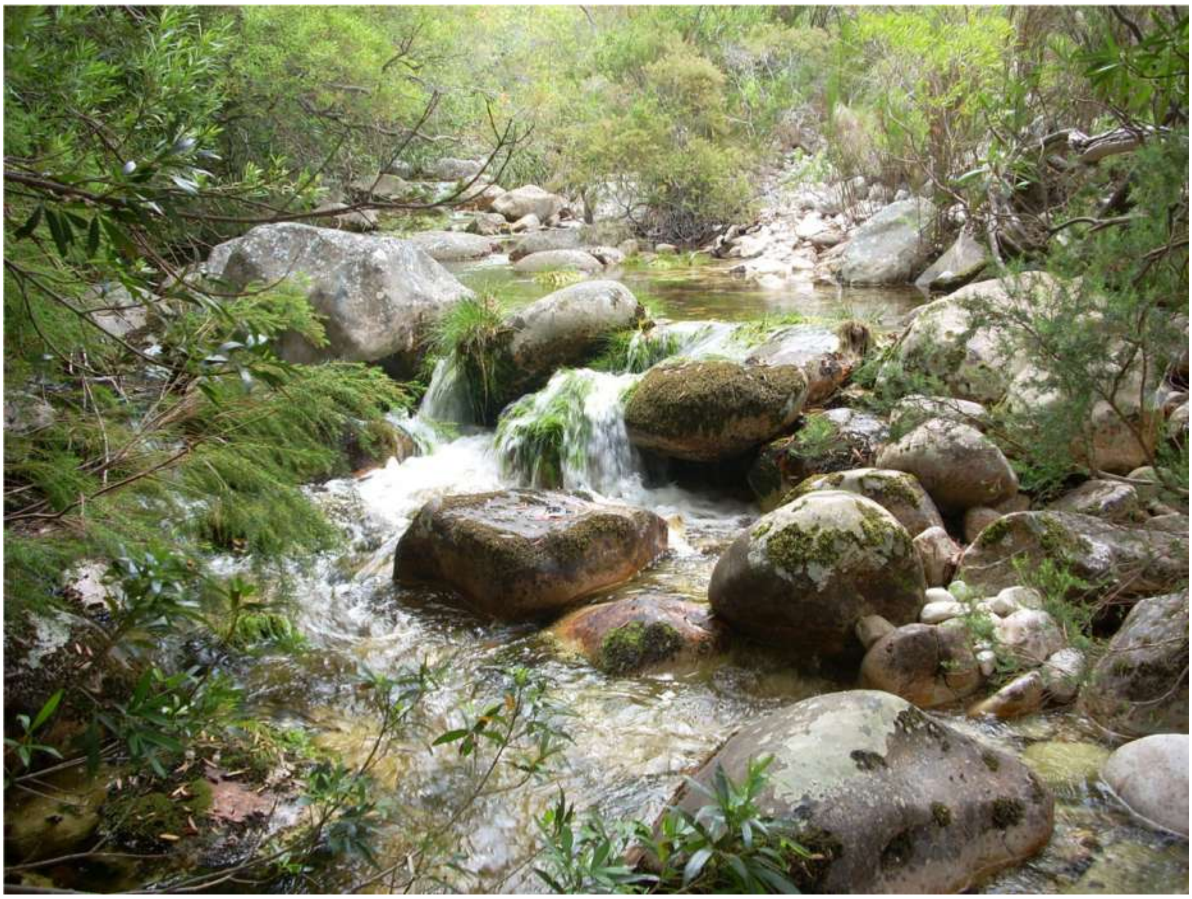
TMGA EXPLORATORY PHASE MONITORING

FINAL REPORT
VOLUME A

REPORT TO THE TMGA AQUIFER ALLIANCE
AND
THE CITY OF CAPE TOWN



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GLOSSARY, ACRONYMS AND ABBREVIATIONS

Glossary

Alluvial aquifer: an aquifer formed of unconsolidated sediments deposited by flowing water (river or stream); typically occurring beneath or alongside a current channel, or in a buried old or palaeo-channel of the river (from Colvin *et al.,* 2007).

Alluvial: a deposit formed by flowing water, often in the valleys of large rivers.

Aquifer: a geological formation, which has structures or textures that hold water or permit appreciable water (sufficient to supply a well or borehole) movement through them (from National Water Act (Act No. 36 of 1998)).

Aquifer-dependent ecosystems (ADE): ecosystems that depend on groundwater in or discharging from an aquifer (Colvin *et al.,* 2007). They are distinctive because of their connection to the aquifer and would be fundamentally altered in terms of their structure and functions if groundwater was no longer available.

Aquitard / aquiclude: a saturated body of poorly permeable rock that is capable of slowly absorbing water from and releasing it to an aquifer. It does not transmit water rapidly enough, by itself, to directly supply a borehole or spring (McGraw-Hill, 1978).

Arenaceous: composed of sand or sandstone.

Argillaceous: composed of very fine-grained material, such as clay, shale, etc.

Base flow: that part of the stream discharge that is not attributable to direct runoff from precipitation; usually sustained by groundwater.

Baseflow recession curve: a recession curve of streamflow so adjusted that the slope of the curve represents the runoff depletion rate of the groundwater.

Borehole: includes a well, excavation, or any other artificially constructed or improved groundwater cavity which can be used for the purpose of intercepting, collecting or storing water from an aquifer; observing or collecting data and information on water in an aquifer; or recharging an aquifer (from National Water Act (Act No. 36 of 1998)).

Cape Fold Belt: folded sedimentary sequence of rocks in the south-western Cape, comprising shales in the valleys and erosion-resistant sandstone forming the mountain ranges.

Capillary fringe: the subsurface layer in which groundwater seeps up from a water table by capillary action to fill pores. Pores at the base of the capillary fringe are filled with water due to tension saturation.

Channel: an open conduit with clearly defined margins that (i) continuously or periodically contains flowing water, or (ii) forms a connecting link between two waterbodies.

Channelled valley-bottom wetland: a mostly flat valley-bottom wetland dissected by and typically elevated above a channel. Dominant water inputs to these areas are typically from the channel, either as surface flow resulting from overtopping of the channel bank/s or as interflow, or from adjacent valley-side slopes (as overland flow or interflow). Water generally moves through the wetland as diffuse surface flow, although occasional, short-lived concentrated flows are possible during flooding events. Small depressional areas within a channelled valley-bottom wetland can result in the temporary containment and storage of water within the wetland. Water generally exits in the form of diffuse surface flow and interflow, with the infiltration and evaporation of water from these wetlands also being potentially significant (particularly from depressional areas). The hydrodynamic nature of channelled valley-bottom wetlands is characterised by bidirectional horizontal flow, with limited vertical fluctuations in depressional areas.

Colluvial: material deposited through gravity.

Confined aquifer: Groundwater below a layer of solid rock or clay is said to be in a confined aquifer. The rock or clay is called a confining layer. A borehole that goes through a confining layer is known as an artesian well. The groundwater in confined aquifers is usually under pressure. This pressure causes water in an artesian well to rise above the aquifer level. If the pressure causes the water to rise above ground level, the well overflows and is called a flowing artesian well.

Conglomerate: this is a rock consisting of individual clasts within a finer-grained matrix that have become cemented together. Conglomerates are sedimentary rocks consisting of rounded fragments.

Discharge area: an area in which subsurface water, including water in the unsaturated and saturated zones, is discharged at the land surface; may be associated with a wetland or a stream (from Colvin *et al.*, 2007).

Drawdown: the difference between the water table level observed during abstraction and the rest water level when no abstraction is taking place (McGraw-Hill, 1978).

Ductile: refers to the ability of a material to deform elastically without fracture, i.e. whether the material can be stretched into a wire.

Ecochannels: TMGA ecological monitoring river channel sites.

Ecoseeps: TMGA ecological monitoring wetland (both seeps and valley-bottom wetlands) sites.

Edaphic: of or relating to the physical and chemical conditions of the soil, especially in relation to the plant and/or animal life it supports.

Flora: the plant species occurring in a particular area; usually recorded as present or absent.

Fractured aquifer: an aquifer that owes its water-bearing properties to water storage and flows through fractures in the rock caused by folding and faulting (from Colvin *et al.*, 2007).

Granitic plutons: a pluton in geology is an intrusive igneous rock (called a plutonic rock) body that crystallized from magma slowly cooling below the surface of the Earth. Plutons include batholiths, dikes, sills, laccoliths, lopoliths, and other igneous bodies. In practice, "pluton" usually refers to a distinctive mass of igneous rock, typically kilometres in dimension, without a tabular shape like those of dikes and sills. Batholiths commonly are aggregations of plutons. The most common rock types in plutons are granite, granodiorite, tonalite, monzonite, and quartz diorite. The term originated from Pluto, the ancient Roman god of the underworld. Outcrop of plutonic granite on the earth's surface requires some kind of erosion to expose the buried granite. Granites may take the form of batholiths; sills and sheets; swarms of plutonic intrusions or migmatite complexes. They form the major part of surface exposure of continental crust.

Greywacke: this is a variety of sandstone generally characterized by its hardness, dark colour, and poorly-sorted, angular grains of quartz, feldspar, and small rock fragments or lithic fragments set in a compact, clay-fine matrix. It is a texturally immature sedimentary rock. The larger grains can be sand- to gravel-sized, and matrix materials generally constitute more than 15% of the rock by volume. The term 'Greywacke' can be confusing, since it can refer to either the immature (rock fragment) aspect of the rock or the fine-grained (clay) component of the rock.

Groundwater: water found in the subsurface in the saturated zone below the water table or piezometric surface i.e. the water table marks the upper surface of groundwater systems.

Groundwater-dependent ecosystems (GDEs): ecosystems that must have access to groundwater to maintain their ecological structure and function (from Murray, 2006, cited in Colvin *et al.*, 2009).

Habitat: the natural home of species of plants or animals.

Hillslope seep: a wetland area located on (gently to steeply) sloping land, which is dominated by the colluvial (i.e. gravity-driven), unidirectional movement of material down-slope. Water inputs are primarily from groundwater or precipitation that that enters the wetland from an up-slope direction in the form of subsurface flow. Water movement through the wetland is mainly in the form of interflow, with diffuse overland flow (sheetwash) often being significant during and after rainfall events. Water leaves a hillslope seep with channelled outflow mostly by means of concentrated surface flow, whereas water leaves a hillslope seep without channelled outflow by means of a combination of diffuse surface flow, interflow, evaporation and infiltration.

Hornfels: this is the group designation for a series of contact metamorphic rocks that have been baked by the heat of intrusive igneous masses and have been rendered massive, hard, splintery, and in some cases exceedingly tough and durable. Most hornfels are fine-grained, and while the original rocks (such as sandstone, shale and slate, limestone and diabase) may have been more or less fissile owing to the presence of bedding or cleavage planes, this structure removed in the hornfels.

Hydraulic conductivity: measure of the ease with which water will pass through earth material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow (in m/d)

Hydraulic gradient: the slope of the water table or piezometric surface; is a ratio of the change of hydraulic head divided by the distances between the two points of measurement.

Hydraulic lift: the process whereby deep rooting plants take up groundwater during the day, and release it at night at shallower depths.

Interflow: lateral movement of water that occurs in the upper part of the unsaturated zone, or vadose zone, that **directly** enters a stream channel or wetland without having occurred first as surface runoff (from www.physicalgeography.net, January 2010).

Intermittently inundated: holding surface water irregularly for changeable time periods of less than one season's duration (but generally for periods of less than 3 to 4 weeks), at intervals varying from less than a year to several years.

Lower foothill River: lower-gradient, mixed-bed alluvial channel with sand and gravel dominating the bed and may be locally bedrock controlled; reach types typically include pool-riffle or pool-rapid, with sand bars common in pools; pools are of significantly greater extent than rapids or riffles. Characteristic gradient is 0.001–0.005.

Mountain stream: steep-gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools; reach types include cascades, bedrock fall, step-pool; approximately equal distribution of vertical and horizontal flow components. Characteristic gradient is 0.04–0.99.

Never inundated: never covered by water for more than a few days at a time (up to one week at most), but saturated with water at least intermittently for one week or more at a time.

Non-perennial: does not flow or hold water continuously throughout the year.

Peat: a dark brown or black organic soil layer, composed of partly decomposed plant matter, and formed under permanently saturated conditions.

Pelitic: of sedimentary rock made up of fine material, such as clay or mud (see also argillaceous).

Perched water table: the surface of a local zone of saturation held above the main body of groundwater by an impermeable layer or stratum, usually clay, and separated from the main body of groundwater by an unsaturated zone.

Perennial: flows or holds water continuously throughout the year.

Permanently inundated: with surface water present throughout the year.

Permanently saturated: where all the pores between the soil particles are permanently filled with water.

Petrography: study dealing with microscopic details of rock, looking at the mineral content and textural relationships.

Phreatic zone: below ground saturated zone up to the top of the water table.

Phyllite: a type of foliated metamorphic rock primarily composed of quartz, sericite mica, and chlorite. The rock represents a gradation in the degree of metamorphism between slate and mica schist. Minute crystals of graphite, sericite, or chlorite impart a silky, sometimes golden sheen to the surfaces of cleavage (or schistosity). Phyllite is formed from the continued metamorphism of slate, under low grade metamorphic conditions. They are usually black or gray, and the foliation is commonly crinkled or wavy in appearance.

Piezometer: narrow diameter piping that is installed through a means of water jetting, augering or drilling to enable measurement of the depth of the groundwater level and also abstraction of groundwater if required for sampling purposes (if the transmissivity of the aquifer is high enough).

Piezometric surface: water table

Quartzite: this is a hard metamorphic rock which was originally sandstone. Sandstone is converted into quartzite through heating and pressure usually related to tectonic compression within orogenic belts. Pure quartzite is usually white to grey. When sandstone is metamorphosed to quartzite, the individual quartz grains recrystallize along with the former cementing material to form an interlocking mosaic of quartz crystals. Most or all of the original texture and sedimentary structures of the sandstone are erased by the metamorphism.

Recharge: a hydrologic process where water moves downward from the earth's surface to groundwater (i.e. the saturated zone). This process usually occurs through the vadose zone below plant roots and is often expressed as a flux to the water table surface.

Seasonal: with water present for extended periods during the wet season but not during the rest of the year.

Seasonally inundated: with surface water present for extended periods (usually more than three to four weeks duration) during the wet season but drying up annually, either to complete dryness or to saturation during the dry season.

Seasonally saturated: with all the spaces between the soil particles filled with water for extended periods (3 – 10 months of the year), usually during the wet season, but dry for the rest of the year (during the dry season).

Semi-confined aquifer: an aquifer that is partly confined by layers of lower permeability material through which recharge and discharge may occur, also referred to as a leaky aquifer (from Colvin *et al.*, 2007).

Shale: This is a fine-grained, clastic sedimentary rock composed of mud, which is a mix of flakes of clay minerals and tiny fragments (silt-sized particles) of other minerals, especially quartz and calcite. The ratio of clay to other minerals is variable. Shale is characterized by breaks along thin laminae or parallel layering or bedding less than one centimetre in thickness, called fissility. (Mudstones, on the other hand, are similar in composition but do not show the fissility).

Slate: this is a fine-grained, foliated, homogeneous metamorphic rock derived from an original shale-type sedimentary rock composed of clay or volcanic ash through low grade regional metamorphism. The result is a foliated rock in which the foliation may not correspond to the original sedimentary layering. Slate is frequently grey in colour especially when seen en masse covering roofs. However, slate occurs in a variety of colours even from a single locality. Slate is not to be confused with shale, from which it may be formed.

Slope: an inclined stretch of ground that is not part of a valley floor, which is typically located on the side of a mountain, hill or valley (includes scarp slopes, mid-slopes and footslopes). Slopes are considered to be those areas where the gradient is steeper than 0.001 (i.e. 1:1000).

Soil profile: a vertical section of the soil through all its horizons and extending to the underlying material.

Soil water: water held in the soil pores (gaps between the particles), in both liquid and vapour phases (McGraw-Hill, 1978) - may be saturated or unsaturated (wet or dry). Measured as **volumetric soil moisture content**, as a percentage of the soil dry weight (% by weight) but sometimes as the volume of water as a percentage of the soil volume (% by volume) or as the depth of water per metre depth of soil (m/m). **Soil saturation** is the water content of a soil when all the pores (total porosity) are filled with water, while the **degree of soil saturation** is the water content of a soil expressed as a percentage of the total porosity (saturated water content).

Spring: a distinct point or area where groundwater emerges at the surface.

Sub-greywacke: texturally and mineralogically immature sandstones that contain more than 15% clay minerals, however the fragments of quartz and feldspar are sub-rounded (not angular). The matrix comprises clay minerals, chlorite and carbonate

Subsurface water - all water which occurs beneath the surface of the earth, including soil moisture, liquid water in the vadose zone and groundwater (from Colvin *et al.,* 2007).

Terrane: a fragment of crustal material formed on, or broken off from, one tectonic plate and accreted — "sutured" — to crust lying on another plate. The crustal block or fragment preserves its own distinctive geologic history, which is different from that of the surrounding areas (hence the term "exotic" terrane). The suture zone between a terrane and the crust it attaches to is usually identifiable as a fault.

Throughflow: lateral movement of water that occurs in the upper part of the unsaturated zone, or vadose zone, which emerges first as surface runoff before entering a waterbody (from www.physicalgeography.net, January 2010).

Throughflow: lateral movement of water that occurs in the upper part of the unsaturated zone, or vadose zone, which emerges first as surface runoff before entering a waterbody (from www.physicalgeography.net, January 2010).

Transitional river: moderately steep stream dominated by bedrock and boulders; reach types include plain-bed, pool-riffle or pool-rapid; usually in confined or semi-confined valley. Characteristic gradient is 0.02–0.039.

Transmissivity: the rate at which a volume of water is transmitted through a unit width of aquifer under a unit hydraulic head (m^2/d); product of the thickness and average hydraulic conductivity of an aquifer.

Unconfined aquifer: these are sometimes also called water table or phreatic aquifers, because their upper boundary is the water table or phreatic surface. Typically (but not always) the shallowest aquifer at a given location is unconfined, meaning it does not have a confining layer between it and the surface. Unconfined aquifers usually receive recharge water directly from the surface, from precipitation or from a body of surface water (e.g., a river, stream, or lake) which is in hydraulic connection with it.

Unconformably: where a series of younger strata do not succeed the underlying older rocks in age or in parallel position, as a result of a long period of erosion or non-deposition.

Upper foothill river: moderately steep, cobble-bed or mixed bedrock-cobble bed channels, with plain-bed, pool-riffle or pool-rapid reach types; length of pools and riffles/rapids is similar. Characteristic gradient is 0.005–0.019.

Vadose zone: the unsaturated zone above the water table and below the ground surface.

Valley floor: the typically gently sloping, lowest surface of a valley – i.e. an elongated, relatively narrow region of low land between ranges of mountains, hills, or other high areas (such as sand dunes), often having a river or stream running along the bottom. For the purposes of the classification system, valley floors exclude areas situated between two valley side-slopes with a gradient of 0.1 or more (i.e. ≥ 1:10). The valley floor typically has a gradient of between 0.001 and 0.1 (i.e. 1:1000 to 1:10).

Vegetation: the structure and floristics of the plant life of a given area, which is distinct due to its broad habitat. Unlike flora (presence and absence), this includes dominance/abundance of plant species.

Water table: the upper surface of the saturated zone of an unconfined aquifer at which pore pressure is at atmospheric pressure, the depth to which may fluctuate seasonally.

Wetland: land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which under normal circumstances supports or would support vegetation typically adapted to life in saturated soil (National Water Act).

Acronyms and abbreviations

^{18}O	Oxygen-18
BH_ID	borehole identity number
CGS	Council for Geoscience
cm	centimetre
CMWL	Cape meteoric water line
D	deuterium (^2H)
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry

EC	Electrical Conductivity
EPM	Exploratory Phase Monitoring
FCG	Freshwater Consulting Group
GEOSS	Geohydrological and Spatial Solutions International (Pty) Ltd;
GMWL	global meteoric water line
H	height
H_Spr	hot spring
km	kilometre
LMWL	local meteoric water lines
m	metre
m/s	metres per second
m^3/d	cubic metres per day
m^3/s	cubic metres per second
Ma	Million years
ma.logger	metres above data logger
mbch	metres below collar height
mbgl	metres below ground level
Mm	millimetres
mm/month	millimetres per month
Mm^3/m	million cubic metres per month
MOD	moderate
MONAREA	monitoring area
mS/m	milliSiemens per metre
^oC	degrees Celsius
OD	outer diameter
ORP	Oxygen Reduction Potential
Pal	Palmiet River
PIEZO_ID	piezometer identity number
R^2	correlation coefficient
RSE	Riviersonderend River
SANBI	South African National Biodiversity Institute
SPR	spring
SRTM	Shuttle Radar Topography Mission
STR	stream
T	Temperature
TDS	Total Dissolved Solids
Temp	temperature
TMG	Table Mountain Group
TMGA	Table Mountain Group Aquifer
TMGAA	Table Mountain Group Aquifer Alliance
TMGA-EMA	Table Mountain Group Aquifer - Ecohydrological Monitoring Alliance
TMGID	Table Mountain Group identity number
TSA	Target Site Areas
UCT	University of Cape Town

V	velocity
W	width
W_G	weir gauge
WL	water level
WL	water level
WQ-F	water quality - field measurements
WQ-I	water quality – isotope measurements
WQ-L	water quality – laboratory measurements
WRC	Water Research Commission

1. INTRODUCTION

1.1 BACKGROUND TO THIS STUDY

The Table Mountain Group Aquifer (TMGA) system extends from the Bokkeveld Mountains in the north to Cape Agulhas in the south, and from Port Elizabeth in the east to Van Rhynsdorp in the west. The TMGA system comprises two key fractured sandstone aquifers, separated by a ~250m thick aquitard. The potential for large-scale groundwater abstraction from the confined aquifer is being investigated in the Table Mountain Group Aquifer Feasibility Study and Pilot Project (TMGA project), a project of the City of Cape Town. The project has been conducted under the auspices of the Table Mountain Group Aquifer Alliance (TMGAA).

The TMGA study has been underway since 2002 and is a phased study. At the end of each phase, decisions are made on whether to proceed with the next phase, and if so, the way forward (Figure 1.1). The main phases of the TMGA Feasibility Study and Pilot Project (hereafter referred to as the TMGA Project) are as follows:

Inception Phase:	Negotiations took place with the Client to finalise the Terms of Reference (ToR) and the budget.
Preliminary Phase:	The study focussed on the selection of the most favourable target areas for wellfields for pilot boreholes. Relevant factors and ramifications of these target areas were considered.
Exploratory Phase:	This phase is intended to verify the predicted aquifer characteristics through borehole siting, drilling and testing of Exploratory Boreholes and thus to refine the siting of the target well-fields and evaluate the risks associated with doing so.
Pilot Testing Phase:	During this final phase a number of boreholes will be drilled to develop at least one wellfield with a target yield of 3 to 5 million m^3/a.

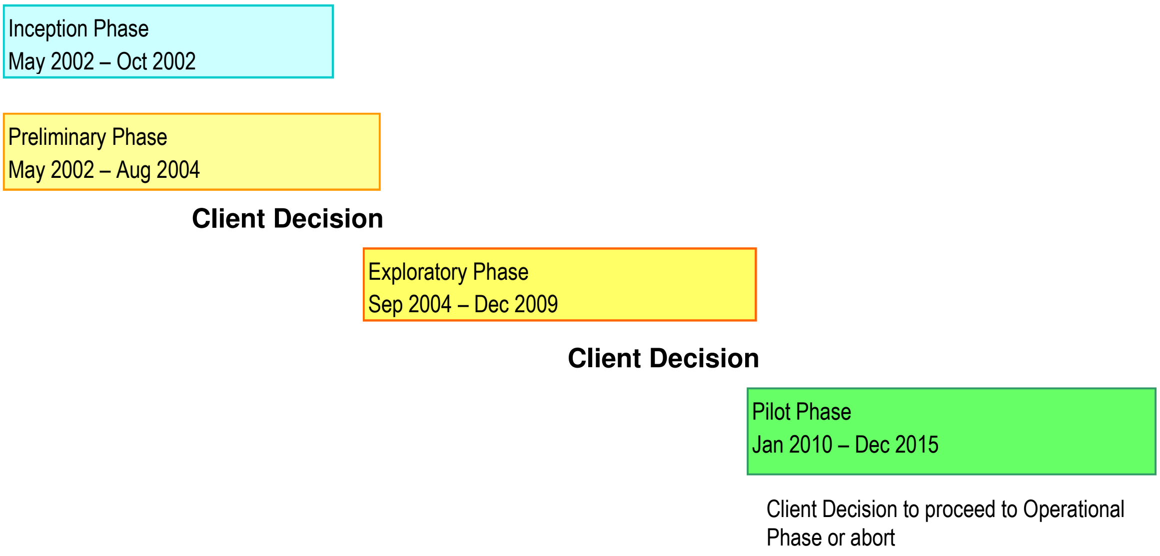

Figure 1.1. Structure and time schedule of TMGA Project.

The Inception and Preliminary Phases are complete and the Exploratory Phase is close to completion. During the Preliminary Phase the need and importance for a task that focussed specifically on monitoring of the surface water, groundwater and the various ecological settings was identified.

Monitoring of the condition of key ecosystem components is thus a requirement of all phases of the TMGA Project from Exploratory to Operational Phases, and monitoring activities are related to the specifics of each project phase. In relation to hydrological and geohydrological monitoring, a regional hydrocensus programme had already been established in 2003. This involves the bi-annual measurement of borehole water levels or stream flow and the collection of samples for chemical and isotope analysis at a large number of sites within the TMGA study area, and the downloading of data from selected DWA flow gauges. Further, an Ecological and Hydro(geo)logical Monitoring Protocol was developed by the TMGAA to cover each of the different phases on the project, and formed the basis of a tender document for Exploratory Phase Monitoring.

1.2 EXPLORATORY PHASE MONITORING

On 7th June 2007 The Director Water Services of the City of Cape Town awarded a contract to the Table Mountain Group Aquifer - Ecohydrological Monitoring Alliance (TMGA-EMA), to implement the Exploratory Phase Monitoring in TMGA study area. The TMGA-EMA comprises:

- GEOSS – Geohydrological and Spatial Solutions International (Pty) Ltd;
- FCG – The Freshwater Consulting Group;
- Coastec
- The Soil Doctor.

The TMGAA Monitoring Task Team established a Review Panel for the duration of this Exploratory Phase Monitoring (EPM) project. This scientific review committee comprises Dr Charlie Boucher, Dr Cate Brown and Dr Kornelius Riemann.

A distinction exists between the Exploratory Phase of the TMGA Project per se, and the Exploratory Phase Monitoring programme. The Exploratory Phase (see Figure 1.1) aims to verify the predicted aquifer characteristics through borehole siting, drilling and testing of exploration boreholes and thus to refine the siting of the possible pilot well-fields and evaluate the risks associated with doing so. This will be undertaken by the TMGAA. It is also charged with overseeing and reviewing the monitoring programme and, using the data and results from this, to refine subsequent monitoring activities.

The EPM is aimed at providing the data that will assist the TMGAA in achieving these aims. The EPM, up to the start of the Pilot-Testing Phase of the project or until a decision is made not to proceed with the project, will concentrate on establishing a study-wide baseline against which future results can be evaluated.

The baseline data set covers areas that may or may not be affected by future abstraction and thus, while some sites may later become near-field or far-field monitoring sites, and some sites may be designated as control sites in future phases of the TMGA, for the purposes of the EPM all monitoring sites have the status of baseline establishment sites.

1.2.1 Terms of Reference

The initial work completed during the EPM by TMG-EMA included a field-based evaluation of the suitability of over 100 sites for ecological monitoring, as listed in the tender document, and the evaluation of the list of hydrocensus boreholes and streamflow sites currently monitored. The TMG-EMA also assessed the feasibility and practicability of various monitoring methods stipulated in the project tender. This resulted in a revised Scope of Work as detailed in the first deliverable of this project, the TMG-EMA Inception Report (City of Cape Town, 2008). Two major departures from the Tender document were the inclusion of piezometer or stream water level monitoring at the ecological monitoring sites, instead of the installation of V-notch streamflow recorders at 10 other sites, as initially intended in the Tender Document, and a broadening of the biological monitoring activities for all three components – vegetation, algae and invertebrates. A field-based revisitation of sites by the TMGA-EMA and the TMGAA Review Panel was conducted as a result of the Inception Phase assessment, and a final list of 38 sites agreed upon[1].

An important component of the EPM is the evaluation of the usefulness or relevance of the sorts of data collected, to assist the TMGAA with the refinement of the monitoring protocols. The focus of the activities in the EPM is therefore threefold: to implementation the monitoring protocols agreed in the Inception Phase; to evaluate the usefulness of the measures; and to build up a baseline picture of 'non-impact' temporal change at the monitoring sites against which future patterns can be compared to infer whether impacts have occurred. These patterns of change will be used by the TMGAA to set Thresholds of Potential Concern (TPC) for the Pilot Phase impact monitoring.

The agreed role of the TMGA-EMA was therefore to:

- Install monitoring equipment at the 38 monitoring sites identified during the Inception Phase of the EPM, modified from the Tender Document list of sites during field visits with the TMGAA (two additional sites were added during 2009 after fires swept through some areas);
- Collect baseline data as described in the Inception Report, covering two annual cycles from April 2008 to March 2010;
- Continue the hydrocensus activities at the agreed surface and groundwater monitoring sites, up until the April 2010 hydrocensus;
- Perform data quality control, data verification and data auditing;
- Undertake preliminary analysis of the monitoring data;
- Interpret the relevance of the data, including:
    - assess selected sites in terms of their feasibility for monitoring infrastructure;
    - evaluate the practicality of the monitoring methods employed; and
    - review and advise on monitoring activities, as input into the TMGA Project's Pilot Phase.

1.2.2 Data collection

The installation of monitoring equipment and repair of existing equipment was carried out during and subsequent to the Inception Phase, and was reported on in the first Annual Report for the monitoring cycle- April 2008 to March 2009. Data collected for the first monitoring cycle, as per the agreed ToRs were as follows:

- A bi-annual hydrocensus at, and chemical analysis, including isotope analysis, of samples from, the agreed-upon monitoring boreholes;
- Bi-annual discharge measurement at and chemical analysis, including isotope analysis, of samples from the agreed-upon regional surface water monitoring sites;
- Downloading and collation of flow data from the DWA gauging weirs listed in the original hydrocensus terms of reference;
- Collection of monthly soil moisture data from five soil profiles at each of five of the ecoseeps;
- Collection of once-off soil chemistry data from each of the ecoseep/ecochannel sites;
- Collection of physico-chemical samples from surface water at ecoseeps/ecochannels: these data were collected during the first monitoring cycle as an additional activity to those specified in the ToRs, in order to help to characterise sites and interpret biological data;

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[1] Two new sites were added in March 2009, after a fire swept through the Nuweberg area.

- Annual monitoring of plant communities and bi-annual monitoring of attributes of individual plant species;
- Seasonal (three times per annum) monitoring of algal biomass and species composition, and
- Seasonal (three times per annum) monitoring of invertebrate assemblages.

1.2.3 Changes to the ToRs

In the First Annual Report provided by the TMGA-EMA, a number of recommendations were made regarding the suitability of the monitoring sites and the usefulness of the various data sets and methods for identifying and interpreting long-term change. These informed the Terms of Reference for the next round of monitoring, but also resulted in some changes to the ecological monitoring conducted during the second data collection cycle of the EPM. These changes included:

- Dropping of bi-annual discharge and water chemistry data collection from a suite of surface flow monitoring sites;
- Dropping of measurement of attributes of individual plants at the sites (plant vigour, water potential, leaf porometry, chlorophyll content);
- Increased effort in collection of invertebrate samples at seep sites, to refine the evaluation of the suitability of this measure for the future;
- Increase in the soil-profile soil moisture monitoring from five to eight ecoseep sites;
- Collection of soil moisture samples from each of the algal sampling points to improve interpretation of results and refine methods, and
- Extension of the collection of multispectral imagery - from a single aerial flight over the study sites to the collection of three sets of imagery and surveying of ground controls for ortho-rectification. Note that only limited analysis of the imagery was undertaken due to existing limitations in the scope of work for the EPM, but the data were considered important for future work in the Pilot Phase of the TMGA project.

In addition, the following activities were added to the scope of works conducted by the TMGA-EMA, within the total approved budget for the project:

- Installation of additional cumulative rainfall gauges in selected TSAs;
- Collection and compilation (but not analysis) of data from a suite of DWA regional boreholes that would not otherwise be monitored;
- Collection and compilation (but not analysis) of data from the TMGA Exploratory Phase Boreholes, and
- Decommissioning of infrastructure at sites that were to be excluded from future monitoring activities.

Despite the changes in the ToRs, all the monitoring activities and data collected during both cycles of the EPM are reported on in this Final Report, for completeness.

1.3 OUTLINE OF THE FINAL REPORT

1.3.1 Report content

With only two years' of data, the examination of "non-impact" baseline temporal trends will naturally be limited to merely commenting on inter-annual change. The focus of the analysis therefore was an updating of the analysis and conclusions drawn during compilation of the First Annual Report, covering the following:

- Provision of a time series dataset for water level / discharge for regional borehole, regional surface water and DWA gauge sites, and an assessment of the usefulness or viability of each of the monitoring points;
- An analysis of the geological and geohydrological attributes of the ecological monitoring sites and assessment of their likely connectivity to the Peninsula Aquifer;
- A classification of sites according to their geohydrological regime (seeps), or low flow characteristics (channels) to the extent that the data allow for this;
- A description of the physico-chemical conditions of the groundwater, surface water and soils and comment in inter-annual patterns;
- A description of the various biological attributes of the sites, with an attempt to identify patterns in the of grouping of sites, or biological entities within sites (e.g. communities), spread over the study area and over seasons, with comment in inter-annual patterns over the two years' of data collection;
- An attempt to explain the grouping of sites in relation to environmental factors – physical, chemical and especially hydrological attributes of the sites;
- An assessment of monitoring methods and monitoring sites in terms of their practicality, and
- Recommendations for changes in the monitoring protocol.

1.3.2 Report structure and layout.

This report is divided into two volumes. Volume A comprises summaries and interpretation of the monitoring data and the evaluation of the monitoring protocols and sites. Volume B is a companion document, containing most of the detailed maps of the sites and sampling locations within sites, detailed geology maps and cross sections, maps and summary details of borehole and surface flow monitoring locations and suitability, and a range of tables and graphs summarising data or site attributes that are referred to in Volume A. The raw data are all provided in a data CD.

Structure of Volume A

Chapter 1 provides the background to the Exploratory Phase Monitoring programme including its relationship to the phases of the TMGA project as a whole.

Chapter 2 lists and describes the 40 ecological monitoring sites in detail, including details of monitoring apparatus installed at each site, as well as information on the geological setting and hydrogeological characteristics of the sites, summary information on rainfall patterns across the study area and within each TSA, and a hydrogeomorphological classification of the sites.

Chapter 3 provides details and analysis of the geohydrology data collected for the EPM. This includes the hydrocensus data from its inception prior to the start of the EPM; details of additional infrastructure established during the EPM such as continuous monitoring at selected sites; information on the Exploratory Phase boreholes established by the TMGAA; and the groundwater monitoring established at the ecological monitoring sites. The results of data analysis at a regional scale is a coarse-level groundwater map for the TMGA study area and, for the ecological monitoring seep sites, an assessment of connectivity to the Peninsula Aquifer, and a categorisation according to hydroperiod, as a basis for the interpretation of patterns found in the biota.

Chapter 4 is similarly structure to Chapter 3, but presents the results of surface flow monitoring. This includes assessment of the usefulness of bi-annual measurement of discharge at localities within the study area, as specified in the original hydrocensus; a re-evaluation of the DWA gauges included in the hydrocensus monitoring lists; low-flow analysis of DWA data from a proposed new set of gauges, with recommendations for data interpretation in the future phases of the TMGA project; and presentation and analysis of the results of surface water level monitoring at the ecological monitoring channel sites, including their preliminary categorisation according to perenniality.

Chapter 5 presents a description of the physico-chemical conditions of the groundwater, surface water and soils. The data from the groundwater and surface hydrocensus sites as well as soil and surface water chemistry from the ecological monitoring sites are presented, with an analysis of trends across the study area. Soil moisture data from monitoring at a subset of ecological monitoring sites is used to show within-site differences in soil moisture regime.

Between-site and seasonal patterns are described for flora and vegetation (Chapter 6), algae (Chapter 7) and invertebrates (Chapter 8), along with an investigation of the extent to which these may be explained by hydrological or physico-chemical variables.

Finally, Chapter 9 is a synthesis and discussion of the main results of monitoring, and, importantly, an assessment of the methods employed during this first year of monitoring. Recommendations are made regarding both the methods and the scope of the programme, for implementation either in the second year of data collection, or in the Pilot Phase.

The following authors contributed to this report:

- Coastec – Barrie Low and Paul Emms.
- Freshwater Consulting Group (FCG) – Dr Geordie Ractliffe, Kate Snaddon and Justine Ewart-Smith, with assistance in data analysis from Dr Denise Schael and Dr Bruce Paxton.
- GEOSS – Geohydrological and Spatial Solutions International (Pty) Ltd - Julian Conrad, Regan Rose, Dale Barrow, Zahn Munch and Marilie Carstens.
- Soil Doctor – Dr Eduard Hoffman.

2. DESCRIPTION OF ECOLOGICAL MONITORING SITES

2.1 INTRODUCTION

The Preliminary Phase of the City of Cape Town's Table Mountain Group aquifer project identified geological structures and formations within some 27 Target Site Areas (TSAs) between Cape Hangklip in the south and Tulbagh in the north, which were to be targeted during the Exploratory Phase of the project. The list of 38 ecological monitoring sites finalised by the TMGA-EMA and TMGAA (see Chapter 1) were located in or immediately adjacent to these TSAs. Two additional sites were added in March 2009, as the result of a fire at Nuweberg in the northern Hottentots Holland Mountains.

Analysis of the geological setting of each ecological monitoring site, for example through interpretation of cross-sections through the geological formations, can provide a first estimate of the likelihood of connectivity between the ecological monitoring sites and the Peninsula Aquifer. All wetlands are dependent on water, as they are defined by the presence of water of sufficient quantity and over a sufficient interval to create conditions to which only specialised biota are adapted. Where groundwater is the source of this water, ecosystems making use of it may be dependent on this water source, to a greater or lesser extent (Hatton and Evans 1998, cited in Cleaver *et al.* (2003)). According to Colvin *et al.* (2007) the degree of dependency of an ecosystem on groundwater ranges from permanent to seasonal through to infrequent, such as only during periods of extended drought.

The likelihood and "strength" of connectivity with the Peninsula Aquifer are therefore important informants to the monitoring programme: the status of each monitoring point *vis a vis* whether or not it could be affected by drawdown of the Peninsula Aquifer, will need to be firmly established for future (e.g. Pilot) phases of the TMGA project, but the preliminary ascertainment of this status was considered an important step in this preparatory work for the EPM.

Rainfall is a key driver of surface hydrology and groundwater recharge, especially for the Peninsula aquifer. Rapid recharge and discharge of groundwater along multiple flow paths are characteristics of the typically high mountain catchments in the TMGA study area (Colvin *et al.* 2009). The distribution and timing of rainfall across the study area is important for understanding spatial and temporal patterns in recharge to groundwater and discharge to surface wetland ecosystems, such as the ecoseeps and ecochannels, and how these affect their biota. Temporal and spatial rainfall patterns across the study area, and differences in rainfall between the TSAs were thus examined using available rainfall data.

A further informant to contextualising the ecological monitoring sites is that of wetland type. Whilst wetlands can be grouped according to many different attributes, the hydrogeomorphic[2] (HGM) wetland classification system is one that focuses on ecosystem functioning (e.g. Kotze *et al.* 2008; MacFarlane *et al.* 2008). Such a functional classification is particularly pertinent for this EPM, given the recognition that geomorphology and hydrology are the driving forces that determine the existence of wetlands (including rivers) and how they function (e.g. SANBI 2009). The HGM system classifies wetlands according to the following attributes:

- Geomorphic setting (position of the wetland within the surrounding landscape);
- Water source and transport (e.g.. precipitation, surface and subsurface water flow and groundwater discharge), and
- Hydrodynamics (the flow and fluctuation of the water once in the wetland, i.e. the direction and strength of water flow within the wetland).

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[2] Hydrogeomorphic types make reference to the hydrology and morphology of the wetland type, and are thus based on wetland functioning (SANBI 2009).

These attributes influence other important abiotic features of a wetland, such as soil and surface water chemistry, the storage and release of water and substrate type, and so also the biotic features such as the quality of habitat, and the types of fauna and flora inhabiting the wetland. This classification system also improves our understanding of the links between ecosystem structure and function (Collins 2005). The HGM approach to wetland classification has been developed and refined for South Africa by SANBI (2009).

In the context of the groups of freshwater ecosystem types that constitute the EPM's ecological monitoring sites, it is useful to classify the ecosystems according to the HGM system, as this will ensure that systems are grouped according to how they function. In any comparison between systems or groups of systems, such as between impacted and unimpacted seeps or river channels, similar systems can be compared against each other.

2.2 METHODS

Geological cross–sections were drawn for all of the ecological monitoring sites or groups of sites, with cross–sections parallel to the dip of the geological formation (i.e. perpendicular to strike) in most instances. In some situations the profile line was not drawn parallel to the geological dip, but rather to a site-specific geological feature to which the ecoseep or ecochannel was considered to be related. The length of the individual cross–sections varied. Shuttle Radar Topography Mission (SRTM) data were used for the ground surface elevation profiles.

Rainfall data were obtained from 13 rainfall stations within the study area (see Appendix 1 of Volume B) that are managed by the South African Weather Services, Infruitec and GEOSS. These were used to compile summaries of rainfall within each of the TSAs, over the years of record and according to season. Non-parametric analysis of variance (Statistica Version 7) in rainfall per TSA was undertaken using data from the years 1999-2009. These were the years where data were available for all sites, and this was considered sufficient for analysis of differences between TSAs. The months of December, January, February and March were used to represent “Summer” and June, July, August and September were used to represent “Winter”.

The ecological monitoring sites were **classified** according to the National Wetland Classification System (SANBI 2009), which incorporates river channels and wetlands. The National Wetland Classification is a broadly hierarchical classification system (Figure 2.1), as follows:

- At a systems level (Level 1) wetlands are classified into Marine, Estuarine or Inland ecosystems, based on connectivity to the open ocean;
- Level 2 is the highest hierarchical level within Inland ecosystems, which assigns each wetland to one of 31 ecoregions[3], and
- Levels 3, 4 and 5 are those of landscape setting, hydrogeomorphic (HGM) type and period of saturation or inundation, also referred to as hydroperiod (SANBI 2009). Each HGM unit can further be classified according to a number of physical, botanical and chemical descriptors, but this detail was not considered necessary for this project.

The different categories within each of four hierarchical levels (Levels 2 to 5), which were used to classify the ecological monitoring sites are illustrated in Figure 2.1. Classification of the ecological monitoring sites deviated in one respect from the National Classification System, by making use of the

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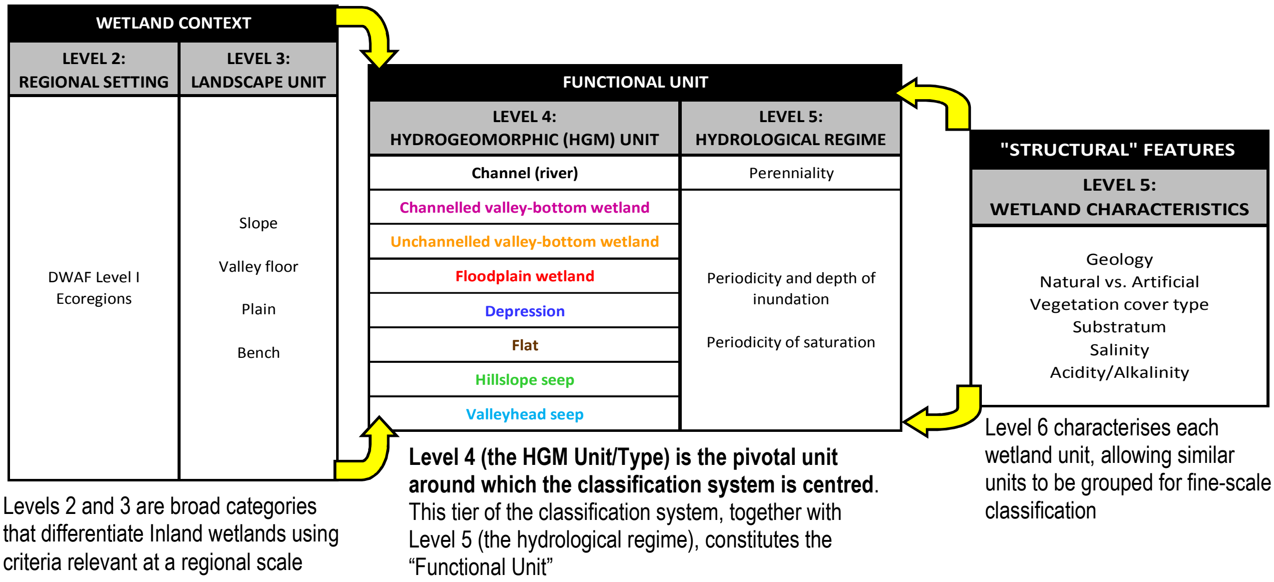
[3] These are the Department of Water and Environmental Affairs Level 1 Ecoregions, which were delineated according to a number of biotic and abiotic factors – specifically physiographic characteristics, climate, geology and soils and potential natural vegetation (Kleynhans *et al.* 2005).

terrestrial vegetation bioregional concept, as described by Mucina & Rutherford (2006), as an alternative descriptor at the regional level (Level 1). The bioregion is intermediate between vegetation types (such as Kogelberg Sandstone Fynbos) and biomes (such as the Fynbos Biome). This approach has been adopted by the current National Freshwater Ecosystems Priority Area (NFEPA) project and the National Wetlands Map project (SANBI), and was deemed appropriate for this study as it does away with the false heterogeneity introduced by the use of ecoregions – i.e. the study area encompasses four ecoregions, but only one bioregion – the Southwest Fynbos Bioregion.

The ecological monitoring sites were **grouped** according to their Level 4 (HGM unit) classification, and the underlying edaphic features. Further **categorisation** of sites according to the duration of saturation or inundation (Level 5 classification) made use of visual estimates of surface water conditions over the study period, and an analysis of the piezometer and water level gauge data. Inundation refers to the occurrence of surface water, and saturation periodicity refers to soil water content in the top 0.5 m of soil. These categorisations are discussed in Chapters 3 and 4.



Levels 2 and 3 are broad categories that differentiate Inland wetlands using criteria relevant at a regional scale

Level 4 (the HGM Unit/Type) is the pivotal unit around which the classification system is centred. This tier of the classification system, together with Level 5 (the hydrological regime), constitutes the "Functional Unit"

Level 6 characterises each wetland unit, allowing similar units to be grouped for fine-scale classification

Figure 2.1. Schematic of the National Wetland Classification system (from SANBI 2009) illustrating the different categories within each of four hierarchical levels (levels 2 to 5) which were used to classify the ecological monitoring sites.

2.3 RESULTS

2.3.1 Spatial distribution of sites

The distribution of all monitoring sites is shown in Figure 2.2. Their location within the prime geological target for the possible abstraction of groundwater, viz. the Table Mountain Group and more specifically the Peninsula Formation, in areas in close proximity to the existing surface water storage dams, is illustrated in Figure 2.3.

2.3.2 Geological setting

A summary of the geology of the study area sites is provided in Table 2.1. Detailed descriptions of the Table Mountain Group (TMG) are provided in the two reports: City of Cape Town (2004) and City of Cape Town (2008). Similar geological formations, generally with the full stratigraphy of the TMG, appear on most of the cross–sections. The TMG is underlain by the basal Malmesbury Group and the intrusive Cape Granite Suite. Although the latter intrudes into the Malmesbury Group (see below), its location at depth is not known, and is therefore not indicated on the cross–sections.

The Malmesbury Group is subdivided into three major tectonostratigraphic domains separated by three major tectonic dislocation zones (Theron *et al.* 1992). The Malmesbury Group of Namibian Age (> 630 Ma) is represented by the Tygerberg Formation (i.e. south-western-most tectonostratigraphic terrane), Franschhoek Formation (central tectonostratigraphic terrane) and Porterville Formation (northern-most tectonostratigraphic terrane). The Tygerberg Formation consists mainly of phyllite, greywacke and hornfels; the Franschhoek Formation of quartzite, subgreywacke, conglomerate, slate and Phyllite; and the Porterville Formation shale and greywacke.

The Cape Granite Suite intruded into the Malmesbury Group towards the end of the Malmesbury Group's main deformation phase, i.e. between 500 – 630 Ma (Gresse and Theron 1992). Several granitic plutons are recognised based on their petrographic and petrochemical properties.

The Cambrian Age (< 550 Ma) Klipheuwel Group unconformably overlies the Malmesbury Group and consists of conglomerate, subordinate sandstone and shale. The Klipheuwel Group has limited occurrence in the study area and is not shown on any of the cross–sections.

Table 2.1. Summary of geological formations.

Geological Age	Super-group	Group	Subgroup	Formation	Approximate Thickness	Intrusives
Quaternary	-	Sandveld/Bredasdorp	-	Various	-	-
Cretaceous	Cape	-	-	-	-	False Bay Suite
Devonian		Bokkeveld	Ceres	Gydo	160	-
		Table Mountain	Nardouw	Rietvlei	200	
Silurian				Skurweberg	400	
				Goudini	115	
			-	Cedarberg	60	
Ordivician				Pakhuis	70	
				Peninsula	1200	
				Graafwater	65	
				Piekenierskloof	150	
Cambrian		Klipheuwel	-	Magrug	1000	
	-	-	-	-	-	Cape Granite Suite
Namibian	-	Malmesbury	-	Porterville	-	-
				Franschhoek		
				Tygerberg		

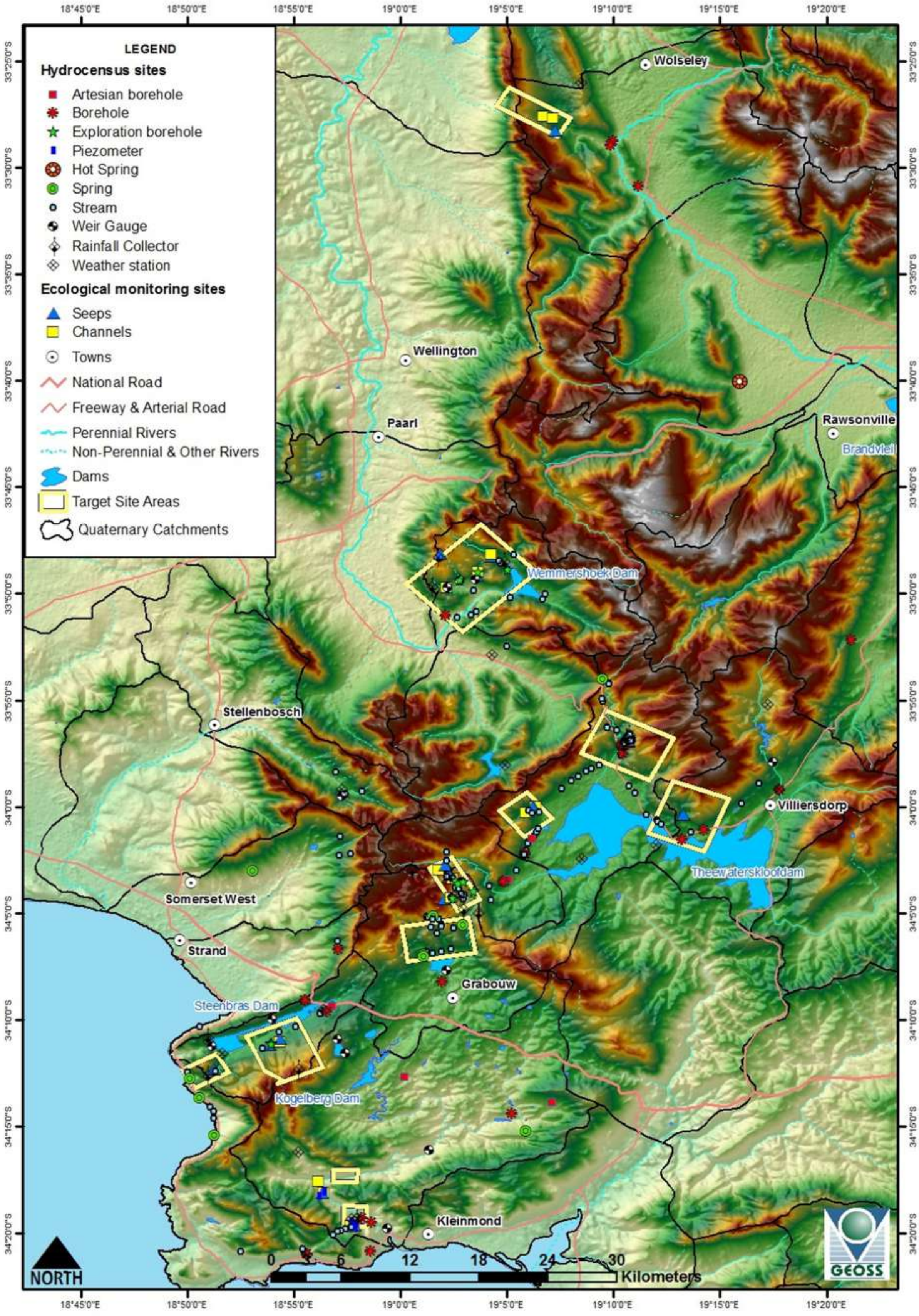


Figure 2.2. **Distribution of the TMGA-EMA monitoring sites across the study area.**

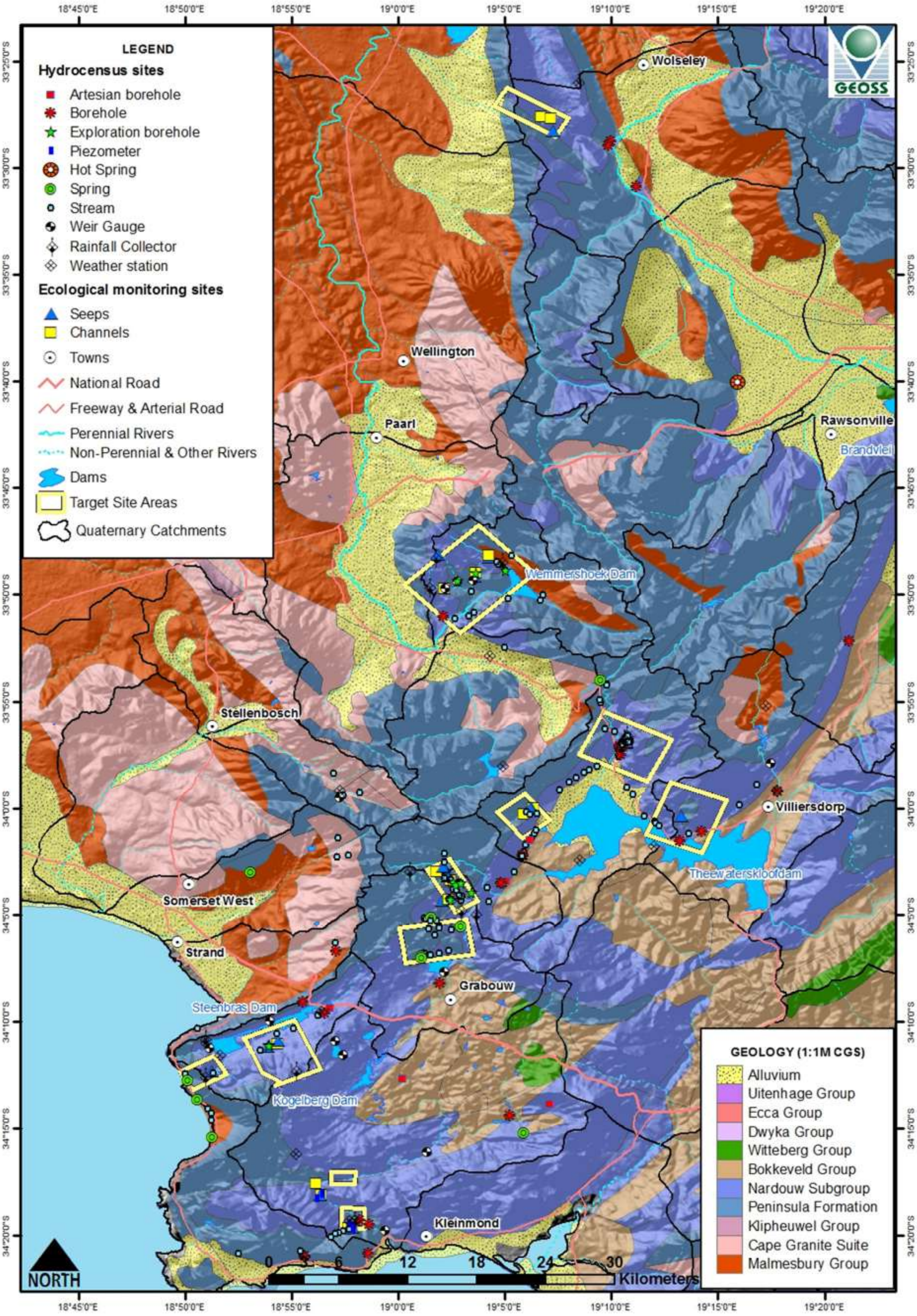


Figure 2.3. Distribution of the TMGA-EMA monitoring sites across the study area and their geological setting (source of geology data: 1:1M Council for Geoscience).

The TMG is divided into eight formations, although not all occur throughout the Cape Fold Belt. Two of the eight, the lowermost Piekenierskloof Formation and the overlying Graafwater Formation, do not occur in the study area, where the Peninsula Formation forms the basal unit of the TMG. The original TMG sediments, comprising mainly quartzitic sand, silt and clay, were deposited in a shallow marine environment (Theron *et al.* 1992). The Peninsula Formation consists of thick bedded quartzitic sandstone with minor shale and siltstone, and is approximately 1200 m thick in the Hottentots Holland area (Theron *et al.* 1992). The Peninsula Formation is highly resistant to weathering, and forms the high relief, topographically dominant mountain ranges in the study area. The Pakhuis Formation, which comprises the Kobe and Steenbras Members, is stratigraphically located above the Peninsula Formation and consists of greyish blue massive diamictite with sandstone (Gresse and Theron 1992). The Cedarberg Formation, with its Soom and Disa Members, conformably overlies the Pakhuis Formation, and comprises dark grey thinly laminated to massive shale, siltstone and sandstone (Gresse and Theron 1992) and forms smooth weathered slopes within the rugged Cape mountains. The Goudini Formation consists of thin bedded quartzitic sandstone with thin shale bands in places. The quartzitic units typically display a reddish-brown weathered discolouration (Theron *et al.* 1992), which is more prominent in the north of the region, particularly in the Cedarberg. The Goudini Formation has thinner bedding and a finer grain size than the overlying Skurweberg Formation, and varies in thickness from about 30 – 115 m (Gresse and Theron 1992). The Skurweberg Formation consists of thick bedded, coarse grained, light grey quartzitic sandstone, and has a total thickness that varies between 206 – 400 m (Gresse and Theron 1992). Like the Peninsula Formation, the Skurweberg Formation is also resistant to weathering and forms a rugged mountainous topography. The Rietvlei Formation is comprised of quartzitic and feldspathic sandstone with minor shale (Gresse and Theron 1992). The Rietvlei Formation (which is the uppermost stratigraphic unit of the TMG) is more thinly bedded than the underlying Skurweberg Formation, and has an average thickness of 200 m (Gresse and Theron 1992). The Goudini, Skurweberg and Rietvlei Formations make up the Nardouw Sub-group.

The Bokkeveld Group, which overlies the TMG, consists of five arenitic formations that alternate with six pelitic formations. The Bokkeveld Group has a very limited occurrence in the study area. Of the 11 formations in the Bokkeveld Group, only the basal Gydo Formation occurs on some of the cross-sections. The Gydo Formation, regarded as pelitic, consists of black shale, mudstone and siltstone, and is approximately 160 m thick (Gresse and Theron 1992).

The pene-contemporaneous False Bay Suite of ~136 Ma-old dolerite dykes is confined to the south-western part of the study area, between the Cape Peninsula and the Kogelberg mountain range. Tertiary and Quaternary sediments of the Sandveld and Bredasdorp Group occur along the coastline of the study area, while younger fluvial sediments are often present underlying larger river systems and large synclinal basins.

The TMG underwent two main phases of deformation. The first phase involved a period of mountain building, known as the Cape Orogeny, which resulted in uplift and thickening, whilst the second phase involved the break-up of Gondwanaland (Gresse and Theron 1992). These events resulted in a network of fractures and faults in the competent geological formations, i.e. quartzitic sandstone, and extensive folding in the more ductile shale layers. Continental movement caused the layers to be “squeezed” into folds with resultant uplift and formation of the Cape Fold Belt Mountains (Gresse and Theron 1992).

2.3.3 Hydrogeological properties of the TMG Superaquifer

The TMG superaquifer is a fractured rock aquifer system. The network of fractures, faults, fissures and joints (collectively called fractures) that resulted from the deformation of the TMG discussed above controls the infiltration, storage and transmissivity of groundwater (DWAF 2001).

The TMG is divided into two main aquifers, i.e. the lower Peninsula Aquifer (comprising the Peninsula Formation) and the upper Nardouw Aquifer (comprising the Skurweberg Formation and quartzitic units of the Rietvlei Formation) (Table 2.2). These are separated by the largely impermeable Winterhoek Mega-aquitard, which is comprised of the Pakhuis, Cedarberg and Goudini Formations. The fractured rock groundwater systems of the tectonically folded TMG constitute a vast aquifer system extending from just north of Nieuwoudtville southwards to Cape Agulhas and eastwards to Port Elizabeth. The volume of the aquifer in the whole area comprises over 100 000 km^3 of water (Hartnady and Hay 2002a).

The Peninsula Aquifer is the thicker of the two aquifers, and it dominates the high mountain ranges of the Western Cape (City of Cape Town 2004). As a result, the Peninsula Aquifer receives more rainfall, and is recharged at a higher rate than the Nardouw Aquifer. The outcrop areas of the Nardouw Aquifer generally occupy the lower-lying mountain ranges and hillslope areas. Estimates of TMG aquifer recharge vary between 7 and 23 %, with some models indicating that recharge may reach a maximum of 30 - 40 % at high elevations (Hartnady and Hay 2002b).

The Peninsula Aquifer discharges water at a variety of surface ecosystems. For instance, the aquifer discharges large volumes of water along fractures at perennial and geothermal springs, or directly into the ocean. The exposed and un- to semi-confined portions of the Peninsula Aquifer contribute to river flow as direct surface runoff (e.g. base flow) or as indirect interflow. Perennial springs are also located where the semi-confined to confined portions of the Peninsula Aquifer make contact with the Winterhoek Mega-aquitard (Colvin *et al.* 2009). The generally unconfined Nardouw Aquifer discharges more weakly as seasonal springs that tend to be more responsive to rainfall events (Colvin *et al.* 2009). The Skurweberg Formation is often exposed within synclinal basins, and can contribute directly to riverine baseflow or springs, particularly where it makes contact with the Winterhoek Mega-aquitard.

Table 2.2. Hydrostratigraphy of the geological formations within the study area.

Superunits	Unit	Subunits	Coincident geological unit
	Quaternary Aquifer		Various discrete alluvial aquifers
	Gydo Mega-aquitard		Bokkeveld Group
Table Mountain Superaquifer (TMG)	Nardouw Aquifer	Rietvlei Subaquifer	Rietvlei Formation
		Verlorenvalley Mini-aquitard	
		Skurweberg Subaquifer	Skurweberg Formation
	Winterhoek Mega-aquitard	Goudini Meso-aquitard	Goudini Formation
		Cedarberg Meso-aquitard	Cedarberg Formation
		Pakhuis Mini-aquitard	Pakhuis Formation
	Peninsula Aquifer	Platteklip Subaquifer	Peninsula Formation
		Leeukop Subaquifer	
	Basement Aquicludes		Cape Granite Suite
			Malmesbury Group

2.3.4 Rainfall patterns over the study area

The distribution of the mean annual precipitation (Figure 2.4) shows that, at a broad scale, the Nuweberg area (including TSAs T4 and T6) receives the highest annual rainfall. The records of rainfall at the weather stations in each of the TSAs provide more appropriate data than those used to create Figure 2.4, as these are the rain gauges closest to the ecological monitoring sites. This means that spatial patterns in rainfall distribution at a broad scale may not be mirrored in the more specific rainfall volumes experienced at these localised points. Also, the rainfall data available at the selected rainfall stations do not cover a long time interval – most have about a decade of recorded data. This means that local averages may not reflect those obtained from much longer-term datasets.

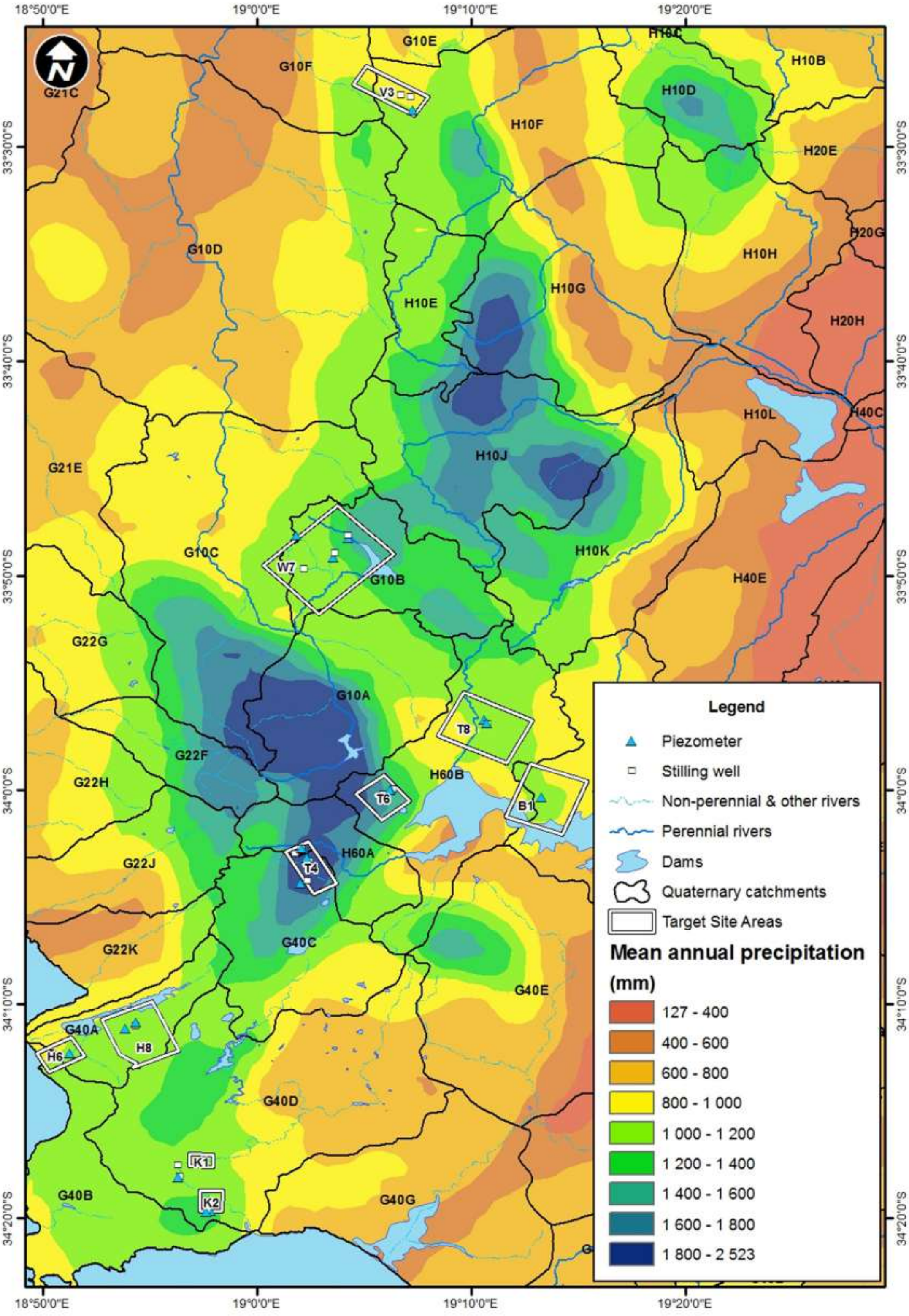


Figure 2.4. **Rainfall distribution and hydrogeological monitoring equipment installed at each of the ecological monitoring sites, based on rainfall grid the created by ARC-ISCW using data from ARC-ISCW and South African Weather Services.**

Figure 2.5 provides the total annual rainfall for the selected weather stations in each TSA over the period 1999 - 2009. A 4th order polynomial trend-line was fitted to the average yearly rainfall across all TSAs, and this shows that 1999, 2003, 2004, 2005 and 2009 were particularly dry years in the sub-region, and 2001, 2002, 2007 and 2008 the wettest of the series (Figure 2.5).

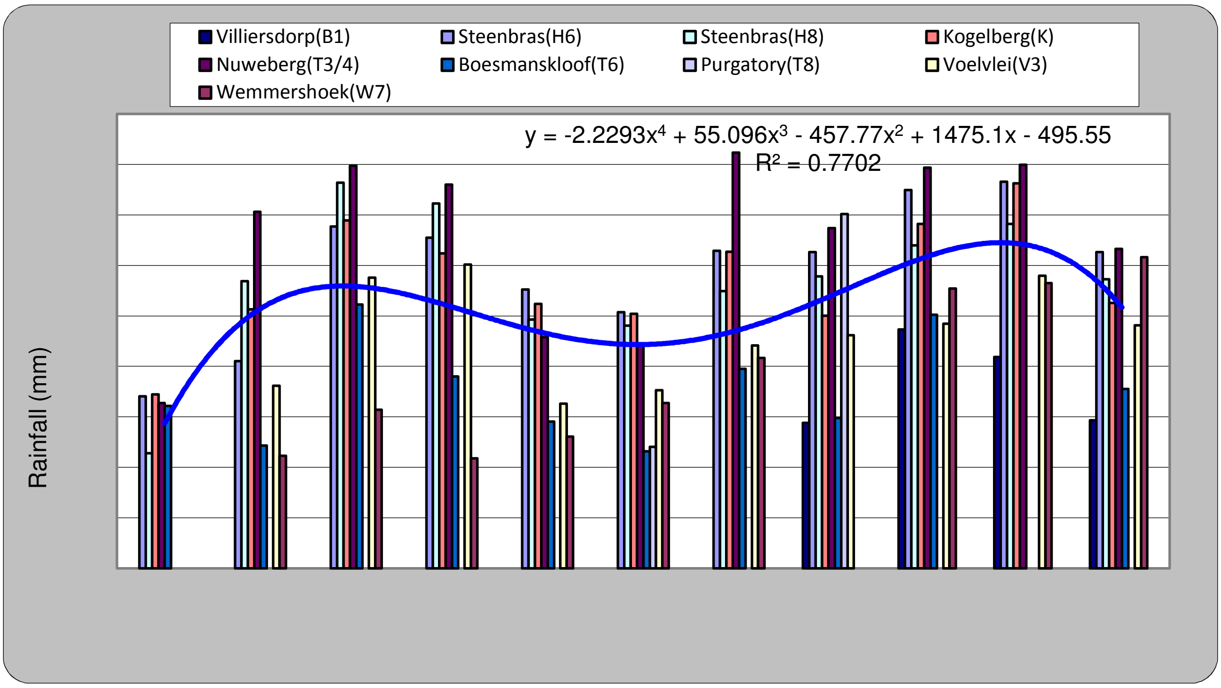


Figure 2.5. **Annual rainfall per TSA, as measured at a representative gauge, for the period 1999 – 2009. The blue trend-line is a 4th order polynomial trend-line fitted to average annual rainfall across all TSAs.**

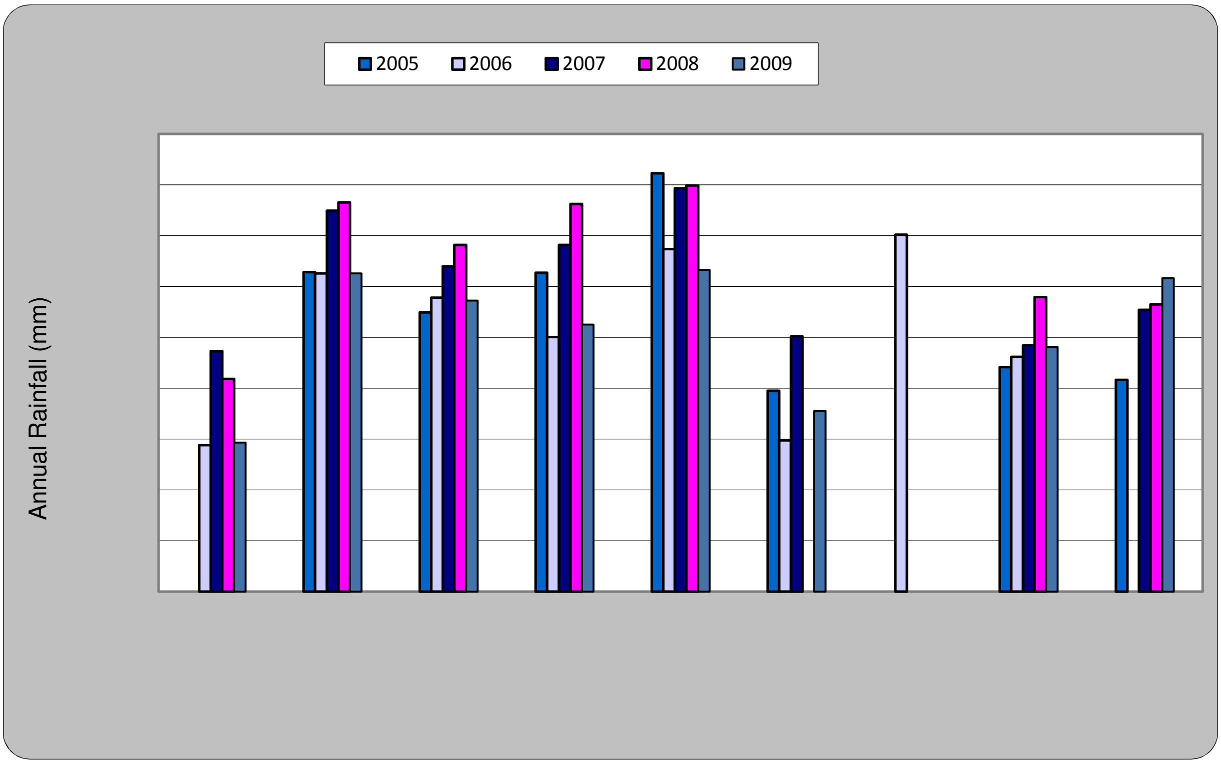


Figure 2.6. **Annual rainfall from a selected rainfall station within each TSA for the period 2005 to 2009.**

Total annual rainfall from 2005 to 2009, taken from a representative rain gauge as close as possible to each TSA (Figure 2.6) illustrates that the Steenbras (H6) and Nuweberg (T3, T4) TSAs received the highest annual rainfall in most years, while Villiersdorp (B1), Boesmanskloof (T6), and Voelvlei (V3) were the driest over the five years. Patterns of summer and winter rainfall over the period 1999 - 2009, expressed as the average total rainfall over four summer (December to March) and four winter months (June to September) present a more detailed picture (Figure 2.7). For instance, W7 was characterised by relatively dry summers, but had the highest winter rainfall along with T3/4 and T8. As might be expected, V3 had dry summers but winter rainfall in this catchment was not substantially different from the other TSAs. Kogelberg had the highest summer rainfall, along with H6/H8 and T3/T4. Average rainfall figures over four summer and four winter months are provided in Table 2.3.

Table 2.3. Rainfall within each TSA for the summer and winter months using average seasonal totals for each year of available data between 1999 and 2009 from a representative rain gauge in each TSA. TSAs with the highest rainfall in each season are indicated by shaded table cells.

TSA	Representative rain gauge	Rainfall over four summer months (Dec – Mar)			Rainfall over four winter months (Jun – Sep)		
		N	*Mean*	*Std Dev*	*N*	*Mean*	*Std Dev*
B1	0022539 0 (TMG535)	11	21.95	8.75	10	148.03	30.87
H6/8	0005760 3 (TMG522)	11	40.10	16.15	10	154.96	28.11
K4	0005829 9 (TMG524)	10	40.81	18.53	9	168.00	52.36
T3/4	0006065 1 (TMG527)	11	35.39	21.43	10	192.35	72.68
T6	20079 (TMG528)	11	13.47	9.70	10	123.46	46.27
T8	Purgatory (TMG539)	4	24.51	12.35	5	191.59	31.67
V3	0042236 9 (TMG536)	10	17.18	9.76	10	133.04	62.47
W7	30453 (TMG531)	11	28.72	13.59	10	213.68	60.56

Analysis of variance in the 1999 – 2009 rainfall data returned significant differences between TSAs for both summer and winter rainfall (Table 2.4), although pair-wise differences in the latter were only significant between W7 (highest winter rainfall) and V3 and T6 (Voelvlei and Boesmanskloof, lowest winter rainfall). Summer differences were significant between the southerly TSAs K (Kogelberg) and H6/H8 (Steenbras) and both T6 and V3, and between T4 (Nuweberg, third highest rainfall) and T6.

The length of the record affects these results, and their significance should be seen in this light, for example T8 is represented by only four years of data. A subset of the data, using a common dataset for all TSAs (four years of data) nevertheless still revealed significant differences in summer rainfall between H6/H8 and T6.

Whilst winter rainfall is clearly the more important driver of aquifer recharge, summer rainfall, along with the moisture-retaining properties of different wetland soils, is likely to exert a considerable influence on the moisture regime and plant and animal survival in wetlands during the hot, dry summer, especially in the surface layers of the soils. This matter is addressed again in Chapter 5 where the patterns in soil moisture, and in particular soil saturation, at the ecological monitoring sites are examined further.

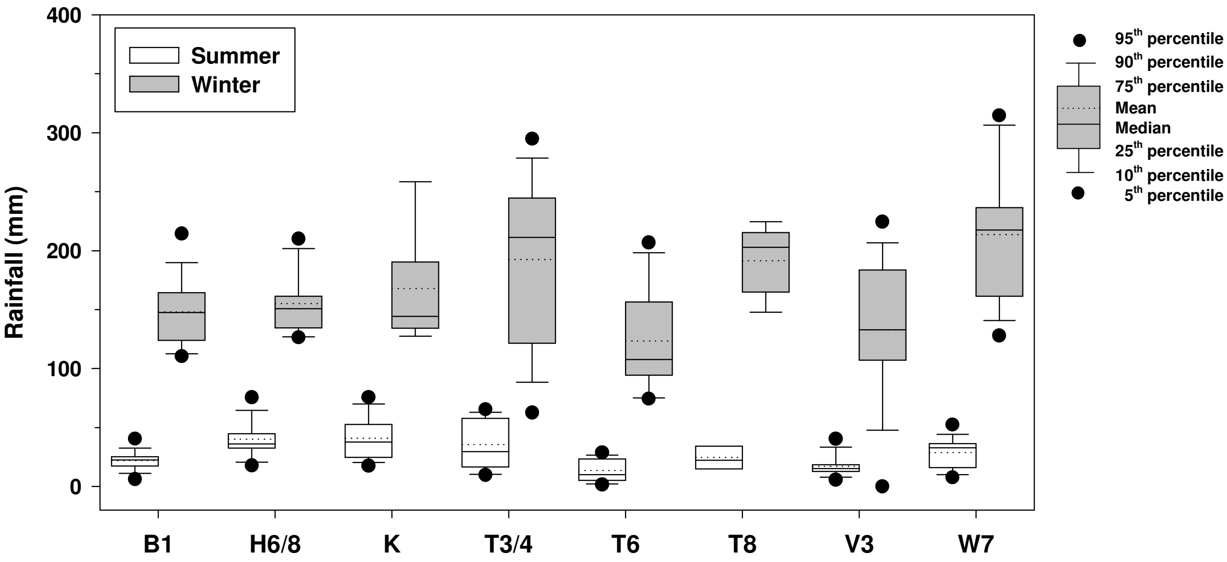


Figure 2.7. Comparison of rainfall over four summer and four winter months within each TSA, based on rainfall data collected from selected gauges in the study area over the period 1999 – 2009.

Table 2.4. (a) Kruskal-Wallis One Way Analysis of Variance on Ranks for rainfall (1999-2009) in the *summer* and *winter* season of the sampled TSAs and (b) Dunn's pair-wise multiple comparison procedure results.

a)

Summer					
Source of Variation	DF	SS	MS	F	P
Between Groups	7	7803.109	1114.73	5.222	<0.001
Residual	71	15155.91	213.463		
Total	78	22959.01			
Winter					
	DF	SS	MS	F	P
Between Groups	7	66059.97	9437.139	3.527	0.003
Residual	66	176570.2	2675.306		
Total	73	242630.2			

b)

Comparison	**Diff of Means**	**Q**	**P<0.05**
Summer			
H6/8 vs. T6	26.631	6.045	Yes
H6/8 vs. V3	22.922	5.078	Yes
K4 vs. T6	27.342	6.057	Yes
K4 vs. V3	23.633	5.115	Yes
T3/4 vs. T6	21.923	4.977	Yes
Winter			
W7 vs. T6	90.222	5.516	Yes
W7 vs. V3	80.645	4.93	Yes

2.3.5 Geohydrological descriptions of the ecological monitoring sites

The physical setting of the ecological sites within each TSA is evident in Figures 2.8 – 2.15. The figures are provided in alphabetical order of the TSAs, as follows:

Figure 2.8	Map of ecological monitoring sites in the B1 (Villiersdorp) TSA.
Figure 2.9	Map of ecological monitoring sites in the H6 and H8 (Steenbras) TSAs.
Figure 2.10	Map of ecological monitoring sites in the K (Kogelberg) TSA.
Figure 2.11	Map of ecological monitoring sites in the T3/T4 (Nuweberg Riviersonderend) TSAs.
Figure 2.12	Map of ecological monitoring sites in the T6 (Boesmanskloof) TSA.
Figure 2.13	Map of ecological monitoring sites in the T8 (Purgatory) TSA.
Figure 2.14	Map of ecological monitoring sites in the V3 (Voelvlei) TSA.
Figure 2.15	Map of ecological monitoring sites in the W7 (Wemmershoek and Zachariashoek) TSA.

Smaller scale maps showing the location of monitoring points (water level, soil moisture, vegetation and algae) as well as channel diagrams (where relevant) for each of the ecological monitoring sites are presented in Volume B: Appendix 2 of this report.

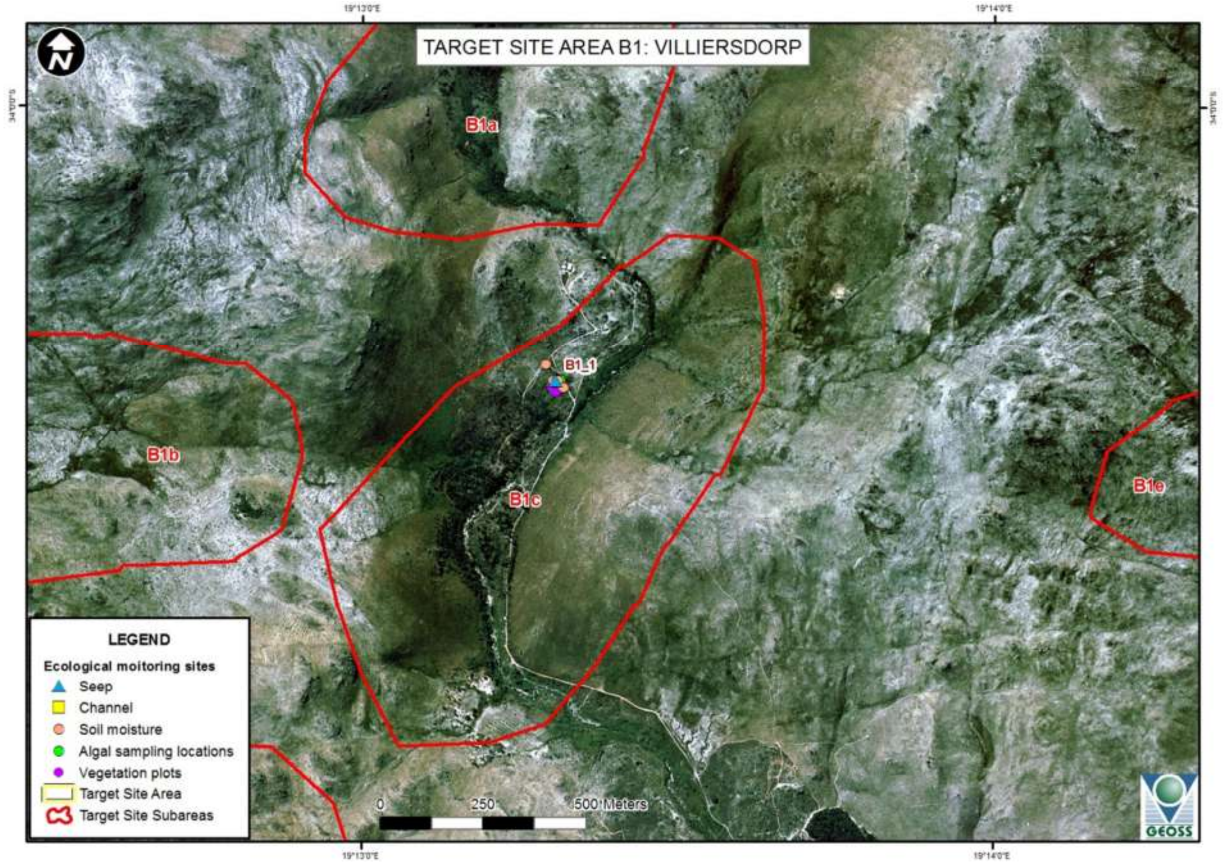


Figure 2.8. Map of the ecological monitoring site in the B1 (Villiersdorp) TSA.

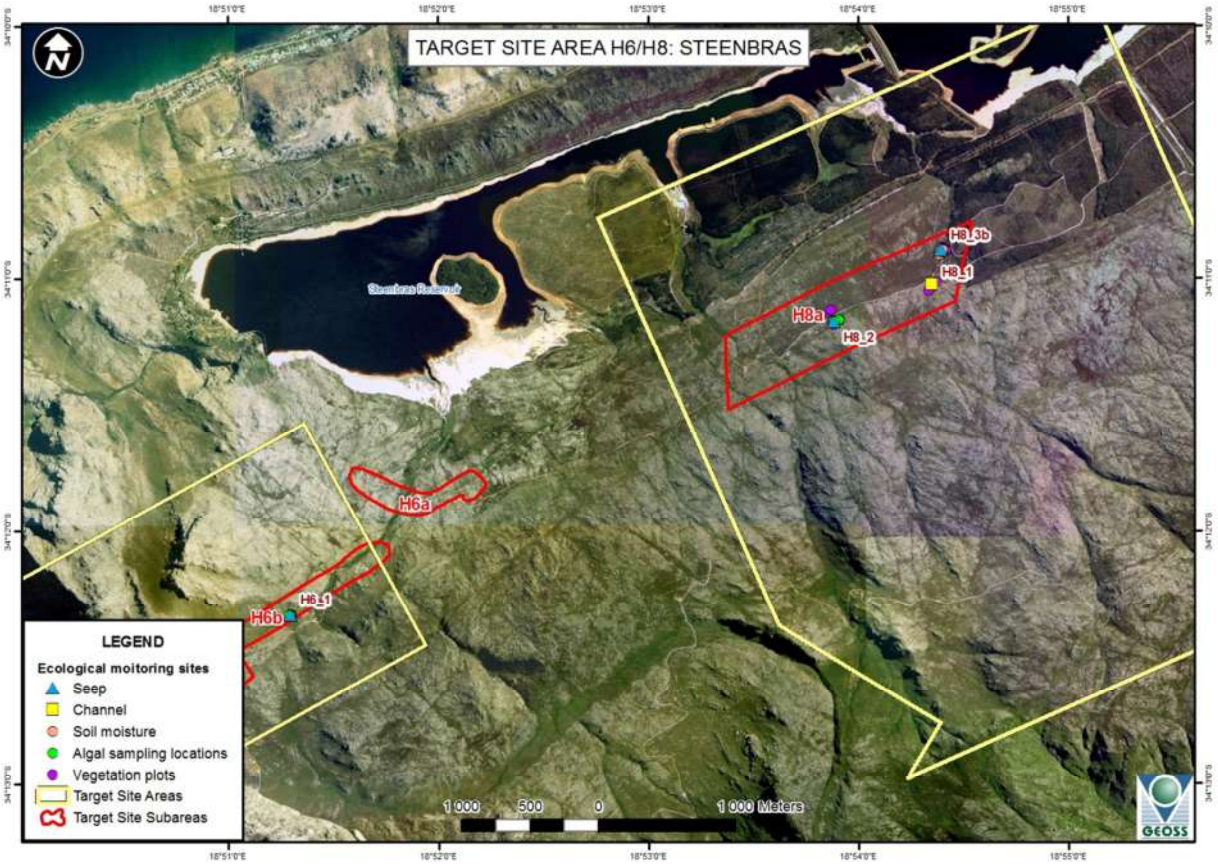


Figure 2.9. Map of ecological monitoring sites in the H6 and H8 (Steenbras) TSAs.

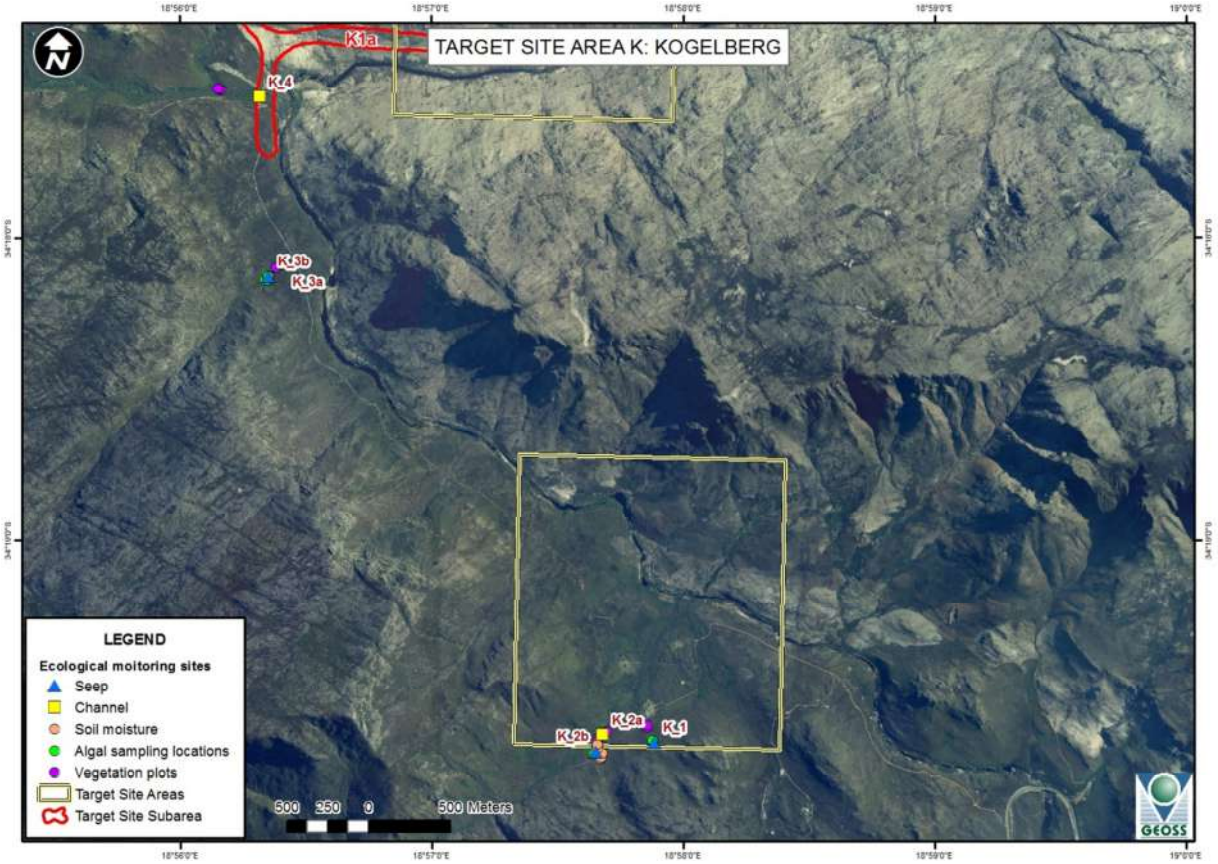


Figure 2.10. Map of ecological monitoring sites in the K (Kogelberg) TSA.

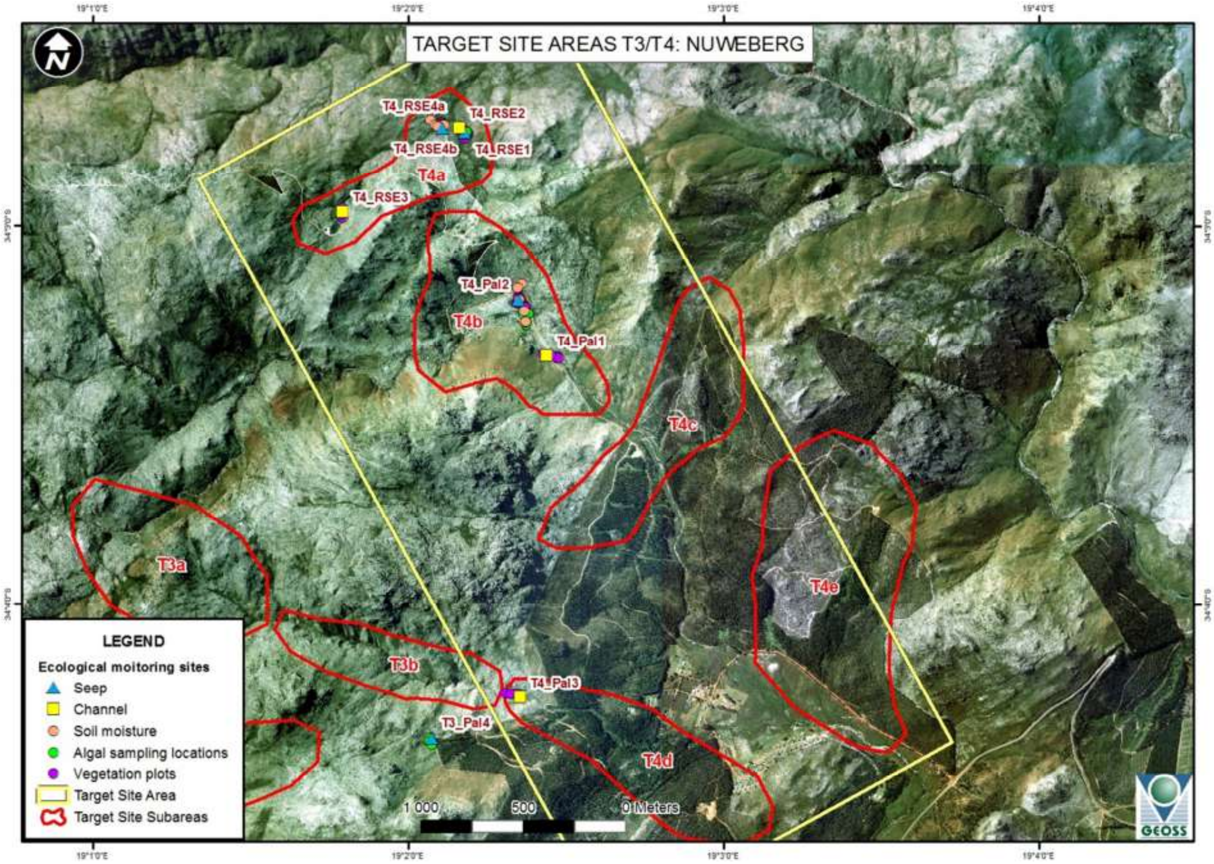


Figure 2.11 **Map of ecological monitoring sites in the T3 and T4 (Nuweberg: Pal = Palmiet River and RSE = Riviersonderend River) TSAs.**

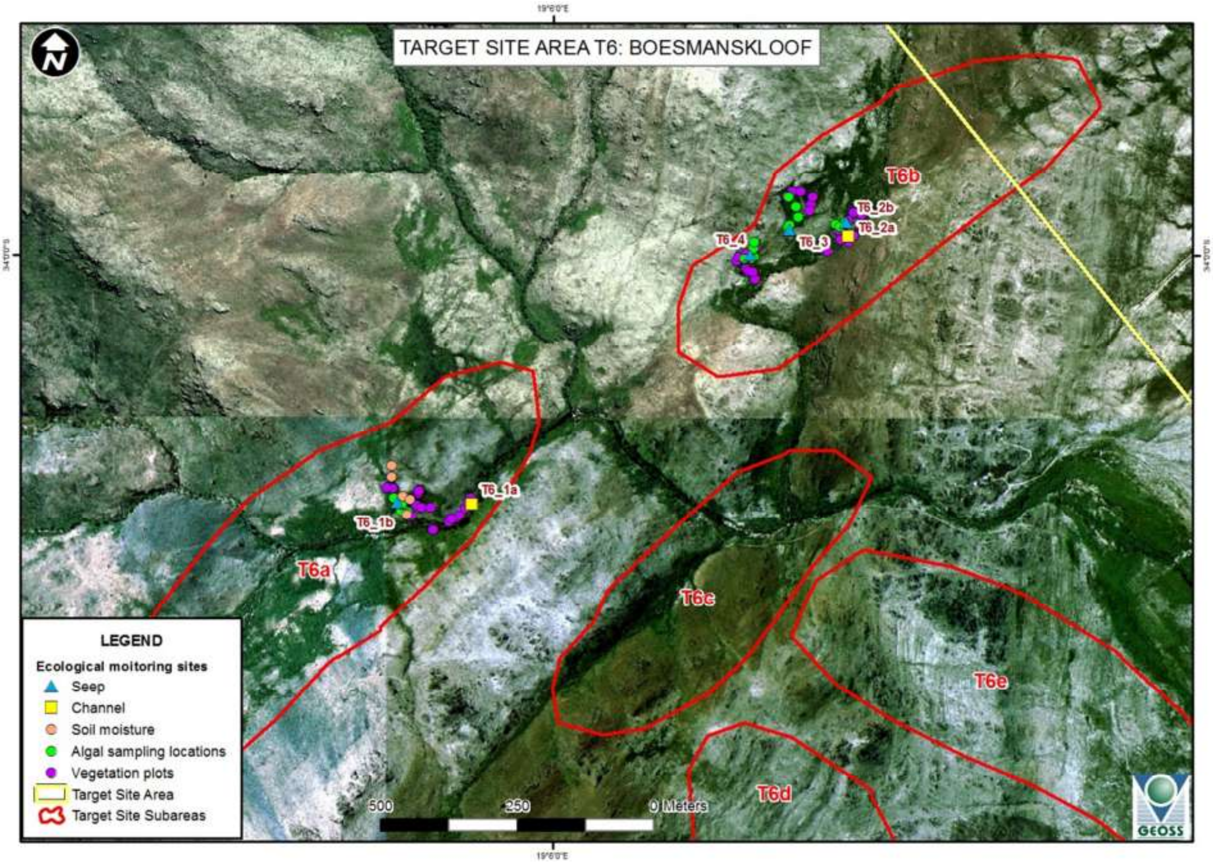


Figure 2.12. **Map of ecological monitoring sites in the T6 (Boesmanskloof) TSA.**

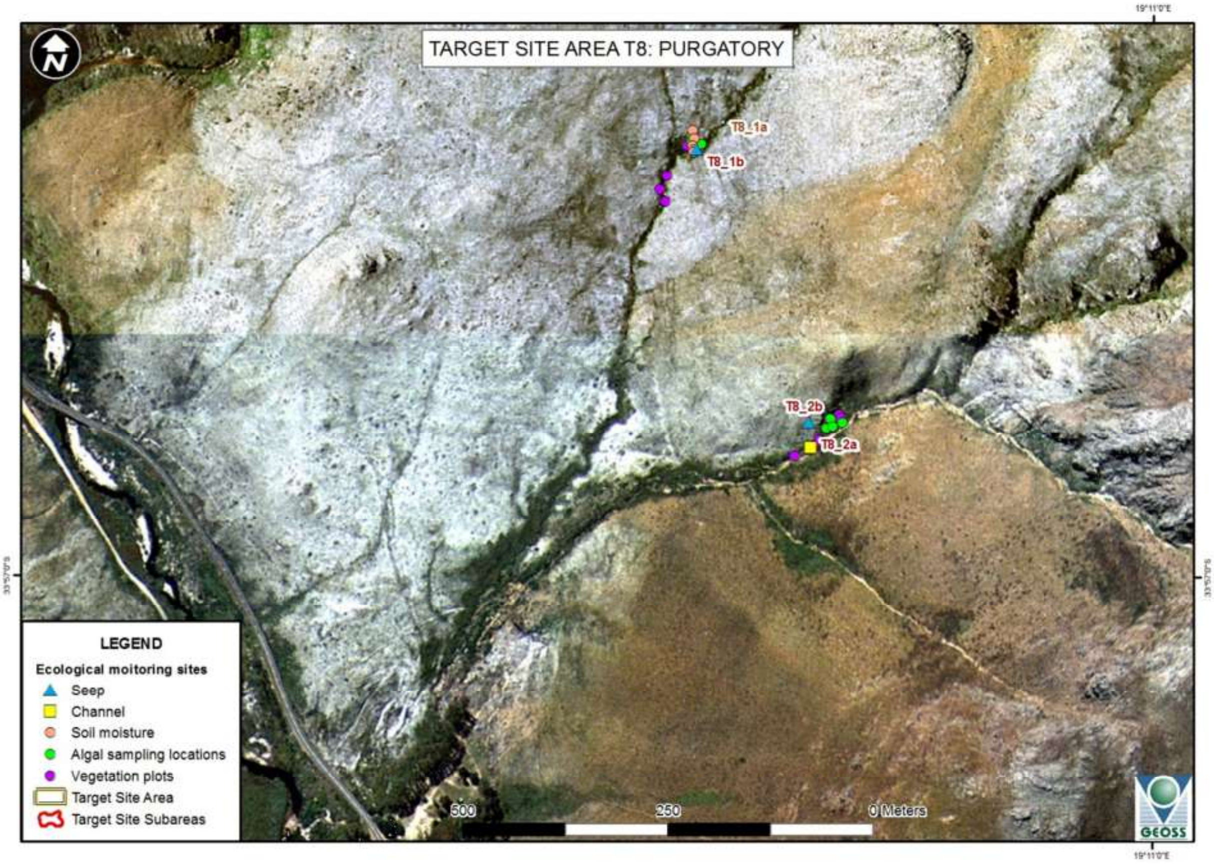


Figure 2.13. Map of ecological monitoring sites in the T8 (Purgatory) TSA.

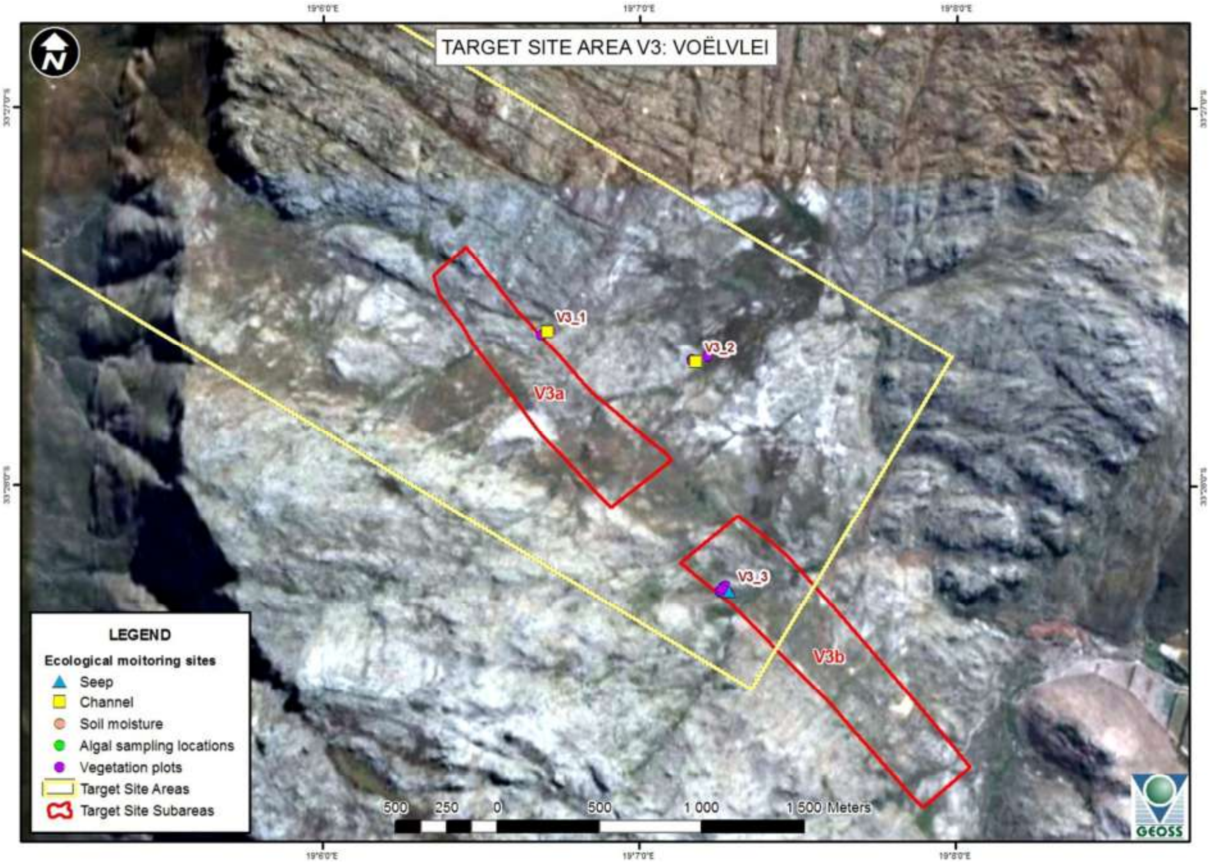


Figure 2.14. Map of ecological monitoring sites in the V3 (Voelvlei) TSA.

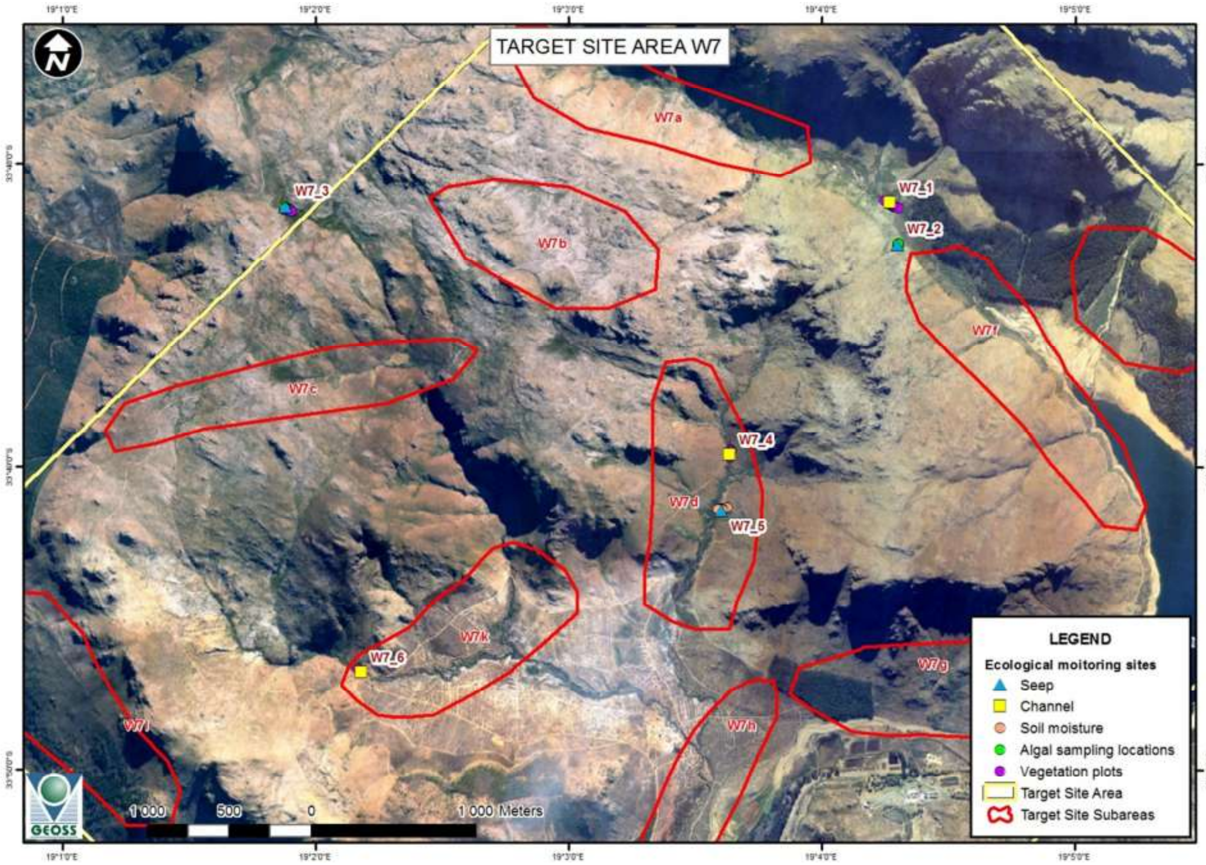


Figure 2.15 Map of ecological monitoring sites in the W7 (Wemmershoek) TSA.

The cross–sections drawn through the geological formations at each of the ecological monitoring sites are shown in Volume B: Appendix 3. These have been interpreted to assess the likelihood of linkage of the ecological monitoring sites to the Peninsula Aquifer, and comments regarding this connectivity are provided in Table 2.4.

Based on geological setting alone, 23 of the 40 sites have a probable to highly probable connectivity to the Peninsula Aquifer. Ten sites appear to be strongly linked to the Nardouw Aquifer, with a further seven sites being possibly influenced by both aquifers. The geological formations at the sites within the Steenbras (H8) TSA result in a relatively low probability of a strong interaction between the Peninsula Aquifer and the ecoseeps or ecochannels, but a relatively high probability of a link to the Nardouw Aquifer (Table 2.5). Similarly, the K_3 sites (Kogelberg inland) are located along the contact between the Skurweberg and Goudini formations, and the channel (K_3a) drains the Skurweberg Mountains to the east. The Peninsula Formation is present, but more than a kilometre north of the site. The high density of fractures in this area, however, does complicate the interpretation of connectivity at these sites.

Two sites located in the Purgatory TSA – T8_1a and T8_1b – and three of the Wemmershoek sites – W7_1, W7_2 and W7_3 - are situated on the Skurweberg Formation, and although all of the sites are close to faults that may connect them with the Peninsula Aquifer, this connectivity is unlikely.

Table 2.5. Geohydrological description of the ecological monitoring sites.

Site	TSA	Geohydrological description of site
B1_1	Villiersdorp	B1_1 (seep) is located in a Cedarberg Fmn (O-Sc) / Pakhuis Fmn (Opa) valley. It is just north of a W/E trending fault, which is down-thrown to the south. The fault may link Skurweberg Fmn (Ss) to the seep laterally and may also link Peninsula Fmn (Ope) to the seep vertically if it is deep enough. Links between the seep and Peninsula Aquifer is possible, but groundwater contributions may be predominantly from the Nardouw Aquifer.
H6_1	Steenbras	H6_1 (seep) is located on the Goudini Fmn (Sg) / Skurweberg Fmn contact. It is also located in close proximity to the SW/NE trending Steenbras fault (which is downthrown to the south-east). Although vertically the site is located well above the Peninsula Fmn (Ope), the possibility does exist that the fault may link the site to the Peninsula Aquifer. Significant seep / Peninsula Aquifer interaction is unlikely however, and so groundwater contribution is most likely from the Nardouw Aquifer.
H8_1		H8_1 (channel) is located on the Rietvlei Fmn (Dr). This is the uppermost formation of the TMG and part of the Nardouw Aquifer. It is located in close proximity to the SW/NE trending Steenbras fault (which is downthrown to the south-east). Although vertically the site is located well above the Peninsula Fmn (Ope), the possibility does exist that the Steenbras fault may link the site to the Peninsula Aquifer. Connectivity to the Nardouw Aquifer is more likely to explain groundwater contribution to summer baseflow.
H8_2		H8_2 (seep) is located close to both H8_1 and H8_3a/b and shares the same relationship to the geological formations. Connectivity to the Nardouw Aquifer is more likely to explain groundwater contribution to the seep.
H8_3a		H8_3a (channel) is located close to H8_1 and shares the same relationship to the geological formations. It is highly probable that the site is connected to groundwater, but probably mostly the Nardouw Aquifer. The Peninsula Aquifer may contribute slightly, as a result of the nearby fault intersecting the Peninsula Formation.
H8_3b		H8_3b (seep) is located adjacent to H8_3a and shares the same relationship to the geological formations. The site is most probably fed by groundwater from the Nardouw Aquifer. The Peninsula Aquifer may contribute slightly, as a result of the nearby fault intersecting this Peninsula Aquifer.
K_1	Kogelberg	K_1 (seep) is located on the Peninsula Fmn (Ope) in very close proximity to a SW/NE trending fault (which is downthrown to the NW). The fault brings the Peninsula Fmn (Ope) and Cedarberg Fmn (O-Sc) into close proximity. There is a high probability that the seep is linked to the Peninsula Aquifer.
K_2a		K_2a (channel) is located on the Cedarberg Fmn (O-Sc), however in very close proximity to a SW/NE trending fault (which is downthrown to the NW). The fault brings the Peninsula Fmn (Ope) and Cedarberg Fmn (O-Sc) into close proximity so that connectivity with the Peninsula Aquifer is highly likely to provide a major component of the groundwater base flow to the river.
K_2b		K_2b (valley-bottom wetland) is located on the Cedarberg Fmn (O-Sc), but is also in very close proximity to a SW/NE trending fault (which is downthrown to the NW). The fault brings the Peninsula Fmn (Ope) and Cedarberg Fmn (O-Sc) into close proximity. There is a high probability that the seep is linked to the Peninsula Aquifer.
K_3a		K_3a (channel) is located on the Skurweberg Fmn (Ss) / Goudini Fmn (Sg) contact, also in very close proximity to a SW/NE trending fault (which is downthrown to the SE). The area has a high density of geological faults, with varying orientations. Peninsula Fmn (Ope) does outcrop to the north of this site, but groundwater contribution from the Peninsula Aquifer to baseflow is very unlikely as the channel drains mainly off the Skurweberg Mountains to the west. Connectivity with the Nardouw Aquifer is highly likely.
K_3b		K_3b (valley-bottom wetland) is located adjacent to K_3a on the Skurweberg Fmn (Ss) / Goudini Fmn (Sg) contact, also in very close proximity to a SW/NE trending fault (which is downthrown to the SE). The area has a high density of geological faults, with varying orientations. Peninsula Fmn (Ope) does outcrop 1.25 km to the north, but groundwater contribution from the Peninsula Aquifer to the seep is very unlikely. Connectivity with the Nardouw Aquifer is highly likely.
K_4		K_4 (Dwars River channel) is located on a W/E trending geological fault, which is downthrown to the north. The channel site is on the faulted contact between the Peninsula Fmn (Ope) to the north and the Skurweberg Fmn (Ss) to the south. The area has a high density of geological faults and so this channel is most probably fed by groundwater from the Peninsula Aquifer.
T3_Pal4	Nuweberg	T3_Pal4 (seep) is on a thrust fault uplifting the Peninsula Fmn (Ope) relative to the Skurweberg Fmn (Ss). Hydrological connectivity with the Peninsula Aquifer is probable, but also with a high probability of connectivity with the Nardouw Aquifer.

Site	**TSA**	**Geohydrological description of site**
T4_Pal1		T4_Pal1 (Palmiet River channel) is located on the Pakhuis Fmn (Opa), however in close proximity to the Peninsula Fmn (Ope), which outcrops to the north. The groundwater contribution to baseflow in the Palmiet is most probably derived from the Peninsula Aquifer.
T4_Pal2		T4_Pal2 (valley-bottom wetland) is located close to T4_Pal1 on the Peninsula Fmn (Ope). The geomorphological setting of the site and the hydraulic gradients and associated groundwater flow directions indicate that this site is most probably linked to the Peninsula Aquifer.
T4_Pal3		T4_Pal3 (channel) is on the lowermost contact of the Pakhuis Fmn (Opa) with the Peninsula Fmn. Hydrological connectivity with the Peninsula Aquifer is highly probable.
T4_RSE1		T4_RSE1 (seep) is on the Peninsula Formation, hence connectivity with the Peninsula Aquifer is highly likely. There is also fracturing and faulting within this formation.
T4_RSE2		T4_RSE2 (channel) is on the Peninsula Formation, hence connectivity with the Peninsula Aquifer is highly likely.
T4_RSE3		T4_RSE3 (channel) is on the Peninsula Formation, hence connectivity with the Peninsula Aquifer is highly likely.
T4_RSE4a		T4_RSE4a (channel) is on the Peninsula Formation, hence connectivity with the Peninsula Aquifer is highly likely.
T4_RSE4b		T4_RSE4b (seep) is on the Peninsula Formation, hence connectivity with the Peninsula Aquifer is highly likely.
T6_1a	Boesmanskloof	T6_1a (Bobbejaan River channel) is located on a SW/NE trending fault downthrown to the north, which brings the Peninsula Fmn (Ope) in the northwest into contact with Pakhuis (Opa) to the southeast. There is a high likelihood that baseflow in this channel is derived as groundwater from the Peninsula Aquifer.
T6_1b		T6_1b (seep) is on Peninsula Formation, hence connectivity with the Peninsula Aquifer is highly likely.
T6_2a		T6_2a (channel) is located on a SW/NE trending fault downthrown to the northwest. To the northwest Peninsula Fmn (Ope) outcrops and to the southeast Pakhuis Fmn (Opa) and Cedarberg Fmn (O-Sc) outcrops. The valley has eroded along the weaker more argillaceous rock type (predominantly shale). However, flow in the channel is more likely to be fed by the Peninsula Fmn that outcrops to the north of the site.
T6_2b		T6_2b (seep) is adjacent to T6_2a with the same relationship with the geological formations, and located on a geological fault that will most probably be fed by the Peninsula Fmn.
T6_3		T6_3 seep is located on the Peninsula Fmn (Ope), hence connectivity with the Peninsula Aquifer is highly likely.
T6_4		T6_4 seep is located on the Peninsula Fmn (Ope), hence connectivity with the Peninsula Aquifer is highly likely.
T8_1a	Purgatory	T8_1a (channel) is located on the Skurweberg Fmn (Ss). The site is to the northwest of a major SW/NE trending fault, which brings Skurweberg Fmn (Ss) to the northwest into contact with Peninsula Fmn (Ope), nonetheless the probability of linkage of this channel to the Peninsula Aquifer is low. However, the area is geologically very faulted and the close proximity of the Peninsula Fmn (Ope) (200 m) indicates that there may be some connectivity with the Peninsula Aquifer. It is highly likely, however, that the channel is fed by the Nardouw Aquifer.
T8_1b		T8_1b (seep) is located on the Skurweberg Fmn (Ss), alongside T8_1a, with the same relationship with geological formations. Thus, connectivity with the Peninsula Aquifer is of low probability, with high probability of a connection with the Nardouw Aquifer.
T8_2a		T8_2a (channel) is on the lowermost contact of the Pakhuis Fmn (Opa) on a major fault system. Hydrological connectivity with the Peninsula Formation is thus probable.
T8_2b		T8_2b (seep) is located on the Pakhuis Fmn (Opa), alongside T8_2a. The site is to the southeast of a major SW/NE trending fault, which brings Skurweberg Fmn (Ss) to the northwest into contact with Pakhuis Fmn (Opa). Nonetheless the close proximity of the Peninsula Fmn (Ope) to the site has relevance. Connectivity of seep to the Peninsula Aquifer is probable.
V3_1	Voëlvlei	V3_1 (channel) is located on the Skurweberg Fmn (Ss). However the site is to the north-east of a major NW/SE trending fault (downthrown to the southeast), which brings the Skurweberg Fmn (Ss) in the north-west into contact with the Peninsula Fmn (Ope) in the southeast. Based on the geomorphological setting of the terrain and the flow directions, it is probable that there is a contribution to baseflow from the Peninsula Aquifer. Connectivity with the Nardouw Aquifer is also highly probable.

Site	TSA	Geohydrological description of site
V3_2		V3_2 (channel) is located on the Skurweberg Fmn (Ss). However the site is to the north-east of a major NW/SE trending fault (downthrown to the southeast), which brings the Skurweberg Fmn (Ss) in the north-west into contact with the Peninsula Fmn (Ope) in the southeast. Based on the geomorphological setting of the terrain and the flow directions, it is probable that there is a contribution to baseflow from the Peninsula Aquifer. Connectivity with the Nardouw Aquifer is also highly probable.
V3_3		V3_3 (seep) is on Peninsula Fmn (Ope) and relatively close to a major fault system and there is thus a high probability that this site is directly linked to the Peninsula Aquifer.
W7_1	Wemmershoek	W7_1 (Drakenstein River channel) is located on the Skurweberg Fmn (Ss) in close proximity to the Drakenstein Fault. The Drakenstein Fault trends NW/SE, with outcrops of the Skurweberg (Ss) to the southwest, and of Basement to the northeast. The channel is most probably connected to the Nardouw Aquifer, possibly via an alluvial aquifer, with unlikely connectivity with the Peninsula Aquifer.
W7_2		W7_2 (seep) is located on the Skurweberg Fmn (Ss) in close proximity to W7_1 and the Drakenstein Fault. The latter trends NW/SE, with outcrops of the Skurweberg (Ss) to the southwest, and of Basement to the northeast. Borehole drilling on the NW extension of this fault showed the fault to be very weathered, clay-rich and having a very low hydraulic conductivity. The seep is most probably lithologically controlled with outflow from the Nardouw Aquifer, with unlikely connectivity with the Peninsula aquifer.
W7_3		W7_3 (seep) is on a W/E trending fault on the Skurweberg Fmn (Ss). Connectivity with the Peninsula Fmn (Ope) via either vertical or lateral connection is possible via the fault, although due to the elevation of this site it is improbable. Connectivity with the Nardouw Aquifer is highly probable.
W7_4		W7_4 (Kasteelskloof River channel) is located on the Pakhuis Fmn (Opa) adjacent to a scree slope. Its location on the Winterhoek Mega-aquitard indicates that groundwater feeding the channel is likely to come from the Nardouw Aquifer. However, the proximity of the Peninsula Fmn (Ope) just beneath the Pakhuis Fmn (Opa) does suggest possible connectivity of this site to the Peninsula Aquifer, but this is unlikely to be strong.
W7_5		W7_5 (seep) is on a scree slope, close to the contact of the Pakhuis Fmn (Opa) and Peninsula Fmn (Ope). It is directly above the Peninsula Fmn (Ope) and the high hydraulic conductivity of scree means that hydrological linkage between this site the Peninsula Aquifer is highly probable.
W7_6		W7_6 (Zachariashoek River channel) is located on a geological fault within the Peninsula Fmn and thus there is a high likelihood of connectivity with the Peninsula Aquifer.

The interpretation of the geological cross-sections is considered preliminary, especially in the light of the complexity of the multiple flow paths within the Peninsula Aquifer. The categorisation of sites according to their possible connectivity to the Peninsula Aquifer, however, could be further refined with examination of geohydrological data, since the EPM of the forty ecological monitoring sites included continuous measurement of groundwater level data at most ecoseeps and channel water level at most ecochannels. This assessment is continued in Chapters 3 and 4.

2.3.6 Description of wetland types

The character of each of the ecological monitoring sites was described according to the five hierarchical levels of the National Wetland Classification System (SANBI 2009), the details of which are presented in Volume B: Appendix 4. The sites fall into four of the 31 ecoregions described for South Africa (Kleynhans *et al.* 2005), with the dominant ecoregion being the Southern Folded Mountains. The characteristics of these ecoregions are given in Table 4.2 of Appendix 4 in Volume B. All of the sites are located in the Southwest Fynbos Bioregion, and lie within two vegetation groups – sandstone fynbos, and shale band vegetation (Volume B: Appendix 4). A brief description of the dominant edaphic features, based on field observations, is added for each site as these features were assessed at a smaller scale than the National Vegetation Map (Table 2.6).

The ecological monitoring sites are all located within the landscape setting of slope or valley floor. The difference between these landscape settings is largely one of gradient, with valley floors being flatter, with gradients generally less than 1:1000 (SANBI 2009). Hillslope seeps occur on slopes, while valley-bottom wetlands occur on valley floors with little or no relief. Hillslope seeps are fed predominantly by subsurface flow from further up the slope (e.g. springs, throughflow, etc) or directly by precipitation, while valley-bottom wetlands are fed mainly by water from the channel with which they are associated, by subsurface discharge from the channel, or by drainage from the surrounding slopes (e.g. surface runoff, or interflow from seeps) (SANBI, 2009)

The ecoseeps are mainly hillslope seeps with (ten) or without (seven) channelled outflow, and four channelled valley-bottom wetlands. One of the channelled hillslope seeps (B1_1) and one of the channelled valley-bottom wetlands (K_2b) lies on colluvial sand (Table 2.6), while the majority lie on sandstone.

The channel sites comprise mostly mountain streams (nine), one of which is on deep alluvial sand overlying a shale band (W7_4), and the others on sandstone. There are four upper foothill rivers, two each on sandstone and colluvial sand on shale, three transitional rivers, all on sandstone, and two lower foothill rivers on sandstone (K_4 and W7_1). One of the sites, T4_RSE2, was not easily classified, as this channel is associated with an extensive valley-bottom wetland, and so the river displays a mix of wetland and riverine characteristics. At this site, the river is mostly an alluvial sandy-bed system, with no cobble and some bedrock. Due to the distinctiveness of the channel, however, the site was described here as a river channel, with the longitudinal zonation as "other". The classification of river channels according to their longitudinal zonation makes use of the geomorphological zonation scheme of Rowntree & Wadeson (1999) (see Glossary).

The grouping of ecological monitoring sites according to HGM type and dominant edaphic features is provided in Table 2.6.

Table 2.6. Groups of ecological monitoring sites, according to HGM type and dominant edaphic features.

Ecosystem category	**Description of features**	**Number in EPM**	**Site names**
1	Hillslope seep, with channelled outflow; colluvial sand over shale	1	B1_1
2	Channelled valley-bottom wetland; colluvial sand over shale	1	K_2b
3	Mountain stream; deep alluvial sand	1	W7_4
4	Upper foothill river; colluvial sand over shale	2	K_2a, T4_Pal1
5	Hillslope seep, with channelled outflow; on sandstone	9	H8_2, H8_3b, K_1, T3_Pal4, T6_1b, V3_3, W7_2, W7_3, W7_5
6	Hillslope seep, without channelled outflow; on sandstone	7	H6_1, T4_RSE1, T4_RSE4b, T6_3, T6_4, T8_1b, T8_2b
7	Channelled valley-bottom wetland; alluvial sand on sandstone	3	K_3b; T4_Pal2, T6_2b
8	Mountain stream; alluvial sand on sandstone	8	H8_1, T4_Pal3, T4_RSE3, T4_RSE4a, T6_2a, T8_2a, V3_1, V3_2
9	Transitional river; alluvial sand on sandstone	3	H8_3a, K_3a, T8_1a,
10	Upper foothill river; alluvial sand on sandstone	2	T6_1a, W7_6
11	Lower foothill river; alluvial sand on sandstone	2	K_4, W7_1
12	"Other" river ; alluvial sand on sandstone	1	T4_RSE2

3. GEOHYDROLOGY

3.1 INTRODUCTION

The EPM includes two types of groundwater monitoring activities:

- Regional hydrocensus, comprising boreholes and streamflow sites that are visited twice a year, plus some Exploration Boreholes drilled as part of the TMGA study, and
- Seep monitoring, by means of piezometers in hand augered, narrow diameter pipes installed in the ecoseeps.

The hydrocensus monitoring was initiated by the TMGAA prior to the EPM, from around 2003. Umvoto Africa completed the work in 2003 and 2004 and GEOSS has collected the data since 2005.

The aim of the regional hydrocensus is to provide baseline monitoring of regional geohydrology and hydrology. This chapter deals with the groundwater component of the hydrocensus. Streamflow monitoring results are discussed in Chapter 4. In addition to streamflow and borehole water level monitoring, water for chemical analyses is collected from some boreholes and stream sites. The results of chemical analyses are discussed in Chapter 5.

An understanding of the dynamics of subsurface water in a wetland is crucial to interpreting both the degree of connectivity to underlying aquifers, and the presence or distribution of different plant and animal species in a wetland. Time-series data, specifically relating to the rate of change of water levels, can be used to identify the relative contribution that groundwater and rainfall make to the creation of a wetland at a local point. Typically, groundwater measurement should take place at more than one point within a wetland, but this was not possible within the constraints of the EPM budget, and a single piezometer was installed in 19 of the 21 ecoseeps. Consensus was that this would provide sufficient information regarding the degree to which groundwater determines the availability of water at or near the wetland surface.

All wetlands, whether or not they have a connection to groundwater, can be categorised by their hydroperiod, defined as the extent to which a wetland is associated with saturated or inundated conditions (i.e. when the subsurface water level is very shallow, at or above the surface) and the duration of these conditions. Hydroperiod is important in determining the animals and plants that will live in a wetland, but is not necessarily controlled by whether or not a site has connectivity to the groundwater, i.e. to an aquifer, because:

- Connectivity between the underlying aquifer and the wetland will affect the rate at which the water table fluctuates vertically (e.g. declines over summer), but it does not necessarily follow that connectivity means that there is surface water in the wetland;
- An aquifer-fed wetland may have a water table that is at, near or some distance below the surface, which tends to remain relatively unchanged over time;
- Fluctuations in water level as a result of rainfall or rain-generated interflow directed into and stored in the wetland may be superimposed on a water level that is maintained by groundwater;
- A wetland that is not connected to an underlying aquifer will have more rapid fluctuations in subsurface water level, linked to the timing and intensity of rainfall, and
- Finally, a wetland may have patches that are groundwater-fed (connected to the aquifer) and others that are rain-fed, especially in slope wetlands where the water table does not follow the ground surface. Typically the more elevated portions of the wetland are more likely to be predominantly rainfall-fed.

Nonetheless, changes in subsurface water levels and surface inundation or saturation (i.e. hydroperiod) can be used as surrogate measures of the more complex changes in some or all aspects of the groundwater regime, for instance, pressure, flow rate, depth (e.g. Eamus and Froend 2006). Thus, monitoring at the ecological monitoring sites included continuous measurement of subsurface water levels at the ecoseeps and streamflow water levels at the ecochannels, allowing for refinement of the interpretation of geological cross-sectional data with respect to aquifer connectivity presented in Chapter 2, as well as categorisation of the ecoseeps and ecochannels in terms of their hydroperiod, presented in this chapter and Chapter 4 respectively.

3.2 METHODS

3.2.1 Exploration Boreholes

Umvoto Africa is managing the drilling of the narrow diameter, dedicated Exploration Boreholes for the TMGA Project, which is being run by the TMGAA. The details of those that have been completed to date are provided in Appendix 5 in Volume B.

The Exploration Boreholes drilled by SA Rock Drills for the TMGAA have recently (August 2009) been equipped with Solinst continuous water level loggers. One of these Exploration Boreholes is artesian and was therefore fitted with a pressure logger. GEOSS is responsible for reading the data from this artesian borehole and for downloading data from the loggers at the other boreholes.

3.2.2 Regional hydrocensus

Hydrocensus sampling runs (streamflow and boreholes) have been conducted by GEOSS bi-annually since summer 2005, and prior to that, by Umvoto Africa since 2003. Earlier hydrocensus records include measurements made during a range of summer months, but from 2008 the measurement period was standardised to April and October, as specified in the hydrocensus terms of reference, and to enable year-on-year comparison of the data. The work takes approximately one month to complete and every effort has been made to complete the work within the month (April or October).

A list of all monitoring boreholes included in the hydrocensus work to date is provided in Volume B: Appendix 5, and, including the Exploration Boreholes, numbers 73. Of this number, 20 boreholes are not being monitored. Five of these are planned Exploration Boreholes that have not yet been drilled and 15 are boreholes that have for some reason been discontinued (refer to Appendix 5 for details). Appendix 5 includes details of the monitoring activities at each borehole – there is no standard set of data collected from all boreholes. Twenty-four continuous water level loggers were installed in selected hydrocensus boreholes as part of the EPM project (i.e. this monitoring programme). Ten of these were installed in Exploration Boreholes, and the other 14 in boreholes in Purgatory, Kogelberg and other areas – six of these are installed in production boreholes and eight in monitoring boreholes.

The two research sites set up with Water Research Commission funding at Kogelberg and Purgatory (Colvin *et al.* 2009) account for two data loggers and the responsibility for downloading and maintaining these loggers was taken over by the TMGA-EMA. Each of these two sites has an artesian borehole equipped with a pressure logger.

Several of the bi-annual and/or continuously logged boreholes are privately owned and are used for water supply. In these cases, owners were consulted and the boreholes were equipped with observation pipes (for the installation of the water level logger and for the recording of manual water level measurements) and a sampling tap. Barometric loggers have also been installed across the study area for the atmospheric correction of the water level data. In addition to these boreholes the Department of Water Affairs (DWA) has also drilled 18 boreholes in the W7 and T4 area for the purposes of regional groundwater level monitoring (GEOSS 2008).

A further 27 boreholes are monitored manually for water level (twice per annum), and others are sampled for chemical analysis. Whilst the addition or discontinuation of sites means that the sampling routine has differed slightly over the sampling period, the number of sites sampled for different parameters during the April 2009 hydrocensus is summarised in Table 3.1.

Table 3.1. Summary of data collected in April 2009

Type	WQ-F	WQ-I	WQ-L	WL
Boreholes and Artesian boreholes	27	12	19	27
Piezometers	5			23
Total	32	12	19	52

WQ-F = water quality - field measurements of pH, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS) and Oxygen Reduction Potential (ORP)

WQ-I = water quality – sample collected for isotope analysis

WQ-L = water quality – sample collected for major ion analysis by an accredited laboratory

WL = water level measured.

3.2.3 Ecological monitoring sites (ecoseeps)

Piezometers were installed at 19 of the 21 ecoseeps (Figure 3.1), to the upper limit of the bedrock (details provided in Volume B: Appendix 5). The most effective method of installing piezometers was found to be by means of a narrow diameter hand auger as a portable air percussion rig was not powerful enough to drill through the weathered bedrock. Slotted PVC screens (50 mm OD) were then installed with a gravel pack, sealed at the surface with bentonite and housed in a lockable steel stand pipe. Each piezometer was equipped with a Solinst Level Logger (Gold) and set to take a reading every 30 minutes.

Figure 3.1. Air percussion drilling, hand augering and final installation of piezometers (note that in the photo on the left the piezometer is located within a firebreak on an existing footpath).

Water level monitoring was initiated at various times at the ecoseeps, from July 2008 to November 2008. The extensive fires that passed through the Steenbras area in the summer of early 2009 resulted in a number of piezometers being burnt. The standpipes and piezometers were cut off at ground level and fortunately all loggers were found intact. Groundwater temperature was also measured by the piezometer data loggers.

When the decision was taken during the Inception Phase of the project to expand the physical monitoring to include the ecological monitoring sites, the ecoseeps T6_1b and T6_2b were not fitted with piezometers because it was thought that the two existing piezometers in the T6 area, namely at T6_3 and T6_4, would suffice. However, based on field observations it was clear that the hydrological functioning of the two seeps was very different from each other and from T6_3 or T6_4. As a consequence of this, their hydroperiod was categorised based on field observations alone (see Section 3.3.2). Similarly, the logger data collected at T3_Pal4 and W7_2 were questionable. At T3_Pal4 the piezometer was drilled into the bedrock on the edge of a firebreak through the seep. This logger recorded constantly dry conditions at a logger depth of 0.75 m bgl, confirmed by manual hydrocensus measurements, despite surface water observed during all site visits. At W7_2, repeated manual hydrocensus measurements showed water to be at the surface, and these agreed with logger readings, but between hydrocensus dates the logged data were spurious, for example indicating a declining water level during the wettest period of the year. These data were also discarded for the analysis, and reliance was made on manual water level measurements and site observations.

3.2.3.1 Defining seep hydroperiod

The degree and duration of saturation or inundation at the ecoseeps was assessed by analysing the water level depth in the piezometers installed at each site (m below ground level or m bgl). Three thresholds, relating to water level were identified, representing conditions of inundation, saturation or dry conditions, viz.:

- Where measured water level was at or above the surface, the seep was considered to be *inundated*. A value of 0.1 m bgl was considered to indicate surface water, to make allowance for variation in topography at the site, capillary action and patchiness in surface water;
- Where water levels were above 0.5 m bgl the wetland was considered to be *saturated*, and
- Where groundwater levels were below 0.5 m bgl the wetland was considered to be in a *dry* phase. The choice of 0.5 m was based on the definition of wetland soils used in the National Wetland Classification (SANBI 2009).

A more extensive dataset was available than for the first annual report, with time series data available for between 16 and 21 months. The periods over which ecoseeps were inundated, saturated or dry were calculated from the available data and were used to describe the hydroperiod of each seep and to place it into one of five hydroperiod categories (Table 3.2).

Table 3.2. Hydroperiod categories used to group sites according to the degree and duration of inundation or saturation at the ecoseeps.

Hydroperiod category	Definition
A	Permanently inundated
B	Seasonally inundated, permanently saturated
C	Seasonally inundated; seasonally saturated
D	Never inundated; seasonally saturated
E	Never inundated; intermittently saturated

3.2.3.2 Assessment of dominant water source and strength of aquifer connectivity

Whilst depth of the water table was the essential criterion for determining hydroperiod, it could not be used to denote aquifer connectivity *per se*, but rather the rate at which the water table fluctuated vertically was found to be of importance in determining the latter. The assumption was that a relatively constant water level, especially during the dry season but regardless of the actual depth to groundwater, is likely to reflect a high probability of connection with an aquifer.

Comment has already been made in Chapter 2 regarding the probability of connectivity between the ecological sites and the Peninsula Aquifer based only on the underlying geology (Table 2.4). In this current chapter, the strength of connectivity was evaluated by examining the behaviour of the piezometric groundwater levels at the ecoseeps over the monitoring period. Graphical methods were used to compare seep water levels over time with rainfall measured at a nearby gauge, in an attempt to assess the relationship between these two variables, and from there to refine the description of the hydrological functioning of the seeps, including speculation as to the dominant source of water for each ecosystem.

3.3 RESULTS

The results of groundwater monitoring during the EPM are presented in the two relatively separate components of the study: the regional hydrocensus and monitoring activities are summarised in Section 3.3.1 below. More detail, including details of bi-annual groundwater measurements, time series plots of all continuously-logged regional boreholes, and the first data from the new TMGA Exploratory boreholes are presented in Appendix 5, sub-sections 5.1 – 5.3 in Volume B of this final report. The focus of the interdisciplinary work, monitoring at the ecoseeps is the subject of Section 3.3.2 below, with time-series graphs presented in Volume B, Appendix 5.4 for ease of reference.

3.3.1 Hydrocensus boreholes

The data collected twice a year from the hydrocensus boreholes are fairly limited for the identification of trends, for example seasonal changes in groundwater behaviour. However, they were used to discern groundwater patterns amongst the Hydrostratigraphic Units in the study area (Figure 3.2). As would be expected given rainfall patterns, groundwater levels in winter tended to be higher in winter (October) than in summer (April) for all the Hydrostratigraphic Units, although in most cases the means were not very different.

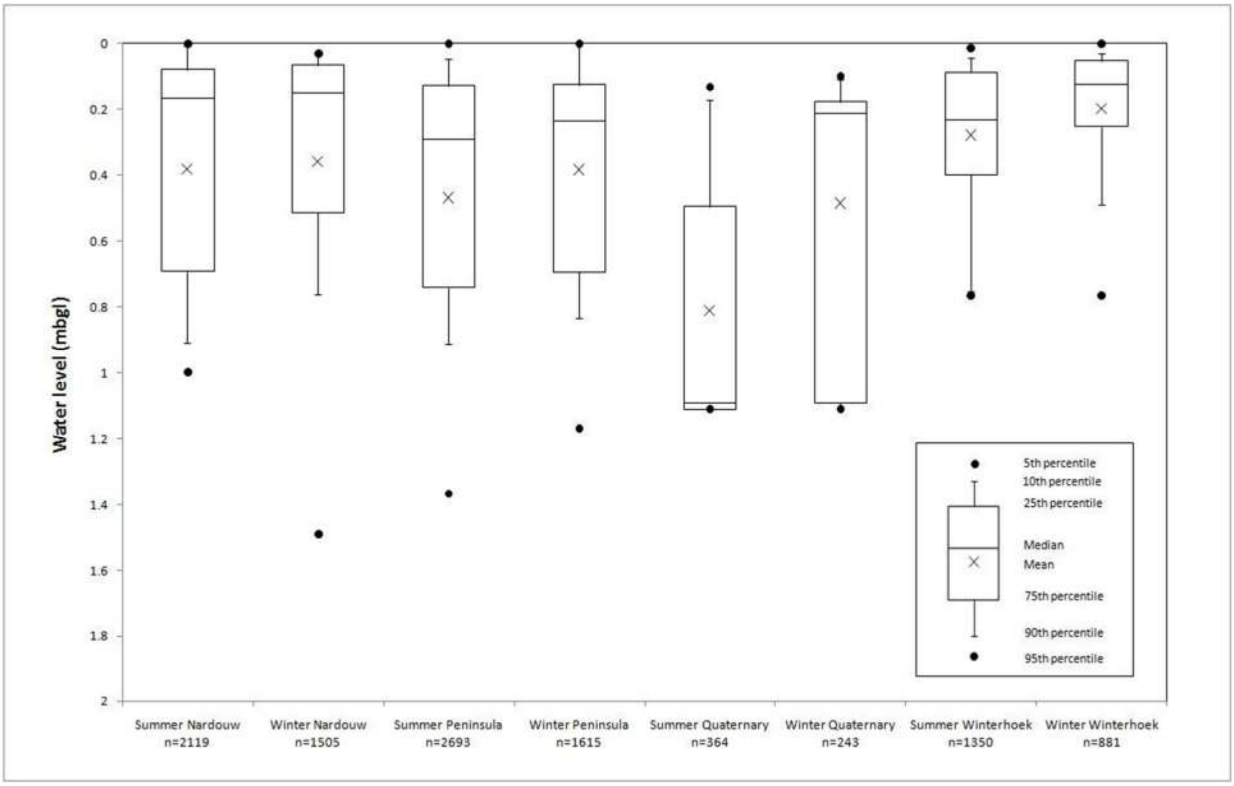


Figure 3.2. **Groundwater level distribution data per Hydrostratigraphic Unit per season. Water level is presented as mbgl = meters below ground level.**

Continuous logger data have been collected since 2008, with at least a year of data for each of the 16 production or monitoring boreholes and longer-term data for the Purgatory and Kogelberg artesian boreholes being monitored. Water level and temperature graphs for all of these are included in Volume B (Appendix 5.4).

As might be expected, seasonal drawdown of the water levels is apparent in the monitoring data, for example at Purgatory and Kogelberg (Figures 3.3 and 3.4). Seasonal fluxes appear to be in the order of 1.5 to 2 m in these boreholes.

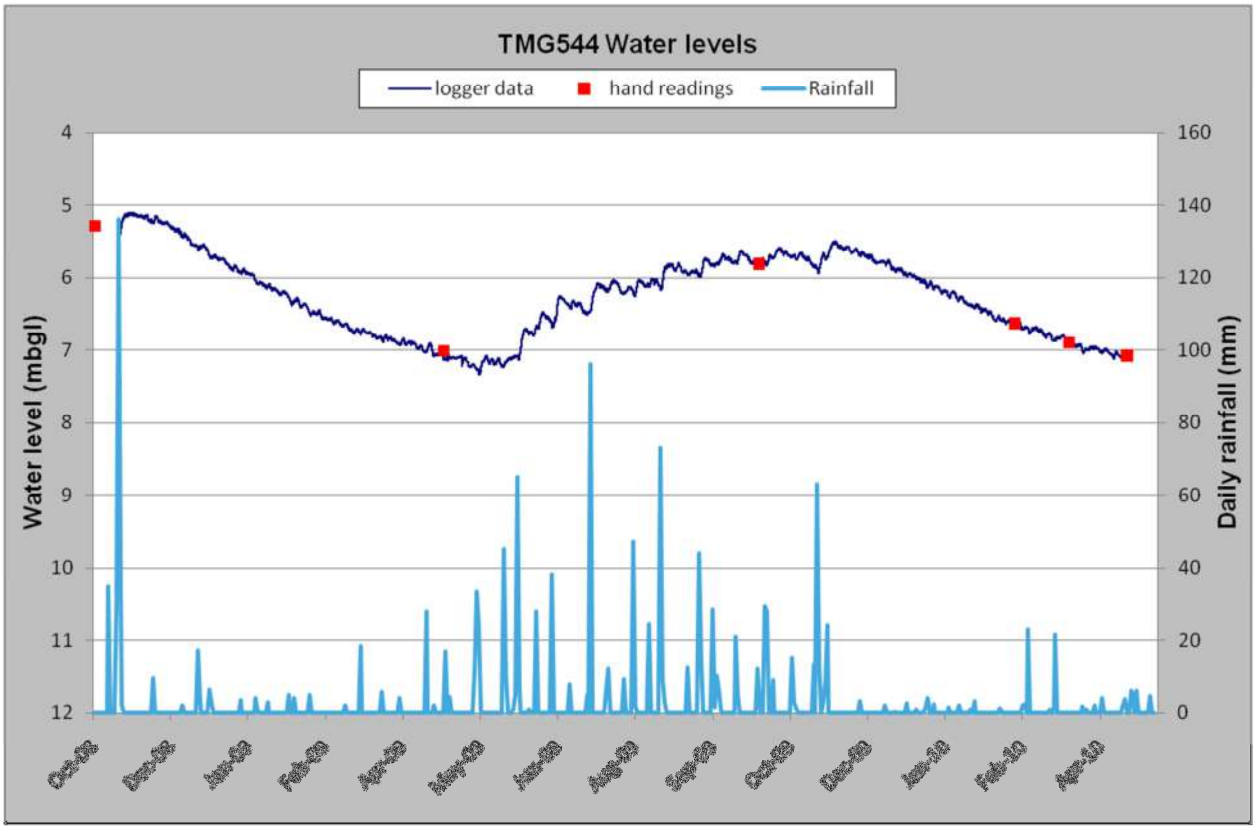


Figure 3.3. Monitoring borehole water level TMG544 (Kogelberg).

Summer water level fluctuations are impacted by abstraction from the production boreholes that are monitored (e.g. Figure 3.5). The production boreholes do not have flow meters which is a drawback, as monthly volumes abstracted must be monitored in order to use the boreholes for assessing possible City of Cape Town abstraction impacts on the groundwater of the region. Discussion needs to be held with the relevant landowners as it is in their interest to monitor the water levels and volumes abstracted. If they are not willing to install and pay for flow meters, then the borehole instrumentation should be removed and used elsewhere.

An assessment of the monitoring data, gaps and data integrity issues and recommendations for improvements in the collection of continuous water level data at these or other boreholes is provided in Appendix 5.

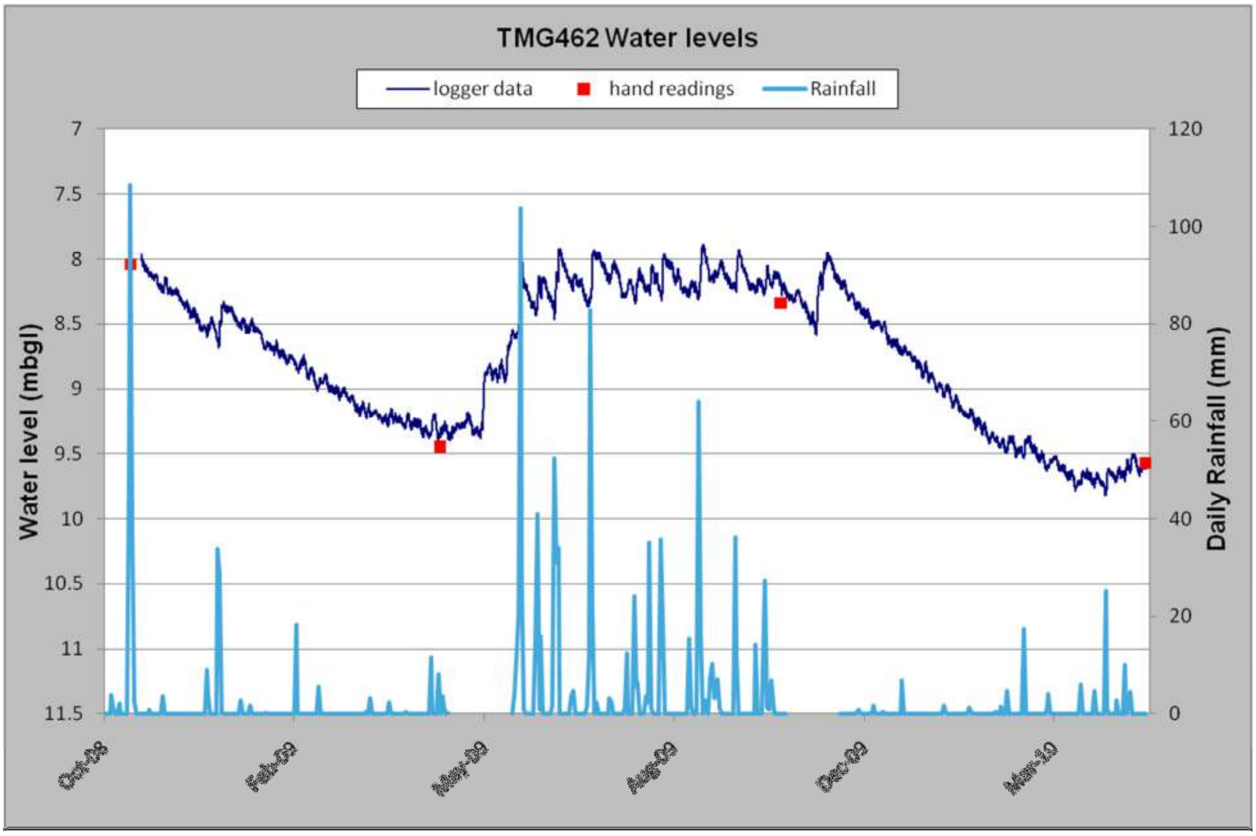


Figure 3.4. Borehole water level TMG462 (Purgatory).

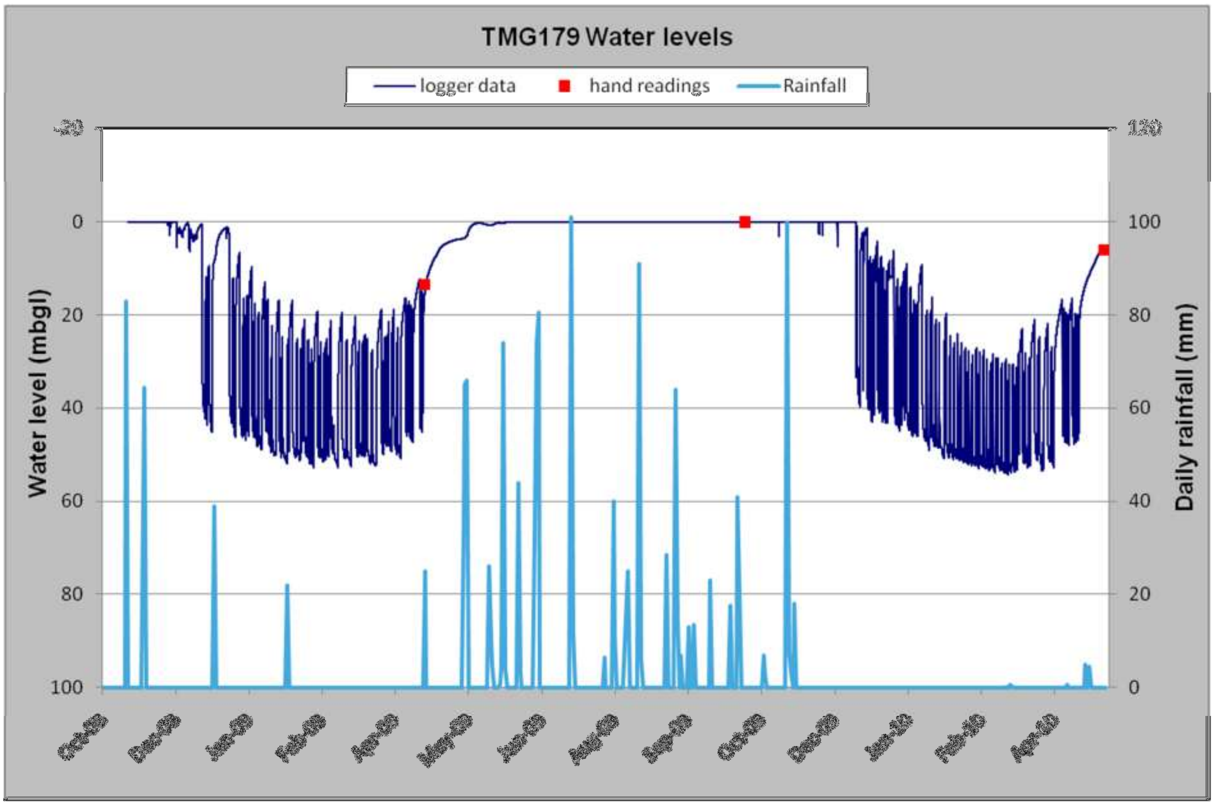


Figure 3.5. Example of water level fluctuations in a production borehole - TMG179 (Patrykskop).

3.3.2 Ecological monitoring sites (ecoseeps)

Average daily piezometer water levels and daily rainfall over the period of record are presented for each ecoseep in Figures 5.27 – 5.43 in Appendix 5 in this report Volume B for ease of reference. The scale of the vertical axis differs between graphs, because the range in water level differed so much between sites, and the presentation of the data sought to reveal as much detail of the water level fluctuation at each individual site.

Logger depth is indicated in most graphs by a pink line. Where the range in water level was substantially above the logger level, the logger position in m bgl is indicated on the graph in text. In some instances, loggers could not be returned to the same position, for example because of root growth or mud accumulation, in which case the date and new level are written on the graph. Manual readings taken during field trips for data download are indicated in red symbols on the graphs. Where wetlands became inundated manual water level readings were above ground level, but logger data levels were cut off above ground level or below logger level.

3.3.2.1 Hydroperiod

Five hydroperiod categories were discerned from the patterns of inundation and saturation, described below with a summary in Table 3.3.

- All the ecoseeps experienced water levels within 0.5 m of the surface for some period in each year, confirming their wetland status, in line with the DWA definition.
- Water levels showed distinct seasonality in all but a few cases, with declines over summer, and varying degrees of response to rainfall events.
- Four ecoseeps (H6_1, H8_2, T4_RSE1 and T4_RSE4b) were never or very rarely inundated (inundation assumed with water levels shallower than 0.1 m bgl), and achieved saturated conditions intermittently (water level closer to surface than 0.5 m bgl) for a total period of between two and four months. These seeps experienced dry conditions for at least six months of the year continuously, over summer. These four ecoseeps were therefore placed in Category E: never inundated, intermittently saturated, seasonally dry.
- Three seeps (K_3b, T6_2b and W7_3) were never or rarely inundated, but were continuously saturated for between seven and eight months of the year, with water within 30 cm of the surface for much of this time, and with a dry phase of between four and five months. These were assigned to Category D: never inundated, seasonally saturated, seasonally dry. No water level data were available for T6_2b, which was added to this category based on field observations of surface moisture over the two annual cycles (Table 3.2).
- Four of the ecoseeps were considered to be Category C seeps: these were seasonally inundated, seasonally saturated, but also experienced dry conditions for some portion of the year, although the duration of each of these phases was variable. The ecoseeps in this category were K_2b, T4_Pal2, V3_3 and W7_5. Of these K_2b was the "wettest", with only short intermittent periods of dryness, and saturation close to the surface for much of the year (Volume B, Appendix 5, Figure 5.32) followed by T4_Pal 2 (Volume B, Appendix 5, Figure 5.34).
- Six ecoseeps were perennially saturated, with water levels within 30 – 40 cm of the surface, and inundated for some to most of the year (four to ten months). These were K_1, T6_3, T6_4, T8_1b, T8_2b, and T3_Pal 4. Water level data for the site T3_Pal4 did not reflect conditions at the site, as mentioned. Here a channel at the edge of the site had a permanent trickle, and surface seepage at places close to the piezometer was observed year-round. Surface water was not present over the whole wetland, however, and the biological monitoring points were only wet at the surface seasonally, which was the basis for assigning this seep to a Category B rather than a Category A hydroperiod.

- Four ecoseeps were considered to be perennially inundated, that is with surface water present year-round – B1_1, H8_3b, T6_1b and W7_2. No water level data were available for T6_1b, and its categorisation was based on the presence of flowing surface water observed on each site visit. Similarly, despite errors associated with the logger at W7_2, widespread surface water was observed year-round at this site.

3.3.2.1 Correspondence between hydroperiod and aquifer type and connectivity

Hydroperiod category was not well correlated with the type of aquifer (Nardouw or Peninsula) to which each of the ecoseeps was putatively linked, based on analysis of the geological cross-sections. However, the interpretation of the geological cross-sections was more or less limited to indicating which aquifer might play a role in the ecoseep hydrology, rather than making a clear statement on the likelihood of there being, for example, strong, weak or no connection. Clearly, it will make no difference whether the water is provided by one or other aquifer, if the connectivity is strong.

The rate of change of water level over the monitoring period, in relation to rainfall patterns, was considered to be a useful pointer of the likely dominance of groundwater versus rainfall as a determinant of seep hydrology and the degree of rainfall / groundwater dominance was considered a measure of the strength of the connectivity of a seep to groundwater. This did show some correlation with ecoseep hydroperiod categories: more perennial systems displayed a stronger connectivity with the underlying aquifer. It was not possible in this analysis to develop a useful regression between rainfall and seep water levels to quantify connectivity, because of the short time series in relation to the variability in the data. Instead, visual interpretation of the pattern of water level change was used to comment on connectivity. The following observations are made in this regard:

- Of the Category E hydroperiod ecoseeps, H6_1 and H8_2 were considered more likely to be fed by groundwater from the Nardouw than the Peninsula Aquifer, whilst there is a strong likelihood that groundwater inputs to T4_RSE1 and T4_RSE4b would come from the Peninsula Aquifer (Table 3.2), based on examination of the geological cross-sections. This emphasises the lack of correlation between seep hydroperiod and aquifer type.

  The latter two seeps showed no evidence of groundwater contribution to water levels (Volume B, Appendix 5, Figures 5.35 and 5.36), instead showing fluxes of up to 0.6 m in response to rainfall events, and a rapid decline to dry conditions in the absence of rainfall. The Nardouw-linked seeps, both in the Steenbras (H8) TSA showed a smaller amplitude in water level fluctuation and a slightly more gradual decline in water levels through summer. Notwithstanding, it appeared that only rainfall is responsible for elevating subsurface water levels at these seeps to within 0.5 m of the surface, suggesting the groundwater contributions to wetland function are low.
- As with the Category E seeps, Category D seeps were considered to be probably linked to either the Peninsula or Nardouw Aquifers, whilst all Category C ecoseeps are probably associated with the Peninsula Aquifer, based on geological cross sections. However, the rapid decline in water levels to around 1 m bgl or lower over the summer in most of these seeps was interpreted as evidence of a low strength of connectivity. An exception was K_2b where, although water levels declined rapidly after winter, these stabilised at just above 0.5 m bgl, indicating the contribution of groundwater to wetland perenniality over summer (Volume B, Appendix 5, Figure 5.32). Of note was the fact that K_2b, T4_Pal2 and T6_2b were all classified as channelled valley bottom wetlands, rather than hillslope seeps. Their topographic position may account for the rapid increase in water levels in these wetlands with the onset of rain (Volume B, Appendix 5, Figures 5.32 and 5.34), since they would receive surface flows from the surrounding slopes that moves more slowly over the flatter valley floor en route to the adjacent channel, thus rapidly inundating valley bottom wetlands. Conversely, the relatively substantial channels associated with these wetlands may explain the

considerable drawdown of water levels at these sites in summer, including the recession of water to below 0.5 m bgl. A similar condition pertained to K_3b (Volume B, Appendix 5, Figure 5.33).

- Category B ecoseeps were predominantly considered to be associated with the Peninsula Aquifer, with the exception of T8_1b (Nardouw Aquifer) and T3_Pal4, which was considered to be associated with both, based on the geological cross sections. In these systems, the generally slow rate of recession of water levels in the absence of rain shown in Volume B, Appendix 5, Figures 5.31, 5.37, 5.38, 5.39 and 5.40 suggests strong connectivity to the underlying aquifers and their dominance in seep function over the summer period.
- Category A ecoseeps showed the same pattern of change in water levels, indicating strong aquifer connectivity.
- Of interest in Category A and B ecoseeps was the large amplitude of water level fluctuation during the summer months. Daily fluctuations of some 10 – 15 cm appeared to be unrelated to summer showers (e.g. T6_3, T6_4 in February 2010) and may reflect diurnal fluxes in evapotranspiration. Here the shallow water table may interact with the rooting zones of wetland plants, which accounts for this pattern in these permanently saturated seeps, which was not apparent in the other, seasonally dry ecoseeps. Larger daily fluxes in water level (up to 25 cm in a single day, e.g. T8_1b) appeared to be linked to short-term increases in water level associated with autumn showers, typically most obvious when water levels are at their lowest. This emphasises that even where a seep is strongly linked to groundwater, rainfall may still be a significant contributor to hydrological functioning at the end of the dry season.
- Linked to the previous point, the effect of fire on plant-drawdown of the water table in summer was marked at site H8_3b. Here the fires that swept through the Steenbras area in December 2008 resulted in no drawdown at all at this site during the following summer months (Volume B, Appendix 5, Figure 5.30). The other H6/H8 seeps were less affected since these are not strongly groundwater fed, and their water levels recede to below the rooting zones of plants in any event. The following summer, the drawdown at H8_3b was some 25 cm, plausibly associated with the recovering vegetation cover at the site. In contrast, the perennial seeps of Kogelberg, Boesmanskloof or Nuweberg showed very little inter-annual difference in water level flux over the summer.
- T8_1b and T8_2b also showed inter-annual differences in water levels, considered to be linked to fire and succession, but less markedly: this area was in a later successional stage at the start of the sampling programme, with already partially recovered vegetation in 2008. Similarly, although B1_1 burnt prior to the start of sampling in 2008, recovery of *Todea barbara* in the vicinity of the piezometer was substantial prior to summer 2008/9.

Table 3.3 summarises the outcome of the assessment of seep hydrology and aquifer connectivity. Five of the ecoseeps combine strong connectivity to the Peninsula Aquifer with a regime of strongly perennial levels of saturation or inundation (shaded dark blue in Table 3.3). Three other strongly perennial systems (light blue) have strong connectivity but probably linked to both the Peninsula and Nardouw formations. A further two perennial seeps with strong groundwater links are more probably fed by the Nardouw Aquifer alone (light green shading). Finally, of the remaining ecoseeps considered to be most likely connected to the Peninsula Aquifer, K_2b is the closest to a perennial system, with only intermittent dryness. These seeps are considered thus to be the most promising from the perspective of long-term monitoring.

Table 3.3 includes the minimum and maximum temperatures recorded by each logger over the sampling period. Analysis of these time series data were precluded by the lack of data on ambient temperature, and the data were included in the data deliverable for purposes of longer-term analysis. Groundwater temperature in the seeps generally varied from 9℃ to 22 ℃, not that dissimilar from surface water temperature. This may be related to the close proximity of groundwater to the land surface in many of the seeps: those whose water levels receded to below 1 m bgl in summer (e.g. T4_Pal2, W7_3) showed lower temperature maxima.

3.4 SUMMARY AND CONCLUSIONS

The following activities were undertaken for this component of the EPM:

- Bi-annual monitoring of water level and / or water chemistry was undertaken at 53 regional hydrocensus sites, including 10 Exploration boreholes, to provide baseline monitoring of regional geohydrology. This adds to a dataset that has been developed since 2003.
- Continuous monitoring equipment was installed at 24 of the boreholes and logging commenced during 2009.
- Piezometers were installed at 19 of the 21 ecological monitoring seep sites (ecoseeps). Water level monitoring was between July 2008 and November 2008 and continued until April 2010, i.e., the end date of this programme.
- The constancy of water levels or the rate of change relative to rainfall patterns was used to estimate the strength of connectivity and compared with the probability of seep connectivity to the Peninsula or Nardouw Aquifers from the geological cross-sections.
- The degree and duration of saturation in the ecoseeps was assessed and each ecoseep was assigned to one of five Hydroperiod Categories, which were defined based on the duration of inundation (wet at the surface) or saturation (wet shallower than 0.5 m bgl). This was compared with the strength of seep connectivity (to either the Peninsula or Nardouw Aquifers).

The major findings of this analysis were:

- All the ecoseeps experienced water levels within 0.5 m of the surface for some period in each year, confirming their wetland status, in line with the DWA definition.
- Water levels showed distinct seasonality, with declines over summer, and varying degrees of response to rainfall events.
- Very little correlation was found between strength of connectivity to groundwater and the type of aquifer (Peninsula or Nardouw) to which the seep was considered to be connected based on geology.
- However, there was fairly strong agreement between systems that are strongly perennial (Category A and B hydroperiod) and their level of connectivity to groundwater.
- The effect of fire on reducing plant-drawdown of the water table in summer appears to be marked immediately following a fire, and for some years afterwards, with little inter-annual variability in summer drawdown of perennial systems in mature vegetation.

A limitation of the analysis is that ecoseep hydroperiod categorisation was based on data collected from a single point in the wetland, whereas these wetlands are likely to display a range in wetness, with a combination of patches that are groundwater-fed (connectivity to the aquifer) and that are rain-fed, particularly given the gradient of the sites,. Every effort was made to locate piezometers in the wettest portion of each site, which means that the hydroperiod category is probably a useful summary of the character of wettest part of the seep.

The shortness of the data record relative to water level variability prohibited quantitative assessment of the relationship between seep water levels and rainfall, as did the fact that rainfall data, despite being taken from the closest rain station, did not always reflect local rainfall. Ongoing monitoring should include local rainfall measurements as these are critical in interpreting the hydrological behaviour of the wetland.

Recommendations for changes in the programme during future phases of the TMGA project are detailed in Chapter 9.

Table 3.3. **Analysis of seep connectivity to aquifers, by type and strength, and seep hydroperiod based on piezometer water levels and field observations. Hydroperiod categories are explained in Table 3.2. G/w = groundwater; WL = water level; Biol = biological. Shading: dark blue = strongly perennial seeps with strong connectivity and linked to the Peninsula aquifer; light blue - strongly perennial seeps with strong connectivity but linked to the Peninsula and Nardouw aquifers; light green = perennial seeps with strong groundwater links but probably fed by the Nardouw Aquifer alone.**

Site	Likelihood of connectivity based on geology cross sections (from Table 2.5)	Comments on behaviour of water level (WL) in piezometer	Field observations on changes in water levels	G/w temp. (min - max)	Seep ranked from wettest to driest	Seep hydro-. period category	Conclusions on strength of connectivity to g/w
B1_1	Links between the seep and Peninsula Aquifer is possible, but groundwater contributions may be predominantly from the Nardouw Aquifer.	**Inundated** (WL within 10 cm of surface) for **4-6 months** in continuous period, July - Dec; **perennially saturated** in top 30 cm.	Piezometer situated above main wetland in which surface water = perennial; site considered to be perennially inundated over most of its area and at biol. sampling points	16 - 18	3	A	Strong
H6_1	Significant seep / Peninsula Aquifer interaction is unlikely, and groundwater contribution is most likely from the Nardouw Aquifer	**Never inundated, seasonally saturated** in intermittent periods between Apr and Dec, total of 3 months, with WL never closer than 30 cm below surface; **seasonally dry** for continuous period **5-8 months**, Sep - May	Agreement with piezometer assessment	12 - 20	21	E	Moderate
H8_2	Connectivity to the Nardouw Aquifer is more likely to explain g/w contribution to summer baseflow.	**Never inundated, seasonally saturated** in intermittent periods between Apr and Dec, total of 2-3 months, with WL never closer than 30 cm below surface; **seasonally dry** for continuous period **5-7 months**, Sep - May	Agreement with piezometer assessment	13 - 22	20	E	Moderate
H8_3b	Highly probable connection to groundwater, but probably mostly the Nardouw Aquifer. The Peninsula Aquifer may contribute slightly, as a result of the nearby fault intersecting the Peninsula Formation.	**Inundated** (WL within 10 cm of surface) for **8-11 months** in continuous period, Apr 2008 - Feb (drier in second year, with WL below 10 cm for 4 months from Jan - April 2010); **perennially saturated** within 30 cm of surface	Surface water present over most of seep area year-round and at all biol. sampling points; site considered to be perennially inundated	14 - 19	2	A	Strong
K_1	There is a high probability that the seep is linked to the Peninsula Aquifer.	**Inundated** (WL within 10 cm of surface) for **3-4 months** in near-continuous period between Sep and Jan; **perennially saturated** within 30 cm of surface	Biol sampling points in part of seep that is drier than the piezometer location, so the latter is not reflective of all wetland; agreement with hydroperiod category, but modified wetness ranking	17 - 22	9	B	Strong
K_2b	Connectivity with the Peninsula Aquifer is highly likely to provide a major component of the groundwater base flow to the river.	**Inundated** (WL within 10 cm of surface) for **5-6 months** in near-continuous period between Jun and Dec; **seasonally saturated for 11 months betw Mar and Jan** with drop in WL Jan-may (below 30 cm) and **intermittently dry** (below 0.5 m) for a total of 15 - 30 d betw Feb and Apr	Agreement with piezometer assessment	16 - 19	11	C	Moderate

Site	Likelihood of connectivity based on geology cross sections (from Table 2.5)	Comments on behaviour of water level (WL) in piezometer	Field observations on changes in water levels	G/w temp. (min - max)	Seep ranked from wettest to driest	Seep hydro-. period category	Conclusions on strength of connectivity to g/w
K_3b	Low likelihood of connectivity with Peninsula, but highly likely that Nardouw provides g/w to seep	**Never inundated**, **seasonally saturated** in continuous **7-8 month** period between May and Dec, with WL within 30 cm of surface for 6 of these months; **seasonally dry for 4 -5 months**, Jan - May	Parts of wetland with surface trickle in winter which appears to be from spring, but close to channel so probably affected by that; field observation agrees with WL data	13 - 19	16	D	Weak
T3_Pal4	Hydrological connectivity with the Peninsula Aquifer is probable, but also with a high probability of connectivity with the Nardouw Aquifer.	**U**nfluctuating WL over dry season, with spikes associated with rainfall; problem with piezometer logger level and data not used	Surface trickle always observed at site, but not at all biol. sampling points, which do not have surface water all year. Hydroperiod based on field observations; WL data not trustworthy	No data	7	B	Strong
T4_Pal2	Probable connectivity to Peninsula Aquifer	Seasonally inundated for up to 8 months May - Jan; seasonally saturated in continuous 10 month period betw May and March; seasonally dry for 2 months Mar-Apr	Agreement with piezometer assessment	11 - 14	12	C	Weak
T4_RSE1	Probable connectivity to Peninsula Aquifer	Inundated fewer than 20 d in a year, seasonally saturated intermittent periods between May and Nov, total of 4 months, with WL within 30 cm of surface for 2.5-3 of these months; seasonally dry for continuous period 6 months, Nov - May	Agreement with piezometer assessment	10 - 22	18 pair	E	None
T4_RSE4b	Definite connectivity to Peninsula Aquifer	Inundated fewer than 10 d in a year, seasonally saturated intermittent periods between May and Nov, total of 4 months, with WL within 30 cm of surface for 3 of these months; seasonally dry for continuous period 6 months, Nov - May	Agreement with piezometer assessment	9 - 21	18 pair	E	None
T6_1b	Probable connectivity to Peninsula Aquifer	no data	All biol sites permanently wet areas; strong flow in channelled seep	No data	3 pair	A	Strong (extrapolation)
T6_2b	Probable connectivity with the Peninsula Aquifer	No data	Never inundated, although channelled valley bottom flows in winter; surface only damp as early as Sept; seasonally very dry at least from Dec - Mar probably for 6 months	No data	17	D	Weak (extrapolation)

Site	Likelihood of connectivity based on geology cross sections (from Table 2.5)	Comments on behaviour of water level (WL) in piezometer	Field observations on changes in water levels	G/w temp. (min - max)	Seep ranked from wettest to driest	Seep hydro-. period category	Conclusions on strength of connectivity to g/w
T6_3	Probable connectivity to Peninsula Aquifer	**Inundated** for **5 months but not** continuously between about Mar - Jan; **perennially saturated** - WL within 30 cm of surface	Agreement with piezometer assessment	11 - 19	8	B	Strong
T6_4	Probable connectivity to Peninsula Aquifer	Wet season variability, Inundated for 3 months Aug - Nov 2008 but not inundated 2009; perennially saturated, WL within 30 -35 cm of surface	Agreement with piezometer assessment	13 - 18	10	B	Strong
T8_1b	Connectivity with the Peninsula Aquifer is of low probability, with high probability of a connection with the Nardouw Aquifer.	**Inundated** (WL within 10 cm of surface) for **7-10 months** in continuous period, May - Jan (drier in second year); **perennially saturated, WL** within 30 cm of surface but in Apr may dip to 40 cm bgl	Agreement with piezometer assessment	12 - 19	5	B	Strong
T8_2b	Connectivity of seep to the Peninsula Aquifer is probable	**Inundated** (WL within 10 cm of surface) for **7-10 months** in continuous period, May - Jan (drier in second year, WL below surface from Dec); **perennially saturated, WL** within 30 cm of surface except for Feb-April, when dips to 40 cm bgl	Agreement with piezometer assessment	12 - 19	6	B	Moderate
V3_3	Highly probable connectivity to Peninsula Aquifer	**Inundated** for 1 **month** May - Jun; **seasonally saturated** in continuous **7 month** period betw Apr and Nov, with WL above 30 cm for 5 of these months; **seasonally dry for 3-5 months** Nov-Apr	Agreement with piezometer assessment, but conditions over most of seep may be closer to Category D	11 - 20	14	C	Weak
W7_2	Most probably lithologically controlled with outflow from the Nardouw Aquifer, with unlikely connectivity with the Peninsula aquifer.	**Inundated** (WL within 10 cm of surface) for **11-12 months**, Apr - Mar (drier in second year, with WL below 10 cm for 1 month in Mar 2010); **perennially saturated** within 30 cm of surface	Always surface water or v damp at all sampling points year-round; wettest of the ecoseep sites; considered to be perennially inundated	15 - 22	1	A	Strong
W7_3	Unlikely that there is connectivity with Peninsula Aquifer, but probably connected with the Nardouw Aquifer	Inundated fewer than 10 d in a year, seasonally saturated in 7-month continuous period between Jun and Feb, with WL within 30 cm of surface for 6-6.5 of these months; seasonally dry for continuous period 5 months, Jan - Jun	Agreement with piezometer assessment	10 - 15	15	D	Weak
W7_5	Probable connectivity with the Peninsula Aquifer	Inundated 2 months Aug-Oct; Seasonally saturated for 5-6 months May - Oct; seasonally dry for continuous period 6-6.5 months, Oct - May	Agreement with piezometer assessment, but conditions over most of seep may be closer to Category D	13 - 22	13	C	Weak

4. STREAMFLOW PATTERNS

4.1 INTRODUCTION

Streams in the Western Cape mountainous areas have highly variable discharge, at least at some times of the year, because of the combination of topography and climate. On the other hand, the summer months are associated with lowest flows that also have a far greater constancy, but which may recede to very low levels (Ractliffe 2009). The degree of intermittency or perenniality has been shown to be the most profound distinguisher between stream type (Poff & Ward 1989), and this has particular relevance for rivers like those in the Western Cape where the summer is without much rain and baseflows are sustained to a large degree by groundwater (Parsons 2004). Monitoring of lowflow therefore is an important component of the TMGA project, since one of the key impacts associated with aquifer drawdown could be expected to be a reduction in lowflow volumes during the period when streams are groundwater fed, with associated impacts on habitat, flora and fauna.

This section of the report addresses the surface water component of the ecohydrological monitoring project. There are three main types of surface water monitoring sites. These are:

- the river / stream sites which are sampled twice a year, as part of the regional hydrocensus work,
- the official DWA gauging stations, where flow is recorded on an ongoing basis,
- channel ecological monitoring sites (ecochannels), which are fitted with stilling wells and data loggers set to measure a water level every 30 minutes.

4.1.1 Hydrocensus

The aim of the regional hydrocensus is to provide baseline monitoring of regional hydrology (in this chapter the term hydrocensus refers to the surface water (streamflow) component of regional hydrology). Monitoring was initiated by the TMGAA prior to the EPM, from around 2003. Umvoto Africa completed the work in 2003 and 2004 and GEOSS has collected the data since 2005. The hydrocensus work comprises bi-annual streamflow measurement in a number of rivers, in October and April of each year, which provides a snapshot of conditions in the targeted river. In the context of the EPM, spot discharge readings can make a very limited contribution to long-term monitoring, if they can establish the degree of perenniality at sites that naturally recede to fairly small flow volumes. Potential lowflow impacts, whilst difficult to quantify from spot measurements, may be categorised into classes of severity, for example:

- No zero records in pre-impact study, but some or all zero flows in post-impact study: this category would identify streams that have been recorded as perennial that then cease to be so, and may be a) totally dry or b) reduced to pools with drying of the raised portions of the bed such as riffles,
- A stream that has been recorded as perennial with flow reaching to the marginal vegetation becomes one where vegetation is droughted in one or more years, whilst perenniality is still maintained.

This coarse approach to detecting flow impacts relies, critically, on selecting only systems that are not affected by any flow alteration, including alien vegetation invasion. Stream observation would need to be during the lowest flows of each year – something that may be impossible to achieve with a once-off annual visit. Also, interpretation of the results must be made with reference to spatially-relevant rainfall data. Finally, any conclusion of a change from perennial to non-perennial state at one site would need to be premised on there being no change in the perenniality of similar streams, particularly in the context of climate change. The uncertainties associated with this approach are thus considerable.

4.1.2 Continuous flow records

Statistical analysis of a continuous record of flow data, such as those collected by DWA at gauges around the country is the most useful, quantitative approach to assessment of flow changes. For the EPM, the focus of hydrological analysis is obviously the low flow (summer period), for reasons mentioned above. Flow frequency analysis (Gordon *et al.* 2004) can supply statistics such as the one-, seven- or 15-day lowflow volume, linked to a probability of occurrence (return period). Such statistics, if based on a period of record during which flows are considered to be natural, can be used as a yardstick against which streamflow levels are compared during a phase of water resource development. However, this approach relies on a reasonable length of flow record, and, importantly, lowflow data that reflect natural conditions.

More specific analysis of baseflows, obtained with the use of flow separation techniques, should be a central component of hydrological analyses. Using graphical separation techniques, baseflow rating curves or recession-curve displacement methods, hydrologists calculate a baseflow index (BFI), which is the portion of baseflow to total flow or run-off. These techniques are described by Hughes and Münster (2000), Smakhtin (2001) and Hughes *et al.* (2003). However the baseflow component does not simply equate to the groundwater inflow to a river but comprises interflow, throughflow and groundwater flow. Analysis of baseflow after prolonged periods without rain, may give a good indication of the groundwater contribution to flow. Moore (1992), Xu *et al.* (2002) and Hannula *et al.* (2003) have developed methods to calculate the groundwater component of baseflow. An excellent review of using baseflow to identify the hydrological effects on baseflow of groundwater abstraction is provided in Evans (2007), and should form the basis of longer-term analysis, once appropriate gauging sites have been finalised.

4.1.3 Ecological monitoring sites (ecochannels)

Flow monitoring at the ecochannels was considered to be essential to provide information on the flow environment to help to interpret biological changes that may occur during monitoring. The focus of the EPM was to determine the importance of the underlying aquifer for summer base flow inputs to each ecochannel and the strength of any aquifer connection. Whilst interpretation of the geological cross-sections (Table 2.5) provided an estimate of the probability of aquifer connectivity, the behaviour of streamflow over the summer period may show the strength of the contribution to baseflow from underlying aquifers. Differences in the biological assemblages at the monitoring sites are also likely to be, at least in part, determined by differences in the flow regime of the study streams. An attempt was thus made to group sites according to the degree or intermittency or the strength of perenniality, using the summer water levels.

4.2 METHODS

4.2.1 River/stream sites visited twice a year

A total of 183 surface water-monitoring sites were listed in the Hydrocensus ToR. There are 350 field sites from which one or more flow measurements have been collected listed in the database provided to the TMGA-EMA at the start of the project by Umvoto. Many of these sites were discontinued prior to the hydrocensus work undertaken as part of this EPM contract, i.e. from 2008. The ToR for field-monitoring in this EPM project included data collection in April and October.

The rivers and stream where discharge was measured twice a year form part of the suite of sites visited in the regional hydrocensus. Discharge was measured using one of three methods:

- Bucket method
- Flow readings across a cross-section using a flow meter

- Flow readings in a pipe using a flow meter.

Although data were collected for almost all sites, the sites were reassessed in light of a better understanding of the conditions needed at a flow site. Sites were evaluated against a simple set of requirements for inclusion in a revised set of sites for future work, *viz*:

- The river should be a first- to third-order stream - monitoring large rivers is unlikely to provide evidence of a substantial shift in summer baseflow because they tend to have many more perturbations and it is difficult to isolate any one cause of changes in flow.
- Flow must be unmodified – sites downstream of dams or abstraction weirs or with run of river abstraction are not useful for monitoring changes that might result from a decline in groundwater inputs. The same applies to afforested areas – sites where active forestry is taking place will provide poor and unreliable evidence of streamflow changes linked to groundwater. In practice, it is not easy to avoid forest areas altogether because of their extent, but location of sites in relation to the forest blocks must be carefully examined.
- Flow at the site must be perennial – bi-annual or other spot flow data are only useful as binary information, i.e. whether perenniality has been maintained or not. Actual values recorded for discharge are likely to be coarse given a) the instruments and b) the site locations (vegetated channels, non-uniform beds etc.).

All sites on the database were assessed. For sites which were not visited as part of the hydrocensus, Google Earth was used to assess upstream development, dams, forestry extent and so on.

4.2.2 DWA flow records

The EPM project ToR listed 12 operational DWA gauging stations in the study area from which data were to be downloaded (Table 4.1). The intention was to generate low-flow frequency curves that could be used for comparison with flow records in future phases of the TMGA project. However, the EPM team found many of these were unsuitable for TMGA project use, because they were located on canals, downstream of dams, or on major rivers with considerable upstream development. The TMGA-EMA identified a new set of gauges that were potentially useful and their data were assessed for usefulness to the study. The major criteria for deciding on usefulness of a gauging weir are that a) the stream must have no unquantifiable upstream water resource developments, b) the weir should be maintained sufficiently to provide confidence in the lowflow data, c) there should be a reasonable time series of data and d) a rating curve should preferable exist in order to convert stage to discharge.

Table 4.1 lists the suite of gauges that were evaluated, and identifies eight gauges proposed for consideration for future data monitoring by the TMGAA. The following are noteworthy:

- Three of the proposed gauges are located in the Zachariashoek valley. Five gauging weirs exist in this area, all of which were discontinued for monitoring in the 1990s. For the TMGA it was considered cost-effective to focus on the recommissioning three of the gauges. A fourth gauge is located at one of the ecochannel sites, and could be restored and equipped if that site were to be monitored in future; data for this gauge exist from 1964 - 1988.
- A new gauge on the Berg River, G1H076, was included in the list of possibly useful gauges (Table 4.1) because of the stream's size and natural catchment. The record is too short to allow for statistical analysis at this stage of the TMGA project, but the gauge is of high quality and the data accurate.
- There were no data on the DWA website for the weirs on three streams in the Jonkershoek Nature Reserve, although rating tables for these weirs were provided. DWA collected data at these sites for some period before they were handed over the SAFCOL and thence to Cape Nature (Frans Mouski DWA Western Cape Hydrology, pers. comm. June 2010). It is highly likely that the data are not trustworthy because the weirs have not been maintained. Nevertheless, these gauges

should be rehabilitated and incorporated into the EPM monitoring, especially since they are situated on unimpacted stream reaches.

- The gauges at Purgatory (du Toits River) and in the T4 TSA (Riviersonderend) have both been discontinued due to access issues and a lack of capacity to undertake the required maintenance to ensure the gauges function accurately. These gauges, however, are ideally placed for TMGA monitoring and efforts should be made to secure their reinstatement.
- A new DWA gauge was constructed on the upper Banhoek River, possibly in 1999, and now all flows – in the river and in associated transfer pipelines - can thus be measured, allowing for a total streamflow record to be calculated at this locality. Such information should be incorporated into the EPM. DWA (Frans Mouski) should however provide advice on which exact gauges are required to be summed, in order to secure the development of a long-term data record reflecting natural flows.

Table 4.1. DWA flow gauging stations evaluated for time series analysis. (*) = non-operational).

DWA Data	Analysis area	Weir location
DWA gauges on initial list provided in the TMGA_EMA ToR. Shaded sites were judged unsuitable because of their location on a modified or large river, or the fact that they do not measure actual rivers		
G2H005	Jonkershoek	Downstream of Kleinplaas Dam
G1H057 (*)	V3	Canal from the Watervals River
G4H007	Kogel	lower Palmiet River upstream of the estuary
G4H023	H8	Transfer from Rockview to Steenbras Dam
G4H030	Kogel	Palmiet River downstream of Arieskraal
Dam -	H6	Steenbras Dam
H6H013 (*)	B1	canal
H6H008 (*)	T4	Riviersonderend at Swarte Water
G1H011	V3	Watervals River at upper Watervalsberge
G1H014(*)	W7	Zachariashoek
G1H018 (*)	W7	Zachariashoek
G1H016 (*)	W7	Zachariashoek
New list of DWA gauges explored for suitability for flow frequency analysis. Shaded sites were judged unsuitable (reason in parenthesis)		
G1H076	Berg / Franschhoek	(new) Upper Berg River (good data; only 1 year)
G2H007	Jonkershoek	Langrivier (no available data)
G2H004	Jonkershoek	Tierkloof River (no available data)
G2H028	Jonkershoek	Swartboschkloof (no available data)
G4H015	Grabouw	Jakkals River @ Lebanon Forest Res. (mostly zero data)
G1H064, G1H032, G1H062	Berg	Banhoek River @ Bosmanshoek (old and new gauges)
H6H007 (*)	Purgatory	Du Toits River

The software AQUAPAK Version 1.05 2007 (Gordon *et al.* 2004) is a general-purpose program that can be used for the processing of time-series data which was used or the flow frequency analysis. Most data needed to be patched where they contained ‘170’, ‘172’ or 173 values. Empty cells were interpolated using Edit>Fill>Series>linear in Excel, but this was not done where error values extended over a considerable period of time. An attempt to patch these gaps through correlation of flows with neighbouring weirs was unsuccessful as correlations between weirs are not strong, and those years of data were excluded from the analysis. If these data (e.g. DWA gauges G1H011) are to be used, a suitable means of patching the data will need to be identified.

The lowflow period was defined as December through March. Flow Duration Curves (FDCs) and Flow Minima routines were developed using AQUAPAK. Before being analysed all low flow discharge values needed to be multiplied by 10 since AQUAPAK does not provide probability distribution estimates for values at resolutions of more than two decimal places. Once the probability distributions were estimated in AQUAPAK, the values were exported to EXCEL after they were divided by ten to correct for the AQUAPAK adjustment. These calculations are apparent in the data and analytical files included in the data CD accompanying this report.

Lowflow frequency analysis

This routine produces an Average Recurrence Interval (ARI) for a summed minimum volume of flow for a defined period of days (1, 7, 15 and 30 days) during the low flow period (Dec-Mar). The summed minimum for a seven day period, for example, would be the minimum value obtained of all values obtained by summing the flow of any seven consecutive days within the defined low flow period, for each year. These summed-flow minima are selected by AQUAPAK and then ranked from highest to lowest, with the highest flows assigned a rank of 1.

The choice of plotting position formulae to calculate probability of exceedence or ARI makes a significant difference to the outcome of the frequency distribution. AQUAPAK uses General Extreme Value (GEV) for calculating plotting the position and ARI. A Weibull distribution (best distribution for low flows) is then fitted by AQUAPAK by means of probability-weighted moments (Gordon *et al.* 2004; Pg. 207). The distribution is plotted on a log axis to emphasize the tails of the distribution.

NOTE: whereas the ARI for peak flows is the number of years a particular flow is greater than a certain value, the ARI for low flows should be read as the number of years a particular flow is less than the corresponding value on the y-axis.

Flow duration curves

Flow duration curves for the low flow period were also produced. AQUAPAK truncates FDC outputs in the text files and thus FDCs were calculated using Excel. These are not reproduced in this report, but are available in the accompanying data CD.

4.2.3 Ecological monitoring sites (ecochannels)

Stilling wells were installed at the each of the ecological channel monitoring sites (ecochannels), so that accurate surface water levels were recorded using water level loggers (Figure 4.1). The details of stilling wells at each site installations are given in Volume B: Appendix 6. These were anchored to boulders with steel rods and house slotted PVC screens (50 mm OD). Each stilling well was equipped

Figure 4.1. Stilling well installation.

with a Solinst Level Logger (Gold) and set to take a reading every 30 minutes. Storms in the winter of 2009 bent the steel anchoring rods some of the stilling wells. These were repaired as soon as possible, but in the light of this it would be better to redesign the stilling wells with a much smaller surface area and to stabilise them with a large foot plate rather than using the anchoring rods.

4.2.3.1 Assessment of stream hydroperiod

Water-level data collected at the ecochannel sites were useful for distinguishing the date on which non-perennial streams dried up each year. However, the absolute value of the water level recorded at each ecochannel could not be compared, as the position of the stilling well may make a large difference, especially when very shallow flow levels are being compared. The data need to be converted to a discharge value through the development of rating tables for each site.

Given the focus of the project on determining low-flow impacts, it was considered important to try to distinguish between perennial streams based on the extent of streamflow reduction in summer: streams whose flow declines to very shallow levels may experience habitat loss, for example loss of connectivity with marginal vegetation. Instead of using hydrological parameters for this, notes on the availability and quality of instream habitat during the December and March field visits and visual observations of flow conditions were used to designate streams into two categories of perennial river: “perennial” and “low”. The hydroperiod categories and descriptions are provided in Table 4.2.

Table 4.2. Hydroperiod categories used to group channel sites according to the duration of flow over summer, and using visual thresholds of reduction in flows that are deemed to have ecological consequences (see text for details).

Hydroperiod category	Definition	Description
A	Perennial	Very strong summer baseflows, especially in riffles where broken water habitat maintained
B	Seasonally low	Decline of summer flows, with exposure of marginal vegetation, conversion of riffles to trickles or shallow runs, or loss of stones in current biotopes
C	Seasonally dry - pools	Stream dries but pools remain which serve as a summer refugium for some taxa
D	Seasonally dry	No surface water present

4.2.3.2 Assessment of dominant water source

The strength of aquifer contribution to streamflow was assessed by examining rates at which streamflow levels receded over a period from spring through summer. Graphical methods were used to display and interpret channel water levels over time, with rainfall measured at a representative gauge presented to assist with interpretation. The rate at which water levels declined over a 60-day period in summer of each year was identified, with the dates chosen to ensure that it was the driest possible period each year. Nevertheless there was still some rainfall in some areas. This allowed for the constancy in streamflow to be used in comparing the importance of groundwater to each of the streams, at least over that, the driest, period.

4.3 RESULTS

4.3.1 Field flow monitoring sites

The 350 locations in the field streamflow database, including the 138 on the hydrocensus list that were monitored during this EPM project, are listed in Volume B: Appendix 6, Figures 6.1-6.9 and Table 6.1, along with the number and temporal distribution of available flow records and an assessment of their potential worth as monitoring sites for the EPM and future phases of the TMGA project. Although 256 sites had some summer flow data, in most cases there were only one or two readings. All sites were assessed, and excluded from a list of potential monitoring points on the basis of:

- Location within alien vegetation or downstream of extensive commercial forestry, since interpretation of discharge readings would be compromised.
- Location on a river with obvious water resource development, or where this was strongly suggested (e.g. by adjacent agricultural or urban land use).
- Any zero-flow records, during any month, as only perennial sites were deemed eligible for inclusion as a flow monitoring site (refer to section 4.2.1).
- Larger rivers were excluded – these are unlikely to show sensitivity to small-scale changes in lowflow discharge associated with aquifer abstraction and therefore would be unlikely to provide early alarm signals of potential flow impacts; also most larger rivers can be assumed to be impacted by water resource developments and identifying the cause of different impacts is difficult.

On this basis, 62 of the 138 sites currently monitored as part of the EPM project were considered to be unsuitable for low-flow monitoring and were excluded from the list. Thirty-eight of the remaining sites on the list, not current monitored, fulfilled the criteria for inclusion in the monitoring programme, making a total list of potential bi-annual flow measurement sites with some historical record. However, a better use of resources would be to identify which of these sites are truly perennial and then to establish long-term monitoring infrastructure at these.

4.3.2 DWA flow records

The length of record used for the low flow analysis at the seven gauges, and some comments on data quality are provided in this section. Actual raw and processed data are provided in the data CD, whilst the locations of DWA gauges within the study area is shown in Volume B: Appendix 6, Figures 6.1-6.9.

DWAF Gauging Weir G1H011A01 Watervals River @ Watervals (Figure 4.2):

- Forty years of record from 1960 to 2004, at which time the gauge was abandoned.
- Many periods of missing data of between six and sixteen days; also up to 15 longer data gaps of ca. 43 days usually associated with winter months (all denoted by “170” values).
- Possible run-of-river abstraction; small farm dams.

DWAF Gauging Weir G1H014A01 Zachariashoek River @ Zachariashoek (Figure 4.3)

- Historical data available for 28 years from 1964-1992, when the gauge was abandoned; gauging was reinstated in 2008 at the request of the TMGA project, recent data from November 2008 – December 2009, continuing.
- Some 70 data gaps during the 1970s, besides the ungauged period, the longest data gap being a period of 57 days: data gap denoted by ‘170’ (and several ‘172’) values.
- Natural and undeveloped catchment (field obs.).

DWAF Gauging Weir G1H016A01 Kasteelskloof River @ Zachariashoek (Figure 4.4)

- Records from 1964, until 12 Nov 1992 (28 years) when the gauge was abandoned but with a five year data gap from October 1969 – June 1974; gauging was reinstated in 2008 at the request of the TMGA project, recent data from November 2008 – December 2009, continuing.
- Few other data gaps, largely data set of good integrity.
- Natural and undeveloped catchment (field obs.).

DWAF Gauging Weir G1H018A01 Bakkerskloof Spruit @ Zachariashoek (Figure 4.5)

- Historical data available for 28 years from 1964-1992, when the gauge was abandoned; gauging was reinstated in 2008 at the request of the TMGA project, recent data from November 2008 – December 2009, continuing.
- Only one other short data gap.
- Natural and undeveloped catchment (field obs.).

DWAF Gauging Weir H6H007A01 Du Toits River @ Purgatory Uitspan (Figure 4.6)

- Dataset contains 28 years of data 1964-1992. Recording at this weir was discontinued in September 1992 because of annual maintenance requirement to ensure accuracy in high flow recording, but lack of capacity to do so and difficulty with access.
- One short gap, but otherwise a good data set.
- Natural and undeveloped catchment.

DWAF Gauging Weir H6H008A01 Riviersonderend @ Swarte Water (Figure 4.7)

- Dataset contains 28 years of data 1964-1992. Recording at this weir was discontinued in September 1992 because of inaccuracy in high flow recording
- A few data gaps, but none longer than 15 days; otherwise a good data set.
- Natural and undeveloped catchment (field obs.).

Low-flow duration curves and the Average Recurrence Intervals for the 1- 7- 15- and 30-day flow minima are provided for the six gauges listed in Table 4.1 i.e. those from which data could effectively be used, and these are presented in Figures 4.2 – 4.8. The four curves on each plot represent the different intervals (one to thirty days). It is important to note that whereas the ARI values used for flow maxima (e.g. in flood analysis) is the number of years a particular flow is *greater* than a certain value, the ARI for low flows is the number of years a particular flow is *less* than the corresponding value on the *Y*-axis. The Y-axis of the graphs represents the summed discharge for the interval under consideration. The X-axis shows the return period for each flow minimum.

For example, in Figure 4.2 the 1:2-year return period flow minimum (i.e. probability 0.5) along the X-axis is shown by a blue vertical line. At the intersection of this line with each of the flow minima curves (1-, 7-, 15- and 30-day), the corresponding Y-axis reading is the cumulative discharge for this return period. In Figure 4.2, the 1:2-year return period 1-day low flow is 0.001 $m^3 s^{-1}$, whilst for a 30-day period it is 0.091 as a summed total or, as a daily discharge, 0.003 $m^3 s^{-1}$ (i.e. 0.091 divided by 30 days). The following can be gleaned from the analysis:

- Comparing streams, G1H011 (Figure 4.2) is on a stream has very low summer baseflows. The Zachariashoek streams (Figures 4.3 – 4.5) have even lower minimum streamflow levels than

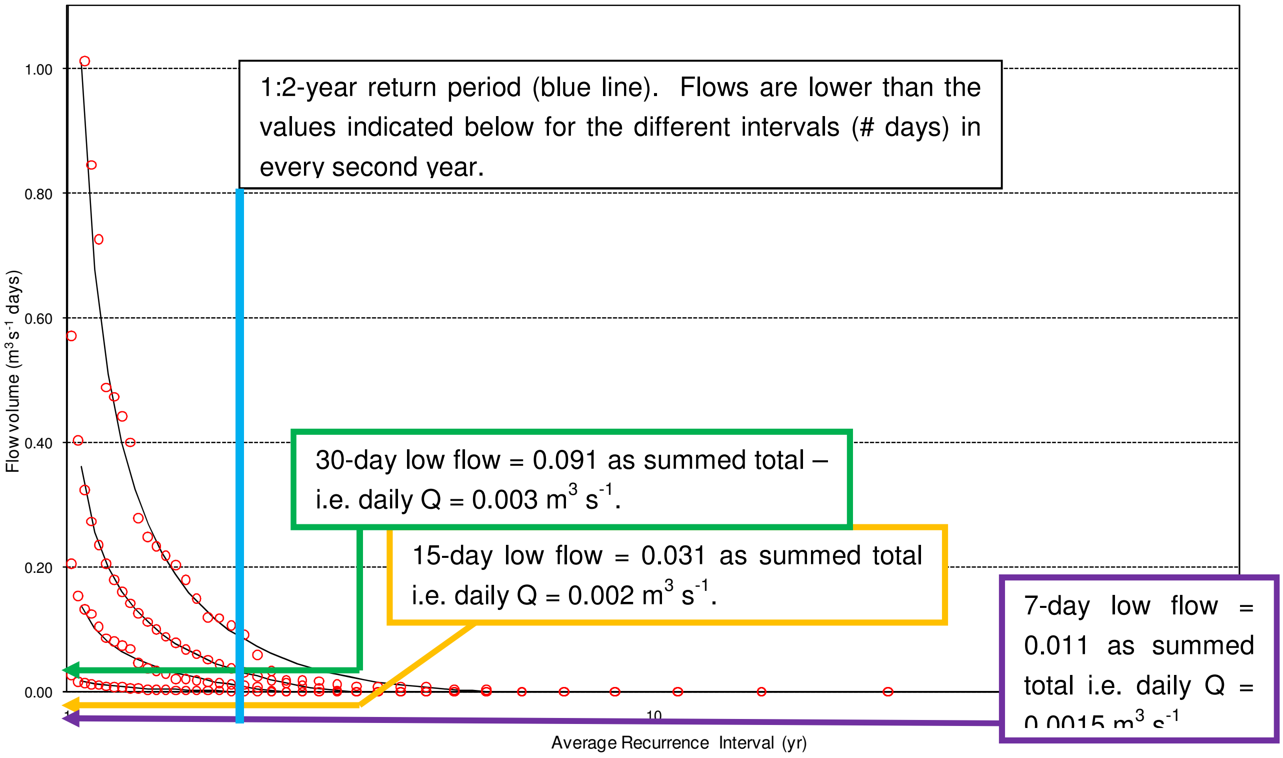


Figure 4.2. Flow frequency analysis for G1H011A01 Watervals River showing observed 1-day, 7-day, 15-day and 30-day flow minima (red circles) and fitted distribution functions (black lines). Flow minima are expressed as a cumulative volume for each (1- to 30-day) period.

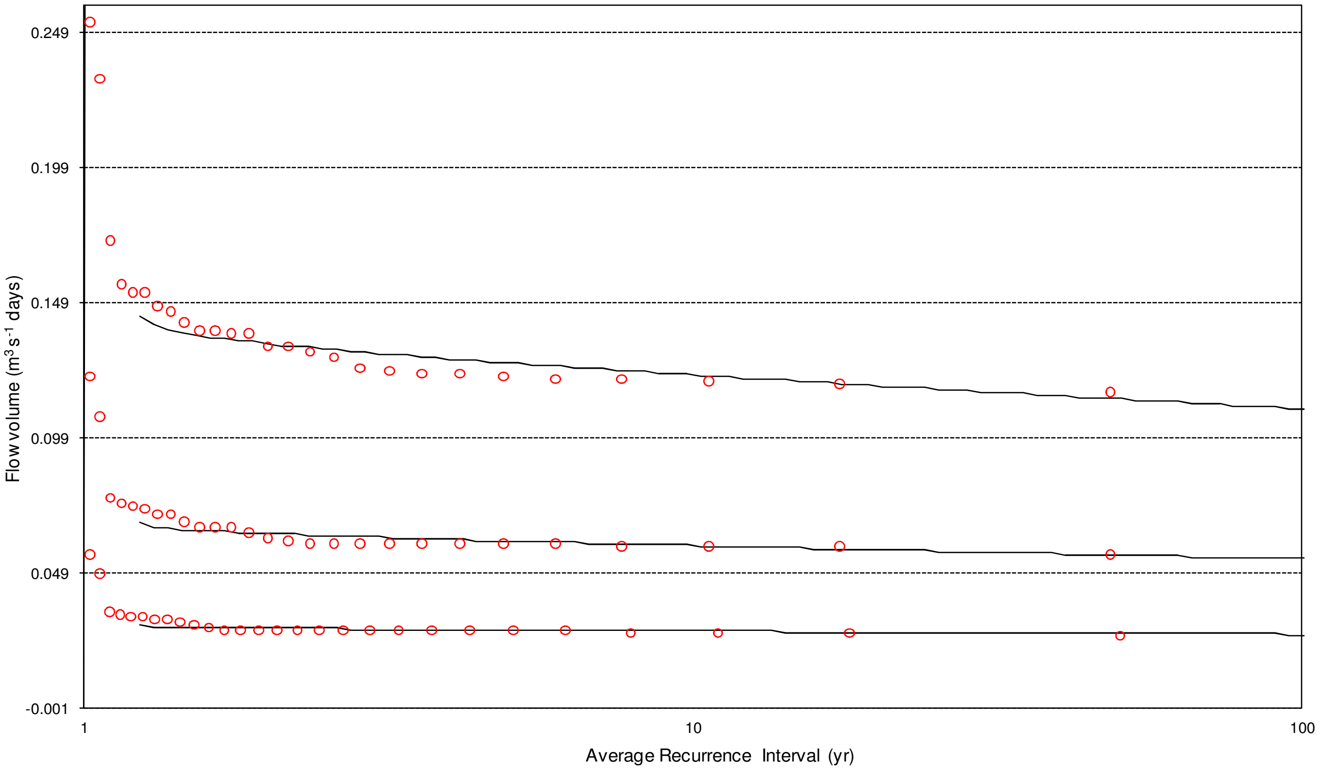


Figure 4.3. Flow frequency analysis for G1H014A01 Zachariashoek River (Dec-Mar 1964-1991, 27 years) showing the ARI (log axis) of observed 1-day, 7-day, 15-day and 30-day flow minima (red circles) and fitted distribution functions (black lines). Flow minima are expressed as a cumulative volume for each period.

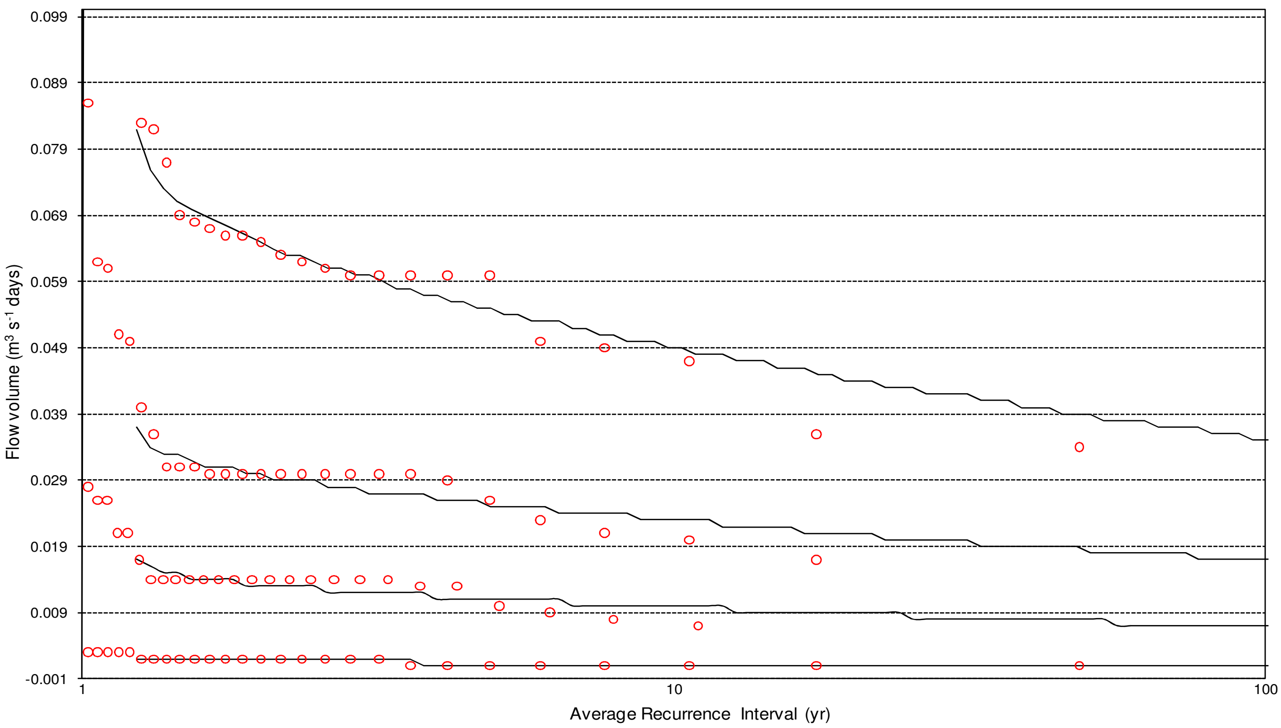


Figure 4.4 Flow frequency analysis for G1H016A01 Kasteelskloof River showing the ARI (log axis) of observed 1-day, 7-day, 15-day and 30-day flow minima (red circles) and fitted distribution functions (black lines). Flow minima are expressed as a cumulative volume for each (1- to 30-day) period.

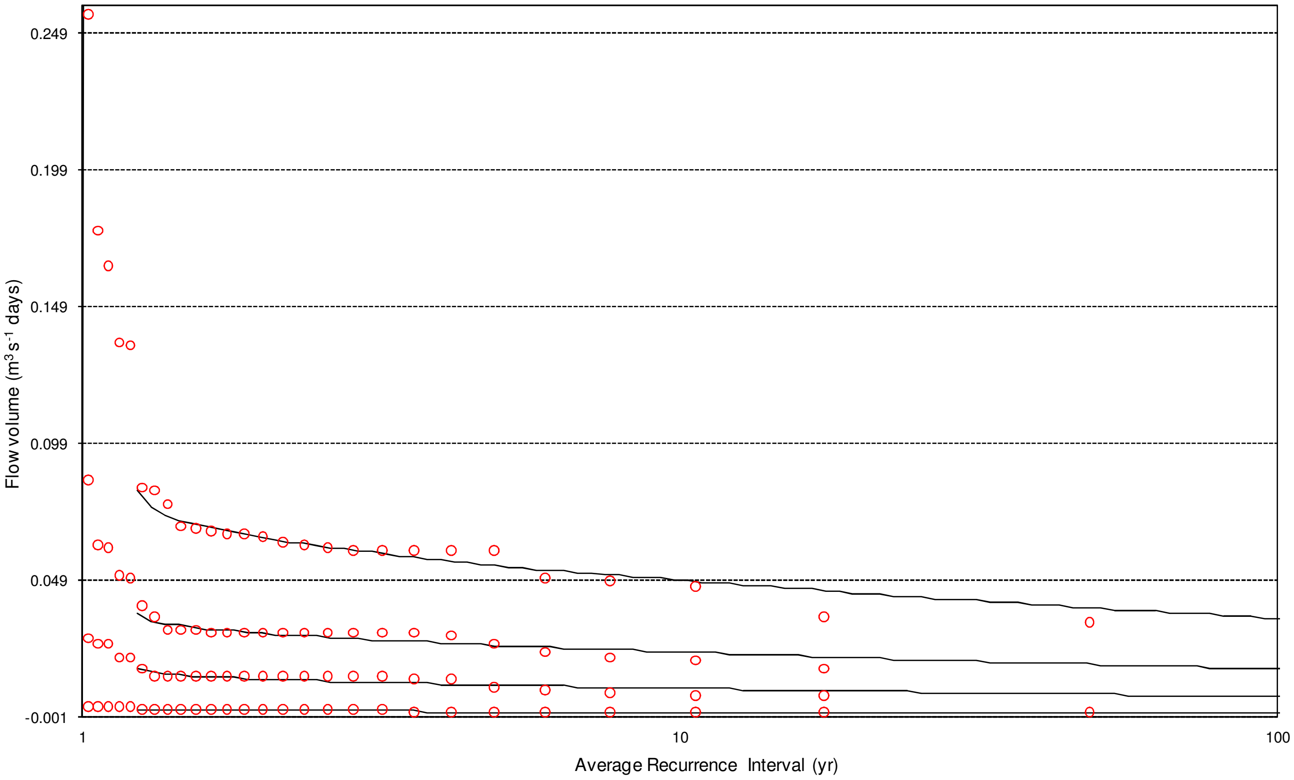


Figure 4.5 Flow frequency analysis for G1H018A01 Bakkerskloof Spruit showing the ARI (log axis) of observed 1-day, 7-day, 15-day and 30-day flow minima (red circles) and fitted distribution functions (black lines). Flow minima are expressed as a cumulative volume for each (1- to 30-day) period.

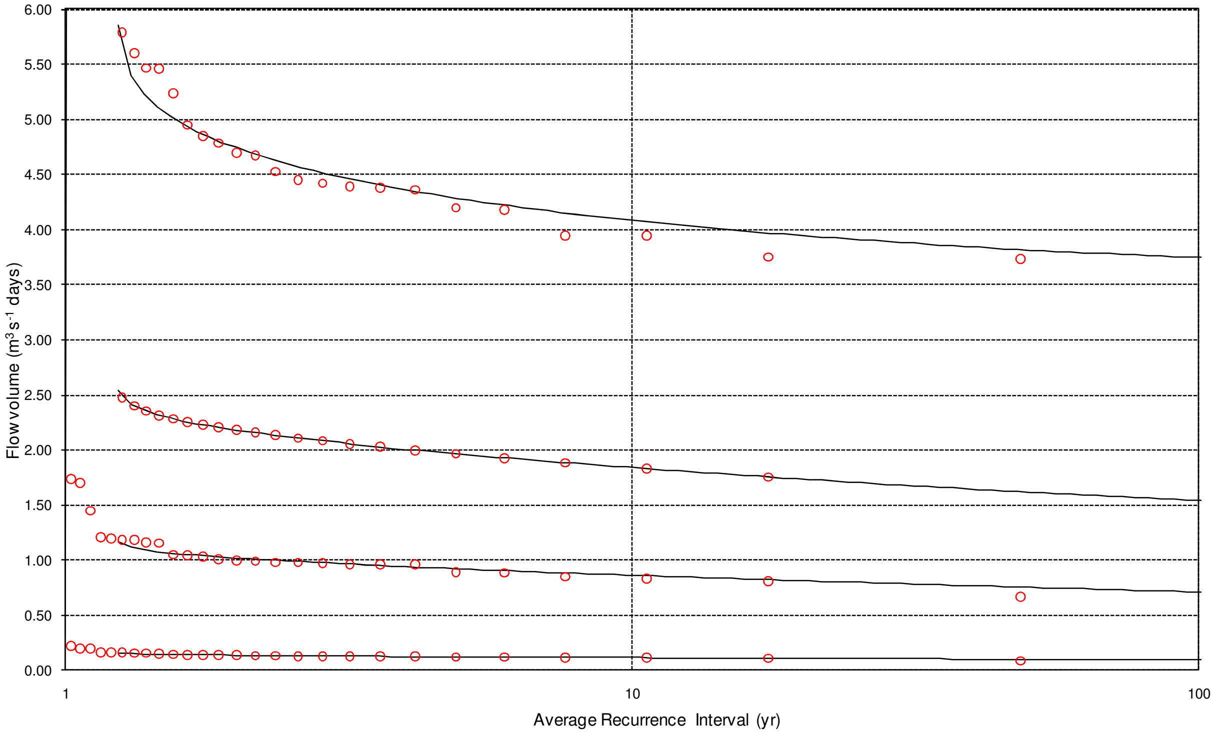


Figure 4.6 Flow frequency analysis for H6H007A01 Du Toits River @ Purgatory showing the ARI (log axis) of observed 1-day, 7-day, 15-day and 30-day flow minima (red circles) and fitted distribution functions (black lines). Flow minima are expressed as a cumulative volume for each (1- to 30-day) period.

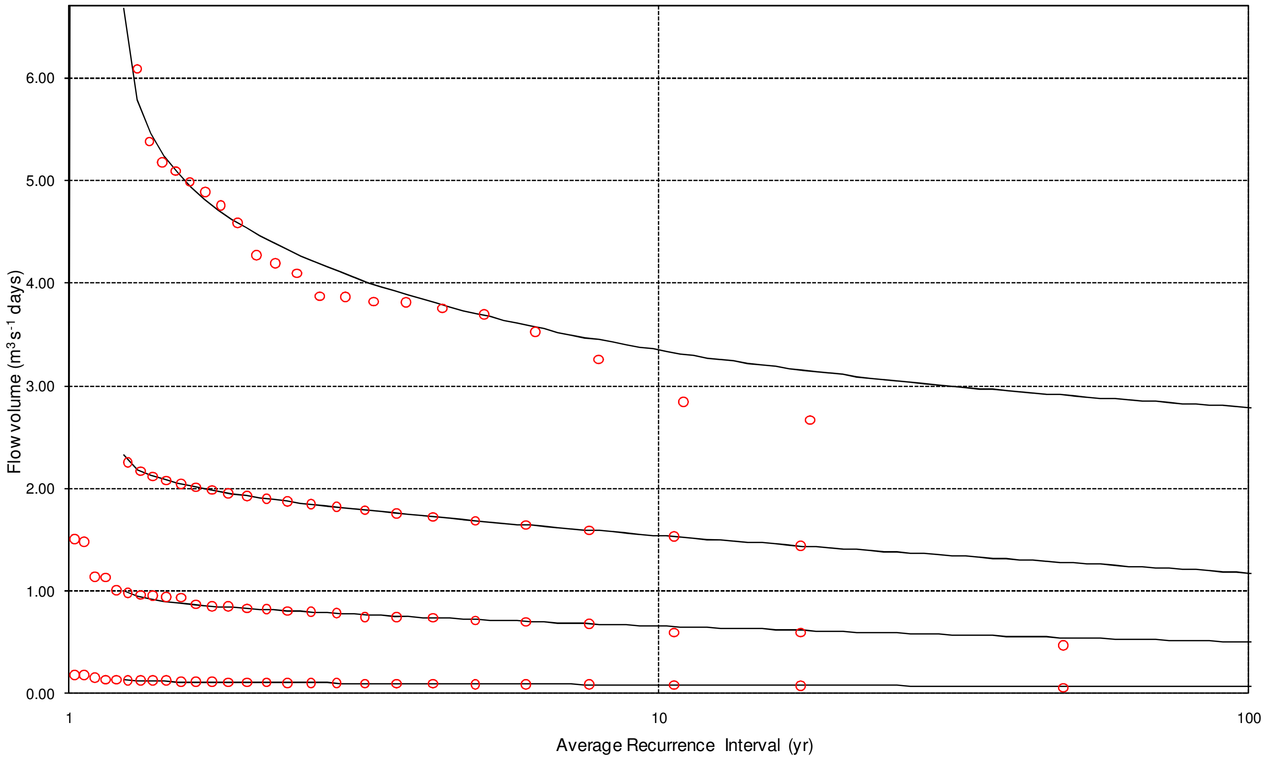


Figure 4.7 Flow frequency analysis for H6H008A01 Riviersonderend @ Swarte Water showing the ARI (log axis) of observed 1-day, 7-day, 15-day and 30-day flow minima (red circles) and fitted distribution functions (black lines). Flow minima are expressed as a cumulative volume for each (1- to 30-day) period.

G1H011, and of these the Zachariashoek River has the strongest flow. The du Toits River (Purgatory; Figure 4.7) on the other hand has a 1:2-year 30-day minimum flow total of 4.53 or 0.15 $m^3 s^{-1}$ daily discharge.

- The 30-day flow minimum identifies the month of lowest flow levels in the year, sometimes regarded as the summer drought. Where the difference between the 1-, 7-, 15- and 30-day flow minima is very little, as long as the values themselves are greater than zero, this indicates a constancy of flow over the summer drought period, and therefore strong groundwater contribution to lowflows. A similar approach has been taken elsewhere by comparing monthly lowflow flow duration curves or flow percentiles (e.g. the Outeniqua rivers, Dr. Cate Brown pers. comm.) – where these are unchanged from one month to the next, they indicate a high constancy of flow that may imply strong groundwater input (or identical patterns of rainfall and runoff from one month to the next which is not very likely).

  Table 4.3 provides a comparison of these lowflow statistics for each of the six gauges analysed. All flows are above zero, except for the 1-day daily lowflow at Kasteelskloof. The differences between the values at each gauge are slight, at least up to the 15-day lowflow statistic, indicating that, at this time of year the rivers are quite strongly dependent on groundwater for their flow.
- Provided there was some flow at a gauge, the gradient of the curves was also used to indicate the severity of extreme flow minima. Shallow curves, such as for the Zachariashoek streams, the du Toits River and the Riviersonderend (Figures 4.3 – 4.5, 4.7 and 4.8) indicate that there is little difference between, for example, the 1:2-year flow minima and the 1:10-year flow minima, i.e. no extremes, which could be an indication of groundwater contributions to streamflow in dry years.
- Importantly, the gradient of the curves for each gauge site can be interpreted to indicate the severity of extreme events with regard to flow minima. Shallow curves, such as the Zachariashoek streams, the du Toits River and the Riviersonderend (Figures 4.3 – 4.5, 4.7 and 4.8) indicate that there is little difference between for example the 1:2-year flow minima and the 1:10-year flow minima. This may be simply because the flow values are zero, but where the values are above zero, this may be seen as evidence of the importance of groundwater contributions to streamflow, which buffer these small streams against drying in dry years.

Table 4.3. Lowflow statistics indicating the contribution of groundwater to surface flow in six unregulated streams for which long-term flow records exist.

Gauge	**1-day flow minimum (daily Q in $m^3 s^{-1}$)**	**7-day flow minimum (daily Q in $m^3 s^{-1}$)**	**15-day flow minimum (daily Q in $m^3 s^{-1}$)**	**30-day flow minimum (daily Q in $m^3 s^{-1}$)**
G1H011 Watervals River	0.001	0.002	0.002	0.003
G1H014(*) Zachariashoek River	zero flow	0.0040	0.0041	0.0044
G1H016 (*) Kasteelskloof River	0.0020	0.0020	0.0020	0.0021
G1H018 (*) Bakkerskloof Spruit	0.0020	0.0020	0.0020	0.0021
H6H007 (*) Purgatory du Toit's River	0.1365	0.1423	0.1446	0.1562
H6H008 (*) Swarte Water Riviersonderend	0.1100	0.1186	0.1278	0.1477

4.3.3 Ecological monitoring sites (ecochannels)

The location of the ecochannels is provided in Volume B, Appendix 6, Table 6.2. Daily average piezometer water levels over the period of record, along with daily rainfall are presented for each ecochannel site in Volume B, Figure 6.10 – 6.25 (collated into Volume B for ease of reference). Note that the scale of the vertical axis differs between graphs. In some instances, the rainfall bars were not discernible against the flow time series and so their presentation has been changed.

Elevated baseflows and flood events at the start of the record capture the end of winter 2008. The major fluctuations in water level at all sites mirrored rainfall patterns and reflect the strong rainfall-runoff relationship in winter months in these systems, characteristic of the Mediterranean climate of the Western Cape. Water levels declined over the summer at all sites, with smaller spikes in response generally only to major summer rainfall. Most sites remained flowing through summer, but the Riviersonderend tributaries (T4_RSE2, 3 and 4a – Volume B, Appendix 6, Figures 6.16 and 6.17) and the Voelvlei sites (V3_1 and V3_2 – Volume B, Appendix 6, Figures 6.21 and 6.22) showed a clear drop in water level to zero flow conditions, and mirrors the conditions in the seeps in these areas, which are characterised by a long seasonally dry phase (see Chapter 3).

This seasonality in streamflow was the basis for the major division of sites in to perennial versus seasonal systems. Within the perennial category, field notes on the quality and availability of biotopes were the basis of differentiating sites into Category A and B ecochannels[4]. Within the non-perennial category, a further distinction was made between those ecochannels that retained water in pools over summer and those that dried completely, which could have implications for refugium and recolonisation in seasonal streams (Categories C and D respectively). The results of ecochannel hydroperiod are presented in Table 4.4, along with information on the probability of connection to the Peninsula or Nardouw Aquifers, based on interpretation of geology (from Chapter 2; Table 2.5).

Also included in Table 4.4 are preliminary comments on the strength of connectivity of the ecochannels with groundwater. The determination of groundwater contributions to summer base flows was beyond the scope of this study but the rate of decline in summer water level was used in to infer the strength of groundwater connectivity, and therefore contribution to baseflow, as weak or strong or moderate. The rate of water level decline, in mm per day, was determined for the driest 60-day period in both years of the monitoring programme, and the average is presented in Table 4.4. The following points are noteworthy:

- Of interest in was that none of the ecochannels was considered to be both Nardouw and Peninsula fed, unlike the situation with the ecoseeps, where many were judged to be influenced by both.
- There was clearly very little agreement between the hydroperiod of a channel and the probability of its being connected to the Peninsula vs. the Nardouw Aquifer. However, the interpretation of the geological cross sections was limited to indicating which aquifer might play a role in the ecochannel hydrology, rather than making a clear statement on the likelihood of their being, for example, strong weak or no connection.

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[4] In the first annual report, three categories of perennial systems (strongly perennial, perennial, and perennial but reduced to low levels in summer) were identified in an attempt to look for relationships between hydrology and biological characteristics at the sites. However, it was later considered that the first two of these categories should be merged as they were too subjective. For the current report, the distinction into two categories of perenniality is still subjective, especially where inter-annual differences in water levels cloud judgement of how much habitat quality is reduced.

- Similarly, there was no correlation between the type of aquifer associated with the ecochannel (Peninsula or Nardouw Aquifers) based on geology, and strength of connectivity, as determined by rates of water level reduction. For example, the streams in the RSE (Nuweberg) area, which are on the Peninsula Formation, all had flows that declined rapidly in the summer, which equated with weak groundwater connectivity (Volume B, Appendix 6, Figures 6.16 and 6.17).
- However, there was relatively good agreement between the major hydroperiod division and the strength of aquifer connectivity: Category C and D ecochannels has rapid rates of decline in water level in the absence of rainfall, whilst Category A and B ecochannels showed relative slow water-level recession rates.
- There was little differentiation between Category A and B, and Category C and D, channels respectively, in terms of their rates of water-level decline and therefore strength of connectivity, suggesting that the finer distinctions in hydroperiod are not associated with differences in groundwater connectivity.

Table 4.4 summarises the outcome of the assessment of ecochannel hydrology and aquifer connectivity. Five of the ecochannels combine strong connectivity to the Peninsula Aquifer with a regime of perennial flow (shaded dark blue in Table 4.4). In the case of the ecochannels the light blue shading represents a different category of hydroperiod / connectivity / aquifer link than those colour-coded light blue in the case of ecoseeps (Table 3.3): in the latter this represented strong perenniality and strong connectivity but a Nardouw and Peninsula link. In the case of ecochannels, none were considered linked to both aquifers, so such a category did not occur. Instead the perennial, Peninsula-linked ecochannels were divided into those with strong connectivity (dark blue) and those with moderate connectivity (light blue). The green shading, as with the ecoseeps, represents perennial systems with strong groundwater links but probably fed by the Nardouw Aquifer.

Four perennial systems probably linked to the Peninsula formation were associated with a moderate strength of connectivity (light blue). A further two perennial ecochannels with strong groundwater links are more probably fed by the Nardouw Aquifer alone than by the Peninsula (light green shading).

4.4 SUMMARY AND CONCLUSIONS

The following activities were undertaken for this component of the EPM:

- An assessment was made of the usefulness of information from a set of DWA gauges specified in the ToR, and an alternative set of flow gauges suggested for analysis. Flow frequency analysis was undertaken to derive flow minima curves for six gauges, illustrating one of the approaches to long term monitoring of streamflow that could be adopted for future phases of the TMGA project.
- Bi-annual monitoring of streamflow and / or water chemistry was undertaken at 138 regional hydrocensus sites listed in the ToR, to provide baseline monitoring of regional geohydrology. This adds to a dataset of some 350 sites that has been developed since 2003.
- Continuous monitoring equipment was installed at 16 of the 19 ecological monitoring channel sites (ecochannels) and continuous water level recording commenced between August and October 2008, until April 2010.
- The hydroperiod of the ecochannels was estimated by analysing changes water levels over summer, coupled with assessment of flow-related habitat changes observed at the sites. Four Hydroperiod Categories were defined on the basis of summer water levels and the extent to which habitat loss occurred, viz. disconnection with the marginal vegetation and / or drying of the stream to pools.
- Building on from the analysis of geological cross sections which inferred the probability of stream connectivity to either the Peninsula or Nardouw Aquifers, the rate of decline in summer flow levels, relative to rainfall patterns was used to make an initial estimate of the strength of connectivity,

which summarises the influence of groundwater on these streams and this was compared to the probable aquifer type and to hydroperiod.

There was poor correlation between the probability of connectivity to one or other aquifer as determined using geological setting, and the strength of groundwater contributions to the channels (strength of connectivity) determined using water levels. i.e. the strength of the contribution to water level in a stream linked to the Peninsula Aquifer or the Nardouw Aquifer appears to be highly variable.

However, the strength of connectivity does appear to play a role in channel hydroperiod, with seasonal streams having weak connectivity to groundwater.

Recommendations for changes in the programme during future phases of the TMGA project are detailed in Chapter 9.

Table 4.4. Analysis of channel sites connectivity to aquifers, by type, categorisation of stream hydroperiod based on water levels in summer, along with observations of habitat availability and indication of rate of summer recession in baseflow and conclusions on strength of aquifer connectivity. Hydroperiod definitions are provided in Table 4.2. Shading: dark blue = perennial channels with strong connectivity and linked to the Peninsula aquifer; light blue - perennial channels linked to the Peninsula aquifer, but with moderate connectivity; light green = perennial channels with strong groundwater links but probably fed by the Nardouw Aquifer alone.

Site	Likelihood of connectivity based on geology cross sections (Table 2.5)	Comments on elevation and behaviour of water level in the channel relative to rainfall and with regard to biotope availability	Channel hydroperiod category	Rate of water level decline over 60 dry days each year	Strength of connectivity
H8_1	Low connectivity with Peninsula, but highly likely that Nardouw provides base flow	Summer flow much lower than winter base flow, sustains hydraulic conditions, but loss of riffle and exposure of instream plants; water level fluxes in response to summer rainfall are also fairly marked, more so than other ecochannels	B	0.69	Moderate
H8_3a	Low connectivity with Peninsula, but highly likely that Nardouw provides base flow	No water level gauge; but downstream of H8_1; similar responses observed	B	No data	Moderate (extrapolation)
K_2a	Strong likelihood of connectivity to Peninsula Aquifer	Constant summer flow; rate of change /decline also very low, as shown by flat slope of plotted line, indicating groundwater contribution; however, flow does recede to fairly low levels at the end of summer	B	0.14	Strong
K_3a	Low connectivity with Peninsula, but highly likely that Nardouw provides base flow	Rate of change /decline in summer flow is very low, as shown by flat slope of plotted line, indicating groundwater contribution; however, flow does recede to fairly low levels at the end of summer	B	0.14	Strong
K_4	Definite connectivity to Peninsula and Nardouw Aquifers	Strong summer flow; rate of change /decline also very low, as shown by flat slope of plotted line, indicating groundwater contribution, year-round good biotope availability	A	0.09	Strong
T4_Pal1	Strong likelihood of connectivity to Peninsula Aquifer	Rate of change /decline fairly low, long period of unfluctuating flow; stream velocities do become slow, but depth maintained and biotopes intact, indicating groundwater contributes to this perenniality	A	0.22	Moderate
T4_Pal3	Strong likelihood of connectivity to Peninsula Aquifer	The stream is at a high altitude, with very low flow at the height of summer; however, the rate of decline in flow is gradual.	B	0.24	Moderate
T4_RSE2	Strong likelihood of connectivity to Peninsula Aquifer	Substantial drop-off of water level with dry conditions from Feb or March; water levels appear to be sustained weakly or not at all by groundwater, which recedes by 0.5 m over a few months of summer	C	6.61	Very weak
T4_RSE3	Strong likelihood of connectivity to Peninsula Aquifer	Similar to T4_RSE2, substantial drop-off of water level with dry conditions from Feb / March; flow appears to be sustained weakly by groundwater, which recedes by 0.2 m over early summer	D	2.81	Weak

Site	Likelihood of connectivity based on geology cross sections (Table 2.5)	Comments on elevation and behaviour of water level in the channel relative to rainfall and with regard to biotope availability	Channel hydroperiod category	Rate of water level decline over 60 dry days each year	Strength of connectivity
T4_RSE4a	Strong likelihood of connectivity to Peninsula Aquifer	Downstream of T4_RSE3 and with the same hydroperiod	D	No data	Weak (extrapolation)
T6_1a	Strong likelihood of connectivity to Peninsula Aquifer	Rapid response to summer rainfall indicates periodic influence of local (surface or subsurface) inflow; rate of decline however is very low, with high base flows maintained, indicating strong groundwater contribution	A	0.05	Strong
T6_2a	Strong likelihood of connectivity to Peninsula Aquifer	Rapid and intense response to summer rainfall indicates periodic influence of local (surface or subsurface) inflow; midsummer base flows decline to low levels but biotopes maintained intact	A	0.04	Strong
T8_1a	Low connectivity with Peninsula, but highly likely that Nardouw provides base flow	No water level gauge; but this site is down-slope from T8_1b; maintained perenniality with high rainfall in 2008/9 but dry in 2009 / 2010	C	No data	Moderate (extrapolation)
T8_2a	Strong likelihood of connectivity to Peninsula Aquifer	Responds only to very high summer rainfall events; rate of decline is moderate, with high base flows maintained, indicating strength of groundwater contribution	A	0.29	Moderate
V3_1	Probable connectivity with the Peninsula Aquifer, and high probability of connectivity with Nardouw	Rapidly declining flows to zero by January, with surface water in shrunken pools only suggests low strength of groundwater contribution	C	1.20	Weak
V3_2	Probable connectivity with the Peninsula Aquifer, and high probability of connectivity with Nardouw	Rapid and intense response to rainfall with rapidly declining flows to zero by January, with no surface water indicates weak groundwater contribution.	D	1.04	Weak
W7_1	The channel is most probably connected to the Nardouw Aquifer, possibly via an alluvial aquifer, with unlikely connectivity with the Peninsula Aquifer.	Strong summer flow and the slow rate of change /decline indicating groundwater contributes strongly to perenniality	A	0.14	Strong
W7_4	Possible connectivity of this site to the Peninsula Aquifer, but this is unlikely to be strong	Dampened response to rainfall and relatively constant summer flow, although recedes to low levels with some exposure of instream vegetation; rate of change /decline also low, indicating moderate groundwater contribution.	B	0.25	Moderate
W7_6	Strong likelihood of connectivity to Peninsula Aquifer	Dampened response to rainfall and highly constant summer flow indicates strong groundwater contribution. Although flows were low in Mar 2009 with some exposure of instream vegetation	B	0.00	Strong

5. PHYSICO-CHEMICAL CONDITIONS OF THE GROUNDWATER, SOILS AND SURFACE WATER

5.1 INTRODUCTION

Physico-chemical properties encompass physical (such as temperature, moisture) and chemical properties (such as electrical conductivity, cation concentrations, pH etc.) properties -) of the soil and / or water medium at a site that together constitute a unique set of opportunities and constraints for living organisms. They are thus major drivers of the plant and animal species / communities that inhabit a particular environment (e.g. Silberbauer & King, 1991). Information on the variations in these driving factors improves our understanding of their influence on the biota (e.g. Malan & Day, 2005), and may explain the variability in the biotic communities at a site.

This chapter describes the seasonal variation in the physico-chemistry of the groundwater (at the hydrocensus boreholes and piezometers), the soils at the ecological monitoring sites, and the surface water (at the hydrocensus springs, rivers, DWA weirs, and the ecological monitoring sites). It was hypothesised that a change in hydroperiod, such as may occur with drawdown of the water table, would precipitate measurable shifts in the physico-chemical properties of that site. If this is true, the drawdown could be monitored using physico-chemical properties as a proxy.

This chapter is divided into three main sections:

1. Chemical conditions at the hydrocensus sites (Section 5.2), including
    - Water chemistry of groundwater and surface water
    - Identification of aquifer isotope signature
2. Physico-chemical analysis of the soils at the ecological monitoring sites (Section 5.3)
    - Topsoil analysis
    - General soil characteristics
    - Soil moisture
    - Soil profile analysis of soil moisture and soil saturation at five selected ecological monitoring sites
3. Surface water physico-chemistry (Section 5.4)

5.2 CHEMICAL CONDITIONS AT THE HYDROCENSUS SITES

5.2.1 Methods

Groundwater and surface water chemistry monitoring was undertaken as part of the bi-annual hydrocensus data collection programme. The list of hydrocensus borehole sites with details of monitoring activities is provided in Volume B (Appendix 5) and of surface water monitoring sites in Volume B (Appendix 6). Field measurements were made of pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), temperature and Oxygen Reduction Potential (ORP), at selected hydrocensus sites, and water samples were collected and analysed for the major nutrients (nitrogen and phosphorus), anions and cations. No water chemistry samples were collected from the piezometers installed in the ecological monitoring wetlands, but this is recommended for the monitoring phase.

Groundwater and surface water pH, EC and nutrients were grouped according to hydrostratigraphic unit (see Table 2.2), and plotted on box and whisker plots.

The cation and anion concentrations data were represented on Piper diagrams. These are triangular (trilinear) diagrams that show the percentage composition of three ions, or groups of ions. The major ions in most natural waters are Na, K, Ca, Mg, Cl, CO_3, HCO_3 and SO_4. For the TMG data, grouping Na and K allowed the major cations to be displayed on one triangular diagram, with Na + K, Ca and Mg comprising the three sides. Similarly, CO_3 and HCO_3 were grouped to create three groups of major anions. The results were plotted as percentages of each cation/anion, based on the original data, which were expressed as meq/litre. The apex of the triangle represents 100% concentration of one of the three constituents. If a sample had two constituent groups present, then the point representing the percentage of each was plotted on the line between the apexes for those two groups. If all three groups were present, the results lie inside the triangle. The diamond-shaped field between the two triangles represents the composition of water with respect to both cations and anions. The cation point is projected onto the diamond-shaped field parallel to the side of the triangle labelled Mg, and the anion point is projected parallel to the side of the triangle labelled SO_4. The intersection of the two lines is plotted as a point on the diamond-shaped field. Thus, the TMG samples could be classified on the basis of the dominant ions.

The water samples collected from the hydrocensus boreholes were analysed for isotopes at BemLab, Somerset West. Stable isotopes, in particular 2H (deuterium, δD) and 18O (δ18O), are used to identify the source of water, as well as processes that have affected it since precipitation. The results were submitted to Dr Chris Harris at the University of Cape Town for interpretation. Regression analyses were performed between δD and δ18O.

There were some initial problems with the samples collected from the installed rainfall collectors, as they use silicon oil to reduce evaporation of the collected sample, which interferes with the isotope analysis. These rainfall collectors were replaced in 2009 with ones that do not use silicon oil. However, the data collected during 2008 were still accurate and were included in the analysis of results discussed below.

5.2.2 Results and Discussion

Water chemistry of groundwater and surface water

The results of the water chemistry analysis of surface and groundwater samples were similar to those found by other researchers working on TMG water (Colvin *et al.* 2009). Electrical conductivity (EC) values were very low for both groundwater and surface water, with average values mostly below 15 mS/m (Figure 5.1). The average EC values for surface waters were lower than for groundwater, which may be a result of the groundwater having had greater contact time with geological formations resulting in a higher mineral content. Average EC values for groundwater tended to be slightly higher in winter, due to increased recharge rates, higher hydraulic gradients and groundwater flows leading to increased dissolution and mobilisation of minerals. This trend also occurred to a certain extent for surface water, which was unexpected as EC is expected to be highest in late summer when low flow in the rivers and streams leads to a concentration of dissolved materials, and lower in winter when the dilution factor is high (e.g. Day 2008). This anomaly may be the result of summer rainfall but may also indicate the strong influence of groundwater in these surface systems.

The highest EC values for groundwater were from the argillaceous and mineralised Gydo Mega-aquitard. EC values were very similar between the Nardouw and Peninsula hydrostratigraphic units.

Grouping the EC data for the hydrocensus springs and streams per TSA (and neighbouring catchments) shows that EC was highest at H6 and Kogelberg (Figure 5.2). The data showed marked spatial differences in average EC at the TSA level. EC appears to be influenced by distance from the coast, with highest values at sites closer to the coast.

The pH values of the groundwater samples ranged from acidic to neutral, with averages ranging from 3.5 to 7. Surface water was more acidic than groundwater in all of the hydrostratigraphic units (Figure 5.3); this is probably due to the leaching of phenolic and other organic acids from plants and roots at

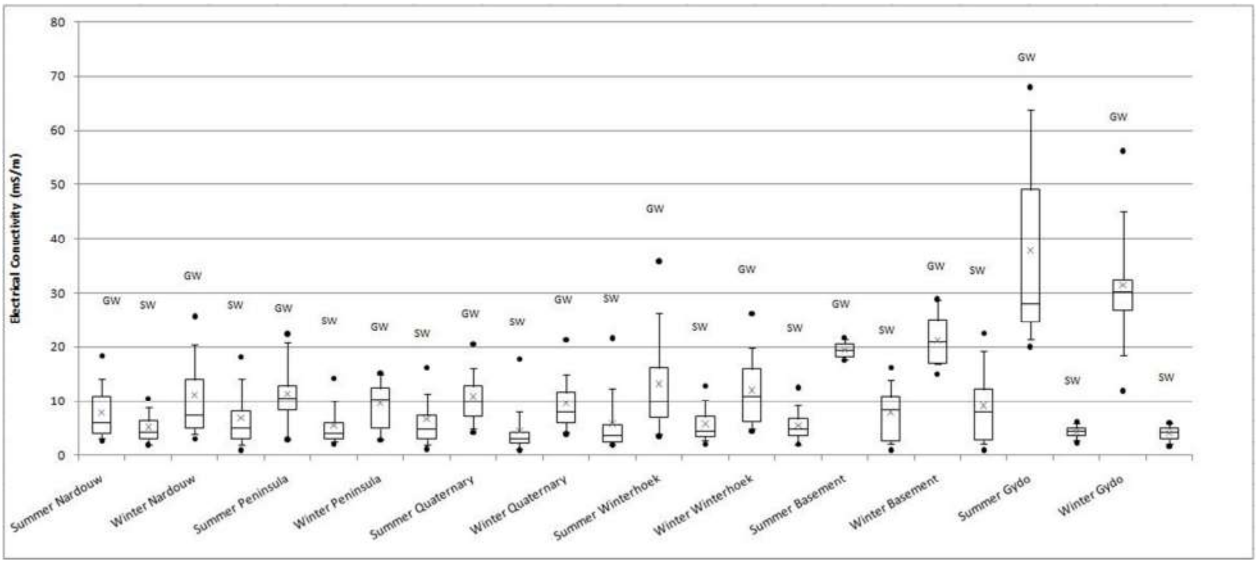


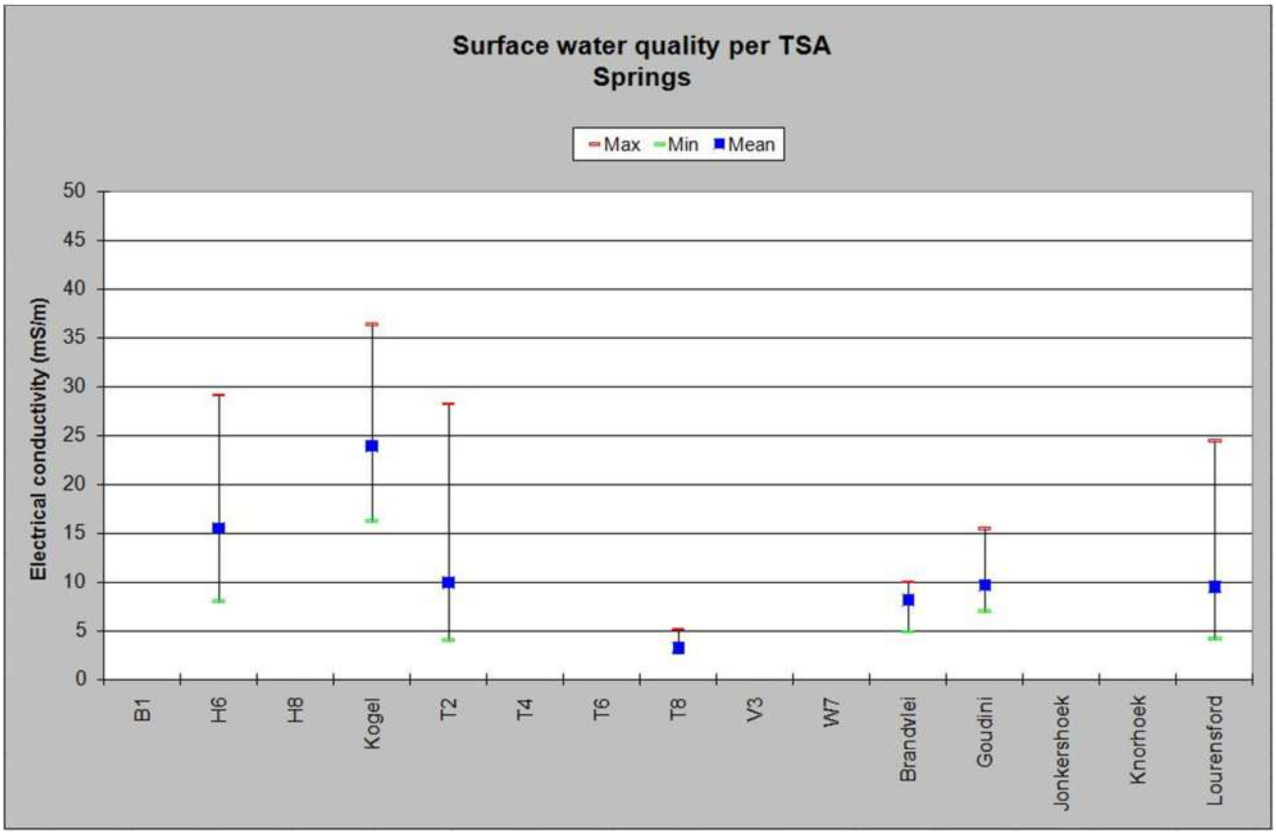
Figure 5.1. **Electrical conductivity of the groundwater and surface water per hydrostratigraphic unit, measured at the hydrocensus sites.**

the surface. The Basement unit samples had the highest pH (Figure 5.3). This formation comprises either granite or argillaceous material, which are known to have more neutral pH waters (e.g. Rebelo *et al.* 2006). The pH of groundwater collected from boreholes and piezometers in the Peninsula Formation was higher than that in the Nardouw (Figure 5.3). pH did not vary substantially with season.

Average total nitrogen was below 2 mg/litre in all units, for both ground- and surface water (Figure 5.4). Where a comparison could be made, total nitrogen tended to be higher in the groundwater than in the surface water, which was unexpected. There were no clear seasonal patterns in the data.

Average total phosphorus was below 0.1 mg/litre in all units, and tended to be higher for surface water than for groundwater (Figure 5.5). Again, there were no clear seasonal patterns.

The concentrations of the major cations and anions at selected hydrocensus sites are represented on Piper diagrams (Figures 5.6 and 5.7), presented for the April 2010 data (the most comprehensive and recent dataset) with separate diagrams for the different sources of data – i.e. hydrocensus boreholes, TMGA Exploration and DWA TMG monitoring boreholes, springs, ecochannels and ecoseeps. The data showed dominance by Na + K cations and Cl anions, in both surface and groundwater. The one significantly anomalous sample (TMG424) was from the Goudini Hot Spring, where Ca-CO_3 dominated.



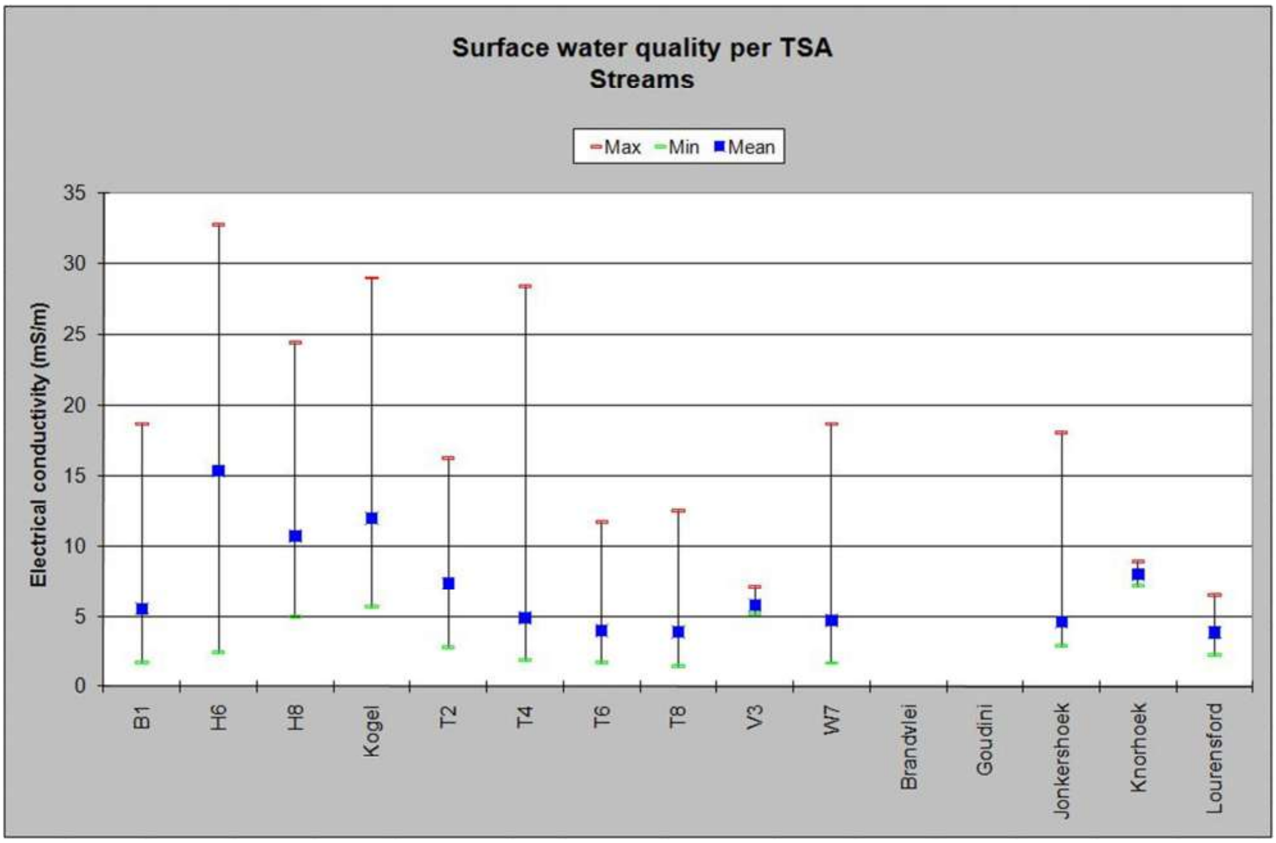


Figure 5.2. **Electrical Conductivity of surface water measured at the hydrocensus springs (top) and streams (bottom), presented per TSA, and including some neighbouring catchments.**

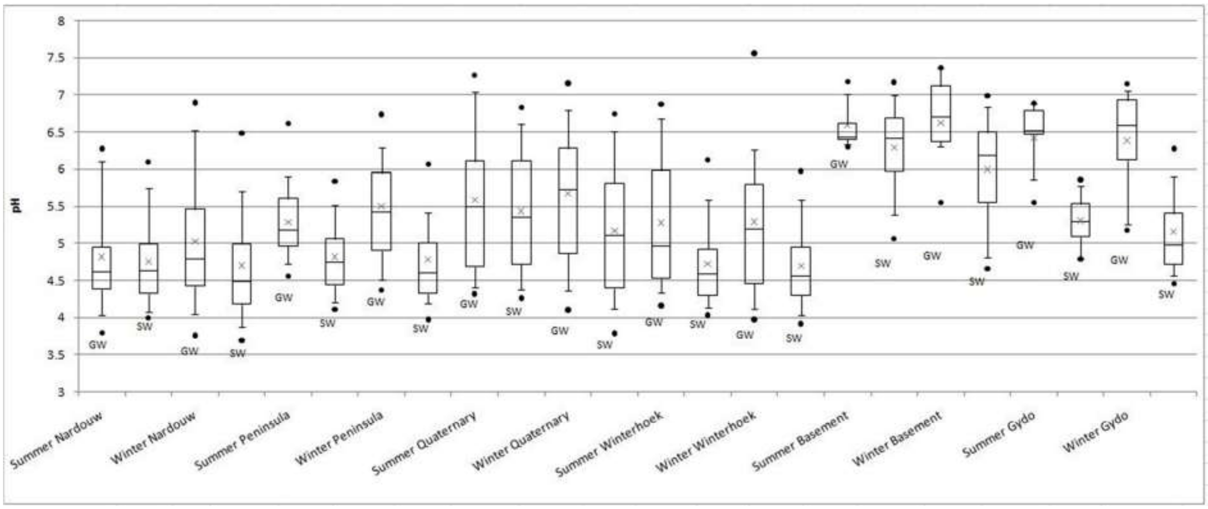


Figure 5.3. pH of the groundwater and surface water per hydrostratigraphic unit, measured at the hydrocensus sites.

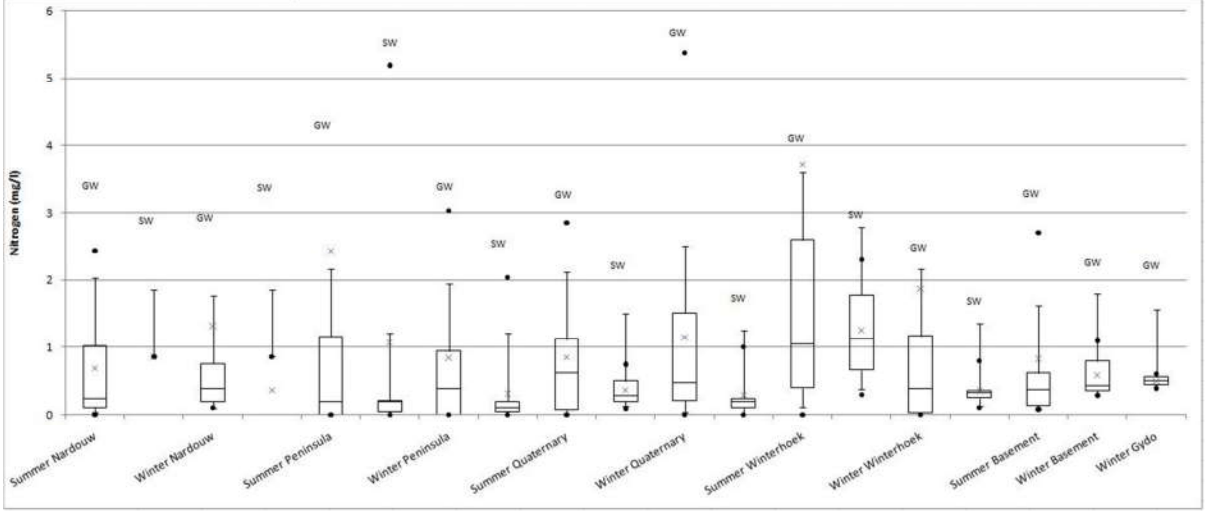


Figure 5.4. Total nitrogen concentrations in the groundwater and surface water per hydrostratigraphic unit, measured at the hydrocensus sites.

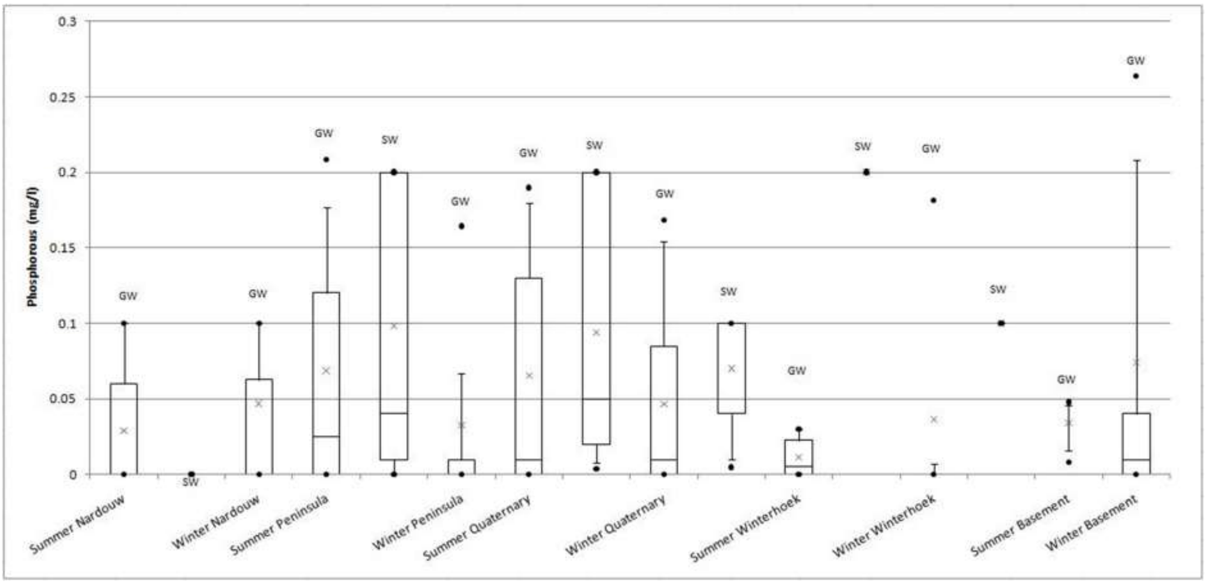


Figure 5.5. Total phosphorus concentrations in the groundwater and surface water per hydrostratigraphic unit, measured at the hydrocensus sites.

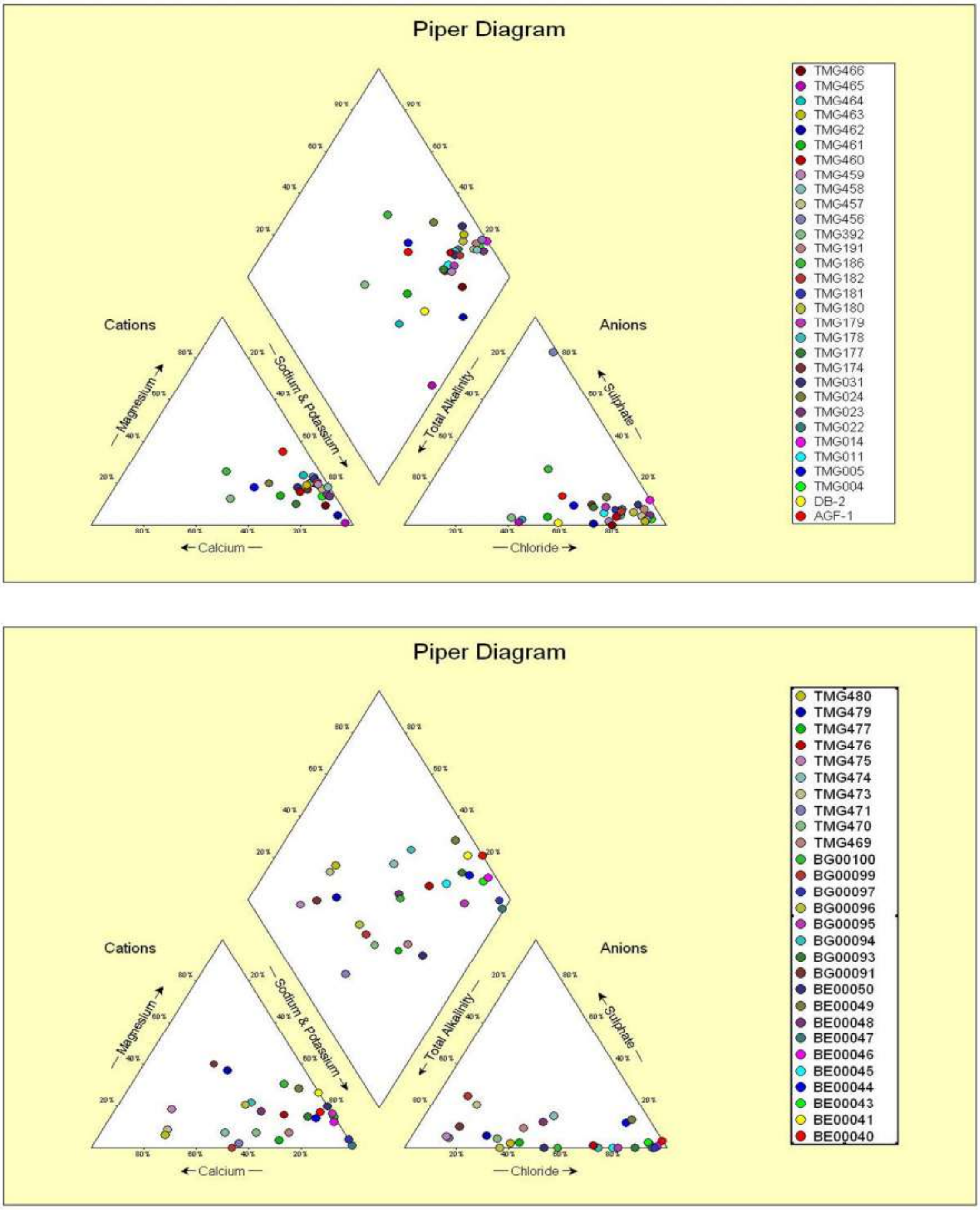


Figure 5.6. Piper diagram from the April 2010 hydrocensus borehole (top) and TMGA Exploration and DWA TMG Monitoring borehole (bottom) data, showing dominance of major ions in groundwater.

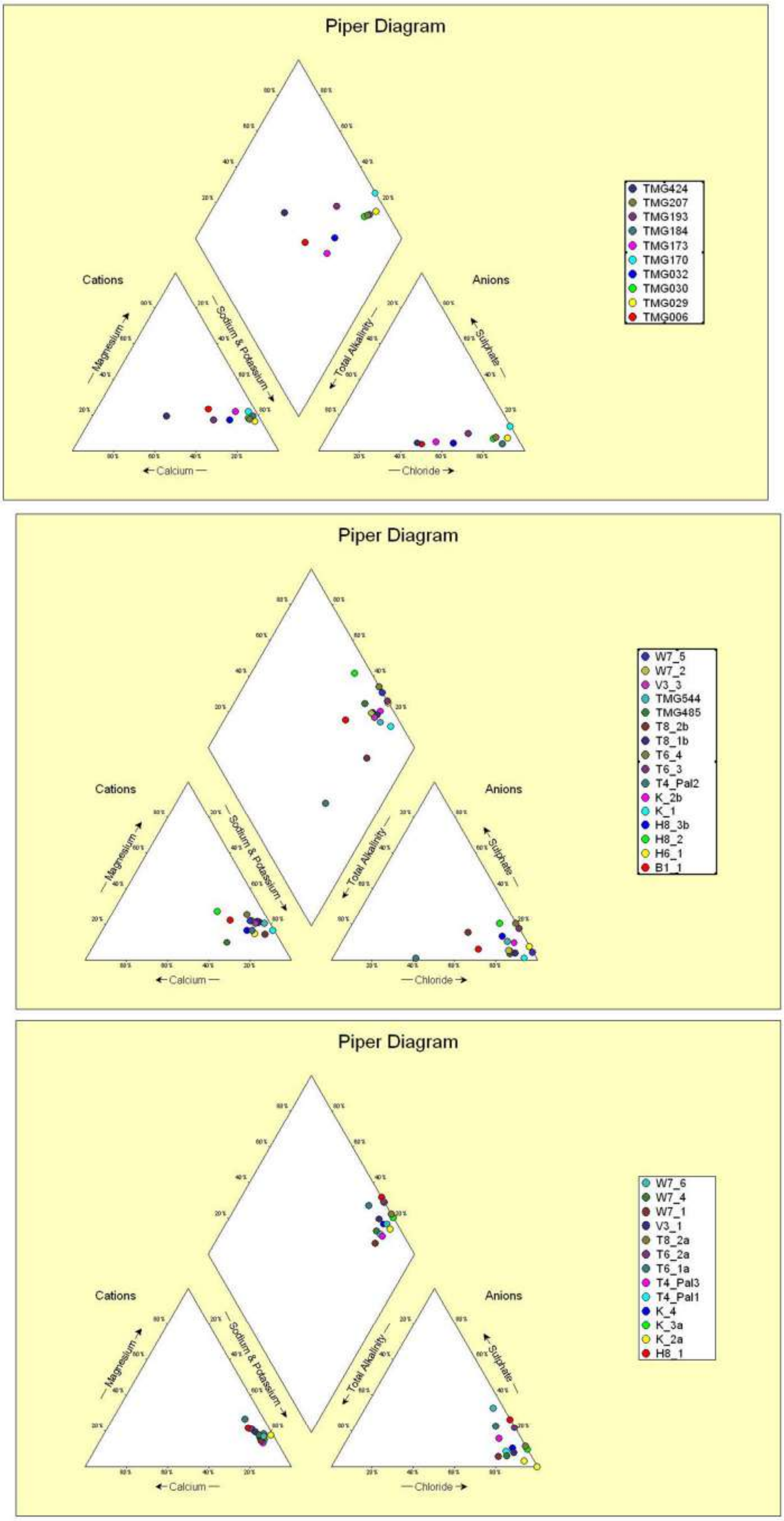


Figure 5.7. Piper diagram from the April 2010 hydrocensus springs (top), ecoseeps (middle) and ecochannels (bottom), showing dominance of major ions in surface water.

Identification of Aquifer Isotope Signature

Craig (1961) showed that there was a correlation between ^{2}H (D) and ^{18}O in precipitation waters world-wide, with a best-fit line of $\delta D = 8\delta^{18}O + 10$, which is known as the global meteoric water line (GMWL). Different areas have their own distinctive local meteoric water lines (LMWL), and Diamond and Harris (1997) plotted a local meteoric water line called the Cape meteoric water line (CMWL) for Western Cape precipitation.

The isotope data from the hydrocensus rainfall collectors and boreholes are compared against the CMWL and GMWL in Figures 5.8 and 5.9 respectively. The rainfall data plotted on or close to the CMWL (Figure 5.8), indicating that, as expected, water falling as rain was unaffected by isotopic processes associated with interaction with the earth's surface, such as evaporation and flow through substrata.

The borehole isotope data showed slight displacement from the CMWL (Figure 5.9), which indicates enrichment of the heavier isotopes, most likely due to exchange with rock minerals or evaporation from an open surface (Domenico and Schwartz 1990). According to Drever (1988), δD is generally unaffected by reactions with aquifer materials at low temperature; and $\delta^{18}O$ is generally unaffected by reaction with silicates at low temperature. If the isotopic composition of a water sample plots close to the MWL and is in a similar position to that of current rainfall data from the same area, then the water is almost certainly derived from rainfall and not groundwater (Drever 1988). This is the case for the TMG boreholes that were sampled for isotopes (Figure 5.9), and this is proof of the very pure water quality of the TMG Aquifer. Due to the lack of isotopic interaction with the TMG rock, the borehole water does not have a unique signature that can be used as a tracer.

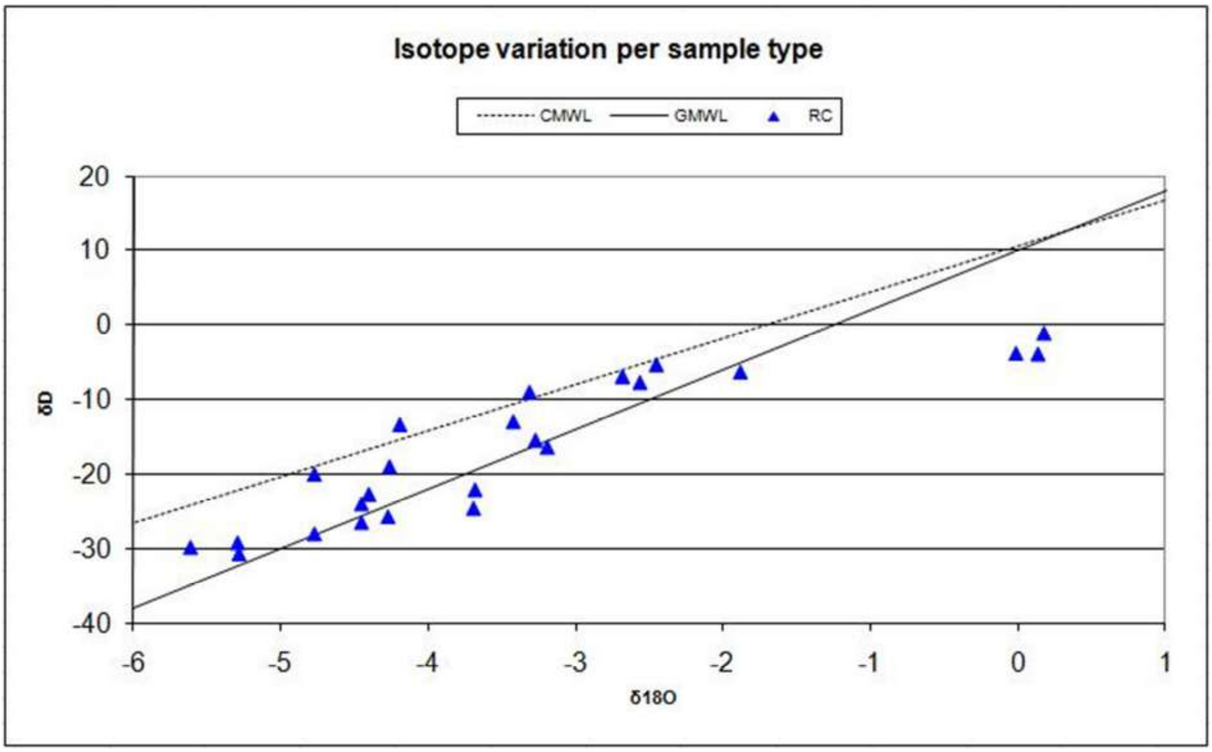


Figure 5.8 Isotopic variations for the data from the rainfall collectors (RC), compared against the Cape meteoric water line (CMWL) and global meteoric water line (GMWL).

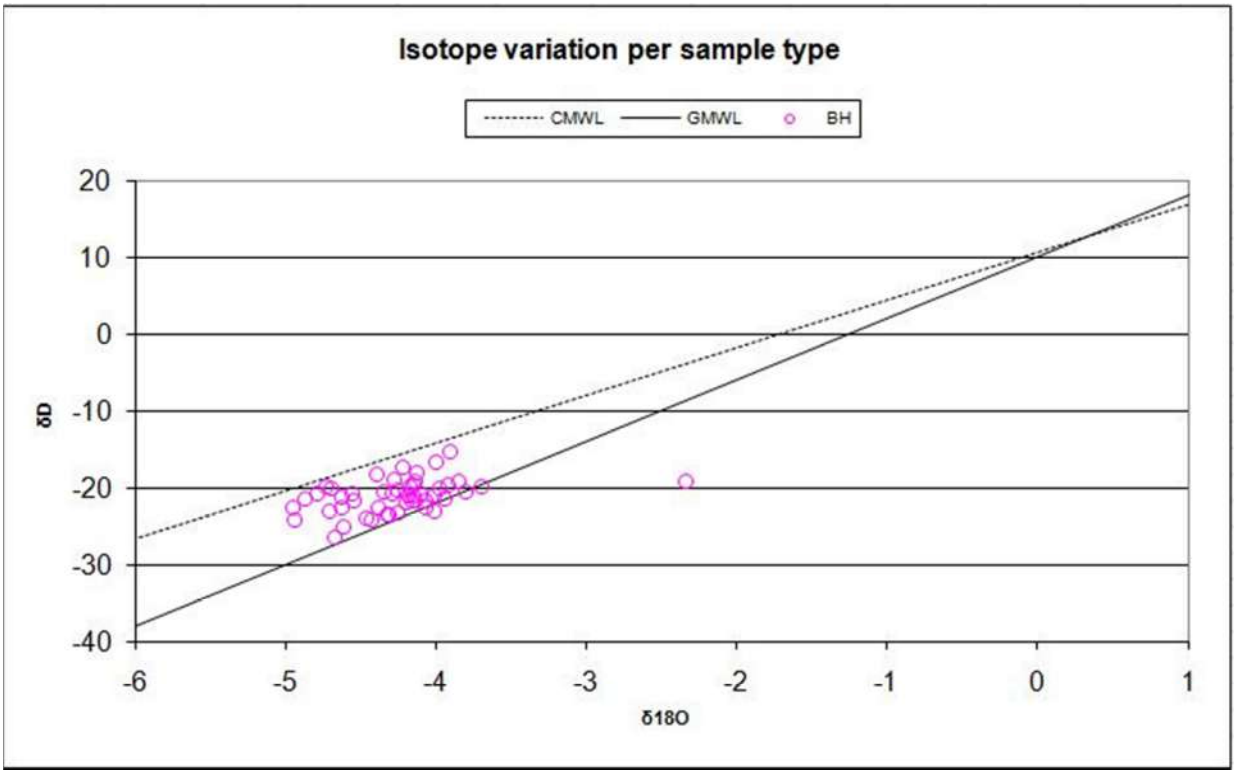


Figure 5.9 **Isotopic variations for the data from the hydrocensus boreholes (BH), compared against the Cape meteoric water line (CMWL) and global meteoric water line (GMWL).**

Different rainfall events can have unique isotopic characteristics or signatures, due to the varying histories of the individual air masses, and the different atmospheric temperatures and the evaporation rates acting on the falling rain drops. These variations can be used to identify sources of runoff during storm events, and to identify the season during which recharge occurs (Drever 1988). For instance, water is more depleted of the heavier isotopes during the winter/spring months due to colder temperatures (Domenico & Schwartz 1990). Figures 5.10 and 5.11 show the borehole isotope data collected in spring (October 2008, 2009) and autumn (April 2009, 2010) compared against the isotope data collected from the rainfall collectors in spring and autumn, respectively. It is evident from the two graphs that the borehole isotopic signatures plotted closer to those of the October rainfall samples, i.e. the winter rains, rather than those of early autumn (April). This indicates that this was the period during which recharge of the groundwater occurred.

The stream sites did not show any clear seasonal variations in isotopes and the data plotted relatively close to the CMWL (Figure 5.12). The interpretation of isotopic signatures for streams and rivers is complicated by the fact that they are exposed to evaporation and some may be fed by groundwater. The TMG study area is large and variation in evaporation and recharge rates may be significant. The hydrocensus rivers and streams were sampled only twice during the year, as specified in the terms of reference, and more frequent (monthly) sampling is required before definite conclusions about surface water isotopes can be drawn.

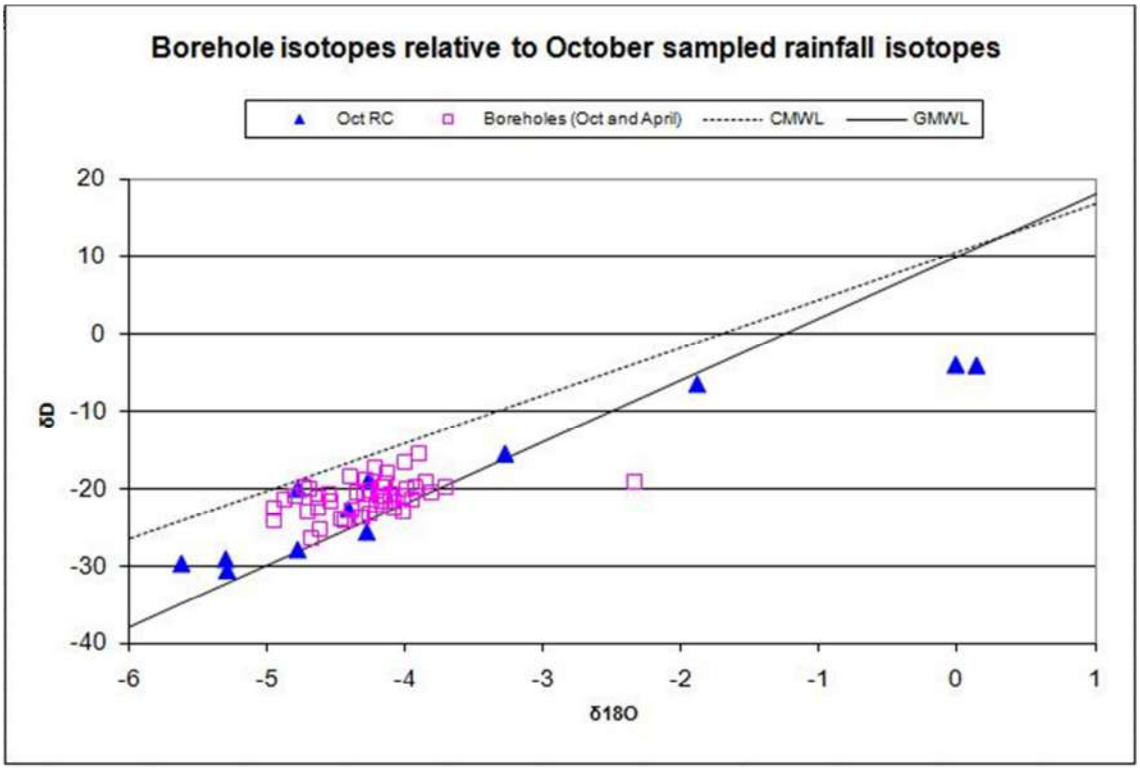


Figure 5.10. Isotope data collected in October (2008 and 2009) and April (2009 and 2010) from the hydrocensus boreholes, compared against the October rainfall collector (RC) isotope data. CMWL = Cape meteoric water line; GMWL = global meteoric water line.

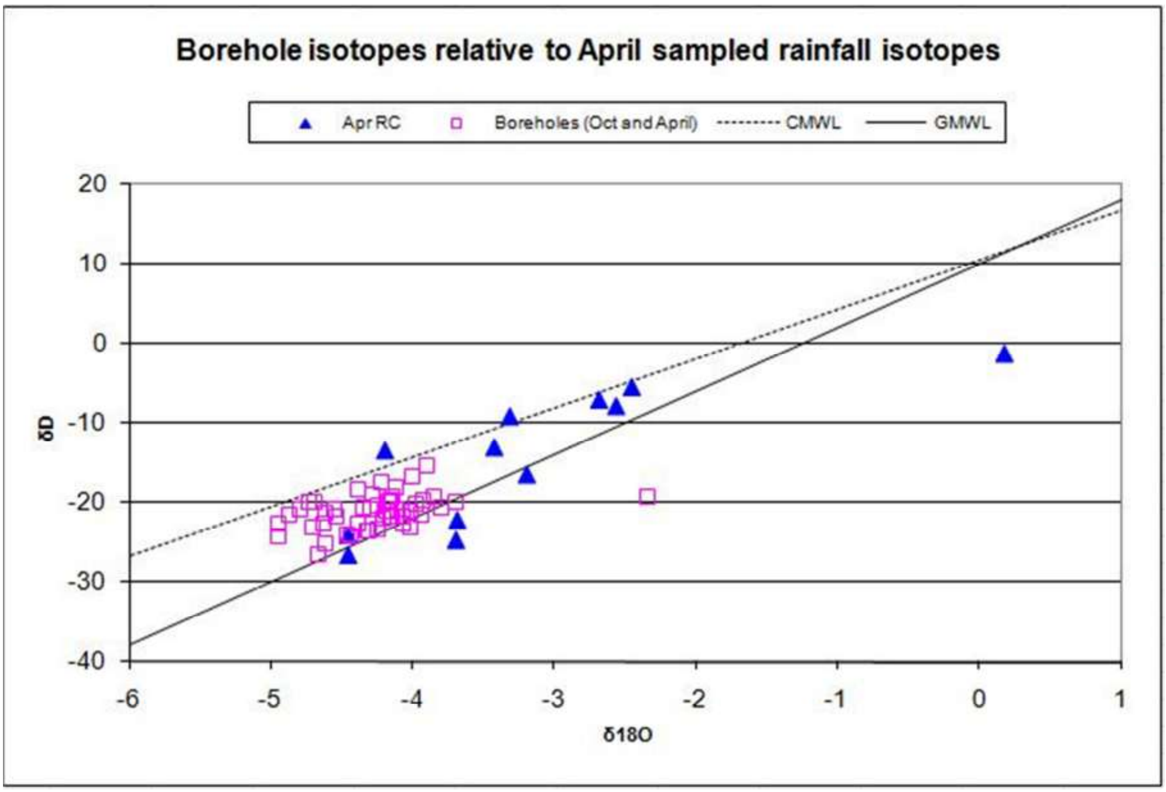


Figure 5.11. Isotope data collected in October (2008 and 2009) and April (2009 and 2010) from the hydrocensus boreholes, compared against the April rainfall collector (RC) isotope data. CMWL = Cape meteoric water line; GMWL = global meteoric water line.

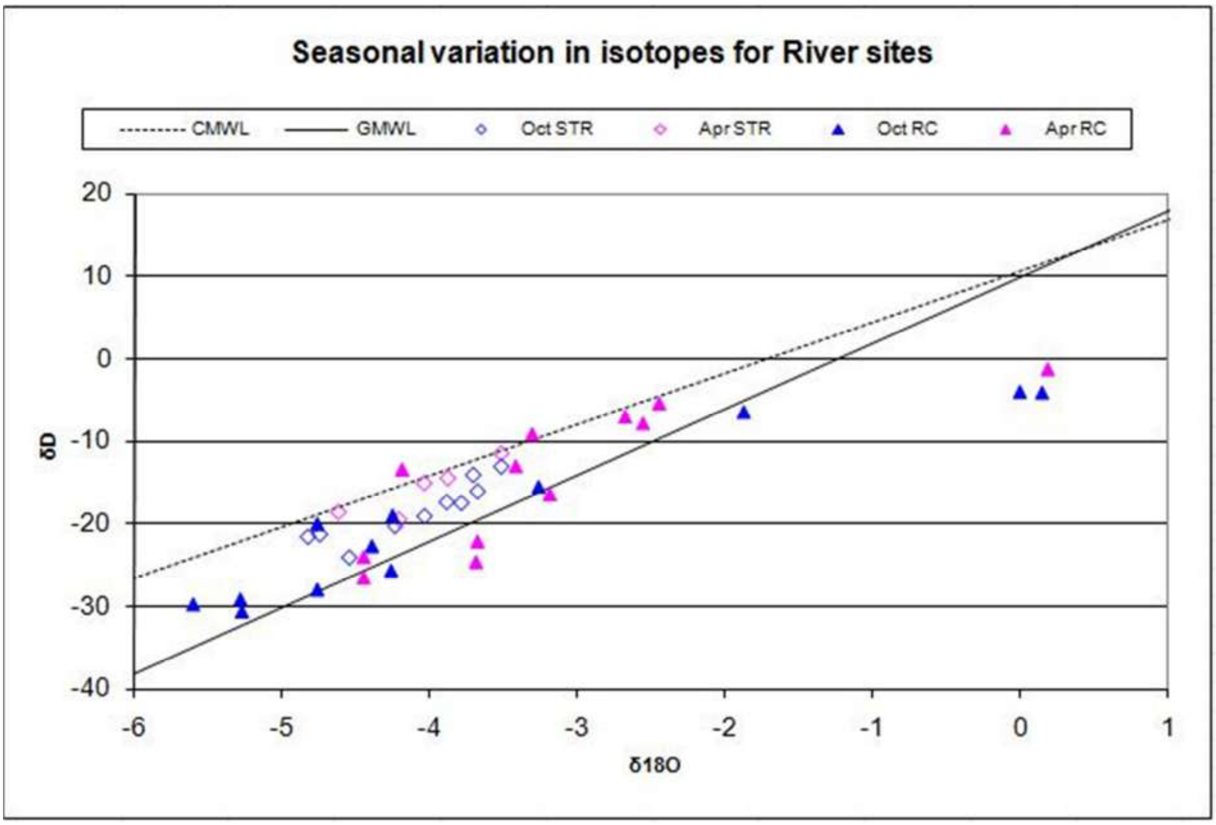


Figure 5.12. **Seasonal variation in isotope signatures for the hydrocensus river and stream (STR) sites, compared against the meteoric water lines, and the isotope data collected from the rainfall collectors (RC). CMWL = Cape meteoric water line; GMWL = global meteoric water line.**

When water evaporates the water left behind is richer in heavier isotopes. When precipitation occurs, the heavy isotope composition of the water is lowered. This means that seawater is relatively rich in heavy isotopes ($\delta^{18}O$ and δD), while rain and snow are relatively poor, and increasingly so the further inland they fall. As previously mentioned, cold temperatures, which are often related to higher elevations, also result in the depletion in $\delta^{18}O$ and δD. Thus, theoretically it should be possible to test for variation in isotope signatures between the TSAs, with the more inland and more elevated TSAs being more depleted in heavy isotopes. These data are presented in Figure 5.13, in which water samples collected from boreholes located outside of TSAs were grouped with the data from the closest TSA, excluding the Brandvlei and Goudini hot springs, which were plotted individually.

The individual data points within a TSA did appear to cluster together (Figure 5.13), indicating that the isotopic characteristics are fairly distinctive within the TSAs. It was anticipated that the sites furthest inland and with the highest elevation would be the most depleted in $\delta^{18}O$ and δD, while relatively low elevation coastal TSAs would be richer. This was not the case, as coastal TSAs Kogelberg (K) and Steenbras (H8) were both depleted, while Wemmershoek (W7) was rich in heavy isotopes (Figure 5.13). An explanation for this may be that all of the TSAs are relatively close together and relatively close to the ocean. The elevation within the individual TSAs also varies considerably, especially at Purgatory (T8), Nuweberg (T4) and Wemmershoek (W7), and this would have affected the data. This could explain the wide spread of data for T8 and T4. Samples taken from the hot springs at Brandvlei were depleted in the heavier isotopes, suggesting that recharge for these sites takes place further inland and / or at higher altitudes than the TMG TSAs.

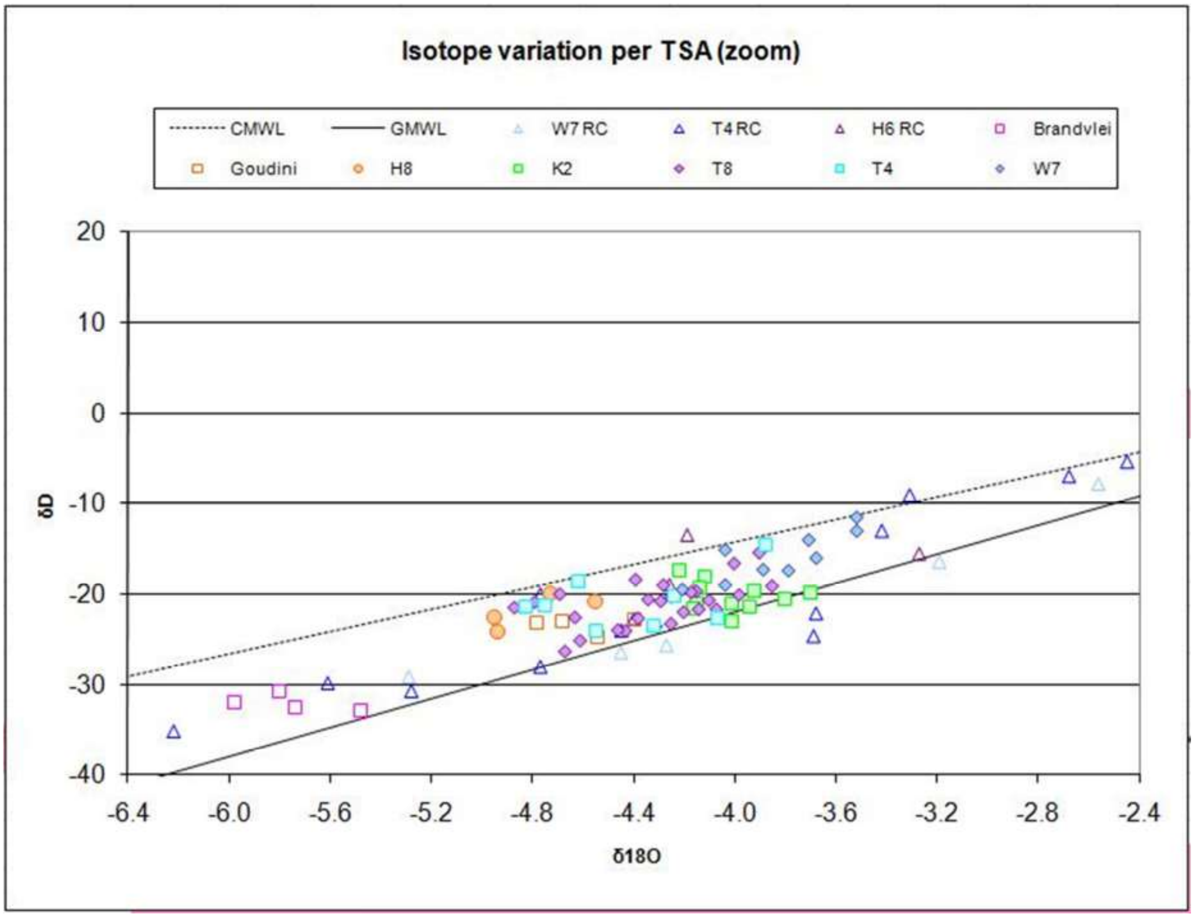


Figure 5.13. **Isotope variation in borehole water per TSA, compared against the meteoric water lines. CMWL = Cape meteoric water line; GMWL = global meteoric water line; RC = rainfall collector;**

5.3 PHYSICO-CHEMICAL ANALYSIS OF THE SOILS AT THE ECOLOGICAL MONITORING SITES

Topsoil (0 – 15 cm) from selected plant communities at the seep and channel sites was analysed for a number of chemical variables, as well as for soil moisture and organic matter content. In addition, a separate soil moisture study commenced in November 2008, with the installation of soil moisture monitoring infrastructure, where detailed soil moisture measurements were made of the soil profile to a maximum depth of 100 cm, at five of the seep wetlands, with the later addition of a further three sites in 2009.

The aims of this component of the study were to ascertain the following:

- Broad physico-chemical attributes of the topsoil at the ecological monitoring sites, and any differentiation between ecosystem types or TSAs based on these attributes;
- Variations in topsoil moisture and organic matter content at the ecological monitoring sites and the relationship (if any) between these variables;
- Variations in soil moisture and soil saturation in the topsoil *and* the subsoil at some of the ecoseeps over the project period, and how this informs our understanding of the movement of water into and through the wetlands. The terms of reference for the EPM did not require the identification of wetlands or rivers that are *dependent* on groundwater, but did require the inference of the *probability and strength of connectivity* between these ecosystems and the

Peninsula Aquifer. These are discussed in Chapters 2, 3 and 4, and the soil moisture and saturation data presented here proved useful as supporting evidence of the dominant supply of water to the ecoseeps as subsurface flow (i.e. groundwater flow, throughflow or interflow[5]) or surface runoff as the direct result of rainfall.

- Categorisation of each of the abovementioned soil moisture monitoring points (five at each sampled site) according to the duration of soil saturation of the top- and subsoil, in support of the hydroperiod categorisation in Chapter 4.

The first aim was achieved through the analysis of only the first year's data, which were deemed sufficient for the characterisation of the topsoil at the ecological monitoring sites – most of the variables measured should not vary substantially between consecutive years. The remaining three aims were achieved through the use of soil moisture data collected over at least one year, but two years' data were available from most of the selected sites.

5.3.1 Analysis of the topsoil at the ecological monitoring sites

Methods

For the chemical analysis of the topsoil, three random hand-augered (to 15 cm) samples were collected from a selection of plant communities at a subset of the study sites. The three samples were then bulked. All of the sites presented here were sampled in late winter/early spring (October/November) 2008. Other sites were sampled in either March or August 2009, but their data have not been included in this report, as the 2008 dataset was more extensive.

Soil samples were air-dried in the sun and thoroughly mixed by hand, and then analysed at BemLab, Somerset West (one replicate from each site only) for texture, pH, electrical resistance (inverse of conductivity), titratable H^+, total phosphorus, Bray II phosphorus[6], exchangeable cations (cations available for exchange between soil solution and soil surface) and base saturation cations (the fraction of exchangeable cations that are base cations), total organic carbon, total nitrogen, cation exchange capacity (total amount of exchangeable cations that can be held by 1 kg of soil), bulk density, and T-value (total cations). Of key interest were the macronutrients essential for plant growth: these are nitrogen, phosphorous, potassium, calcium, magnesium and sulphur (Brady, 1974). Time and costs prevented analysis for the latter as well as micronutrients such as iron, manganese, molybdenum and zinc.

In October/November (winter/spring) 2008 and in March (summer) 2009 three additional soil samples from selected plant communities were augered to 15 cm in order to measure organic matter content and soil moisture. Two soil samples augered to 10 cm were collected from each of the algal sampling points at all the ecoseeps in September 2009 and March 2010, also to measure organic matter content and soil moisture at these points. Each sample was sealed in the field in two plastic zip-lock

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[5] Interflow is the lateral movement of water that occurs in the upper part of the unsaturated zone, or vadose zone, that **directly** enters a stream channel or wetland without having occurred first as surface runoff. Throughflow is similar, but must emerge first as surface runoff before entering a waterbody. Interflow is slower than throughflow but faster than groundwater flow. (Definition from www.physicalgeography.net, January 2010)

[6] Bray II P gives some indication of phosphorus availability, but with this "availability" varying greatly amongst organisms

bags to prevent water loss and stored at -5 to -10°C in a portable fridge. Soil moisture was calculated from the difference between wet and dry weights. Organic matter content was determined by comparing the weight of the dry samples and that after ignition.

Data analysis was aimed at identifying spatial and temporal differences in soil properties, for example between channels and seeps, between seasons, and between TSAs. The relationship between soil moisture and organic matter was also examined, with analyses done separately for the 2008/9 and 2009/10 data due to the different sampling methods used. Univariate (ANOVA, Kruskal-Wallis and regression) and multivariate methods (PRIMER, see Chapter 6 for a detailed description of these methods) were employed in the analysis. Multivariate analysis of the relationships between sites, based on their soil chemistry, was performed using normalised data where necessary, and Euclidean distance as a measure of similarity between sites, as recommended for environmental variables (Clarke & Warwick, 1994).

Results and Discussion

i) General soil characteristics

A selection of results of the general topsoil analysis of the 2008 samples is provided in Table 5.1. As can be expected in the sandstone substrata of the Cape mountains, the soils are typically acidic and oligotrophic (i.e. infertile) (Kruger 1979; Low 1980; Low & Bristow 1983; Cowling 1992) and provide major challenges to nutrient uptake by plants (Low 1980; Low 1981; Lamont 1982) (Table 5.1). Soil pH values were amongst the lowest observed for Cape fynbos soils (Low, unpublished data).

The soils had high electrical resistance, which is generally inversely proportionate to soil fertility, and reflects a trend in Cape sandstone soils studied to date (Low, unpublished) (Table 5.1). Low levels of both total and Bray II levels of phosphorus (P) were recorded (Table 5.1). In other recent soils surveys, Fernwood and Champagne soils associated with bottomlands and seeps in Bainskloof and Zachariashoek had total P levels of 35 (+/-7) (mean (+/-1 S.E.)) and 120 (+/- 24) mg/kg (Fynn Corry, Freshwater Research Unit, UCT, unpublished data), the latter comparing well with the TMG sites. Bray II P levels of 0.8 (+/- 0.1) and 1.9 (+/- 0.1) mg/kg respectively in the Bainskloof and Zachariashoek samples, however, were substantially lower than the TMG samples, particularly in the seep sites where Bray II phosphorus in the soils was double that of the channel banks. However, because of high seasonal and inter-annual variation in Bray II P in wetland soils (Low 1984), these comparisons need to be treated with caution.

Total carbon levels in the TMG samples, although variable across the sites, were mostly typical of wetlands within the Western Cape, where carbon content of wet and seasonally wet habitats typically ranges from 2-2.5% (Fynn Corry, Freshwater Research Unit, UCT, unpublished data; Whitkowski and Mitchell 1987). High carbon content, much higher than any of the TMGA sites, has been recorded in acid hillslope seep wetlands in Hermanus, in soils bordering on peaty (12% total carbon). Peaty soils are brownish-black organic soils formed in acidic, anaerobic wetland conditions. They are composed mainly of partially-decomposed, loosely compacted organic matter with a high percentage of carbon. Carbon content of 50% is typical of the sphagnum peat moss peat in the Northern Hemisphere. The South African soil classification uses a carbon content of > 10 % as a guideline (DWAF 2005).

Another important characteristic of these soils is the carbon to nitrogen ratio (Table 5.1). Soils from agricultural and humid areas tend to have low ratios of 10:1 to 12:1, but this ratio increases to 20:1 and more in soils which are peaty or have high amounts of organic matter (Brady 1974). Low (1984) found C:N ratios of between 25.1 and 41.0 for a range of mountain fynbos topsoils at Cape Point, several with seasonal wetting. The C:N ratio for the TMG soils ranged between 10 and 20:1.

There was a clear linear correlation between total carbon and total nitrogen (R^2 = 0.872) (Figure 5.14), which corresponds with findings elsewhere that in oligotrophic soils, higher levels of organic matter and carbon are often associated with elevated nutrient concentrations, as indicated in the studies of Low (1984) for Cape mountain fynbos on sandstone soils and Low & Pond (2003) for deep sands and sandstones of the Jakkals and Verlorenvlei Rivers in the Northern Sandveld. Higher carbon content in itself does not necessarily imply an increase in *available* nitrogen, however, as the majority of nitrogen contained in the soil (95%) is trapped in the form of organic matter (e.g. Whitehead 2000, Ashma & Puri 2002). This matter must be mineralised by soil organisms in order to release the nitrogen for plant use.

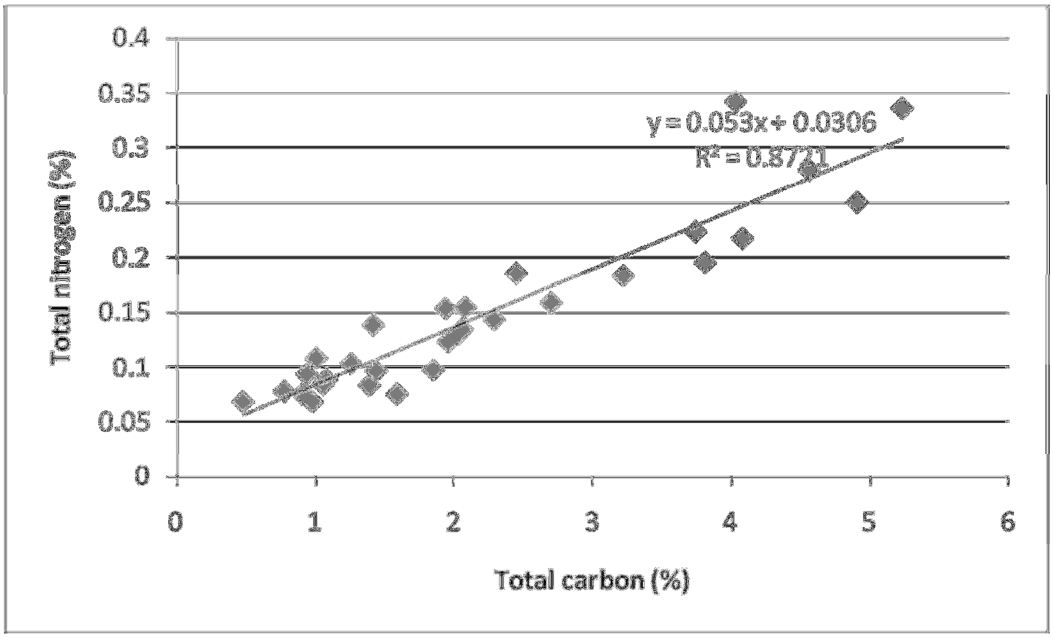

Figure 5.14 Total carbon *versus* total nitrogen for topsoil collected from selected ecological monitoring sites for the TMGA study, sampled in October/November 2008.

A linear relationship was shown between cation exchange capacity (CEC) and total carbon (R2 = 0.724) (Figure 5.15). This is a key feature of the study area, in that sandstone has an inability to impart any mineral (and clay) fraction of consequence (as inferred by Low and Bristow 1983). As organic colloids have far larger surface areas than that of clays of mineral soils (Brady 1974) and by implication, greater nutrient exchange capacities, the high correlation between CEC and OM could well imply that organic matter plays a role – possibly crucial - in nutrient adsorption and exchange.

The soils generally contained low amounts of exchangeable cations (Table 5.1), particularly of Na and K (Figure 5.15), a feature typical of sandstone soils (Kruger 1979; Low 1980; Low & Bristow 1983; Cowling 1992; Low unpublished data). This does not match the hydrocensus site chemical data, where Na + K were the dominant cations (Section 5.2.2). This may relate to processes of ion exchange in soils versus water. The soil chemistry at B1_1 was quite different to that at the other ecoseeps (Table 5.1). This was especially so in terms of exchangeable Ca and Mg (Figure 5.16), total P, total N and CEC and T-value. This might be in part due to the influence of the underlying shale (Cedarberg Formation; Table 2.5).

A comparison between the soils collected from the ecoseeps *versus* those from ecochannels, using the multivariate ANOSIM procedure in PRIMER, did not yield a significant result for any of the variables measured, indicating that, overall, the soils were not different.

Multivariate analyses of the combined ecoseep and ecochannel data showed that there were significant differences between soils from sites collected in different TSAs (Global R = 0.354; p = 0.001), with B1 being an outlier (Figure 5.17). No significant differences were found between soils collected from ecoseeps that were assigned to the five hydroperiod categories, nor for the soils collected from the ecochannels assigned to the four hydroperiod categories (Table 4.2).

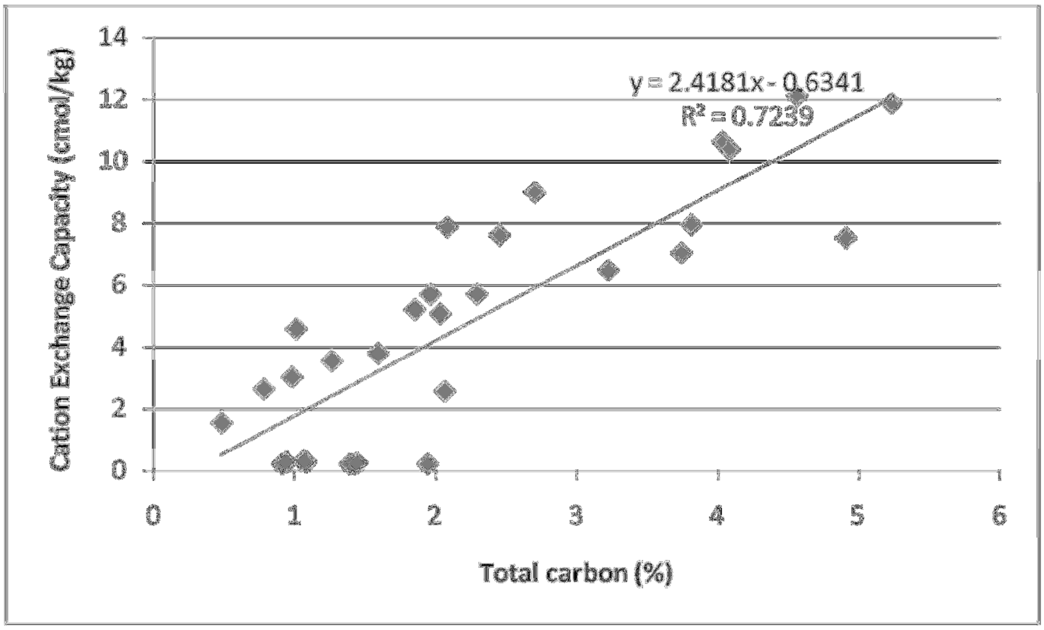

Figure 5.15 **Cation Exchange Capacity *versus* Total Carbon for topsoil collected from selected ecological monitoring sites for the TMGA study, sampled in October/November 2008.**

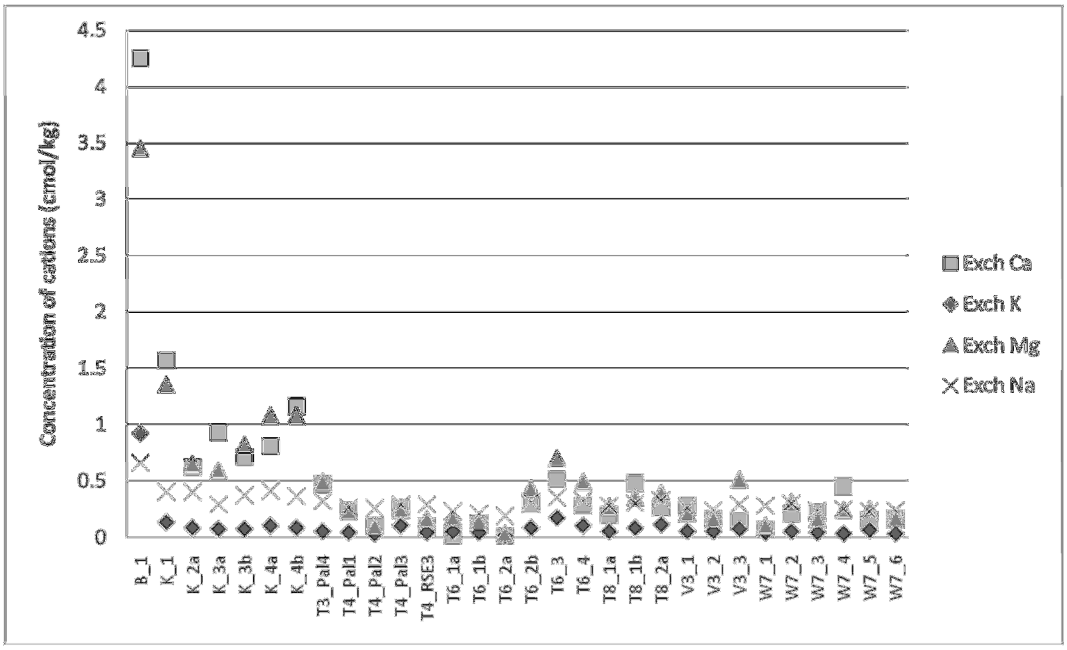

Figure 5.16. **Cation concentrations in the topsoil, per site sampled in October/November 2008.**

Table 5.1 **Selected soil variables for ecoseep and ecochannel topsoil samples collected from a subset of the ecological monitoring sites in October/November 2008.**

	pH	Resistance (Ohm)	Total P (mg/kg)	Bray II P (mg/kg)	Exch. Na cmol(+)/kg	Exch. K cmol(+)/kg	Exch. Ca cmol(+)/kg	Exch. Mg cmol(+)/kg	Total N (%)	Total C (%)	CEC cmol(+)/kg	T-Value (cmol/kg)	C/N ratio
SEEPS													
B1_1	3.3	1660	118	53	0.66	0.92	4.25	3.45	0.342	4.03	10.63	16.21	11.78
K_1	3.2	3540	46	7	0.40	0.13	1.57	1.35	0.196	3.81	7.95	8.14	19.44
K_3b	3.0	4900	8	3	0.37	0.07	0.71	0.82	0.155	2.08	7.87	6.75	13.42
K_4b	2.9	4020	19	2	0.36	0.08	1.16	1.08	0.218	4.08	10.38	8.91	18.72
T3_Pal4	3.1	4760	17	4	0.32	0.05	0.47	0.49	0.159	2.7	8.99	6.07	16.98
T4_Pal2	3.5	8230	12	3	0.26	0.03	0.10	0.10	0.078	0.78	2.64	1.71	9.96
T6_1b	3.5	4730	19	3	0.21	0.04	0.12	0.14	0.069	0.98	3.02	2.04	14.20
T6_2b	3.0	4490	31	3	0.24	0.04	0.17	0.35	0.168	2.43	4.88	4.06	14.46
T6_3	2.9	3070	28	5	0.35	0.17	0.51	0.70	0.224	3.74	7.04	7.11	16.70
T6_4	3.1	2900	32	8	0.33	0.10	0.28	0.49	0.336	5.23	11.86	8.56	15.57
T8_1b	3.1	3940	21	4	0.3	0.08	0.48	0.35	0.186	2.45	7.61	5.41	13.17
V3_3	3.1	3540	43	7	0.29	0.07	0.14	0.51	0.154	1.94	0.21	4.81	12.60
W7_2	3.4	3190	12	4	0.30	0.05	0.21	0.31	0.084	1.39	0.21	2.35	16.55
W7_3	3.4	4850	27	4	0.24	0.04	0.22	0.16	0.089	1.08	0.27	2.78	12.13
W7_5	3.5	5190	25	4	0.23	0.06	0.15	0.25	0.085	1.06	0.3	2.73	12.47
Mean	**3.2**	**4148**	**33**	**8**	**0.33**	**0.13**	**0.71**	**0.71**	**0.175**	**2.68**	**5.77**	**5.99**	**14.88**
SD	**0.2**	**1472**	**28**	**13**	**0.11**	**0.22**	**1.06**	**0.84**	**0.088**	**1.51**	**4.22**	**3.74**	**3.01**
CHANNELS													
K_2a	3.2	2940	27	3	0.40	0.08	0.62	0.65	0.184	3.22	6.47	6.25	17.50
K_3a	3.4	4040	6	3	0.29	0.07	0.93	0.59	0.098	1.85	5.20	3.95	18.88
K_4	2.9	3310	42	4	0.41	0.10	0.81	1.08	0.280	4.56	12.1	9.66	16.29
T4_Pal1	3.2	5310	11	2	0.26	0.04	0.24	0.23	0.109	1.01	4.58	3.09	9.27
T4_Pal3	3.2	4730	10	2	0.29	0.10	0.26	0.24	0.076	1.59	3.79	2.92	20.92
T4_RSE3	3.3	4970	8	2	0.29	0.04	0.09	0.16	0.131	2.03	5.06	3.94	15.50
T6_1a	3.1	3820	27	5	0.23	0.05	0.01	0.17	0.104	1.26	3.54	2.34	12.12
T6_2a	3.5	13650	8	2	0.19	0.01	0.01	0.03	0.069	0.48	1.54	1.18	6.96
T8_1a	3.3	5590	20	2	0.28	0.05	0.20	0.27	0.144	2.29	5.70	4.36	15.90
T8_2a	3.8	3380	47	4	0.33	0.11	0.26	0.39	0.124	1.96	5.69	3.66	15.81
V3_1	3.5	3890	46	4	0.26	0.05	0.28	0.21	0.135	2.06	2.56	3.96	15.26
V3_2	3.6	4950	22	4	0.24	0.05	0.16	0.16	0.139	1.42	0.21	2.88	10.22
W7_1	3.7	4900	18	3	0.28	0.04	0.07	0.10	0.076	0.91	0.21	1.86	11.97
W7_4	3.6	7590	11	3	0.25	0.03	0.45	0.24	0.097	1.44	0.24	2.64	14.85
W7_6	3.8	4290	9	2	0.24	0.03	0.16	0.17	0.094	0.94	0.27	2.27	10.00
Mean	**3.4**	**5157**	**21**	**3**	**0.28**	**0.06**	**0.30**	**0.31**	**0.124**	**1.80**	**3.81**	**3.66**	**14.09**
SD	**0.3**	**2611**	**14**	**1**	**0.06**	**0.03**	**0.28**	**0.27**	**0.053**	**1.02**	**3.22**	**2.05**	**3.88**

P = phosphorus; Exch. = exchangeable; Na = sodium; K = potassium; Ca = calcium; Mg = Magnesium; N = Nitrogen; C = carbon; CEC = cation exchange capacity; SD = standard deviation

ii) Organic matter and soil moisture

Examining the data collected from the plant communities in 2008 and 2009, significant differences in topsoil moisture between the ecochannels and ecoseeps were found only at Boesmanskloof (T6) and Purgatory (T8) (Table 5.2). Differences in organic matter content between ecochannels and ecoseeps were only significant at Boesmanskloof and Voelvlei (V3). Thus, soil moisture and organic matter content were fairly similar between ecosystem types.

There were significant differences in soil moisture between TSAs for ecoseeps in summer only, and in winter and summer for ecochannels (Figures 5.17 and 5.18; Tables 5.3 and 5.4). The same results were obtained for organic matter content. The wetting of the seeps in winter reduces the dissimilarity between TSAs, possibly because when seep soils reach saturation they cannot become wetter, whereas the extent to which a seep dries out can vary. The lack of a significant difference between TSAs in terms of the organic matter content of ecoseep topsoil in winter is puzzling, as there were no significant seasonal shifts in this variable (Table 5.3).

The causal relationship between organic matter and soil moisture is not necessarily straightforward, although there was a significant linear relationship between these two variables in winter/spring but not in summer (Figures 5.19 and 5.20). Drenching of soils (either from rainfall or from a raised water table) replaces the air in the soil with water, and the biological uptake of oxygen leads to the depletion of oxygen and anaerobic (reducing) conditions. These conditions lead to a slowing down of organic matter decomposition (Brady 1974). Wetlands that are fed more or less consistently throughout the year by groundwater, for instance, show an accumulation of organic matter and may tend to be peaty (Batchelor *et al.* (2002) in Malan and Day 2005).

Drying out of soils, such as occurs in seasonal wetlands, allows oxygen to enter the soil, thus providing atmospheric oxygen to the plant roots, microbes and other micro-fauna (Collins 2005). This leads to faster rates of organic matter decomposition.

Table 5.2. Statistical results for comparisons of soil moisture and organic matter content, between ecosystem types, and season of sampling. Only significant results ($p < 0.05$) are shown.

Factor	Site	Comparison	Statistic	p
Soil moisture	Boesmanskloof (T6)	*Ecosystem type:* ecoseeps vs. ecochannels	Kruskal-Wallis ANOVA: H = 10.98	p < 0.005
Soil moisture	Purgatory (T8)	*Ecosystem type:* ecoseeps vs. ecochannels	Two-way ANOVA: F = 4.311	p < 0.05
Organic matter	Boesmanskloof (T6)	*Ecosystem type:* ecoseeps vs. ecochannels	Kruskal-Wallis ANOVA: H = 13.474	p = 0.001
Organic matter	Voelvlei (V3)	*Ecosystem type:* ecoseeps vs. ecochannels	Two-way ANOVA: F = 14.013	p = 0.001
Soil moisture	Kogelberg (K)	*Seasons:* winter/spring vs. summer	Two-way ANOVA: F = 6.415	p < 0.05
Soil moisture	Palmiet (T4)	*Seasons:* winter/spring vs. summer	Kruskal-Wallis ANOVA: H = 10.690	p = 0.001
Soil moisture	Boesmanskloof (T6)	*Seasons:* winter/spring vs. summer	Kruskal-Wallis ANOVA: H = 4.181	p < 0.05
Soil moisture	Voelvlei (V3)	*Seasons:* winter/spring vs. summer	Kruskal-Wallis ANOVA: H = 14.86	p < 0.001
Soil moisture	Wemmershoek (W7)	*Seasons:* winter/spring vs. summer	Two-way ANOVA: F = 7.929	p < 0.01

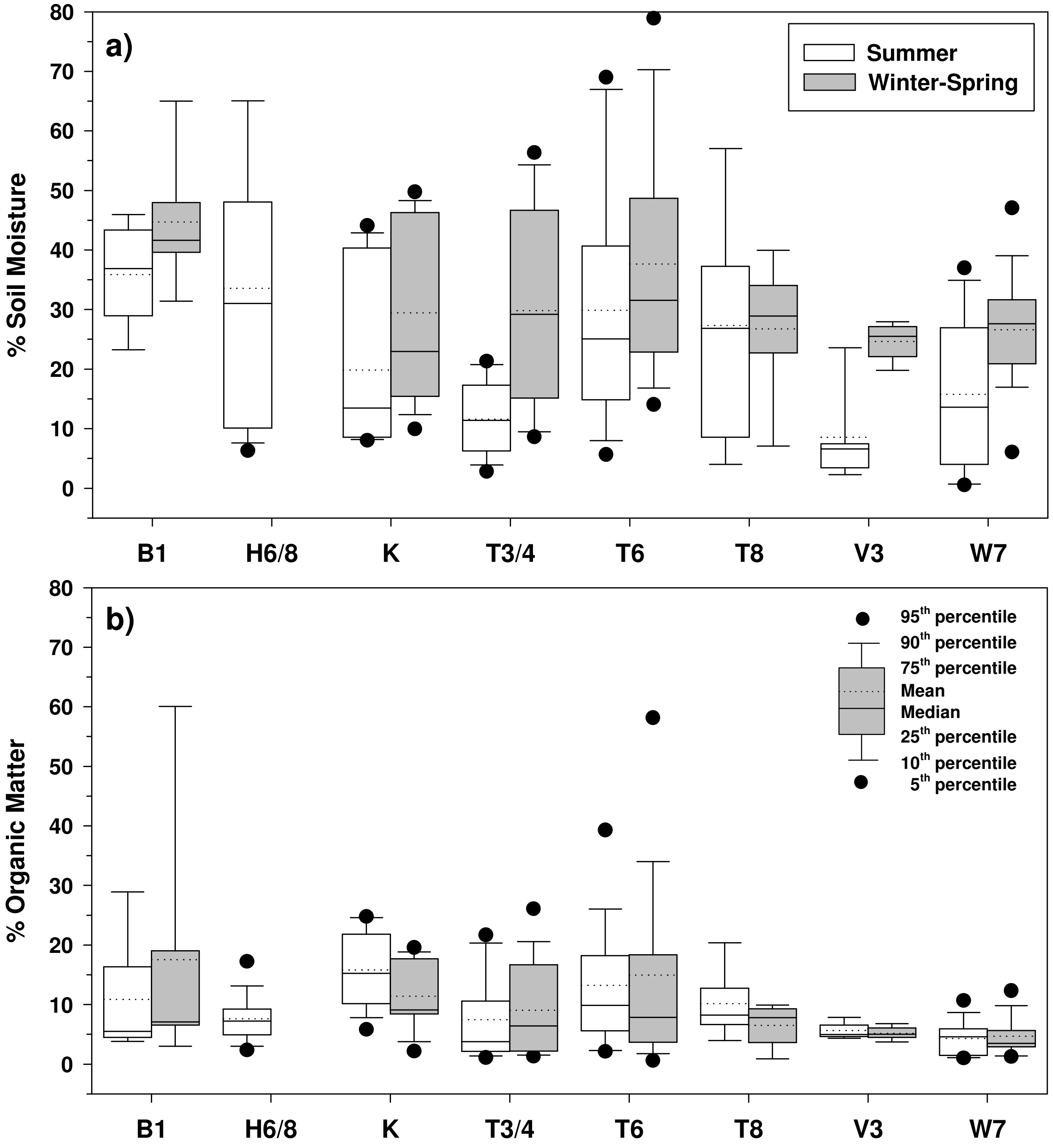

Figure 5.17 **Box and whisker plots for ecoseeps showing a) soil moisture and b) organic matter for each TSA sampled in summer and winter seasons. There were no data for the H6/8 sites for winter-spring.**

It might be predicted, therefore, that those wetland sites that are regarded as perennially wet (either inundated or saturated) (category A and B in the hydroperiod categorisation described in Chapter 3, and provided in Table 3.2) will have higher levels of organic matter than the seasonal wetlands. This was tested using ANOVA, comparing soil moisture content and organic matter across the hydroperiod categories, for both ecoseeps and ecochannels.

At the ecoseeps, soil moisture was significantly different between hydroperiod categories in summer only (Table 5.3 and Figure 5.21). These differences were between A and C, D and E soils, and also between B and C soils. There did appear to be a trend towards drier soils, especially in summer, from category A through to category E. The exception was in winter/spring when category D soils were wetter on average than A, B and C soils, which is unexpected.

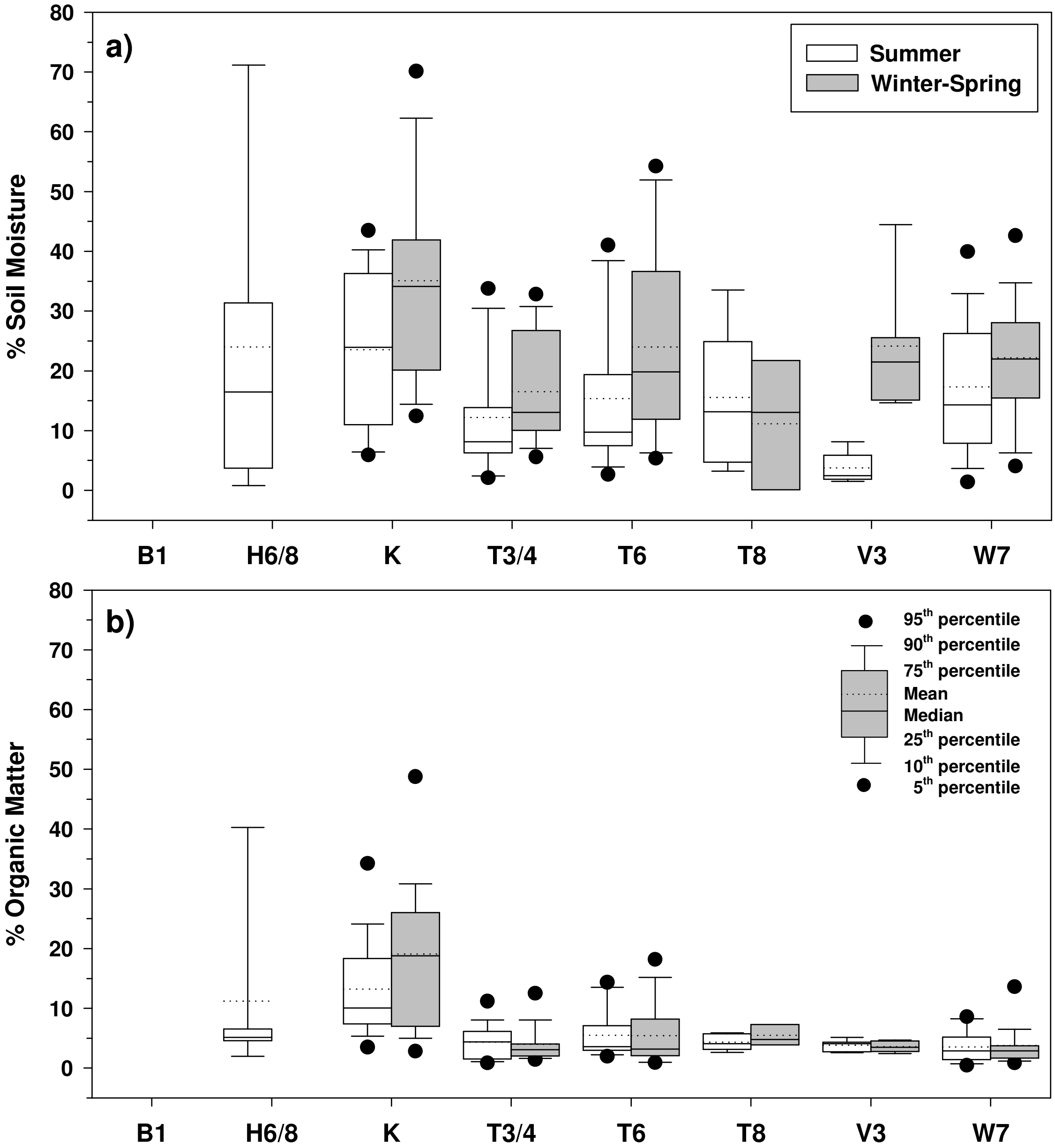

Figure 5.18. Box and whisker plots for ecochannels showing a) soil moisture and b) organic matter for each TSA sampled in summer and winter seasons. H6/8 sites did not have winter-spring data; B1 only has seeps.

In terms of organic matter, there were significant differences between the hydroperiod categories in the ecoseeps; in both winter/spring and summer. However, there were only pair-wise differences in summer; these were between category B soils and A, C and E soils. B soils had a higher organic content than all other categories (Figure 5.21).

An unexpected anomaly occurred in the case of category A and E soils in the seeps, where the summer soil moisture data returned higher mean and median values than those measured in winter / spring (Figure 5.21a). Part of this discrepancy may be related to the fact that sampling for the winter/spring period was carried out over a number of months, and even into late November.

Soil moisture was significantly different between hydroperiod categories for the ecochannels in summer only, with no significant pair-wise differences (Table 5.4). This can clearly be seen in Figure

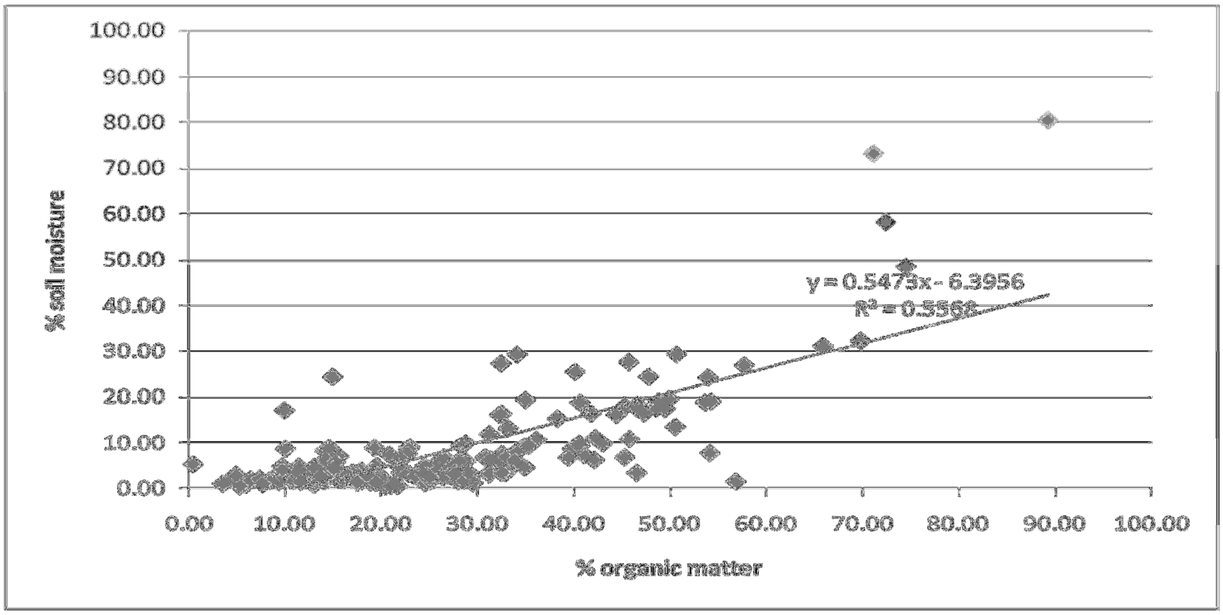

Figure 5.19. **Organic matter and soil moisture from selected topsoils in the TMGA study: all sites – winter/spring (October/November) 2008.**

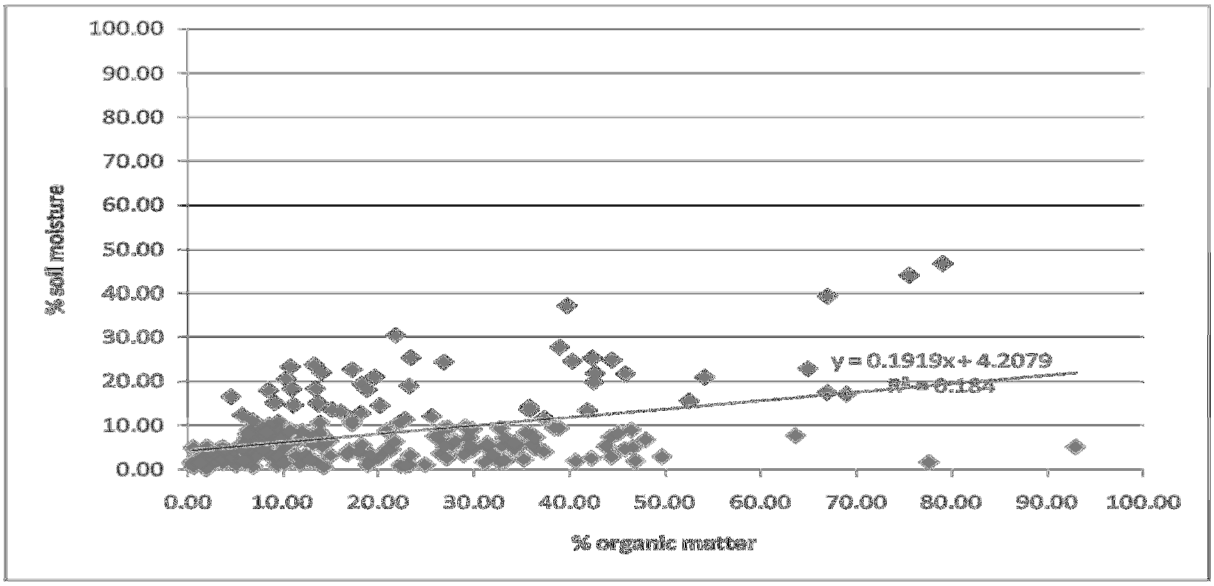

Figure 5.20. **Organic matter and soil moisture from selected topsoils in the TMGA study: all sites – summer (March) 2009.**

5.22, where in summer the B category soils are shown to be wetter than all other categories. Organic matter content was significantly different between hydroperiod categories in both winter/spring and summer (Table 5.4). Pair-wise tests showed that in winter/spring, there were significant differences between A and C, B and C, and D and C category soils, with C category soils being slightly richer in organic matter than other categories.

Patterns in soil moisture and organic matter between hydroperiod categories did not show a consistent decrease in these two variables from the perennially saturated or inundated systems through to those that dry out. Category A seeps did, however, show little seasonal variation in soil moisture, as would be expected for perennially inundated soils, but these soils were generally drier with lower organic matter content than the other categories. For channels it must be noted that the

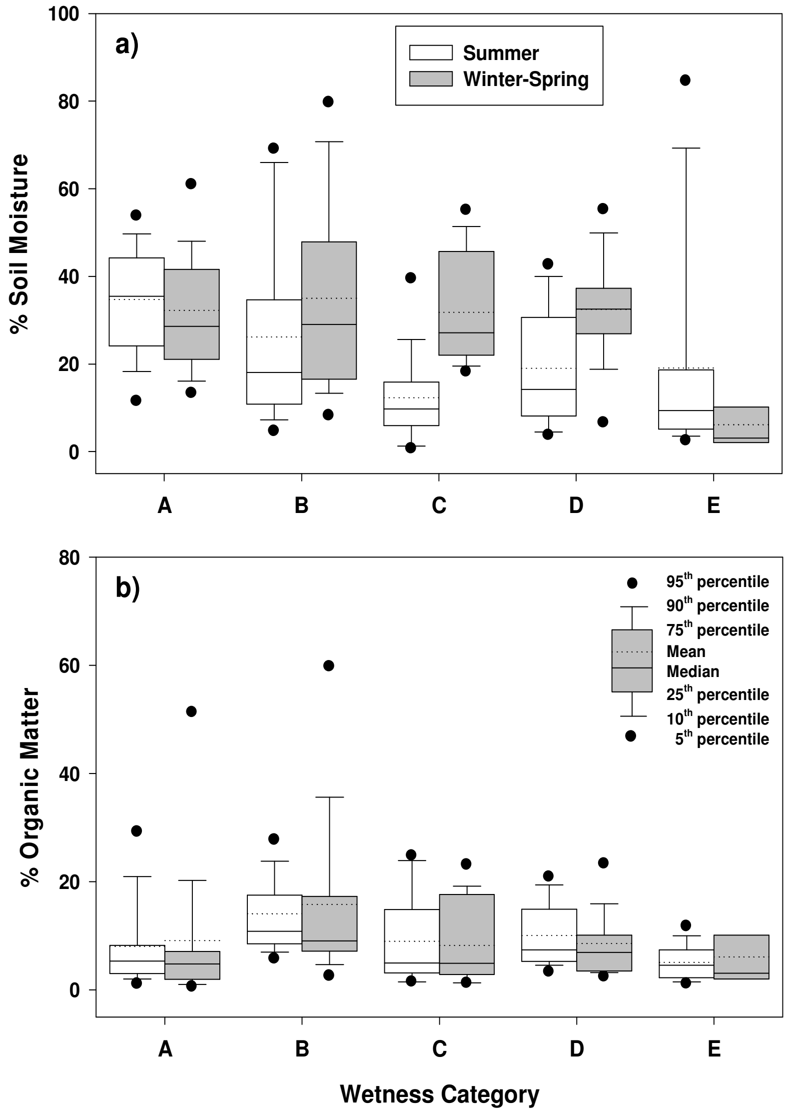

Figure 5.21. **Box and whisker plots of ecoseep topsoil a) moisture and b) organic matter data by hydroperiod.**

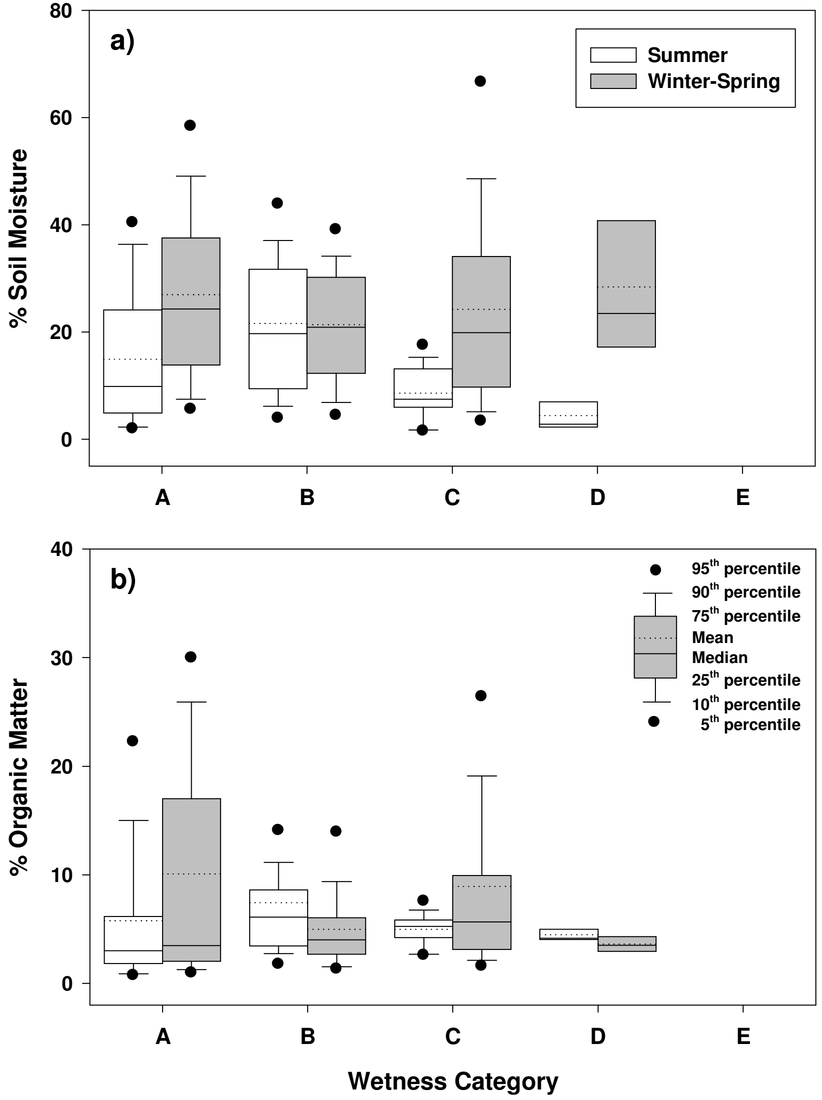

Figure 5.22. **Box and whisker plots of ecochannel topsoil a) moisture and b) organic matter data by hydroperiod categories.**

Table 5.3. **ANOVA and Kruskal-Wallis results table for differences in soil moisture and organic matter in the topsoil at the ecoseeps. Significant results ($p < 0.05$) are shown in red.**

Comparison	Test	Result
Between TSAs		
Soil moisture in winter/spring	1-way ANOVA	p > 0.05
Soil moisture in summer	1-way Kruskal Wallis	H = 38.556; d.f. = 7; p < 0.001
	Post-hoc pair-wise differences: Dunn's Test (only significant results)	B1 vs T4 (Q = 3.543) B1 vs V3 (Q = 75.958) H6/H8 vs T4 (Q = 40.167) H6/H8 vs V3 (Q = 59.125) T6 vs T4 (Q = 36.742) T6 vs V3 (Q = 55.7)
Organic matter in winter/spring	1-way Kruskal Wallis	p > 0.05
Organic matter in summer	1-way Kruskal Wallis	H = 31.951; p < 0.001
	Post-hoc pair-wise differences: Dunn's Test (only significant results)	K vs T4 (Q = 48.723) K vs V3 (Q = 53.286) K vs W7 (Q = 67.786) T6 vs W7 (Q = 45.2)
Between hydroperiod categories		
Soil moisture in winter/spring	1-way ANOVA	p > 0.05
Soil moisture in summer	1-way Kruskal Wallis	H = 40.267; d.f. = 4; p < 0.005
	Post-hoc pair-wise differences: Dunn's Test (only significant results)	A vs C (Q = 5.748) A vs D (Q = 3.332) A vs E (Q = 4.607) B vs C (Q = 3.144)
Organic matter in winter/spring	1-way Kruskal Wallis	H = 12.191; d.f. = 4; p < 0.05
	Post-hoc pair-wise differences: Dunn's Test	No significant differences between pairs
Organic matter in summer	1-way Kruskal Wallis	H = 27.884; d.f. = 4; p < 0.001
	Post-hoc pair-wise differences: Dunn's Test (only significant results)	A vs B (Q = 4.086) B vs C (Q = 3.581) B vs E (Q = 4.568)

hydroperiod categorisation was based on water levels **within** the channel. The wetness of the channel bank topsoil sampling points, taken from bank plant communities, was not necessarily linked to the water levels within the channel. In the case of the seeps, the hydroperiod categorisation was based on the level of groundwater as measured in the piezometers installed at each of the sites. These measurements, as has been discussed previously, do not necessarily reflect the levels of moisture retained in the surface layers of the seeps.

The lack of a clear match between hydroperiod categorisation and the topsoil moisture results is an important finding. It suggests, firstly, that factors other than groundwater level or in-channel water level might be responsible for surface moisture patterns. Secondly, the soil moisture data reflect measurements taken over the whole site, and it was very clear from field observations that topsoil

Table 5.4. **ANOVA and Kruskal-Wallis results table for differences in soil moisture and organic matter in ecochannel topsoil. Significant differences are presented in red text.**

Comparison	Test	Result
Between TSAs		
Soil moisture in winter/spring	1-way ANOVA	$p < 0.05$
Soil moisture in summer	1-way Kruskal Wallis Post-hoc pair-wise differences: Dunn's Test (only significant results)	H = 16.398; d.f. = 6; $p < 0.05$ K vs V3 (Q = 3.745)
Organic matter in winter/spring	1-way Kruskal Wallis Post-hoc pair-wise differences: Dunn's Test (only significant results)	H = 27.748; $p < 0.001$ K vs W7 (Q = 4.53) K vs T4 (Q = 4.376) K vs T6 (Q = 3.783)
Organic matter in summer	1-way Kruskal Wallis Post-hoc pair-wise differences: Dunn's Test (only significant results)	H = 24.145; $p < 0.001$ K vs W7 (Q = 4.697)
Between hydroperiod categories		
Soil moisture in winter/spring	1-way ANOVA	$p > 0.05$
Soil moisture in summer	1-way Kruskal Wallis Post-hoc pair-wise differences: Dunn's Test	H = 12.8; d.f. = 3; $p = 0.005$ No significant differences between pairs
Organic matter in winter/spring	1-way Kruskal Wallis Post-hoc pair-wise differences: Dunn's Test (only significant results)	H = 18.817; d.f. = 3; $p < 0.001$ A vs C (Q = 3.764) B vs C (Q = 3.315) D vs C (Q = 2.874)
Organic matter in summer	1-way Kruskal Wallis Post-hoc pair-wise differences: Dunn's Test (only significant results)	H = 27.884; d.f. = 4; $p < 0.001$ A vs B (Q = 4.086) B vs C (Q = 3.581) B vs E (Q = 4.568)

moisture varied substantially over each site. This variability does not appear to be necessarily influenced by the source of water for the seep or channel site (e.g. rainfall *versus* groundwater), but may well be the most important feature driving the functioning and composition of biological assemblages. Furthermore, organic matter content may well be a critical determinant of surface moisture patterns.

Lastly, it must be noted that comparison of the % soil moisture between sites may produce spurious results, as this variable is strongly influenced by the nature of the soils. For instance, sandy soils will uniformly hold less water than fine silty soils. While it is acceptable to compare the same soils over time, it is inadvisable to compare across sites.

As mentioned, organic matter is not expected to show any seasonal variation, and this was borne out by the data.

Analysis of the soil moisture data from soils collected at all of the algal sampling points in September 2009 and March 2010 produced a useful result. As mentioned above, the data were not compared between sites, but rather between seasons by looking at the % difference between soil moisture measured in the soils collected from ecoseeps in September *versus* March (Figure 5.23). There is a clear increase in the % difference in soil moisture from category A soils through to category D soils, with a slight decrease to category E soils. Specifically, category A soils were found to be significantly different to all other categories. This trend confirms the categorisation of the ecoseeps according to hydroperiod – fluctuations in soil moisture across the perennially wet ecoseeps are less than those in ecoseeps that dry out either for a season or longer.

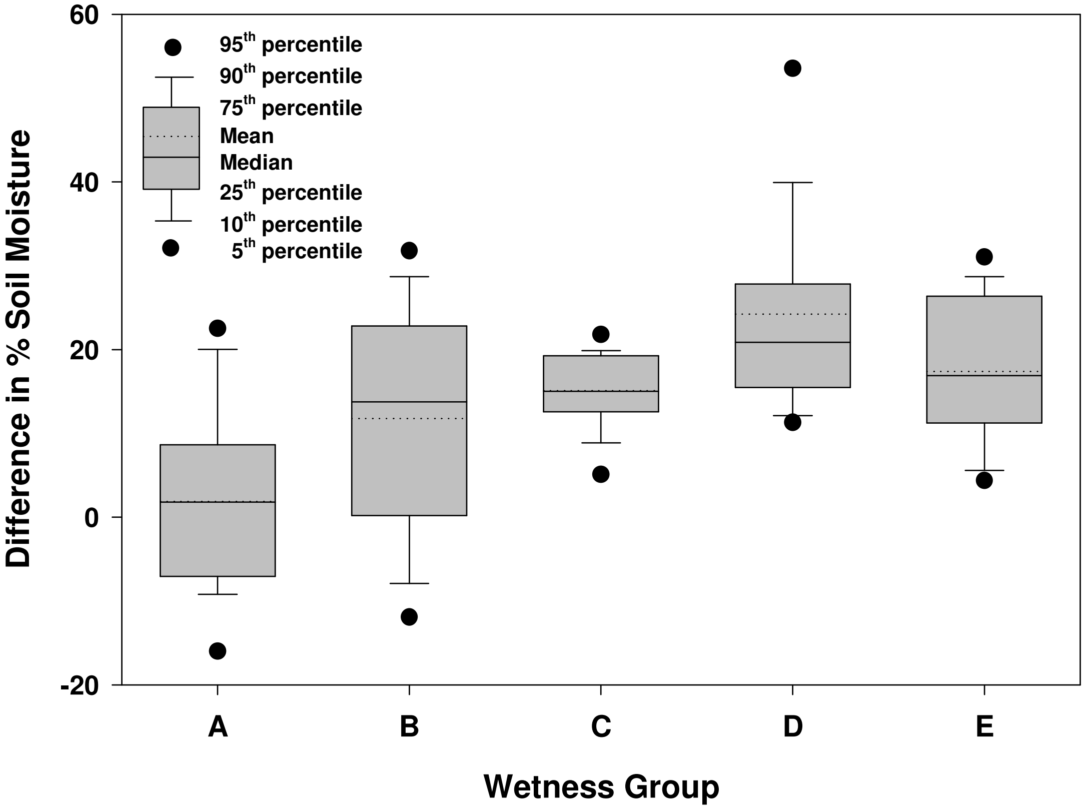

Figure 5.23. **Box and whisker plots of the % difference in soil moisture in ecoseep topsoil collected in September 2009 and March 2010 from the algal sampling points, per hydroperiod categories.**

5.3.2 Soil profile analysis of soil moisture and soil saturation at five selected ecological monitoring sites

Methods

Soil moisture was measured at eight of the ecological monitoring sites: Villiersdorp (B1_1), Steenbras (H8_3b), Kogelberg (K_2b), Palmiet (Nuweberg) (T4_Pal2), Riviersonderend (Nuweberg) (T4_RSE4b), Boesmanskloof (T6_1b), Purgatory (T8_1b) and Wemmershoek (W7_5). Measurements were made at five different points (access tubes) per site, installed along transects as illustrated in Figure 5.24.

Probe 1 was placed outside the wetland, while Probe 2 was always installed just outside of the upslope edge of the wetland. Probes 3 and 4 were generally installed midway between the upslope and downslope edges, while Probe 5 was installed at the downslope edge of the wetland/seep, often on the bank of a nearby stream or river. The locations of the soil moisture probes were not necessarily close to the algal and invertebrate sampling points, and sometimes were some distance away from them.

Moisture was measured with a Diviner 2000 capacitance probe, from SENTEK environmental innovations, Australia. The instrument consists of a small data logger connected to a probe, which is inserted into a 52 mm (inside diameter) PVC access tube. Measurements were taken at every 100 mm, as the instrument was lowered into the access tube. Three readings were taken as replicates at each access tube, so the volumetric soil moisture readings (% $m^3.m^{-3}$) represent the average moisture for every 100 mm in depth. Every access tube was installed by augering a hole of a slightly smaller diameter than the access tube, as deep as possible, or at least up to 1000 mm. The 52 mm diameter access tube was then pressed into the soil to fit as tightly as possible, with a length of 100 mm protruding from the soil. All the access tubes were closed at the bottom with a PVC stopper and at the top with a cap.

The positions of the probes were recorded using a Garmin Quest GPS, and these are shown on the site maps presented in Volume B: Appendix 2. The access tubes at five sites (B1_1, H8_3b, K_2b, T8_1b and W7_5) were installed during October 2008 and the first readings were taken at the beginning of November 2008.

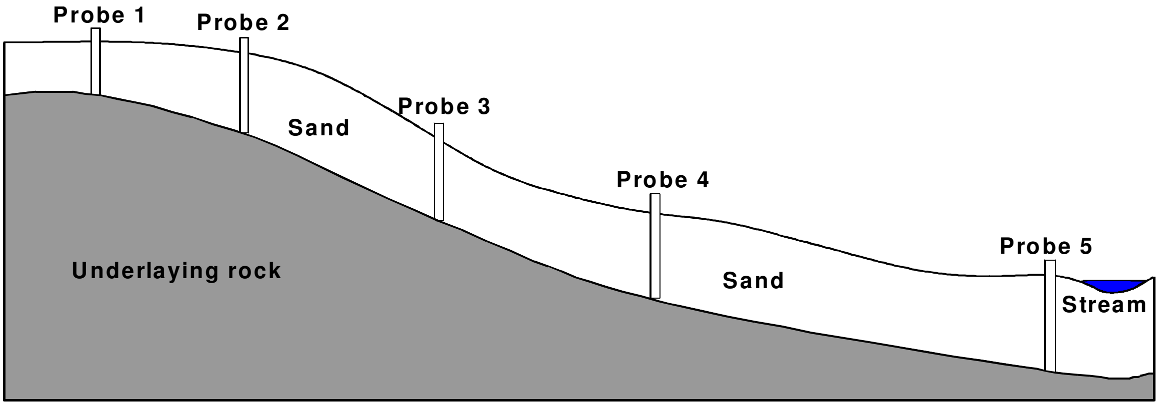

Figure 5.24. Schematic cross-section of an ecological monitoring site, showing the placement of the five soil moisture access tubes. Vertical scale is enhanced.

Three more sites (T4_Pal2, T4_RSE4b and T6_1b) were added in April 2009, and readings commenced shortly thereafter. The instrument was calibrated for the specific soil conditions encountered during installation of the access tubes. Soil moisture readings were taken monthly up to April 2009, thereafter on a two weekly basis. The data were used to plot the variations in average moisture at each depth, over one year.

The degree of saturation for each depth layer was determined from the soil moisture dataset collected at each access tube, on each occasion. These data were used to calculate the degree of saturation (s-value) (Hillel, 1980) using the following equation:

$$s = \Theta/\Theta_s$$

where Θ = average volumetric moisture content of the layer ($m^3.m^{-3}$)

Θ_s = saturated volumetric moisture content of the layer ($m^3.m^{-3}$)

During the winter months, saturated volumetric pressure readings were taken at the measuring points where the soil profile was visually saturated. The variation in the degree of saturation was plotted for the period November 2008 to May 2010 at each depth. An s-value of 0.9 was taken as saturation point for the coarse sandy material present at all the sites. This is higher than values for wetland soils of the interior, mainly because of the very coarse sandy material found in the TMG sandstones. An s-value of 0.7 was assumed to be the point above which a soil is considered to be wet.

The degree of saturation of the topsoil (0 - 30 cm, and a total for < 50 cm) was compared with the level of the water table (i.e. the piezometer readings) and linear regression equations were determined. The assumption was that a good correlation between saturation in the topsoil and the behaviour of the water table is an indication of dependence on subsurface flow, as opposed to surface runoff from rainfall.

Results

i) Soil moisture and degree of saturation

Soil moisture values differed considerably within sites, from site to site, and between different depth layers, and did not give a clear indication of whether the soils were saturated. Water storage capacities of soils are influenced by soil properties such as organic matter, clay, sand and gravel content. The sandy soils that originate from TMG sandstones will drain to a value below 0.9 (saturation value, see above) within a few hours after a rainfall event, if they are not groundwater-fed. Soil in the vadose zone (unsaturated zone above the water table) that is in contact with the water table will have an s-value of 0.9. The saturation values for the soils, especially of the topsoil (i.e. the top 30cm) provided a slightly more meaningful picture in terms of the length of time during which the wetland soils could be categorised as saturated *versus* unsaturated, and how this varied with time. It is the saturation, rather than wetness, of wetland soils that has a major influence over soil chemistry (see Section 5.3.1), nutrient uptake, morphology (e.g. Collins 2005), and the species of plants, algae and invertebrates that can inhabit the wetland.

The saturation data are presented below, while the graphs of soil moisture (using data up to November 2009) are presented in Volume B: Appendix 7.

Fluctuations in the degree of saturation of the soils at the Villiersdorp site (B1_1) from November 2008 to end of April 2010 are illustrated in Figure 5.25. The degree of saturation of the topsoil (no subsoil data were collected at B1_1-1 due to inability to access these layers) at B1_1-1 and B1_1-2 (Probes 1 and 2 in Figure 5.24) showed a normal drying cycle, with soil moisture declining until the end of April 2009, and re-wetting during the winter rainfall season to reach saturation July 2009, then drying again into 2010. At these points, the topsoil drained quickly, remaining saturated for less than one month (Figure 5.25). The subsoil at B1_1-2 showed a similar pattern – remaining low until May 2009, after which the subsoil showed a sharp increase in saturation values, and then a fairly rapid decrease towards October 2009. This was probably due to rainfall, and a temporary accumulation of this water in the deeper soil layers (down to a maximum of 70 cm). This water flowed as subsurface flow downhill away from B1_1-2, feeding into the seep itself (see below). The rapid response of the soil saturation values (s-values) at B1_1-1 and B1_1-2 to rainfall indicates the influence of rainfall as opposed to subsurface water flow. The soil at these two points was seasonally to intermittently saturated in the top- and subsoil.

The degree of saturation at access tubes B1_1-3 and B1_1-5 showed seasonal variation in the topsoil but not in the subsoil. The variation in s-values in the topsoil matched the variations in the depth of the water table (Piezometer graph) (Figure 5.25). Soil moisture remained constant in the subsoil (deeper than 40 cm) at B1_1-3, B1_1-4 and B1_1-5, and was at the estimated saturated moisture level for this soil (Figure 5.25). The soil at B1_1-4 remained saturated in the top- and subsoil throughout the year. The subsoil at B1_1-5 dried to below saturation point over the drier summer of 2010. The lack of fluctuation in soil saturation, primarily in the subsoil, indicates that the seep is fed by fairly constant subsurface flow at these three points, which may originate as groundwater, as suggested in Chapters 2 (Table 2.5) and 3 (Table 3.3). The lower three sampling points were perennially to seasonally saturated in the topsoil and perennially saturated in the subsoil. This matches the placing of B1_1 in the category A for hydroperiod (Chapter 3), with a high probability of a strong connection with either the Nardouw or Peninsula Aquifers. The soil moisture probes cannot measure surface inundation.

The degree of saturation of the top- and subsoil at access tubes H8_3b-1 and H8_3b-2 at the Steenbras site varied considerably, in accordance with rainfall (Figure 5.26). These two access tubes were situated outside and at the edge of the seep respectively, are clearly rainfall dependent, and can be categorised as seasonally to intermittently saturated in the topsoil and seasonally to intermittently saturated in the subsoil. Soil moisture in the top- and subsoil at access tube H8_3b-3 remained at or near saturation throughout the year. This point is closest to the piezometer at this site, and this perennial saturation is matched by the data from the piezometer, and the categorisation of the seep, as a whole, in hydroperiod category A. The sharp decline in degree of saturation at H8_3b-4 in the top 10 cm during December 2008 and January 2009 (Figure 5.26) was probably due to evaporation after the wetland burned in January 2009. The s-values for the subsoil at H8_3b-4 and the top- and subsoil at H8_3b-5 remained at 0.9 throughout the year. It seems that while H8_3b-1 and H8_3b-2 are rainfall dependent, the rest of the points are influenced by a fairly constant subsurface flow, which could be groundwater. The soil at these points was perennially saturated in the top- and subsoil, which does suggest a high probability of connectivity with groundwater (see also Table 3.3).

Variations in saturation of the top- and subsoil were similar at all measuring points at the Kogelberg site (Figure 5.27). S-values declined until the end of April 2009 as the soil dried out, and then increased sharply with the first rainfall of winter, in both the top- and subsoil at all access tubes, and remaining at or near saturation, with some variation, through winter before drying again. The highly variable saturation of the soils at all of the measuring points indicates that they may be influenced primarily by rainfall. The behaviour of the top- and subsoil at K_2b supports the categorisation of this ecoseep as a seasonally saturated, seasonally inundated seep – category C. Connectivity with groundwater is likely to be moderate, possibly only seasonal (see also Table 3.3).

The degree of saturation of the top- and subsoil at measuring points T4_Pal2-1, T4_Pal2-2 and T4_Pal2-5 at the Palmiet (Nuweberg) site appeared to be rainfall dependent, as shown by the sharp increases in saturation during the winter rainfall season (Figure 5.28). This matches the behaviour of the water table, which also appears to be influenced primarily by rainfall, with weak connectivity to groundwater sources (Table 3.3). The saturation profile at T4_Pal2-2 showed the fastest response to rewetting due to rainfall or drying out (Figure 5.28). At T4_Pal2-5 (lowest position in the wetland) the water that flowed laterally through the soil towards this point was responsible for the increase in the degree of saturation in soil layers deeper than 30 cm, especially after the November 2008 rainfall. Saturation at this measuring point decreased for the rest of the period, an indication that water flowed out of the wetland and into the Palmiet River, and was not retained at this lowest point in the wetland. This point sits on an elevated alluvial (i.e. well draining) floodplain terrace. Saturation of the topsoil at T4_Pal2-3 (placed next to the piezometer) and T4_Pal2-4 fluctuated in accordance with the piezometer readings (Figure 5.28). The topsoil at these two sampling points remained saturated after the winter rainfall, which may just be the result of water accumulating within the Palmiet River valley floor and being retained by the organic-rich soils of this valley-bottom wetland.

The degree of saturation of the topsoil at all of the access tubes at the Riviersonderend site (measured only from April 2009) fluctuated on a clearly seasonal basis, responding closely to rainfall in this catchment (Figure 5.29). Access to the deeper subsoil layers was only achieved at T4_RSE4b-

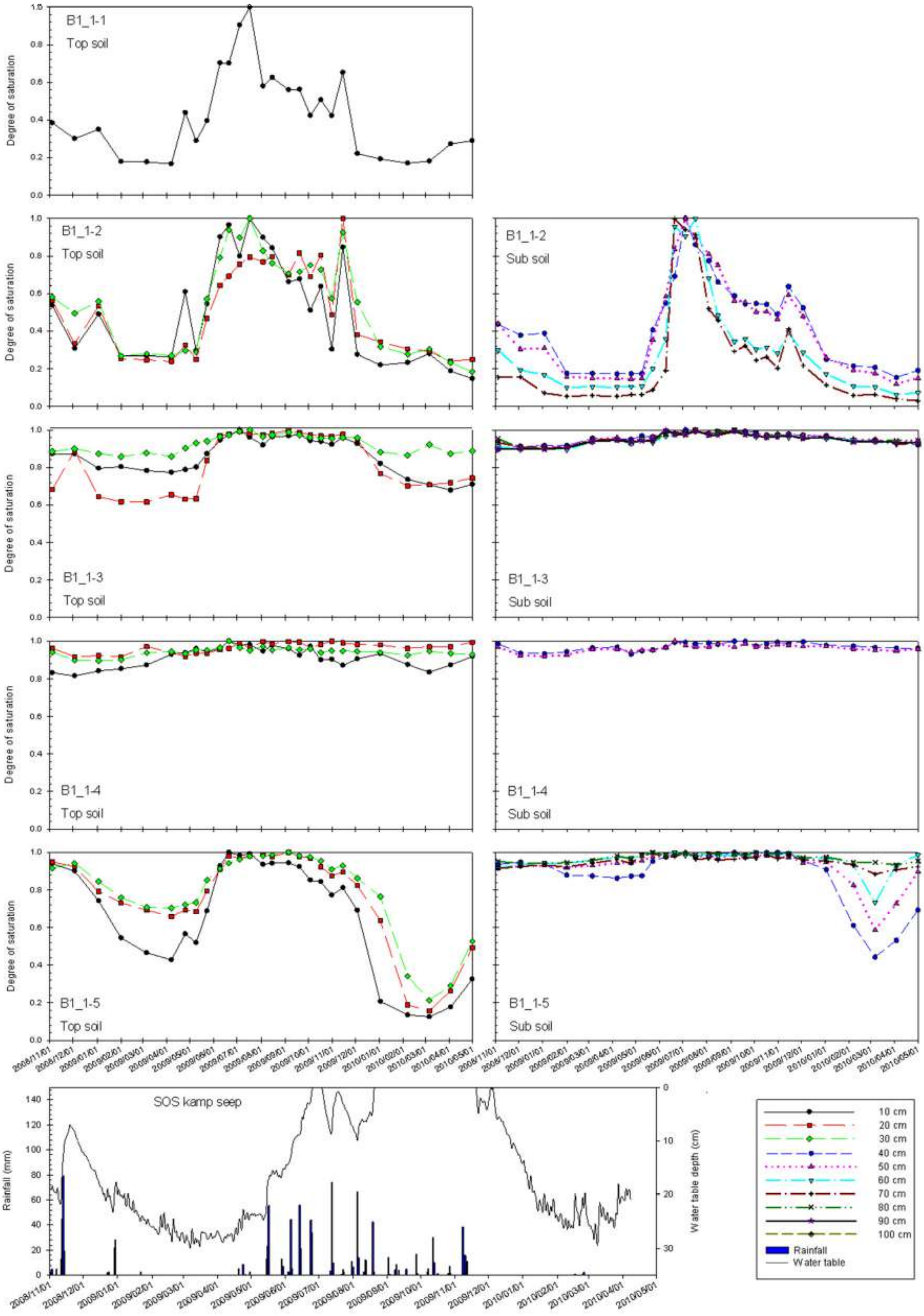

Figure 5.25. **Saturation values for the top- and subsoil depth layers, rainfall and the depth of the water table at the Villiersdorp (B1_1) site.**

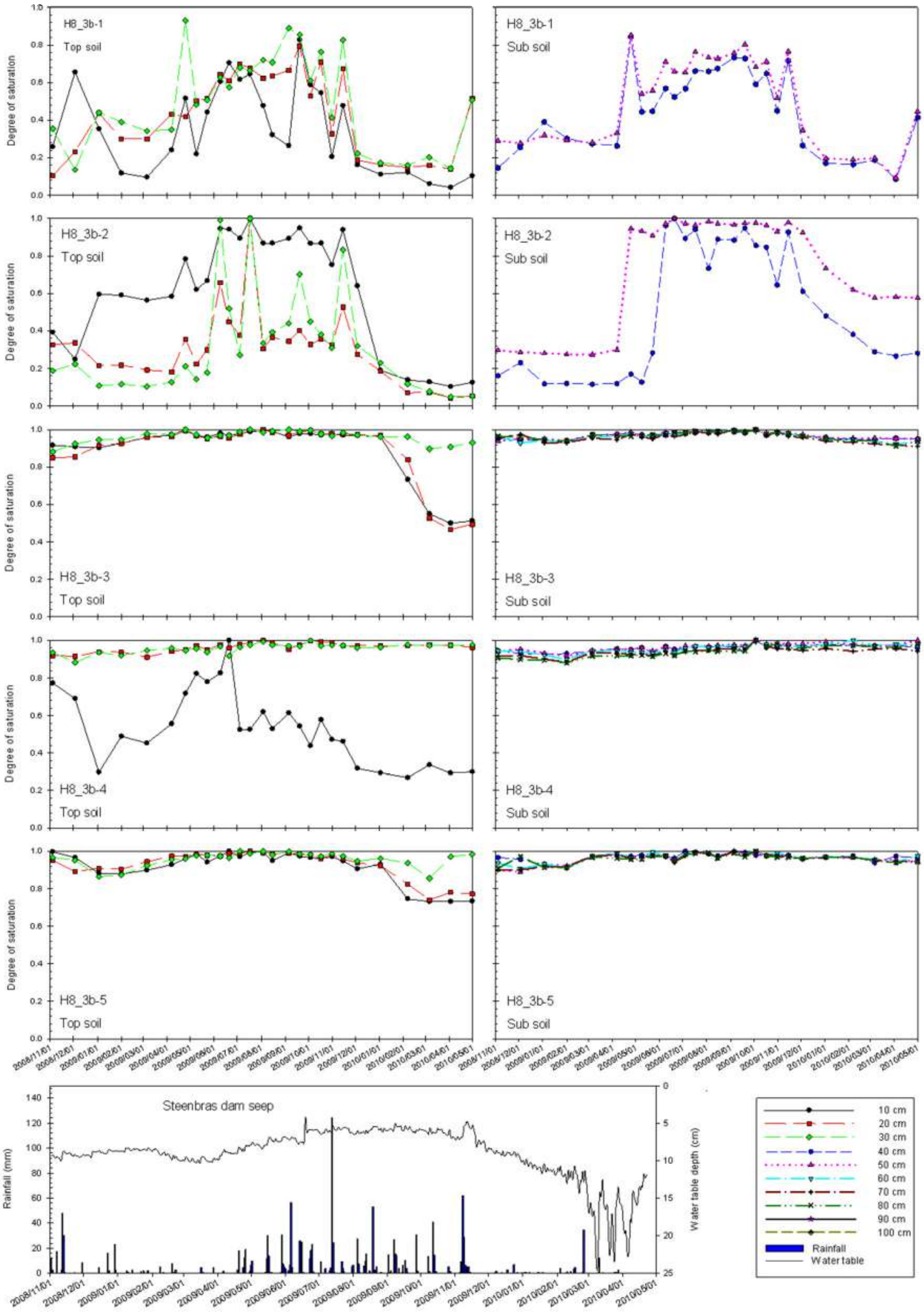

Figure 5.26. **Saturation values for the top- and subsoil depth layers, rainfall and the depth of the water table at the Steenbras (H8_3b) site.**

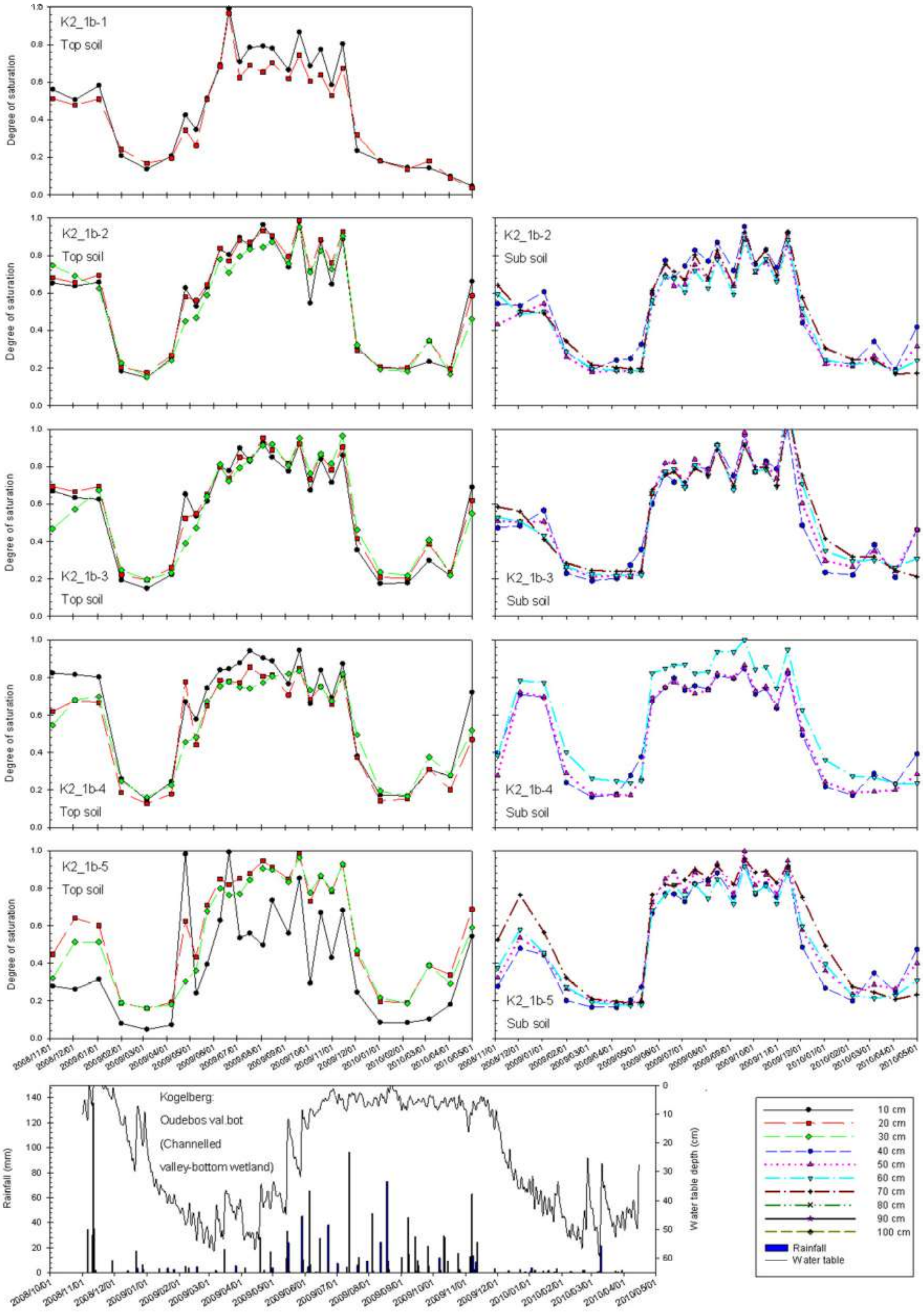

Figure 5.27. **Saturation values for the top- and subsoil depth layers, rainfall and the depth of the water table at the Kogelberg (K_2b) site.**

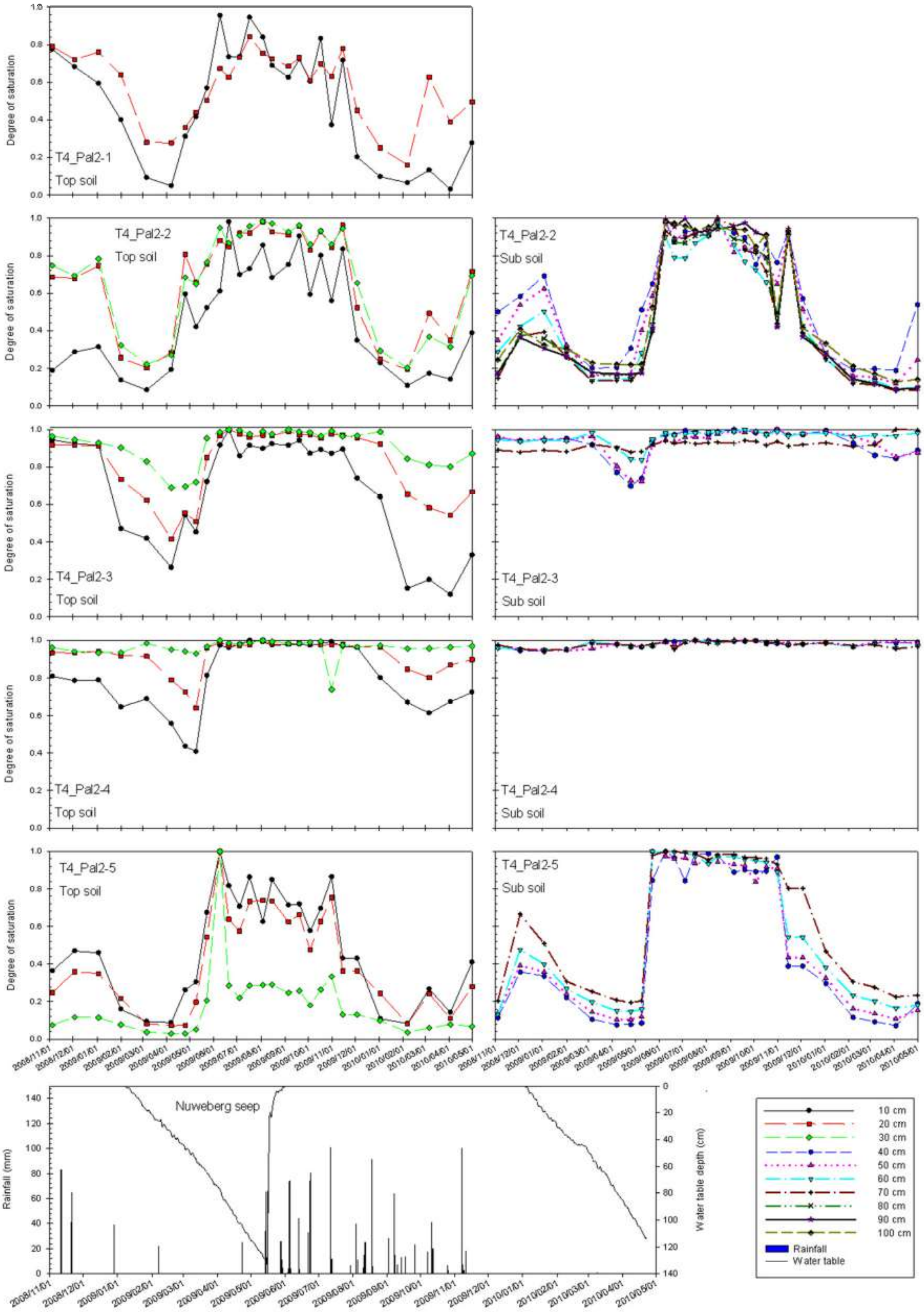

Figure 5.28. **Saturation values for the top- and subsoil depth layers, rainfall and the depth of the water table at the Palmiet (Nuweberg) (T4_Pal2) site.**

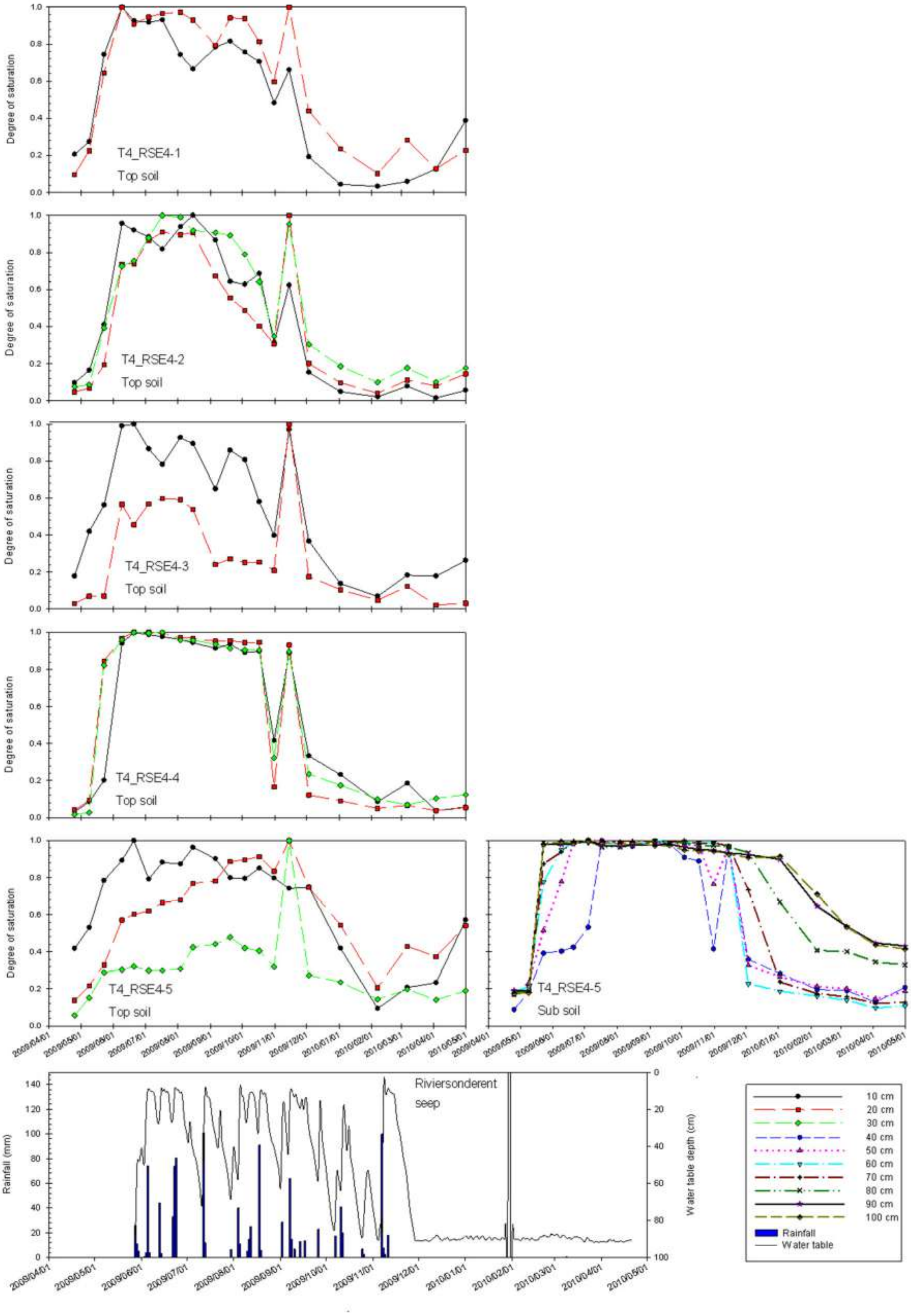

Figure 5.29. **Saturation values for the top- and subsoil depth layers, rainfall and the depth of the water table at the Riviersonderend (Nuweberg) (T4_RSE4b) site.**

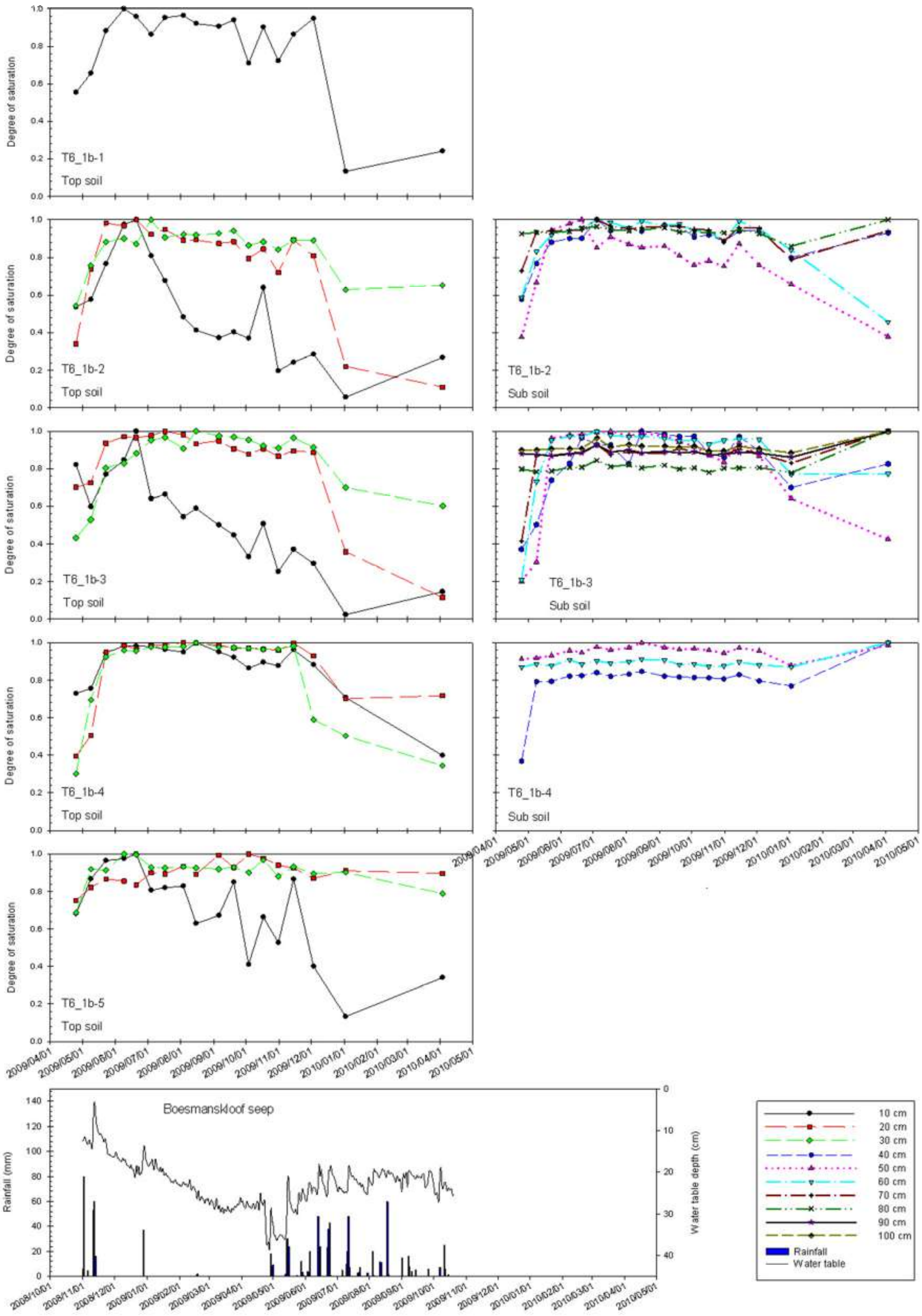

Figure 5.30. **Saturation values for the top- and subsoil depth layers, rainfall and the depth of the water table at the Boesmanskloof (T6_1b) site.**

5, so there were insufficient data to make clear conclusions at this site. The degree of saturation of the topsoils at T4_RSE4b-1, T4_RSE4b-2 and T4_RSE4b-3 appears to be rainfall dependent, while that at T4_RSE4b-4 and T4_RSE4b-5 appears to be influenced by the subsurface flow of water probably from positions higher in the landscape.

The degree of saturation of the topsoil at measuring points T6_1b-1 and T6_1b-2 at the Boesmanskloof (T6_1b) site showed an increase from end April to June 2009 (Figure 5.30). This appeared to be due mainly to rainfall. From July to October 2009, variations in saturation of the topsoil at these two points were due mainly to rainfall and evapotranspiration. The degree of saturation of the subsoil at T6_1b-2, however, remained fairly constantly close to saturation. Saturation of the topsoil at T6_1b-3, T6_1b-4 and T6_1b-5 remained high from the beginning of June 2009 through to December 2009/January 2010 (Figure 5.30). The degree of saturation at these three points is probably not rainfall dependent, and the constancy of saturation is an indication of the influence of groundwater at these points. All of the measuring points were seasonally saturated in the topsoil, and the subsoils varied from perennially to seasonally saturated, matching the categorisation of this ecoseep as a category A seep (Table 3.3).

Topsoil at T8_1b-2 and T8_1b-2 (Purgatory) reached saturation point intermittently and for a brief period (less than two months) during June and July 2009 and again in November 2009 after rainfall (Figure 5.31). The topsoil at these two points responded fairly closely to rainfall. The topsoil and subsoil at measuring points T8_1b-3, T8_1b-4 and T8_1b-5 remained near saturation from June 2009 through to at least February 2010. T8_1b-3 was seasonally saturated in both the top- and subsoil, and T8_1b-4 and T8-1b-5 were perennially saturated. The degree and consistency of saturation at these three sampling points indicate the strong influence of subsurface flow, which may be groundwater (most likely the Nardouw Aquifer) as suggested in Table 3.3. The degree of saturation of the topsoil at T8_1b-3, the measuring point closest to the Piezometer, correlated well with the depth of the water table.

The changes in degree of saturation at the Wemmershoek (W7_5) site are illustrated in Figure 5.32. Saturation at all of the soil moisture sampling points fluctuated on a clearly seasonal basis, with the three lowest points in the ecoseep remaining saturated almost continuously from June to December 2009. These data correspond with the hydroperiod category – category C – assigned to this ecoseep (Table 3.3). The exception was W7_5-5, where the top- and subsoil remained wet or saturated throughout the year (Figure 5.32). W7_5-1, W7_5-2 and W7_5-3 showed the greatest fluctuations over the period of investigation, which may be due to the fact that the steep upper end of this wetland is on a well-draining scree (Volume B: Appendix 3). The degree of saturation at access tubes W7_5-4 and W7_5-5 fluctuated seasonally in the top 60 cm, while the deeper soils remained close to saturation. These latter two sites are probably fed by subsurface flow at the deeper levels, which may originate as groundwater, but is also likely to be subsurface flow of water flowing from the higher measuring positions. The seasonal fluctuations in soil saturation are an indication of, at most, a weak connectivity with groundwater, as indicated in Table 3.3.

It can be seen that the soil moisture of measuring positions outside and on the upslope edge of the wetlands/seeps (Probes 1 and 2 in Figure 5.24) are all strongly influenced by rainfall – i.e. soil moisture fluctuates fairly widely, in response primarily to rainfall, and are generally intermittently to seasonally saturated (Table 5.5). In order to gain an understanding of the dominant supply and flow of water into and through a wetland, it is more useful to examine the data from measuring points in the wetland itself and below it, i.e. Probes 3, 4 and 5. However, it is important to collect data from at least one point outside of and upslope from each wetland, as this allows a comparison with soil water dynamics outside of the wetland. The design of the future monitoring phase needs to take this into account.

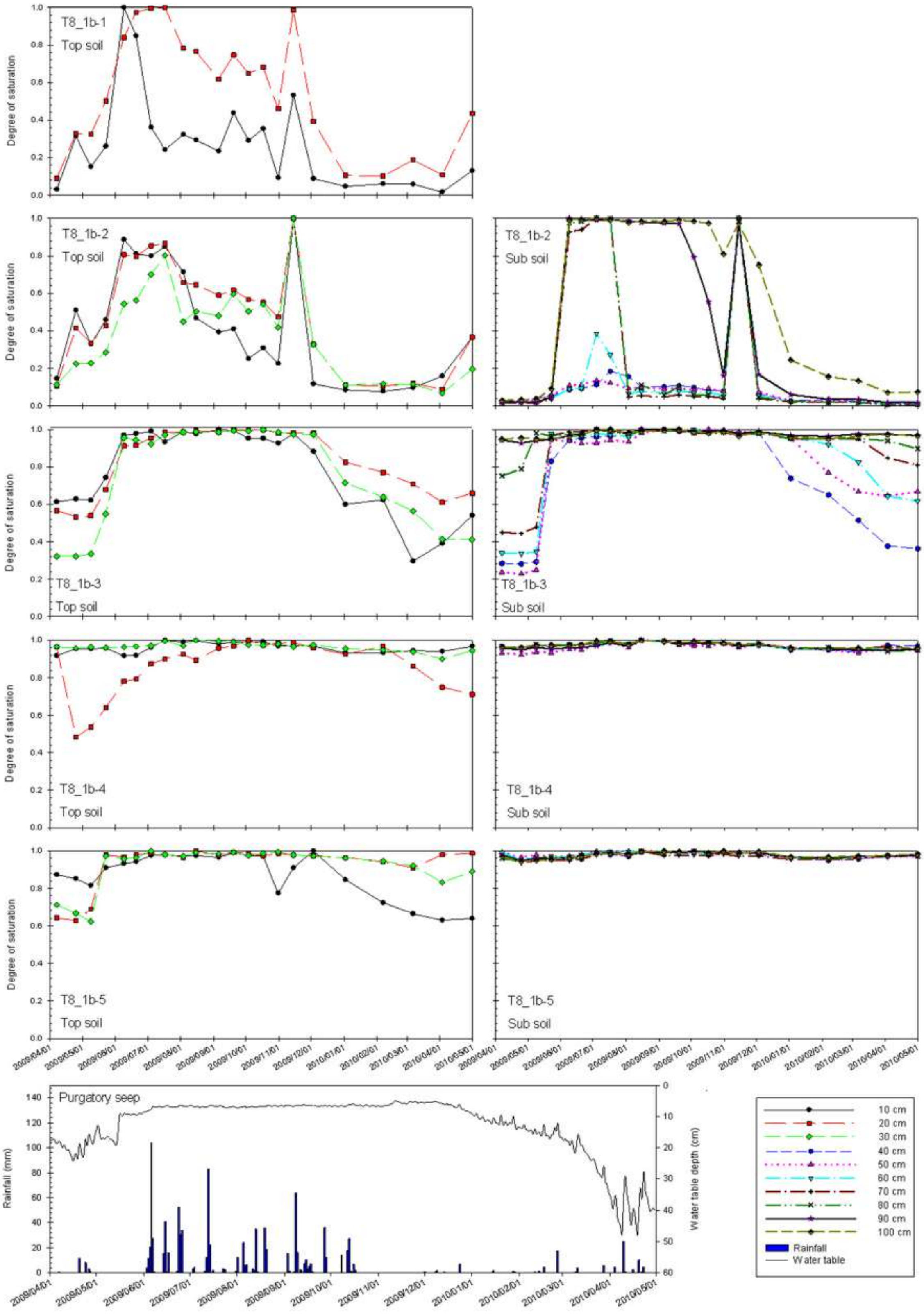

Figure 5.31. **Saturation values for the top- and subsoil depth layers, rainfall and the depth of the water table at the Purgatory (T8_1b) site.**

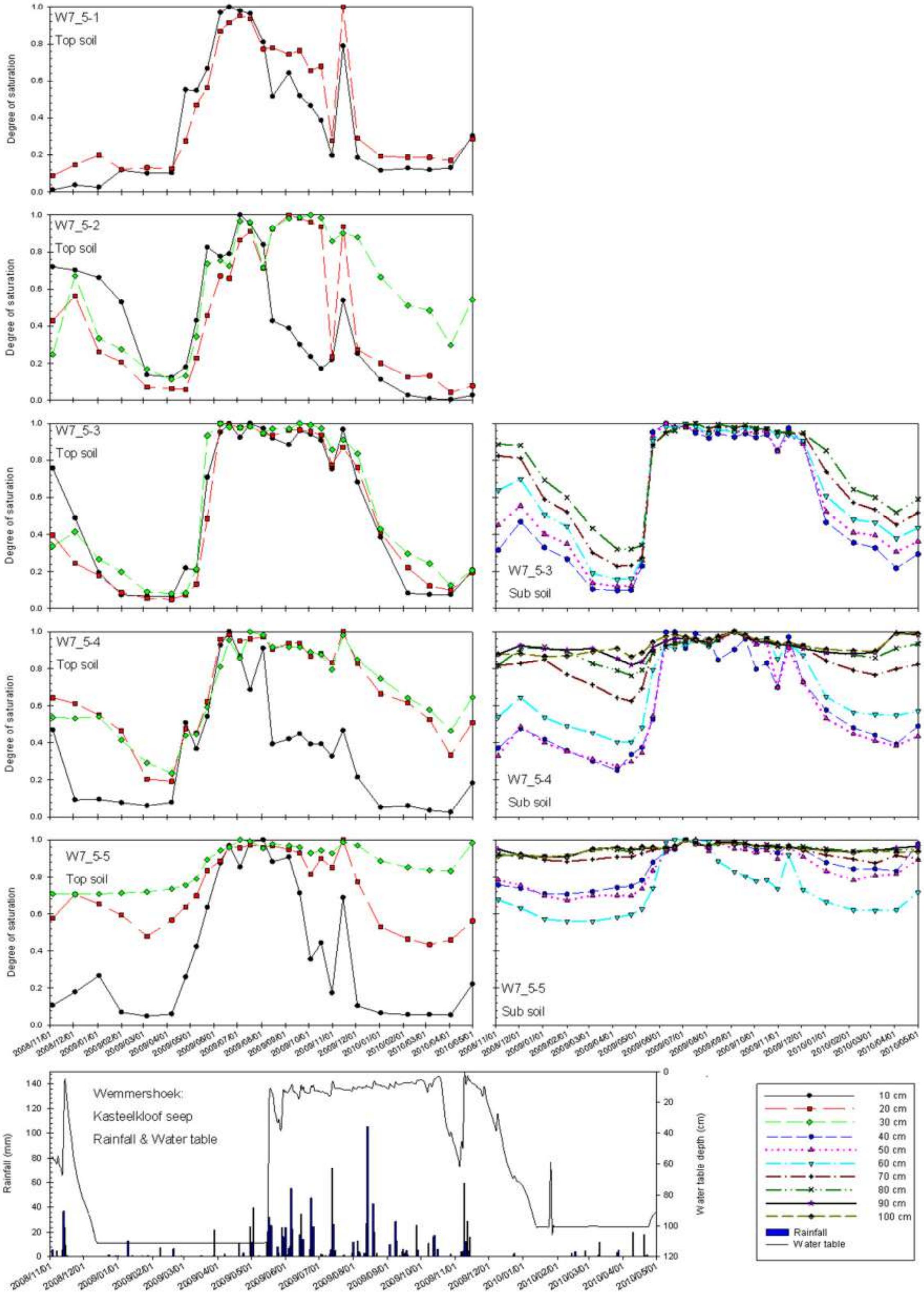

Figure 5.32. Saturation values for the top- and subsoil depth layers, rainfall and the depth of the water table at the Wemmershoek (W7_5) site

Table 5.5 **Summary of results for soil saturation of the topsoil and subsoil at the five measuring points over the project period. No data (-) where subsoil was inaccessible. Saturation value = 0.9. Hydroperiod and strength of connectivity for the whole ecoseep taken from Chapter 3, and recorded opposite the soil moisture sampling point closest to the ecoseep piezometer.**

Access tube	Topsoil (0 – 30 cm) saturation	Subsoil (> 30 cm) saturation	Hydroperiod (Chapter 3)	Proposed strength of connectivity (Chapter 3)
B1_1-1	intermittent	-		
B1_1-2	seasonal	intermittent		
B1_1-3	perennial	perennial	A	strong
B1_1-4	perennial	perennial		
B1_1-5	seasonal	perennial		
H8_3b-1	intermittent	intermittent		
H8_3b-2	seasonal	seasonal		
H8_3b-3	perennial	perennial		
H8_3b-4	perennial	perennial	A	strong
H8_3b-5	perennial	perennial		
K_2b-1	intermittent	-		
K_2b-2	seasonal	seasonal		
K_2b-3	seasonal	seasonal		
K_2b-4	seasonal	seasonal	C	moderate
K_2b-5	seasonal	seasonal		
T4_Pal2-1	intermittent	-		
T4_Pal2-2	seasonal	seasonal		
T4_Pal2-3	seasonal	perennial	C	weak
T4_Pal2-4	perennial	perennial		
T4_Pal2-5	intermittent	seasonal		
T4_RSE4b-1	seasonal	-		
T4_RSE4b-2	seasonal	-		
T4_RSE4b-3	intermittent	-	E	none
T4_RSE4b-4	seasonal	-		
T4_RSE4b-5	seasonal	seasonal		
T6_1b-1	seasonal	-		
T6_1b-2	seasonal	seasonal		
T6_1b-3	seasonal	seasonal	A	strong
T6_1b-4	seasonal	perennial		
T6_1b-5	seasonal	-		
T8_1b-1	intermittent	-		
T8_1b-2	intermittent	seasonal		
T8_1b-3	seasonal	perennial	B	strong
T8_1b-4	perennial	perennial		
T8_1b-5	perennial	perennial		
W7_5-1	intermittent	-		
W7_5-2	seasonal	-		
W7_5-3	seasonal	seasonal	C	weak
W7_5-4	seasonal	seasonal		
W7_5-5	seasonal	perennial		

It is not possible to ascertain groundwater *dependency* using this method. However, the behaviour of the soil moisture, and specifically soil saturation, in the topsoil and the subsoil, and how this fluctuates at the different soil depths, do give an indication of whether the wetland is fed primarily by rainfall, or by subsurface flow, which *may* be groundwater flow. There is strong agreement between the saturation of the top- and subsoil at the ecoseeps and the proposed "strength" of connectivity between the ecoseeps and groundwater resources (Table 3.3) (Table 5.5). Ecoseeps that were found to be perennially saturated, especially in the topsoil, are the ones most likely to have strong connectivity with groundwater.

iii) Relationship between soil saturation, the water table and rainfall

The component of the subsurface flow that can be attributed to groundwater can be ascertained by looking at the relationship between soil saturation, the water table and rainfall. It is probable that a close correlation between soil saturation and the water table is an indication of the influence of groundwater, whereas a weak correlation with the water table and a strong correlation with rainfall would indicate the predominance of rainfall as a driver of soil saturation.

Soil saturation in the top- and subsoil at B1_1-3 correlated strongly with the depth of the water table, while the water table had a moderate correlation with rainfall (Table 5.6). This site is located on Cedarberg shale (Table 2.5 and Volume B: Appendix 3), and the water table remains shallow at this site all year round (Figure 3.3). This seep is located fairly close to a fault that connects the site laterally with the Skurweberg Formation and vertically with the Peninsula Formation, so the likelihood of this seep being fed by groundwater is high, which could come from either the Nardouw or Peninsula Aquifers, or both. In summer, the water table would be expected to drop, as a result of evaporation and evapotranspiration. This did not occur, and soil moisture remained high – at or close to saturation (Figure 5.25) – in the top- and subsoils at the lower measuring points throughout the year. While this does point towards the strong influence of groundwater, it is also possible that the high organic content at this site leads to the retention of moisture in the soils, especially during the summer months. Water sitting in the deeper soil layers moves up through the soil profile as a result of capillary action. Soil saturation at this site might be attributable to both groundwater and the retention of rainfall.

H8_3b is located on the Rietvlei Formation, the uppermost band of the formation of the TMG (see Table 2.5), which consists of sandstone with minor shale. The water table remains shallow at this site, and the top- and subsoils at the lower measuring points remain at or close to saturation (Figure 5.26). Water table depth did not correlate strongly with rainfall, but there was a moderate correlation between soil saturation in the upper layers and the depth of the water table (Table 5.6), indicating a moderate likelihood of connectivity with groundwater. This site may be fed by groundwater from the Rietvlei Formation (Nardouw Aquifer) or from nearby faults up and down the slope from the seep (Volume B: Appendix 3).

The soil saturation at K_2b-4 correlated strongly with the depth of the water table, and the water table at this site had a moderate to weak relationship with rainfall (Table 5.6). These results suggest a highly likely connectivity with groundwater, with rainfall playing a minor role. Although the sandy topsoil and profile of the seep is thought to be underlain by Cedarberg shale, it is also located on a fault that brings the Peninsula and Cedarberg formations together (Table 2.5), so it is highly likely that this wetland is fed by groundwater.

T4_Pal2 is located on the Peninsula Formation, with a direct link with the Peninsula Aquifer (Table 2.5). The Peninsula Formation consists of thick bedded quartzitic sandstone with minor shale and siltstone, and is generally a highly transmissive formation. The soil moisture in the top- and subsoils at the lower measuring points (Probes 3, 4 and 5, Figure 5.24) generally behave similarly, and are either seasonally or perennially saturated (Table 5.5; Figure 5.28). T4_Pal2-5 is an exception, but this is probably due to the location of this probe on a dry bank above the Palmiet River – water flowing past this point drains quickly into the river (see above). The water table does drop fairly low in summer (below 1 m; Figure 3.11), and the decline is slow, which may be due to the fact that water drains into this valley-bottom wetland from the surrounding seeps and slopes (valley-bottom wetlands do accumulate water from the surrounding landscape, as opposed to seeps that are characterised by the downhill seepage of water away from the wetland (SANBI 2009)). The soils at this site are of medium to coarse sand and drain well. The underlying bedrock is also transmissive and thus also "drains" well, explaining the drop in the water table when rainfall and recharge decrease, and evapotranspiration rates increase in summer. There was a weak correlation between rainfall and the water table at this site, and a strong correlation between soil saturation and the depth of the water table (Table 5.6), indicating that the likelihood of connectivity with groundwater at this site is high.

Table 5.6. Correlations between rainfall and the water table, and between soil saturation and the depth of the water table.

Site and sampling point closest to ecoseep piezometer	Correlation coefficient for rainfall *vs* water table depth	Correlation coefficients for soil saturation (total for the top 50 cm)*vs* water table depth				Correlation coefficient for soil saturation (total for the soil profile) *vs* water table depth	Probability of being fed by ground-water based on soil saturation	Likelihood of connectivity to ground-water based on geology (Chapter 2)	Hydroperiod (Chapter 3)
		10 cm	20 cm	30 cm	Top 50 cm				
B1_1-3	0.61	-0.88	-0.95	-0.87	-0.94	0.919	high	highly likely	A
H8_3b-4	0.18	-0.77	-0.72	-0.53	-0.75	0.762	moderate	highly likely	A
K_2b-4	0.49	-0.87	-0.86	-0.92	-0.92	0.925	high	highly likely	C
T4_Pal2-3	0.34	-0.77	-0.90	-0.90	-0.92	0.914	high	probable	C
T4_RSE4b-3	-	-0.89	-0.82	-	-0.89	0.642	moderate	highly likely	E
T6_1b-3	0.64	0.18	-0.30	-0.85	-0.68	0.842	high	probable	A
T8_1b-3	0.31	-0.78	-0.73	-0.77	-0.77	0.741	moderate	highly likely	B
W7_5-3	0.55	-0.38	-0.37	-0.35	-0.34	0.289	low	probable	C

There were data gaps at T4_RSE4b which precluded a useful analysis at this site. However, there did appear to be a strong correlation between the saturation of the topsoil and the depth of the water table (Table 5.6). This was not borne out in the whole soil profile, where the correlation with water table was weaker.

At T6_1b, there was a moderate correlation between rainfall and the water table, and a variable correlation between soil saturation and the water table, which strengthened with soil depth (Table 5.6). The results for this site are inconclusive. The correlation between rainfall and the depth of the water table was very weak at T8_1b, with a moderate to strong correlation between soil saturation and the water table (Table 5.6). This suggests that connectivity with the groundwater is probable at this site.

W7_5 is located on a scree slope close to the contact between the Pakhuis and Peninsula Formations (Table 2.5). The hydraulic transmissivity of scree increases the probability of connectivity with the Peninsula Aquifer. However, soil saturation at W7_5-3 correlated very weakly with the depth of the water table, which in turn correlated moderately with rainfall (Table 5.6). The saturation curves at all of the measuring points showed fairly uniform seasonal saturation (Figure 5.32), with few fluctuations once the soil became saturated in winter. This was observed in both the top- and subsoils at the lower measuring points (Table 5.5). It is most likely that this seep is fed primarily by rainfall.

5.4 SURFACE WATER PHYSICO-CHEMISTRY

5.4.1 Methods

At least three replicate measurements of pH, electrical conductivity (EC) and water temperature were taken *in situ* at all ecological monitoring sites that had sufficient surface water at the time of the field visits to take readings. Portable Crison water chemistry meters were used in the field. In addition, from May 2008 for the ecochannels and from September 2008 for the ecoseeps until March 2009, three replicate samples of clean water were collected from each site, where possible, for laboratory analysis of inorganic nitrogen, in the form of nitrates, nitrites and ammonium, and inorganic phosphorus, in the form of total inorganic phosphorus and orthophosphates, the group of phosphate ions readily available for uptake by biological organisms (Dallas and Day 2004). Although a short dataset, this was considered sufficient for the determination of the nutrient status of all monitoring sites.

Data analysis was mostly limited to univariate single factor ANOVAs, as there were too many data gaps to attempt a multivariate approach. For instance, statistical comparisons between nutrient levels in the seeps and rivers were only possible in March 2009, when the same data were collected from all sites.

5.4.2 Results and discussion of wetland water chemistry

The pH of the seeps ranged between 3.5 and 5 fairly consistently throughout the sampling period and across the study area, with no significant seasonal pattern (Figure 5.33) or differences between sites. EC was far more variable, however, and although there were no significant differences between months, between-site differences were rather marked (Figure 5.33). EC ranged between 2 and 10 mS/m, always in the range indicative of very pure water and typical of oligotrophic systems. EC tended to be lower in March 2009 in comparison with May and September 2008 (Figure 5.33). The highest EC was measured in September 2008 at K_1, while all of the Kogelberg ecoseeps, along with H6_1 at Steenbras, had higher ECs than other sites (Figure 5.33). This was consistent with the water chemistry data recorded at the hydrocensus boreholes and piezometers (Section 5.2), where elevated ECs were recorded in the springs and boreholes in the Kogelberg and Steenbras TSAs, the TSAs closest to the coast, thus suggesting a possible groundwater link with the surface ecosystems.

The values for both pH and EC are typical of unimpacted freshwater ecosystems of the Western Cape, which tend to be acidic, with low concentrations of minerals and salts. The pH of the surface water at the seep sites was consistently higher than that measured in the topsoil, where pH did not rise above 3.5 (Section 5.3.1).

Temperatures were strongly seasonal with significant differences between months ($F = 14.028$; $p < 0.001$), ranging between 8 and 30°C (Figure 5.33). Water temperatures were generally highest in March, at the end of summer, and lowest in September, at the end of winter, as would be expected.

Temperature differences between sites were not clear or consistent over time (Figure 5.33). In general the warmer seeps were B1_1, H8_3b, K_3b, T6_4 and W7_2. A possible explanation for the consistently elevated temperatures at B1_1 is that here the soils generally remain wet throughout the year (Figure 5.25) and were observed to be rich in organic matter (see Section 5.3.2). The warmer temperatures measured at B1_1 may thus be due to heat energy generated from the probably permanent chemically reducing conditions in the seep. This is despite the fact that this seep is well shaded by rooted plants, such as the dense stands of *Todea barbara* at this site. T4_Pal2, T4_RSE1 and W7_3 were the coolest of the ecoseeps, in most months (Figure 5.33).

Total inorganic nitrogen (TIN) was usually below 0.05 mg/litre in the seeps (Figure 5.34), well below the threshold value between oligotrophy and mesotrophy, which is 0.5 mg/litre (Table 5.7) (DWAF

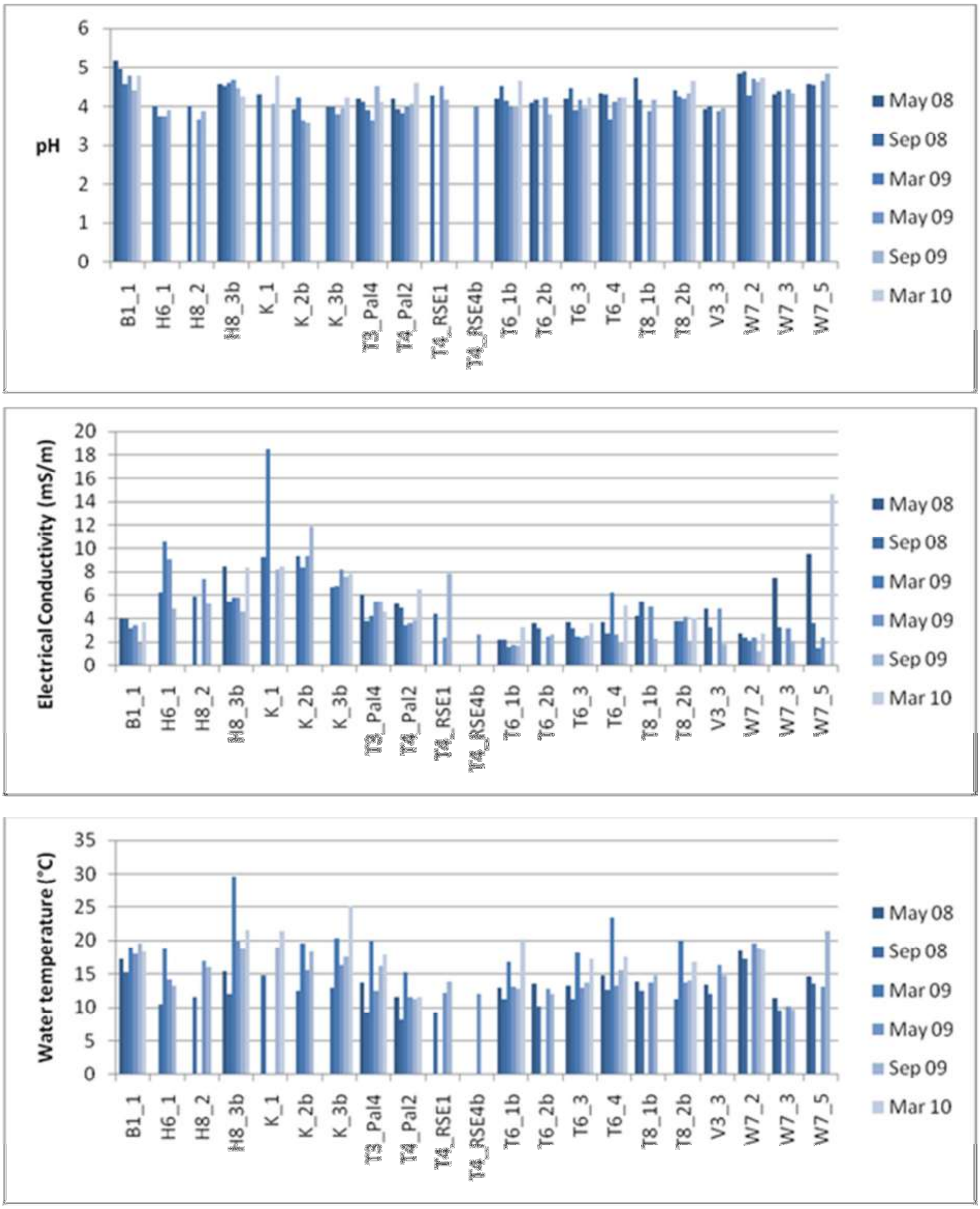

Figure 5.33. **Spot measurements of pH (top), electrical conductivity (middle) and water temperature (bottom) taken at the ecoseeps in May 2008, September 2008 and March 2009.**

1996, 2002). Values were generally highest in September, although not significantly so, where the data allowed for comparison. It is likely that nitrogen in its various forms is flushed into the wetlands from the surrounding catchment and groundwater, peaking at the end of winter, and is then taken up by plants over the spring (when soil moisture and ambient temperatures are optimal for nutrient uptake) and summer. The exceptions to this trend were T3_Pal4 and T8_2b, where nitrogen concentrations were considerably higher in March 2009. The high TIN concentration at T3_Pal4 was attributable mainly to a substantially elevated nitrate reading, which might be related to the fire of January 2009, although no concomitant elevation in phosphorus concentration was recorded at this time (Figure 5.34, bottom). The high value at T8_2b was attributable to a very high ammonium concentration. The ionised form of ammonia, ammonium (NH_4^+) is not toxic but when ammonium is present in the unionised ammonia form it is highly toxic, even at concentrations below 1 mg/litre. Given the prevailing temperature and pH at the site, only some 3% of the ammonium would be present in the unionised form, or 0.08 mg / litre, which is within the non-toxic range (DWAF 2002). Natural waters tend to have an ammonium concentration below 0.1 mg/litre, so the concentration recorded here is quite elevated, with no obvious explanation, raising the possibility of sampling error. However, the individual nitrogen compounds are analysed from separate water samples, suggesting the data are indeed valid.

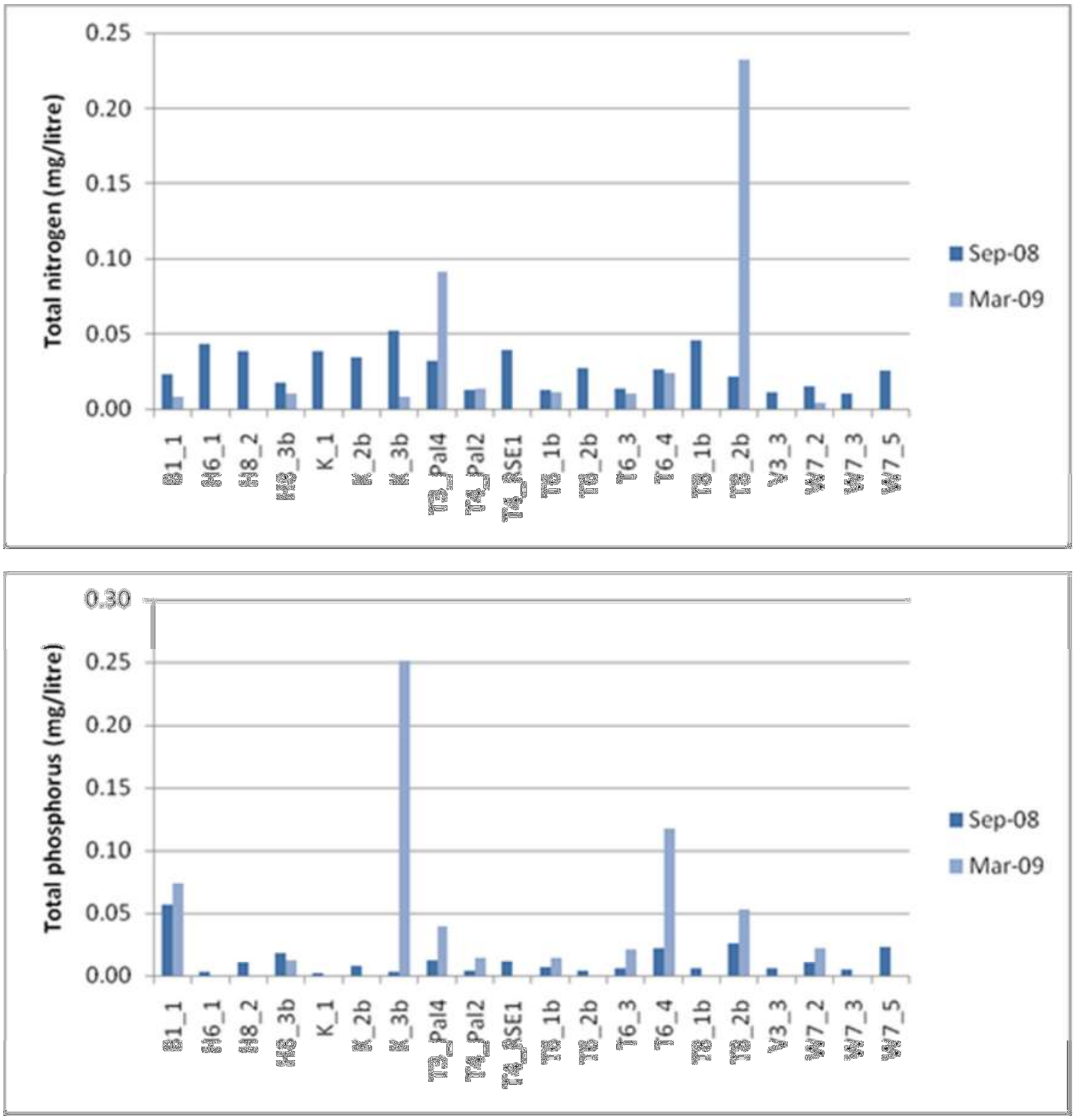

Figure 5.34. **Total inorganic nitrogen (top) and total inorganic phosphorus (bottom) measured in seep wetlands in September 2008 and March 2009. Nutrient data were not collected in May 2008.**

Soluble inorganic phosphorus (ortho-phosphate) was found to be below the threshold between oligotrophy and mesotrophy which is 0.02 mg/litre suggested by Malan and Day (2005) (Table 5.7), placing the seeps in the oligotrophic category, with the exception of B1_1 which had orthophosphate levels indicative of mesotrophy (Figure 5.35). These are once-off measurements during each month of sampling so interpretation of the data is limited.

Unlike nitrogen, total phosphorus was significantly higher in March than in September ($F = 8.855$; $p < 1\%$), as was orthophosphate. This may have been due to an increase in the reducing conditions in the seeps at this time, i.e. an increase in temperature and decomposition of organic material. Also, the sampling in September was conducted during heavy rains, which may have diluted the nutrient levels at that time. Interestingly, chlorophyll-*a* levels (see Chapter 7) in the March sampling were substantially greater than in September. These high phosphorus and orthophosphate levels in the ecoseeps do suggest that algal growth in the seeps is probably not limited by phosphorus. Overall, orthophosphate measurements were not significantly different between March and September.

Table 5.7 Iterative reviews of benchmark SRP category boundaries for trophic levels in inland aquatic systems (values in mg/l) (after Malan and Day 2005).

DWAF 1996	**DWAF 2002**	**Malan & Day 2005**
Median SRP (ortho-phosphate or PO_4) (mg/l)		
	Natural ≤ 0.005	
Oligo- ≤ 0.005	**Good** 0.0051 - 0.025	**Oligo-** ≤0.02
Meso- 0.005 - 0.025	**Fair** 0.0251 - 0.125	**Meso-** 0.0201 - 0.125
Eutro- 0.02501 - 0.25	**Poor** > 0.125	**Eutro-** > 0.125

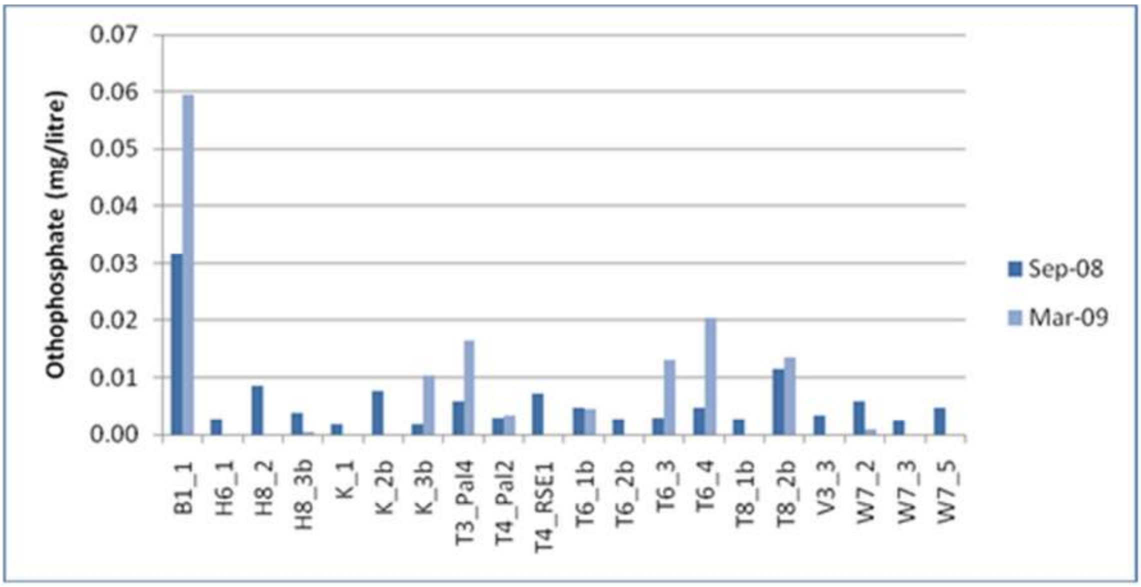

Figure 5.35. Orthophosphate measurements from the seep wetlands, taken in September 2008 and March 2009.

Nitrogen and phosphorus are amongst the major nutrients responsible for plant and algal growth in any ecosystem, and are useful measures of trophic status or productivity (e.g. DWAF 1996; Dallas and Day 2004; Malan and Day 2005). Elevated concentrations of inorganic nitrogen and phosphorus are seldom found in unimpacted freshwater ecosystems, especially in the well-leached mountainous areas of the Western Cape (FCG unpublished data). The major source of inorganic nitrogen in aquatic ecosystems is from surface runoff from the surrounding catchment (Dallas and Day 2004), probably contributed indirectly from decomposition of plant and animal material. Nitrogen may also be more readily available in wetlands as a result of contributions from free-living nitrogen-fixing bacteria, which tend to be most active at the surface of waterlogged soils (Magdoff and Bouldin 1970).

Ammonium ions occur naturally in acidic waters as a product of the breakdown of nitrogen-containing organic matter. Ammonium is usually a minor component of dissolved nitrogen compounds in natural waters, because it is converted to nitrite and nitrate through aerobic bacterial activity. The relative proportion of ammonium in the total dissolved nitrogen concentration may be greater under conditions of low oxygen availability, however, which would retard the aerobic conversion of ammonium to nitrite and nitrate. Such conditions are common in saturated wetlands with highly organic soils. Thus, ammonium can be the dominant nitrogen-based ion in acidic, waterlogged soils (B. Low, pers. comm.). Floating or submerged aquatic plants such as algae remove nutrients, particularly ammonium and phosphate, and to a lesser extent nitrate, rapidly and efficiently in oligotrophic waters (McColl 1974), whilst rooted plants more readily utilise the oxidised form of inorganic nitrogen, namely nitrate. These oxidised forms of nitrogen, i.e. nitrates and nitrites, can also often be found in naturally high concentrations in groundwater (Dallas and Day 2004), probably due to the fact that it is not actively being incorporated into plant biomass through photosynthesis.

Under oxidising conditions phosphorus readily interacts with a number of cations and precipitates out of the water in insoluble compounds, especially at low pH (Dallas and Day 2004; DWAF 1996). Phosphorus may also adsorb onto humics and sediment particles such as iron and aluminium ions, and it tends to accumulate in shallow, vegetated wetlands, mostly in forms which make it unavailable for uptake by plants (DWAF 2002; Dallas and Day 2004). However, under chemically reducing conditions (i.e. where oxygen is low, such as can occur in polluted or eutrophic waterbodies, but also common in marshy wetlands) the phosphorus is released from the sediments into its soluble orthophosphate form (Dallas and Day 2004), which represents the amount immediately available for uptake by plants (DWAF 2002). Phosphorus can also be released into suspension as a result of high rainfall, due to the mobilisation of wetland sediments.

The DWAF determination of boundary values between nutrient status categories for inland waters is based on measurements of TIN and Soluble Reactive Phosphorus (SRP) (DWAF 1996, 2002). SRP represents the amount of orthophosphate in the water plus an undetermined but small fraction of poly-phosphate (US EPA 1999a). Whilst the boundary between oligotrophic and mesotrophic conditions for nitrogen has consistently been set as 0.5 mg/l, and between meso- and eutrophic conditions as 2.5 mg/l, phosphorus levels associated with different trophic states have been revised over the past decade. Two iterations of the benchmark boundaries for the determination of trophic status based on levels of SRP, often referred to as orthophosphates, (DWAF 1996, 2002) and an independent review (Malan and Day 2005) are presented in Table 5.7. In the latter study, the distinction between oligo- and mesotrophic (medium) trophic status based on SRP was suggested as 0.02mg/l (rather than 0.005mg/l) provided that the results of tests are greater than the detection limits.

In describing trophic status it is also important to examine actual values of algal or macrophyte biomass or productivity: for example, where shading precludes plant growth, productivity may be low irrespective of nutrient availability, which is probably the case at B1_1. At this site the organic content of the soils was observed to be high (Section 5.3.2) and the soils in the lower part of the wetland remained permanently saturated (Figure 5.25), thus potentially providing for the reducing conditions that could result in elevated orthophosphate (Figure 5.35). The site is heavily shaded by dense growths of ferns and other plants, which diminish the amount of sunlight reaching the soil and inhibit photosynthetic activity. These features may explain the relatively high nutrient levels at the site and would be in support of the statement above regarding the warm temperatures recorded at B1_1.

5.4.3 Results and discussion of river channel water chemistry

The ecochannels were found to be of a similar pH to the ecoseeps – acidic, with pH values fluctuating within a slightly wider range, between pH of 3.5 and 6. There were no significant differences between months, although pH tended to peak in December, and sometimes March (Figure 5.36). In the Western Cape, winter rainfall tends to increase the flushing of acidic plant tannins into watercourses, thus lowering the pH in high rainfall / runoff months. This would explain the higher pH in December and March (summer). The pH recorded at T8_2a was consistently higher than all other sites in all months (Figure 5.36).

All the ecochannels had the low EC values (Figure 5.36) characteristic of unimpacted Western Cape rivers. The measurements from Steenbras and Kogelberg sites were substantially higher than those from all the other TSAs, a finding which matches the elevated EC measurements collected from the ecoseeps, and the springs and boreholes in these two TSAs during the hydrocensus.

Although differences between months were not found to be significant, EC was the highest in May at most sites, especially again the Kogelberg and Steenbras TSAs. This is likely to be linked to the first flushes of minerals and salts from the surrounding catchments, before continuously elevated winter runoff dilutes this effect. An exception to this was at the Purgatory sites T8_1a and T8_2a where EC was highest in December. EC tended to be at its lowest in March at most sites (Figure 5.36). EC is expected to be highest in late summer, however, when low flow in the river will lead to a concentration of dissolved materials, and lower in winter when the dilution factor is high (e.g. Day, 2008). Local catchment characteristics, such as the amount and timing of summer rainfall which may have had some influence over the transport of minerals and salts within these catchments, may explain this anomaly.

In all months, EC tended to be lower in the Boesmanskloof (T6) and Wemmershoek (W7) TSAs (Figure 5.36). The Wemmershoek catchment receives the most winter rainfall of all the TSAs (Table 2.3) which could lead to greater overall dilution of dissolved material – the ecochannels at Wemmershoek were categorised as either perennial or “low” perennial (Table 4.3). T6_1a and T6_2a were also categorised as being perennial rivers.

Water temperatures (Figure 5.36) ranged between 10 and 30°C, as in the case of the ecoseeps, and were lowest in May and highest in December. Differences between months were significant ($F = 82.747$; $p \ll 0.001$).

The nutrient levels showed that the water in the ecochannels was oligotrophic with regards to both TIN (DWAF 1996) and orthophosphates, using the criteria of Malan and Day (2005). TIN was generally less than 0.03 mg/litre (Figure 5.37), with the exception of December samples taken at K_3a, T4_Pal3, T4_RSE2 and W7_6, which were high. TIN was also high in March at the latter site. December measurements of TIN were significantly higher than in May ($F = 4.139$; $p < 2\%$). This December peak may be the result of the flushing of nutrients into the rivers throughout winter and during the November/December rains, leading to a peak in early summer, as was observed for the ecoseeps in September.

The levels of total phosphorus recorded in the ecochannels were generally slightly higher than those recorded in other larger but unimpacted foothill rivers, for example the upper Berg River (Justine Ewart-Smith, UCT pers. comm.), but were almost always below 0.02 mg/litre. The exception to this was a high total phosphorus record at T8_1a in May 2008, which was anomalous, and may have been an error. Total phosphorus was almost always at its lowest in December, significantly so in comparison with both May and March ($p < 1\%$). This mirrors the orthophosphate data, where concentrations generally peaked in December, suggesting that in this month some mobilisation of soluble phosphorus occurred from the inorganic form, perhaps related to temperature and / or oxygen levels in the streams.

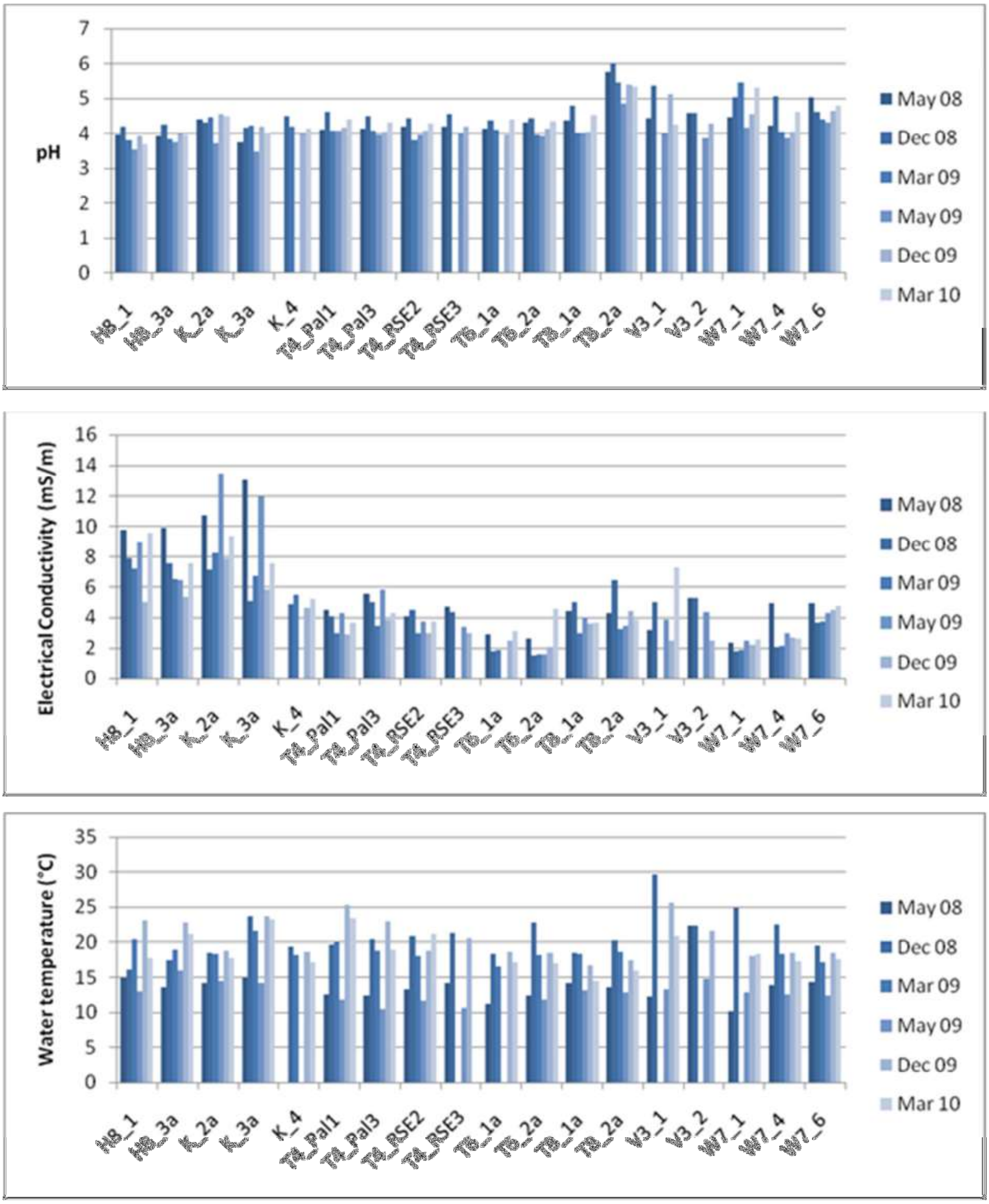

Figure 5.36. **Spot measurements of pH (top), electrical conductivity (middle) and water temperature (bottom) taken at the river channel sites in May 2008, December 2008 and March 2009.**

Nutrient levels in the river channels were substantially lower than in the seeps, although not significantly so in March, the only month when a comparison of all sites could be made. Statistical analysis was impaired here, however, by the large number of seep sites from which water samples could not be collected. A larger dataset, including the second cycle of sampling trips, should provide a better basis for examination of differences in nutrient status between seep and channel sites.

It is expected that nutrient levels will be higher in the seeps, for a number of reasons. Phosphates tend to accumulate in sediments rather than in surface water (e.g. Dallas & Day 2004). Under the reducing conditions in waterlogged wetland soils (which may or may not be due to high organic matter content in the wetland soils), these phosphates become available. Further, as discussed above, nitrogen-fixing bacteria tend to be most active in waterlogged topsoils, converting atmospheric nitrogen to the ammonia form (see Section 5.4.2), possibly in higher concentrations than in river water, where there is free availability of dissolved oxygen. Basically, wetlands may act as sinks for nutrients that are then washed into rivers where they are diluted and taken up by plants and algae. A similar comparison between nutrient levels in surface water collected from seeps versus rivers has not been found in the local scientific literature, or indeed elsewhere. These hypotheses need to be tested further with a larger dataset, in order to improve our understanding of the nutrient dynamics of these ecosystems, and how these relate to hydroperiod, and so how they could be affected by groundwater drawdown.

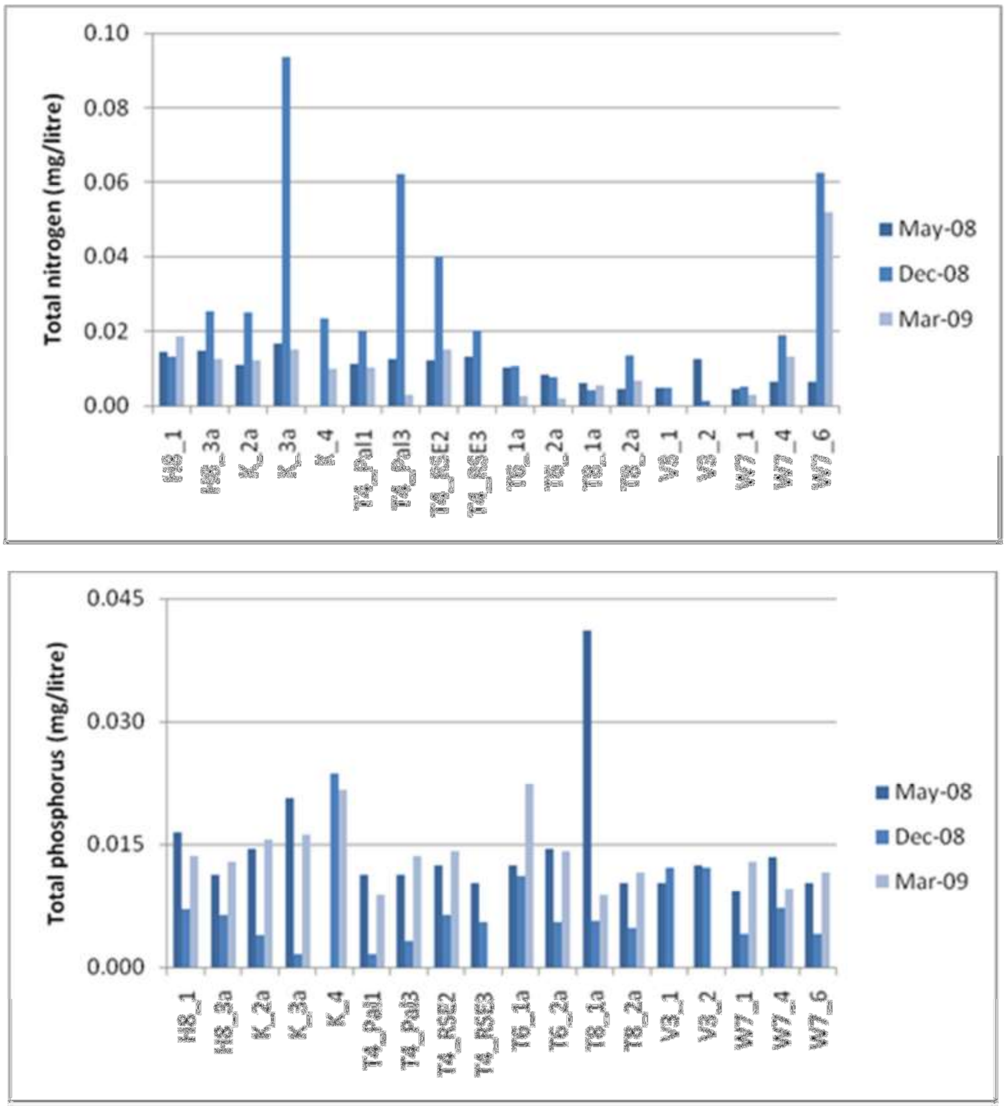

Figure 5.37. **Total inorganic nitrogen (top) and total inorganic phosphorus (bottom) measured in the ecochannels (where surface water was present) in May and December 2008 and March 2009.**

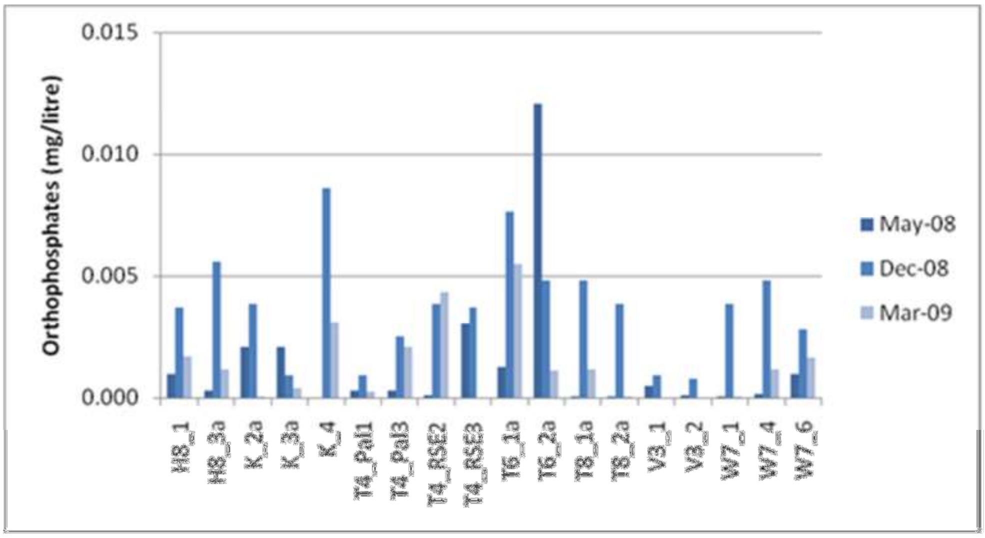

Figure 5.38 Levels of orthophosphate measured in the ecochannels, in May 2008, December 2008 and March 2009.

5.5 SUMMARY AND CONCLUSIONS

5.5.1 Water chemistry at the hydrocensus sites

EC was very low at all of the groundwater and surface water hydrocensus sites, with averages mostly below 15 mS/m. The average EC values for surface waters were lower than for groundwater, and this is attributed to greater contact time with geological formations resulting in a higher mineral content. A slight increase in EC was observed in winter for groundwater and, to a lesser extent, for surface water. This is expected for groundwater, where increased recharge rates, higher hydraulic gradients and groundwater flows in winter lead to increased dissolution and mobilisation of minerals. However, EC is expected to be higher in surface water in summer, so this may indicate the strong influence of groundwater. EC was highest in samples from the argillaceous and mineralised Gydo Mega-aquitard, while values were very similar between the Nardouw and Peninsula hydrostratigraphic units. The data showed marked spatial differences in average EC at the TSA level. EC appeared to be influenced by distance from the coast, with highest values at sites closer to the coast – Kogelberg and Steenbras.

The pH values of the groundwater samples were acidic to neutral, with averages ranging from 3.5 to 7. Surface water tended to be more acidic than groundwater in all of the hydrostratigraphic units; this is probably due to the leaching of phenolic acids from plants and roots at the surface. The Basement unit samples had the highest pH – this formation can comprise either granite or argillaceous material and these lithologies are known to have more neutral pH waters. The pH of groundwater collected from boreholes and piezometers in the Peninsula Formation was higher than that in the Nardouw. pH did not appear to vary substantially with season.

Average total nitrogen was below 2 mg/litre in all units, for both ground- and surface water, and tended to be higher in the groundwater than in the surface water. Total phosphorus was below 0.2 mg/litre in all units, and tended to be higher for surface water than for groundwater. There were no clear seasonal patterns in the nutrients data.

The ground- and surface water samples were all dominated by the Na + K and Cl ions. The one significantly anomalous sample was collected outside the TMG study area from the Goudini Hot Spring, where Ca-CO_3 dominated.

The water chemistry data collected from the hydrocensus sites are useful for the characterisation of the ground- and surface water across the study area, however, these variables are unlikely to be important for monitoring of the effects of groundwater abstraction. There is unlikely to be a measurable change in these variables with drawdown.

5.5.2 Isotope data from the hydrocensus sites

The rainfall data plotted on or close to the Cape meteoric water line (CMWL), indicating that, as expected, water falling as rain was unaffected by isotopic processes associated with interaction with the earth's surface, such as evaporation, flow through substrata, etc. The borehole isotope data showed only slight displacement from the CMWL, which indicates some enrichment of the heavier isotopes, but the data were in a similar position to the rainfall data, indicating that the groundwater originates from local rainfall. Due to the lack of isotopic interaction of borehole water with the TMG rock, as a result of the fairly rapid recharge-discharge patterns within the TMG aquifers, the water does not have a unique signature that can be used as a tracer. The isotope data did show that the winter rainfall is most responsible for aquifer recharge, as expected.

Isotope signatures did not show any relationship with elevation or distance from the coast, although there was some indication of clustering of isotope data within the TSAs. The hydrocensus groundwater and surface water sites are perhaps too close together to show much spatial differentiation.

5.5.3 Topsoil chemistry at the ecological monitoring sites

As can be expected in the sandstone substrata of the Cape mountains, the soils are typically acidic and oligotrophic and provide major challenges to nutrient uptake by plants. Soil pH values were extremely low, and were amongst the lowest observed for Cape fynbos soils. The soils had high electrical resistance, which is generally inversely proportionate to soil fertility, and low total and available (Bray II) levels of phosphorus and total nitrogen. Mean phosphorus levels in the ecoseeps were more than double those for the ecochannels.

Total carbon values were typical of Western Cape wetlands, ranging up to just over 5% - none of the soils could be characterised as being peaty. The C:N ratio for the TMG soils ranged between 10 and 20:1. As found elsewhere in the oligotrophic soils of the Western Cape, there was a clear linear correlation between total carbon and total nitrogen - higher levels of organic matter are often associated with elevated nutrient concentrations. This does not necessarily mean that these nutrients are available to the biota, as most of the nitrogen is trapped in the form of organic matter, and must be mineralised by bacteria before being released. A strong correlation was found between total carbon and cation exchange capacity, suggesting organic matter could play a key role as a colloid in an otherwise clay-free environment.

The soils were richer in calcium and magnesium, than in sodium and potassium, which is the opposite of the results for the ground- and surface water hydrocensus sites. This may relate to the chemical and physical processes governing ion exchange in soils *versus* water.

The soils at the Villiersdorp site (B1_1) were quite different to those at the other seep sites, especially in terms of exchangeable Ca and Mg, total P, total N and CEC and T-value. It is likely that the underlying geology (Cedarberg Formation) has a major influence on soil chemistry – this is echoed by the fact that the dominant vegetation type at this site is shale band vegetation, rather than the sandstone fynbos at most sites.

Ecoseep topsoil was not significantly different in terms of chemistry to ecochannel soil, but there were significant differences between soils analysed from different TSAs. There were no significant differences between soils collected from ecoseeps or ecochannels assigned to different hydroperiod categories.

5.5.4 Soil moisture and organic matter content of the topsoil

Soil moisture and organic matter content were both significantly different between ecoseeps and ecochannels only at Boesmanskloof, while soil moisture was significantly different between the two ecosystem types also at Purgatory, and organic matter significantly different at Voelvlei. As expected, there was no significant seasonal variation in organic matter content in the topsoil, but soil moisture was significantly higher in winter/spring than in summer in most TSAs, with the exception of Villiersdorp (B1), Steenbras (H6/H8), Riviersonderend (T4_RSE) and Purgatory (T8). Soil moisture showed a weaker linear relationship with organic matter content in summer than in winter/spring. In summer, therefore, wetter soils are not necessarily those found to have a higher organic content, while in winter, the wetter soils tend to be those that have a higher organic content.

Both soil moisture and organic matter content were significantly different between TSAs in summer, but this was only true of ecochannel soils in winter/spring. At least for the ecoseeps, then, drying out of the seeps leads to greater differentiation between TSAs.

The causal relationship between organic matter and soil moisture is not necessarily straightforward. Wetlands that are fed more or less consistently throughout the year by groundwater, for instance, show an accumulation of organic matter and may tend to be peaty. This is probably due to the depletion of oxygen in waterlogged soils, and the concomitant slowing down of organic matter decomposition. Drying out of soils, such as occurs in seasonal wetlands, allows oxygen to enter the soil, thus providing atmospheric oxygen to the plant roots, microbes and other micro-fauna, which speeds up organic matter decomposition.

This inter-relationship between soil moisture and organic matter content was not clearly borne out by the linking of soils with the hydroperiod categories assigned to the ecological monitoring sites. In the ecoseeps, soil moisture was significantly different between hydroperiod categories in summer only. These differences were between A and C, D and E soils, and also between B and C soils. There did appear to be a trend towards drier soils, especially in summer, from category A through to category E. The exception was in winter/spring when category D soils were wetter on average than A, B and C soils, which is unexpected.

In terms of organic matter, there were significant differences between the hydroperiod categories in the ecoseeps; in both winter/spring and summer. However, there were only pair-wise differences in summer; these were between category B soils and A, C and E soils. B soils had a higher organic content than all other categories.

It should be noted that the assignment of hydroperiod categories to the ecoseeps and ecochannels was achieved through the analysis of water levels. The lack of a clear fit with the topsoil moisture data suggests, firstly, that factors other than groundwater level or in-channel water level are responsible for surface moisture patterns. Secondly, the soil moisture data reflect measurements taken over the whole site, and it was very clear from field observations that topsoil moisture varied substantially over the site. This variability does not appear to be necessarily influenced by the source of water for the seep or channel site (e.g. rainfall *versus* groundwater), but may well be the most important feature driving biological assemblages. Furthermore, organic matter content may well be a critical determinant of surface moisture patterns.

Lastly, it must be noted that comparison of the % soil moisture between sites may produce spurious results, as this variable is strongly influenced by the nature of the soils. For instance, sandy soils will uniformly hold less water than fine silty soils. While it is acceptable to compare the same soils over time, it is inadvisable to compare across sites.

It appears that soils that are wetter for longer tend to have relatively high organic matter content. High organic matter content is often associated with higher nutrient levels. It follows that any droughting of seep or channel soils will have an adverse effect on both water and nutrient retention and thus on the species composition and productivity of the biota inhabiting the site.

Analysis of the soil moisture data from soils collected at all of the algal sampling points in September 2009 and March 2010 produced a useful result. As mentioned above, the data were not compared between sites, but rather between seasons by looking at the % difference between soil moisture measured in the soils collected from ecoseeps in September *versus* March (Figure 5.23). There is a clear increase in the % difference in soil moisture from category A soils through to category D soils, with a slight decrease to category E soils. Specifically, category A soils were found to be significantly different to all other categories. This trend confirms the categorisation of the ecoseeps according to hydroperiod – fluctuations in soil moisture across the perennially wet ecoseeps are less than those in ecoseeps that dry out either for a season or longer.

It is essential that the monitoring programme incorporate a detailed and well-designed soil moisture sampling protocol. Due to the lack of confidence in comparisons of soil moisture between sites, it is best to sample extensively in a few seeps, with comparisons over time. The data required for such comparisons will come from the proposed transects of soil moisture probes through a smaller number of wetlands (see Chapter 9, Table 9.1).

5.5.5 Soil profile analysis of soil moisture and soil saturation

Soil moisture values differed considerably within sites, from site to site, and between different depth layers, and did not give a clear indication of whether the soils were saturated. Water storage capacities of soils are influenced by soil properties such as organic matter, clay, sand and gravel content. The sandy soils that originate from TMG sandstones will drain to below saturation point within a few hours after a rainfall event, if they are not groundwater-fed. The saturation values for the soils, especially of the topsoil (i.e. the top 30cm) provided a slightly more meaningful picture in terms of the length of time during which the wetland soils could be categorised as saturated *versus* unsaturated, and how this varied with time. It is the saturation, rather than wetness, of wetland soils that has a major influence over soil chemistry, morphology, and the species of plants, algae and invertebrates that can inhabit the wetland.

The soil moisture at measuring positions outside and on the upslope edge of the wetlands/seeps (Probes 1 and 2) are all strongly influenced by rainfall – i.e. soil moisture fluctuates fairly widely, in response primarily to rainfall, and soils are generally intermittently to seasonally saturated. In order to gain an understanding of the dominant supply to the wetland and how this water behaves over time, it is more useful to examine the data from measuring points in the wetland itself and below it, i.e. Probes 3, 4 and 5. However, it is important to collect data from at least one point outside of and upslope from each wetland, as this allows a comparison with soil water dynamics outside of the wetland. The design of the future monitoring phase needs to take this into account.

It was not possible to ascertain groundwater *dependency* using this method. However, the behaviour of the soil moisture, and specifically soil saturation, in the topsoil and the subsoil, and how this fluctuates at the different soil depths, do give an indication of whether the wetland is fed primarily by rainfall, or by subsurface flow, which *may* be groundwater flow, and whether the influence of groundwater is strong or weak. Ecoseeps that were found to be perennially saturated, especially in the topsoil, are the ones most likely to have strong connectivity with groundwater. There is strong agreement between the saturation of the top- and subsoil at the ecoseeps and the proposed “strength” of connectivity between the ecoseeps and groundwater resources. These were B1_1, H8_3b, K_2b, T4_Pal2, T6_1b, T8_1b and W7_5. Only T4_RSE4b seemed to have a weak connectivity with groundwater resources.

This result is contradicted to a certain extent by the assessment of correlation between soil saturation in the top 50 cm and the depth of the water table over time at each ecoseep. Only W7_5 appeared to have a very low probability of connectivity with groundwater, while the data for T_1b were inconclusive.

5.5.6 Relationship between soil saturation, the water table and rainfall

The component of the subsurface flow that can be attributed to groundwater can be ascertained by looking at the relationship between soil saturation, the water table and rainfall. It is probable that a close correlation between soil saturation and the water table is an indication of the influence of groundwater, whereas a weak correlation with the water table and a strong correlation with rainfall would indicate the predominance of rainfall as a driver of soil saturation.

Soil saturation in the top- and subsoil at B1_1-3 correlated strongly with the depth of the water table, while the water table had a moderate correlation with rainfall. This site is located on Cedarberg shale, and the water table remains shallow at this site all year round. This seep is located fairly close to a fault that connects the site laterally with the Skurweberg Formation and vertically with the Peninsula Formation, so the likelihood of this seep being fed by groundwater is high, which could come from either the Nardouw or Peninsula Aquifers, or both. In summer, the water table would be expected to drop, as a result of evaporation and evapotranspiration. This did not occur, and soil moisture remained high – at or close to saturation – in the top- and subsoils at the lower measuring points throughout the year. While this does point towards the strong influence of groundwater, it is also possible that the high organic content at this site leads to the retention of moisture in the soils, especially during the summer months. Water sitting in the deeper soil layers moves up through the soil profile as a result of capillary action. Soil saturation at this site might be attributable to both groundwater and the retention of rainfall.

The water table at H8_3b remains shallow at this site, and the top- and subsoils at the lower measuring points remain at or close to saturation. Water table depth did not correlate strongly with rainfall, but there was a moderate correlation between soil saturation in the upper layers and the depth of the water table, indicating a moderate likelihood of connectivity with groundwater. This site may be fed by the Nardouw Aquifer or from nearby faults up and down the slope from the seep.

The soil saturation at K_2b-4 correlated strongly with the depth of the water table and rainfall, and rainfall had a moderate to weak relationship with rainfall. These results suggest a highly likely connectivity with groundwater, with rainfall playing a minor role. Although the sandy topsoil and profile of the seep is thought to be underlain by Cedarberg shale, it is also located on a fault that brings the Peninsula and Cedarberg formations together, so it is highly likely that this wetland is fed by groundwater.

T4_Pal2 is located on the Peninsula Formation, with a direct link with the Peninsula Aquifer. The Peninsula Formation consists of thick bedded quartzitic sandstone with minor shale and siltstone, and is generally a highly transmissive formation. The soil moisture in the top- and subsoils at the lower measuring points generally behave similarly, and are either seasonally or perennially saturated. T4_Pal2-5 is an exception, but this is probably due to the location of this probe on a dry bank above the Palmiet River – water flowing past this point drains quickly into the river. The water table does drop fairly low in summer (below 1 m), and the decline is slow, which may be due to the fact that water drains into this valley-bottom wetland from the surrounding seeps and slopes (valley-bottom wetlands do accumulate water from the surrounding landscape, as opposed to seeps that are characterised by the downhill seepage of water away from the wetland (SANBI 2009)). The soils at this site are of medium to coarse sand and drain well. The underlying bedrock is also transmissive and thus also “drains” well, explaining the drop in the water table when rainfall and recharge decrease, and evapotranspiration rates increase in summer. There was a weak correlation between rainfall and the water table at this site, and a strong correlation between soil saturation and the depth of the water table, indicating that the likelihood of connectivity with groundwater at this site is high.

There were data gaps at T4_RSE4b which precluded a useful analysis at this site. However, there did appear to be a strong correlation between the saturation of the topsoil and the depth of the water table. This was not borne out in the whole soil profile, where the correlation with water table was weaker.

At T6_1b, there was a moderate correlation between rainfall and the water table, and a variable correlation between soil saturation and the water table, which strengthened with soil depth. The results for this site are inconclusive. The correlation between rainfall and the depth of the water table was very weak at T8_1b, with a moderate to strong correlation between soil saturation and the water table. This suggests that connectivity with the groundwater is probable at this site.

W7_5 is located on a scree slope close to the contact between the Pakhuis and Peninsula Formations. The hydraulic transmissivity of scree increases the probability of connectivity with the Peninsula Aquifer. However, soil saturation at W7_5-3 correlated very weakly with the depth of the water table, which in turn correlated moderately with rainfall. The saturation curves at all of the measuring points showed fairly uniform seasonal saturation, with few fluctuations once the soil became saturated in winter. This was observed in both the top- and subsoils at the lower measuring points. It is most likely that this seep is fed primarily by rainfall.

In conclusion, the degree of saturation of the soil at the ecoseeps is useful as an indication of the *strength* of the connection between the seep and the groundwater, while an assessment of the correlation between soil saturation (especially of the upper layers (< 50 cm) of soil) and the depth of the water table over time provides an indication of the *likelihood* of connectivity with groundwater. The data generally do confirm the proposed likelihood and strength of connectivity with groundwater presented in Chapters 2 and 3.

5.5.7 Surface water physico-chemistry at the ecological monitoring sites

EC and pH measured at the ecoseeps and ecochannels were low, as shown at the hydrocensus sites and in the topsoil, and as expected for unimpacted freshwater ecosystems in the mountains of the Western Cape. The pH of the surface water was consistently higher than that measured in the topsoil. There were no clear seasonal trends in the EC and pH data, although EC tended to be lowest in summer at both the ecoseeps and ecochannels. As for the hydrocensus data, this is unexpected, and may be an indication of the influence of groundwater. Temperature at all sites was highly seasonal.

Nutrient levels – total phosphorus and total nitrogen – were well below the levels provided as the threshold between oligotrophy and mesotrophy. The exception was the site at Villiersdorp, B1_1, which had total phosphorus levels indicative of mesotrophic conditions. This may be due to the relatively high organic content of this site, which, as discussed above, is often associated with high nutrient levels. There were insufficient nutrient data to find seasonal patterns (nutrient samples were only collected from September 2008 from the ecoseeps), but nitrogen tended to be lower in spring, and phosphorus higher in summer. The latter may have been due to an increase in the reducing conditions in the seeps at this time, i.e. an increase in temperature and decomposition of organic material. Under chemically reducing conditions (i.e. where oxygen is low, such as can occur in polluted or eutrophic waterbodies, but also common in marshy wetlands) phosphorus is released from the sediments into its soluble orthophosphate form, which represents the amount immediately available for uptake by plants.

Nutrient levels in the river channels were substantially lower than in the seeps, although not significantly so in March 2009, the only month when a comparison of all sites could be made.

Statistical analysis was impaired here, however, by the large number of ecoseeps that were dry and so could not be sampled. It is expected that nutrient levels should be higher in the seeps, for a number of reasons. Phosphates tend to accumulate in sediments rather than in surface water. Under the reducing conditions in waterlogged wetland soils (which may or may not be due to high organic matter content in the wetland soils), these phosphates become available. Further, nitrogen-fixing bacteria tend to be most active in waterlogged topsoil, converting atmospheric nitrogen to the ammonia form, possibly in higher concentrations than in river water, where there is free availability of dissolved oxygen. Basically, wetlands may act as sinks for nutrients that are then washed into rivers where they are diluted and taken up by plants and algae. A similar comparison between nutrient levels in surface water collected from seeps *versus* rivers has not been found in the local scientific literature, or indeed elsewhere. These hypotheses could to be tested further during the monitoring phase, in order to improve our understanding of the nutrient dynamics of these ecosystems, and how these relate to hydroperiod, and so how they could be affected by groundwater drawdown. However, there is unlikely to be any change in the nutrient status of these ecosystems, so nutrients may not be good indicators of change.

6. FLORA & VEGETATION

6.1 INTRODUCTION

Fundamental to the TMGA study is an understanding of the character of resident channel and seep plant communities and their behaviour relative to groundwater or hydrological patterns. Wetland and riverine plants in the Cape fynbos are restricted to very narrow habitats and are thought to be sensitive to small changes in such habitat, for example increases in soil pH, nutrient levels, fire frequency and alterations to both level and seasonality of subsurface and / or groundwater, as much as for historical biogeographic reasons. Many if not most species in these habitats are dependent on perennial or at least seasonal wetting (obligate wetland species), and have life cycles which are thus dependent on such processes.

6.1.1 Background

The monitoring sites in the TMGA study occur within two major vegetation types as described by Mucina & Rutherford (2006). The Kogelberg, Steenbras, Nuweberg and Boesmanskloof sites fall under Kogelberg Sandstone Fynbos, with the SOS, Purgatory, Wemmershoek, Zachariashoek and Voelvlei sites comprising Hawequas Sandstone Fynbos.

At a finer scale, all fynbos vegetation types contain habitats that may be classified as ‘wetland’ of one or another type. These wetland ecosystems vary from seeps of differing permanency and origin, to narrow restio alluvia of mountain streams, to fynbos peats and mires (see Sieben, 2003; Sieben *et al.*, 2004). Within these wetlands, often a single species is dominant, sometimes in zones within the wetlands, and different species may occupy apparently identical ecological niches in contrasting geographical areas, or even in neighbouring wetlands. Structurally the fynbos wetlands are mainly restioid or ericaceous but many are dominated by Poaceae (Rebelo *et al.*, 2006). The Cyperaceae (sedges) are also often a key co-dominant or dominant group in many wetlands and they can be prominent in various riverine situations, particularly along the lower wet bank (pers. obs.).

Whilst general accounts of the Cape flora and vegetation have been written by numerous authors including Kruger (1978), Taylor (1978), Campbell (1985 & 1986), and Cowling & Holmes (1992), none focuses specifically on rivers and wetlands, except, perhaps, in passing. A general description of wetland vegetation of the Fynbos Biome is provided by Boucher in King (1986), whilst Campbell (1985) in his structural classification of mountain vegetation in the Fynbos Biome recognises 63 types (essentially plant communities) of which several fall under Azonal Restioid Fynbos (excessive waterlogging), Wet Ericaceous Fynbos, Wet Proteoid Fynbos (largely seeps), and Closed-Scrub Fynbos (largely channels). Pertinent to the TMGA study is the occurrence of Nuweberg and Landdros Wet Ericaceous Fynbos in the Hottentots Holland Mountains.

Mucina & Rutherford (2006) recognise an azonal vegetation type they term Fynbos Riparian Vegetation which has many of the species encountered in the present study. They describe this type as follows: “Narrow, flat or slightly sloping alluvial flats supporting a complex of reed beds dominated by tall palmiet (*Prionium serratum*) and restios (*Calopsis, Cannomois, Ischyrolepis* and *Rhodocoma*), low shrublands with moisture-loving species of *Berzelia, Cliffortia, Helichrysum,* etc., with tall riparian thickets of *Metrosideros angustifolia* and *Brachylaena neriifolia* in places”.

However, apart from the work of Sieben (2003) there appear to be no published studies specifically examining the plant life of Cape montane riverine and wetland ecosystems. Although there has been no systematic assessment of Cape montane floras and vegetation, general classifications or descriptions exist for the Cape Floristic Region (e.g. Campbell, 1985); several uncoordinated flora and vegetation assessments also exist at a subregional to local level and these indicate an array of both wetland and riverine communities in the Western and Southern Cape. Localities include the Cederberg (Taylor, 1996), Jakkalsrivier catchment (Kruger, 1974), Jonkershoek (Werger *et al.*, 1972), Kogelberg (Boucher, 1977 & 1978), the southern Cape mountains (Bond, 1981), Southern Langeberg (McDonald, 1993a, 1993b, 1993c), Swartboschkloof (McDonald, 1988), Table Mountain (Glyphis *et al.*, 1978; Laidler *et al.*, 1978; McKenzie *et al.*, 1977) and Zachariashoek catchment (Van Wilgen & Kruger, 1985). A number of unpublished descriptions of riparian vegetation in particular are related to Instream Flow Requirement studies undertaken for the Department of Water Affairs by a number of independent consultants. The results of these studies are more difficult to access because they are unpublished, but nevertheless contribute useful information about riparian vegetation and wetlands, including the driving forces shaping their internal zonation patterns (for example Boucher's (2001) botanical study for the Breede River Instream Flow Assessment).

In the feasibility period prior to the current study, Boucher & Brown (2004) described the vegetation of the TSAs within which the current set of ecological monitoring sites is located. Vegetation units at each site were mapped onto 1:10 000 colour orthophotos, and then visited on foot and the dominant species recorded, together with some 164 plant communities. Plant communities were classified into the following vegetation types:

1. Woodlands
2. Fynbos riparian shrublands
3. Fynbos seeps, bogs and mires
4. Fynbos dryland communities
5. Grassland seeps, bogs and mires
6. Undescribed communities

6.1.2 Aims of this study component

A number of approaches to the vegetation-monitoring component of the TMGA study were adopted.

Wetland delineation and imaging

A component of the EPM is the exploration of multispectral imaging at a landscape-level to indicate plant vigour in the delineated wetland areas. To this end, the study area was flown on three occasions for the capture of imagery. This TMGA-EMA programme only included the capture of the imagery, whilst the actual analysis of the data was a limited exercise, because of budget constraints, and will be taken further by the TMGAA.

The extent of wetland at each of the ecoseeps was mapped, and the general length of each channel comprising ecochannel sites was identified on the orthophotographs produced for this project.

Flora and vegetation

The focus of the study was to describe the flora at each site and its relationship to the hydrological characteristics of the site, as well as the description of major plant communities within and across the sites, based on plant species cover and structure from a number of sample plots at each site.

The aims of this component of the study were:

- to record the plant species (flora) present at each site;
- to describe the plant communities at each site in terms of species cover, structure and dominance (vegetation), based on sampled plots

- to investigate differences amongst the flora and vegetation, specifically the extent to which these differences are correlated with:
  - a) geographical shifts in species distributions (e.g. north-south)
  - b) TSA area, which would imply TSA is a surrogate for some environmental factor defining the species complement of the communities in the TSA
  - c) ecosystem type (seep or channel riparian zone[7])
  - d) wetness or hydroperiod characteristics of the site.
- to provide baseline information for long-term monitoring of change in plant species presence and absence, and cover and abundance

Individual species responses

Four measures of the physiognomy and physiology of individual plant species were identified, and seasonal data were collected from tagged plants at each site during the first year of the monitoring project. This was discontinued for the second year, after the assessment by the project team, but is reported on here for completeness.

The aim of this component of the EPM was ultimately to identify responses by different species across the winter / summer seasons under natural conditions, for each parameter measured. Typical species responses would include the changes in plant phenology, overall plant vigour, and responses of plant physiology. Species response profiles could then be examined to find atypical behaviour of species in the future for example during development of the aquifer resource. It is acknowledged that such a set of species response profiles would take a far larger sampling effort to compile; the focus of this EPM's first annual monitoring cycle was on how well these methods might work and with which species. The selected measures were:

Plant vigour: The height of and a count of the percentage of green leaves and shoots on selected plant species was used to describe general plant vigour.

Sap pressure: This reflects the water potential of the plant, and is a good indicator of moisture stress.

Leaf stomatal conductance: this indicates the degree to which the stomata are open and measures the amount of water lost per unit area per time from the leaf, it is strongly influenced by the number of stomata present and on which side of the leaf they occur, and

Leaf chlorophyll: a measure of the amount of chlorophyll present in a leaf; plant stress is measured through loss of chlorophyll from the leaves of a given species

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[7] The classification of the ecological monitoring sites in terms of the national Wetland Classification System identified seeps and channels as different wetland ecosystem types. In the context of plant communities, these are often simply referred to as different plant habitats. However, for continuity the term ecosystem type has been continued in this chapter

6.2 METHODS

6.2.1 Seep and channel delineation and NDVI

The delineation of the seeps and channels comprising the ecological monitoring sites was necessary to define the “area of interest”, both for ongoing monitoring, but also for the application and analysis of multispectral imaging, described below.

A high resolution differential Trimble or Leica GPS, both with equal accuracy, set on 0.5 m intervals was used to delineate the boundary of each seep, with an accuracy of within a cm (horizontal) and two cm (vertical). The seep was demarcated by walking its perimeter, with the outer edge demarcated by the presence of presumed obligate wetland species selected for this purpose. The most obvious line of separation between wetland and dryland communities was captured. Thus obligate species ‘outliers’ were not included in the wetland perimeter, whilst the obligate indicator species had to be dominant species in each system mapped. Obligate seep species use were *Berzelia lanuginosa, Cannomois virgata, Cliffortia graminea, Elegia mucronata, E.capensis, Grubbia rosmarinifolia, Kniphofia uvaria*, *Leucadendron salicifolium, Osmitopsis asteriscoides, Psoralea* spp.*, Todea barbara* and *Ursinia caledonica.*

The outer edge of riverine communities was more difficult to map, because of problems of access and loss of GPS signal where vegetation was tall. In the end, aerial photography from the NDVI study (see section below) was utilised for the mapping of channels, with subtleties in vegetation pattern discerned from both colour (RGB) and infrared (NIR) photography.

Fieldwork for riparian and wetland community delineation was undertaken between May and July 2009, but not for the Steenbras and certain Nuweberg sites (burnt in summer 2008/9).

Aerial photography for determining Normalised Difference Vegetation Index (NDVI)

NDVI is a method of multispectral imaging calculated from two bands – the visible red (R) and near-infrared (NIR) as follows:

$$\mathbf{NDVI} = (NIR - R)/\ (NIR + R)$$

It is a recognised measure of plant vigour and biomass health or greenness. The method is used in the wine industry in South Africa to assess crop quality and enable farmers to achieve constant yield of crops. NDVI will measure the seasonal variation (winter/summer) in plant vigour, and should allow for early detection of stress in the wetland systems in the event of over abstraction of groundwater, as well as long-term wetland shrinkage.

The NDVI analysis calculates differences in the infrared reflectance over two time intervals for each pixel in an image. Imagery from the two (or more) time intervals thus needs to be precisely registered. Also, the area of interest (the extent of a seep or channel site) should be kept the same for each time interval, and should avoid inclusion of extraneous material into the image (e.g. the edge of an aeroplane wing or large non-permanent object on the ground), within the designated area of interest.

Flights were undertaken in “winter” 2008 (6 December) and summer 2008 (14 March 2009). Owing to severe weather during the winter-spring period in 2008 and problems with the aircraft, the “winter” flight was delayed until December.

Photographic imagery was collected for both time periods for all of the study area, and full colour spectrum (RGB) photography was used to map the area of interest for the seeps and the portions of channels comprising the ecological monitoring sites, for use in the NDVI analysis. However, the analysis of NDVI imagery was limited to the K_1 seep site as a result of budget constraints and with consent of the client. The ERDAS programme administered by Dr Julian Smit, (AfriMap, University of

Cape Town), was chosen for this analysis. The degree of difference in infrared between the two seasons was calculated using the orthoviewer technique developed by AfriMap.

6.2.2 Flora and vegetation

Sampling

The vegetation at most of the sites was fairly varied, and therefore sampling was stratified across the wetland, with three, rarely two, plots established in each major vegetation unit visually identified at the site. Seventeen of the sites were homogeneous and one physiognomic unit was mapped in each; 13 sites were associated with just two physiognomic units, whilst ten sites were defined by three or more physiognomic units. The plots within each physiognomic unit were labelled alphanumerically (A1, A2, A3, or B1, B2, B3), with the letter denoting the physiognomic unit and the number the plot number. In total, 227 plots at the 40 ecological monitoring sites were established over the study period. A small number of these were sampled in 2008/9 only, as a result of fire, whilst some 18 plots were only established in 2009/10, replacing burnt plots and including dryland plots for comparative purposes.

A galvanised metal stake labelled with an aluminium tag was placed at the bottom right hand corner to mark the plot. In the case of channels, plots were laid out along the river, with the narrow part of the plot perpendicular to the channel. Plot size varied, depending on community width and homogeneity of the vegetation. Virtually monospecific stands of *Prionium serratum* palmiet, for example, would have a plot size of 1 m x 1.5 m to 1 m x 2 m, whilst mature riverine communities, which are more complex in their species numbers and vertical structure, had larger plot sizes. The size varied from 5 m x 3 m (3 m often the general width of riverine vegetation on the upper bank) to 10 m x 10 m or larger (tall riverine thicket to forest). In the case of river channels, narrow plots were placed along the river, with the long axis paralleling the channel. A coordinate was recorded for each plot using a hand-held Garmin 60 GPS.

Plots were sampled using the Braun Blanquet ("BB") method as described in Braun Blanquet (1932) but applying the Zurich-Montpellier approach of Werger (1974). In each plot, all species names were recorded and given a percentage cover; vigour was also documented. Species were identified in the field or specimens returned to the laboratory, as described in section 6.2.2. Other data recorded included dominant plant height, disturbance, rock cover, soil moisture, aspect and slope.

Species which had poor or non-existent flowering material were identified in the field where possible based upon previous experience with these groups. Use was made of Coastec's wetland/riverine "kitsgids" or rapid guide, which comprises plant material lodged in A5 plastic envelopes. This collection was augmented through colour photocopying specimens (A4 size) from the TMGA study and storing these in a file which could be taken into the field. Reference specimens were photocopied and placed into a ringback file to enable ease of field identification, as well as to provide a tool for easy identification for future monitoring teams.

All flowering material was collected, pressed, dried, labelled and sent either to the Compton Herbarium at Kirstenbosch, or to various taxonomy specialists.

Where there was sufficient material, specimens were collected in triplicate: one for the "kitsgids", one for the Compton or Grahamstown Herbaria and one for Cape Nature.

Data analysis

The vegetation plot data were entered into the plot module of the SaSFlora database (SaSFlora, 1998 - 2010) where percentage cover was converted to BRAUN Blanquet cover values (<1% = + or 0.1; 1 – 5% = 1; 6 – 25% = 2; 26 – 50% = 3; 51 – 75% = 4 and 76 – 100% = 5). This was undertaken mainly so that eventually comparisons could be made with vegetation plots from elsewhere in the Cape flora. However, for this study, percentage cover was used in the analysis.

The environment / habitat of each of the sample plots was characterised according to:

- Wetland Ecosystem type – seep or riparian (channel) wetland
- Site – representing local factors that might determine species complement
- TSA – representing a slightly broader geographical entity, incorporating differences in annual rainfall etc.
- Seep or channel hydroperiod (seeps, as per Table 3.3; channels, as per Table 4.4).

A group of computer-based programs specifically developed for multivariate and statistical analyses of multispecies data was used to investigate the relationships within and among the 71 plant community units. These programs collectively form the software package PRIMER (Plymouth Routines in Multivariate Ecological Research) Version 6, developed at the Plymouth Marine Laboratory, United Kingdom (Clarke & Warwick 1994). The methods are detailed in Appendix 7 of Volume B.

Initially, geographical patterns in the relationships of the different TSAs were sought, at the level of their floras, that might have a bearing on between-site comparison and, for the future, for the selection of sites in a monitoring programme designed to detect change e.g. in the location of control vs impact sites.

The first hypothesis tested was that the flora and vegetation of different wetland types (seep or riparian (channel) wetland) should be significantly different, because of the major differences in habitat, especially hydrology, that characterise these.

A second hypothesis, the main focus of the EPM, was that hydroperiod, or wetness, should result in plant community differences that are discernible across a spectrum from perennial to intermittent. The major species responsible for these differences could then act as indicators in the future, and their appearance or disappearance used to infer change in ecosystem hydrology.

At the outset of this analysis, it was clear that there was more than one plant community at most of the sites, but only one designation of site hydroperiod based on the piezometer or water level record, as described in Chapters 3 and 4. For the channel sites this was not such a problem, as plots were generally located in similar situations, adjacent to the edge of the channel. However, in the case of seeps, observations of the variability in moisture regime across the sites during the study period indicated that the single hydroperiod category attributed to the site as a whole did not describe the hydrology of different parts of the site adequately. Characterising the hydroperiod of each of the sometimes nine different plots, spread over the wetland, according to this one hydroperiod factor, was considered spurious. Two changes in the analysis were made to address this, within the limitations of the data:

Firstly, the degree of association between the flora of each ecoseep and its hydroperiod was examined, to determine whether there was a distinguishable suite of “wet seep” species and “dry seep” species.

Secondly, a number of the soil moisture probes was located close to vegetation plots, and the moisture regime at these points was described and categorised (see Section 5.3.2). A subset of 42 vegetation plots was identified which were each within 10 m of a soil moisture probe, and thus deemed to be associated with a fine-scale hydrological descriptor. The analysis of plant community differences related to variation in soil moisture regimen was thus conducted using the data from the 42 selected plots.

In addition to multivariate methods, the proportion of functionally obligate wetland and riverine species in each wetland type was calculated to determine if there were statistical differences in the proportion of seep or channel obligates and of terrestrial species in the flora of the ecoseep and ecochannel sites (Student's T-test with unequal variances; STATISTICA Version 8). Each species recorded in the samples was coded according to whether it was a riverine (= channel) or wetland (= seep) obligate or both, or whether it was terrestrial (i.e. dryland species not normally associated with wetland or riverine ecosystems). These preferences for one or other wetland ecosystem type, whilst sometimes subjective, were derived from detailed field observations recorded within SaSFlora (1998 – 2010), from the Cape botanical conspectus (Goldblatt & Manning, 2000), a review of the literature, and from personal experience in the field. Details of wetland (seep) and riverine (channel) obligacy or terrestrial affinity thus assigned to the species recorded at the ecological monitoring sites are included in Volume B: Appendix 7, Table 7.1.

6.2.3 Individual species responses

For both physiognomy (morphology of the plant) and physiology, five leaves from each of at least three individuals per community were labelled with an aluminium tag with the site name and plant number. Plants were selected randomly throughout each site to reduce trampling effects.

A variety of growth forms was assessed and these were:

i) tall, deep rooted shrubs (e.g. *Leucadendron salicifolium*);

ii) shallow rooted, mid high shrubs e.g. *Berzelia lanuginosa*;

iii) small to dwarf shrubs e.g. *Erica hispidula*; and

iv) shallow rooted restioids e.g. *Elegia mucronata* and cyperoids e.g. *Neesenbeckia punctoria.*

For each plant the following environmental details were also recorded: altitude, micro environmental details such as erosion, soil colour and broad soil type, and prevailing weather conditions. Observations were undertaken in winter 2008 and summer 2009.

Physiognomy

A 5 m yardstick was used to measure the height of selected individuals. Very few plants exceeded 5 m and in such a case, an approximate measurement was recorded. An aluminium tag with the site name and plant number was tied to the plant to ensure the same individual was assessed in subsequent surveys. At each assessment a digital photograph of each individual was taken from a fixed point (i.e. the distance and direction were noted the first time and used in subsequent monitoring), with the images appearing in Volume B: Appendix 8.2. The vigour of each plant was subjectively estimated by recording percentage of healthy shoots and leaves.

Physiology

Water potential (sap pressure)

Plant water potential or plant moisture water stress (PMS) was measured with a Scholander Bomb. PMS integrates the soil moisture tension in the rooting zone (the water supply), the resistance to water movement within the plant, and the demands for transpiration imposed by the environment (heat load, humidity, wind, etc.). Such a measurement thus indicates the inherent water status of a plant.

Shoots - or stems as in the case of aphyllous graminoids - of selected species were removed with a pair of secateurs and placed in the pressure chamber of a Scholander Bomb. Nitrogen gas was used to apply pressure to the shoot or stem and pressure readings taken when the plant exuded sap at its cut end. The pressure required to force the sap out is equal to the internal (sap) pressure in the plant when it was cut. The higher the pressure needed to do this, the higher the water stress (low water potential) in the plant. The pressure is expressed as a negative value, where readings with greater negativity indicate higher stress. Plants were sampled in winter 2008 (daylight) and summer 2009 (pre-dawn), but with a further winter 2009 pre-dawn sampling from Kogelberg added to the analysis to determine the outcome of this approach between similar seasons (see below).

Leaf porometer

A Decagon Leaf Porometer, model SCI, was used to measure stomatal conductance on selected species - effectively how much water is lost per unit area per time from the leaf – through measuring the vapour flux from the leaf to the atmosphere under natural conditions. Vapour flux is determined from the vapour pressure gradient between the diffusion path and the known vapour conductance through the fixed path, and this is the stomatal conductance.

The device consists of a hand held enclosure with a cable connected to a leaf clip sensor. The sensor is designed to maintain ambient air temperature and humidity around the leaf. The clip is clamped over the leaf and a reading is taken after about a minute. The readings are expressed as millimols m^{-2} sec^{-1}. Only broad leaved species were assessed as this method does not cater for narrow or ericoid leaves, or aphyllous photosynthetic stems.

During the winter 2008 sampling, porometer readings were obtained from the top side of the leaf. After consultation with other botanists, it was recommended that the bottom surface of the leaf should be measured. It was found that top surface leaf measurements were too time consuming to obtain as fynbos leaves generally have fewer stomata there with the majority being located on the leaf under-surface. Thus both top and bottom porometer readings were taken during the summer 2009 sampling period, whilst bottom readings only were recorded from winter 2009.

Species were selected on strict criteria - based on the presence of broad-leaves (a limitation of the technique). Where possible, leaves were sampled on the northern side of the plant, except where access to the plant was difficult. Leaves of *Metrosideros angustifolia* were often too narrow on the northern side, in which case the broader, shaded leaves were sampled. Several species with thicker leaves, such as *Platylophus trifoliatus* and *Brachylaena neriifolia*, did not always respond consistently.

Chlorophyll content meter

The CCM-200 Chlorophyll content meter was used for measuring leaf chlorophyll and is an easy to use hand held device that provides rapid and precise readings for monitoring plant stress and leaf senescence on broad-leaved plants. The device can store up to 4000 measurements, which makes it ideal for fieldwork. Chlorophyll measurement is by way of a leaf sensor clip which is attached to the top of the leaf and the resultant chlorophyll reading taken. The device works well on broad-leaved plants but not at all on ericoid-leaved species or aphyllous stems. Leaves of a consistent age, size and position were sampled.

Data analysis

For all the species-response data, an attempt was made to describe “typical” response profiles of the different species and to discern seasonal differences in these responses, by graphical presentation and univariate statistical analysis of differences.

6.3 RESULTS AND DISCUSSION

6.3.1 Seep and channel mapping

Most seeps in the study were delineated using an accurate differential GPS, as described in the methods, providing baseline data for future monitoring. Maps appear in Volume B: Appendix 1. Channels were not mapped in this way owing to access and GPS signal difficulties in dense vegetation, which is a limitation on this approach.

The GPS-mapped seeps and channel locations were overlaid onto the aerial photography taken for the study (see section 6.3.2), using ArcMap. The resolution of these photographs was too coarse to enable accurate mapping of seep and channel edges, and are not considered to be useful for monitoring of changes in this edge over time. Determining the edge of each riparian zone was particularly difficult where the line between riparian and seep vegetation is blurred.

6.3.2 Normalised Difference Vegetation Index (NDVI)

To test NDVI as a method for measuring change in vegetation state, a comparison of the Oudebos_K1_seep was made between December 2008 and March 2009. The changes in infrared reflectance between the two seasons was calculated using the orthoviewer technique, at four levels - a change of 5%, 10%, 15% or 20% in reflectance respectively, which were chosen to illustrate how the method may be adjusted depending on which level of change is of interest or regarded as ecologically significant.

Figure 6.1 clearly shows the position of the K_1 seep (bright green in the RGB image, indicated by an arrow) surrounded by the grey-brown of dryland fynbos; the more intense green in the upper part of the same image is the K_2a channel site. In the second photograph, the near infrared (NIR) image shows the seep and channel as red, generally indicating those plants which are not stressed. The next four images represent differences in plant response between December 2008 and March 2009, over a period in which rainfall and soil moisture decreased. The four figures show reflectance differences of 5, 10, 15 and 20% respectively. The colours represent the direction of change: red = reduction in reflectance, associated with less vigour, black = no change; green = an increase in reflectance / vigour.

In the “5% image”, most of the area is red, meaning a reduction in reflectance (i.e. of 5% or more) and suggesting an increase in stressed plants. A small portion of the site is unchanged (black), whilst patches of the seep and channel vegetation has increased in reflectance (green). In the “20% image”, far less of the area has undergone a 20% (or greater) change in reflectance, as might be expected. The red portions are restricted to the dryland parts of the site, whilst the seep and channel areas are shown as black, indicating that their reflectance, as a surrogate for water stress, was unchanged over the time interval, using 20% change as a threshold.

These results illustrate the different conclusions that may be drawn, depending on the thresholds that are set for the calculation of change in reflectance, but also that the technique has considerable potential to quantify change at a landscape level.

6.3.3 Flora

A complete list of the plant species (total species complement for the study; composite lists for each site; individual site lists) identified at each of the 40 sampling sites is provided in the data CD. The following section provides some general but noteworthy observations on the floristic composition of each TSA and, separately, of each of the sites

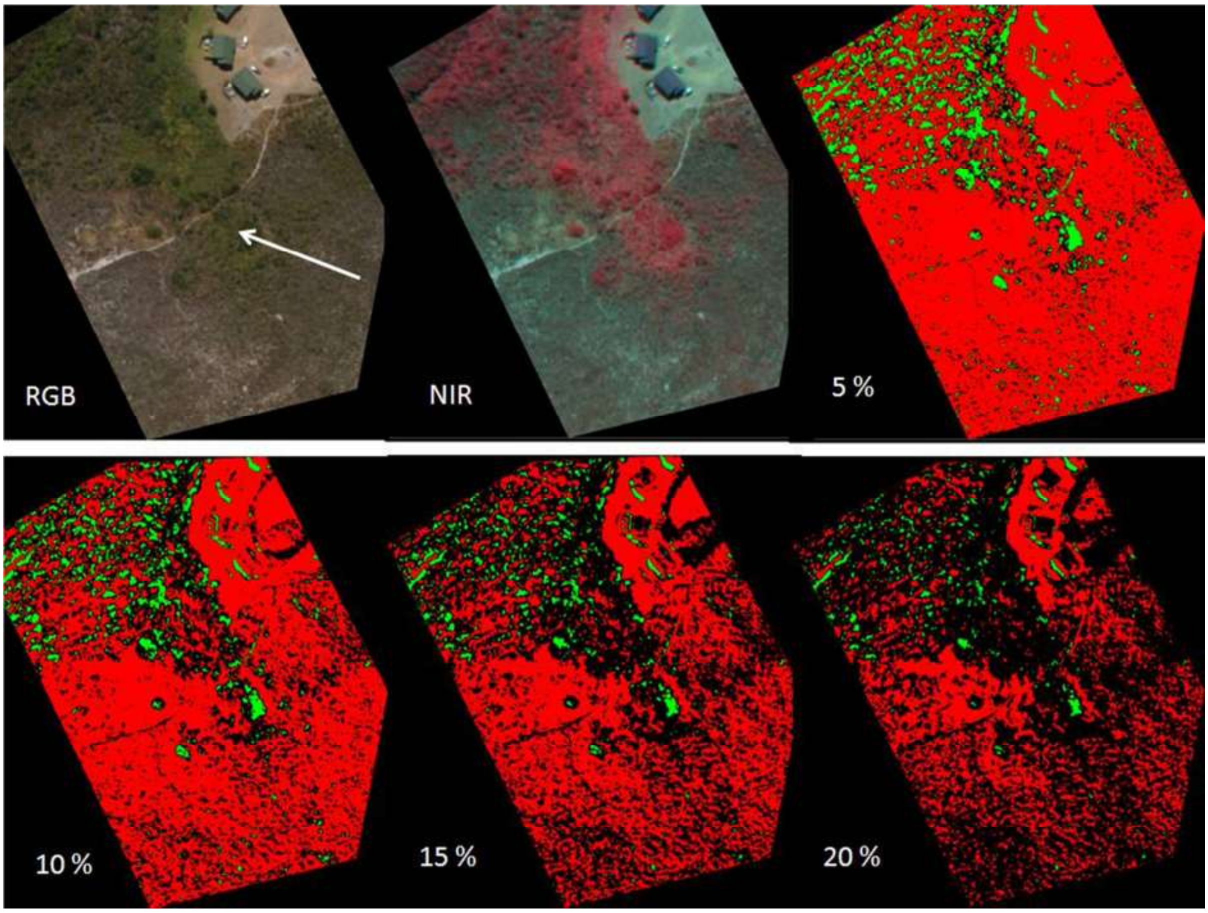

Figure 6.6.1. Comparison of December 2008 and March 2009 aerial photos for NDVI changes set at 5% to 20% at the Oudebos K1 seep (arrowed, top left). The last four images indicate the response of the fynbos vegetation to decreased wetting (lower rainfall and soil moisture status) over this period. In general red indicates vegetation which has become more stressed, green indicating no or little stress–manly the seep and channel) and black where there has been no change. RGB = standard colour photo with red/green/blue, and NIR = near infrared.

6.3.3.1 Family dominance

In comparison with the Cape Floristic Region (CFR) flora (Goldblatt & Manning, 2000) the ecological monitoring sites were characterised by a high concentration of species in few families: 61.4% of the species in the study are confined to just six families (Table 6.1), whereas for the whole CFR, these families contain only half (30.6%) of this percentage. This is probably due to the specialised character of wetland habitats. In terms of the contribution of major families to species richness, an important difference between the wetlands comprising the ecological monitoring sites and the CFR is the dominance of the Restionaceae (Cape reeds) in the former, whilst this group is only ranked eighth in terms of its species richness for the CFR. Similarly, the Ericaceae, Cyperaceae and Poaceae make a proportionally higher contribution to species richness in these wetlands than do they to the CFR. The dominance of the graminoids (reeds, sedges, grasses and rushes) is significant as this group has been found to be prominent in wetland and riverine studies elsewhere in both montane (e.g. Sieben, 2003) and lowland (Low & Pond, 2003) systems in the Cape. This coarse-level observation may be a useful measure to monitor, since a shift from dominance by these families may indicate change in habitat conditions away from those that define the wetland flora.

Table 6.6.1. Contribution of major plant families present in TMGA wetlands to species richness, compared with that of the Cape Floristic Region (CFR). Data are provided for seeps and channels, and collectively for TMGA wetlands, and for the CFR as a whole. The number of species in each family is given, along with the percentage that this number is of the total number of species. The ranking of each plant family is given in brackets. The ranking of families in the case of the CFR includes additional plant families not represented in this table, hence rankings are not listed as 1 to 6.

FAMILY	TMGA: SEEPS (245 species)	TMGA: CHANNELS (280 species)	TMGA: ALL SITES (355 species)	CFR (9000 species)
RESTIONACEAE	40 (16.3%) (1)	47 (16.8) (1)	53 (14.9%) (1)	318 (3.5%) (8)
ASTERACEAE	38 (15.5%) (2)	30 (10.7%) (3)	48 (13.5%) (2)	1036 (11.5%) (1)
ERICACEAE	24 (9.8%) (3)	34 (12.1%) (2)	42 (11.8%) (3)	658 (7.3 % (4)
CYPERACEAE	22 (9.0%) (4)	26 (9.3%) (4)	33 (9.3%) (4)	206 (2.3%) (12)
POACEAE	16 (6.5%) (5)	24 (8.6%) (6)	26 (7.3%) (5)	207 (2.3%) (11)
PROTEACEAE	12 (4.9) (6)	12 (4.3%) (6)	16 (4.5%) (6)	330 (3.7%) (7)
Total	**152 (62.0%)**	**173 (61.8%)**	**218 (61.4%)**	**2755 (30.6%)**

Note: when adding channel and seep species, the total is more than that of the fourth column, as some species occur in both ecosystem types.

6.3.3.2 Geographical patterns

The TSAs represent geographical locations, significant differences between which have been found for summer and winter rainfall (section 2.3.4), with the Kogelberg (K) and Steenbras (H) TSAs generally wetter in summer and the Wemmershoek (W7), Nuweberg (T3, T4) and Purgatory (T8) locations receiving greater winter rainfall, at least over the last decade of record. Similarly, soil moisture differences were found between some of the TSAs, with summer soil moisture being greatest at B1_1 and very low in TSA T4_RSE and V3 (refer to section 5.3.1). The only chemistry differences observed at the level of TSA was that of higher electrical conductivity in surface and groundwater at Kogelberg and Steenbras.

The cluster dendrogram (Figure 6.2a) and ordination plot resulting from MDS analysis (Figure 6.1b) show the relationship between the TSA areas based on their floristic composition as a whole. For this analysis the total list of species recorded in each TSA as a whole was compared. The cluster plot shows the branching off of TSA units at different levels of similarity, and these relationships are presented in 2-dimensional space in the MDS plot Figure 6.2b, where the distance between points is a reflection of the degree of similarity between them. The greater the distance, the lower the similarity; there is less than 50% similarity between the different TSA's.

The spatial separation of TSAs shows some correspondence to the differences in summer rainfall and soil moisture levels as described above (refer to Table 2.3 for details), with TSAs T4_RSE and V3 (low soil moisture in summer) separating at low levels of similarity. However, rainfall / moisture did not explain the similarity between W7 (wettest winters, wet overall) and T6 (generally low rainfall, although higher than V3).

Some consideration should be given to the fact that very different levels of effort were spent in each TSA, corresponding to both the number and the type of sites visited during the study, and this may skew the patterns quite markedly. An example is TSA B1, where the flora is represented by the

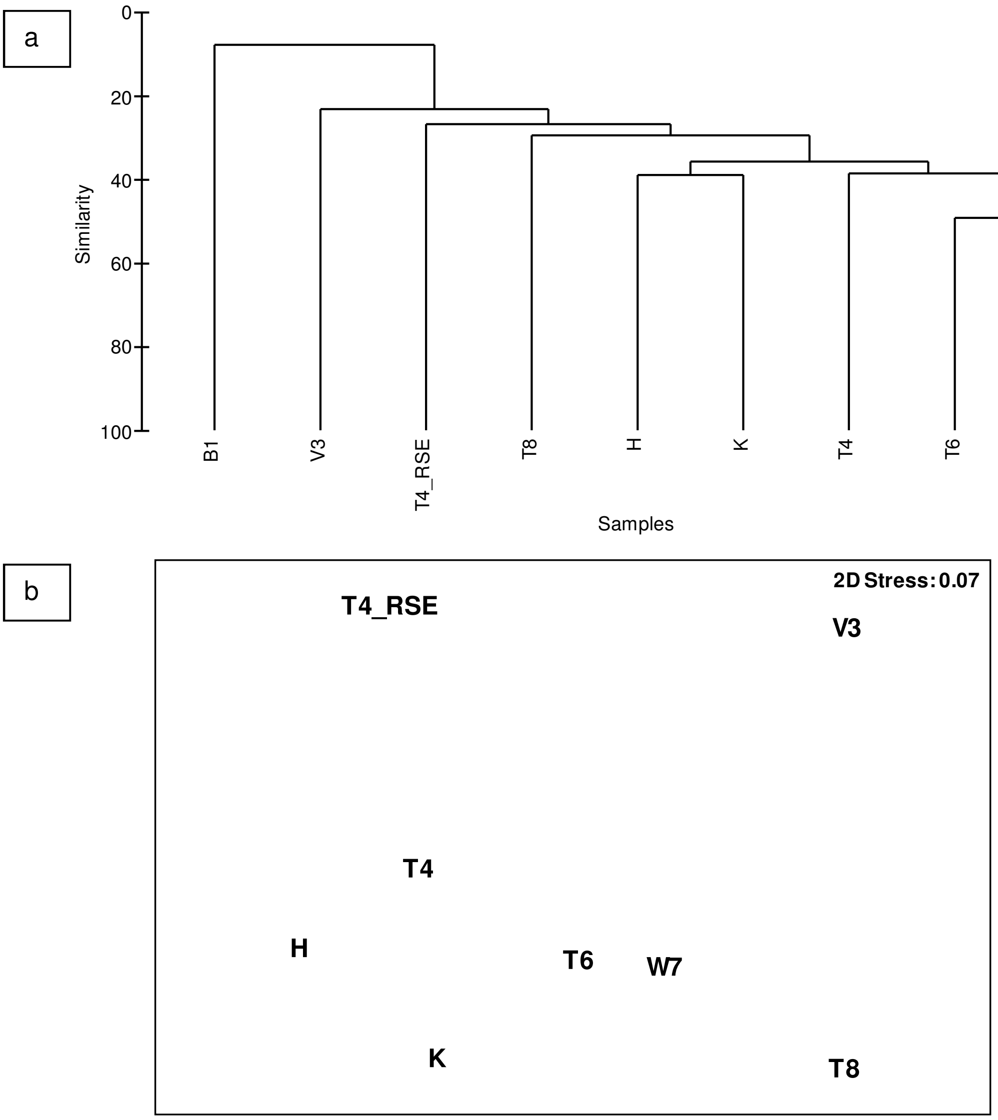

Figure 6.6.2. **Cluster (a) and MDS (b) plots of the relationship between TSAs based on comparison of their floristic composition (species presence). The distance between points is an approximation of the Bray-Curtis similarity between TSA floras. TSA B1 is not shown in the MDS plot because of the magnitude of difference from the other TSAs.**

species list from only one locality, and this is substantially dissimilar from the other TSAs (so different that it could not be represented in Figure 6.2b).

Indeed, where the individual sites are compared on the basis of their flora (Figure 6.3), there is very little tendency for sites to group by TSA, with the exception of the Wemmershoek and Zachariashoek sites which lie in adjacent catchments. Instead, as will be pointed out below, a clear trend was observed – separation of sites according to ecosystem type (namely seep or river channel: solid or open symbols) with an added dimension being that of hydroperiod (colour coded according to the figure key).

Two important observations from this analysis were the floras of ecoseeps and ecochannels were shown to be distinct except for those channels that were categorised with hydroperiods C (drying seasonally to pools) and D (seasonally dry). These “dry channels” (denoted in Figure 6.3 by open

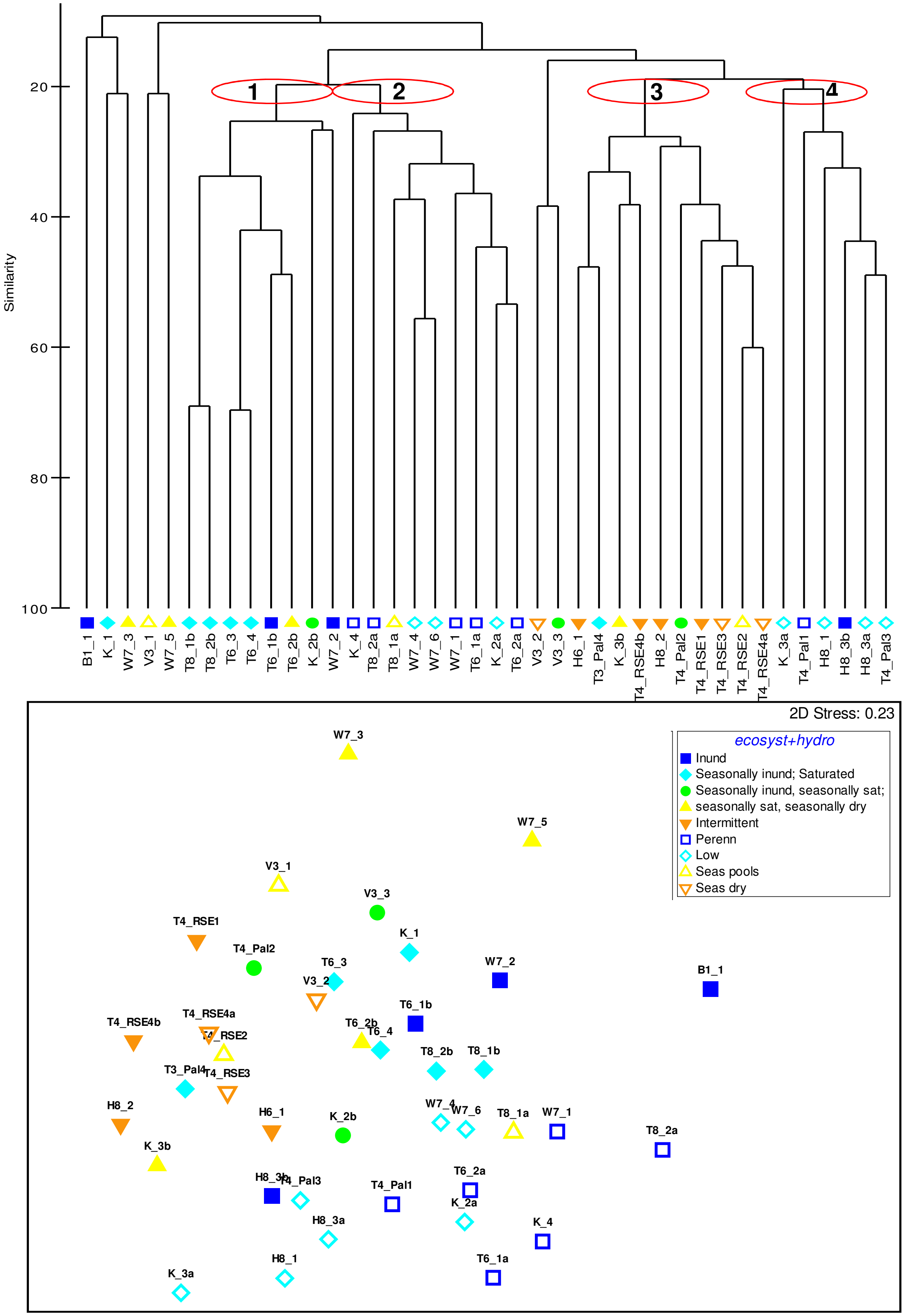

Figure 6.6.3. **Relationship between sites based on their flora. Seeps are solid symbols, channels hollow symbols, with hydroperiod as per the key. Red ovals denote groupings that were subjected to SIMPER species analysis.**

yellow and orange triangles) grouped together with the seasonally saturated and intermittent seeps (solid yellow and orange triangles), although there was some spread in the data.

6.3.3.3 Differences in seep flora based on hydroperiod

A SIMPER analysis was undertaken to identify the species differences between the different seep hydroperiod groups, as identified in Figure 6.3. Here the non-perennial channels, whose flora was shown to be similar to the seeps, were included in the analysis.

At 20% similarity, four main groups of sites were identified (Figure 6.3a, numbered in red ovals). The SIMPER routine in PRIMER was used to compare the plant species that were most responsible for the difference between the group of "wet" seeps (Group 1 in Figure 6.3a, comprising eight sites) and group comprising "dry" seeps and seasonal channels (Group 3 in Figure 6.3a, comprising ten sites), based on their floristic composition. The results (Table 6.2) show that the floras of the two groupings differ substantially in actual species presence, not only in the relative occurrence. Group 1 ecoseeps had more species that were unique to this group, similar species richness in both groups. Also, the species that were present in the "wet" seeps occurred more evenly at the sites, as indicated by the larger average occurrence in Table 6.2. These differences in species complement in seep groups of different hydroperiod may be important to track in the future: the implication that is suggested is that drying out of a seep may then be associated with shifts in those species that are predominantly associated only with "wet" seeps.

Since the vegetation sampling protocols adopted for channels allowed for the association with hydroperiod to be examined at community level, this is addressed in section 6.3.4.

6.3.3.4 Habitat signatures

The proportion of functionally obligate wetland and riverine species in the plant communities of seep and channel sites, and of terrestrial species, was calculated for the TMGA ecological monitoring sites (see Volume B: Appendix 8.3 for the designation of each species as seep or channel obligate, or non-wetland (terrestrial)). Seeps supported a larger proportion of obligate wetland species than their channel counterparts (t-test, $p = <0.05$). The channel communities, as might be expected, supported significantly higher proportions of true riverine species (t-test, $p = <0.0001$) with on average 14.7 % of the flora comprising river obligates at the channel sites, as against only 2.3 % at the seep sites (Table 6.3). The high proportion of species with an affinity for both river and wetland habitats (48.6 and 51.5% respectively, no significant difference) in both channel and seep communities emphasises that at least parts of these ecosystem types are not fundamentally distinct entities that support unique floras. Especially in mid and high altitude montane areas, channels are narrow and riparian zones often fed by seepage from the valley slopes, creating an ecotonal environment between the two hydrogeomorphic entities which is reflected in species whose affinity is for both. In addition, many channel species were collected from sandy river banks with an edaphic and moisture character (see elsewhere in this report) more similar to seeps than the adjacent rocky channel. Correspondingly, mid-channel endemics such as *Isolepis digitata* and *Pseudobaeckia africana* are unlikely to colonise seeps due to their habitat specificity. Comparable trends are echoed in a number of Western Cape montane and lowland rivers, and high altitude wetlands (Low & Pond, 2003; Low, unpubl.) included as reference (Table 6.4).

Proportion of terrestrial (i.e. dryland) species was slightly higher in the seeps (38.4 vs 31.9%; $p = <0.05$), suggesting that this habitat may have a lower specificity and is more homogenous than that of the channels. Seasonal droughting would also play a role, particularly on the seep edges where many of the terrestrial species were recorded.

Table 6.6.2. SIMPER results showing differences in species occurrence in the group of perennially inundated or saturated ecoseeps (Group 1 in Figure 6.3) and in the group of ephemeral ecoseeps and seasonal channels (Group 3 in Figure 6.3), identified through Cluster analysis. The taxa contributing to 50 % of between-group dissimilarity are shown. Average dissimilarity between the paired groups is provided for each species, as well as the Dissim / SD ratio. The taxa that were best differentiators between the vegetation groupings are those with a higher Dissim / SD. The abundance data are relative occurrence of the species in each of the sites included in each grouping. Shaded cells show species that were present in only one of the groups under comparison, emphasizing the fact that changes in species complement, rather than simply relative abundances were responsible for much of the differences between the floras of these groupings.

	Group 1: "Wet" seeps	**Group 3: "Dry" seeps and channels**			
Species	**Av.occurrence**	**Av.occurrence**	**Av.Diss**	**Diss/SD**	**Contrib%**
Struthiola myrsinites	0.88	0	3.64	2.14	4.51
Pteridium aquilinum subsp. aquilinum	0.75	0	2.96	1.57	3.66
Cassytha ciliolata	0.88	0.2	2.9	1.46	3.59
Anthochortus graminifolius	0.63	0	2.54	1.2	3.14
Osmitopsis asteriscoides	0.63	0.2	2.4	1.06	2.97
Berzelia lanuginosa	0.38	0.8	2.34	1.08	2.9
Erica intervallaris	0.5	0.9	2.05	0.94	2.53
Epischoenus gracilis	0.25	0.5	2.03	0.92	2.51
Restio bifarius	0	0.5	2.02	0.91	2.5
Elegia asperiflora	0.75	0.5	1.98	0.94	2.45
Leucadendron salicifolium	0.5	0.3	1.93	0.94	2.39
Neesenbeckia punctoria	0.5	0.1	1.91	0.96	2.37
Psoralea gigantea	0.5	0	1.89	0.96	2.34
Erica hispidula	0.63	1	1.59	0.72	1.97
Tetraria bromoides	0.38	0	1.54	0.73	1.9
Ischyrolepis curviramis	0.25	0.2	1.38	0.68	1.71
Widdringtonia nodiflora	0.38	0	1.31	0.75	1.63
Cliffortia graminea	0.25	0.1	1.18	0.62	1.45
Restio dispar	0	0.3	1.14	0.63	1.42
Villarsia manningiana	0	0.3	1.12	0.63	1.39
Penaea mucronata	0.25	0	1.06	0.54	1.32
Restio purpurascens	0.13	0.2	1.04	0.59	1.28
Elegia mucronata	0	0.3	1.02	0.64	1.26
Leucadendron xanthoconus	0.13	0.2	1.01	0.59	1.25

Linked with the above and of particular significance, is the high degree of terrestrial (i.e. dryland) species which are present when a composite list is considered. Terrestrial species act as vagrants or even facultative wetland/riverine dwellers in these systems. The TMGA seeps collectively had 51.5% representation of normally terrestrial species, slightly more than high altitude wetlands in the Du Toits Kloof Mountains (45.2%) but lower than those on the upper plateau of the Kouebokkeveld (Turret Peak) and the lower Cedarberg valleys (Driehoek) where the percentage of terrestrial species was 65.2 and 58.8 percent respectively.

Table 6.3. Proportion of riverine (channel), seep (wetland), wetland/riverine obligates, and terrestrial (dryland) species occurring in the channels (top table) and seeps (bottom table) of the TMGA study

	% R	% W	% R/W	% T
T6_1A Channel	33.3	0.0	44.4	22.2
T6_2A Channel	18.2	3.6	45.5	32.7
K2A Channel	18.8	3.1	40.6	37.5
K3A Channel	8.7	4.3	54.3	32.6
K4 Dwars Channel	15.9	4.5	50.0	29.5
T4_PAL1 Channel	13.6	5.1	45.8	35.6
T4_PAL3 Channel	16.3	4.1	51.0	23.7
T4_RSE2 Channel	3.7	3.7	70.4	22.2
T4_RSE3 Channel	8.8	2.9	61.8	26.5
T4_RSE4 A Channel	11.4	5.7	57.1	25.7
T8_1A Channel	13.1	3.3	40.1	42.6
T8_2A Channel	15.5	1.7	48.3	34.5
H8_1 Channel	10.0	8.0	44.0	38.0
H8_3A Channel	11.5	3.8	55.8	28.8
V3_1A Channel	8.7	10.9	32.6	47.8
V3_2A	8.6	8.6	39.7	43.1
W7/1 Channel	23.4	4.7	43.8	28.1
W7/4 Channel	18.9	5.7	39.6	35.8
W7/6 Channel	17.2	3.4	39.7	39.7
Mean	14.7	4.8	48.6	31.9
SD	6.5	3.1	8.2	5.7
T6/1B Seep	2.6	7.7	53.8	35.9
T6/2B Seep	3.3	3.3	50.0	43.3
T6/3B Seep	0.0	0.0	52.9	47.1
T6/4 Seep	0.0	4.0	56.0	40.0
K1 Seep	4.9	2.4	39.0	53.7
K2B Seep	0.0	8.9	53.6	39.3
K3B Seep	0.0	9.5	61.9	28.6
T3_PAL4 Seep	5.6	8.3	47.2	38.9
T4_PAL2 ValBot Seep	0.0	14.3	51.4	34.3
T4_RSE1 Seep	0.0	18.2	59.1	22.7
T4_RSE4 B Seep	5.3	0.0	57.9	36.8
T8/1B Seep	3.0	6.1	54.5	36.4
T8/2B Seep	2.8	5.6	50.0	41.7
B1/1 Seep	0.0	3.4	65.5	31.0
H6/1 Seep	2.6	15.4	43.6	38.5
H8/2 Seep	2.2	8.7	30.4	58.7
H8/3B Seep	3.4	3.4	60.3	32.8
V3/3 Seep	2.8	11.1	38.9	47.2
W7/2 Seep	7.7	0.0	69.2	23.1
W7/3 Seep	0.0	25.0	40.0	35.0
W7/5 Seep	0.0	12.8	38.5	48.7
Mean	2.3	7.5	51.5	38.4
SD	2.3	6.5	9.5	8.8

Table 6.4. Characterisation of the TMGA seeps and channels in terms of their numbers and proportional representation of obligate wetland and riverine, or terrestrial, species. The number of species of each category in the wetland flora is provided, with percentage of total species number in brackets. Data for selected mid and high altitude montane wetlands and rivers of the south-western Cape are included for comparison (Low, unpubl. data, taken from SaSFlora, 1998 - 2010).

Wetland	Obligate riverine (channel) species	Obligate wetland (seep) species	Obligate river/wetland species	Terrestrial species	Total
TMGA seeps	8 (3.3)	26 (10.6)	84 (36.6)	127 (50.6)	245 (100)
TMGA channels	25 (8.9)	25 (8.9)	93 (33.2)	137 (48.9)	280 (100)
Reference seeps					
Driehoek (Cederberg)	0 (0.0)	8 (9.4)	27 (31.8)	50 (58.8)	85 (100)
Du Toits Kloof Mountains	0 (0.0)	25 (34.2)	15 (20.5)	33 (45.2)	73 (100)
Helpmekaar (Kouebokkeveld Valley)	0 (0.0)	16 (25.8)	21 (33.9)	25 (40.3)	62 (100)
Schoongezicht (Kouebokkeveld Valley)	0 (0.0)	8 (32.0)	9 (36.0)	8 (32.0)	25 (100)
Turret Peak (Kouebokkeveld Mountains)	1 (2.2)	8 (17.4)	7 (15.2)	30 (65.2)	46 (100)
Vredelus (Kouebokkeveld Mountains)	0 (0.0)	12 (27.9)	15 (34.9)	16 (7.2)	43 (100)
Wadrif (Kouebokkeveld Valley)	0 (0.0)	5 (13.5)	24 (64.9)	8 (21.6)	37 (100)
Reference rivers					
Elandspad	24 (21.1)	11 (9.6)	39 (34.2)	40 (35.1)	114 (100)
Twenty Four Rivers	19 (16.0)	9 (7.6)	36 (30.3)	55 (46.2)	119 (100)
Witels	20 (23.5)	5 (5.9)	29 (34.1)	31 (36.5)	85 (100)
Witte	15 (12.7)	16 (13.6)	41 (34.7)	46 (39.0)	118 (100)

The TMGA channels had a combined total of 48.9% terrestrial species, somewhat higher than most other rivers for which data are presented, with the exception of the Twenty-fours River, which had a similar percentage of terrestrial species (46.2%).

These patterns suggest that plant communities could change quite drastically if conditions conducive to expansion by their terrestrial species complement were to prevail, for example as a result of drawdown of groundwater, as wetland endemics “leak” from the system and are replaced by terrestrial (or facultative) species.

The percentage occurrence of terrestrial species in the TMGA ecoseeps and ecochannels comprising the Category A and B wetness or hydroperiod groupings was compared with those in the Category D and E seeps and Category D channels, in an attempt to investigate whether terrestrial vagrants were more prolific in seeps where hydroperiod was shorter. Significant differences were found for seeps (t-test, p = 0.03) but not for channels (p=0.08). Nevertheless, this approach has much merit, and may be refined once species identities are finalised. A second aspect of this analysis that warrants attention is the actual designation of obligacy status to the different species; most of the observations of species obligacy have been derived from accurate field observations over a number of years.

However there are still a number of species for which such accurate information does not exist, for example those species for which obligacy is inferred from species lists from known habitats and not direct observation. A more rigorous assessment of actual habitat occurrences in the CFR for these species would greatly enhance the reliability of obligacy designation in the region and should be undertaken for this study.

6.3.4 Vegetation

A list of vegetation sample plots established in each major physiognomic unit / vegetation stand identified at each ecoseep and ecochannel site is provided in Volume B: Appendix 8.2, along with the Braun Blanquet table. The location of each of the 227 sampled plots is shown in the maps in Volume B: Appendix 2. Species and cover data recorded from the 227 plots sampled in the study are provided in the accompanying data CD.

6.3.4.1. Patterns in community structure

At the level of individual plot data, the same relationship between seep and channel vegetation as was displayed by the floristic analysis was evident, with seeps being distinct from channels, except for Hydroperiod Category C and D ecochannels grouping with the ecoseeps (Figure 6.4). One other exception was that the T8_1a channel site, designated Category C, and clearly has a plant community that locates it within typical perennial riparian communities (arrow, Figure 6.4).

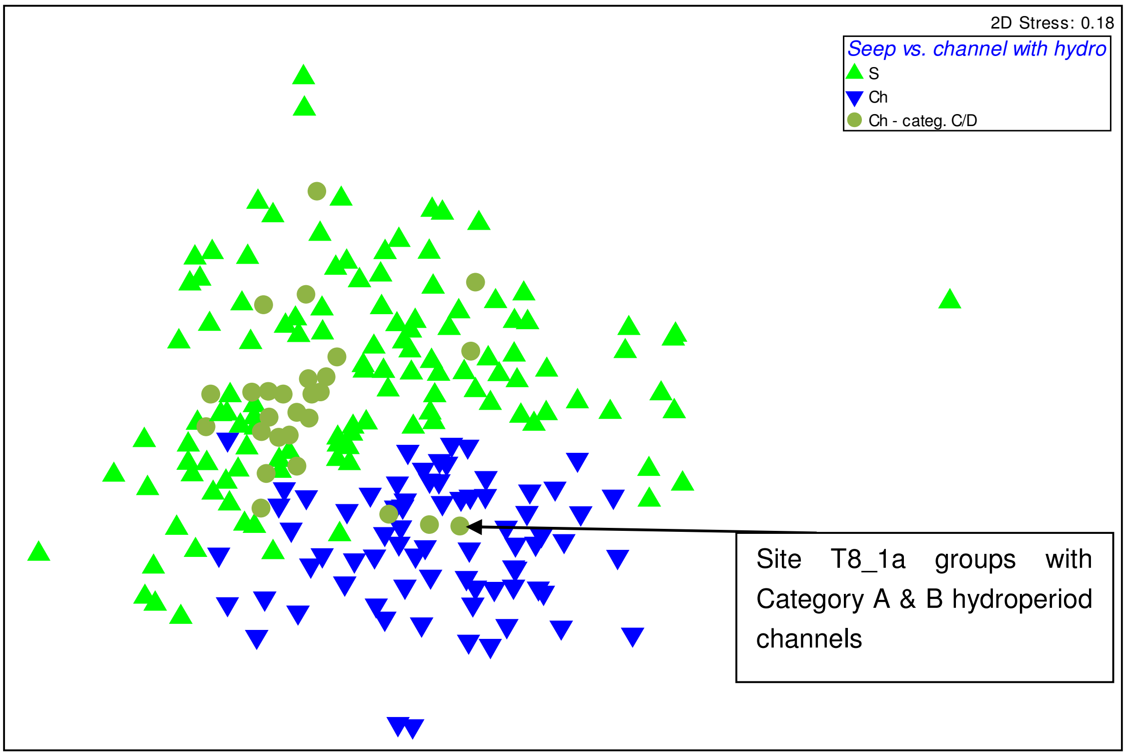

Figure 6.6.4. Results of MDS analysis of 227 vegetation plots at the 40 ecological monitoring sites. Plot samples are not labelled but show the clear distinction between plant communities sampled in the ecoseeps and perennial channel plots. A group of seasonal channels (Hydroperiod Categories C and D) group along with the ecoseeps, with the exception of T8_1 (arrow) whose communities have an affinity with perennial channels.

Using the Braun Braun Blanquet ("BB") data, Boucher (TMGAA review team) provided an analysis of community structure for incorporation into this report. He identified 45 communities or sub-communities, which are detailed in the BB table in Appendix 8.4 of volume B. However, Table 6.4 provides a summary schematic showing the spread of the 43 communities across the 40 ecological monitoring sites. Site hydroperiod is colour coded A – D or A – E (channel and seep respectively), although it is important to note that the basis for determining hydroperiod differed between seeps and channels. What is clear from the BB tables and the summary is that

- Riparian communities are distinct from seep communities, with some exceptions: as with the multivariate analysis, Boucher's communities from Category C and D channels contain typical seep communities.
- Furthermore, a group of ecochannels from Steenbras, Kogelberg and Nuweberg has stronger affinities with ecoseep community structure, on the basis of the prevalence of Berzelia-dominated communities there. This is possibly due to the narrower channels not supporting mature riparian scrub containing typical riverine species such as *Metrosideros angustifolia, Brachylaena neriifolia* and *Brabejum stellatifolium.*
- Many of the channel communities identified by Boucher included plots from different sites – i.e. were transcendent of site affinity.
- This was not so for the seeps, where Boucher's communities largely followed the physiognomic units (Plot A's, B's etc.), with a community only occasionally including plots from more than one site.
- Category A and B hydroperiod channels (light and dark blue) tended to have a greater diversity of communities, and similar communities across sites. These also differed from drier channels, which either shared community affinity with seeps, or were distinguished by their own community. An exception was Site T8_1a which grouped with the wet channels.
- No obvious relationships between communities at sites with similar hydroperiod were observed in the ecoseeps.

Further investigation of relationships between hydroperiod and plant communities, the focus of this study, was undertaken using multivariate analysis, but separating out the channels and seeps.

1.3.4.2. Channel communities

Multivariate cluster analysis and MDS of the channel communities from the plot data are shown in Figure 6.5 and 6.5. The clustering (Figure 6.5) demonstrates a close affinity between replicate samples of communities at the individual sites (i.e. those taken from the same physiognomic units), as well as a grouping across sites of similar communities defined by Boucher (e.g. Community group 3, including plots from T6_1a, T6_2a, and K_2a). There were some noticeable anomalies, however, for example the multivariate analysis showed a split in Community Group 2 samples from the Palmiet River (T4_Pal1) (green squares in the lower portion of Figure 6.5). Similarly, Boucher's Community Group 4 was fairly widely dispersed, suggesting that the grouping of samples in the BB analysis in this case may require revision or resampling of field plots.

Figure 6.6b show that vegetation communities were strongly differentiated according to hydroperiod, despite hydroperiod being defined at a site level only. A 2-way analysis of similarity (ANOSIM) examining hydroperiod differences, but crossed with the community defined by Boucher as a grouping factor to account for variability in communities at the sites, showed a very high level of differentiation (Table 6.5), with strong gradients in community pattern associated with hydroperiod. These results

Table 6.4. Schematic showing the spread of Boucher's 45 Braun Blanquet plant communities across the ecological monitoring sites. Channel sites are shown first, then seeps, both in alphabetical order. Sites are colour coded to differentiate hydroperiod categories (refer to Tables 3.3 and 4.4 for details).

Community	H8_1	H8_3a	K_2a	K_3a	K_4	T4_Pal1	T4_Pal3	T4_RSE2	T4_RSE3	T4_RSE4a	T6_1a	T6_2a	T8_1a	T8_2a	V3_1	V3_2	W7_1	W7_4	W7_6	B1_1	H6_1	H8_2	H8_3b	K_1	K_2b	K_3b	T3_Pal4	T4_Pal2	T4_RSE1	T4_RSE4b	T6_1b	T6_2b	T6_3	T6_4	T8_1b	T8_2b	V3_3	W7_2	W7_3 (top)	W7_5
Brachylaena neriifolia-Prionium serratum Riparian Fynbos Shrublands	■	■	■		■	■					■	■	■					■																						
Prionium serratum-Askidiosperma chartaceum Riparian Fynbos Shrublands						■																																		
Prionium serratum-Ischyrolepis subverticillata Riparian Fynbos Shrublands			■								■	■																												
Prionium serratum-Pseudobaeckea africana Riparian Fynbos Shrublands	■	■				■	■						■					■	■																					
Isolepis digitata subtype of Prionium serratum-Pseudobaeckea africana Riparian Fynbos Shrublands		■											■																											
Berzelia squarrosa group of Prionium serratum-Pseudobaeckea africana Riparian Fynbos Shrublands						■	■												■																					
Erica labialis subtype of Prionium serratum-Pseudobaeckea africana Riparian Fynbos Shrublands							■																																	
Gnidia oppositifolia subtype of Prionium serratum-Pseudobaeckea africana Riparian Fynbos Shrublands						■													■																					
Brachylaena neriifolia-Calopsis paniculata Riparian Fynbos Shrublands						■							■	■			■		■																					
Species common to the Rivers in the South-Western Fynbos Biome	■	■	■		■	■	■				■	■	■	■			■	■	■																					
Todea barbara Wetlands											■									■																				
Brachylaena neriifolia-Cunonia capensis Riparian Forest											■																													
Isolepis costata Wetlands																■				■											■									
Berzelia lanuginosa Wetland Fynbos Shrublands								■		■															■		■								■					
Berzelia lanuginosa-Erica parviflora Wetland Fynbos Shrublands																■																					■			
Elegia capensis form of the Berzelia lanuginosa-Erica parviflora Wetland Fynbos Shrublands											■	■				■	■																							
Berzelia lanuginosa-Restio dispar Wetland Fynbos Shrublands	■																					■				■														
Berzelia lanuginosa-Grubbia rosmarinifolia Wetland Fynbos Shrublands	■	■		■																		■	■			■														
Erica tegulifolia form of the Berzelia lanuginosa-Grubbia rosmarinifolia Wetland Fynbos Shrublands							■																																	

Community	H8_1	H8_3a	K_2a	K_3a	K_4	T4_Pal1	T4_Pal3	T4_RSE2	T4_RSE3	T4_RSE4a	T6_1a	T6_2a	T8_1a	T8_2a	V3_1	V3_2	W7_1	W7_4	W7_6	B1_1	H6_1	H8_2	H8_3b	K_1	K_2b	K_3b	T3_Pal4	T4_Pal2	T4_RSE1	T4_RSE4b	T6_1b	T6_2b	T6_3	T6_4	T8_1b	T8_2b	V3_3	W7_2	W7_3 (top)	W7_5
Restio ambiguus form of the Berzelia lanuginosa-Grubbia rosmarinifolia Wetland Fynbos Shrublands																							■																	
Berzelia lanuginosa-Elegia mucronata Restioid Fynbos Wetlands									■													■	■																	
Restio pedicellatus form of Berzelia lanuginosa-Elegia mucronata Restioid Fynbos Wetlands																							■																	
Ehrharta ramosa form of Berzelia lanuginosa-Elegia mucronata Restioid Fynbos Wetlands																						■																		
Calopsis nudiflora form of Berzelia lanuginosa-Elegia mucronata Restioid Fynbos Wetlands								■	■																															
Berzelia lanuginosa-Galium spurium Wetland Fynbos Shrublands																																			■	■				
Leucadendron xanthoconus form of Berzelia lanuginosa-Osmitopsis asteriscoides Transitional Wetland Fynbos Shrublands																					■																			
Osmitopsis asteriscoides Wetland Fynbos Shrublands																																	■	■				■		
Osmitopsis asteriscoides-Tetraria bromoides Shaleband Wetlands																																	■	■						
Osmitopsis asteriscoides-Penaea mucronata Wetlands																																						■		
Ischyrolepis curviramis Restioid Fynbos Wetlands																													■			■								
Ischyrolepis curviramis-Micranthus alopecuroides Restioid Wetlands																																								■
Ischyrolepis curviramis-Psoralea gigantea Restioid Wetlands																															■			■						
Ischyrolepis curviramis-Restio confusus Restioid Wetlands										■					■																									
Erica cristiflora form of Ischyrolepis curviramis-Restio confusus Restioid Wetlands															■																									
Anthochortus laxiflorus-Ursinia caledonica Restioid Fynbos Wetland																												■												
Psoralea pinnata (cf.)-Myrsine africana Shrubland Fynbos Wetland																								■																
Elegia juncea Wetland Fynbos Shrubland																												■											■	
Elegia juncea-Merxmuellera cincta Wetland Fynbos Shrubland																												■				■								
Cliffortia graminea Wetlands																															■									
Searsia angustifolia Wetlands																																							■	
Cannomois virgata Wetlands																																■								

suggests that streamflow hydroperiod appears at the very least to represent a good surrogate for water availability to riparian plants, and that plant community structure appears to respond to this gradient in water availability.

Category C sites were not cohesive, however: as shown in the floristic analysis, plant communities at T8_1 were highly similar to Category B sites, and the hydroperiod categorisation of this site, at least from the perspective of the vegetation, does not hold. Further, although the plant communities at V3_2 group with the other Category D sites, V3_1 communities are very different in composition.

The SIMPER routine in PRIMER may be used to identify the species in any chosen group of samples that best characterise the group. This was run for the hydroperiod groups, in an attempt to identify "diagnostic species" for each hydroperiod category. However, this was not possible, since the differences in plant community within each hydroperiod group precluded the identification of a single or set of species that should be present at all sites (or all plots) of a given hydroperiod.

The importance of this finding for future monitoring is that, while channel hydroperiod as defined in this study appears to have a bearing on plant community, this is only when variability in the vegetation across sites is accounted for: sites with the

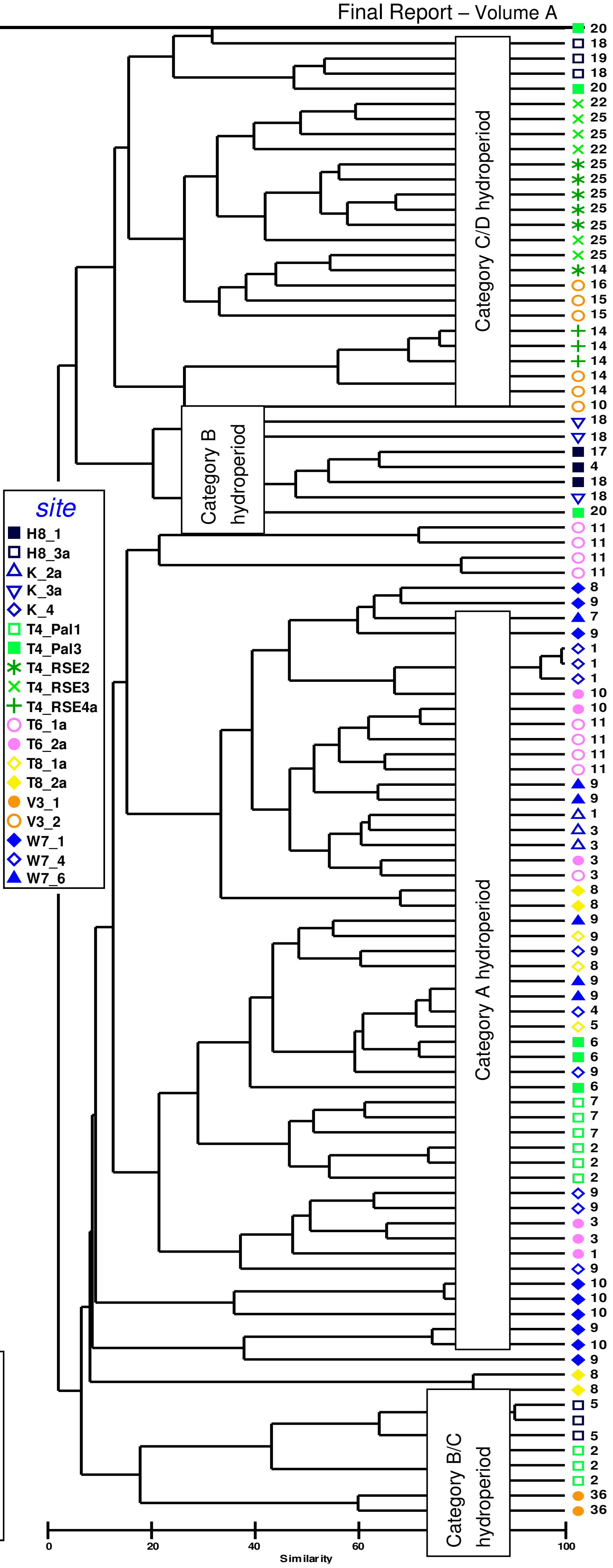

Figure 6.6.5. Cluster analysis of ecochannel plant communities. Sites are colour-coded, whilst the numbers refer to Boucher's community groupings as per Table 6.4.

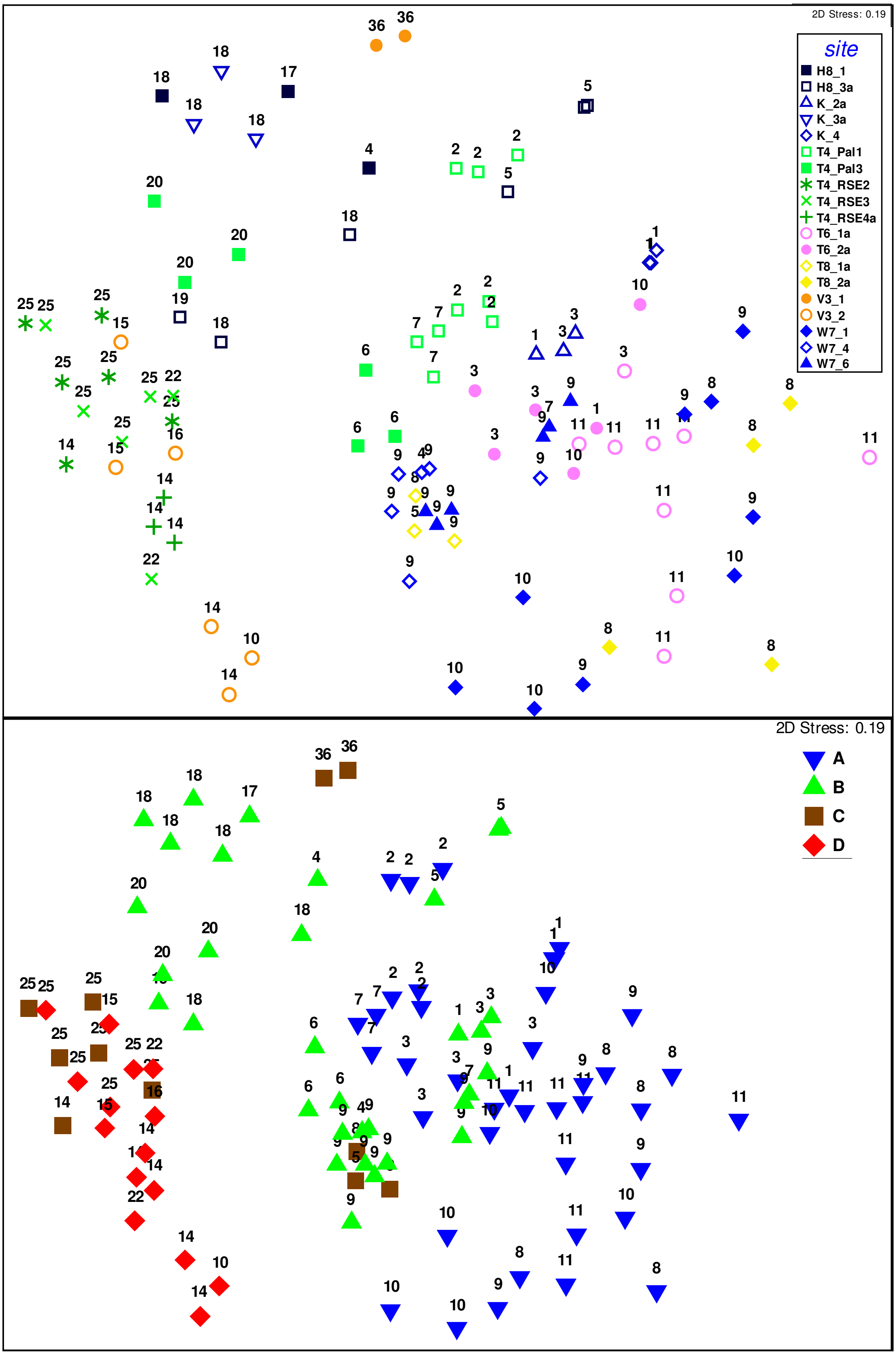

Figure 6.6.6. MDS plot of the relationship amongst the plant communities of channel plots. The plots are numbered according to their affinity to Boucher's community groupings as per Table 6.4. Colour coding (a) is according to site as per Figure 6.5, and (b) according to hydroperiod category for each site.

Table 6.5. Results of 2-way ANOSIM analysis for differences between CHANNEL samples grouped according to hydroperiod and across Boucher's community groupings.

Groups	Statistic	P level	Significant
GLOBAL R – differences between community groups	0.64	0.001	Yes
Pairwise groups			
GLOBAL R – differences between hydroperiod	0.61	0.001	Yes
Pairwise groups			
Category A vs. Category B	0.64		No
Category A vs. Category C	0.76		Yes
Category A vs. Category D	0.96		Yes
Category B vs. Category C	-0.06		No
Category B vs. Category D	groups too small		Yes
Category C vs. Category D	0.68		Yes

same hydroperiod may thus have significant differences in community structure, which makes the selection of "control" and "impact" sites in a monitoring programme complex.

1.3.4.3. Ecoseep communities

The distribution of communities over the ecoseep sites (Figure 6.7) showed similar trends as those observed in the case of ecochannels, namely a fairly clear site affinity, where most of the samples from each site were generally highly similar, as shown by the close grouping of site symbols in Figure 6.7. In most cases, as previously stated, Boucher's communities were synonymous with the plots within one or two physiognomic units at each site. Where these communities extended over more than one site, there was generally poor correspondence between samples as represented in the multivariate analysis: for example Community 12 (*Todea barbara* wetlands) was described at B1_1 and T6_16 (both circled in Figure 6.7). This may suggest that site affinity is somehow still stronger than the community groupings, but this apparent dichotomy needs to be further tested using more sites.

This variability in plant community was evident even within samples taken from seemingly similar physiognomic units, illustrating fine-scale differences in seep vegetation. Whilst the floristic analysis, on the basis of the total species lists for each site, showed a fairly good separation of "dry" and "wet" seeps (Figure 1.3) this same differentiation was not apparent at the fine and quantitative scale of plant communities from plot data at the sites. The ANOSIM returned a significant but very small R-value (Global R = 0.14, p = 0.003) indicating that the grouping of plant communities across the study area was largely independent of wetness category, as defined for the site as a whole. The failure of a single, site-based measure of wetness to describe the hydrological character of all communities at a site is not unexpected. However, it is also possible that the measure of wetness, based as it is on the position of the water table in the piezometer, does not reflect the amount and timing of soil moisture levels that influence plants themselves, certainly in the seeps. This matter is explored further in the following section using a subset of seep samples with linked soil moisture data.

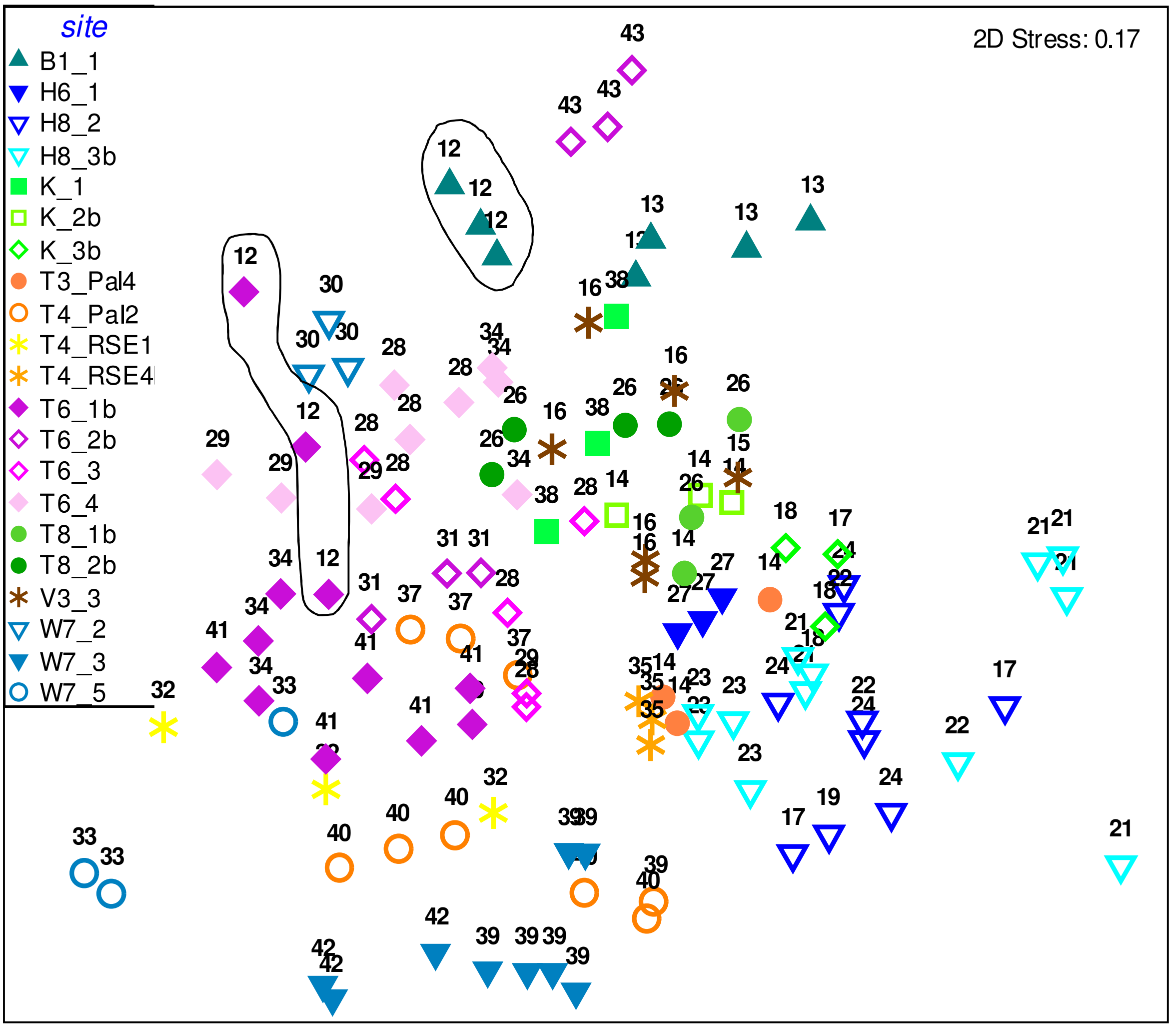

Figure 6.6.7. **MDS plot of the relationship amongst the plant communities of seep plots. The plots are numbered according to their affinity to Boucher's community groupings as per Table 6.4. Colour coding is according to site. Boucher's Community 12 is highlighted (circled) to illustrate how site affinity appears for the most part to override Community identify.**

Relationship between seep communities and soil moisture patterns

Since the seep hydroperiod categories at the scale of the whole site bore little relationship to community patterns, a subset of 19 vegetation plots which were closest to, and not more than 10 m from, vertical soil moisture probes were identified. The classification of the soil moisture regime (in Table 5.5) was used as a basis for analysis of similarities in the plant communities, linked to these probes. The decision to restrict the set of samples was because in the analysis using the first cycle of data, many of the probes were linked to more than one vegetation plot and this did not give satisfactory results. However, the current analysis unfortunately also failed to find a relationship between any measure of soil moisture or wetness and the plant community recorded at the vegetation plots. This may simply reflect the fact that the link between vegetation plot and soil moisture probe may have been at an inadequate spatial scale.

6.3.4 Individual plant responses

Plant vigour

The percentage of green leaves and shoots on selected plant species was recorded in the winter/spring 2008 and summer 2009 sampling periods. The difference between each time period was calculated and presented in Volume B: Appendix 8.5. Not all plant species occurred at all of the sites, and this is a major limitation of the study where direct comparisons are necessary. (In fact plant species homogeneity is not a strong facet of the overall study, as sites were selected on the basis of groundwater rather than biological characteristics.) Results were species and site specific. Even so, for the majority of species and sites there was not a significant change between the sampling times in either green shoot or leaf percentages. Overall average change in percentage of green leaves and shoots showed a general decrease between the two sampling periods, most likely due to seasonal changes in phenology (e.g. Pierce, 1984). Although there is no agreement as to major growth flushes in fynbos, proteas and several other groups are known to display a summer flush (Pierce, 1984) and this would suggest leaves and shoots should display a summer increase, at least in *Leucadendron* spp. Whilst there were site to site differences, it is unclear if these differences were due to a change in soil moisture content, temperature, wetland type or another factor(s).

Water Potential (sap pressure)

Results of the water potential or sap pressure data collection are presented in Volume B: Appendix 8.5. There was a significant relationship between temperature and recorded sap pressure (linear regression for the 2008 (winter / spring) data $p < 0.001$, $R^2 = 0.1$ and 2009 (summer) data $p<0.001$, $R^2=0.221$). The regressions, even though significant, do not show a very strong relationship, indicating that there are other factors such as species and time of data collection that also factor into readings. This is a key criticism of daylight measurements and the main reason behind a shift to pre-dawn sampling from summer 2009. Following discussions with further experts in the field and a 24 hr sampling Scholander Bomb study at the Kogelberg K_2b seep, it was decided to change the sampling to the pre-dawn hours between 02h00 and 06h00.

Despite the differences in collecting strategy, t-tests, or Mann-Whitney non-parametric t-tests were carried out to examine differences in sap pressure between winter / spring 2008 (data collected during the day) and summer 2009 (data collected pre-dawn) for species that were collected for both sampling periods. The overall results of 75 pair-wise comparisons (26 sites and 32 species) showed sap pressure to be significantly higher ($p<0.05$) in 2009 than 2008 in 77% of the tests. This indicates that there is a large seasonal difference: even pre-dawn summer readings were generally far lower than those of daytime winter / spring. Given that the end of summer is drier than that of winter/spring, the result is expected and most likely reflects summer increase in temperature and soil droughting.

The winter data collected during September 2009 (i.e. in the second monitoring cycle) were included in this revised annual report, for the purposes of illustrating the usefulness of this method to detect seasonal change, but using a consistent pre-dawn sampling strategy. Data from the Kogelberg TSA were selected for presentation. T-tests or Mann-Whitney U comparisons between summer and winter/spring 2009 Scholander Bomb values collected on different wetland plant species at six Kogelberg sites are thus presented in Table 6.6, and the graphs of the different species responses in Figure 6.8.

Differences between the two seasons may be grouped into three broad categories: species which show a decrease in sap pressure change in winter; species which show little change at all, and species which show some positive change. Marked decreases are shown by *Berzelia lanuginosa*

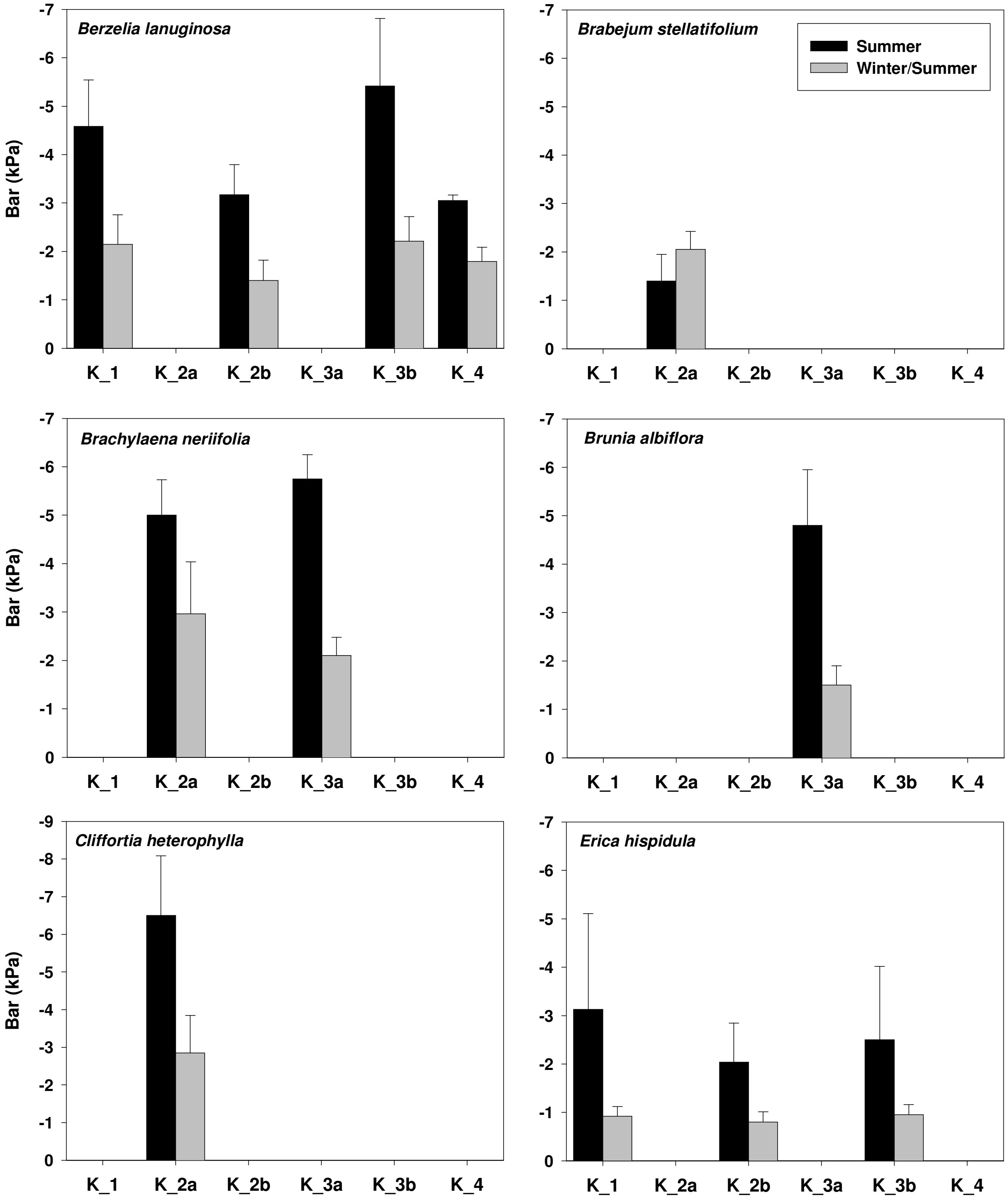

Figure 6.8. **Comparisons between summer 2009 and winter/spring 2009 pre-dawn Scholander Bomb values collected on different wetland plant species at six Kogelberg sites.**

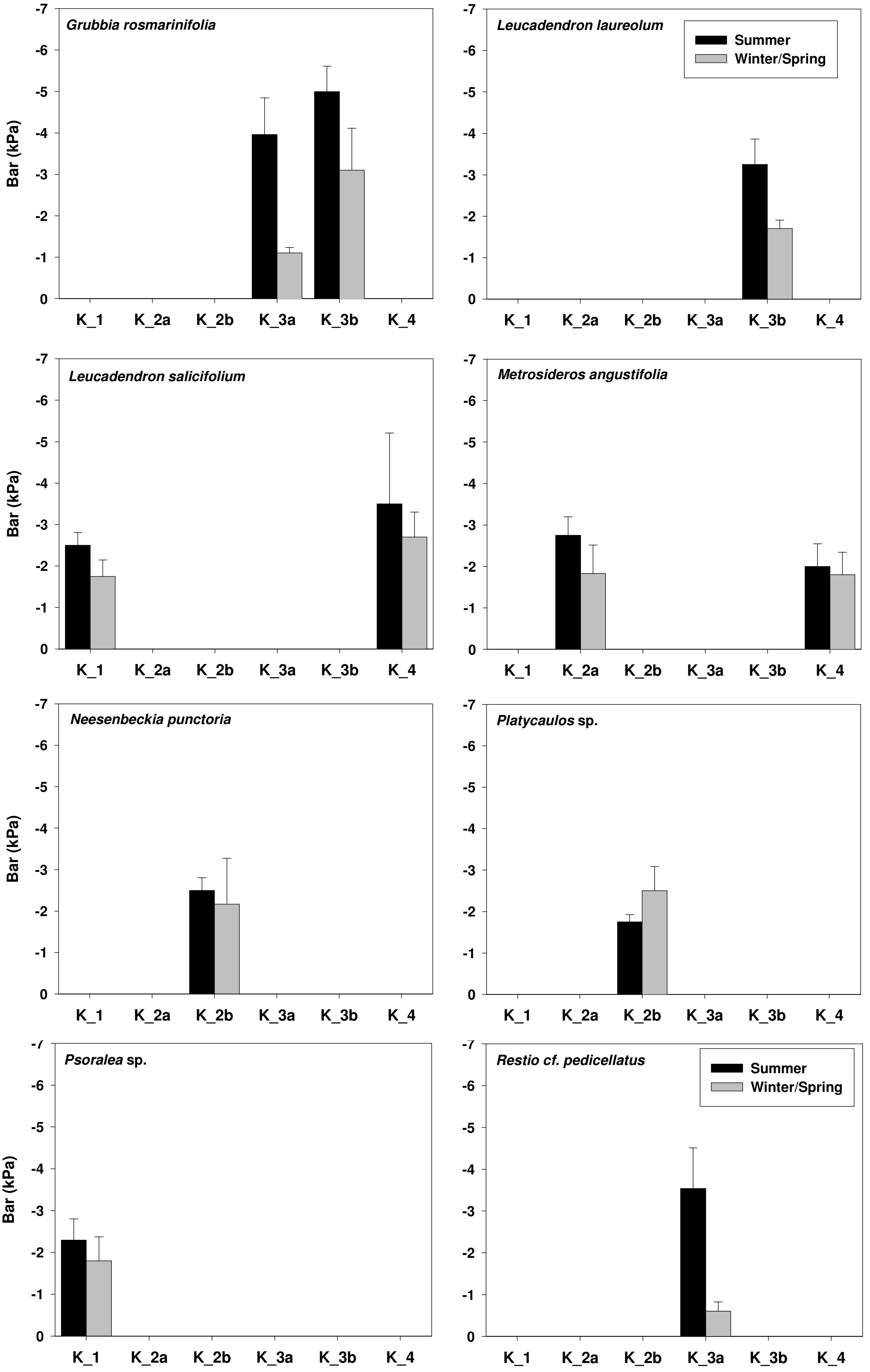

Figure 6.8 cont. Comparisons between summer 2009 and winter/spring 2009 pre-dawn Scholander Bomb values collected on different wetland plant species at six Kogelberg sites,

Table 6.6. T-test or Mann-Whitney comparisons between summer and winter/spring 2009 Scholander Bomb values collected on different wetland plant species at six Kogelberg sites. Statistically significant (P <0.05) differences between summer and winter values are highlighted in red. Data that did not have a normal distribution were analysed using the Mann-Whitney Rank Sum test.

		t-test results				**Mann-Whitney Rank Sum Test Results**				
Site	**Species**	**Difference in Means**	**t**	**d.f.**	**P**	**Difference in Medians**	**T**	**n(small)**	**n(big)**	**P**
K_1	***Berzelia lanuginosa***	-2.44	-5.573	11	<0.001					
	Erica hispidula					-1.5	21	6	6	0.002
	Leucadendron salicifolium	-0.75	-3.354	8	0.01					
	***Psoralea* sp.**	-0.492	-1.51	9	0.165					
K_2a	***Brabejum stellatifolium***	0.65	2.197	8	0.059					
	Brachylaena neriifolia	-2.036	-3.654	10	0.004					
	Cliffortia heterophylla	-3.65	-4.459	9	0.002					
	Metrosideros angustifolia	-0.917	-2.75	10	0.02					
K_2b	***Berzelia lanuginosa***	-1.767	-5.368	9	<0.001					
	Erica hispidula	-1.236	-3.294	10	0.008					
	Neesenbeckia punctoria					-0.625	22	5	6	0.177
	***Platycaulos* sp.**	0.75	2.739	8	0.026					
K_3a	***Brachylaena neriifolia***	-3.65	-13.007	8	<0.001					
	Brunia albiflora	-3.3	-6.063	8	<0.001					
	Grubbia rosmarinifolia					-3.125	45	5	6	0.004
	Restio* cf. *pedicellatus	-2.936	-6.539	10	<0.001					
K_3b	***Berzelia lanuginosa***	-3.208	-5.296	10	<0.001					
	Erica hispidula					-1	45	5	6	0.004
	Grubbia rosmarinifolia	-1.9	-3.599	8	0.007					
	Leucadendron laureolum	-1.55	-5.363	9	<0.001					
K_4	***Berzelia lanuginosa***					-1.313	15	5	6	0.004
	Leucadendron salicifolium					-0.875	37.5	5	8	0.724
	Metrosideros angustifolia	-0.2	-0.606	9	0.56					

(three sites), *Brachylaena neriifolia* (two sites), *Cliffortia heterophylla*, *Restio pedicellatus*, *Grubbia rosmarinifolia* and *Brunia albiflora*.

Erica hispidula, *Metrosideros angustifolia* and *Leucadendron laureolum* displayed lower differences. Both *Brabejum stellatifolium* and the restio *Platycaulos* sp. surprisingly produced increases in sap pressure and this might relate to consistent supply of water in perennially wet soils.

Miller *et al*. (1984), although using a different method, nevertheless provide one of the few accounts of xylem pressure conductances in the region. They showed broad grouping within major families and functional groups within the fynbos, over a range of -0.1 to -0.4 MPa (bar). Proteoids (here represented by *Leucadendron salicifolium*, *Brabejum stellatifolium* and *Leucadendron laureolum*) showed consistency over the study area indicating a possible mechanism for conserving water under stress (see also Specht, 1972). Ericoid and restioid groups were less consistent in their patterns of water use. Miller *et al.* (1984) suggest that rooting depth (and therefore access to soil moisture) plays a key role in influencing sap pressure.

For long term monitoring, these data will need to be coupled with soil moisture content, ground water table and other relevant environmental data. Each plant species has its own adaptation to stress and stressors, therefore sites will only be able to be compared where they have the same species, preferably in similar communities; however as discussed above, very few sites have similar plant communities and species dominants.

Leaf Porometer

A summary of the porometer data is presented in Volume B: Appendix 8.4. Due to data collection inconsistencies and difficulties – many species were not broad-leaved (an absolute pre-requisite for this method to work) whilst some would permit measurement during one season (leaves were sufficiently thin for the probe) and not in another (leaves had thickened) - there was insufficient data to compare between the two sampling periods. From the data in hand it does not appear that there is a difference between winter/spring 2008 and summer 2009. More consistent data collection with analysis against key environmental factors would be needed to fully determine the efficacy of this method for use in long term biological monitoring.

Fynbos leaf conductances were measured by Miller *et al.* (1984) who found values of between 1 and 20 mmols/sec. These measurements, taken in summer, compare with the lower levels from the TMGA study. Clear patterns were displayed between wet and dry systems and this suggests that droughting will impact on the water relations of plants – and therefore their distribution, for example through drawdown in a seep or river channel.

Leaf Chlorophyll Content

Leaf chlorophyll levels were not consistently higher or lower from site to site in 2008 or 2009 for each plant species that could be assessed. The summary of chlorophyll levels is presented in Figure 5a-c, Volume B. A series of t-tests, or Mann-Whitney non-parametric t-tests, was carried out for species that were collected for both sampling periods by each site. There were 35 pair-wise comparisons made, with 63% showing no significant difference between sampling periods. In the cases where there was a significant pair-wise comparison, 2009 was greater than 2008 the majority of the time and this might well support a summer growth flush in the fynbos (sensu Pierce, 1984). An inconsistency occurred within the same species where different sites showed different responses. Once again, more data would need to be collected, correlated and analysed with relevant environmental factors in order to fully determine how effective this method would be for long term monitoring.

However, it appears that different leaf thicknesses have a major influence on chlorophyll detection, making this an unsatisfactory method to be used in future (Prof. Valdon Smith, pers.comm.).

6.4 SUMMARY AND CONCLUSIONS

6.4.1 NDVI

Multispectral imagery was collected from the study area in December 2008 and March 2009. Its usefulness in providing a quantifiable measure that represents change in plant vigour was explored, for a single site within the Kogelberg. The results illustrate that wetland areas may readily be distinguished from terrestrial areas, and that clear seasonal shifts in reflectance can be measured, using different thresholds of change. Different conclusions may be drawn, depending on the thresholds that are set for the calculation of change in reflectance. Nevertheless the technique has considerable potential to quantify change at a landscape level, particularly as it enables, by virtue of the wide flying strip, a greater area, with additional channels and seeps, to be assessed.

6.4.2 Flora and vegetation

A total of 227 vegetation plots were sampled for the purpose of describing the plant communities within and across sites. Three sampling plots, rarely two, were established in each of between one and four stands of vegetation (physiognomic units).

At the level of the floristic composition of the 40 ecological monitoring sites, an interesting revelation from the study was that ecochannels with seasonal hydroperiods grouped together with seasonal seeps, whilst “wet” channels and “wet” seep plots were grouped into their own separate clusters. The plant species differences between the “wet seeps” and “dry seeps plus dry channels” may be useful as indicators of species replacement in the future.

At a community level (plot-data) the vegetation was differentiated similarly according to Ecosystem type, a similar separation of channels, dry channels and seeps, and wet seeps, but there was more variability in the patterns, as might be imagined. Probably the most distinguishing feature of the vegetation study was that the samples from each area showed a generally high level of site affinity.

In the channels, community patterns were generally apparent across sites, that is, plots of the same community designation at different sites were more similar than were plots at a single site of different community affiliation – this would be expected in a study to identify broad community groupings. Also, there was a good relationship between the groupings of plant communities and their hydroperiod, suggesting that strong gradients in community pattern associated with hydroperiod. These results suggests that streamflow hydroperiod appears at the very least to represent a good surrogate for water availability to riparian plants, and that plant community structure appears to respond to this gradient in water availability.

The situation in the seeps was somewhat different. The grouping of plot samples from the same designated BB Community was largely a result of the fact that a separate community (or more than one) was described for each site rather than being defined across the spectrum of sites. Samples of the same BB community from different sites, however, did not group together in the multivariate analyses, suggesting a low level of congruence between the two methods in defining communities.

The vegetation study did not show any meaningful clustering of neither seep samples, nor any significant association between plant communities and seep wetness categories. No relationship was found between any measure of soil moisture and the plant community recorded at the vegetation plots. This may simply reflect the fact that the soil moisture measurement was not conducted at an appropriate spatial scale for these links to be made.

The implication of these results is that the sampling effort within each wetland requires reconceptualisation. Wetlands display a range in soil moisture conditions, and sampling needs to be conducted at a scale that is appropriate to characterise plant community shifts within the wetland, associated with moisture regimes.

6.4.3 Habitat signatures

The proportion of functionally obligate wetland and riverine species in the plant communities of seep and channel sites, and of terrestrial species, was calculated for the TMGA ecological monitoring sites. The designation of habitat signature (seep, channel obligate or terrestrial) was based on literature and numerous field observations. The seeps collectively had just fewer than 50% representation of normally terrestrial species, whilst channels had some 47% terrestrial species. An examination of whether terrestrial vagrants were more prolific in seeps or channels where hydroperiod was shorter was not conclusive, but could be improved by a more rigorous determination of wetland obligacy / terrestrial affinity.

Nevertheless, this approach is regarded as offering a great deal in terms of change monitoring in the future. The results suggest that plant communities could change quite drastically if conditions conducive to expansion by their terrestrial species complement were to prevail, for example as a result of drawdown of groundwater, as wetland endemics “leak” from the system and are replaced by terrestrial (or facultative) species.

6.4.4 Individual species responses

Four measures of the physiognomy and physiology of individual plant species were identified, and seasonal data were collected from tagged plants at each site[8] viz. Plant vigour, Leaf stomatal conductance, Leaf chlorophyll content and Sap pressure.

Greatest promise was shown by the determination of differences between summer and winter sap pressure. In general, individual species responded similarly to seasonal changes, with three broad categories of responses. These could be used at an individual site level to track change over time in relative stress levels encountered by plants, and should be coupled with soil moisture, air temperature and other environmental measures, e.g. rainfall. Since each species has its own adaptation to stress and stressors, sites will only be able to be compared where they have the same species, preferably in similar communities. Unfortunately not all plant species or plant communities occurred at all of the sites; in fact each seep wetland was shown to have unique aspects, which is a major limitation of the study where direct comparisons are necessary.

Monitoring of vigour stomatal conductance and chlorophyll in tagged plants has provided some useful data, although any changes between seasons were too small to measure accurately. There is also the spectre of human error when other fieldworkers estimate measurements around plant vigour. Whole plant photography is also difficult as plants tend to become overgrown due to post-fire successional growth. Both the porometer and chlorophyll meter have limited application as leaves need to be both broad and thin; most species do not fit this category.

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[8] These comments pertain to the first cycle of monitoring, since a decision was taken by the Project Team and Client to discontinue the physiological aspects of the study

7. BENTHIC ALGAE

7.1 INTRODUCTION

In surface freshwater ecosystems, a diverse community of algal species grows on substrates such as cobbles and boulders, soils, and submerged fronds or roots of plants. Benthic algae are the most dominant and conspicuous of these organisms, and constitute the most important group of primary producers in autotrophic aquatic ecosystems, providing energy for the sustenance of higher trophic levels of the food web, such as macroinvertebrates and fish. Algae (including diatoms) frequently grow in association with other organisms such as fungi, bacteria and protozoa. A diverse and productive algal community is essential for the maintenance of the overall health of an aquatic ecosystem. In rivers, benthic algae are frequently referred to as “periphyton”.

Algal communities are essentially the interface between the physico-chemistry of the ecosystem and the biotic components of the aquatic food web. Benthic algae are particularly suited to monitoring anthropogenic change to ecosystems because they have short life cycles allowing a rapid response to changing conditions. They are characteristically the first organisms to respond to and recover from stress (Lowe and Pan 1996). Furthermore, algal productivity and algal species composition are highly responsive to changes in nutrient levels, light availability, water temperature, and flow (in lotic systems) or the level of inundation or saturation (in lentic systems) (Biggs 2000; Biggs and Kilroy 2000; Hildrew and Giller 1994). Detecting changes in algal biomass or shifts in community structure therefore provides a useful means of monitoring the impacts of human intervention (Low and Pan 1996).

Aquifer drawdown could result in the following changes, all of which would vary in proportion to groundwater dependency (e.g. Parsons and Wentzel 2001; Cleaver *et al.* 2003; Colvin *et al.* 2007, 2009):

- Reduced water depth or inundation/saturation (in wetlands);
- Duration of saturation (in wetlands);
- Reduced baseflow in rivers (as a result of reduced input from springs and also alluvium aquifers);
- Decreased water velocities, as a result of decreased baseflows; and
- Increased water temperature.

If the abstraction of water from the Peninsula Aquifer does indeed result in these shifts, it is expected that the benthic algal communities in the wetlands and rivers that are strongly dependent on the Aquifer would show an early response.

The analysis of the first cycle of baseline monitoring data led to the identification of the kinds of algal species assemblages that can be expected to inhabit niches within the ecoseeps and ecochannels. *A priori* categorisation of each ecoseep and ecochannel according to the dominant hydrodynamic characteristics of each site, or hydroperiod, provided a baseline for identifying the key biological indicators that respond to changes in the hydrological character of these sites over time.

The extent and period of inundation or saturation of a freshwater ecosystem may arguably be the most important variables defining that ecosystem and therefore its algal community, because it affects nutrient supply, light penetration, temperature and herbivory (Goldsborough and Robinson 1996). The following hypotheses will therefore be tested in this analysis of the full benthic algal dataset:

Hypothesis 1: There will be significant differences in algal biomass and species assemblage between seeps or channels with different hydroperiod categorisations.

Hypothesis 2: Algal community structure will vary in response to seasonal cycles of wetting and drying.

Unlike the first cycle report, this report does not provide an account of biomass and species over time and space *per se*. Rather, it focuses on these hypotheses and endeavours to link the structure of the benthic algal communities to hydrological characteristics. Although this involved analyses of the full dataset, only those analyses that indicated a response by the benthic algal communities to changes in hydrological characteristics are presented.

The following sections describe the algal data collected during the EPM conducted by the TMG-EMA, and the analysis of these data. Tentative predictions are made regarding the expected shifts in algal biomass and assemblages in response to abstraction of water from the Peninsula Aquifer, and recommendations for ongoing monitoring are provided.

7.2 METHODS

7.2.1 Field methods

A quantitative approach to establishing algal biomass and composition was used for this study. Replicate samples of the algae covering submerged stones in run biotopes in the channels and in the surface sediment of seeps and valley-bottom wetlands were collected in May 2008 and 2009 (wetlands and channels), September 2008 and 2009 (wetlands only), December 2008 and 2009 (channels only) and March 2009 and 2010 (wetlands and channels). Some of the river sites were too dry to sample in March 2009 and 2010.

For the river channels, benthic algae were sampled by scraping, brushing and rinsing five stones from the run biotope at each sampling site. Each stone was brushed and rinsed until no change was seen in the colour of the rinsing water. The sampled stones were removed from the river channel so that they would not be resampled in subsequent collections. The same run biotope was sampled on each occasion. At three of the river channel sites (H8_3a, T4_RSE2 and T8_1a) there were no stones that could be sampled (i.e. not embedded, and of the right approximate size), and so the sediment in a run biotope was sampled, using the wetland protocol.

For the seeps and valley bottom wetlands, five replicate samples of surface sediment were collected using an adapted syringe, which allowed the top 1 cm of soil to be collected from a circular sample approximately 2 cm in diameter. The five sampling points were marked with PVC pipes, so that the same points could be sampled on each occasion.

At the wetland sites and the three river sites that lacked stones, additional collections of algae were made by pinch-collecting from sediments and root mats, or from submerged vegetation, in order to ensure that there was sufficient material for all analyses. All samples were stored on ice in the field, until they were returned to the laboratory for processing.

Fires at Steenbras and Nuweberg in January 2009 burnt four of the seep sites (H6_1, H8_2, H8_3b, and T4_RSE1) completely and burnt the riparian vegetation around three of the river channel sites (H8_1, H8_3a, and T4_RSE2). Following the fire, the PVC pipes at the seeps were replaced, generally in the same location as before, with the exception of H8_2, where the burn allowed for the location of more appropriate sampling points, closer to the wetter parts of the seep.

7.2.2 Laboratory methods

In the laboratory, a 30 ml sub-sample from each replicate was removed and preserved in 1.5 ml of Lugol's solution for the identification and enumeration of species. The sediment algal samples were mixed with distilled water, and at least 30 ml of supernatant extracted from each sample, and preserved in 1.5 ml of Lugol's solution for identification. The remainder of each river stone sample, and the replicate sediment samples were frozen until further processing. Each sample was divided in two and one half was analysed for total organic content as ash free dry mass (AFDM) and the other for chlorophyll-*a (*Chl *a)*, which provides a relative measure of autotrophic biomass.

For ADFM: Total dry weight was measured on filtered samples dried at 60 ºC for 1 hour. The samples were then burnt in an oven at 400 ºC for 4 hours. The difference between the dry weight and the weight of the remaining ash is the organic component (i.e. AFDM) of the algae.

For chlorophyll-*a*: 30 ml of methanol was added to each sample, which was then boiled at 70 ºC for 3 minutes to increase extraction efficiency and to fix the chlorophyll by destroying the enzymes. Absorbance was measured at a wavelength of 665 nm with a spectrophotometer, and background absorbance was measured at 750 nm.

To normalise algal biomass, the surface area of the stones and sediment comprising each sample was measured. For the stones, a regression equation for surface area was developed (Freshwater Consulting Group, unpublished data), which relates stone surface area to three easily-measured axes. The dimensions of each stone were measured as the longest axis (x), the longest horizontal axis perpendicular to x (y), and the longest vertical axis perpendicular to both x and y (z), and the following equation applied:

$$\mathbf{y\ (surface\ area\ in\ cm^2) = 0.014x + 33.819\ (xy + xz + yz)}$$

For sediment samples, the surface area of the 5 circular samples taken from sediments was calculated as 5 x $\pi r2$, where r = 1.25cm (the diameter of the syringe was 2.5 cm). Both biomass indicators were expressed as mg per m^2 of stone or sediment.

An improved Neubauer Haemacytometer with chamber depth of 0.1 mm was used for counting algal cells during species identification. A glass cover slip was placed on the grid areas of the haemocytometer, ensuring that one edge of the cover slip was just over the lip of the haemocytometer furrow. A portion of each sub-sample was drawn into a Pasteur pipette and spread under the cover lip by capillary action when the tip of the pipette was placed on the furrow near the edge of the cover slip. Cells were enumerated using the following equation:

$$\mathbf{Cells\ per\ ml = [(Counted\ cells/(area\ counted \times depth\ of\ chamber)) \times 1000] \times Dilution}$$

The cells in an area of at least 3 mm^2 were identified down to the lowest taxonomic level possible using the keys in Collins (1918), Cox (1996), de la Rey *et al.* (2004), Denys (2004), John *et al.* (2002), Potapova and Charles (2005), Prescott (1970) and Taylor *et al.* (2007), and counted using a compound light microscope at 400 times magnification.

7.2.3 Data analysis

The five samples collected at each site were treated as replicates.

Species composition data: The relationships between benthic algal assemblages at the different sites were analysed using the PRIMER and PERMANOVA multivariate statistical package, described in Section 6.2.1. All data were square root transformed to normalise the vast range in taxon abundance evident at both the ecoseeps and ecochannels. For the ecoseeps only, the DISTLM tool packaged within PERMANOVA was used to determine which physical and chemical variables best describe the spatial and temporal patterns in species composition.

Biomass data: Analysis of variance (ANOVA) was used to examine differences in algal biomass between various temporal and spatial factors considered in the assessment. All data were assessed for normality and homogeneity of variances using Levene's test of Homogeneity. Chl *a* concentrations for ecoseeps were log (x+1) transformed while ecochannel data were square root transformed to correct heteroscedastic data. Post-hoc pair-wise analyses were undertaken using Tukey HDS tests. All univariate analyses were performed using STATISTICA 9.

7.3 RESULTS AND DISCUSSION OF ECOSEEP BENTHIC ALGAE

7.3.1 Algal biomass

Algal biomass within ecoseeps (as measured by Chl *a*) showed significant spatial and temporal variation during the duration of this study. Although algal biomass was not significantly different between years (Table 7.1), clear seasonal patterns were evident, with the highest biomass generally found towards the end of the growing season in late summer (March 2009 and 2010; Figure 7.1). Highly significant differences between sites and TSAs in all seasons (Table 7.1), suggests that variation in algal biomass at sites is driven by a host of interacting site-specific characteristics. Nevertheless, significant differences between hydroperiod categories were found in the summer between categories A (permanently inundated), C (seasonally inundated with seasonal saturation) and E (intermittently saturated) ecoseeps.

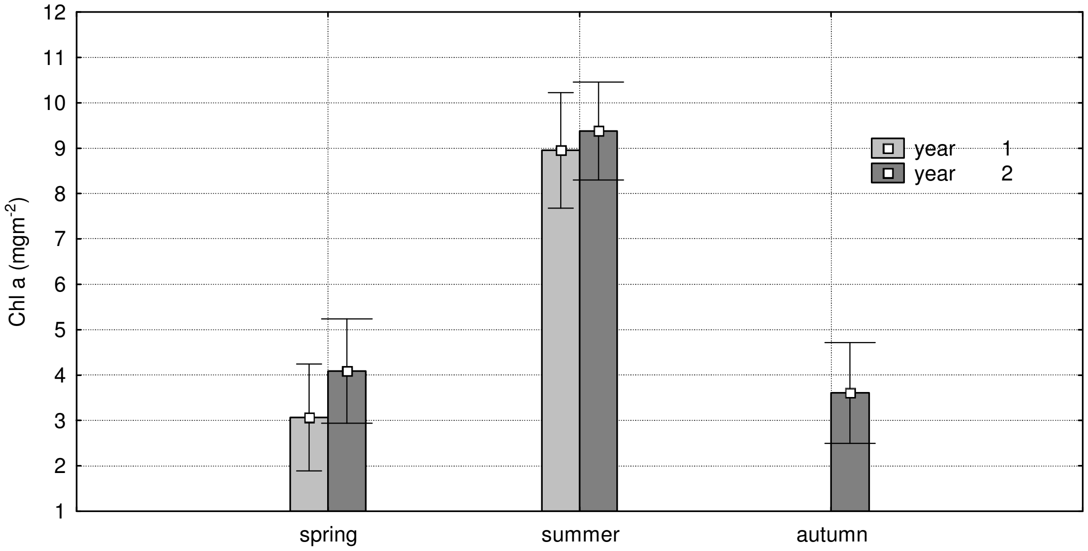

Figure 7.1 **Mean Chl a for all ecoseeps in spring (Sep 2008 = year 1; Sep 2009 = year 2), summer (March 2009 = year 1; March 2010 = year 2) and autumn (May 2009 = year 2).**

Considering the highly significant difference in ecoseep biomass between seasons (Figure 7.1 and Table 7.1), further analyses considered spatial changes within each season. Autumn data, as represented by May 2008 and May 2009 were excluded from these analyses, because autumn is a variable time for sampling and potentially contributes unnecessary variability to the analysis of patterns in the algal data, thus the algal successional sequence is considered to begin in spring, move through summer and autumn, and end in winter, when algal structural composition is generally reset over the cold high rainfall period.

Figure 7.2a shows a weakly positive relationship between groundwater level and mean Chl *a* concentrations during September, but this relationship is not significant. By contrast, a significant positive relationship (r=0.4239, p=0.001) between groundwater level and Chl *a* concentration was evident during the summer (Figure 7.2b) when ecoseeps are at their driest. Thus, permanently saturated ecoseeps where the water level during the summer is at or near the surface (indicated by categories A and B) generally have a lower mean benthic algal biomass relative to the seasonally or intermittently saturated ecoseeps represented by categories C, D and E. The relationship between groundwater level and benthic algal biomass is particularly clear when only the permanently or seasonally inundated ecoseeps are considered (Figure 7.3), which suggests that drier ecosystems

Table 7.1 ANOVA and Tukey's pair-wise tests for differences in algal biomass data (as chlorophyll-*a* concentrations) between temporal factors (i.e. years and seasons) and spatial factors (i.e. sites, HGM types and hydroperiod) and the interaction between these factors. The red text depicts significant differences

Factor	**Results of ANOVA**
Years	F = 2.94 p= 0.087
Seasons	F=27.12 p<0.0001 ***Pair-wise comparisons of season:*** Spring (September) vs Summer (March) p<0.0001 Spring (September) vs Autumn (May) p<0.0001 Summer (March) vs Autumn (May) p=0.0097
Site Site x season	F=8.96 p<0.0001 F=2.65 p<0.0001 Pair-wise comparisons between sites and between sites in seasons show T3_Pal4 in summer and autumn, T4_RSE1 in spring and summer and W7_5 in the summer to be the most significantly different from other sites and seasons..
HGM type HGM type x season	F=2.82 p = 0.061 F= 0.68 p = 0.61
TSA TSA x season	F=7.55 p<0.0001 F=24.28 p=0.004 Pair-wise comparisons between TSAs and between TSAs in seasons show Riviersonderend in the spring and summer is significantly different from the other TSAs
Hydroperiod categories Hydroperiod category x season	F=10.27 p = 0.0001 F=2.5 p=0.11 Pair-wise comparisons between hydroperiod categories and between hydroperiod categories in seasons show Category E in the summer to be significantly different from all other categories in all seasons. Category C in the summer is significantly different from Category A in the summer.

that are never inundated vary in their response to desiccation stress. For instance, most of the category E sites had a high algal biomass in summer (above the curve in Figure 7.2b) – dominated by the blue-green algae with their thick mucilaginous coatings that protect the algal cells from drying – while the category D sites had a lower biomass (below the curve in Figure 7.2b). It is predicted that benthic algal biomass in category A and B ecoseeps will increase as they move from perennially inundated (category A) and seasonally inundated but perennially saturated (category B) to seasonally inundated with dry periods in the summer months (category C).

Considering that the significant regression in Figure 7.3 is driven largely by the category C ecoseeps, it appears that the shift from some level of permanent saturation to a situation where there are periods of drying out represents a clear biological change in algal biomass. The threshold of change seems to occur when the groundwater level at the end of summer drops below approximately 0.5 meters below the surface (Figure 7.3). If the algal biomass exceeds 11 mg m^{-2} during the summer but the groundwater is maintained above 0.5 m, then it can be assumed that the ecoseep is impacted by non-hydrological related impacts such as an increase in nutrients, light penetration (canopy cover) or non-hydrological changes in water temperature (possibly due to loss of shading from canopy vegetation). However, should the water level drop below 0.5 m and the algal biomass exceeds 11 mg m^{-2}, then hydrological related impacts such as drying out would be expected. Should the ecoseep shift to a system that is rarely inundated (category D) or never inundated (category E), then a

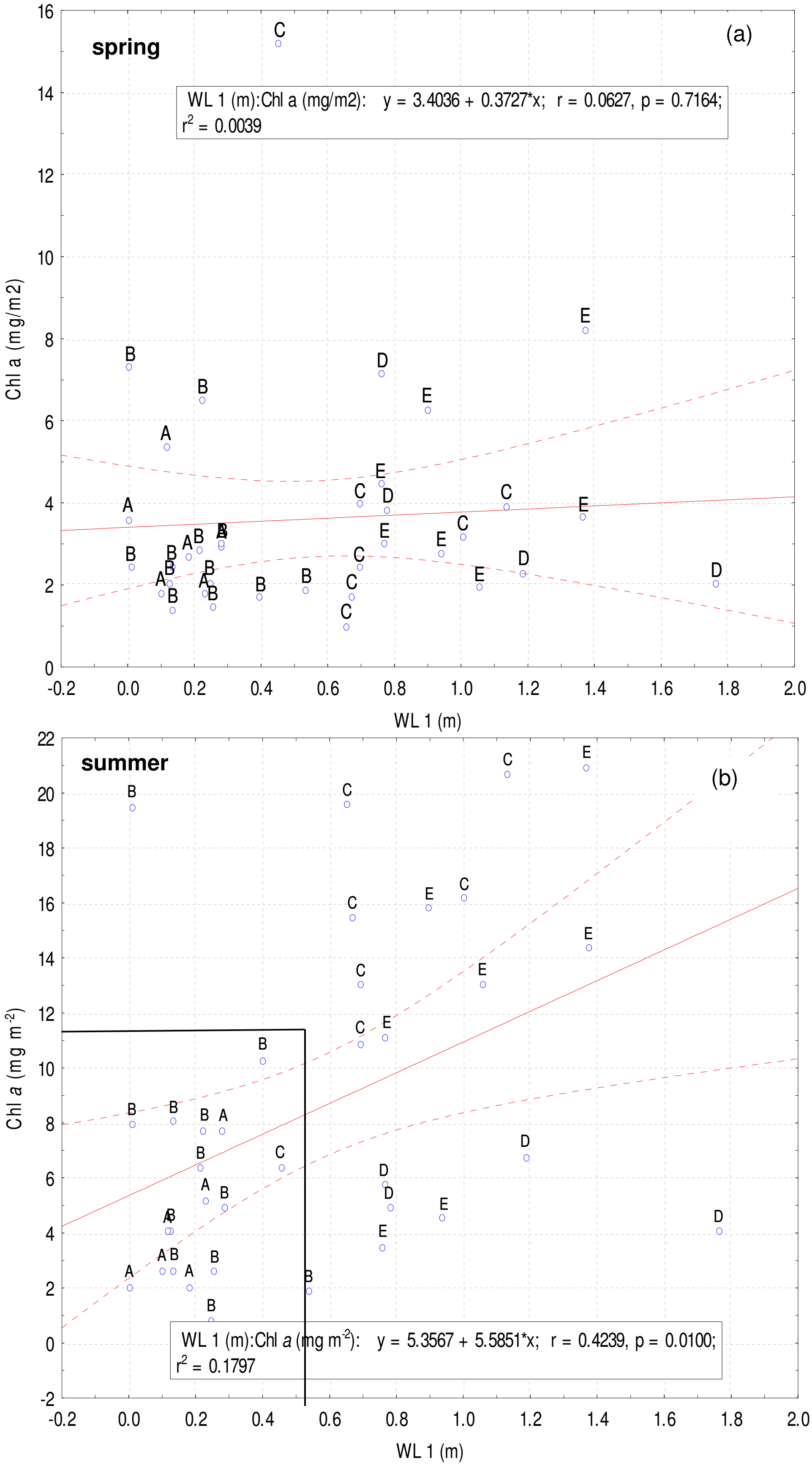

Figure 7.2. **Linear regression of mean Chl a (mgm^{-2}) and depth to groundwater (m bgl) averaged over one month prior to sampling (WL1) measured at each site during (a) September 2008 and 2009 (spring) and (b) March 2009 and 2010 (summer). The letters marking each data point represent its hydroperiod category.**

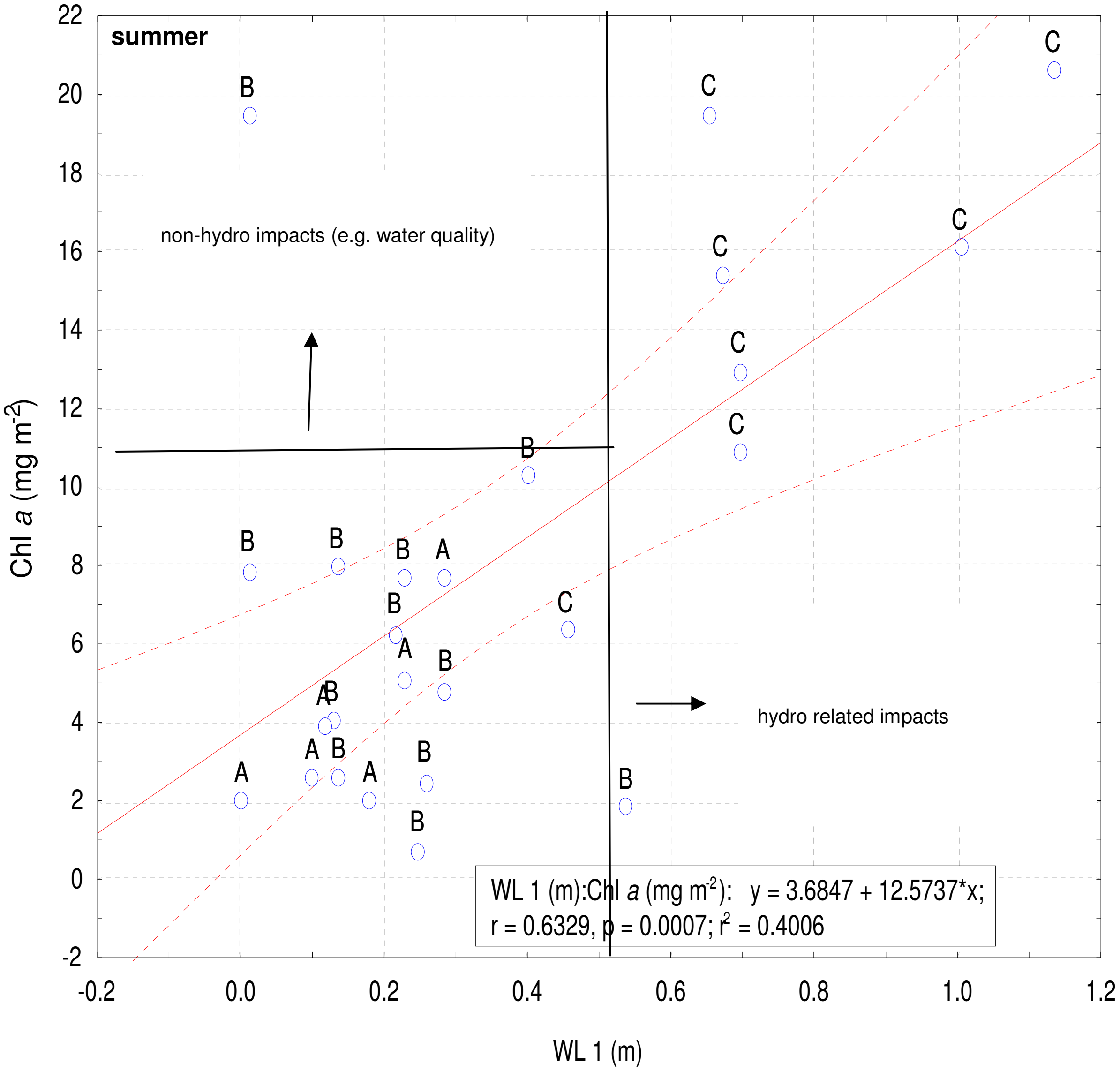

Figure 7.3. **Linear regression of mean Chl a (mg m^{-2}) and groundwater level from the surface (m) averaged over one month prior to sampling (WL1) measured at permanently or seasonally inundated ecosystems (categories A, B and C) in March 2009 and 2010 (summer).**

Significant change in the community composition and biomass can be expected, although the threshold of change cannot be determined from these data.

Although the spring data showed no significant relationship with groundwater level in its current, unimpacted state, it is predicted that a change from perennial saturation (category A and B ecoseeps) to only seasonal saturation (category C ecoseeps) will result in a stronger positive relationship between groundwater level and algal biomass. The threshold of change will depend on the point at which this regression curve is significantly different from the baseline data presented in Figure 7.2a.

7.3.2 Algal community structure

Diatoms, green algae and blue-green algae dominated the benthic algal community in all samples collected during this study, as expected. Other groups such as yellow-green algae, brown-algae, euglanoids and tribophytes were collected occasionally but these taxa did not contribute significantly to the abundance of taxa recorded.

A priori defined factors including years, seasons and hydroperiod were used to assess differences in the benthic algal community structure at different temporal and spatial scales. Variability between TSAs and sites was also considered, although an assessment of differences between these spatial factors was not one of the project objectives. Although PERMANOVA is considered a more powerful tool for assessing differences between various factors, ANOSIM was used to assess if algal communities were different between years because two samples (year 1 and year 2) did not provide enough degrees of freedom to run the PERMANOVA routine for this factor. Thus, a mixed model nested design with fixed[9] factors (month and hydroperiod) and random[10] nested factors (site and TSA) formed the basis for this analysis.

Significant inter-annual differences in benthic algal community structure between September 2008 and March 2009 (year 1) and September 2009 and March 2010 (year 2) were evident from the results presented in Table 7.2 and Figure 7.4. This is not surprising, considering that the annual rainfall in year 2 was considerably less than in year 1. Further analyses were therefore undertaken separately for year 1 and 2. Significant seasonal differences were also evident in both years suggesting a predictable shift in community structure from the end of the wet season (September) to the dry season (March) (Table 7.2 and Figure 7.5). Despite these temporal patterns in benthic community structure, the high level of variability between sites within each season during both years (Table 7.2) meant that no clear patterns between hydroperiod categories could be established.

An analysis between benthic community structure and seven physico-chemical variables was undertaken to establish whether patterns could be identified between them. The analysis was limited to those variables where the data was available for all sites over a period. The seven variables were:

- Groundwater level averaged over the preceding month (WL1) (which correlated strongly with groundwater level averaged over the preceding 3 months);
- Temperature averaged over the preceding month;
- Rainfall averaged over the preceding 3 months;
- % soil moisture content per replicate
- pH;
- Conductivity, and
- Hydroperiod.

Based on the DISTLM analysis, this set of variables explained only 27.76% of the total variability in the algal community structure. Of these variables, rainfall (13.86%) and conductivity (3.8%) were the best predictors of community structure across years, seasons and sites. Thus, it would appear that

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[9] Fixed factors are those where the analyst is specifically interested in the differences between those factors; whereas,

[10] Random factors are those where the main analysis between fixed factors happens to be complicated by a number of other factors, which are sampled in a random manner from a larger set of options.

benthic algal community structure in ecoseeps sampled in this study are driven by recent rainfall and nutrient concentration (with conductivity as a proxy), rather than other characteristics such as groundwater level, % soil moisture and hydroperiod. As discussed in Chapter 5, however, there may well be a significant link between the closeness of the water table to the surface of a wetland and the consequent extent and duration of soil saturation, and the levels of nutrients, which, in turn, govern the composition of the algal communities. The role of fluctuating water depth on wetland nutrient status has not been resolved in the literature, and there is much uncertainty as to the links between these variables. Also, exposure of wetland sediments during dry periods increases the rate of organic matter decomposition, and may lead to the release of nutrients during subsequent inundation (Schoenberg and Oliver 1988). A change in water table depth as a result of groundwater drawdown, could impact on nutrient levels and the composition of the algal communities. Algal biomass did not detect the annual shifts in algal community structure, suggesting that the latter is more sensitive to external drivers. This sensitivity could explain why spatial patterns linked to hydrological variables are obscured by site-specific variables.

Despite the lack of spatial patterns in benthic algal community composition, temporal patterns between a relatively wet year (year 1) and a dry year (year 2) and between the wet season (September) and the dry season (March), suggest that individual sites monitored over time may show shifts in community structure. Due to the inter-site variability recorded in this study, comparisons between sites have limited value for monitoring. The future monitoring programme should aim to increase the intensity of sampling within fewer sites, thus allowing analysis of temporal shifts within the site.

Table 7.2 ANOSIM and PERMANOVA results summarizing the effect of year, season, site, TSA and hydroperiod categories on benthic algal community structure in the ecoseeps. ANOSIM Rho-values (R) values are provided for the overall comparison between year 1 (2008/2009) and year 2 (2009/2010). Pseudo F values and significance levels are provided for the output of the PERMANVOA analysis.

Factor	**Overall**	**Pair-wise comparisons**		
		component	**Pseudo-F**	**p-value**
Year	R=0.236; P=0.001	n/a		
YEAR 1				
Month	Pseudo-F = 24.57; p = 0.0001	May 08 vs Sep 08: May 08 vs Mar 09: Sep 08 vs Mar 09	2.31 2.34 2.27	0.001 0.001 0.001
Site	Pseudo-F = 5.1; p = 0.0001	n/a		
TSAs	Pseudo-F =4.22; p = 0.0001	n/a		
Hydroperiod	Pseudo-F = 3.87; p = 0.0001	With the exception of A and B, all other categories were significantly different.	-	-
YEAR 2				
Month		May 09 vs Sep 09: May 08 vs Mar 10: Sep 09 vs Mar 10:	1.95 2.45 2.38	0.001 0.001 0.001
Site	Pseudo-F = 5.03; p = 0.0001	n/a		
TSAs	Pseudo-F =4.08; p = 0.0001	n/a		
Hydroperiod	Pseudo-F = 3.58; p = 0.0001	All categories were significantly different from each other in all months.	-	-

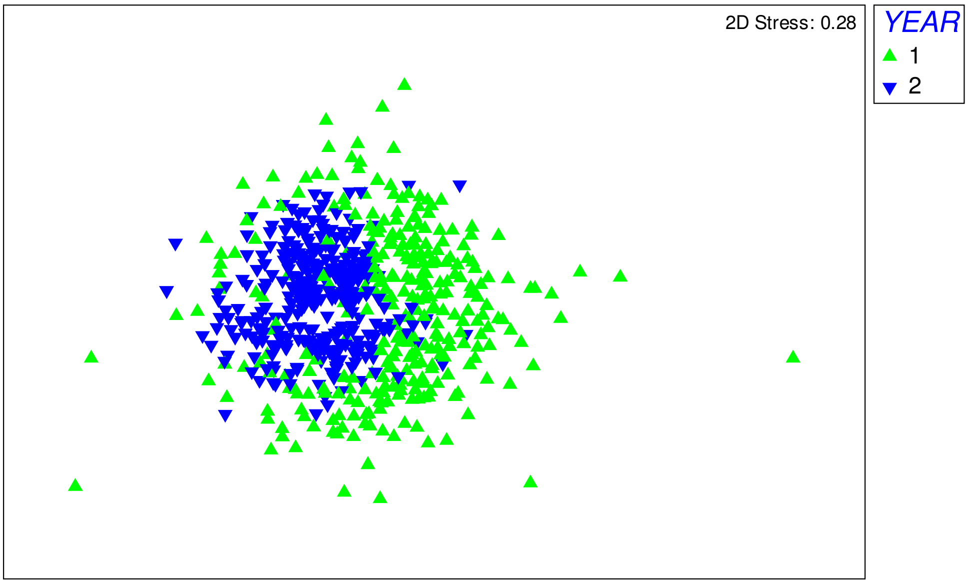


Figure 7.4. **Two-dimensional MDS plot of the replicate algal communities sampled at all ecoseeps during year 1 (September 2008 and March 2009) and year 2 (September 2009 and March 2010), showing the distinct inter annual difference in communities.**

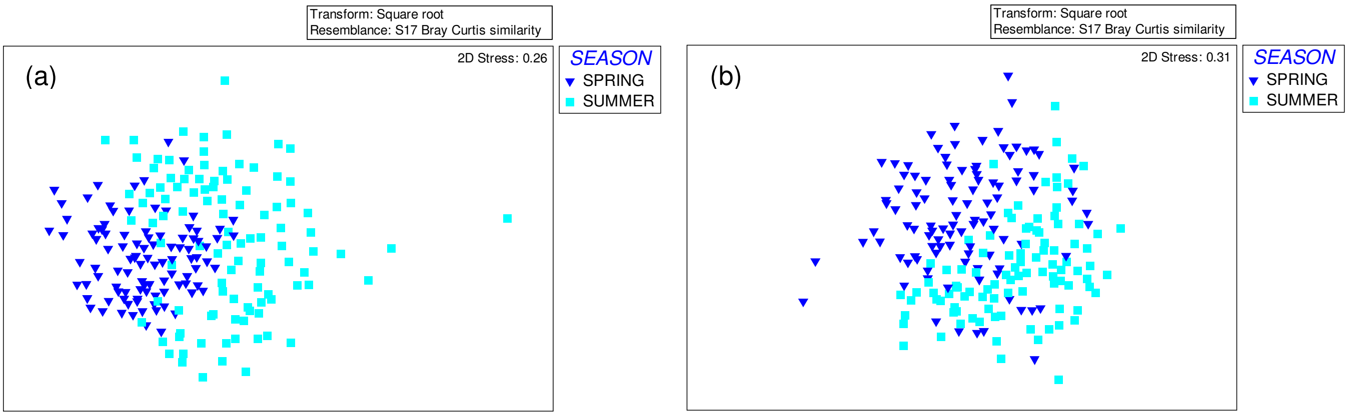


Figure 7.5. **Two-dimensional MDS plot of the replicate algal communities sampled in the ecoseeps during (a) year 1 (September 2008 and March 2009) and (b) year 2 (September 2009 and March 2010), showing the distinct differences in community composition between the wet and the dry season.**

7.3.3 Morphological forms of algae in the ecoseeps

Changes in the relative proportion of algal divisions such as diatoms, blue-greens and green algae, and changes in the relative proportion of different morphological forms (e.g. single cells, colonial or filamentous) have been used elsewhere to detect flow related impacts in rivers (Biggs 2000; Watts *et al.* 2008). Here, algal taxa in the ecoseeps grouped by hydroperiod categories and season showed a clear change in the relative proportion of different forms in both the wet season (September) and the dry season (March) (Figure 7.6), with the exception of Category E ecoseeps where there was no clear pattern of change in form at sites, possibly due to the variable response of algal communities to extreme desiccation (see section 7.3.1). Category E ecoseeps were thus excluded from the analysis.

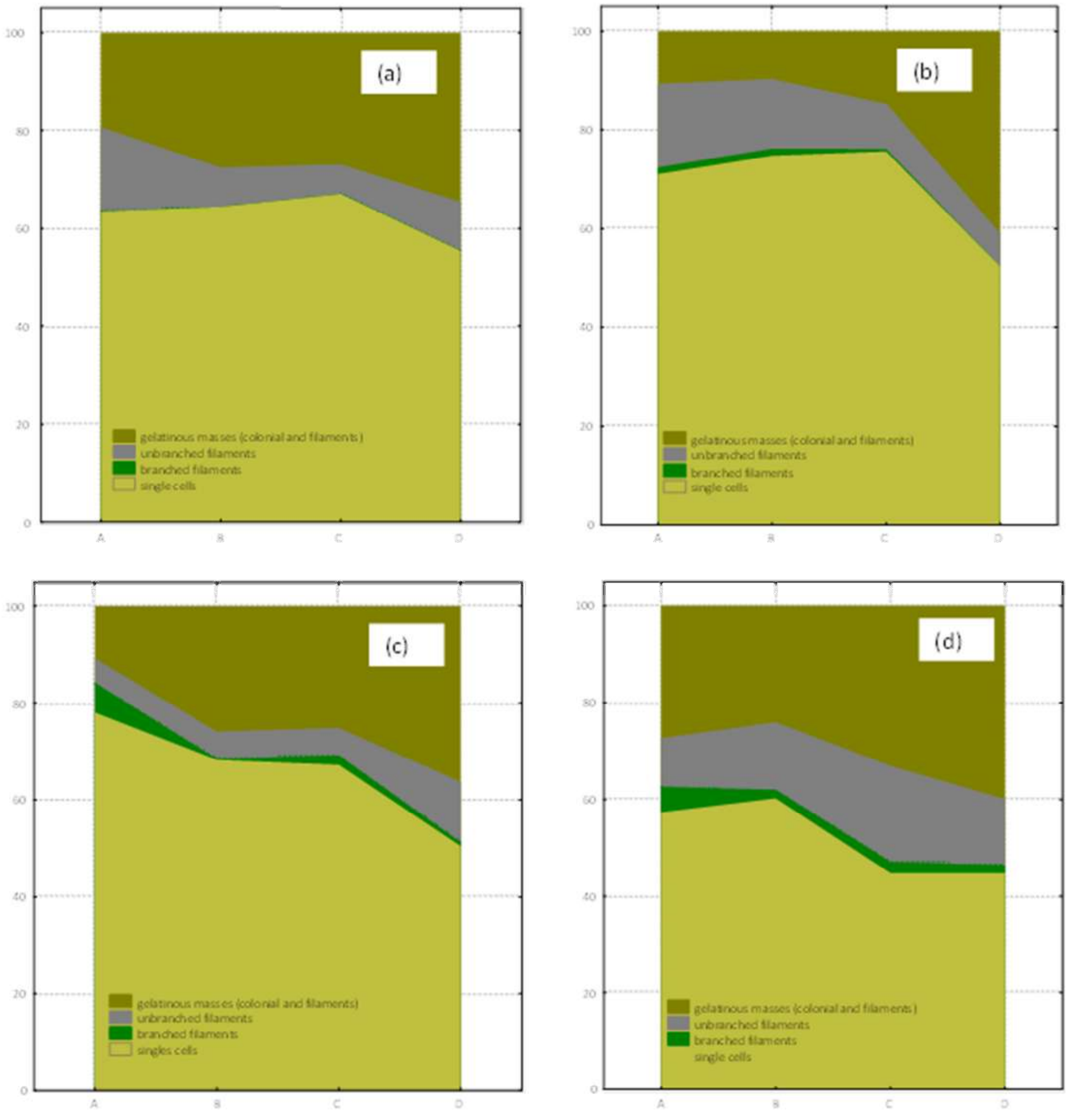


Figure 7.6. **Relative proportion of algal cell abundance grouped by morphological form in ecoseeps, averaged for each hydroperiod category in (a) September 2008, (b) March 2009, (c) September 2009 and (d) March 2010.**

Although filamentous or colonial taxa within gelatinous masses generally contributed a significant proportion of the total abundance, there was a clear increase in the proportion of taxa in gelatinous masses from sites that are perennially or seasonally inundated or saturated (categories A and B) relative to those that dry out during the summer (category C and D). It is interesting to note that March 2010 (which was drier than March 2009) showed a higher proportion of taxa in gelatinous masses, even for category A and B ecoseeps, suggesting that algal form is sensitive to inter-annual variations in hydrological conditions.

In all instances, single celled taxa were dominant, as expected in pristine aquatic ecosystems. These taxa were mostly diatoms (predominantly *Eunotia* spp. and *Navicula* spp.) and green algae (e.g. *Chlorococcum sp.).* The taxa within gelatinous masses sampled during this study were predominantly blue-green algae. The patterns of change in algal morphological form shown in the TMG ecoseeps placed in the different hydroperiod categories support findings elsewhere. For instance, in the Florida Everglades, it was found that wetland sites that undergo frequent desiccation are dominated by benthic blue-green algal mats, while those that are perennially inundated tend to be dominated by diatoms and green algae (Browder *et al.* 1996, in Goldsborough and Robinson (1996)).

In terms of thresholds of change in community characteristics, these data suggest that to maintain Category A and B ecoseeps in their natural state, the relative proportion of single-celled taxa in spring and summer should not decrease below 60% while taxa contributing to colonial and filamentous gelatinous masses should not exceed 30%.

7.4 RESULTS AND DISCUSSION OF ECOCHANNEL BENTHIC ALGAE

7.4.1 Benthic algal biomass

Chl *a* concentrations, which represent algal biomass, were significantly lower in the ecochannels than in the ecoseeps (compare Figures 7.1 and 7.7), suggesting that ecoseeps are more productive environments than their channel counterparts. This may be partly a result of differences in nutrient supply between these ecosystems and the absence of flow disturbances in the ecoseeps. Chl *a* concentrations peaked in summer (December 2008) with a mean of approximately 3 mg m^{-2}. In comparison, relatively unimpacted reaches in the Berg and Molenaars rivers, both foothill rivers, were characterised by summer values for Chl *a* of 0.8 – 2.9 mg m^{-2} (Justine Ewart-Smith, Freshwater research Unit, UCT pers. comm.). Impacted reaches of the Palmiet River, sampled in December 2008 and January 2009, were found to be higher, at between 2 and 8 mg m^{-2}. Ecochannels with sandy substrates (i.e. H8_3a, T4_RSE2 and T8_1a) had a much higher biomass relative to ecochannels with stone substrates, and were therefore excluded from further analysis.

Algal biomass within the ecochannels, like the ecoseeps, showed significant spatial and temporal variation over the project period. No significant differences were found between years (Table 7.3), but clear seasonal differences were evident between spring (lowest biomass) and summer (highest biomass) and spring and autumn (similar to summer) (Table 7.3 and Figure 7.7). Highly significant differences between sites in all seasons, HGM types in autumn and summer, and TSAs in autumn were observed during this study, yet no differences between hydroperiod categories were found in any season. It is probable that these patterns are obscured by site-specific variables that contrast significantly between all sites. Differences within each season (only spring and summer – see section 7.3.1) were considered for further analysis because temporal differences in ecochannel biomass between these two periods were highly significant.

Chl *a* concentrations for spring (December 08 and December 09) and summer (March 09 and March 10) were plotted against water depth taken at each replicate stone (Figure 7.8), to establish whether algal biomass responds to hydrological changes at the ecochannel sites. The weak but significant negative linear relationship ($r= -0.2303$; $p=0.0008$) in Figure 7.8 suggests that as water depth decreases across seasons and hydroperiod categories, algal biomass increases.

This relationship was strengthened ($r= -0.3458$; $p=0.0009$) when only sites classified as hydroperiod A were included (Figure 7.9). Figure 7.9 indicates that deep sites with low biomass characterise the wetter spring sampling period, whereas shallower sites during the dry period are characterised by higher benthic algal biomass.

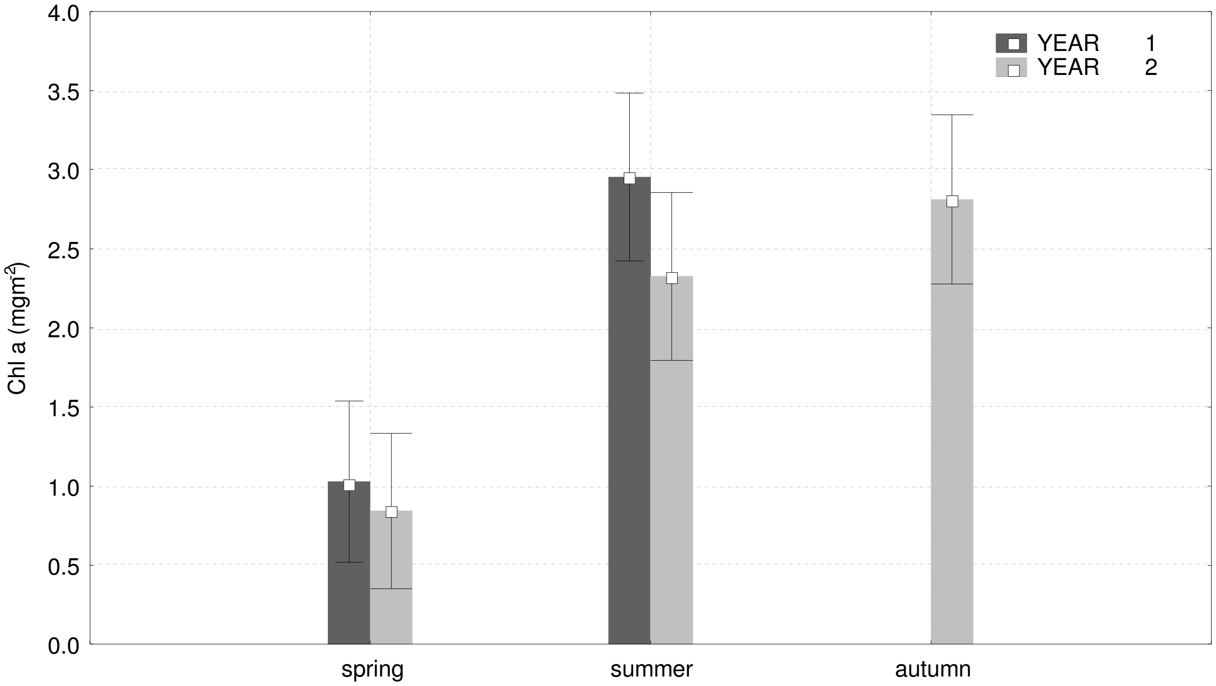


Figure 7.7. **Mean Chl a for all ecochannels in Sep 2008, March 2009 (year 1) and May 2009, December 2009 and March 2010 (year 2).**

Table 7.3. **ANOVA and Tukey's pair-wise tests for differences in algal biomass data (as chlorophyll-*a* concentrations) between temporal factors (i.e. years and seasons) and spatial factors (i.e. sites, HGM types and hydroperiod categories) and the interaction between these factors. The red text depicts significant differences**

Factor	**Results of ANOVA**
Years	F = 2.502 p= 0.115
Seasons	F=66.14 p<0.001 ***Pair-wise comparisons of season:*** Spring (December) vs Summer (March) p<0.0001 Spring (December) vs Autumn (May) p<0.0001 Summer (March) vs Autumn (May) p=0.87
Site Site x season	F=10.7 p<0.0001 F=2.40 p<0.001
HGM type HGM type x season	F=11.05 p=0.0001 F=2.55 p=0.02 ***Pair-wise comparisons of HGM and season:*** Autumn: Mountain Stream vs Transitional p=0.006 Spring: no significant differences Summer: Transitional vs Lower Foothill p=0.0006
TSA TSA x season	F=3.41 p<0.005 F=1.98 p=0.0029 ***Pair-wise comparisons of HGM and season:*** Autumn: Palmiet vs Voelvlei p=0.025 Spring: no significant differences Summer: no significant differences
Hydroperiod categories Hydroperiod category x season	F=0.13 p = 0.0.878 F=1.87 p=0.099

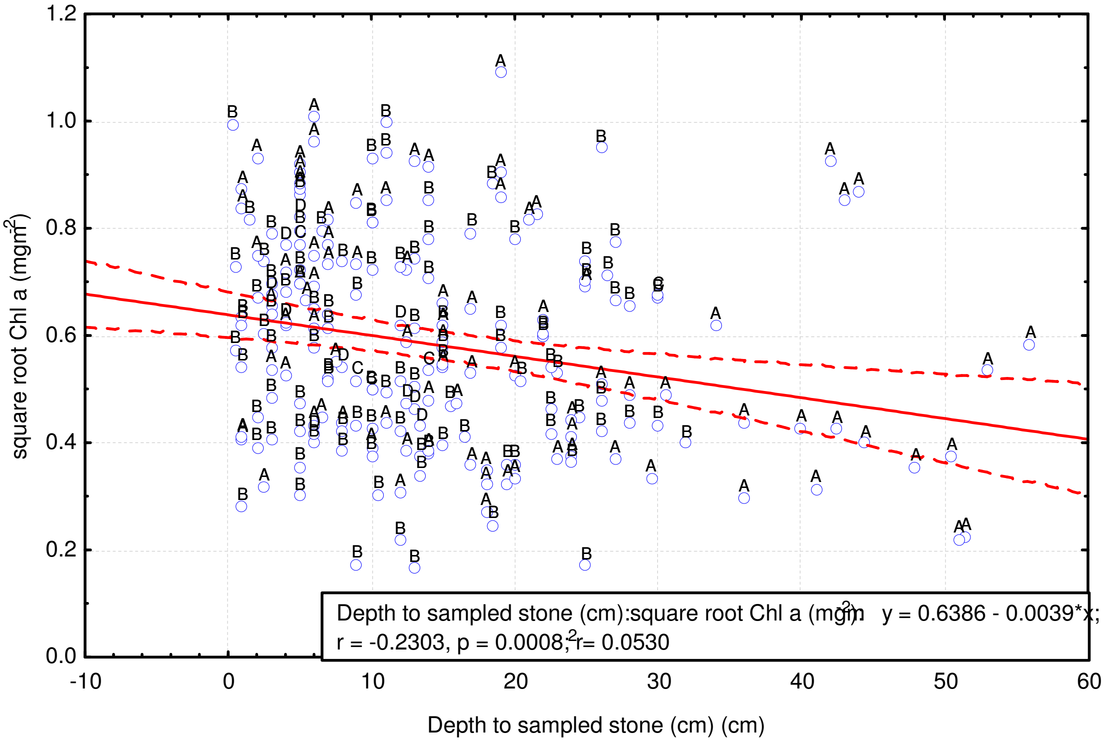


Figure 7.8. Linear regression of mean Chl a (mg m^{-2}), square root transformed, and surface water depth at each replicate stone sample in spring (September 2008 and 2009 and summer (March 2009 and 2010). Letters refer to hydroperiod category.

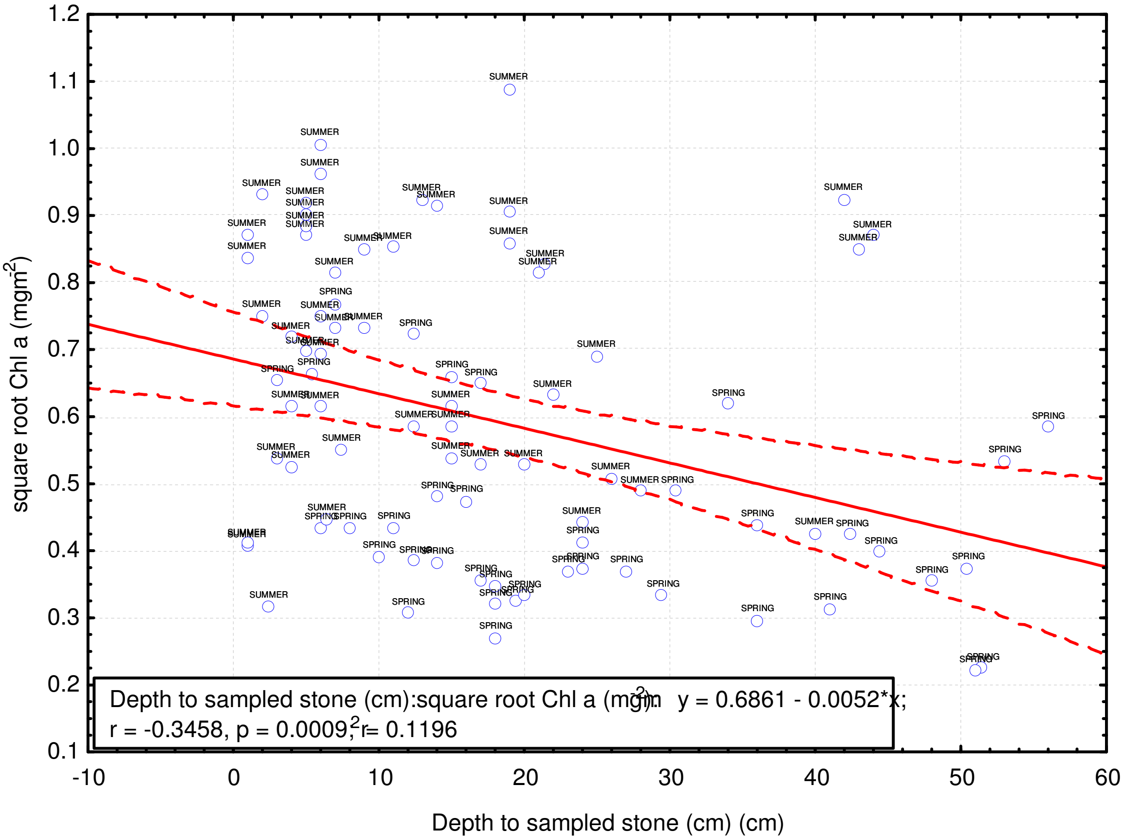


Figure 7.9. Linear regression of mean Chl *a* (mg m^{-2}), square root transformed, and surface water depth measured at each replicate stone sample in September 2008 and 2009 (spring) and March 2009 and 2010 (summer), for sites classified as hydroperiod A, i.e. strongly perennial rivers.

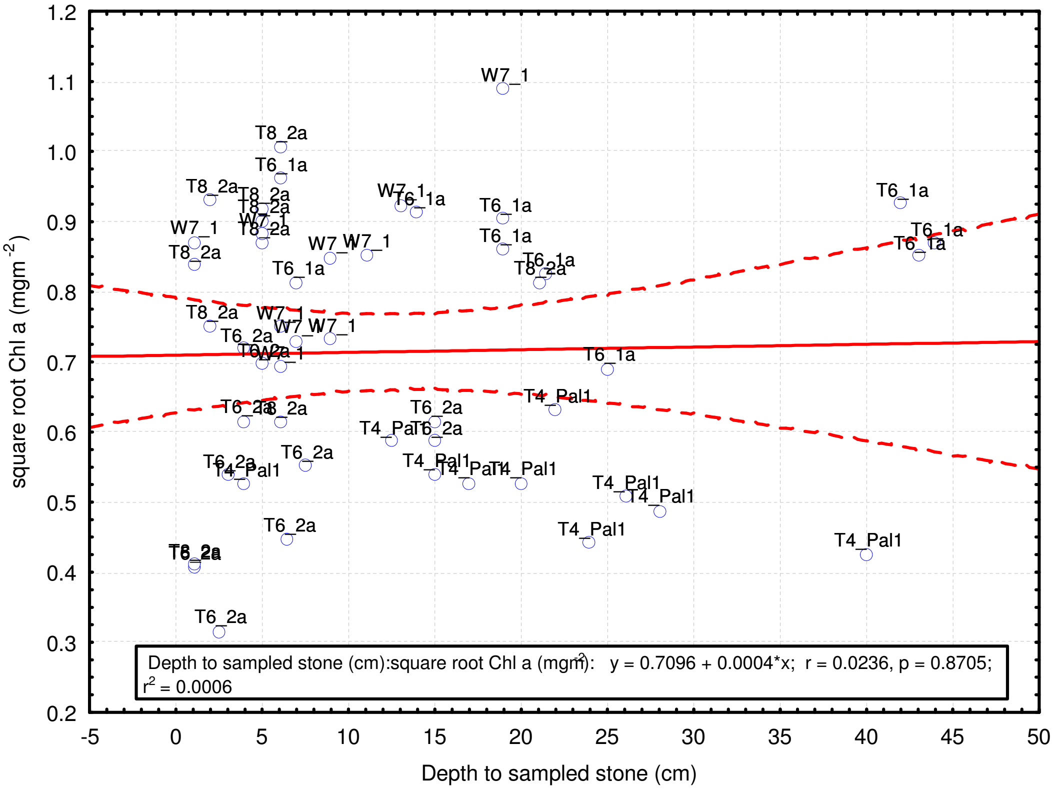


Figure 7.10. Linear regression of mean Chl *a* (mg m^{-2}), square root transformed, and surface water depth measured at each replicate stone sample during summer (March 2009 and 2010). Each replicate data point is labeled with the site name.

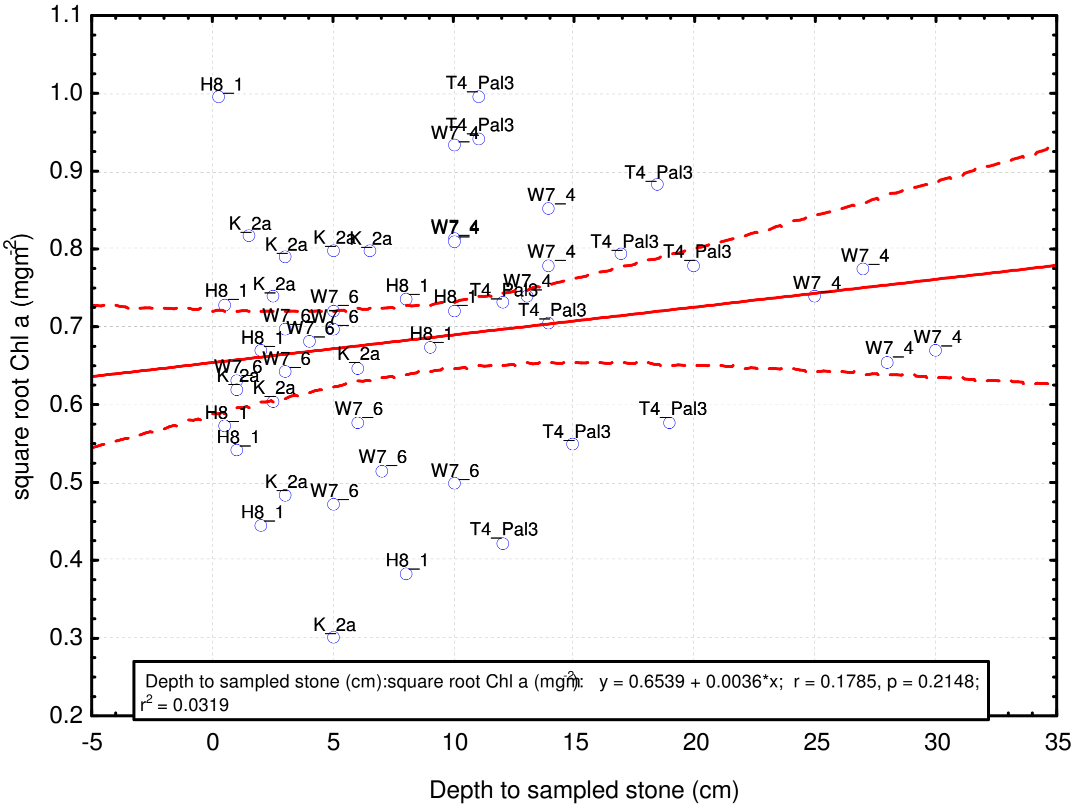


Figure 7.11. Linear regression of mean Chl *a* (mg m^{-2}), square root transformed, and surface water depth measured at each replicate stone sample during summer (March 2009 and 2010) for hydroperiod category B ecochannels only. Each replicate data point is labeled with the site name.

Unlike the ecoseeps, which are not influenced by current velocity, benthic algal biomass in rivers is influenced by the shear stresses created by current velocity. Biggs *et al.* (1998) describe the “subsidy stress” relationship between benthic algae and current velocity in rivers. This relationship suggests that, in oligotrophic environments such as those in this study, biomass increases as flow velocity increases from zero due to an increase in the mass transfer of nutrients to benthic algal mats. However, at a certain critical velocity, the advantages of increased nutrient supply are outweighed by the increase in shear stress, which results in a net reduction in algal biomass as algal mats are sloughed from the bed.

The ecochannels seem to adhere to this assertion in the summer months only, when water depths are shallow and velocities are low (Figure 7.10), since algal biomass increased slightly with depth, but this relationship is not significant (r=0.024; p=0.871). This is somewhat supported by the stronger positive relationship between hydroperiod category B ecochannels (i.e. perennial rivers that are reduced to very low flow and shallow depths in the summer) and water depth, although this relationship is also not significant (r=1.785; p=0.215) (Figure 7.11). Essentially, linking hydrological characteristics with algal biomass in rivers requires interpretation of depth data *in parallel with flow velocity data.*

7.4.2 Algal community structure

Ecochannels were dominated by diatoms, green algae and blue-green age throughout the study period, although yellow-green and brown-green taxa were also recorded in low abundance.

A significant but weak difference in ecochannel benthic algal community structure was evident between years based on a multivariate analysis of similarity performed on the algal community data (ANOSIM) (Table 7.4, Figure 7.12). Thus, as for the ecoseeps each annual sampling period was treated separately for further analyses. A mixed model nested design with fixed factors (month and hydroperiod group) and random factors nested within month (site and TSA) was used to test for spatial and temporal variations in algal species composition.

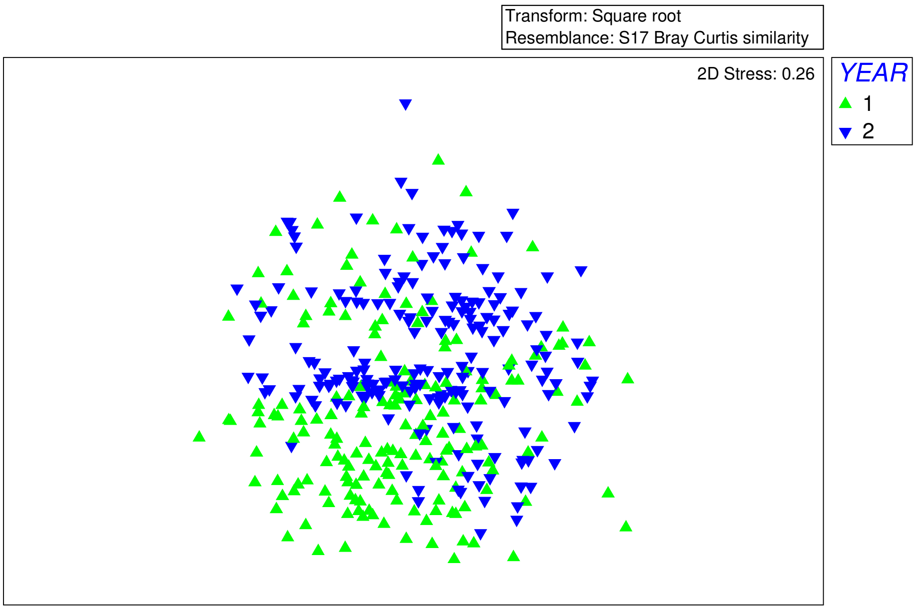


Figure 7.12. **Two dimensional MDS plot of the replicate algal communities sampled at all ecochannel sites during year 1 (September 2008 and March 2009) and year 2 (September 2009 and March 2010).**

Significant differences between months were found in both years but the differences were weak compared with those found for ecoseeps (compare Table 7.2 and Table 7.4, Figure 7.13). The strength of the seasonal differences was considerably lower than the inter-site differences and had

Table 7.4. ANOSIM and PERMANOVA results summarizing the effect of year, season, site, TSA and hydroperiod categories on benthic algal community structure in ecochannels. ANOSIM Rho-values (R) values are provided for the overall comparison between year 1 (2008/2009) and year 2 (2009/2010), and pseudo F values and significance levels are provided for the output of the PERMANVOA analysis. Significant relationships are marked red.

Factor	**Overall**	**Pair-wise comparisons**		
		component	**Pseudo-F**	**p-value**
Year	R=0.141; P=0.001	n/a	N/A	N/A
YEAR 1				
Month	Pseudo-F = 2.847; p = 0.001	May 08 vs Dec 08: May 08 vs Mar 09: Dec 08 vs Mar 09	1.85 1.83 1.29	0.001 0.001 0.051
Site	Pseudo-F = 5.57; p = 0.001	n/a		
TSAs	Pseudo-F =5.00; p = 0.001	n/a		
Hydroperiod	Pseudo-F = 4.37; p = 0.001	All categories were significantly different from each other in all months.	-	-
YEAR 2				
Month	Pseudo-F = 2.33; p = 0.01	May 09 vs Dec 09: May 08 vs Mar 10: Dec 09 vs Mar 10:	1.54 1.49 1.54	0.012 0.011 0.008
Site	Pseudo-F = 6.73; p = 0.0001	n/a		
TSAs	Pseudo-F =5.40; p = 0.001	n/a		
Hydroperiod	Pseudo-F = 5.02; p = 0.001	All categories were significantly different from each other in all months.	-	-

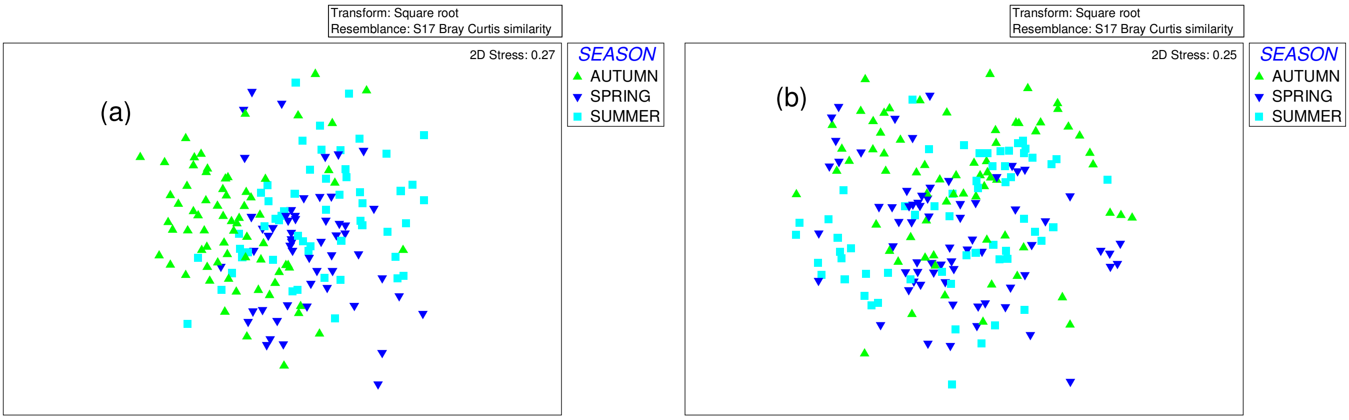


Figure 7.13. Two-dimensional MDS plot of the replicate algal communities sampled in the ecochannels during (a) year 1 (September 2008 and March 2009) and (b) year 2 (September 2009 and March 2010.

the greatest pseudo-F value (indicative of the strength of the relationship). Similarly, the pseudo-F value for inter-site differences in the second year were higher than that between seasons (months), TSAs and hydroperiod categories. Thus any relationship between hydrological character and algal community structure will be obscured by the high site-specific differences in community structure which are driven by site related environmental factors that could not be determined in this study.

7.4.3 Morphological forms of algae in the ecochannels

Proportional changes in the contribution of major algal divisions (i.e. diatoms, green algae and blue-green algae), as well as changes in the proportion of algal form are used elsewhere as an indicator of change in rivers (Watts *et al.* 2008, Biggs 2000). Biggs (2000) found that a reduction in baseflow velocities, accompanied by a concomitant increase in nutrient supply, led to an increase in the biomass of filamentous green algae. Specifically, his predictions are as follows:

- A decrease in baseflow velocities in summer (exacerbated, for instance, as a result of groundwater abstraction) will potentially lead to an increase in biomass of filamentous green algae, an increase *or* decrease in biomass of stalked diatoms and short filamentous communities, and a decrease in biomass of mucilaginous communities (diatoms and single-celled algae).
- A decrease in water depth, and a concomitant increase in mean and maximum water temperatures (also a probable consequence of the lowering of the water table) should lead to an overall increase in algal biomass (see section 7.4.1), particularly where there is little or no shading by riparian vegetation.

Potential biomass changes were discussed in section 7.4.1 but changes in the morphological form of benthic algae sampled in ecochannels (Figure 7.14) support some of the predicted changes suggested by Biggs (2000). Mean proportional contribution of different morphological forms of algae for each hydroperiod and in each sampling period are presented in Figure 7.14. During December 2008 (spring), the relative proportion of single celled taxa (mostly diatoms and green algae) was considerably lower for category D ecochannels compared with category A, B and C ecochannels. Single celled taxa were replaced largely by colonial and filamentous taxa in mucilaginous masses in seasonally dry ecochannels, as represented by the category D ecochannels. The relative proportion of single celled taxa remaining in category A and B rivers in the dry summer (March 2009) stayed constant at a similar level to that measured in the category D ecochannels, with an increase in the proportion of taxa in gelatinous masses. A slight increase in the relative proportion of single celled taxa was observed in category A and B ecochannels during autumn (May 2009), but a similar decrease to that observed in spring in single celled taxa was apparent in autumn. Whereas the decrease in single celled taxa was matched by an increase in unbranched filaments in spring (Figure 7.14a), the decline in single celled taxa in autumn (Figure 7.14c) was associated with an increase in taxa in gelatinous masses. This pattern is consistent with a general response to desiccation stress, where taxa in mucilage are able to survive periods of drying. A similar pattern in the changes in proportion of algal form was observed in the second year (Figure 7.14d and e). However, the distinct change in community composition was between category B and C rather than between category C and D ecochannels, as was the case in the first year. Rainfall was lower in the second year and therefore, this change may have been a response to hydrological stress (increased temperatures, reduced depths and velocities in seasonal rivers (category C), which was not experienced in the previous wetter year.

In terms of thresholds of change in community characteristics, these data suggest that to maintain Category A and B ecochannels in their natural state, the relative proportion of single-celled taxa in spring should not decrease below 50% while taxa contributing to colonial and filamentous gelatinous

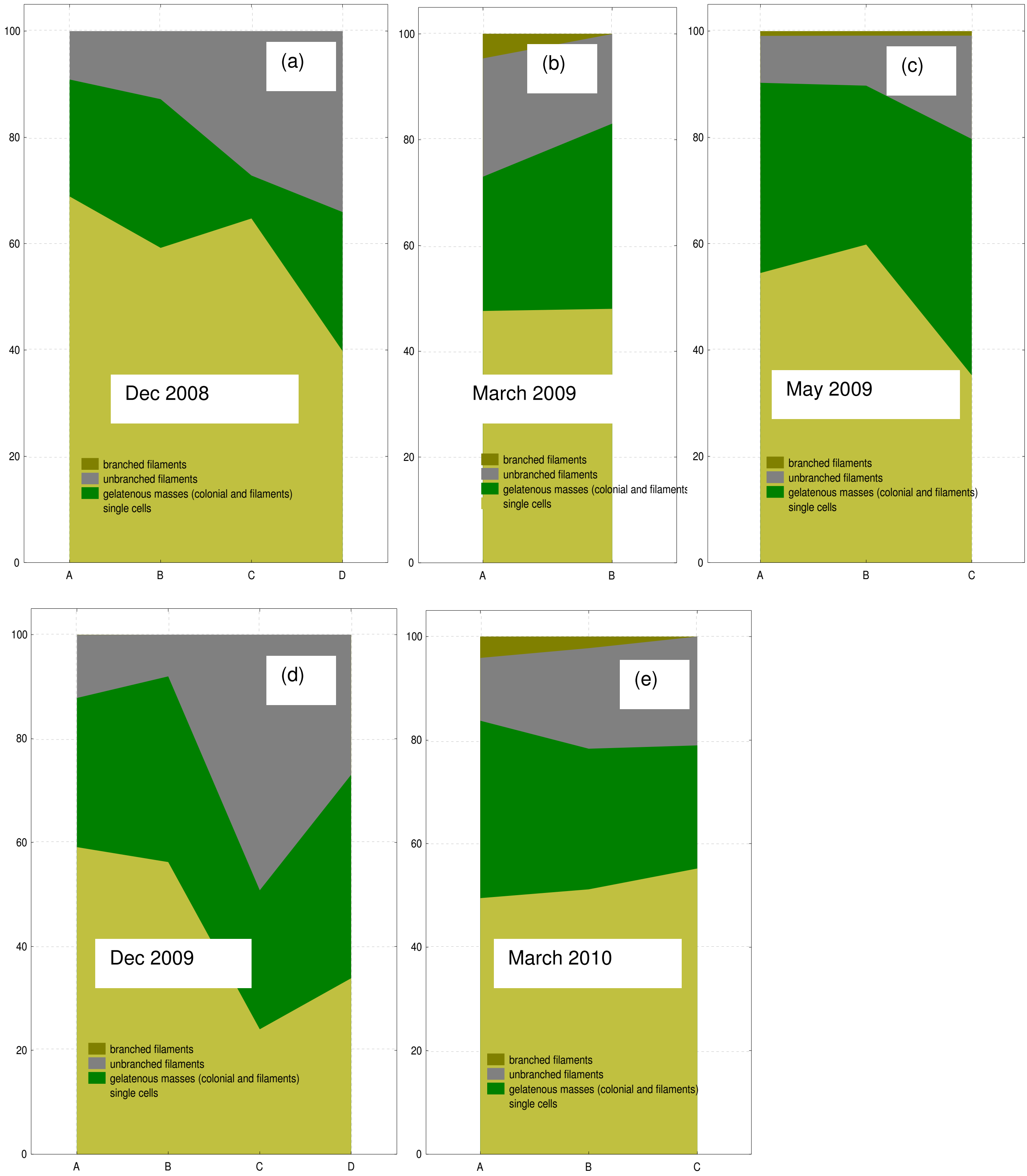


Figure 7.14. **Relative proportion of algal cell abundance grouped by morphological form in ecochannels, averaged for each hydroperiod category in (a) December 2008, (b) March 2009, (c) May 2009, (d) December 2009 and (e) March 2010.**

masses should not exceed 30%. During the summer months, single-celled taxa should be maintained above a relative contribution of 40% and gelatinous masses should not exceed 40% contribution.

The relationships between the ecochannel algae structure and the hydroperiod categories were generally much weaker than those found for the ecoseeps. It is possible that, in terms of the productivity and the species composition of the algal communities inhabiting these systems, the ecoseep hydroperiod categories are more distinct from each other than those developed for the ecochannels.

7.5 SUMMARY AND CONCLUSIONS

This component of the EMP endeavoured to address the following hypotheses:

Hypothesis 1: There will be significant differences in algal biomass and species assemblage between seeps or channels with different hydroperiod categorisations.

Hypothesis 2: Algal community structure will vary in response to seasonal cycles of wetting and drying.

Based on various indicators presented in this report and summarised in Table 7.5, both these hypotheses can be accepted as true, although the relationships with hydroperiod categorisations were weak.

Algal biomass, measured as chlorophyll-*a* was significantly lower in the ecochannels than in the ecoseeps. Exceptions to this were the ecochannels where sediment was sampled in the absence of stones and so, since substrate type has a major influence over algal growth, these samples were outliers, and should be excluded from future monitoring. Algal productivity is better assessed by the measurement of the mass of chlorophyll-*a* per m^2 than by AFDM of the sediment as other plant material, invertebrates, silt and organic debris influence the latter.

Algal biomass was consistently higher in the driest season (March 2009 and 2010) relative to the spring period (September 2008 and 2009 in the case of ecoseeps, and December 2008 and 2009 in the case of ecochannels).

In terms of seasonal assessments, the May 2008 data were rarely included in the analyses because it was not logical to compare a previous autumn sample with spring and summer following the winter. Autumn is a variable time for sampling and potentially contributes unnecessary variability to the analysis of patterns in the algal data, thus the algal successional sequence is considered to begin in spring, move through summer and autumn, and end in winter, when algal structural composition is generally reset over the cold high rainfall period. It is recommended that future sampling focus on the spring and summer periods within the same successional sequence.

The strongest relationship between any component of the benthic algae and hydrological variation observed during this assessment was between ecoseep biomass in summer and groundwater level averaged over the month preceding sampling. This relationship shows clearly that algal biomass increases as aquatic habitats in ecoseeps become shallower and warmer. The thresholds discussed in section 7.3 can be used as an indicator of ecological change related to both non-hydrological and hydrological impacts (e.g. as a result of water abstraction from the Peninsula Aquifer).

Benthic algal biomass in ecochannels increased significantly with a reduction in water depth during the spring and summer using all data across all hydroperiod categories. This relationship was improved which the inclusion of only category A ecochannels which are strongly perennial. Category B ecochannels did not however show the same pattern possibly because these sites are not characterised by base flows that lead to sloughing which seems to maintain the significant relationship between biomass and depth in the spring time for category A ecochannels. Consideration

Table 7.5. Summary of key findings for benthic algae in the ecoseeps and ecochannels.

Ecosystem Type	Indicator	Relationship to hydrology	Threshold of change
ECOSEEPS	Chl *a* concentrations (benthic algal biomass	Significant increase in benthic algal biomass with desiccation stress	WL 1 = 0.5 and Chl a = 11 mgm^{-2}
	Species assemblage structure	Significant temporal change in community structure – could be linked to seasonal drying out over the growing season	none
	% contribution of taxa in gelatinous masses	Increase in % contribution of taxa in gelatinous masses	A and B hydroperiod categories in spring and summer: single celled taxa > 60% and gelatinous masses< 30%
ECOCHANNELS	Chl *a* concentrations (benthic algal biomass	Both an increase and a decrease in algal biomass with a decrease in water depth.	A and B hydroperiod categories in spring: single celled taxa > 50% and gelatinous masses< 30% A and B hydroperiod categories in summer: single celled taxa > 40% and gelatinous masses< 40
	Species assemblage structure		none
	% contribution of taxa in gelatinous masses	Increase in % contribution of taxa in gelatinous masses	none

of current velocity and its role in the balance between nutrient supply and sloughing caused by shear stress is imperative for establishing relationships between benthic indicators and hydrological characteristics.

In terms of algal species composition, ecoseeps showed a clear temporal change in assemblage structure at an interannual scale and at a seasonal scale. While significant shifts in ecochannel communities were found at both the interannual and seasonal scales, these relationships were weak.

For both ecoseeps and ecochannels algal species composition showed strong site signatures. In both cases, site specific differences were stronger than differences between any of the other spatial factors included in the analytical design. These site specific differences in biomass are probably the result of site-specific environmental drivers that obscure the establishment of a relationship between algal species community structure and hydrological character.

Specific recommendations for ongoing monitoring as they pertain to each indicator in the report are summarised in Table 9.1 (Chapter 9).

8. INVERTEBRATES

8.1 INTRODUCTION

8.1.1 Invertebrates as a monitoring tool

Invertebrates are an important component of biodiversity within river ecosystems, particularly within the Cape Floral Kingdom, where 64% of the 300 recorded species of aquatic fauna are endemic (Picker & Samways, 1996). They also occupy a myriad of habitats within the riverscape and their presence, survival and reproduction is predicated on the unique combination of structural features (e.g. substratum composition and flow), ambient conditions (e.g. chemistry or temperature), and biotic conditions such as the availability of food, the density of competitors or the presence of predators.

No two species utilise the resources or respond to the conditions pertaining in a place in precisely the same way. As a result, changes to ecosystems, such as those associated with pollution, flow alteration or physical interference represent differential shifts in the character, quality and suitability of species' habitats. Such changes subtly or otherwise alter the presence, survival and reproduction of one or more species, often leading to an increase in one species to the detriment of another.

Because of their relatively short life spans (usually < one year), invertebrate assemblages respond quite rapidly to changes in ecosystem properties, and are thus useful for use in monitoring programmes. For instance, the Department of Water Affairs uses a rapid bioassessment tool for monitoring ecosystem integrity. However, such a coarse assessment tool was considered unequal to the task of detecting early signs of ecosystem change that could arise as a result of future exploitation of the TMG aquifer. Instead, semi-quantitative species-level data were collected over the summer and autumn period, to provide baseline information against which future collections could be compared.

Very little is known world-wide about the fauna inhabiting seasonally inundated hillslope seeps, and to the knowledge of the authors no prior sampling of these systems had been undertaken in the Western Cape. As an exploration of their use in monitoring change in wetland hydrology, the fauna supported in these ecosystems was sampled during the wet season.

8.1.2 Flow as a driver of invertebrate community characteristics

Rivers in Mediterranean regions such as the Western Cape all show strong seasonality in physical conditions. Gasith & Resh (1999) proposed a number of hypotheses regarding the consequences of the seasonality of flow on biota of Mediterranean streams. Those that are relevant in terms of lowflow conditions include:

- faunal abundance should be highest in summer, which provides an annual window period for growth and reproduction, in the absence of flooding and with warmer temperatures.
- species diversity will decline in late summer, when evenness is low as a result of dominance by species that can tolerate the conditions associated with summer drought or low flow – e.g. high temperatures, low oxygen levels, reduced habitat space
- invertebrate species composition and abundance will shift rapidly between late summer and winter, with the reduction in temperatures and onset of higher flows

In rivers that are strongly perennial, the low-flow period is not considered to be as harsh as in those systems that experience extreme drying. It is therefore hypothesised that, for the TMG study rivers, the faunal assemblages of strongly perennial streams should differ from those with very low summer flows or the loss of flow. This difference should be most marked in the late summer when stress in the less perennial rivers is greatest.

With regard to the seeps, the following hypothesis was tested:

- faunal density, species richness and species with aquatic rather than terrestrial affiliation should be highest in the seeps with the longest hydroperiod,

In addition, the seasonality in invertebrate community at the single site sampled repeatedly in the year was investigated, albeit in a limited way given the selection of only one site.

8.2 METHODS

The ToR for this study specified the use of the rapid bioassessment method, SASS5: The South African Scoring System, Version 5 to provide a measure of ecological integrity for each site. This method was used where possible, in the channel habitats (Section 8.2.1), but the method of invertebrate collection was changed for the seeps as described in section 8.2.2 below.

8.2.1 Channels

SASS5 is described in detail in Dickens & Graham (2002). SASS5 involves kick-sampling to disturb the stream bed so that invertebrates are dislodged from the substratum and vegetation, and retained on a hand-held 950 µm-mesh sieve attached to a 300mm x 300mm frame. Sampling was conducted separately in three biotopes - (1) stones in and out of current (SIC/SOOC, or simply S), (2) vegetation (V) and (3) gravel / sand / mud (GSM). The sample from each biotope was placed in a basin and each taxon recorded, at the level of invertebrate family. Each invertebrate taxon has a pre-assigned SASS “sensitivity score” based on its general susceptibility to or tolerance of pollution, with sensitive taxa being assigned higher scores. Interpretation of the sample results is based on two values: the SASS5 total score which is the summed sensitivity scores of all taxa present, and the average score per taxon (ASPT), which is the SASS5 score divided by the number of taxa.

In addition to generating SASS indices, the samples collected using the SASS techniques were returned to the laboratory for identification and enumeration of the species present, so as to provide information on invertebrate community structure. Because the collection of SASS samples follows a reasonably strict protocol, these data were regarded as semi quantitative, and allowed for comparison of abundance differences and species assemblage structure changes between sites. This information is useful in long-term monitoring programmes, as it provides for more detailed insights into the changes in species, which might occur before major changes in the coarser-level SASS data are identified.

Samples were collected from up to three biotopes at each site, in May and December 2008, March, May and December 2009 and March 2010. At some sites the GSM biotope was not present, as a natural feature of the river reach. At other sites the vegetation or SIC / SOOC biotopes were not available in December and / or March as a result of receding water levels.

8.2.2 Seeps

Seep sampling for invertebrates was conducted at three of the five locations from which algae were collected, and the positions of collection were marked with white pipes. Given the hillslope setting of the seep sites, surface water, even in the wet season, was too shallow to allow for sweep-net sampling of invertebrates as initially envisaged. The approach used was to extract one soil core of 50 cm^3 at each sampling locality, providing three replicate samples for each seep site. Because of very low densities achieved in the 2008 sampling, this sampling effort was trebled for the September 2009 fieldwork to improve data analysis. Also, given the findings in the first annual reporting cycle – that soil moisture differences within the wetland may be a determining factor in whether or not invertebrates were present, and their densities – soil moisture grab samples were collected at each sampling point. Table 8.1 indicates the invertebrates samples collected from the seep sites during the monitoring period. The numbers of the three pipes at which these samples were collected, out of the five that were established for algal sampling, are indicate in the table (P1, P2 etc.). These three locations were chosen on the basis of being the wettest localities at the site. Also indicated in red text are the samples that contained animals – indicating that most sites only supported invertebrates in some portions of the seep, and that two sites were devoid of invertebrates in 2009.

8.2.3 Data management and analytical methods

Summaries of species richness and invertebrate abundances were created using Excel software. Analysis of the relationships between invertebrate assemblages at the different sites was undertaken using the PRIMER multivariate statistical package, described in Appendix 8.1 of Volume B. In these analyses, quantitative rather than presence-absence data were used. Although a 4th-root transformation of abundance data is usually recommended for comparison of samples with highly variable abundances (Field *et al.* 1982), the invertebrate densities obtained from the kick sampling were not as variable as those obtained from more intensive sampling methods or from more enriched sites and the less severe square root transformation was employed.

Table 8.1 Schedule of seep sites sampled for invertebrates over the monitoring period. For each site the number of the three pipes (P#) that were used for invertebrate sampling is given, out of the five pipes established at each site. Samples in red text indicate that they did contain invertebrates, whilst samples in black text were devoid of animals.

TMG Site	Sep 08	Sep 09	2008 Sample Points	2009 Sample Points
B1_1	X	X	P1, P3, P5	P1, P3, P5
H6_1	X	X	P1, P4, P5	P2, P3, P5
H8_2	X	X	P1, P2, P5	P1, P2, P4
H8_3b	X	X	P2, P4, P5	P2, P4, P5
K_1	X	X	Sample points not recorded, one sample with invertebrates	P1, P2, P4
K_2b	X	X	P1, P3, P4	P1, P3, P4
K_3b	X	X	P1, P3, P5	P1, P2, P4
T3_Pal4	X	X	P1, P4, P5	P1, P4, P5
T4_Pal2	X	X	P1, P2, P5	P1, P2, P5
T4_RSE1	Empty	X	P1, P2, P4	P1, P2, P4
T6_1b	X	X	P1, P2, P5	P1, P2, P5
T6_2b	X	Empty	P1, P3, P5	P1, P3, P5
T6_3	X	X	P1, P2, P5	P1, P2, P5
T6_4	X	X	P1, P3, P5	P1, P3, P5
T8_1b	X	X	P1, P3, P4	P1, P3, P4
T8_2b	X	X	P1, P2, P4	P1, P2, P4
V3_3	X	X	P1, P2, P3	P1, P3, P5
W7_2	X	X	P1, P3, P5	P1, P3, P5
W7_3	X	X	P1, P2, P3	P1, P2, P3
W7_5	Empty	X	P1, P4, P5	P1, P4, P5

8.3 RESULTS AND DISCUSSION: INVERTEBRATE ASSEMBLAGES IN SEEPS

8.3.1 Species richness and abundance

A total of 30 invertebrate species were collected from the seep sites in September 2008 and this increased to 49 in 2009, with an overall taxonomic richness of 63 species. The densities in 2008 were very low, with a maximum of 7 individuals per sample and a total of only 82 individuals collected. In 2009 the increased sampling effort resulted in up to 45 individuals in a sample, and a total count for all samples of 543 individuals, demonstrating that the sampling methods employed are able to produce data for analysis.

Given the low numbers and poor relationships identified in the 2008 data between species richness or abundances and any of the hydrological indices, the presentation of data the follows refers to the 2009 results.

Both faunal densities (indicated as abundance per unit volume) and the number of taxa recorded were greater at the more perennial sites (Figure 8.1), although there were two striking exceptions to this, namely at T3_Pal4 and K_1, both Category B ecoseeps. The hydroperiod status of T3_Pal4is doubtful (refer to discussion in Chapter 3) and the locations of invertebrate sampling points at both sites were in a much drier part of the wetland than where the piezometer was located. The patterns in abundance and number of taxa in some of the hydroperiod Category C and D wetlands was contrary to what might be expected: abundances were not uniformly lower at Category D sites than at Category C sites. Here again, some site-specific issues may have clouded the results: T4_Pal2 is a valley bottom wetland, which in September is inundated with standing water up to 30 cm, unlike all the other seeps where surface water is only present at most in a thin film. Sampling here with the same technique may thus have misrepresented the actual numbers of invertebrates at the site.

Furthermore, C or a D category (see Chapter 3) seeps were distinguished from one another on the basis of the duration inundation, as opposed to the duration of saturation, which was similar for C and D categories, and may be a more important habitat criterion for invertebrates than inundation.

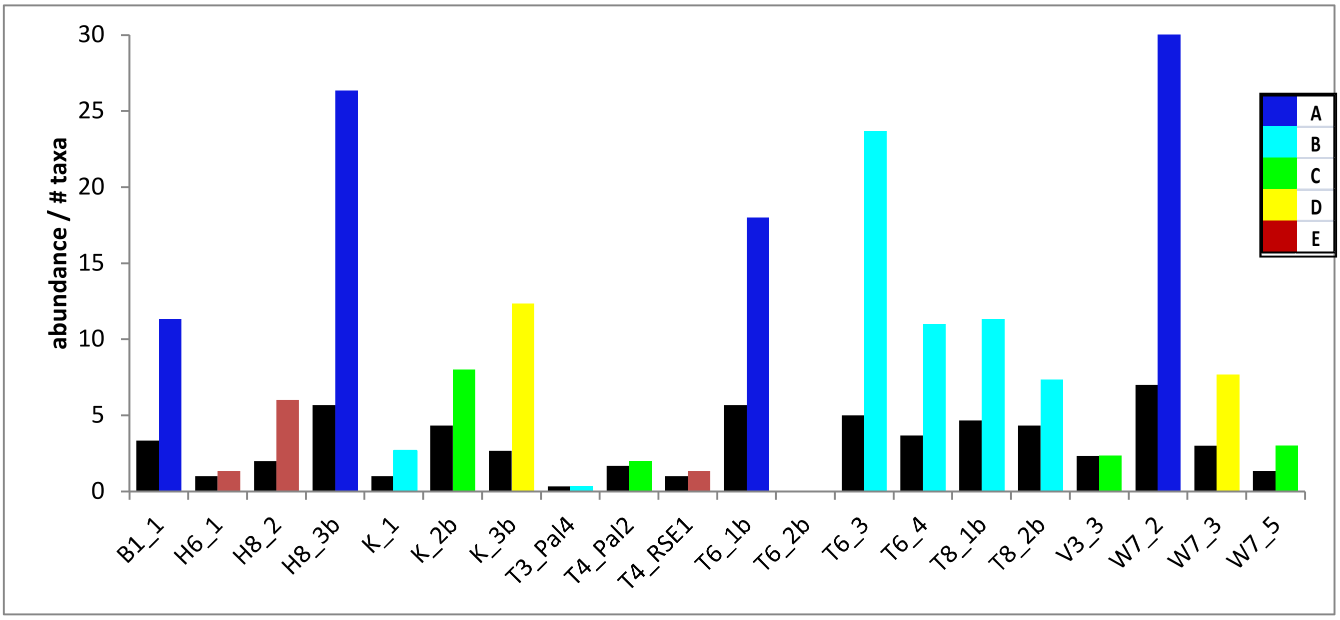


Figure 8.1. Invertebrate abundance (colour bars) and number of species per site (black bars) at the seep wetlands. Abundance bars are colour-coded according to the hydroperiod classification developed in Chapter 3, shown in the key.

Box and whisker plots (Figure 8.2) summarise seep invertebrate abundances and taxon richness per hydroperiod category. An analysis of variance showed significant differences in the number of taxa associated with seeps of different hydroperiod (ANOVA results F = 3.48, p = 0.035), with post-hoc Tukey's test returning a significant pairwise difference between Category A and E sites but not any other pairwise differences.

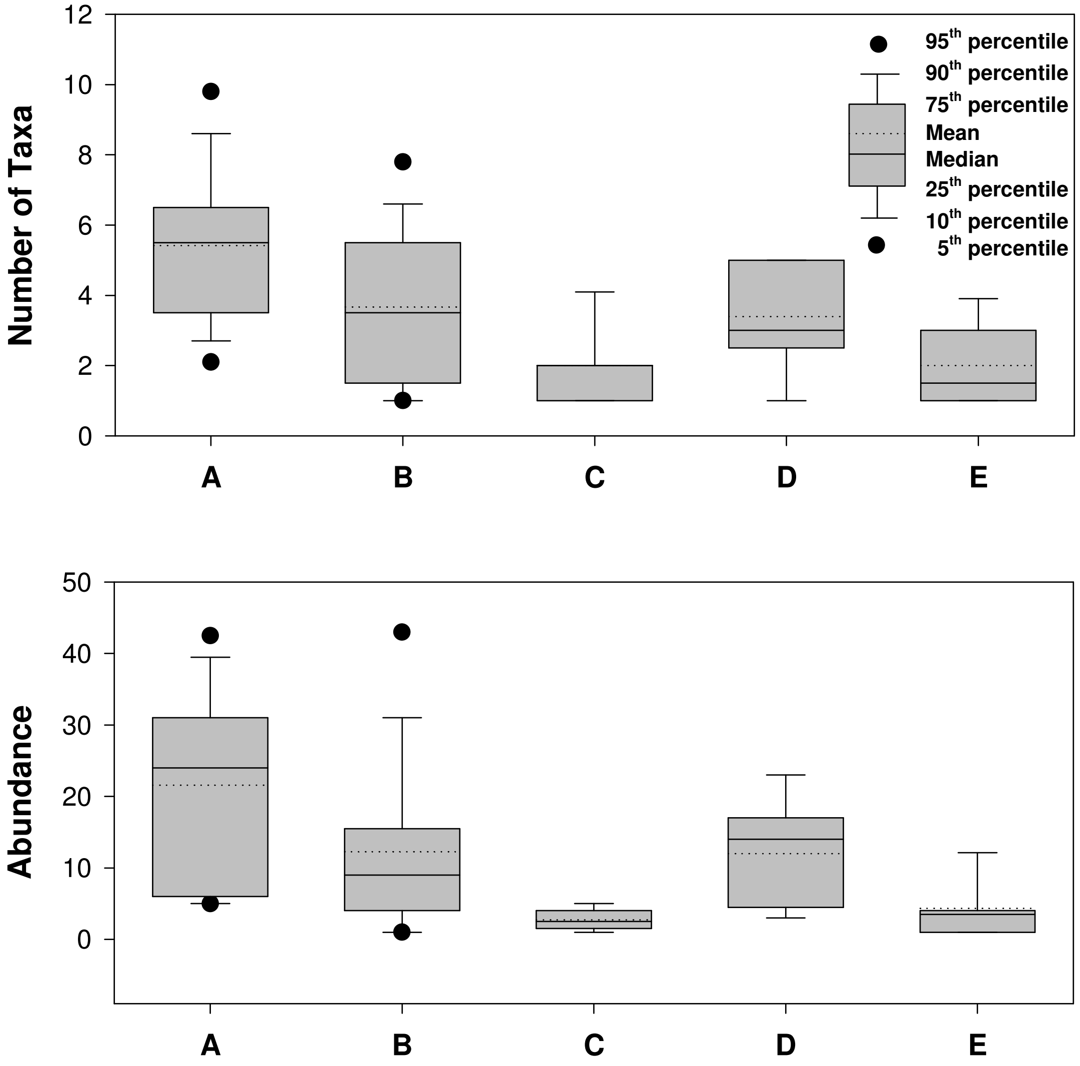
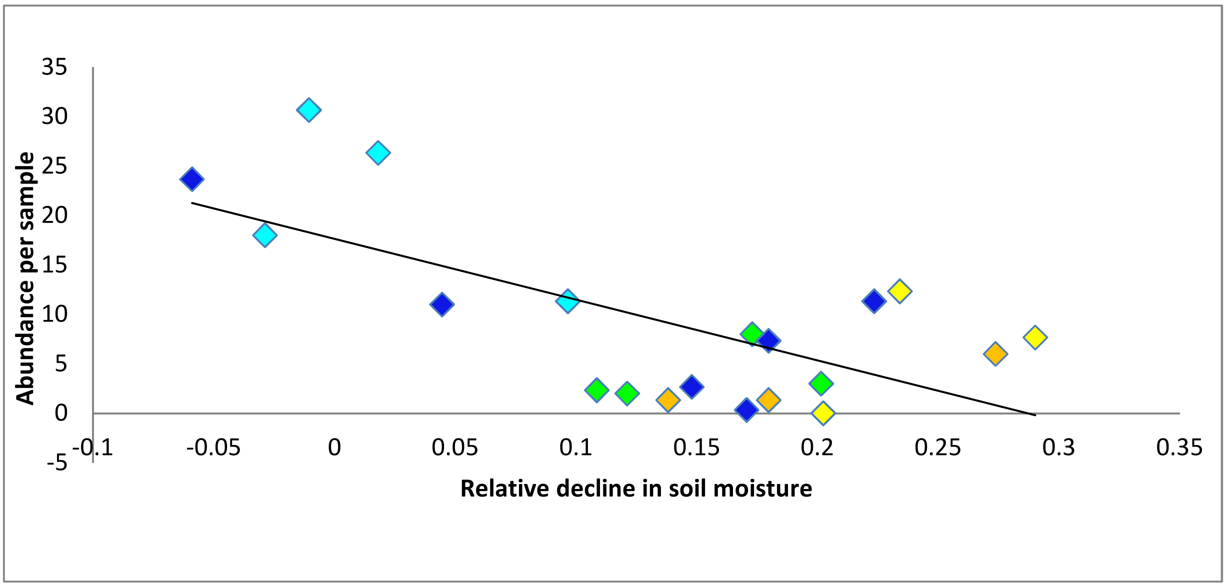


Figure 8.2. Box and whisker plots summarising invertebrate abundances and taxon richness per hydroperiod category at the ecoseeps.

It is noteworthy that even with the additional sampling effort, there were still samples that were devoid of any animals (Table 8.1), emphasising the finding in the first annual report that seeps support invertebrate assemblages only in some patches (these were found to be the wetter sampling points in 2008). Soil moisture grab samples were collected in the second year of sampling from each individual invertebrate (and algal) sampling point, in September 2009 and March 2010. One of the major problems that became obvious with these soil moisture data arose from the fact that soil texture was variable between and within the sites. The calculation of the percentage moisture by weight can only allow for comparison between sampling points if the substrate holding the water is similar – calculating percentage water by weight of a sandy vs. a peaty soil precludes comparison between them. The data can be used over time, for example comparing the change in % soil moisture at different sites. In order still to utilise the information in some way, therefore, the change in soil moisture content between September 2009 and March 2010 was calculate, as a useful surrogate for some estimate of soil moisture hydroperiod" of each of the invertebrate sampling points. A regression between the number of species and total abundances in seep samples September 2009 and the % change in soil moisture content between March and September 2009 was highly significant ($r = 0.669$ $R^2 = 0.45$, $p < 0.001$). The relationships between these variables are shown in Figure 8.3, with points colour coded according to seep hydroperiod. Interestingly, the Category D seeps were those that lost the greatest percentage of their September moisture, yet these were the seeps (with the exception of T6_2b) which had higher than expected taxonomic richness and abundances.



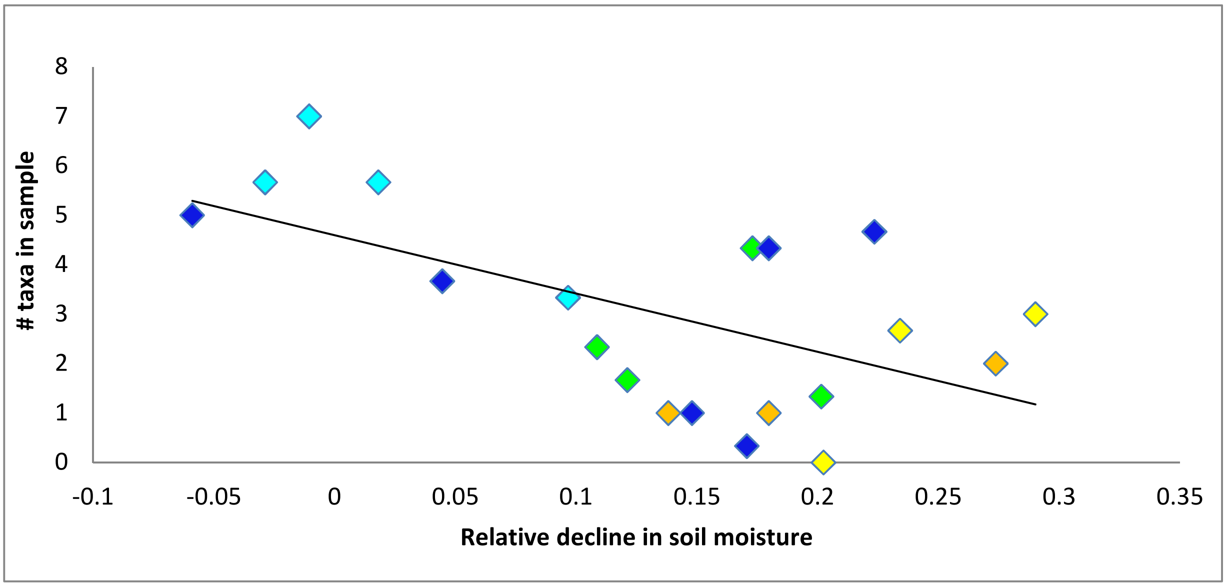


Figure 8.3. **Relationship between the percentage change in moisture at invertebrate sampling points and (top) invertebrate abundance and (bottom) taxon richness. Points on the graph are average for the site, colour-coded according to hydroperiod of the site as per Figure 8.1.**

8.3.2 Invertebrate community structure

All sample replicates that contained invertebrates were subjected to multivariate analysis to identify the similarities in invertebrate assemblages within and between wetlands.

ANOSIM performed on the groupings of invertebrate samples, grouped according to their *a priori*-assigned hydrological groupings, failed to demonstrate significant differences. Nor were there apparent differences between sites on the basis of wetland type or TSA. It is probable that site-based characterisations are too coarse to find a relationship with biotic patterns, partly because of within-site variability in invertebrates. This finding is contrary to the algal data, where seep patterns were stronger than in the channels.

The result of the MDS analysis using invertebrate averages per site is shown in Figure 8.4, overlaid with the hydroperiod category of each site, which confirmed that community patterns did not readily express seep hydrology in the same way that the univariate measures of total abundance and richness were shown to do. The same analysis was repeated with the individual replicate samples (not site averages) without adding insight into any relationships. It is probable that insufficient sampling effort has been expended in relation to the variability within and between sites. However, given the onerous laboratory processing, it would appear that this aspect of invertebrate fauna in seeps does not lend itself to use as a monitoring tool.

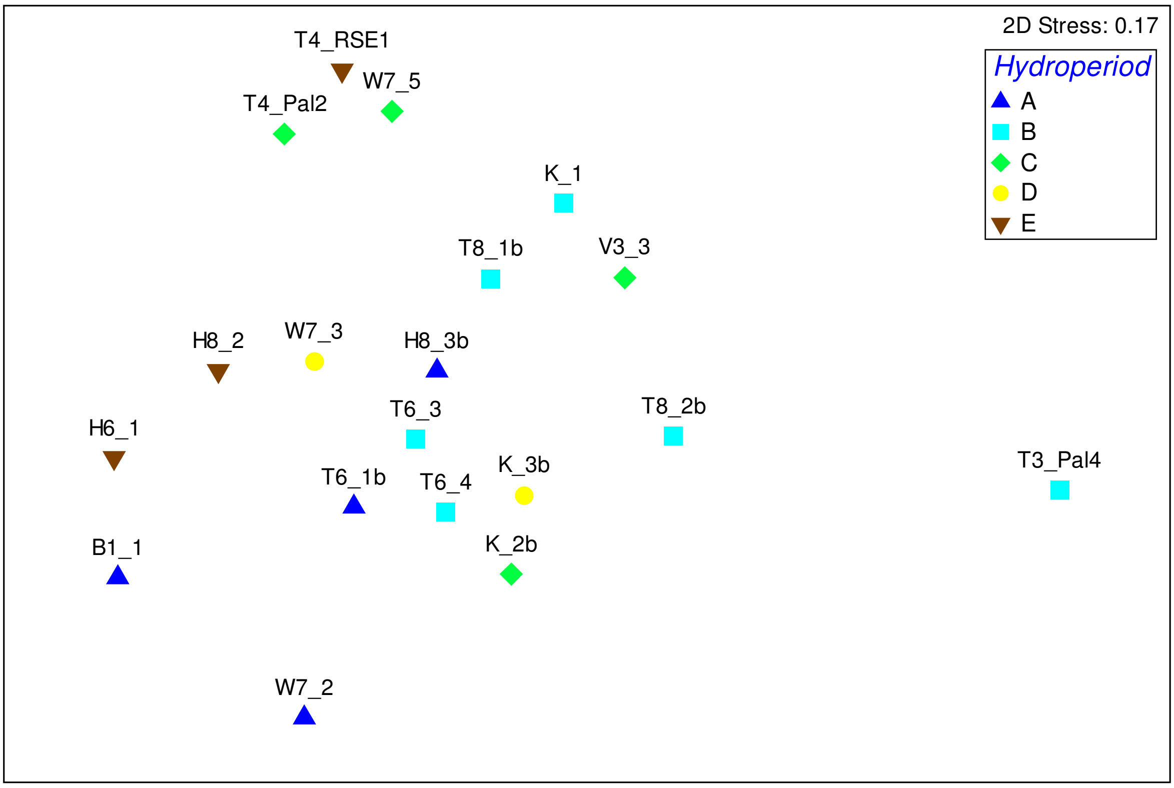


Figure 8.4. MDS results showing the relationship between samples of invertebrate assemblages in seeps, overlaid with the hydroperiod category of the site from which the samples were taken.

A final measure of community structure examined was the relative proportions of taxa that occupy terrestrial, aquatic or semi-aquatic habitats, shown per site in Figure 8.5. These affinities were derived from the taxonomic literature. No particular trend is evident in these results, which is understandable given the variety of soil moisture levels at different sampling points within each site. Insufficient material was available to conduct an analysis on a per-sample basis. Nevertheless, these data might be useful as a baseline against which comparisons can be made in future as they provide a first picture of invertebrate assemblages in the seep habitats.

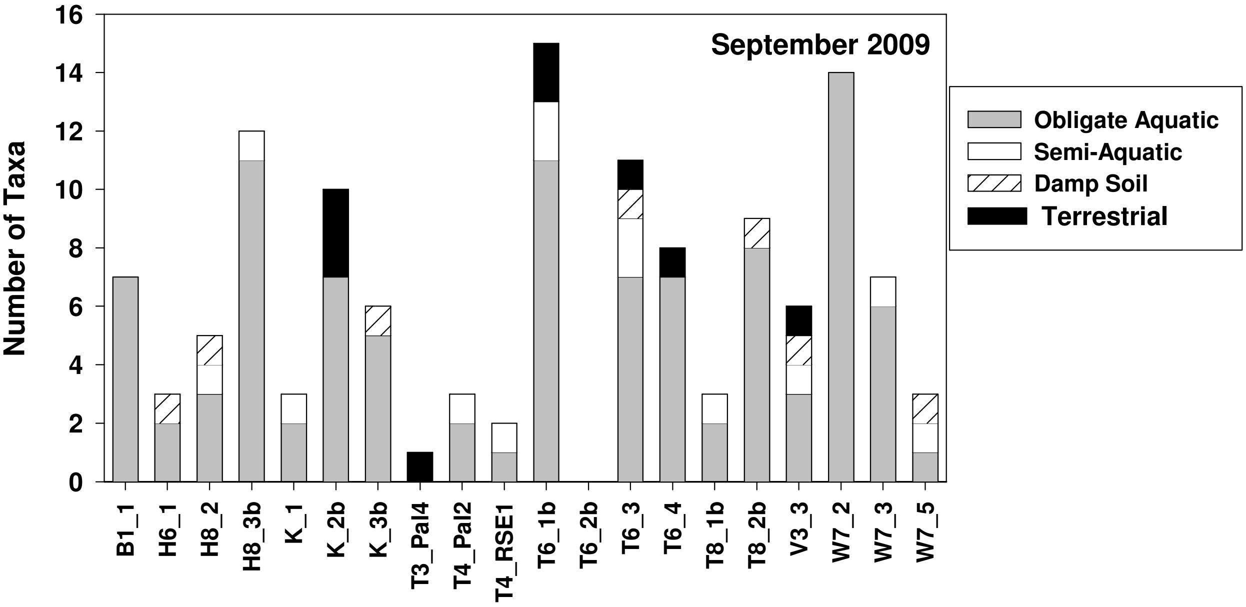


Figure 8.5. **Number of taxa in different habitat groups identified in samples collected at seep sites in September 2009. Number of samples collected at each site is listed in Table 8.1.**

8.4 RESULTS AND DISCUSSION: INVERTEBRATE ASSEMBLAGES IN RIVERS

In general the riverine invertebrate fauna in the TMGA catchments have a very high level of species richness, with a total of 256 taxa recorded from the 18 sites over the three sampling periods (Table 8.5). There were 35 different trichopteran species, 22 ephemeropteran (8 each from the Baetidae and Leptophlebiidae), 16 plecopteran species, all from the Notonemouridae, and 20 odonate taxa. The greatest species richness was in the Diptera, which sported 63 taxa, 48 of which were chironomid species. However, the Coleoptera were unusually rich, with 12 families present and a total of 45 species, 17 of which were from the family Dytiscidae alone. A full species list per site is provided in the data spreadsheets accompanying this report. Table 8.5 provides a summary of the total number of species recorded per TSA to date over the study period, with a breakdown for each of the main orders of stream invertebrates found. Obvious bias in the richness per TSA will be produced as a result of uneven sampling effort, with some TSAs having two and others three sites. Also, the drying of rivers at V3 and some at T4_RSE also would have affected overall species complements, as no samples were taken in these rivers in March '09. Nevertheless, T6, W7 and K1 support the highest biodiversity, with approximately twice the species complement as V3, the area with the lowest species count.

Large differences in the types of species inhabiting the sites are also apparent from this summary, for example six species of the amphipod *Paramelita* in the Kogelberg against only one found in Boesmanskloof (T6). Whilst T4_RSE had the second lowest species total, the beetle diversity was considerable, including the only representatives in the study area of the family Hydrochidae, rare and poorly described elongated water scavenger beetles. This may indicate differences in the species pool available to each site, but will have to be verified as additional data are collected.

8.4.1 Seasonal patterns in invertebrate assemblages

Abundance and richness patterns

A summary of seasonal differences in invertebrate richness and abundance per site is provided in Figure 8.6, with the vegetation and stones biotopes shown separately. A composite summary of the abundances of each major invertebrate order in the ecochannels in May '08, December '08 and March '09 is provided in Figures 8.7 – 8.10. In terms of the invertebrate abundances, the results show:

- Average richness was greatest in December and declined through the late summer and autumn period to May (Figure 8.6a): the May samples, with a few exceptions, reflect late autumn conditions but prior to the onset of winter spates. This is a time when many species emerge from the river having completed their life cycles, and abundances are generally lower, as was demonstrated in vegetation samples in this study (Figure 8.6b). There were was no difference in average abundance in stones biotope across calendar months. This seemingly supports the hypotheses that faunal abundance should be highest in summer, and that diversity should decline in late summer, as described in the introduction to this chapter.
- However, a more detailed examination of inter-site patterns (Figures 8.7 – 8.10) revealed a massively variable pattern of change over time in the abundances of the major groups, and in richness. Virtually equal numbers of sites demonstrated highest numbers in May, December or March, indicating that seasonality in abundances, even per invertebrate order, was not clear throughout the study area. Even at the level of individual sites, there were interannual differences in the pattern of month-to-month change in abundance and richness. Some of the variation in the data may be explained by:
    - The H8 sites were sampled in December 2008 immediately after a fire had swept through the catchment, as were T4_Pal2 and T4_RSE2 in March 2009. These sites returned amongst the highest abundances of the whole sampling exercise. At T4_RSE2, the abundance was driven by the presence of over 500 very early instar coenagrionid damselfly nymphs, and over 150 individuals of the chironomid *Polypedilum* spp. This rather unusual situation may have been related to the fire that burnt the valley bottom seep through which this channel drains. The T6 sites also showed dramatic increases in abundance in March 2010, following a fire that swept through the catchment there. The standard deviation bars in Figure 8.6, especially in the case of the vegetation, underscores the use of this biotope by very large numbers of animals after fire.[11]
    - With the exception of T4_RSE2 (high numbers after the fire), abundances at the Category D sites (dry in summer) were lower than the perennial sites.
    - A further anomaly was at V3_1 in March 2010: this site dries out, but a sample was taken from vegetation in residual pool habitat some 2 km downstream of the site and revealed a plethora of species and high overall abundance in this summer-drought refugium.

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[11] Most fires, certainly the ones recorded during the EPM burnt at most some of the outer zones of the riparian area, but instream vegetation was still plentiful.

These simple measures of community structure thus do not appear to hold promise for monitoring. The semi-quantitative sampling approach, combined with sampling in three biotopes requires some modification in order to improve the accuracy of abundance estimates: summing invertebrate numbers across biotopes may be problematical as the biotopes are sampled in a different manner (for example a unit time in stones and an area or length of sweeping in vegetation). Also, apparently minor changes in the effort expended on each sample may be reflected in the variation in the data,,[12] and more emphasis should be placed on the repeatability of the sampling protocol. Defining areas for sampling at each site, and ensuring their comparability may help in this regard.

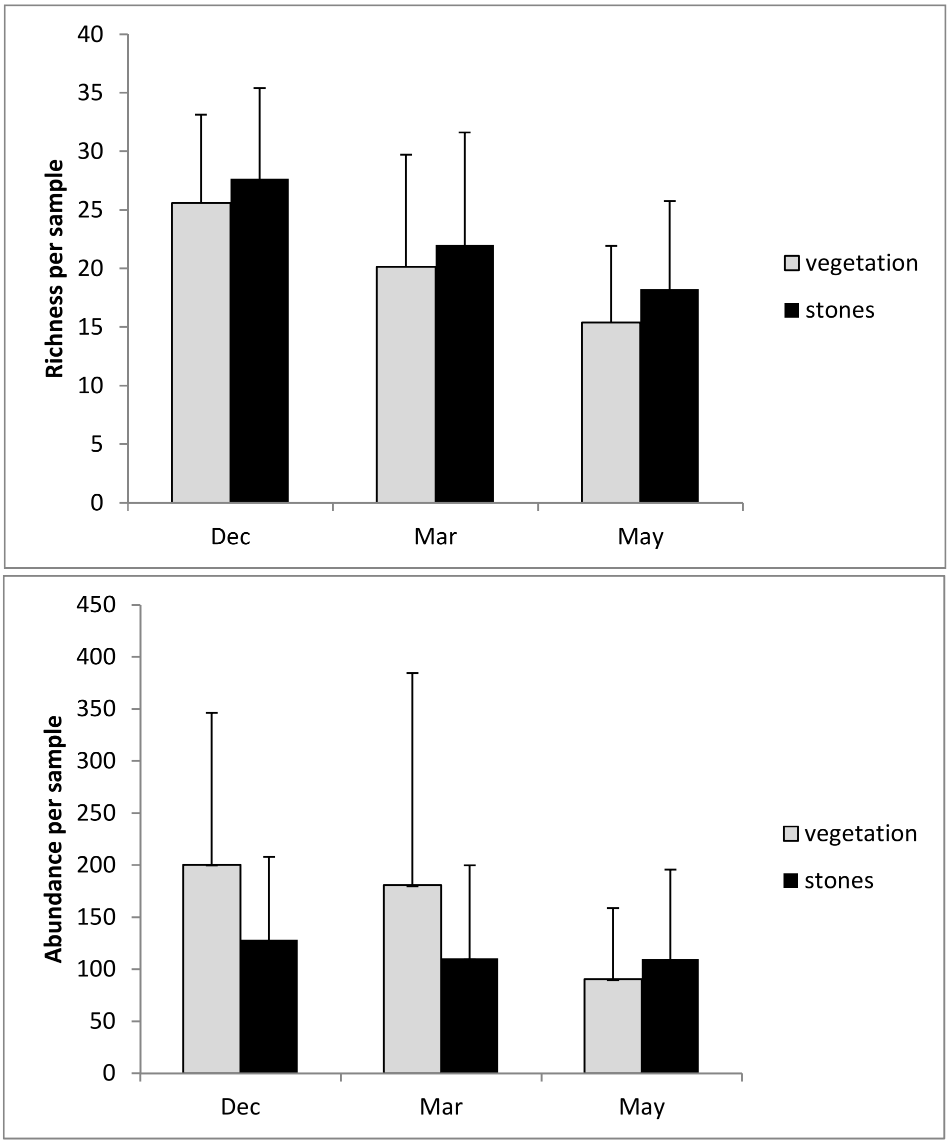

Figure 8.6. **a) average (std dev) species richness per sample at the ecochannel sites for each calendar month, incorporating both years for which data were collected and b) average (std dev) abundance per sample. The stones and vegetation biotopes are shown separately.**

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[12] This is not such a concern in the SASS method in terms of generating SASS scores, since they are based on presence-absence information, but ensuring that the unit effort expended per sample is strictly adhered to is of utmost importance here.

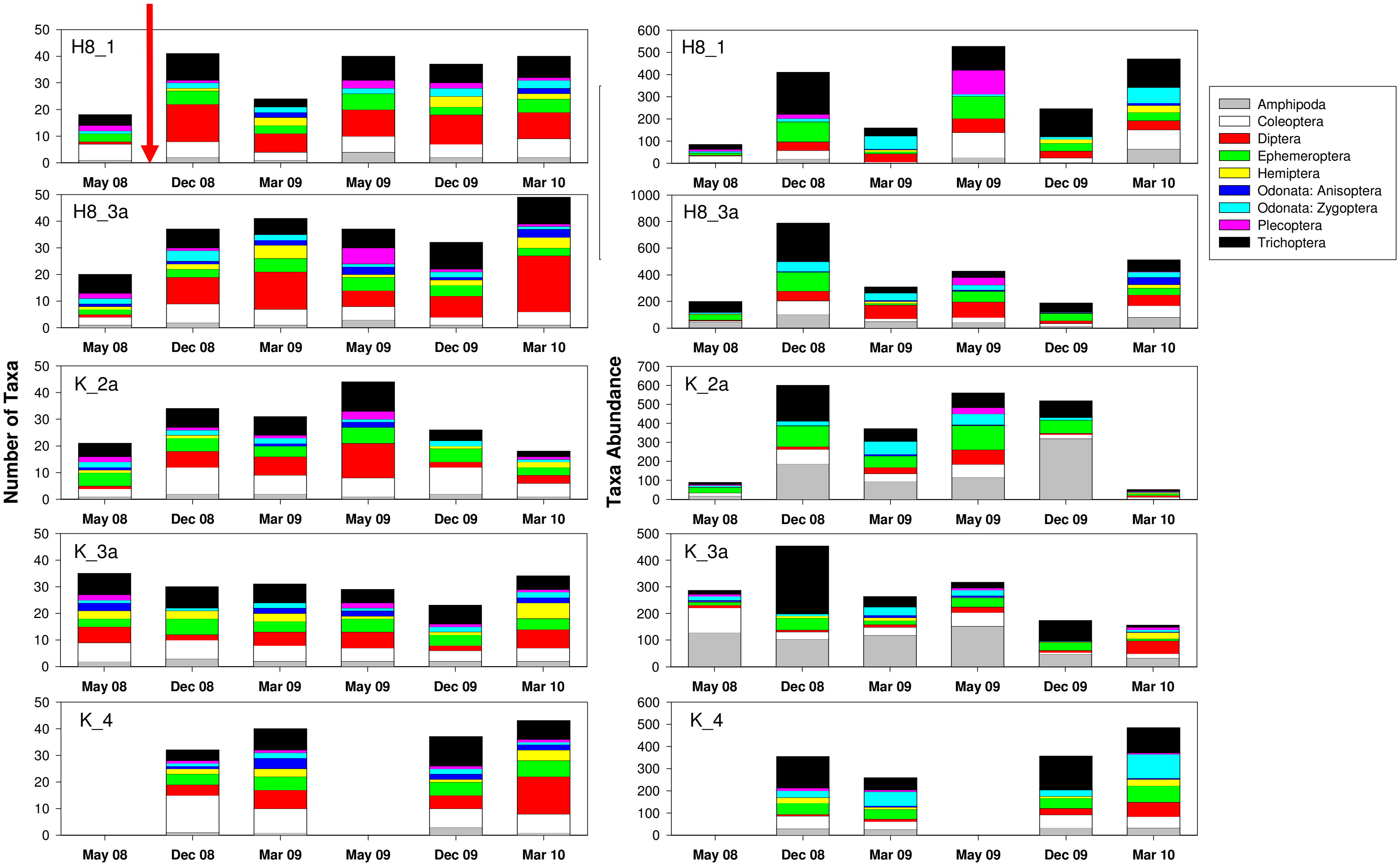

Figure 8.7. **Composite summary of taxon richness (left) and invertebrate abundance (right) over the study period, broken into the major invertebrate orders at the ecochannels: Steenbras (H8) and Kogelberg (K) sites.** Y-axis scale varies in the case of taxa abundance (number per sample, all taxa). Arrows denote fire in the catchment (H8 only).

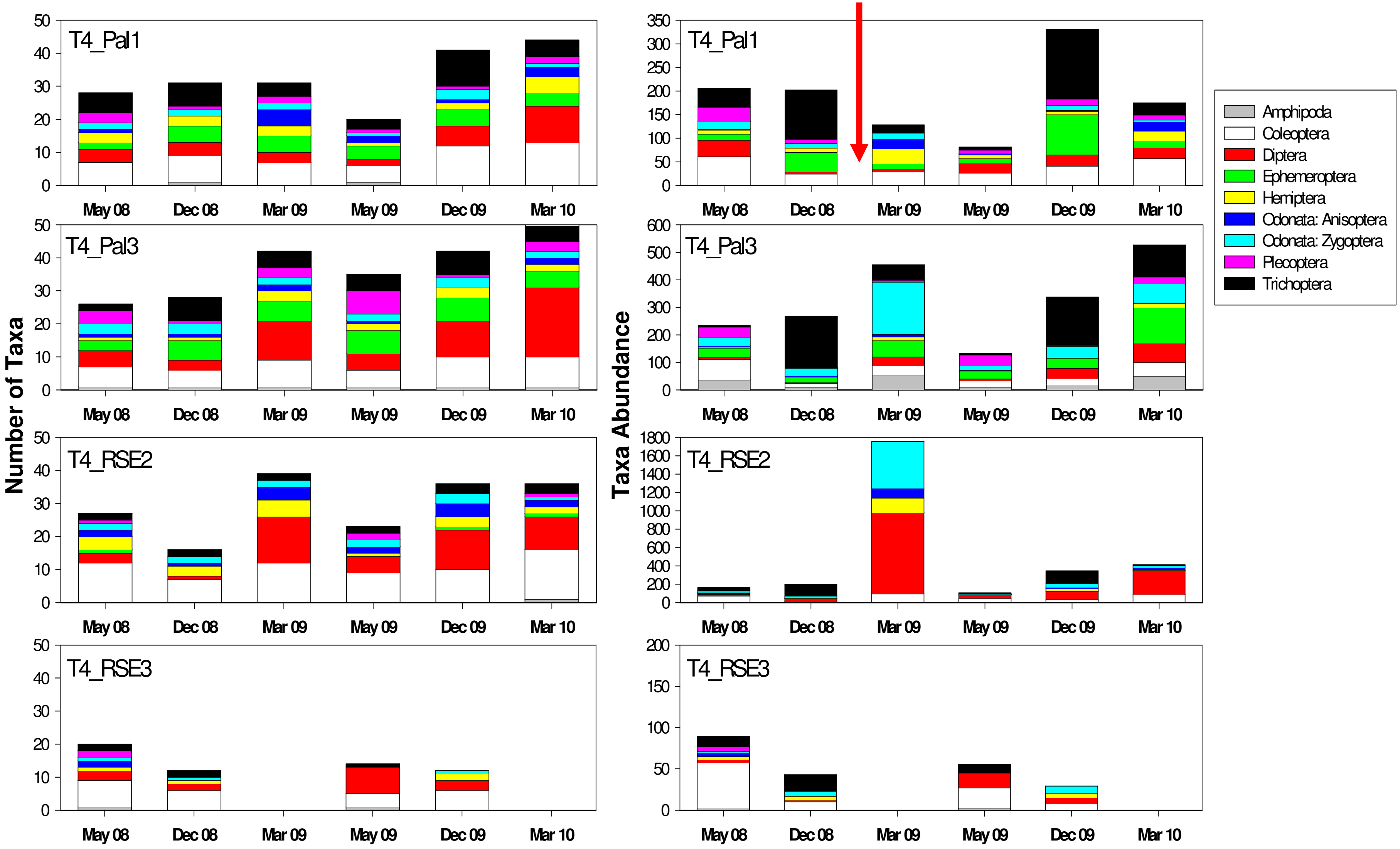

Figure 8.8. **Composite summary of taxon richness (left) and invertebrate abundance (right) over the study period, broken into the major invertebrate orders at the ecochannels: Palmiet and Riviersonderend (Nuweberg – T4) sites.** Y-axis scale varies in the case of taxa abundance (number per sample, all taxa). Arrows denote fire in the catchment.

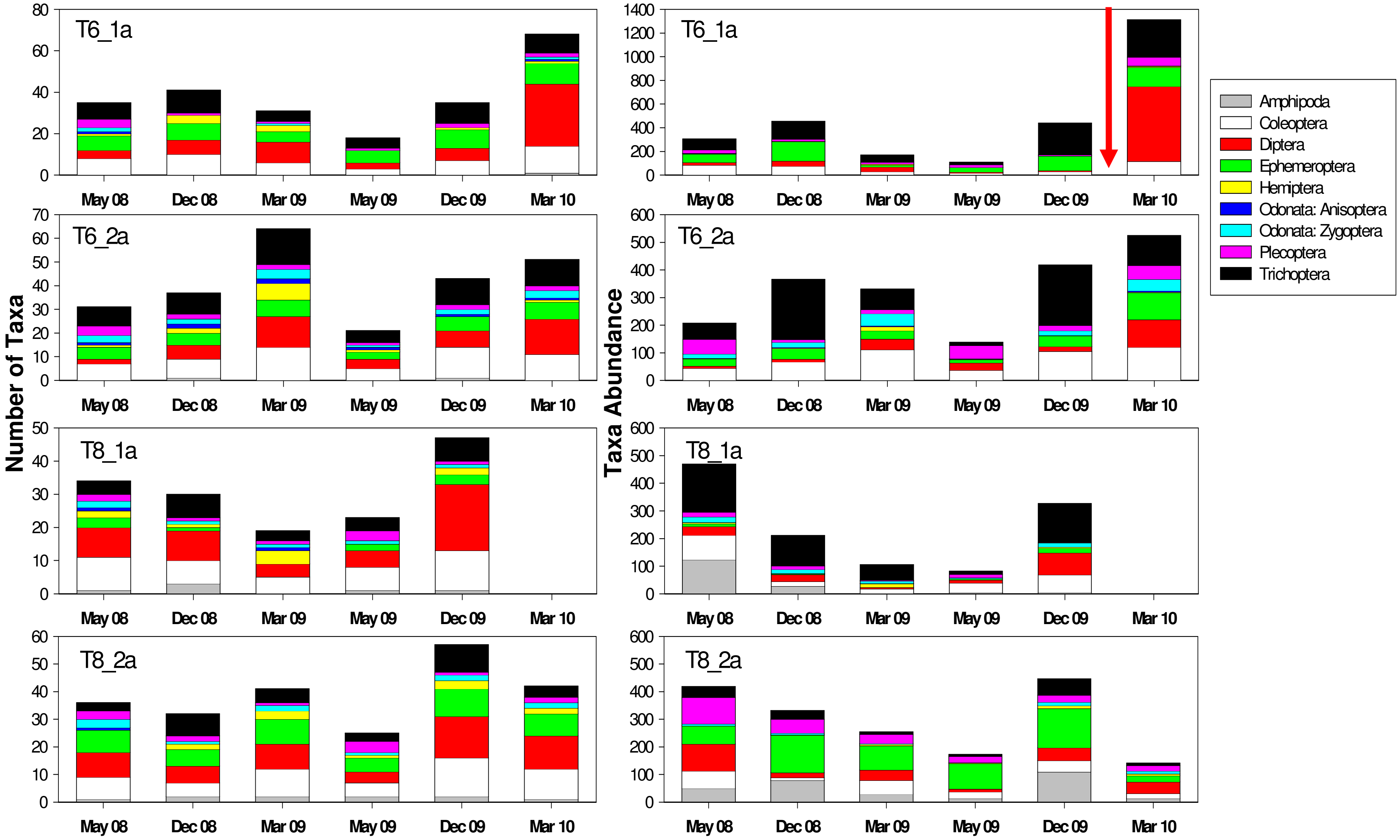

Figure 8.9. **Composite summary of taxon richness (left) and invertebrate abundance (right) over the study period, broken into the major invertebrate orders at the ecochannels: Boesmanskloof (T6) and Purgatory (T8) sites.** Y-axis scale varies in the case of taxa abundance (number per sample, all taxa). Arrows denote fire in the catchment (T6 only).

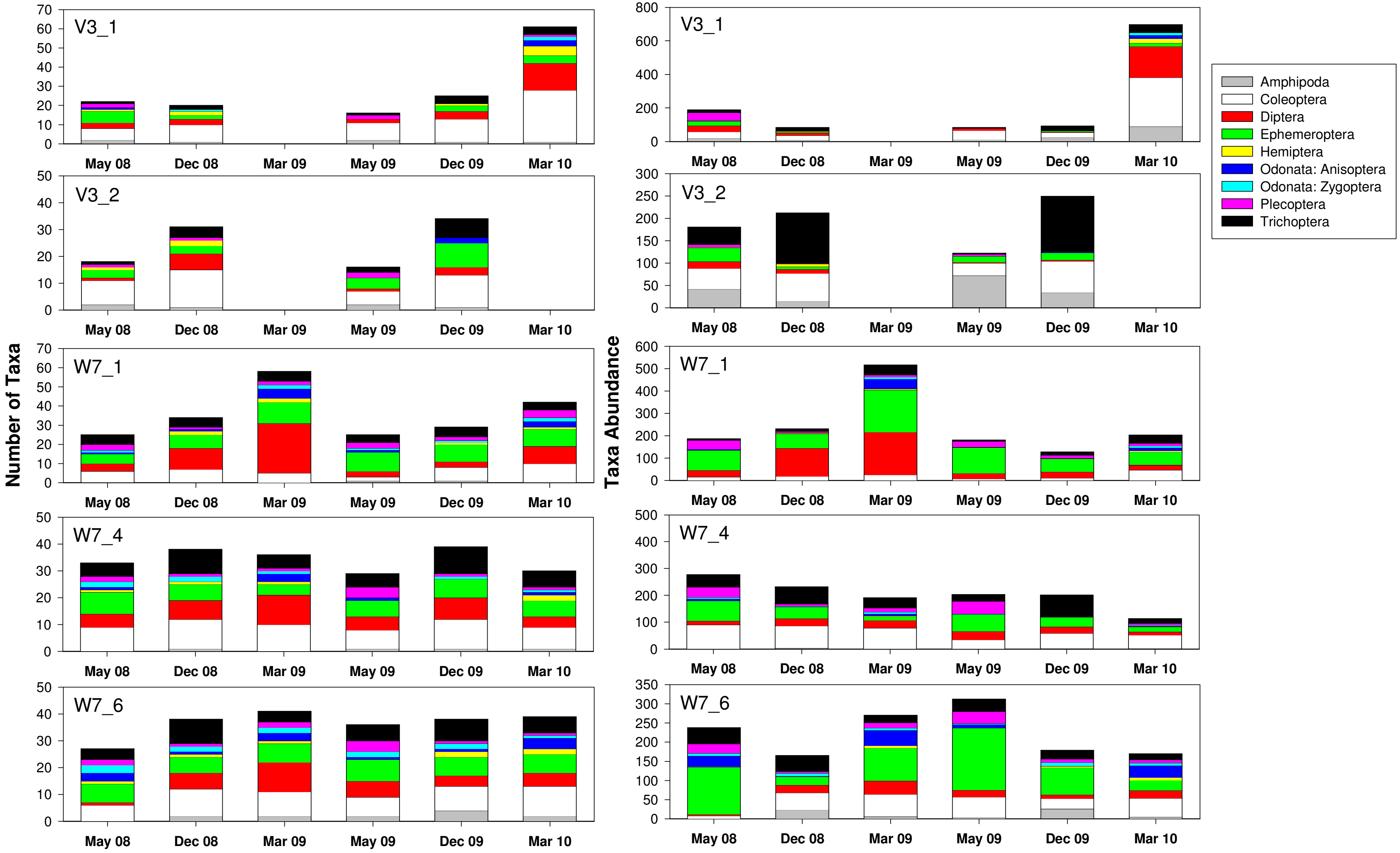

Figure 8.10. **Composite summary of taxon richness (left) and invertebrate abundance (right) over the study period, broken into the major invertebrate orders at the ecochannels: Voelvlei (V3) and Wemmershoek (W7) sites**. Y-axis scale varies in the case of taxa abundance (number per sample, all taxa).

Invertebrate community structure

Seasonal differences in community composition were expected to be substantial, given the strong seasonality of factors like temperature and flow. One-way ANOSIM analysis of differences by month showed a significant but small difference (ANOSIM R-value = 0.17, p<0.001), which is illustrated in the MDS plot of the samples, coded by calendar month and year of sampling (Figure 8.11). This is an interesting finding for the TMGA monitoring as a whole, as it illustrates that invertebrate community structure in the mountain stream reaches is considerably less defined by temporal drivers than their foothill river counterparts (e.g. Ractliffe 2009). However, other factors such as biotope and spatial differences across sites could also be responsible for reducing the strength of seasonal pattern.

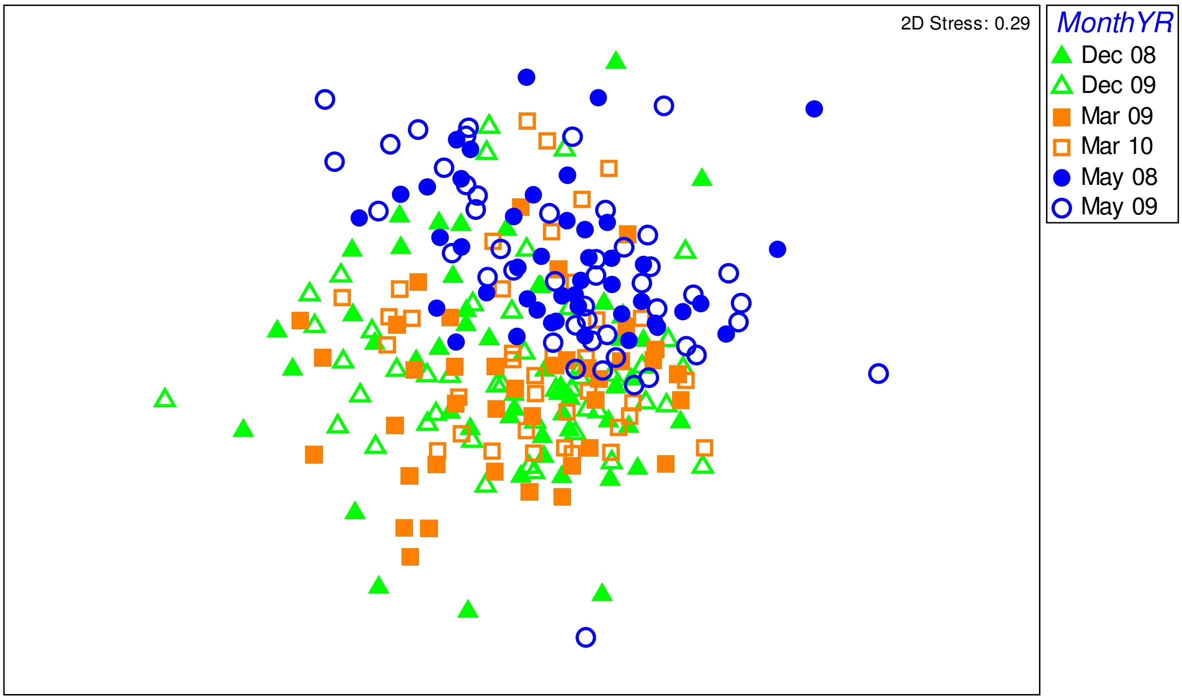

Figure 8.11. MDS Plot of ecochannel samples showing shifts in community composition between December March and May.

8.4.2 The influence of hydroperiod on invertebrate assemblages

Differences between sites based on hydroperiod were examined in a two-way ANOSIM using month and hydroperiod as factors. Stones and vegetation biotopes were analysed separately, to reduce the "noise" associated with these factors. ANOSIM results are shown in Table 8.2 whilst the MDS plot is provided in Figure 8.12, indicating the hydroperiod affiliation of each sample, defined in Section 4 of this report. Samples were well differentiated according to hydroperiod, at the level of separating Category A and B sites from Category C and D sites, but within these subgroups the differentiation was poor, for both stones and vegetation biotopes. Interestingly, community composition was more well-defined in vegetation samples, with the stones biotopes being associated with a wider range in assemblages and a larger degree of overlap in samples from different hydroperiods. This stronger differentiation of vegetation samples is reflected in the higher R-values in the ANOSIM analysis (Table 8.2).

Pairwise ANOSIM differences (Table 8.2) between groups based on hydroperiod were greatest between Category B and C sites in the both the stones biotope (R-value 0.597) and vegetation biotope

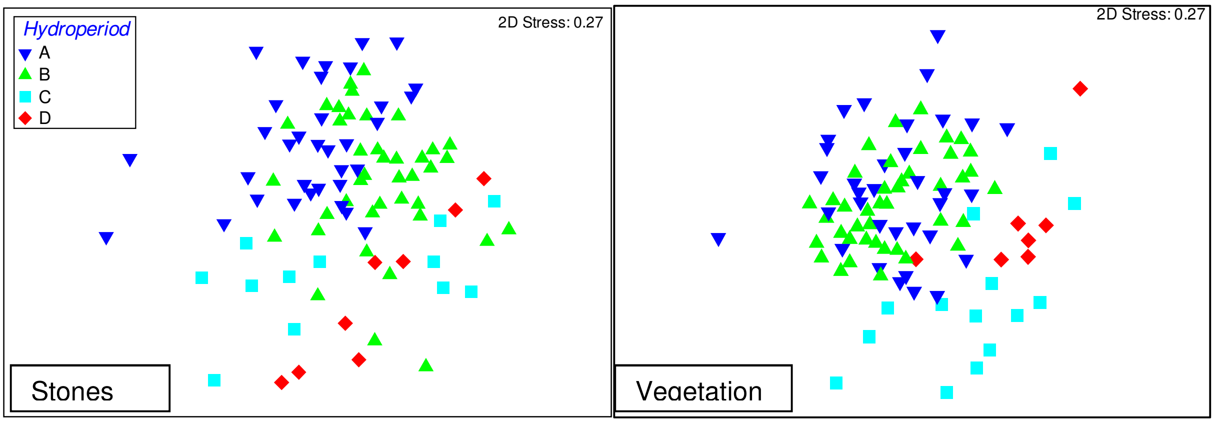

Figure 8.12. MDS Plot of ecochannel samples showing stones and vegetation communities according to hydroperiod.

Table 8.2. Results of a 2-way ANOSIM testing for significant differences in invertebrate assemblages between calendar month (representing season) and hydroperiod. R values represent the strength of the difference between pairs, with 1 equivalent to a complete dissimilarity and 0 indicating no difference. All comparisons significant at p <0.01 unless indicated.

Stones	**GLOBAL R – differences**	**Pairwise differences**	
between month	0.199 (0.001)	Dec, Mar	0.164
		Dec, May	0.219
		Mar, May	0.219
between Hydroperiod	0.316 (0.001)	A, B	0.139
		A, C	0.500
		A, D	0.455
		B, C	0.597
		B, D	0.545
		C, D	-0.0066 (not significant)

Vegetation	**GLOBAL R – differences**	**Pairwise differences**	
between month	0.307 (0.001)	Dec, Mar	0.233
		Dec, May	0.398
		Mar, May	0.311
between Hydroperiod	0.408 (0.001)	A, B	0.177
		A, C	0.593
		A, D	0.490
		B, C	0.741
		B, D	0.664
		C, D	-0.112 (not significant)

(R-value 0.741). Within the grouping of perennial sites, however, the differences were very small (R-values 0.164 and 0.177 respectively). The ANOSIM analysis comparing months again showed a generally low overall differentiation (Global R = 0.199 and 0.307 for stones and vegetation respectively), as a result of very small differences between samples from the summer months (December and March), but larger differences between both of these and May samples.

8.4.3 Measures of persistence

In a comprehensive review of the scientific literature on invertebrate community dynamics, Jackson & Fűreder (2006) highlighted the paucity of studies of aquatic fauna where the temporal scale of investigation exceeded three years. A key finding of such studies was that insect populations show considerable inter-annual variability both in size and densities, community structure and life history attributes, that are the result of climatic conditions, chiefly hydrological characteristics. The variability in numbers and composition between sampling events shown in this study conform to such findings. However, over long time frames, communities are regarded as being relatively persistent, in that the fauna of a river reach could be expected to be present over long time frames.

Townsend *et al.* (1987) defined persistence as the extent to which the species complement of an assemblage remains unchanged over a time period encompassing at least one complete population turnover. This measure is free of densities of animals, and thus less prone to intra- and inter-annual dynamics in populations. The Bray Curtis dissimilarity measure (when based on presence –absence data) is also a measure of persistence used in the recent literature (e.g. Scarsbrook 2002; Beche & Resh 2007) and that has become popular in long-term monitoring studies. The natural range in persistence of different sites will differ, largely as a result of the amplitude of environmental fluctuations. Persistence studies can also track changes caused by incremental transformation of an environment, for example by acid rain, or, indeed, changes in groundwater level.

Bray-Curtis persistence values were calculated for each biotope sample at each site, comparing the year-on-year samples for each of the three calendar months (May, December, March). Whilst the data cannot be used to infer change in the short term, they represent the first of a time series that could track the behaviour of invertebrate communities at impact and control sites during future phases of the TMGAA, and are thus provided in Table 8.3.

Although the hydroperiod Category A and B sites were not shown to be different on the basis of their invertebrate communities, summaries of the Bray-Curtis persistence values were derived for each of the different hydroperiod groups (Figure 8.13). No clear pattern is evident from these first values, except for the observation that a) persistence values appeared to be somewhat lower in the vegetation samples, particularly in the seasonal streams and that b) summertime persistence values were generally higher than those in autumn, although not by much.

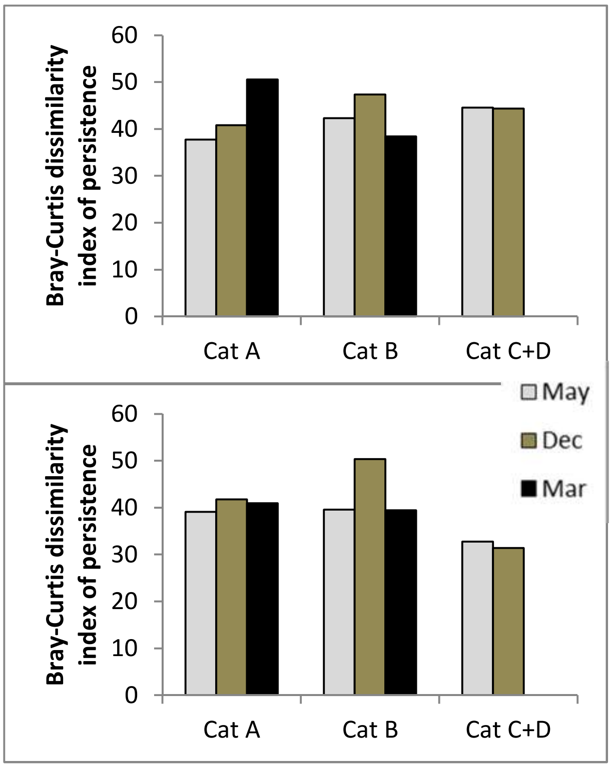

Figure 8.13. Bray-Curtis persistence for year-on-year samples of invertebrates from (top) stones and (bottom) veegtetation biotopes, for each calendar month sampled.

Table 8.3. **Bray-Curtis Persistence values for year-on-year comparison of invertebrate assemblages in three biotopes at the ecochannel sites.**

	MAY 2008 vs 2009	DEC 2008 vs 2009	MAR 2009 vs 2010
H8_1 - S	43.14	38.46	34.78
H8_1 - V	32.43	38.30	47.62
H8_3a - G	45.45	47.06	33.33
H8_3a - S	32.00	45.45	
H8_3a - V	45.00	52.17	28.13
K_2a - S	29.79	50.00	24.24
K_2a - V	43.24	65.00	46.67
K_3a - S	43.90	45.71	41.03
K_3a - V	40.82	45.71	30.43
K_4 - S		9.76	47.62
K_4 - V		12.90	40.82
T4_Pal1 - G	16.67	17.39	24.00
T4_Pal1 - S	30.30	46.81	43.90
T4_Pal1 - V	48.28	40.00	44.44
T4_Pal3 - G			51.28
T4_Pal3 - S	38.89	53.33	50.79
T4_Pal3 - V	47.06	61.54	48.98
T4_RSE2 - G	18.18	0.00	32.00
T4_RSE2 - S	55.56		
T4_RSE2 - V	48.28	36.36	45.28
T4_RSE3 - G	16.67	20.00	
T4_RSE3 - S	41.67	58.82	
T4_RSE3 - V	42.86		
T6_1a - S	48.89	52.00	48.72
T6_1a - V	51.61	54.55	47.89
T6_2a - G	32.00	48.65	32.43
T6_2a - S	13.33	57.14	56.00
T6_2a - V	34.29	60.00	38.81
T8_1a - G	51.28	47.37	
T8_1a - S	38.89	35.90	
T8_1a - V	0.00	37.84	
T8_2a - S	47.37	49.12	48.57
T8_2a - V	27.91	44.07	37.50
V3_1 - G	42.86	11.11	
V3_1 - S	30.77	47.06	
V3_1 - V	37.50	20.00	
V3_2 - G	25.00	41.86	
V3_2 - S	56.00	35.71	
V3_2 - V	35.29		
W7_1 - G	0.00	0.00	21.43
W7_1 - S	48.78	30.00	58.46
W7_1 - V	33.33	38.89	36.36
W7_4 - G	25.00	22.22	38.10
W7_4 - S	64.00	56.60	31.37
W7_4 - V	37.50	51.06	32.43
W7_6 - G	0.00	11.76	26.09
W7_6 - S	44.44	41.94	48.39
W7_6 - V	30.77	38.71	41.86

8.4.4 SASS indices of river integrity

SASS5 was included in the original ToR as the major thrust of the invertebrate monitoring component of the study. Interpretation of SASS5 results is facilitated by guidelines (Dallas 2007) that use the combination of SASS5 score and ASPT to set thresholds corresponding to one of the Ecological Status classes. The use of Ecological Classes was introduced by the Department of Water Affairs and Forestry as a standardised way of categorising the condition of the ecosystem, or ecosystem component. They were used in both the EWR and Catchment Management Plans to describe present and future desired conditions in the river, and thus have been adopted here as way of presenting our assessment. The Classes, A to F, are defined in Table 8.4. These classes are based on the range of scores recorded for all sites in each bioregion, for example where Class A sites are defined by the range of the 90th to 100th percentile of all scores in that bioregion (see Dallas 2007 for more detail). SASS5 is used as a valuable tool in ecological assessments, but it does have its short-comings. Firstly, it is primarily an index to detect pollution (nutrient and organic) in perennial river systems and, as such, the tolerances and sensitivities of taxa are based on those parameters. Secondly, the guidelines for interpretation are based on percentiles of sites / SASS samples collected to date, and will (and have in the past) shifted as the data set upon which they are based explands. Furthermore, the interpretation guidelines (and SASS in general) are intended for use in perennial rivers.

Table 8.4. Ecological Classes defined by the Department of Water Affairs and Forestry, used for interpretation of SASS River Health data.

STATUS CLASS	DESCRIPTION
Class A	100% of potential value; unmodified, natural.
Class B	80-99% of potential value; largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the assumption is that ecosystem functioning is essentially unchanged.
Class C	60-79% of potential value, moderately modified. A loss and change of natural habitat and biota has occurred, but basic ecosystem functioning appears to be predominantly unchanged.
Class D	40-59% of potential value, largely modified. A loss of natural habitat, and taxa and a reduction in basic ecosystem functioning has occurred.
Class E	20-39% of potential value, seriously modified. The loss of natural habitat, taxa and ecosystem functioning is extensive.
Class F	0-19% of potential value, modifications have reached a critical level and there has been an almost complete loss of natural habitat and biota. In the worst cases, basic ecosystem functioning no longer exists

It is seldom that such a comprehensive data as the TMGA collection set is collected in rivers that are, by selection, virtually without anthropogenic impact, barring the possible effects of fires and the very limited alien presence. Of interest, therefore, is the spread of data points, relative to the SASS interpretation guidelines, with the bulk of data falling into the Class B Ecological Class, and some into Class C. In the perennial ecochannels there was a slight tendency for March scores to be lower than those in May or December. This does not necessarily imply a reduction in integrity: for example, at H8_3a, the lower ASPT than usual may be the result of the very high number of taxa found there in March both years of sampling (refer to Figure 8.6), which has the effect of lowering the ASPT even without the loss of sensitive species. A similar phenomenon occurred at T4_Palmiet 1 in the March 2009 sample – both of these following fire in the catchments. Other of the Class C scores cannot be attributed to any obvious cause, and could simply reflect variability or a degree of human error.

The Hydroperiod Category C/D ecochannels displayed a wide range in SASS / ASPT scores. These cannot be interpreted according to the SASS guidelines, but rather reflect the fact that a) non-perennial streams tend to have a different faunal complement, with a greater number of tolerant or cosmopolitan taxa, and especially ones that have life cycles that include resting or aerial stages so as to avoid harsh summer conditions and b) therefore over summer as conditions become harsher, flow- and water quality-sensitive taxa leave the river to a few tolerant fauna would be associated with low scores in the SASS method.

In an assessment of the biological condition of heavily flow-impaired, but naturally perennial, rivers (Klein Palmiet, Koekedouw Rivers) where water quality was nevertheless good, SASS5 results were in a Class D or E, which led to the conclusion that flow reduction had caused a loss in invertebrate integrity (Ractliffe & Jonker 2010; Ractliffe *et al.* 2010). These limited results suggest that the SASS scores could be used in a very general was as a measure of reduction in ecosystem integrity as a result of changes in perenniality. However, interpretation would need to take into account the variability in results, under natural conditions, such as that demonstrated in SASS results discussed above. Other univariate measures such as species richness, total abundance or persistence may be just as if not or more informative.

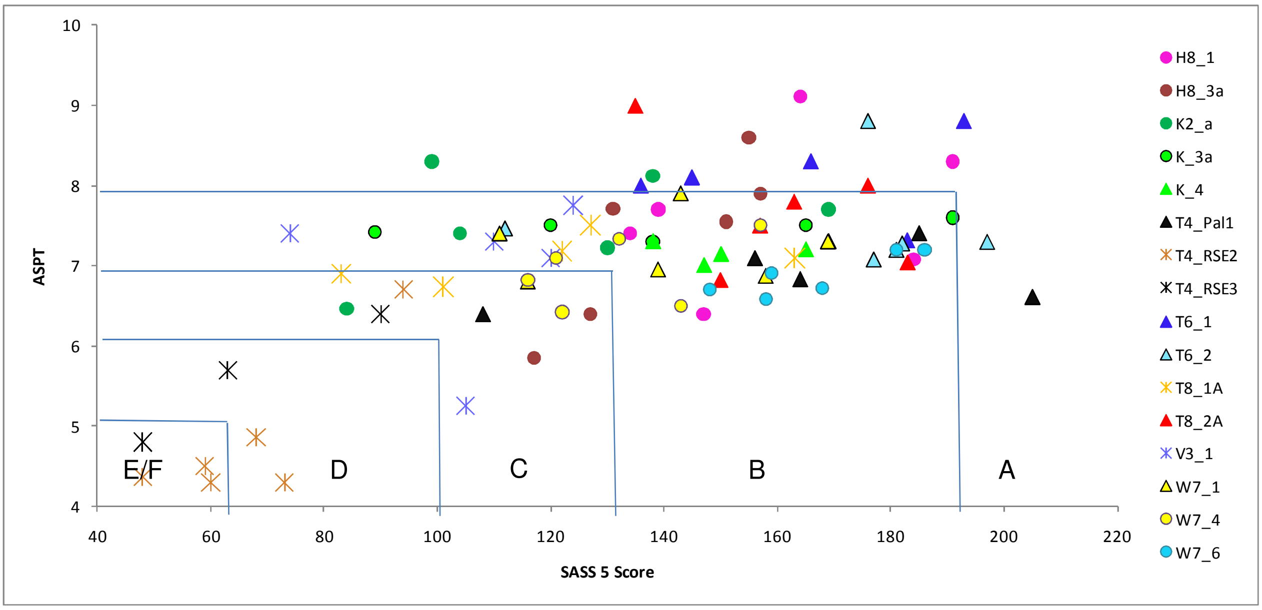

Figure 8.14. Summary of SASS5 results per site over the monitoring period. Sites with triangle symbols are Hydroperiod Category A, circles Hydroperiod B and stars Hydroperiod Category C/D. The guidelines for interpretation of River Health Class (A-F) are shown, but are relevant for perennial rivers only.

8.5 SUMMARY AND CONCLUSIONS

The invertebrate sampling conducted as part of the TMGA study included the following:

- An attempt to find a relationship between metrics describing community structure (richness, abundance) and the dry-season hydrological regime (hydroperiod) of the site.
- Multivariate techniques were also used in an attempt to see whether similarities in invertebrate communities tracked hydrological and seasonal drivers.

- Finally the SASS indices were computed for the ecochannel sites, to provide an overall measure of ecosystem integrity.

8.5.1 Seep invertebrate patterns

In the first year of sampling densities were extremely low and nearly half the samples were devoid of animals. What was hinted at by those data was that there might be a relationship between the surface moisture and invertebrate presence. With the substantial increase in numbers collected by intensified sampling in the second year, along with surface soil moisture samples taken at each invertebrate sampling point, a very useful relationship emerged between both species richness and invertebrate abundance (density) and the percentage soil moisture. This means that within a site and at a single point over time, there is the potential to compare simple measures of invertebrate community – density, richness – to test the hypothesis that these measures will decline with decreasing moisture. Such a measure has good potential to be used in the next phase of the TMGAA, something not apparent in the first annual reporting cycle. The increased effort associated with processing the samples, however, is a constraint: processing mud samples to separate out the fauna is labour intensive although not highly technical.

Community patterns did not readily express seep hydrology (i.e. the designated hydroperiod classification) in the same way that the univariate measures of total abundance and richness were shown to do. However, since hydroperiod was determined at a site scale, and the samples themselves showed high within-site variability linked with surface moisture, such a result is not surprising, and does mean that multivariate approaches cannot identify such a relationship.

As with the vegetation “habitat signature” information presented in chapter 6, the proportions of obligate aquatic invertebrates, semi-aquatic and damp soil/terrestrial forms at each of the ecoseeps was examined. No pattern was apparent between groups of sites of based on hydroperiod. Again, the problem of envisaging the ecoseeps as uniform units of sampling has been shown through these results to be problematic, and illustrates very clearly that a revised approach is required for the next phase of monitoring.

8.5.2 Channel invertebrate patterns

Significant differences were found between communities based on both season and biotope, a feature well established in other studies in the Western Cape (e.g. Ractliffe 2009, Harrison 1965). However, the seasonal differences were far less marked in the ecochannels than in studies focussing on foothill rivers.

The expectations and hypotheses set out at the start of this chapter were that faunal abundance should be highest in summer because, being characterised by the absence of flooding and by warmer temperatures, summer should provide an annual window period for growth and reproduction. Although trends were present based on the averages across all sites and biotopes, invertebrate abundances at each ecochannel, somewhat surprisingly, showed no consistent pattern of summer maximum densities and winter declines. Autumn abundances were highest at some of the sites, possibly because the effects of winter floods in reducing invertebrate abundance may not yet have been apparent – sampling was carried out after some initial autumn rains, but before any major floods. Also temperature, a major driver of productivity, is generally lower in mountain reaches than in the foothills, with concomitantly less difference invertebrate biomass between summer and late autumn / winter.

At other sites March was characterised by the highest abundances. This was largely so for the sites which had experienced late summer fires through the catchment. Similar peaks in abundance were observed after the December 2008 fires in the Steenbras catchment, and after the Boesmanskloof fires in December 2009. It is interesting that invertebrate abundances showed this increase, whilst no effects were apparent in algal biomass (Chlorophyll-*a* concentration), or in the nutrient concentrations in the water column.

The invertebrate communities of ecochannel sites were readily differentiated by hydroperiod, but only between perennial and seasonal sites. The latter were generally associated with lower abundances and richness, with some exceptions, e.g. after fire and in late summer refugia. This clear difference in fauna related to low-flow features of a site appears on the surface to be a good basis for making predictions about the trajectory of change that might be expected with a reduction in summer baseflow, for example, that the fauna of a perennial river might become more like that of a seasonal river below some critical threshold reduction in flow. However, it is improbable that such a simplistic transformation of the fauna would be the consequence of hydrological change, since differences between ecochannels were related to more than just their hydroperiod. It is probable that the monitoring programme will need to develop a picture of the natural community flux for each individual stream site, and track this over time, in a true BACI (before-after, control-impact) design, rather than attempt to find changes in the affiliation of sites to one or other category.

Examining community persistence is an approach that monitors community change in such a way that the natural fluctuation in community composition and trajectories of change over medium time scales can be compared across sites in a meaningful way.

Finally the SASS5 indices do provide a coarse measure of the overall and general integrity of the ecochannels, and have been shown in other studies to be responsive to *inter alia* lowflow impacts, unlike some indices that identify water quality impacts only. The usefulness of this measure is that it is widely used and the ecosystem status classes that are provided in the output are readily understood by most managers.

9. SUMMARY AND DISCUSSION

The focus of the activities in the EPM has been threefold: 1) to implement the monitoring protocols agreed in the Inception Phase; 2) to evaluate the usefulness of the data collected; and 3) to build up a baseline dataset of pre-impact conditions at the monitoring sites, against which future monitoring data can be compared in order to assess whether impacts have occurred.

The monitoring activities comprised:

- A broad, regional hydrocensus of groundwater and streamflow, including water quality monitoring, and
- A focused ecological monitoring programme at 40 wetland (ecoseeps) and channel sites (ecochannels) within the study area.

Table 9.1 summarises the monitoring strategies employed during the EPM, their potential for inclusion in future monitoring and recommended changes for the next phase. Additional explanation of these recommendations is provided in the sections below.

9.1 HYDROCENSUS

The hydrocensus work has generated a time series dataset for water level / discharge for regional borehole, regional surface water and DWA gauge sites, and an assessment of the usefulness or viability of each of these monitoring points.

The value of long-term time-series data is obvious, as it allows for statistical analysis of, in particular, water level or flow minima that can be used to establish actual, quantitative thresholds that highlight potential impacts during the resource development phase. In this light, the installation of 24 continuous water level loggers was an important task of the EPM. However, problems with maintenance of monitoring equipment have hampered the quality of the data, for example flood-damage. In addition, the absence of a stage-discharge relationship has meant that, where a streamflow logger has been reinstated after flood damage, new water levels may be somewhat different to previous data. More secure reinstallation of the water level recorders in streams to be continued in the monitoring programme is essential, along with accurate benchmarking of logger levels and the development of stage discharge relationships. What was useful during this phase of the monitoring was the identification of thresholds of water level linked to the quality of instream habitat – something just as important even with proper discharge data. The method of assessing this, however, was subjective and not particularly reproducible (e.g. does instream vegetation habitat quality become impaired with the loss of half or all patches of submerged vegetation), and consideration should be given to better measurement / recording of this aspect.

Of the 73 boreholes monitored as part of the hydrocensus work, only 51 are monitored for water level, 24 through loggers and a further 27 through bi-annual visits with manual monitoring (some boreholes are monitored only for water quality). One of the drawbacks of the relatively sparse coverage of boreholes, therefore, is that the data are too coarse for the compilation of a high confidence groundwater map for the study area, which would be of use in long-term monitoring and for the identification of groundwater dependent ecosystems. The inclusion of a greater number of boreholes in future monitoring phases has cost implications, which will need to be assessed by the TMGAA. Furthermore, aside from the Exploration Boreholes, nearly half of the monitored boreholes are production boreholes without accurate abstraction records. It is considered inappropriate to include data from production boreholes as baseline data for monitoring of groundwater abstraction. A better solution would be to relocate loggers from production boreholes to dedicated monitoring boreholes, where this is feasible.

Table 9.1. Proposed ranking for inclusion in Monitoring Protocol for Pilot Phase Monitoring (PPM): 1 = very useful, directly relevant for measuring OR interpreting change; may need some changes; 2 = may be useful, especially if some changes are implemented; 3 = some uses but cumbersome and/or costly, could be dropped from PPM.

Information	Parameters	Data collection	Data processing	Data analysis	Usefulness in detecting change	Ranking for incl. in PPM	Suggested changes
Hydrological / geohydrological monitoring							
Climatic variables	Rainfall, evaporation, wind speed, wind direction, air temperature.	Field readings. EFFORT: moderate – access to site, field readings. EXPERTISE: medium – field experience EXPENSE: initially high – installation of specialised equipment; ongoing – low – access to sites.	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Presentation and interpretation of data and temporal pattern. EXPERTISE: medium– statistical analysis of data and interpretation of patterns. EXPENSE: low – access to statistical software.	Essential data for describing the sites, differences between TSAs and sites, etc.	1	Rainfall required at the local level of ecological monitoring sites
Hydrocensus – groundwater levels	Borehole water levels, borehole artesian flow, borehole flow	Some data collected in the field bi-annually, some from data loggers. EFFORT: moderate – access to site, field readings, plus download data from loggers. EXPERTISE: medium – field experience EXPENSE: initially high – installation of specialised equipment; ongoing – low – access to sites..	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Presentation and interpretation of data and temporal pattern. EXPERTISE: medium -high – statistical analysis of data and interpretation of patterns, links with other datasets. EXPENSE: moderate – data analyst with access to statistical software.	Logger data more useful than the bi-annual and essential for monitoring. Possibility of groundwater map to be used to infer groundwater connectivity.	1	Preferential collection of logger data; expansion to better regional coverage of boreholes.; agree upon data analysis (indices etc.)
Hydrocensus – streamflow monitoring	Stream flow at 138 regional field sites	Data collected in the field bi-annually. EFFORT: moderate – access to sites in natural condition (off roads). EXPERTISE: low-medium – easy technical training for collecting field data. EXPENSE: moderate – travel to many sites.	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Presentation and interpretation of time series over the medium- and long term. EXPERTISE: medium– statistical analysis of data and interpretation of patterns. EXPENSE: low – data analyst with access to statistical software.	Only useful to describe change in perenniality; not useful if sites are impacted by other stresses e.g. .forestry. Difficult to achieve standardised assessment of “categories” of low flow	3	Redirection of resources may be prudent.
DWA river flow	Daily discharge measurements	Downloading data from DWA website EXPERTISE: low-medium - competent technician. EXPENSE: low.	Data patching according to agreed protocols	Presentation and interpretation of data and temporal pattern. EXPERTISE: medium to high – statistical analysis of data and interpretation of patterns, links with other datasets. EXPENSE: moderate – data analyst with access to	Lowflow statistics and baseflow separation with analysis is extremely useful where streamflow records are long enough	1	Reinstate monitoring at “useful” DWA gauges; investigate recommissioning Jonkershoek gauges; agree upon data analysis (indices etc.)

Information	Parameters	Data collection	Data processing	Data analysis	Usefulness in detecting change	Ranking for incl. in PPM	Suggested changes
				statistical software.			
Ecological monitoring sites – water level and flow	Data loggers for water level, stream height	Field readings and downloading data from loggers. EFFORT: moderate – access to site, field readings, downloading data EXPERTISE: medium – field experience EXPENSE: initially high – installation of specialised equipment; ongoing – low – access to sites.	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low..	Presentation and interpretation of data and temporal pattern. EXPERTISE: medium to high – statistical analysis of data and interpretation of patterns, links with other datasets. EXPENSE: moderate – data analyst with access to statistical software.	Essential data for discerning hydrological change at the ecosites, and for links to biological measures	1	Improve the objectivity of the assessment of flow-linked habitat quality in channels for categorisation of perenniality; secure flow gauges and develop stage discharge relationships
Chemical Conditions at the hydrocensus sites							
Chemistry of ground- and surface water	pH, Electrical Conductivity, Total Dissolved Solids, temperature and Oxygen Reduction Potential, major nutrients, anions and cations.	Part of the bi-annual hydrocensus data collection programme; field measurements plus loggers, plus water samples collected from boreholes, piezometers or rivers EFFORT: moderate - access to sites EXPERTISE: moderate – experience with use of probes, and field handling of samples EXPENSE: moderate – access to sites, field assistant(s), portable fridge or good cooler box with ice required	Water samples sent to BemLab, Somerset West. EFFORT: low – external laboratory EXPERTISE: low (outsourced) EXPENSE: moderate – laboratory costs	Variety of statistical and graphical techniques, including chemical diagrams. EXPERTISE: high –knowledge of data analysis methods and interpretation of results required EXPENSE: moderate – data analyst with access to statistical software.	Data do show main chemical characteristics of groundwater in comparison with surface water, and also enables a seasonal comparison.	1	Include ecoseeps and ecochannels in Hydrocensus WQ monitoring. Suggested parameters to focus on = Temperature, Conductivity, nutrients (incl. TIN, NO2+3, NH4, Total P and orthoP)
Isotope analysis	Stable isotopes, 2H (deuterium, δD) and 18O (δ18O)	Water samples collected from cumulative rainfall gauges (see above), boreholes, piezometers and rivers EFFORT: moderate - access to sites, plus water sample collection EXPERTISE: low – experience with field handling of samples necessary EXPENSE: moderate – access to sites, field assistant(s), portable fridge or cooler box with ice required	Isotope analysis at BemLab, Somerset West. EFFORT: low – external laboratory EXPERTISE: low (outsourced) EXPENSE: high – laboratory costs	Regression analyses, compared against the relevant Meteoric Water Lines. EXPERTISE: high –knowledge of data analysis methods and interpretation of results required EXPENSE: moderate – data analyst with access to graphical and standard statistical software	Not very useful for detecting change, as groundwater signature is very weak. TSAs too close together to differentiate based on isotope signature. However, does improve understanding of groundwater recharge, e.g. timing.	2	Restrict sampling to small set of sites
Physico-chemical analysis of the soils at the ecological monitoring sites							
General soil chemistry of the	soil texture, pH, electrical	Topsoil sampled from a selection of plant communities at a subset of the study sites,	Soil samples air-dried in the sun and thoroughly	Statistical analysis of the results	Good for characterisation of sites,	3	ONCE-OFF data set for monitoring sites would

Information	Parameters	Data collection	Data processing	Data analysis	Usefulness in detecting change	Ranking for incl. in PPM	Suggested changes
topsoil	resistance, titratable H^+, total P, Bray II P, exchangeable cations, base saturation cations, total organic carbon, total nitrogen, cation exchange capacity, bulk density, and T-value	by bulking three random samples hand-augured to 15 cm within each plant community. EFFORT: moderate - access to sites, hand-auguring EXPERTISE: low – experience with auguring and field handling of samples necessary EXPENSE: moderate – access to sites, field assistant	mixed by hand; processed by BemLab, Somerset West. EFFORT: low – external laboratory EXPERTISE: low, some sampling handling experience (most outsourced) EXPENSE: moderate – laboratory costs but once-off	EXPERTISE: high –knowledge of plant-soil interactions, statistical methods and interpretation of results EXPENSE: moderate – data analyst with access to multivariate and standard statistical and software	but probably not sensitive to impacts associated with Aquifer drawdown.		be useful, all data collected in one season. A sub-set of parameters could be analysed: pH, resistance, total P, Bray II P, Exch. Na, Exch. K, Exch. Ca, Exch. Mg, Total N, Total C, CEC
Soil moisture of topsoil	% soil moisture	Three soil samples augured to 15 cm collected from various plant communities at each site. Sampling in winter/spring and in summer. EFFORT: moderate - access to sites, hand-auguring EXPERTISE: low – simple field techniques EXPENSE: low-moderate – access to sites, field assistant, portable freezer	Laboratory processing: samples weighed wet, air-dried and re-weighed; % soil moisture = difference between wet and dry weights EFFORT: low EXPERTISE: low /moderate - laboratory experience EXPENSE: low	Statistical analysis of the data. EXPERTISE: high –knowledge of statistical methods and interpretation of results EXPENSE: moderate – data analyst with access to multivariate and standard statistical and software	Soil moisture patterns deemed essential, key determinant of wetland biota and must be closely linked with the depth of the water table. These methods = too invasive and too coarse; replace with soil moisture profiles.	3	Should be dropped, in favour of a more detailed design for soil moisture transects assessing the whole soil profile.
Organic matter content of topsoil	% organic matter	Collected as part of soil moisture of topsoils (above) EFFORT: moderate - access to sites, hand-auguring EXPERTISE: low – experience with auguring and field handling of samples necessary EXPENSE: moderate – access to sites, field assistant, portable freezer	Laboratory processing: air-dried samples weighed before / after combustion EFFORT: low EXPERTISE: low /moderate - laboratory experience EXPENSE: low –.	Statistical analysis of the data. EXPERTISE: high –knowledge of statistical methods and interpretation of results required EXPENSE: moderate – data analyst with access to standard statistical software	Organic matter content does seem to influence and be influenced by soil moisture; organic matter not likely to change significantly , so not a monitoring variable *per se*.	3	Collect as once-off dataset as part of soil chemistry sample run (see above)
Soil moisture / saturation of the soil profile	Volumetric soil moisture and saturation value (s)	Measured at 8 ecoseeps, at 5 PVC access tubes installed along transect; moisture measured at every 100mm depth, as deep as possible, using capacitance probe instrument, a Diviner 2000; measurements initially monthly, then bi-monthly; data collected on datalogger.	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Generation of soil moisture curves, calculation of soil saturation values, depth of water table, movement of soil. EXPERTISE: high –	Essential – enables the determination of depth of the water table, assessment of local variation in soil moisture and soil saturation. . Very important to	1	Soil probes must be located at the biota sampling points – much local variation in soil moisture, so need to assess movement of soil water as close to the

Information	Parameters	Data collection	Data processing	Data analysis	Usefulness in detecting change	Ranking for incl. in PPM	Suggested changes
		EFFORT: initially high – drilling of holes for instalment of probes; ongoing = moderate - access to sites and downloading data. EXPERTISE: low – experience with auguring and field handling of samples EXPENSE: initially high – instalment; ongoing low – access to sites; cost of purchase or rental of capacitance probe		interpretation of data and results required EXPENSE: moderate – data analyst with access to standard statistical software	determine soil moisture in the subsoil and the topsoil as water table may always be deeper than 30cm but can still be influenced by groundwater flow.		ecological monitoring points as possible; must be installed at each ecological monitoring site, even if that means reducing sites.
Surface water chemistry	pH, EC, temp, total N, total P, orthophosphate, ammonium, nitrites and nitrates	Field measurements of pH, EC, temp and water sample collection. EFFORT: moderate – access to sites, using probes and collecting water samples. EXPERTISE: low – experience with portable probes and field handling of samples required EXPENSE: low – access to sites, portable freezer or cooler box with ice; access to freezer.	Nutrient analyses performed by UCT Oceanography Dept. EFFORT: low – laboratory analysis of nutrients EXPERTISE: low (outsourced) EXPENSE: moderate – laboratory costs	Statistical analysis of the data. EXPERTISE: high –knowledge of statistical methods and interpretation of results required EXPENSE: moderate – data analyst with access to standard statistical software	Useful to interpret algal biomass and species composition - strongly influenced by nutrient levels. Seasonal availability of nutrients and links with organic matter and soil saturation / hydroperiod worth investigating further.	1	These should be included in Hydrocensus monitoring; VERY NB to ensure detection limits in analytical procedures = very low (0.001 mg/l)
Flora and vegetation							
Remote sensing	NDVI – near infrared detection of changes in vegetation stress	NIR and RGB aerial photos taken twice a year; also requires field- or orthophoto-based mapping of wetland areas to define area of interest EFFORT: moderate - aerial flight EXPERTISE: high – specialised photographic equipment and techniques EXPENSE: high but good return ito spatial coverage	Processing of images EXPERTISE: high – specialised techniques EXPENSE: moderate / high –access to specialised software	Comparative analysis of images from different seasons EXPERTISE: high – specialised techniques and botanical specialist input essential EXPENSE: moderate / high – data analyst with access to specialised software	Very useful for detecting change over only three months (pilot study) and also for allowing examination of systems outside the formally established monitoring sites	1	
Mapping of vegetation (GPS)	Use of high resolution GPS to walk around and record wetland boundaries	Was done as once-off exercise to identify ecoseeps but could be repeated annually or inter-annually EFFORT: moderate - access to sites EXPERTISE: moderate – experience in use of differential GPS; plant identification in the field EXPENSE: moderate – costs for site visit and hire of Differential GPS (plus operator)	Input of GPS data into ArcMap as shape files EXPERTISE: low-medium - competent technician. EXPENSE: low.	Comparative analysis of images from different years EXPERTISE: moderate – experience with ARC GIS EXPENSE: moderate – data analyst with access to ARC GIS software	Much more restricted scope that the NDVI; also relies on subjective assessment of wetland edge; difficult if two observers over a period of time	3	use as once-off to identify extent of field monitoring sites and / or subunits

Information	Parameters	Data collection	Data processing	Data analysis	Usefulness in detecting change	Ranking for incl. in PPM	Suggested changes
Change in flora composition	Comparison of species presence over time	Collection of full list of plant species from each community identified at each site EFFORT: moderate - access to sites, defining and identifying spatial extent of each community at a site in the field EXPERTISE: moderate - high – experience with species identification, collection and sample curating EXPENSE moderate – access to sites, time consuming / team of workers	Verification of plant identification (outsourced - sometimes presents time constraint) Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Univariate and multivariate analysis of presence / absence data, and cross-reference to other TMG datasets – esp. hydroperiod/ wetness categories. EXPERTISE: high – experience with multivariate statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to multivariate and standard statistical software	Useful for check of overall species loss / replacement by dryland species; relies on species presence and absence; some difficulty in identifying all species present where community extends over a large area – missed species may complicate comparisons between datasets i.e. sampling entities must be spatially explicit to allow the same area to be evaluated each time	2 – complementary to vegetation study; data collected simultaneously	Need to evaluate added value of flora vs quantitative plots
Change in vegetation / plant community structure	Comparison of species cover-abundance in established plots over time intervals	Collection of plant cover-abundance data from selected plant communities EFFORT: moderate - access to sites, easier location of sampling unit (pegged plots) than with flora; time consuming / team of workers EXPERTISE: moderate - high – experience with species identification, collection and sample curating EXPENSE moderate – access to sites, team of workers	Verification of plant identification (outsourced - sometimes presents time constraint) Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Univariate and multivariate analysis of quantitative data, and cross-reference to other TMG datasets – esp. hydroperiod/ wetness /soil moisture categories. EXPERTISE: high – experience with statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to multivariate and standard statistical software g	Most useful quantitative approach for field-based vegetation monitoring; immediate changes based on shifts in dominance; interpretation of change could be based on identifying shifts in indicator species, has to take into account natural senescence, which is where complementary approach of flora is useful	1	Annual monitoring, with potential to monitor only every second or third year in longer term
Change in morphology	Comparison of – plant appearance - shoots and leaves	Photography of individual plants and recording of change in appearance (% vigour) and senescence EFFORT: moderate - access to sites and location of tagged specimens EXPERTISE: low / moderate – angle and scale of photograph important EXPENSE low if only performed annually,	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Statistical comparison of seasons	Rather subjective method as relies on the interpretation of the observer	3	

Information	**Parameters**	**Data collection**	**Data processing**	**Data analysis**	**Usefulness in detecting change**	**Ranking for incl. in PPM**	**Suggested changes**
		along with vegetation / flora; second season visit doubles access costs					
Sap pressure	Comparison of sap pressure	Measurement of pre-dawn sap pressure on selected species through use of a Scholander Bomb EFFORT: moderate/high - access to sites heavy equipment, pre-dawn sampling onerous EXPERTISE: low/moderate –some experience in use of equipment EXPENSE moderate – one instrument purchased; hiring costs of second; second season visit doubles access costs	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Statistical comparison of seasons / time intervals EXPERTISE: high – experience with statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to standard statistical software g	Reliable method for determining plant stress, but pre-dawn sampling requirement and heavy equipment not easy for sites without easy accessibility	2	
Leaf conductance	Comparison of gas loss from the leaf	leaf stomatal conductance using a Leaf Porometer EFFORT: moderate - access to sites and location of tagged specimens EXPERTISE: low EXPENSE low if only performed annually, along with vegetation / flora; second season visit doubles access costs	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Statistical comparison of seasons / time intervals EXPERTISE: high – experience with statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to standard statistical software g	Not a particularly reliable method for a number of reasons: can only be used on thinner broad leaves, and not on aphyllous plants which dominate in some sites; also occasional unreliable readings depending on state of individual plants	3	
Leaf chlorophyll	Comparison of chlorophyll from leaves in stressed and unstressed plants	Measurement of leaf chlorophyll with portable instrument; provides rapid and precise readings for monitoring plant stress and leaf senescence on broad-leaved plants.	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Statistical comparison of seasons / time intervals EXPERTISE: high – experience with statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to standard statistical software g	Works well on broad leaved plants but not on ericoid leaved species or aphyllous stems; thickness of leaf affects reliability of reading.	3	
Algae							
Algal biomass	Chlorophyll-a and Ash Free Dry Weight per stone surface (rivers) or	Ecochannels – 5 stones from same run scrubbed of algae; ecoseeps – 5 circles of surface sediment collected from each of 5 sampling points. .	Laboratory processing EFFORT: moderate, several processing	Univariate and multivariate analysis of data, and cross-reference to other TMG datasets – esp. water	Very useful – algal biomass is affected strongly by season (possibly relating to	1	Only measure chlorophyll-a, not AFDW, as the latter affected by silt,

Information	Parameters	Data collection	Data processing	Data analysis	Usefulness in detecting change	Ranking for incl. in PPM	Suggested changes
	wetland sediment	EFFORT: moderate - less at ecoseeps than at ecochannels, where scrubbing of rocks takes time and effort; access to sites EXPERTISE: low – experience with handling of samples in the field, scrubbing of rocks EXPENSE moderate – access to sites, access to freezer (portable if freezing samples in the field) and no expensive equipment required.	procedures. EXPERTISE: moderate – laboratory handling of samples; experience in chlorophyll extraction process required EXPENSE: moderate – chemicals, filter papers etc., access to furnace.	chemistry, soil chemistry, hydroperiod/wetness / moisture categories. EXPERTISE: high – experience with statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to multivariate and standard statistical software	seasonal availability of nutrients), with highest biomass recorded during the drier months. Links to site hydrological regime was strongest for ecoseeps, where algal biomass increased as aquatic habitats became shallower and warmer. Links between hydrological regime and algal biomass in ecochannels probably affected by flow velocities (i.e. shear stress).		invertebrates, plant material; reduce to twice a year - collection in spring (start of algal growth season – September for ecoseeps, December for ecochannels) and summer (peak of growth season – March). Focus on sites in hydroperiod categories A, B and C for the ecoseeps. The sampling regime should include a measurement of near-bed current velocity at the ecochannels, to understand the relationship between biomass and changes in base flow conditions.
Algal species composition and taxon diversity	Algal cells per m^2 and total number of taxa identified; index of community similarity	Ecochannels – sub-sample of biomass sample; ecoseeps – additional sample of surface sediment collected at each sampling point. EFFORT: moderate - less at ecoseeps than at ecochannels, where scrubbing of rocks takes time and effort. EXPERTISE: low – experience with handling of samples in the field, scrubbing of rocks EXPENSE: moderate – costs for site visit but no expensive equipment required.	Samples preserved in Lugol's Solution for storage; Identification to species where possible, and counting of algal cells in sub-sample, using Haemacytometer EFFORT: moderate, processing of ecoseeps samples takes time. high – identification of species and counting takes time and effort, EXPERTISE: low – laboratory handling of samples; high – experience with algal	Univariate and multivariate analysis of data, and cross-reference to other TMG datasets – esp. water chemistry, soil chemistry, hydroperiod/wetness categories. EXPERTISE: high – experience with statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to multivariate and standard statistical software	Useful – algae are the primary producers and so represent the interface between the physico-chemical conditions at a site and the flora and fauna inhabiting it. Algal species composition was, however, strongly affected by site signatures, which were stronger than differences between any of the other spatial factors. Thus, algal species composition	2	Use key individual sites (i.e. those that show strong connectivity to the Peninsula Aquifer) to monitor potential temporal shifts in species assemblage structure, rather than attempt to find spatial patterns. More intensive replication within these sites over time may show changes related to hydrological characteristics specific to these sites, rather than comparing algal

Information	Parameters	Data collection	Data processing	Data analysis	Usefulness in detecting change	Ranking for incl. in PPM	Suggested changes
			species identification EXPENSE: moderate – external expertise required, microscope and Haemacytometer;		should be assessed within sites over time and not between sites.		communities between sites. Samples for nutrient analyses need to be collected at each sampling occasion. Collection in September and March (seeps); December and March (channels).
Algal morphological form	% contribution of taxa in gelatinous masses	As for above.	As for above, with identification of algal morphological form.	Univariate analysis of data, and analysis of shifts over time, and between hydroperiod categories. EXPERTISE: high – experience with statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to standard statistical software	Very useful – relative proportion of algal forms shifts over time, with some links with hydroperiod. At the ecoseeps (clearest trends) there was a clear increase in the relative proportion of taxa in gelatinous masses from sites that are perennially or seasonally inundated or saturated to those that dry out during the summer. The pattern is consistent with a general response to desiccation stress, where taxa in mucilage are able to survive periods of drying.	1	Continue to measure species community structure at sites in hydroperiod categories A to C for ecochannels, and A to D at the ecoseeps. Sites in hydroperiod category E do not contribute to an understanding of this relationship and thus monitoring of these sites should be discontinued in favour of more intensive replication in the wetter ecoseeps.
Invertebrates							
Invertebrate species composition and taxon diversity	Species relative abundance per each of 3 biotopes; richness; index of community similarity	Ecochannels – collect using SASS protocol – semi-quantitative Ecoseeps – cores taken at each of three locations, linked to soil moisture. EFFORT: moderate – field work. EXPERTISE: low / moderate – experience with sampling techniques	Samples preserved in 97% alcohol for storage; Identification to species where possible, and counting EFFORT: moderate, processing of ecoseeps samples takes time. high –	Univariate and multivariate analysis of data, and cross-reference to other TMG datasets – esp. water chemistry, hydroperiod/wetness categories.	Invertebrates in seeps show promising links to moisture; channel invertebrates show multivariate differences according to hydroperiod; use similarity index to	1	Collection in September and March (seeps); December and March (channels); intensify seep sampling effort (larger sample volume); possibly restrict channel samples to stones + veg

Information	Parameters	Data collection	Data processing	Data analysis	Usefulness in detecting change	Ranking for incl. in PPM	Suggested changes
		EXPENSE: moderate – costs for site visit but no expensive equipment required.	identification of species and counting takes time and effort, EXPERTISE: low – picking of samples; high – experience with species identification EXPENSE: moderate – external expertise, microscope	EXPERTISE: high – experience with statistical analyses and interpretation of patterns in the context of a multi-disciplinary programme. EXPENSE: moderate – data analyst with access to multivariate and standard statistical software	assess interannual persistence in species complement		biotope only
Invertebrate “health” index	SASS total score and ASPT	Only in ecochannels, application of SASS protocol EFFORT: moderate – field work. EXPERTISE: low / moderate – experience with sampling techniques EXPENSE: moderate – costs for site visit but no expensive equipment required.	Input of data into Excel spreadsheet EXPERTISE: low-medium - competent technician. EXPENSE: low.	Calculation and interpretation of SASS metrics EXPERTISE: moderate / high simple analysis but interpretation in context of TMGA tricky EXPENSE: moderate – data analyst with access to multivariate and standard statistical software	SASS on its own has shortcomings; metrics can be used to track overall change in invertebrate scores, which should decline with natural or unnaturally low summer flows; scores = system specific	1	SASS scores in March only, but may need to be in Dec and March where systems are naturally non perennial as with some of the sites

In relation to surface flow measurement, the DWA gauges initially stipulated for data acquisition were assessed to be largely not useful in providing long-term data on natural characteristics against which change can be measured. A revised list has been provided, along with all available data. The status of these has been confirmed by the DWA. It is considered crucial that a more extensive database of flow measurements from small, unregulated streams be developed. This would be useful not only for this project, but as baseline data for other flow-related monitoring projects throughout the south-western Cape. For instance, data are no longer collected at two crucial gauges (du Toits and Riviersonderend) and the reinstatement of these is a matter of supreme importance, given the dearth of good data in unregulated streams. Similarly, sorting out the ownership and accessing water level measurements at any of the three gauged sites in Jonkershoek will provide historical records for this area that do not currently exist in usable form. Also, some expertise in patching larger gaps in time-series datasets is required to produce clean data for analysis. Flow frequency analysis was undertaken to derive flow minima curves for seven gauges, illustrating one of the approaches to analysis of long-term streamflow data that is proposed for adoption in future phases of the TMGA project. Baseflow analysis was not undertaken for this project, given the limitations on comprehensive data analysis, but should be included in future reports. The software IHAV 7 (The Nature Conservancy 2006) is a useful free software that could be used for the analysis of both groundwater and surface-flow data. It is strongly recommended that the TMGAA workshop the sorts of analyses and indices that are most appropriate in this regard, with the monitoring consultants to maximise the quality of analysis.

The bi-annual monitoring of streamflow and / or water chemistry at 138 regional hydrocensus sites was also considered to have numerous problems, both in relation to the actual location of sites as well as the timing of field visits. Given the dearth of useful DWA gauges, field monitoring could add value to a regional hydrological monitoring programme, but, it is argued, only under certain conditions. Flow measurements in October and April have little value, as they are subject to discharge changes associated with autumn or spring rains, and seldom provide any insight into flow minima in a stream. A classification of streams in terms of flow perenniality could be considered, but it may be more prudent to redirect resources here into the acquisition of accurate and continuous flow data, at the ecosites and DWA gauges.

The water chemistry data collected at the hydrocensus sites were useful for the characterisation of the hydrostratigraphic units within the study area. Chemical differences between the hydrostratigraphic units were not marked, however, and so these data cannot reliably be used as tracers for the different aquifers. Some parameters did show some response to the main drivers influencing water chemistry, such as evaporation, contact with the underlying geology, rainfall and storm runoff, distance from the coast, etc. For instance, seasonal shifts in water chemistry were found for some parameters, and there were some differences between surface and groundwater, which points towards the different processes that influence water sources below and above ground. Measurement of those parameters that are sensitive to change or that show some differentiation between sites or seasons, should be continued as part of the regional monitoring programme, in order build on the characterisation of the sub-region. These include EC, temperature, total phosphorus and total nitrogen. pH and the concentrations of the major cations and anions remained fairly constant between seasons and sites, and so do not tell us anything particularly useful.

Due to the lack of isotopic interaction of borehole water with the TMG rock, as a result of the fairly rapid recharge-discharge patterns within the TMG aquifers, the water does not have a unique signature that can be used as a tracer. The isotope data are unlikely to be sensitive to the impacts associated with groundwater drawdown, as recharge should be unaffected, however, once again, the isotope data do provide us with useful information on the nature – e.g. timing and elevation - of recharge. For instance, the data showed that the winter rainfall is most responsible for aquifer recharge, as expected.

Isotope signatures did not show any relationship with elevation or distance from the coast, although there was some indication of clustering of isotope data within the TSAs. The TSAs are possibly too close together to differentiate between them based on isotope signature.

9.2 ECOLOGICAL MONITORING SITES

For the focused ecological monitoring programme, a concerted effort was made to determine the probability and extent to which each ecological monitoring site is associated with underlying aquifers. Following on from this was a characterisation of each site according to (geo)-hydrological regime and biological characteristics, and how these relate to each other.

The determination of the probability of connectivity with underlying aquifers, particularly the Peninsula Aquifer, was considered a pre-requisite for inclusion of the ecological monitoring sites in a future monitoring programme for this project, where the likely impacts of aquifer drawdown will be the focus. However, while connectivity between the underlying aquifer and the ecological monitoring sites will affect the rate at which the water table fluctuates vertically (e.g. declines over summer), it does not necessarily follow that surface water will be present at the sites. The hydrological regime, on the other hand, reflects the variation in ground- and surface water levels over time, and may be driven to a greater or lesser degree by groundwater. The hydrological regime of wetlands and rivers is regarded as a major driver of the biota occurring in them – for instance, wetlands are defined by the presence of water of sufficient quantity and over a sufficient interval to create conditions to which only specialised biota are adapted. Indeed, the relationships identified between the biological parameters and the hydrological regime at the ecological monitoring sites will be used by the TMGAA to set Thresholds of Potential Concern (TPC) for the Pilot Phase impact monitoring.

9.2.1 Aquifer connectivity and rainfall

Geological maps and cross-sections were used to infer the *probability* of connectivity of the ecological monitoring sites with the Peninsula or Nardouw Aquifers, whilst ground- or surface-water level fluctuations were used to categorise the *strength* of connectivity. There was no clear link between the probability of connectivity as gleaned from the geological cross-sections and the strength of groundwater inputs to the seeps or channels (strength of connectivity) as determined from interpretation of the water levels at the sites.

Based on geological setting alone, 23 of the 40 ecological monitoring sites have a probable to highly probable connectivity to the Peninsula Aquifer. Ten sites appear to be strongly linked to the Nardouw Aquifer, with a further seven sites being possibly influenced by both aquifers. The geological formations at the sites within the Steenbras (H8) TSA result in a relatively low probability of a strong interaction between the Peninsula Aquifer and the ecoseeps or ecochannels, but a relatively high probability of a link to the Nardouw Aquifer. Similarly, the K_3 sites (Kogelberg inland) are located along the contact between the Skurweberg and Goudini Formations, and the channel (K_3a) drains the Skurweberg Formation in the Paardeberg Mountain to the east. The Peninsula Formation is present, but more than a kilometre north of the site. The high density of fractures in this area, however, does complicate the interpretation of connectivity at these sites. Two sites located in the Purgatory TSA – T8_1a and T8_1b – and three of the Wemmershoek sites – W7_1, W7_2 and W7_3 - are situated on the Skurweberg Formation, and although all of the sites are close to faults that may connect them with the Peninsula Aquifer, this connectivity is unlikely.

One of the major inputs into the analysis of groundwater connectivity is the effect of local rainfall. Significant differences were demonstrated between TSAs, in total annual rainfall and in its distribution, over summer and winter months. For instance, W7 was characterised by relatively dry summers, but had the highest winter rainfall along with T3/4 and T8. V3 had dry summers but winter rainfall in this catchment was not substantially different from the other TSAs. Kogelberg had the highest summer rainfall, along with H6/H8 and T3/T4.

Rainfall data used for interpretation of fluctuations in subsurface water levels at the ecological monitoring sites were often not adequately coupled with local catchment weather, which should be rectified to improve the accuracy of the analysis: rainfall measurement at the sub-catchment level should be introduced, to provide local-scale data for each ecological monitoring site carried forward in future phases of monitoring.

9.2.2 Ecoseep / ecochannel hydrology and soil moisture

The constancy of water levels or the rate of change relative to rainfall patterns at the ecological monitoring sites was used to estimate the strength of connectivity and compared with the probability of seep connectivity to the Peninsula or Nardouw Aquifers based on the geological cross-sections. Very little correlation was found between strength of connectivity to groundwater and the type of aquifer (Peninsula or Nardouw) to which the ecoseep or ecochannel was considered to be connected based on geology. For example, the streams in the RSE (Nuweberg) area, which are on the Peninsula Formation, all had flows that declined rapidly in the summer, which equated with weak groundwater connectivity.

In order to determine the dominant hydrological regime at each of the ecoseeps and ecochannels, hydrological data were collected from a single point (piezometers at the ecoseeps, water level gauges at the ecochannels) at most of the sites. The degree and duration of saturation, inundation or dry conditions at the ecoseeps was assessed using water level depth thresholds to distinguish between states. Five hydroperiod categories were defined: A, permanently inundated, B, seasonally inundated, permanently saturated, C, seasonally inundated, seasonally saturated, D, never inundated, seasonally saturated, and E, never inundated, intermittently saturated. For the ecochannels, the behaviour of the streamflow over the summer period was used as a means of determining the degree or intermittency or the strength of perenniality of flow. Four hydroperiod categories were defined: A, perennial, B, seasonally low but perennial, C, seasonally dry but persisting as pools, and D, seasonally dry.

There was very little agreement between the hydroperiod of the ecoseeps and ecochannels and the probability of connectivity to the Peninsula *versus* the Nardouw Aquifer. However, there was relatively good agreement between the major hydroperiod divisions and the strength of aquifer connectivity. For instance, there was fairly strong agreement between ecoseeps that are strongly perennial (Category A and B hydroperiod) and their level of connectivity to groundwater. Category C and D ecochannels had rapid rates of decline in water level in the absence of rainfall, whilst Category A and B ecochannels showed relative slow water-level recession rates.

Soil moisture data were collected from transects at a limited number of ecoseeps, although not specifically linked to biological monitoring plots or sampling points. The behaviour of the soil moisture, and specifically soil saturation, in the topsoil and the subsoil, and how this fluctuated at the different soil depths, gave an indication of whether the ecoseeps are fed primarily by rainfall, or by subsurface flow, which *may* be groundwater flow, and whether the influence of groundwater was strong or weak. There was strong agreement between the saturation of the top- and subsoil at the ecoseeps and the proposed “strength” of connectivity between the ecoseeps and groundwater resources. Ecoseeps that were found to be perennially saturated, especially in the topsoil, are the ones most likely to have strong connectivity with groundwater.

Secondly, particularly as a result of the sloping nature of most of the sites, the ecoseeps are likely to display a wider range in wetness, with a combination of patches that are groundwater-fed (connectivity to the aquifer) and that are rain-fed.

This aspect of the monitoring is crucial: understanding the functioning of the site, in terms of the inputs and movement of water is a key to establishing hypotheses about the biological response, and then tracking these over time. It does appear from the results presented in this report that the biological communities at the ecological monitoring sites respond temporally to changes in the hydrological characteristics of the sites, and thus it may be hypothesised that they will respond to a spatial gradient of, for instance, soil moisture, across the site. The way in which the data were collected for this study did not allow for the testing of this hypothesis, as physical data were not collected at each biological sampling point. This should be the minimum dataset collected for perhaps a reduced number of ecological monitoring sites (see Section 9.2.5), with a more carefully designed matrix of transects within each site.

9.2.3 Chemistry

The once-off collection of topsoil chemistry data did allow the characterisation of most of the ecological monitoring sites. As can be expected in the sandstone substrata of the Cape mountains, the soils are typically acidic and oligotrophic, with low ECs and characteristic anion/cation signatures. None of the soils can be described as being peaty.

Topsoil chemistry was not significantly different between the ecoseeps and ecochannels, apart from total phosphorus which was considerably higher at the seeps than the channels. There does seem to be a link between organic matter content, soil moisture and nutrient levels at the ecoseeps, and this deserves more attention in contextualising conditions at each of the sites.

The topsoil chemistry data showed that conditions at the site at Villiersdorp, B1_1, were significantly different to all other sites.

The spot measurements of surface water chemistry are of little value. EC and temperature showed predictable seasonal shifts, being highest in summer and lowest in winter. pH showed little seasonal variation and, while being consistently higher than that of the topsoils, was fairly consistent between sites.

Nutrient levels – total phosphorus and/or orthophosphates, and total nitrogen – were well below the levels provided as the threshold between oligotrophy and mesotrophy, and were substantially lower in the ecoseeps than in the channels. B1_1 had total phosphorus levels indicative of mesotrophic conditions, which may be due to the relatively high organic content of this site. Nutrient levels should be monitored as an important driver or limiting factor in these ecosystems, which may be influenced by organic matter content, which may itself be influenced by soil moisture.

9.2.4 Biological responses

Aside from the collection of baseline data, an important focus of this monitoring phase was the identification of, 1) hydrological characteristics that can best be used to describe and discriminate between sampling sites, and 2) the biological parameters that respond to the hydrological regime. Biological monitoring typically uses community data, or some aspect of communities (e.g. biomass, or growth form) or some integrated parameter used to reflect an aspect of a community (e.g. diversity, or ecosystem health indices). The relationship between any of these and flow or water level data is not well established.

Some links between the biological component of the EPM – vegetation, algae and invertebrates – and stream or seep hydroperiod or surface moisture / saturation levels were identified during this monitoring period. Common patterns in community composition or structure across the study area were not cut and dried, however, even within high-level comparisons between ecochannels and ecoseeps. Plant communities recorded at a local level (plot data) did not fit neatly into the broad vegetation categories assigned *a priori*. Relationships to ecoseep or ecochannel hydrology or hydroperiod were spread along a gradient. This is probably to be expected – the particular assemblage of species in any ecosystem reflects the patchiness and variability of landscape and landscape process both in space and time. A striking aspect of the biological sampling was the high degree of site (or within-site) specificity in the communities identified. For algal species composition, for instance, the most significant dissimilarities were between sites. The move in the second year of monitoring toward establishing links at a within-site scale, notably between soil moisture changes and both algal biomass and invertebrate numbers, has shown much promise for the future monitoring protocols.

The conclusion of these endeavours is a strong recommendation that a monitoring programme needs to see each site as being an independent unit of evaluation. As such, the hydrological functioning of the site, including rainfall, surface moisture and groundwater levels needs to be better understood, so that hypotheses relating to change in the associated biota can be established for that site. Monitoring thus becomes evaluation of the trajectories followed by the monitored components at each site. Here measures like the persistence and stability of the biota from year to year can be compared across sites, rather than the absolute composition of any biological entity. These parameters are easily calculated from multivariate analysis packages, but require a) species-level and b) quantitative data.

It is this requirement that is the basis of a strong motivation that the quantitative community measures – vegetation plot data, algae and invertebrate species sampling, be retained into the Pilot Phase of the TMGA project.

Other recommendations included in Table 9.1 relate to scaling down the temporal replication of sampling from three to two periods per annum for invertebrates and algae, and annual monitoring for vegetation. The physiology measures, with the possible exception of measuring sap pressure, are not regarded as priorities.

Although the analysis was limited, the NDVI approach has much to offer. It is recommended that the TMGA and client look to redirecting funds, possibly from less important component of the remaining EPM work, to the refinement of this approach, or at the very least to allow another summer flight to be captured.

9.2.5 Sampling sites

Ecological monitoring sites will need to be rationalised for the next monitoring phase. The project has clarified the status of most of the sites, and developed a subset of sites that are a) most probably linked geologically to the Peninsula Aquifer, b) are perennial and c) appear to have relatively strong connectivity to groundwater. It is recommended that at least these sites be included in the future monitoring programme (Table 9.2).

Table 9.2 **List of ecological monitoring sites recommended for inclusion in the next phase of monitoring. The likelihood and strength of connectivity with either the Peninsula or the Nardouw aquifers, and the hydroperiod category assigned to each site, are summarised from data presented in Chapters 2 - 5 of this report.**

Site	Likelihood of connectivity based on geology cross sections	Comments on behaviour of water level	Hydroperiod category	Conclusions on strength of connectivity to groundwater	Probability of being fed by groundwater based on soil saturation (ecoseeps only)
B1_1	Links between the seep and Peninsula Aquifer is possible, but groundwater contributions may be predominantly from the Nardouw Aquifer.	Inundated (WL within 10 cm of surface) for 4-6 months in continuous period, July - Dec; perennially saturated in top 30 cm.	A	Strong	High
H8_3a	Low connectivity with Peninsula, but highly likely that Nardouw provides base flow	No water level gauge; but downstream of H8_1; similar responses observed	B	Moderate (extrapolation)	-
H8_3b	Highly probable connection to groundwater, but probably mostly the Nardouw Aquifer. The Peninsula Aquifer may contribute slightly, as a result of the nearby fault intersecting the Peninsula Formation.	Inundated (WL within 10 cm of surface) for 8-11 months in continuous period, Apr 2008 - Feb (drier in second year, with WL below 10 cm for 4 months from Jan - April 2010); perennially saturated within 30 cm of surface	A	Strong	Moderate
K_1	There is a high probability that the seep is linked to the Peninsula Aquifer.	Inundated (WL within 10 cm of surface) for 3-4 months in near-continuous period between Sep and Jan; perennially saturated within 30 cm of surface	B	Strong	-
K_2a	Strong likelihood of connectivity to Peninsula Aquifer	Constant summer flow; rate of change /decline also very low, as shown by flat slope of plotted line, indicating groundwater contribution; however, flow does recede to fairly low levels at the end of summer	B	Strong	-
K_2b	Connectivity with the Peninsula Aquifer is highly likely to provide a major component of the groundwater base flow to the river.	Inundated (WL within 10 cm of surface) for 5-6 months in near-continuous period between Jun and Dec; seasonally saturated for 11 months betw Mar and Jan with drop in WL Jan-may (below 30 cm) and intermittently dry (below 0.5 m) for a total of 15 - 30 d betw Feb and Apr	C	Moderate	High
K_3a	Low connectivity with Peninsula, but highly likely that Nardouw provides base flow	Rate of change /decline in summer flow is very low, as shown by flat slope of plotted line, indicating groundwater contribution; however, flow does recede to fairly low levels at the end of summer	B	Strong	-
T3_Pal4	Hydrological connectivity with the Peninsula Aquifer is probable, but also with a high probability of connectivity with the Nardouw Aquifer.	Unfluctuating WL over dry season, with spikes associated with rainfall; problem with piezometer logger level and data not used	B	Strong	-

Site	Likelihood of connectivity based on geology cross sections	Comments on behaviour of water level	Hydroperiod category	Conclusions on strength of connectivity to groundwater	Probability of being fed by groundwater based on soil saturation (ecoseeps only)
T4_Pal1	Strong likelihood of connectivity to Peninsula Aquifer	Rate of change /decline fairly low, long period of unfluctuating flow; stream velocities do become slow, but depth maintained and biotopes intact, indicating groundwater contributes to this perenniality	A	Moderate	-
T4_Pal3	Strong likelihood of connectivity to Peninsula Aquifer	The stream is at a high altitude, with very low flow at the height of summer; however, the rate of decline in flow is gradual.	B	Moderate	-
T6_1a	Strong likelihood of connectivity to Peninsula Aquifer	Rapid response to summer rainfall indicates periodic influence of local (surface or subsurface) inflow; rate of decline however is very low, with high base flows maintained, indicating strong groundwater contribution	A	Strong	-
T6_1b	Probable connectivity to Peninsula Aquifer	no data	A	Strong (extrapolation)	High
T6_4	Probable connectivity to Peninsula Aquifer	Wet season variability, Inundated for 3 months Aug - Nov 2008 but not inundated 2009; perennially saturated, WL within 30 -35 cm of surface	B	Strong	-
T8_2a	Strong likelihood of connectivity to Peninsula Aquifer	Responds only to very high summer rainfall events; rate of decline is moderate, with high base flows maintained, indicating strength of groundwater contribution	A	Moderate	-
T8_2b	Connectivity of seep to the Peninsula Aquifer is probable	Inundated (WL within 10 cm of surface) for 7-10 months in continuous period, May - Jan (drier in second year, WL below surface from Dec); perennially saturated, WL within 30 cm of surface except for Feb-April, when dips to 40 cm bgl	B	Moderate	-
W7_1	The channel is most probably connected to the Nardouw Aquifer, possibly via an alluvial aquifer, with unlikely connectivity with the Peninsula Aquifer.	Strong summer flow and the slow rate of change /decline indicating groundwater contributes strongly to perenniality	A	Strong	-
W7_4	Possible connectivity of this site to the Peninsula Aquifer, but this is unlikely to be strong	Dampened response to rainfall and relatively constant summer flow, although recedes to low levels with some exposure of instream vegetation; rate of change /decline also low, indicating moderate groundwater contribution.	B	Moderate	-

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