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DEPARTMENT OF WATER AFFAIRS AND FORESTRY

DIRECTORATE OF WATER RESOURCES PLANNING

BREEDE RIVER BASIN STUDY

GROUNDWATER ASSESSMENT

NINHAM SHAND CONSULTING SERVICES

MBB

JAKOET & ASSOCIATES

Groundwater Consulting Services cc

DEPARTMENT OF
WATER AFFAIRS AND FORESTRY

BREEDE RIVER BASIN STUDY

GROUNDWATER ASSESSMENT

Final

MAY 2003

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AUTHOR	**:**	**G Papini**
PROJECT NAME	**:**	**Breede River Basin Study**
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BREEDE RIVER BASIN STUDY

GROUNDWATER ASSESSMENT

EXECUTIVE SUMMARY

The objectives of this study were to assess the significance and distribution of groundwater resources in the Breede River catchment, estimate the amount of abstraction and degree of stress it may be causing and to indicate the scope for further development of groundwater resources. This was achieved by a review of all available literature and obtaining yields and quantities from all significant schemes. The characterisation of important aquifers and assessment of the groundwater balance (recharge versus consumption) allowed for identification of further groundwater potential.

The geohydrology of the Breede River catchment is controlled by the occurrence of the rocks of the Table Mountain Group (which form the mountainous areas), the occurrence of high levels of faulting and folding in the syntaxis area of the upper catchment and the variable rainfall, being highest in the mountainous areas in the west. These factors result in a catchment with highest groundwater potential in the west, where recharge, yields and abstraction potential are greatest and the quality is the best. As a result of these factors, the western half of the catchment is also the area with the greatest groundwater use.

Total groundwater use in the catchment is around 100 million m^3/a, far less than the annual recharge of 640 million m^3/a. The majority of this recharge (75%) takes place in the western 29% of the catchment. A significant component of recharge that occurs in the mountains rapidly becomes baseflow that feeds streams and recharges the alluvial aquifer in the valley bottoms. Other recharge mechanisms include throughflow (or upflow) from the TMG to Malmesbury, Bokkeveld and alluvial aquifers and direct precipitation.

Fractured and confined to semi-confined aquifers occur within the consolidated rocks of the Breede catchment. In these aquifers, the groundwater is usually under pressure and artesian conditions may be present where the piezometric surface is above ground level. The other important aquifer types found in the catchment are the unconsolidated sand deposits which make up the alluvial aquifers. Groundwater levels in the alluvial aquifers are close to surface and yields of from 10 – 15 ℓ/s are common from shallow (<30m) boreholes supplying irrigation schemes in the valleys. The fractured aquifers are less extensively used in the upper Breede catchment because of difficulty in accessing drilling sites on the rugged terrain.

Boreholes in these aquifers are usually deeper than those drilled in the alluvium. The groundwater quality in all aquifers in the upper Breede is generally excellent (<450 mg/ℓ). As one moves down the catchment, the quality deteriorates, particularly in poorly transmissive rocks such as the Bokkeveld and Karoo. A way to increase the groundwater production in irrigation areas is to mix marginal quality groundwater with less saline surface water. There is limited information of chemical indicators other than TDS but it is expected that the alluvial aquifers may have elevated concentrations of nitrate as a result of irrigation of vineyards that are situated on most of the alluvium in the valleys. Groundwater is not considered to contribute significantly to the salinisation of the middle Breede. A review of the literature on salinisation in the middle Breede catchment concludes that groundwater contributes as little as 1% - 2% of the salt load to the river.

Assessment of the land under irrigation and average water requirements per crop provide an estimate of the total water demand for irrigated agriculture in the Breede catchment. The balance of irrigated land not supplied by irrigation boards gives an indication of water supplied by farmer's own schemes, which includes boreholes. The percentage of irrigation supplies made up by groundwater is estimated at 32% in the upper Breede catchment. Irrigation use of groundwater in the middle Breede catchment is around 18 million m^3/a. Groundwater consumption in the lower Breede is predominantly domestic and stockwatering and is estimated to comprise approximately 4 million m^3/a.

Future groundwater exploitation, especially for any large scale schemes, should be concentrated on the alluviual, Bokkeveld or TMG aquifers of the western part of the catchment. Smaller scale abstraction schemes in the eastern half of the catchment will have to exploit the TMG aquifers, since these are the areas of best recharge and quality. Constraints to increased groundwater use in the middle and lower Breede include saline groundwater and poorly transmissive aquifers.

The groundwater contribution to river flow or baseflow in selected sub-catchments was assessed using several hydrograph separation techniques. The results indicate that the baseflow is approximately 30% of mean annual run-off in the upper and middle Breede catchment but only about 10% using the linear interpolation method. The linear interpolation is considered to be more representative of the groundwater contribution to stream flow. Gauged river flow data give higher percentages for the groundwater component of river flow than modelled (WR90) data, possibly indicating the role of irrigation return flow in developed catchment (e.g. the Hex) in the upper Breede.

Four groundwater abstraction schemes have been used as examples of potential conjunctive use schemes with costs provided. Groundwater schemes are not able to deliver the volumes of water typical of surface water schemes, however, in the Breede Catchment, potential exists for conjunctive use schemes to maximise basin yield in areas adjacent to large dams. For example, a 64 borehole wellfield on the eastern side of the Rawsonville alluvial aquifer is estimated to be able to deliver around 5 million m^3/a at a unit cost of R1,16 / m^3.

Existing groundwater use is largely by individual farmers irrigating close to the source of groundwater. There is potential for communal schemes in many parts of the catchment but these should be focused where there is potential for new irrigation areas and where the soils are suitable for irrigation. Aquifers that could be exploited for irrigation in various regions of the Breede catchment are indicated. Crops that are not as sensitive to elevated salinity as grapes should also be investigated since groundwater quality in the middle and lower Breede may exclude development of vineyards.

BREEDE RIVER BASIN STUDY

GROUNDWATER ASSESSMENT

CONTENTS

Page No.

CONTENTS

Page No.

CONTENTS

Page No.

TABLES

CONTENTS

Page No.

CONTENTS

Page No.

FIGURES

APPENDICES

BREEDE RIVER BASIN STUDY

GROUNDWATER ASSESSMENT

1. INTRODUCTION

1.1 TERMS OF REFERENCE

The specific objective related to the groundwater component of the Breede River Basin Study (BRBS) in DWAF's original terms of reference stated :

"Determine the extent to which groundwater is used in the basin, its potential as a future water source and where feasible, the interaction between surface water resources and groundwater".

As part of the groundwater assessment, the activities undertaken and topics discussed include :

- Reviewing all available literature and data,
- Obtaining yields and qualities of all significant schemes,
- Characterising all aquifers and assessing the groundwater balance (recharge versus consumption),
- Identifying suitable groundwater sources,
- Groundwater contribution to river flow in selected catchments assessed by hydrograph separation,
- Assessing the scope for conjunctive use in selected sub-catchments and estimating costs for scheme development,
- Assessing the potential impacts on surface flow reduction as a result of groundwater abstraction schemes,
- Groundwater contributions to river salinity versus the role of irrigation return flow.

The interchange between surface and groundwater, particularly within the upper Breede catchment, results in a risk of 'double-accounting' when evaluating potential water resources. There is a need to understand the role and relative importance of groundwater versus surface water in different geomorphologic settings within catchments and this has been achieved by presenting conceptual models of surface / groundwater interaction in the various terrain types of the Breede catchment. Baseflow separations of hydrographs in selected quaternary catchments have been conducted to provide estimates of the contribution of groundwater to surface flow.

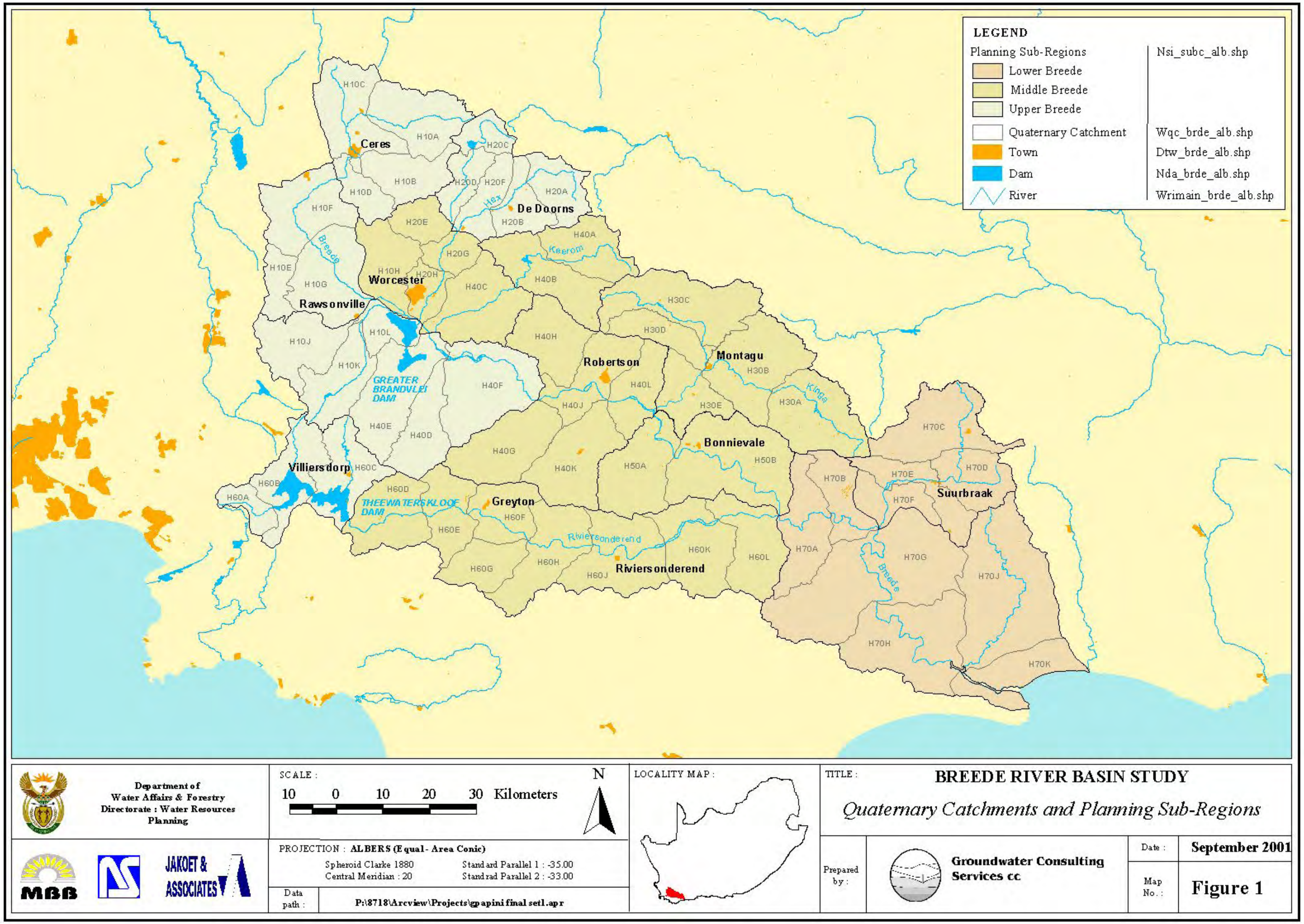
The identification of suitable sources has been incorporated with examples of groundwater schemes where there is potential for groundwater to augment surface water supplies. These conjunctive use examples require thinking of aquifers as storage components, like dams and reservoirs, whose utilisation needs to be integrated into overall catchment management. The close relationship between surface and groundwater resources in the upper Breede catchment necessitates evaluation of the impacts of groundwater abstraction on river flow. Ultimately, any bulk abstraction groundwater scheme has the potential to affect catchment hydrology and the need to manage over-exploitation is critical if groundwater is to be integrated with surface schemes and approved by environmental agencies and other stakeholders. Other important components of the groundwater component of the BRBS include a review of the role of groundwater in contributing to river salinisation, an assessment of groundwater recharge and groundwater use in the catchment.

1.2. EXTENT OF STUDY AREA

The Breede River Basin has its headwaters in the Skurweberg and Gydoberg Mountains in the Ceres area and extends 200km downstream to the mouth at Witsand. The catchment may be split into six main drainage regions – the Ceres Basin, the upper Breede River Basin (Michell's Pass to the Brandvlei Dam), the Hex River catchment, the middle Breede River (from Brandvlei Dam to the confluence of the Riviersonderend), the Riviersonderend catchment and the lower Breede area. However, in this report, the Breede catchment is split into the upper, middle and lower areas as per Figure 1. The quaternary sub-catchments corresponding to the upper, middle and lower catchments areas are presented in Table 1. The Jan du Toit (H10H), Worcester (H20G and H) and Nuy (H40C) catchments are included in the upper Breede catchment.

TABLE 1 : DIVISION OF THE STUDY AREA

DIVISION	QUATERNARY SUB-CATCHMENTS	AREAS
Upper Breede Catchment	H10, H20, H40C,D,E,F and H60A, B, C	Ceres, Wolseley to Goudini, Rawsonville, Hex River Valley, Worcester, Nuy, Moordkuil and Villiersdorp areas
Middle Breede Catchment	H30, H40, H50 and H60 D-L	Moordkuil to Bonnievale and the Riviersonderend Valley
Lower Breede Catchment	H70	Bonnievale to Cape Infanta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Middle Breede
Upper Breede
Quaternary Catchment
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De Doorns
Worcester
Rawsonville
Robertson
Montagu
Bonnievale
Villiersdorp
Greyton
Riviersonderend
Suurbraak
GREATER BRANDVLEI DAM
THEEWATERSKLOOF DAM
Breede
Hex
Keerom
Kingna
Riviersonderend
H10A
H10B
H10C
H10D
H10E
H10F
H10G
H10H
H10J
H10K
H10L
H20A
H20B
H20C
H20D
H20E
H20F
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H40A
H40B
H40C
H40D
H40E
H40F
H40G
H40H
H40J
H40K
H40L
H50A
H50B
H60A
H60B
H60C
H60D
H60E
H60F
H60G
H60H
H60J
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H60L
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H70C
H70D
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H70H
H70J
H70K
Department of Water Affairs & Forestry
Directorate : Water Resources Planning
MBB
JAKOET & ASSOCIATES
SCALE :
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LOCALITY MAP :
TITLE :
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Prepared by :
Groundwater Consulting Services cc
Date :
September 2001
Map No. :
Figure 1

2. GEOLOGY

2.1 DESCRIPTION OF THE GEOLOGICAL UNITS

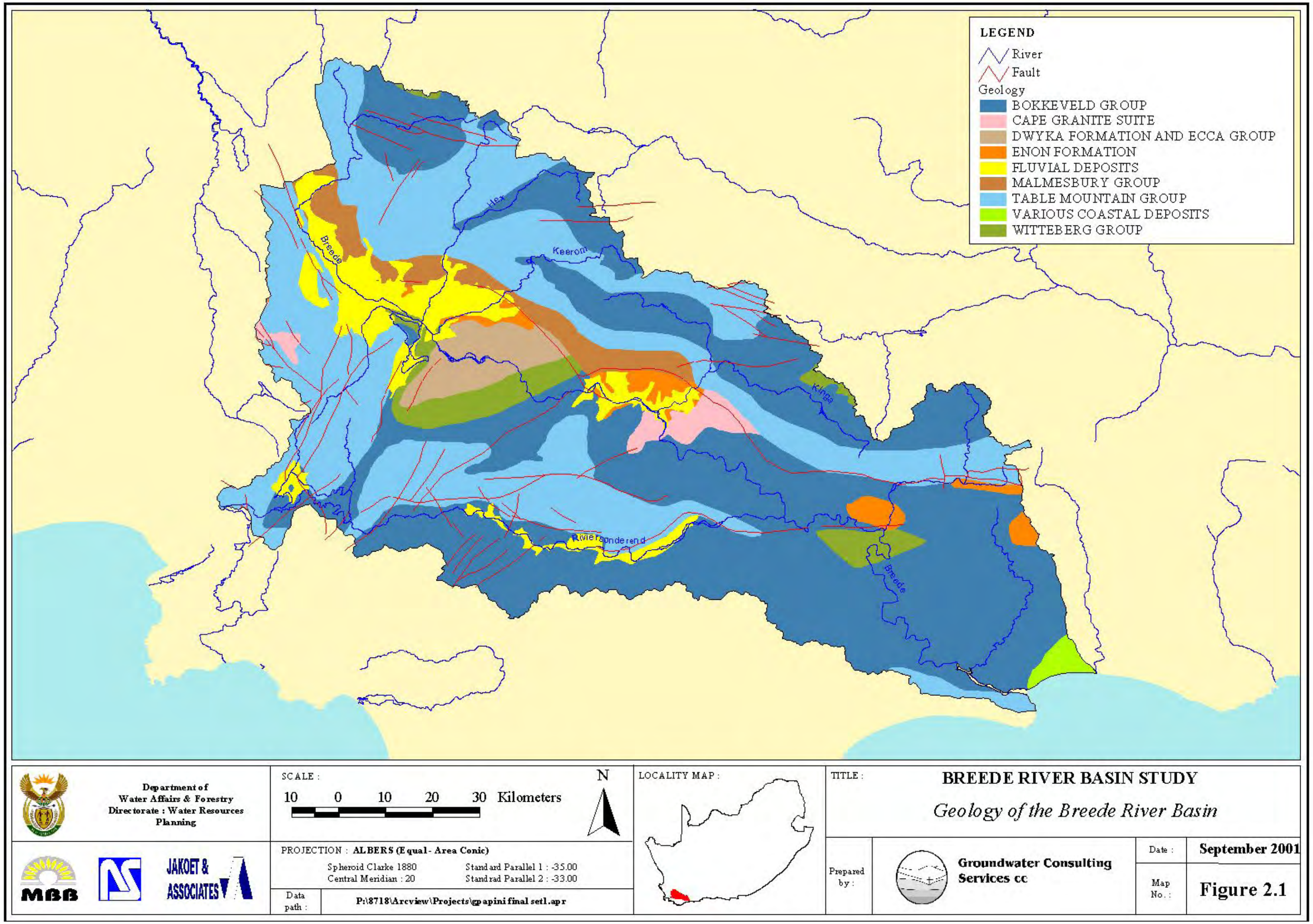
Geological formations in the Breede River catchment range from the Late Proterozoic Malmesbury basement through Palaeozoic Cape and Karoo cover rocks, to isolated outliers of the Mesozoic Uitenhage Group, the Cenozoic Bredasdorp Group and various Quaternary surficial deposits (Figure 2.1). The mountains are mostly formed of sandstone of the Cape Supergroup while shale and siltstone of the Malmesbury and Bokkeveld Groups usually underlie the valleys and areas of subdued relief. A wide variety of terrace gravels, scree, ferricrete, soils and alluvium cover the valley floors and mountain slopes throughout the area.

The upper and middle Breede Basins comprise most of the area known as the Cape syntaxis - a zone in which the western and southern branches of the Cape Fold Belt meet. The syntaxis, with its very high mountains (2 249m in the Matroosberg), forms a prominent watershed between rivers flowing west (Berg River), north (Olifants and Doring Rivers), East (Breede and Riveriersonderend Rivers) and south (Bot, Klein and Nuwejaars Rivers). The Worcester and Ladismith 1:250 000 geological maps (3319 and 3320) cover the upper and middle reaches of the catchment while the Riversdale 1:250 000 geological map (3420) depicts the lower reaches and mouth of the Breede River at Cape Infanta.

2.1.1 Malmesbury Group

From Ashton in the east through to Wolsley in the northwest, metamorphosed sediments of the Precambrian Malmesbury Group are exposed between the mountainous Table Mountain Group rocks. In the Breede River valley, the Malmesbury metasediments consist of phyllite, medium-grained to gritty greywackes, feldspathic quartzite, limestone, dolomite and feldspathic and calcareous grits. Greenstones in the Malmesbury Group consist of large concordant bodies (deformed during pre-Cape tectonism) and younger intrusive dykes, sills or plugs, which have only been affected by the Cape orogeny. The greenstones are usually highly weathered and sheared and may be partly replaced by calcite and chert.

Malmesbury sedimentation has always been considered as one of a geosynclinal basin fringing the western and southern margins of the Kalahari Craton. The sandstone-limestone sequences are correlated with shallow shoreline depositional environments whereas the greywackes are considered deeper water shelf sediments. The age of the Malmesbury is from ± 1200 to 500 Ma.


LEGEND
River
Fault
Geology
BOKKEVELD GROUP
CAPE GRANITE SUITE
DWYKA FORMATION AND ECCA GROUP
ENON FORMATION
FLUVIAL DEPOSITS
MALMESBURY GROUP
TABLE MOUNTAIN GROUP
VARIOUS COASTAL DEPOSITS
WITTEBERG GROUP
Breede
Hex
Keerom
Kinga
Riviersonderend
Department of
Water Affairs & Forestry
Directorate : Water Resources
Planning
SCALE :
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LOCALITY MAP :
TITLE :
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Prepared by :
Groundwater Consulting Services cc
Date :
September 2001
Map No. :
Figure 2.1

2.1.2 Cape Granite

The Malmesbury metasediments are intruded by a number of composite granite plutons dated at between 630 and 500 Ma (Burger and Coertze 1973, 1976). The plutons were intruded into the Malmesbury sediments towards the end of the latter's main deformational phase and consequently exhibit elongation parallel to the anticlinal axes of the Malmesbury Group. Within each pluton several different types of granite types have been recognised.

In the Breede River catchment, three granitic plutons are recognised: the Worcester granite fragment; the Robertson pluton and the Greyton pluton. The Worcester granite fragment is found in small patches north of the Worcester fault between Worcester and Robertson and is intensely deformed, exhibiting gradations from crushed granite to a mylonite north of Worcester. Towards Robertson in the east, the granite becomes more schistose and coarse grained. Unlike other granite plutons of the Cape Granite Suite, this granite does not show intrusive contact relationships with the Malmesbury rocks. The Robertson granite is exposed over an area of about 31 km^2 between the Langeberg Range in the north and the Worcester Fault in the south and is mostly composed of medium to fine-grained granite. Various dykes, veins and sheared zones are related to both the pre-Cape and Cape orogenic events (Dunlevey, 1984). The Greyton pluton is located about 7 km northwest of Riviersonderend and has a strike length of about 8 km and is 1 km wide. The granite is medium to coarse-grained and sheared parallel to it's contact with Malmesbury sediments, suggesting syntectonic intrusion.

Quartz porphyry dykes intrude the Malmesbury Group in the Worcester Valley and are related to the final stages of the emplacement of the Cape Granite Suite. A large number of dolerite dykes are intrusive into the Malmesbury and granites throughout the area. They tend to occur in swarms, having either a northwesterly or northeasterly strike. The dykes are generally in the order of 3 to 20m wide and can rarely be traced for more than a few kilometres along strike.

2.1.3 Table Mountain Group

The Cape Supergroup, which comprises in excess of 90% of the outcrop in the Breede River valley, has been differentiated into the lowermost, predominantly arenaceous Table Mountain Group, which unconformably overlies the Malmesbury Group and Cape Granites. The predominantly argillaceous Bokkeveld and alternating shales and sandstone of the Witteburg Groups conformably overlie the Table Mountain Group. The Table Mountain Group is largely coarse-grained (arenaceous) with a ratio of arenaceous to argillaceous sediments of 90:10 (Meyer, 1999) and has a total thickness of approximately 2800m.

Eight formations are recognised in the Breede Basin (Table 2.1) with the Peninsula Formation being the most important in the area with a maximum thickness of approximately 2000m in the north.

TABLE 2.1 : FORMATION NAMES, THICKNESS AND LITHOLOGY FOR THE TABLE MOUNTAIN GROUP

FORMATION	MAXIMUM THICKNESS	LITHOLOGY
Rietvlei	200m	Brown weathering, thinly bedded, medium-grained feldspathic sandstone and minor shale
Skurweberg	380m	Light-grey, thickly bedded feldspathic sandstone
Goudini	210m	Reddish brown quartzitic sandstone
Cedarberg	75m	Dark grey shale, siltstone and silty sandstone
Pakhuis	70m	Thinly bedded quartzitic sandstone and diamictite
Peninsula	2000m	Thickly bedded coarse-grained quartzitic sandstone
Graafwater	25m	Thinly bedded sandstone, siltstone and shale
Piekenierskloof	50m	Coarse-grained quartzitic sandstone and conglomerate

The Piekenierskloof is the basal formation of the Table Mountain Group but has limited outcrop width due to steep topography. The Graafwater comprises a purplish to reddish, thin-bedded sandstone, siltstone and shale but thins to the south. The Peninsula Formation forms the main mountain ranges of the basin, namely: the Witzenberge, the Hexrivierberge, the Langeberge, the Riviersonderendeberge, the Stettynsberge, the Du Toitsberge and the Slanghoekberge. The Peninsula Formation is primarily planar-bedded, light-grey quartzitic sandstone. The upper contact varies from a normal sharp, concordant contact to a gradational one. Its uppermost beds occasionally display a zone of complex intraformational folds.

The Pakhuis Formation occurs throughout the area and the basal member is characterised by sharp, narrow, cuspate anticlinal folds alternating with broad-bottomed synclines with near-vertical or even overfolded flanks. The resultant canoe-shaped structures attain a maximum thickness of 200 to 300 m across and are filled with diamictite. A sandstone unit follows the glacially deposited diamictite with conglomerate lenses in upward-coarsening cycles. The argillaceous Cedarberg Formation forms smoothly weathered slopes, which characterise this Formation and make it an outstanding marker horizon amidst the otherwise rugged-weathering Table Mountain Group. The bluish-black shale is pyrite-bearing and weathers to ash-white, finely laminated clay. The Cedarberg Formation generally coarsens upwards and has a gradational contact with the overlying Nardouw Subgroup.

The Nardouw Subgroup comprises the three upper Formations of the Table Mountain Group - the Goudini, Skurweberg and Rietvlei Formations. The Goudini Formation varies from 115m near the Goudini Spa (its type area) to about 75m north of Ceres. It is comprised of light-coloured medium-grained quartzitic sandstones (with bed thicknesses >0.5 m) interbedded with reddish-weathering, micaceous siltstone beds. The overlying Skurweberg Formation is characterised by thick-bedded, coarse-grained, light-grey quartzitic sandstones, which generally weather positively and form the major mountain peaks of the Skurweberg and Hex River Ranges. The Skurweberg Formation is approximately 200m thick at it's type area near Ceres and thickens to the south. The Rietvlei Formation is about 200 m thick in the Hex River Valley and consists of alternating light-grey quartzitic sandstone and feldspathic sandstone with lesser shale. The boundary with the overlying Bokkeveld is generally sharp but in the Gydo Pass (north of Ceres) is transitional, comprising a 7m thick alternation of dark and light-grey sandstone, siltstone and shale beds.

2.1.4 Bokkeveld Group

The predominantly fine-grained Bokkeveld Group underlies large parts of the lower lying terrain in the Breede catchment. Five arenitic formations with alternating pelitic formations give rise to the hogback topography around Ceres and the Hex River Valley (Table 2.2). The Bokkeveld Group thins southward and south of Robertson, the interbedded Bokkeveld sandstone units are poorly developed and the group can only be subdivided into the Ceres and Bidouw subgroups.

TABLE 2.2 : FORMATION NAMES, THICKNESS AND LITHOLOGY OF THE BOKKEVELD GROUP

FORMATION	THICKNESS	LITHOLOGY
Bidouw Subgroup		
Karoopoort	40 m	Siltstone, shale and minor mudstone
Osberg	30 m	Sandstone, shale, mudstone and siltstone.
Klipbokkop	400 m	Micaceous siltstone and mudstone
Wuppertal	26 m	Sandstone, siltstone and shale
Waboomberg	200 m	Shale, siltstone and immature sandstone
Ceres Subgroup		
Boplaas	60 m	Grey, fine to medium-grained feldspathic sandstone
Tra-tra	300 m	Dark-grey shale, mudstone and siltstone
Hex River	55 m	Light-grey, fine to medium-grained feldspathic sandstone
Voorstehoek	300 m	Mudstone, shale and siltstone
Gamka	70 m	Feldspathic sandstones and siltstones
Gydo	160 m	Dark-grey shale, mudstone and siltstone

The Gydo Formation displays a gradual upward coarsening with siltstone and fine-grained sandstone layers progressively increasing in the upper half. Thin layers of pyrite and calcite and a wide variety of invertebrate fossils occur especially in the lower carbonate-bearing shales. The fine to medium-grained feldspathic sandstones and siltstones of the Gamka Formation reach a thickness of 70 m around Ceres but the unit is only 15 m thick near McGregor.

The Voorstehoek Formation follows concordantly on the Gamka sandstone beds and consists predominantly of dark-grey mudstone, shale and siltstone. The Hex River Formation builds a prominent series of reddish-brown-weathering cliffs along the eastern margin of the Hex River Valley. There is a marked reduction in the maturity and extent of the sandstone units southwards. The Tra-tra Formation is an upward coarsening unit with shale and mudstone predominant in the basal sequence and siltstone with a number of thin (~ 6m) but conspicuous and continuous sandstone horizons occurring higher up in the Formation. The Boplaas Formation reflects the general southward decrease in sand content of the Bokkeveld Group; relatively mature sandstone on the northern flanks of the Riviersonderend Mountains becomes an alternating sandy shale and siltstone unit south of Riviersonderend.

The Waboomberg Formation conformably succeeds the Boplaas Formation and is about 200 m thick northeast of Ceres. It consists primarily of dark-grey siltstone in the lower half, overlain by dark-grey carbonate-bearing shale and mudstone. In the Koue Bokkeveld, the Wuppertal Formation consists of upper and basal sequences of fine to medium-grained sandstone, separated by interbedded dark-grey siltstone, shale and micaceous sandstone. The arenaceous units thin south of Prince Alfred Hamlet and the unit becomes indistinguishable from the underlying Waboomberg Formation. The Klipbokkop Formation thickens to around 300 m at Gydo and Karoopoort and comprises a sequence of alternating micaceous siltstone and mudstone with argillaceous sandstone interbeds.

The uppermost 30 m of the succession is generally more arenaceous. In the Warm and Koue Bokkeveld, the 30 m Osberg Formation can be subdivided into prominent arenaceous basal and upper parts separated by a central shale, mudstone and siltstone sequence. The proportion of sandstone decreases southwards. The Karoopoort Formation consists of dark-grey siltstone, sandy shale and minor mudstone beds and is 40 m thick at the type section at the southwestern entrance to Karoopoort in the Ceres District. South of the Langeberg Range, the overlying Osberg and Karoopoort Formations can no longer be unambiguously distinguished and the upper boundary of the Klipbokkop Formation is taken below the first typical micaceous, light-grey siltstone and sandstone beds of the Witteberg Group.

2.1.5 Witteberg Group

The predominantly arenaceous Witteburg Group is divided into seven formations (Table 2.3) that follow conformably on the Bokkeveld Group. South of Swellendam, outcrops of Witteberg are restricted and represented by the reddish-brown micaceous, quartzitic sandstone with interbedded bluish-grey shale of the Wagendrift Formation.

The Wagendrift Formation has a total thickness of about 135 m north of Ceres increasing to 165m in the Montagu District. Along the Riviersonderend River the Wagendrift Formation is greater than 400 m in total thickness although exhibits a gradual decrease in grain size and sand content southward. The Blinkberg Formation is medium-grained, thick-bedded, light-grey quartzitic sandstone, which always forms prominent relief where it outcrops.

The Blinkberg is approximately 90 m thick in the Gydoberg north of Prince Albert Hamlet but thins southward to 50 m in the Worcester-Robertson area, and only 15 m thick at its southernmost outcrop near Greyton. At its type area just north of Karoopoort, the Swartruggens Formation is 300 m thick and is also found in the vicinity of the Brandvlei Dam, south of Ashton, in the mountains east of Montagu where it is intensely folded and around Greyton. The rocks of this formation typically weather yellow to reddish brown and are distinctly micaceous. The arenaceous Witpoort Formation is topographically the most prominent of the Witteberg Group. It attains a maximum thickness of 380 m in the Ceres District but thins to 65 m just north of the Brandvlei Dam near Worcester.

TABLE 2.3 : FORMATION NAMES, THICKNESS AND LITHOLOGY OF THE WITTEBERG GROUP

FORMATION	THICKNESS	LITHOLOGY
Lake Mentz subgroup		
Waaipoort	37 m	Shale, mudstone and siltstone
Floriskraal	25 m	Feldspathic and quartzitic sandstone, siltstone and micaceous shale
Kwekvlei	37 m	Shale and siltstone
Weltevrede subgroup		
Witpoort	380 m	Quartzitic sandstone, pebbly sandstone and thin conglomerate layers
Swartruggens	300m	Siltstone, mudstone and thin-bedded sandstone
Blinkberg	90 m	Quartzitic sandstone
Wagendrift	400 m	Sandstone, siltstone and sandy shale

Good outcrops of the Kweekvlei Formation are rare and the shales are only exposed at Gannaberg and Gensbokkop, west of Robertson. Excavations next to the Breede River on the Worcester-Rawsonville road have shown that the shale is markedly graphitic.

The Floriskraal Formation occurs north of the Brandvlei Dam and consists of several thick yellow-brown-weathering, medium-to-coarse grained, often feldspathic, quartzitic sandstone beds, which alternate with siltstone and sandy micaceous shale. The Waaipoort Formation marks the top of the Witteberg Group and consists of shale, mudstone, siltstone and intermittent thin sandstone units.

2.1.6 Karoo Supergroup (Dwyka, Ecca and Uitenhage Groups)

Rocks of the Karoo Supergroup are only found south of the Langeberg Range between Worcester and Robertson, and in a small outlier at Greyton. The Karoo rocks have been preserved in the Breede and Riviersonderend valleys on the down-thrown southern sides of the Worcester and Riviersonderend Faults. The Dwyka is up to 485 m thick and consists mainly of a hard, massive, dark grey-green tillite, which weathers yellowish brown. Arenaceous zones, from 1 to 3 m thick, form important marker horizons which, although they are discontinuous, do persist regionally along the same stratigraphic horizons. The Dwyka Group is largely covered by younger alluvial deposits south and south-west of Worcester.

The five formations of the Ecca Group are well represented between Worcester and Robertson and are comprised of shale, mudstone and siltstone units with intercalated sandstone beds. The formational names, thicknesses and lithologies are presented in Table 2.4. The Uitenhage basins of the southern Cape were initiated during the first stages of the break up of Gondwanaland (Middle Jurassic). Large tensional displacements on southward dipping normal faults (up to 6 km in the case of the Worcester Fault) caused basins to develop along the synclinal axes of the Cape Fold Belt (Lock *et al*, 1975). Active boundary faulting controlled sedimentation and the Enon conglomerate was deposited as northward-building alluvial fans, grading downslope into alluvial plain sandstone between Worcester and Ashton.

TABLE 2.4 : FORMATION NAMES, THICKNESS AND LITHOLOGY OF THE ECCA GROUP

FORMATION	THICKNESS	LITHOLOGY
Waterford	30 m	Sandstone with intercalated pelitic units
Tierberg	300 m	Laminated shale, mudstone and siltstone
Collingham	45 m	Shale, siltstone and mudstone
Whitehill	30 m	Carbon-bearing, pyritic, black shale
Prince Albert	120 m	Shale with intermittent silty and cherty layers

Only the basal Enon Formation of the Uitenhage Group has been identified at Worcester and between Worcester and Robertson. The Kirkwood sandstone is present between Robertson and Ashton. The Enon Formation consists of massive, poorly sorted, matrix-supported conglomerate with a sandy matrix at Worcester but a reddish, highly calcareous mudstone matrix near Robertson. The Enon Formation also occurs at Swellendam and in the upper reaches of the Slang River on the eastern margin of the catchment.

2.1.7 Bredasdorp Group

The Bredasdorp Group was deposited on a marine-cut platform, up to 25 km wide in the southern Cape, which gently slopes seaward from an elevation of 90 m above sea level. Rocks of this Group are limited to the south-east of the Breede River catchment near Witsand. They comprise the 130-m thick, aeolian, cross-bedded calcarenite of the Wankoe Formation and the 100 m thick, partly consolidated dune sands of the Strandveld Formation.

2.1.8 Alluvium and Other Unconsolidated Quaternary Sediments

Alluvium, varying from fine loam and silty soil to sand and gravely sands, occur in the watercourses and flood plains of the larger rivers of the Breede Catchment. The main alluvium deposits are found along the Breede, Riviersonderend and Hex Rivers and their tributaries. Light grey to pale red sands, weathering products of the Table Mountain sandstone and Bredasdorp calcarenite, cover large parts of the coastal plain north of Witsand. Scree deposits are confined to the foothills of the Riviersonderend, Breede and Potberg Ranges. The boundary between alluvium, terrace gravel, pediment gravel and scree is not always clear. Around Worcester a distinction is made between gravely alluvium and sandy alluvium but it usually consists of a mixture of sand, silt and gravel. The composition of the alluvium varies from quartzose sands in the Table Mountain sandstones to silty in areas underlain by Malmesbury, Bokkeveld and Karoo rocks. Old alluvium-filled channels, overlain by younger alluvium and pediment have been intersected in boreholes near mountains.

Geophysical surveys of the Breede between Wolseley and Worcester showed that thick alluvium is mainly associated with the main tributaries such as the Holsloot, Molenaars, Jan du Toit and Waboom Rivers and, to a lesser extent, with the Breede River itself east of Wolseley. The thickness of the deposits varies from 20 to 40 m and attains a maximum west and south-east of Rawsonville. The deposits are also comprised of boulder deposits, which increase in thickness upslope away from the Breede River and sandy alluvium.

2.2 STRUCTURE AND TECTONICS

The Breede River catchment occupies most of the Syntaxis Domain of the Cape Fold Belt. The Syntaxis Domain is the area where the easterly striking Southern Cape Fold Belt and north-northwesterly striking Western or Cedarberg Fold Belt merge and curve towards the southwest. The Syntaxis Domain contains a series of tightly folded synclinal and anticlinal structures related to both the southern and western arcuate fold belts. The Saldanian and Cape orogenies were periods of intense deformation, which resulted, at least in the case of the Cape orogeny, in the intensely folded strata we see in many of the mountain ranges of the Western Cape.

2.2.1 Saldanian Orogeny

The basement sequence of the Malmesbury Group was deformed in late Precambrian to Cambrian times by the Saldanian Orogeny, which culminated before, and continued till after, the intrusion of the Cape Granite Suite between 630 and 500 Ma.

2.2.2 Cape Orogeny

Rocks of the Cape and Karoo Sequences, following upon a major post-Saldanian unconformity, were folded by the Permo-Triassic Cape Orogeny. This deformational episode reactivated some structures in the basement but produced a strong overprinting of structures in areas of intense Cape orogenic activity.

2.2.3 Faulting

Between 135 and 130 Ma ago South America separated from Southern Africa and caused tensional displacement on southward dipping, east-west faults in the southern and western Cape. The largest of these are the Worcester and Riviersonderend Faults. It has been suggested that some of these faults may coincide with earlier thrust faults, which could account for the remnants of zones of breccia that overlie basement rocks, for example, east of Robertson and immediately north of the Worcester Fault. The displacement or throw along the faults varies from a few metres to more than 6 000 m in the case of the Worcester Fault at Worcester. Large variations in displacement occur along strike and are accompanied by a strong curvature of the fault line (e.g., the Worcester Fault east of Robertson) that is characteristic of listric faults associated with rifting and the development of sub-basins such as exhibited by the Enon Formation.

Apart from the easterly trending normal faults, there are also a large number of north-westerly and north-easterly striking faults. The north-westerly faults have a tendency to merge with the main easterly trending faults, but the north-easterly faults appear younger. The north-westerly and north-easterly striking faults can be related to the normal easterly trending faults in a single north-south extensional regime (rifting) or could have developed slightly later in a dextral shear regime.

3. CHARACTERISATION OF BASIN HYDROGEOLOGY

3.1 AQUIFER TYPES FOUND IN THE BASIN

A saturated porous rock unit, or a single or group of interconnected water-filled fractures, which are capable of transmitting groundwater and of yielding economically significant quantities of groundwater to boreholes/wells or springs are termed aquifers. Vegter (1995) suggested that only this definition of 'aquifer' be used to avoid confusion. The storage properties and the hydraulic conductivity (or transmissivity) of rocks dictate the aquifer potential of the rock unit. Storage (under unconfined conditions) is expressed as a fraction of the volume of groundwater held per unit volume of rock, while the hydraulic conductivity of the rock is a reflection of the rate that water can move through a rock unit. Generally speaking, the greater the hydraulic conductivity and porosity, the greater the aquifer's water supply potential.

The determination of aquifer hydraulic parameters (transmissivity and storativity) requires borehole test pumping, preferably with several surrounding monitoring boreholes to obtain representative results. Pump tests of boreholes are not always carried out and data on the aquifer's hydraulic properties are usually only collected during research projects and during some town water supply projects but seldom during agricultural supply projects.

Porosity can be defined as primary porosity or secondary porosity. The primary porosity of a rock mass is the porosity related to the soil or rock matrix, while the secondary porosity is due to an alteration of the rock structure by some secondary activity (including fracturing, faulting or weathering). Primary aquifers consist of sediments or rock with primary openings (e.g. alluvium), while secondary aquifers consist of fractured and weathered rock. Bodies of saturated rock which are less permeable than aquifers, for example clay, are known as aquitards and can form confining layers. Although not capable of directly yielding water to boreholes, they are important components of any groundwater system as they are capable of holding, or controlling the release of water to aquifers.

The 1: 500 000 hydrogeological maps produced by DWAF differentiate between the following aquifer types and have been used in describing the aquifers in the Breede Basin:

- fractured aquifers (or secondary aquifers),
- fractured and inter-granular aquifers (mixed primary and secondary aquifers),
- intergranular aquifers (primary aquifers).

3.1.1 Fractured Aquifers

Fractured rock aquifers are by far the most important in the Breede River catchment and cover in excess of 90% of the catchment area. Of the fractured aquifers, the Table Mountain Group and Bokkeveld aquifers are the most important, while rocks of the Malmesbury, Bokkeveld and Witteberg Groups and the Karoo Supergroup can also yield water under fractured conditions.

Hydraulic parameters are not readily available for the various aquifers of the Breede catchment. The little data that exists is usually limited to boreholes drilled in the TMG and Bokkeveld rocks. For the TMG and Bokkeveld aquifers in the Hex River Valley, Rosewarne (1981) determined a transmissivity of from 23 to 110 m^2/day and storage coefficient of from 1 x 10^{-3} to 3.5 x 10^{-5} (0.1% - 0.004%); which is representative of semi-confined to confined aquifer conditions. In the Rawsonville–Goudini area the TMG aquifer is unconfined to semi-confined, with leakage in areas overlain by saturated alluvium.

3.1.2 Fractured and Intergranular Aquifers

The fractured and intergranular aquifers consist mainly of moderately weathered, medium to coarse-grained granite of the Cape Granite Suite. Groundwater is contained within intergranular interstices in the saturated zone and in jointed and occasionally fractured bedrock. This aquifer type is found primarily north of the Worcester Fault. This aquifer type is not considered to be an important regional aquifer in the Breede Basin, as it comprises less than 1% of the catchment area.

3.1.3 Intergranular Aquifers

The unconsolidated aquifers consist of the Tertiary to Quaternary coastal deposits and alluvial deposits. They are occasionally semi-consolidated but groundwater occurs within granular interstices in the porous medium. Although the intergranular aquifers cover large areas of the Breede and Hex River valleys they have variable thickness and may be largely unsaturated where they are poorly developed (< 10 m). Areas where there is extensive development of alluvium and where the intergranular aquifers comprise an important resource include:

- Wolseley to Goudini (including the Slanghoek River valley),
- the Rawsonville area,
- Worcester to Nuy,
- the Modder River valley,
- the Robertson area.

The alluvial sands, gravels and boulders beds in the Breede River valley do not normally attain a thickness of more than 20 to 30m (Whittingham, 1976), although there are some areas in the Hex River valley where the alluvium is believed to be in excess of 50m. The major utilisation of the intergranular aquifers is in the Rawsonville and Hex River Poort areas.

The Hex River alluvial system (Rosewarne, 1981) has transmissivity of from 20 – 280 m^2/day and storage coefficient of 1 x 10^{-1} to 1 x 10^{-3} (10% - 0.1%). The alluvial aquifer in the Rawsonville – Goudini area has been defined as semi-confined with delayed yields (Rosewarne, 1981) but in upper parts of the catchment has confined conditions due to clay layers. The aquifer reportedly has a specific yield of 1% – 5% and average transmissivity of 285 m^2/day.

Coastal deposits are not well represented in the Breede catchment although the calcarenites and dune sands of the Bredasdorp Group (Wankoe and Strandveld Formations) comprise a locally important aquifer north-east of Witsand and at Cape Infanta.

3.1.4 Fault Zones and Contact Zone Aquifers

A number of major faults exist in the basin, the best known of which is the Worcester fault. Very little is known about the water-bearing properties of the Worcester fault especially, where it occurs under a covering of alluvium. Where it outcrops, high yielding boreholes have been drilled in the TMG side (north) of the fault (Van Zijl, 1979). It has been speculated (Smart, 1998) that faulting in incompetent sedimentary rocks (i.e. shale) results in the formation of a low permeability rock flour which results in a closed fault. However, in competent quartzitic sandstone units, a highly transmissive breccia forms in the fault zone. There is also a belief that the north-south trending faults in the basin are more closed (compressional faults), while the east west trending faults are open (tensional faults) (Hay, pers comm.). However some of the larger east west faults (like the Worcester faults) may also be barriers to groundwater flow. Boreholes drilled for the Oudtshoorn Municipality on the Worcester Fault were dry.

Lithological boundaries represent favourable zones for development of openings where there is local flexure and rock competence contrast (e.g. mudstone – sandstone contact). Unconformities at lithological contacts are likely to be more productive due to weathering effects at the contact (Smart, 1999).

3.2 GROUNDWATER OCCURENCE

3.2.1 Springs

Springs and seeps are zones where groundwater rises to the surface under hydrostatic pressure. The areas of daylight are usually zones of either intense bedrock fracturing and faulting (thus preferential pathways) or zones where impermeable horizons control groundwater flow. High hydrostatic pressures are often encountered in the fractured aquifers found in the Breede catchment – these heads are a result of the large elevation differences between the mountainous recharge areas and the valley bottoms where the springs occur. Springs in the TMG rocks are often associated with permeability changes in the bedrock or where the topography is lower than the water table. As an example of the former occurrence, the relatively impermeable barrier formed by the Cedarberg Formation Shale, often results in springs occurring along the shale contact. Local scale springs associated with a change in bedrock permeability usually have variable flow, while stronger thermal springs associated with large faults tend to have steady flows throughout the year indicating they tap groundwater from a larger and deeper source.

Numerous variable flow springs exist and are used by farmers and landowners in the Breede catchment, but no comprehensive record of springs is available. The yields of several variable flow springs have been documented, for example, from farms in the Tygerbos Kats Valley and

Vrede areas: Massiesbrand: 2,2. – 6,7 ℓ/s; Boegoefontein: 1 ℓ/s – 13,4 ℓ/s and Varkieskloof: 1,9 – 4 ℓ/s. Prince Alfred Hamlet and Montagu utilise springs as their primary potable water source.

There are in excess of ten thermal springs that issue forth from the Table Mountain Group quartzites (Diamond, 1997), four of which are located in the Breede Basin (Table 8.1). The temperature of the water in these springs ranges from 27°C to 64 °C. The occurrence of the Brandvlei hot spring, the strongest flowing and hottest spring in South Africa (> 125 ℓ/s and 64°C) is evidence of the existence of open fissures extending to great depths (2 - 3 kms) which can transmit groundwater to surface. Oxygen and hydrogen isotope ratios of thermal spring waters indicate that the springs are recharged from a colder and isotopically more fractionated weather system, such as during a previous colder climate regime, or at high altitude (Diamond, 1997), with high altitude rain being the probable source.

TABLE 3.1: SOME THERMAL SPRINGS IN THE BREEDE RIVER CATCHMENT

LOCALITY	FLOW	USE
Brandvlei	125 ℓ/s	Prison domestic supply
Rawsonville (Drieneringsloot)	33 ℓ/s	Irrigation
Goudini	4 ℓ/s	Irrigation of gardens and spa
Tweefontein (Hex River Poort)	8 ℓ/s	Too saline (EC ~ 300 mS/m)

3.2.2 Borehole Distribution

An analysis of borehole distribution will give an indication of the realised potential of local aquifers but not that of undrilled aquifers. The draft 1: 500 000 hydrogeological map of Cape Town indicates areas of major borehole concentration in the Hex River Valley, the Rawsonville area, and the Nuy and Vink valley areas and in the upper reaches of the Riviersonderend Valley. The plan indicates borehole densities of up to 2,5 boreholes per km^2 in the Hex Valley, west of Goudini, in the Slanghoek Valley, in the Ceres Valley and in the Vink and Nuy Valleys.

A high concentration of boreholes is also indicated in upper Riviersondered Valley (Villiersdorp) and the Modder River Valley. These areas are all underlain by Table Mountain and Bokkeveld Group rocks. The compilation of the 1: 500 000 map is based on available data in the NGDB. In reality there are far more boreholes than shown on the map – in the Hex River valley borehole concentrations are expected to be above ten boreholes per km^2.

During the data collection process a local pump installation and maintenance company (Spilhaus) provided data on the number of boreholes they maintain in different areas, namely:

- Ceres Valley – 150 boreholes
- Wolseley to Romans River – 50 boreholes
- Romans River to Goudini Spa – 120 boreholes
- Goudini to Brandvlei – 200 boreholes

These figures are under-estimates of the total number of boreholes in existence, since many boreholes are equipped and maintained by organisations other than Spilhaus. Whittingham (1976) found that there were 626 boreholes between Wolseley and the Brandvlei Dam. It is estimated that the total number of boreholes is more than double that of the Spilhaus totals.

The borehole numbers decrease dramatically with distance away from the upper and middle catchment. Data is sparse in the areas below Bonnievale, but discussions with local farmer's co-operatives suggests that borehole densities in the Bonnievale – Swellendam area would be less than 0,25 boreholes/km^2 (1 borehole per 4 km^2). In the area between Swellendam and Riviersonderend, the borehole density is expected to be even lower.

3.3 CHARACTERISATION OF BASIN HYRDOGEOLOGY

3.3.1 Borehole Depths

Borehole depths are usually a function of the target aquifers, which in the most intensive agricultural areas are the Table Mountain Group and lower Bokkeveld. In many settings this requires drilling through the Bokkeveld and Witteburg rocks to intersect the Table Mountain Sandstone at depths often in excess of 100 m below surface. The lower Bokkeveld is believed to behave as a good aquifer in the upper catchment areas because of it's highly folded and fractured nature and proximity to recharge areas (the TMG). In the Hex Valley irrigation areas, borehole depths have increased with increasing demand on groundwater, for example, in 1960 1,7% of boreholes were deeper than 150m, whereas in 1980, 59% were deeper than 150m. This is also a function of the increased ability to drill deeper boreholes. Average borehole depths for some of the main agricultural areas are given in Table 3.2.

TABLE 3.2: AVERAGE BOREHOLE DEPTHS (ROSEWARNE, 1981)

LOCALITY	AVERAGE DEPTHS
Ceres Valley	30 –60m
Hex River Valley	60% > 150m
*Rawsonville/Goudini area	30 – 40 m
Bree River to Bothashalt (upper Breede Valley)	120 – 160m.
Villiersdorp (upper Riviersonderend Valley)	90 –120 m

* The predominance of shallow borehole depths in the Rawsonville area is of interest as they may indicate that the bedrock TMG aquifer is largely unexploited (Rosewarne, 1981). However, recharge of the alluvium from the underlying TMG aquifer is thought to be significant and therefore large-scale abstraction from the TMG may result in declining water levels in the alluvium.

The depths of boreholes obtained from the National Groundwater Database (NGDB) for the Table Mountain Group and the Bokkeveld Group for the Breede River catchment are presented in Table 3.3. The data indicate that boreholes drilled into the TMG tend to be drilled to greater depths than those drilled into the Bokkeveld. 66% of boreholes in the Bokkeveld Group are less than 80 m deep compared to 56% of TMG boreholes. Similarly, 13% of TMG boreholes are greater than 150 m deep compared with 7% of boreholes drilled into the Bokkeveld.

TABLE 3.3: DEPTHS OF BOREHOLES IN THE TMG AND BOKKEVELD ROCKS

DEPTH (m)	TMG No. of b/hs	TMG %	TMG Cum %	BOKKEVELD No. of bhs	BOKKEVELD %	BOKKEVELD Cum %
0-20	6	2,6	2,7	43	6,6	6,6
20-40	37	16,6	19,3	104	16,1	22,7
40-60	33	14,8	34,1	114	17,5	40,2
60-80	38	17,1	51,1	138	21,2	61,5
80-100	38	17,0	68,2	103	14,9	77,3
100-120	13	5,8	74,0	38	6,1	83,2
120-140	24	10,7	84,8	60	9,2	92,4
>140	34	15,2	100	49	7,6	100,0
TOTAL	**223**	**100,0**		**649**	**100,0**	

3.3.2 Groundwater Levels

Natural rest water levels below surface in the catchment vary dependant on elevation above sea level, topographic setting, geological formation and the time of year. In the base of the valleys in the middle and upper parts of the catchment, water levels are shallow. Generally, rest water levels are less than 10m below surface. The shallowest water levels are found in the Klipheuwel, Uitenhage and Sandveld units, while water levels are deeper in the Bokkeveld, Witteberg and Ecca units. Rest water level variations for the different geological units (Meyer, 2000) are shown in Table 3.4.

TABLE 3.4: REST WATER LEVELS IN DIFFERENT GEOLOGICAL UNITS

GEOLOGICAL UNIT	PERCENTAGE OF BOREHOLES IN SET DEPTH RANGE (m BELOW SURFACE)				
	<10m	10-20m	20-30m	>30m	No. of Bh's
Malmesbury	74	16	7	3	1310
Cape Granites	81	11	5	3	770
Klipheuwel	86	0	9	5	21
Table Mountain	78	12	6	4	528
Bokkeveld	70	15	8	7	1280
Witteberg	64	17	9	10	286
Dwyka	65	21	6	8	96
Ecca	65	26	7	2	127
Beaufort	78	23	0	0	23
Uitenhage	68	6	6	19	16
Sandveld	85	9	3	3	1751
Bredasdorp	82	10	5	3	122
Alluvium	74	15	6	5	297

Groundwater levels fluctuate depending on the season, rainfall patterns and aquifer utilisation. Water levels are generally lower in the summer months (October – April) when irrigation abstraction increases, but recover over the winter rainfall months. Summer pumping and winter-recharge aquifer management in the Agter-Witzenberg, which is the valley west of the Ceres Valley but outside of the Breede catchment, has shown that groundwater levels dropped by an average of 30 m (and a maximum of 80m) during the 1994/95 pumping season but recovered at the end of the following winter (Weaver *et al*, 1998).

In the alluvial aquifers, water level fluctuations over the pumping season (September – April) are comparatively small: an average of 1,25 m in Rawsonville area from 1979 – 1980, whereas higher drawdowns are noted in the deep bedrock aquifers. Documented summer drawdowns in TMG aquifers (Rosewarne, 1977, 1981) include:

- 10m in the Ceres Valley (Rosewarne, 1995) recovering to 3m below surface by the end of winter,
- 18 m in the Wabooms area,
- 4 m in the Jan DuToits area,
- 11 m in the Brandwacht area,
- 65 m in the De Doorns area of the Hex River valley,
- 1 – 2 m around Rawsonville.

Comparison of the water levels in the bedrock and the alluvium indicates that groundwater in the bedrock underneath the alluvium is under pressure, resulting in upward flow from bedrock to the alluvium (Rosewarne, 1981). Where large-scale abstraction takes place from bedrock aquifers that are overlain by saturated alluvium, there may be some leakage from the alluvium to the underlying fractured rock. This is thought to be the case in the Hex Valley in summer where downward leakage has been invoked (Rosewarne, 1980).

Artesian flow is seen in a number of alluvial boreholes in the Rawsonville and Jan du Toits area, where a confining clay layer exists. In bedrock boreholes artesian flow has been observed in the Brandwacht area, the Jan du Toits area, the Wabooms area and in the Slanghoek area. Artesian conditions fluctuate and are strongest during the winter recharge period. Boreholes drilled near the Brandvlei hot spring gave artesian flows up to 20 ℓ/s.

3.3.3 Water Strikes

Data on water strikes in boreholes drilled was obtained from the National Groundwater Database (NGDB) at the Department of Water Affairs and Forestry. Data is predominantly for boreholes drilled into the Table Mountain Group and the Bokkeveld Group rocks, since these rocks host over 80% of the successful boreholes drilled in the Breede Catchment. The sample population included 872 water strikes, 649 for the Bokkeveld and 223 for the TMG.

To ascertain water strike variability with depth, the total number of groundwater intersections obtained for different depth intervals was noted. The data for the TMG and Bokkeveld boreholes is presented in Figure 3.1. The number of intersections in each 10 m depth interval, expressed as a proportion of the total number of intersections for the entire depth range of all boreholes, was taken as the probability of striking water within that depth interval.

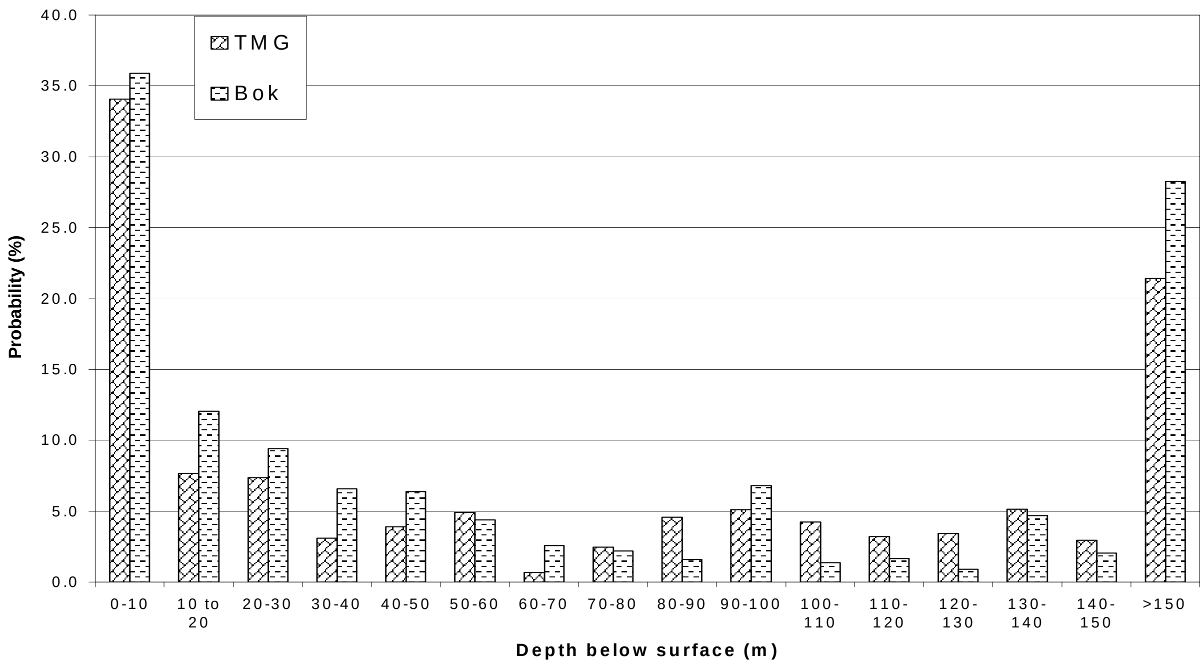


Figure 3.1: Distribution of water strike depths in the TMG and Bokkeveld Groups

Figure 3.1 indicates that:

- The probability of intersecting groundwater within 10 m of the surface is around 35%. However, these water strikes are unlikely to yield substantial amounts of groundwater as they probably represent shallow seepage.

- The probability of encountering water strikes at depths greater than 150 m increases significantly for both Groups. This is probably more a reflection of the >150m range being 'open ended' in that it includes all boreholes deeper than 150m. If this category is split into 10m intervals for the next 100m, the probability per 10m interval would be between 2 –3, which is similar to the 10m intervals from 60m and deeper.

- The highest probability of striking water is within 60m of the surface.

- The probability of striking water deeper than 60m (if corrections are made for the >150m open end category) is relatively constant from 60m.

- The probability of getting water strikes at depths of > 150 m is higher in Bokkeveld Group rocks than in TMG rocks.

3.3.4 Borehole Yields

Borehole yields (blow yields) from the National Groundwater Database were provided by DWAF for the different aquifers in the various sub-regions as per Table 3.4. The yields were split into the following classes: dry; 0,1 – 0,5 ℓ/s; 0,5 – 1 ℓ/s; 1 – 2,5 ℓ/s; 2,5 – 5 ℓ/s; 5 – 10 ℓ/s and greater than 10 ℓ/s. The database includes some 1 184 records for dry and wet boreholes. This number of boreholes represents a small sample of the total number of boreholes in the catchment. The 2001 Hex River Valley census, conducted for the Reserve determination, identified 711 boreholes.

The distribution of borehole yields for the whole of the Breede Catchment is illustrated in Figure 3.2. This graph shows that:

- dry boreholes account for 26% of the records.
- 42 % of all the boreholes listed in the NGDB yield less than 0,5 ℓ/sec.
- 33% of all boreholes have yields exceeding 5 ℓ/s.
- boreholes with yields of between 0,5 – 5 ℓ/sec account for only 13% of the total number.

The low number of boreholes in the middle range of yields suggests that boreholes either encounter decent yields (>2,5 ℓ/sec) or are poor yielding. This suggests that, generally speaking, boreholes drilled deep into fractured environments provide good yields, whereas shallow holes only intersect seepage and provide low yields. Alternatively, the lack of intermediate yields may indicate the willingness of drillers to report yields in excess of 5 ℓ/s, as any lesser yield is not considered suitable for irrigation purposes.

The borehole data from the NGBD for the Breede River Catchment show that of the wet holes drilled, 60% are drilled into the Bokkeveld Group, 21% in the Table Mountain Group, 8% in alluvium, 6% in the Malmesbury Group and 3% in the Witteburg Group. These figures indicate that the Bokkeveld is the most drilled aquifer in the catchment. This is primarily because it occupies low-lying accessible positions in the base of valleys. The yield distribution of boreholes based on the geological groups (excluding the Witteburg, which is of minor importance) is presented in Figure 3.3:

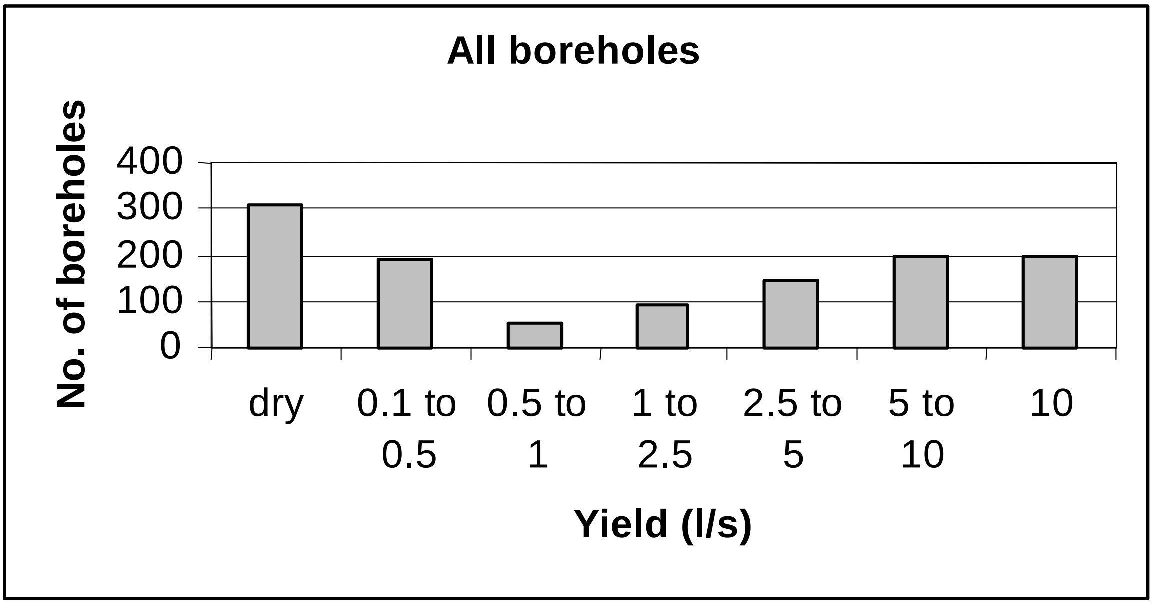


Figure 3.2 : Distribution of borehole blow yields for Breede River Catchment

Figure 3.3 indicates a significant number of dry boreholes and low yielding (< 1 ℓ/s) boreholes but an increasing number of higher yielding boreholes for the TMG and Bokkeveld. The alluvial aquifer has a high proportion of dry and low yielding boreholes (71% < 1 ℓ/s) with decreasing numbers of higher yielding boreholes whereas the Malmesbury has a fairly uniform distribution in all yield classes.

A brief summary of the predominant aquifers and their yields for each sub-region is given below and summarised in Table 3.5:

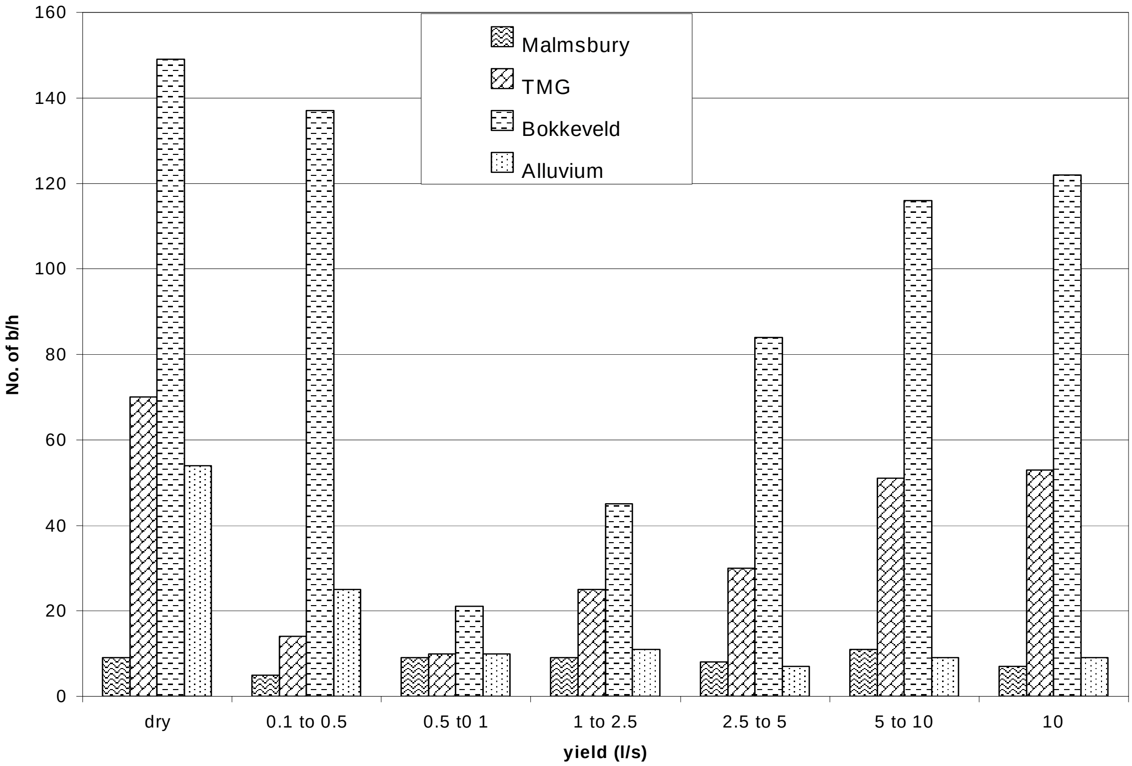


Figure 3.3 : Yield distribution of geological groups comprising major aquifers in the Breede Catchment

- In the Ceres Valley most boreholes are situated in the Bokkeveld Group and yields are high with 58% of boreholes having yields greater than 5 ℓ/s.

- From Wolseley to Goudini there is a lot of groundwater abstraction from the alluvium, however, deep fractured aquifers in the Malmesbury Group are also utilised in the Wabooms, Jan du Toits and Hartebees Valleys. There is a low success rate (65% dry boreholes) in this area and only 10% of the borehole have recorded yields of greater than 5 ℓ/s.

- For the Hex River Valley, most boreholes are situated in the Bokkeveld but only 17% have yields greater than 5 ℓ/s.

- In Worcester area, the Malmesbury Group is an important aquifer but abstraction from the alluvium particularly in the De Wet probably accounts for most of the abstraction.

- The borehole data for the Rawsonville to Moordkuil sub-region does not highlight the importance of the Rawsonville alluvial aquifer which various DWAF reports indicate as an important local aquifer for viticulture in that area. The NGDB data utilised does not cover the abstraction of alluvial groundwater from abstraction trenches ('putte'), which is a popular abstraction method in the area.

- The Villiersdorp sub-region has a high incidence of dry boreholes drilled but also has 43% of recorded boreholes with yields of greater than 5 ℓ/s, 75% of which are drilled in Bokkeveld Group rocks. Further down this sub-catchment, in the Riviersonderend Valley, the percentage of high yielding boreholes is only 5% and in over 50% of successful boreholes the yield is less than 0,5 ℓ/s.

- In the Robertson sub-region yields are high with 40% of boreholes having yields greater than 5 ℓ/s. The Bokkeveld Group comprises the main aquifers in this area but groundwater quality is a constraint for irrigation unless there is mixing with good quality surface water.

- The Montagu area is similar to Robertson with a moderately high percentage (35%) of high yielding boreholes in the Bokkeveld.

- In the Bonnievale and Ashton areas there is very little groundwater use because of the lower yields and quality constraints.

- In Barrydale there is significant use of groundwater, however, to the south in Suurbraak and Buffeljags, there is limited groundwater use because of adequate surface water supplies

- From Swellendam to Witsand, although a number of boreholes have been drilled, many are dry or have yields of less than 0,5 ℓ/s. Poor quality also constrains the use of groundwater in these sub-regions.

High yielding boreholes in the middle and upper Breede Basin do not appear to be limited to specific formations. Moderate (3 - 7 ℓ/s) to high yielding (> 7 ℓ/s) boreholes occur in the Table Mountain Group, the Bokkeveld, the Witteburg and the Malmesbury Groups in all valley settings where these rocks occur. Rosewarne (1981) found that in the Hex Valley, borehole yields in the shale formations and sandstone formations of the Bokkeveld are similar. What is noticeable from the data is the deterioration in the utilisation and potential of the Bokkeveld Group rocks with distance downstream. Possible reasons for this may be that in the lower catchment the Bokkeveld is far less faulted and folded (and therefore possesses significantly lower hydraulic conductivity) than in the middle and upper catchments and the absence of the TMG, which is believed to play a significant role recharging the Bokkeveld aquifers.

TABLE 3.5 : SUMMARY OF BOREHOLE DATA FOR THE DIFFERENT SUB-REGIONS OF THE BREEDE VALLEY CATCHMENT

SUB-REGION	NO. OF BHs	% DRY BHs	% B/H YIELD > 5 ℓ/sec	% BREAKDOWN OF AQUIFERS WITH YIELDS > 5 ℓ/s
1 Ceres Valley	116	23	58	Bok 73; TMG 27
2 Hex River Valley	150	32	17	Bok 77; TMG 23
3 Koo Valley	14	7	50	Bok 57; TMG 43
4 Wolseley–Goudini	51	65	10	Alvm 80; Malm 20
5 Worcester	74	24	26	Alvm 37; TMG 32; Malm 31
6 Rawsonville–Moordkuil	100	22	46	Bok 48; TMG 35; Alvm 6; Dwyka 2.
7 Villiersdorp	133	39	43	Bok 75; TMG 25
8 Riviersonderend	129	29	5	Dwk 50; Bok 33; Malm 17
9 Robertson	215	13	40	Bok 53; TMG 26; Malm 12; Alvm 5
10 Montagu	66	24	35	Bok 61; TMG 30; Dwk 9
11 Bonnievale	9	11	18	Bok 50; TMG 50
12 Swellendam	No Boreholes Recorded			
13 Malgas	80	31	0	None

In the Rawsonville area boreholes are reportedly capable of being pumped at constantly high yields without noticeable dwindling of the yield. This may be due to the very large volumes stored in this aquifer and the active recharge of the alluvium from streams flowing out of the mountains (e.g. the Holsloot and Molenaars) and upward flow from the underlying Table Mountain Group aquifers. In most other areas of the upper Breede catchment, particularly in the fractured aquifers, there is a decline in borehole yields from the beginning to the end of the pumping season and into successive pumping seasons when there has been below average winter rainfall. The borehole success rate for high yielding boreholes used for irrigation supply in some areas of the upper Breede Valley is provided in Table 3.6.

The results from Whittingham's survey shows far higher success rates than the NGDB data in Table 3.5. Whittingham's survey appears to have only covered boreholes drilled for irrigation and not included stock watering, domestic or dry boreholes. As a result these data are skewed towards the higher yielding boreholes.

TABLE 3.6 : SUCCESS RATE (YIELD > 5 ℓ/sec) OF BOREHOLES DRILLED FOR IRRIGATION SUPPLY IN THE UPPER BREEDE CATCHMENT (WHITTINGHAM, 1976)

LOCALITY	SAMPLE NUMBER	SUCCESS RATE	NGDB SUCCESS RATE (> 5 ℓ/sec)
Breerivier to Bothahalt	N=160	75%	10%
Slanghoek	N=25	40%	
Worcester area Brandwag/Waaihoek/Goudini/Brandvlei	N=110	55%	26%
Rawsonville	N=350	85%	46%

3.3.5 Groundwater Quality

Previous studies in the middle Breede between 1989 and 1994 have indicated that the salinity (TDS) of groundwater abstracted from a particular aquifer is strongly dependent on the transmissivity of the aquifer at the point of extraction. This is because high transmissivity aquifers have reduced groundwater residence times and therefore limited dissolution of soluble minerals from within the formation. Average groundwater quality for the various geological formations found in the middle Breede have been presented in previous studies by Whittingham (1976), Bertram (1989), Jolly (1990 – Table 3.7) and Greef (1990). Although groundwater quality is often related to aquifer lithology, in the Breede Basin, proximity to recharge areas appears more important. In general, the Table Mountain Group aquifers have by far the best quality water, followed by the alluvium and the Bokkeveld Group aquifers.

TABLE 3.7 : AVERAGE GROUNDWATER SALINITY (EC) FROM GEOLOGICAL FORMATIONS FOUND BETWEEN BRANDVLEI DAM AND ROBERTSON

GROUP	EC (mS/m)	GROUP	EC (mS/m)
Alluvium	67	Bokkeveld	93
Ecca	142	Table Mountain	15
Dwyka	234	Malmesbury	109
Witteberg	278		

Groundwater quality is generally excellent (EC < 80 mS/m) in the Table Mountain sandstones and in other aquifers in proximity to recharge areas. This includes the upper Breede Valley, the Rawsonville-Goudini area and the Villiersdorp area where the EC is generally < 70 mS/m (Figure 3.4). This groundwater can, however, be corrosive to distribution systems, for example, in the Ceres Valley, where corrosion of pumps and piping is common. An area of brackish water is present (EC > 150 mS/m) in the Worcester, Brandwacht and eastern Jan Du Toits areas where the groundwater is not suitable for irrigating vines or fruit trees. This brackish water is confined to the Uitenhage, Karoo and Malmesbury rocks and, in places the overlying alluvium.

Groundwater higher up in the Breede catchment is Na-Cl-HCO_3 dominated whereas below irrigated areas there is an increase in the Ca and SO_4 content particularly in the alluvial aquifers as a result of leaching of fertilizers from irrigated land. Unfortunately many of the borehole records in the NGDB do not have water quality data, making it difficult to compare the quality in different aquifers for the whole catchment. However, there are sufficient measurements of electrical conductivity (EC) from the TMG and the Bokkeveld aquifers from the whole catchment to compare the water quality between these important aquifers (Figure 3.5).

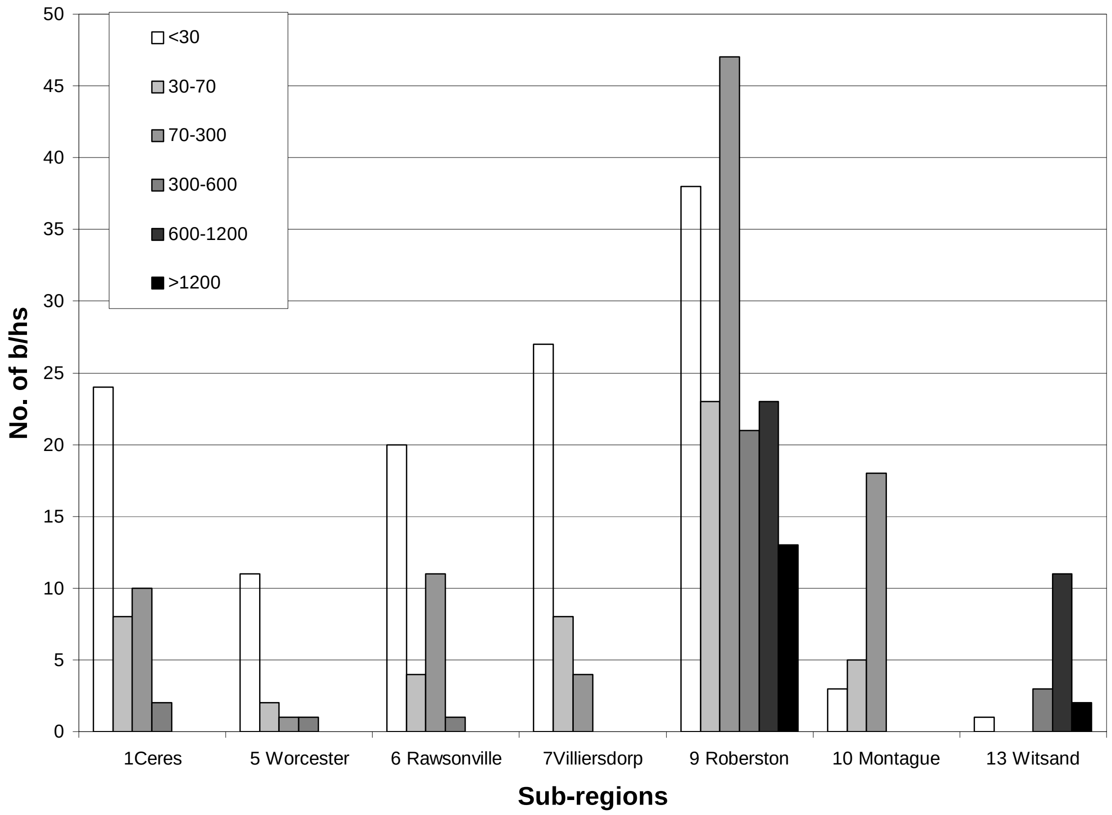


Figure 3.4: Comparison of EC (mS/m) distribution in groundwater from selected sub-regions

Figure 3.5 illustrates better water quality in the TMG aquifers compared to the Bokkeveld. The graph shows that most TMG boreholes have EC less than 30 mS/m, whereas the greatest number of boreholes in the Bokkeveld have EC predominantly in the 70-300-mS/m range. The bimodal distribution of quality in Bokkeveld aquifers is a function of the location of aquifers: in the upper and middle basin areas, only 2% of Bokkeveld boreholes have EC above 300 mS/m. Below Robertson, 30% of Bokkeveld boreholes have EC above 300 mS/m. In the Riviersonderend and Swellendam areas to the coast, the percentage of boreholes with EC > 300 mS/m is 40%.

In the lower Breede groundwater becomes increasingly saline due to the predominance of naturally salt-bearing rocks (Bokkeveld and Karoo rocks), lower rainfall, distance from recharge areas and low hydraulic conductivity of the rocks that dominate the coastal plain. An exception is the Potberg mountain range, which has a MAP of 500 mm and consists of Table Mountain Group rocks. Although the Potberg is thought to constitute a better groundwater resource, groundwater abstracted at Cape Infanta (adjacent to Potberg) is moderately saline (EC 133 – 222 mS/m). This may be due to the marine influence (salt load from sea spray) and because of leakage of saline water from the Bokkeveld and Bredasdorp rocks which overlie the Cape Infant TMG aquifer (Visser, 1999).

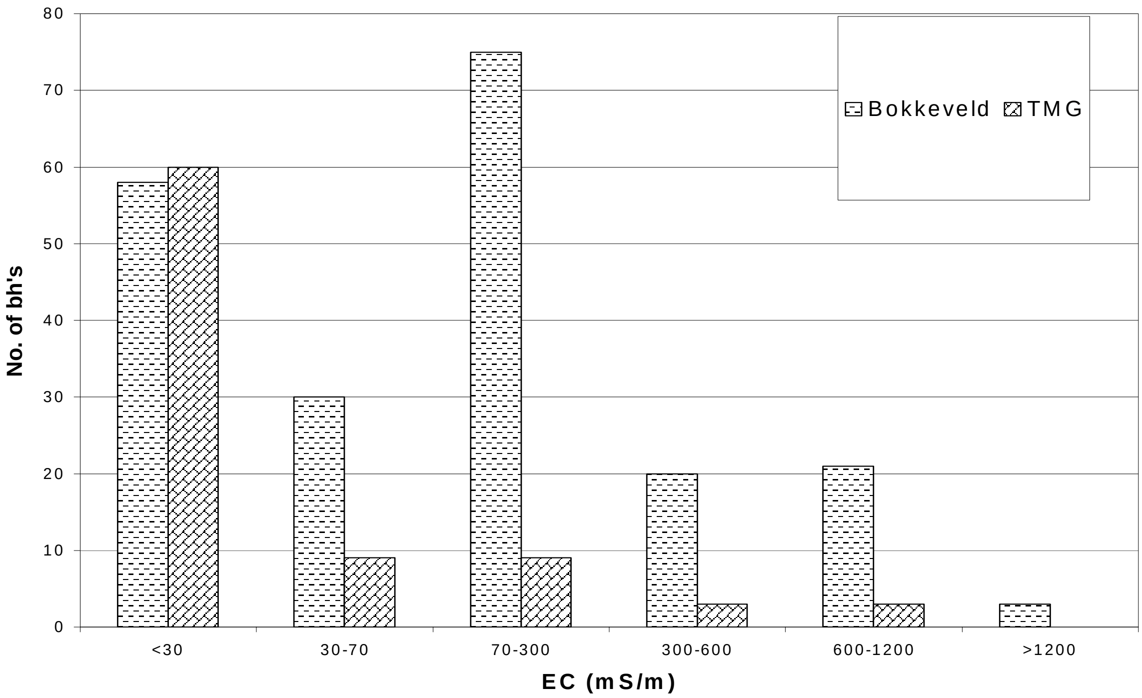


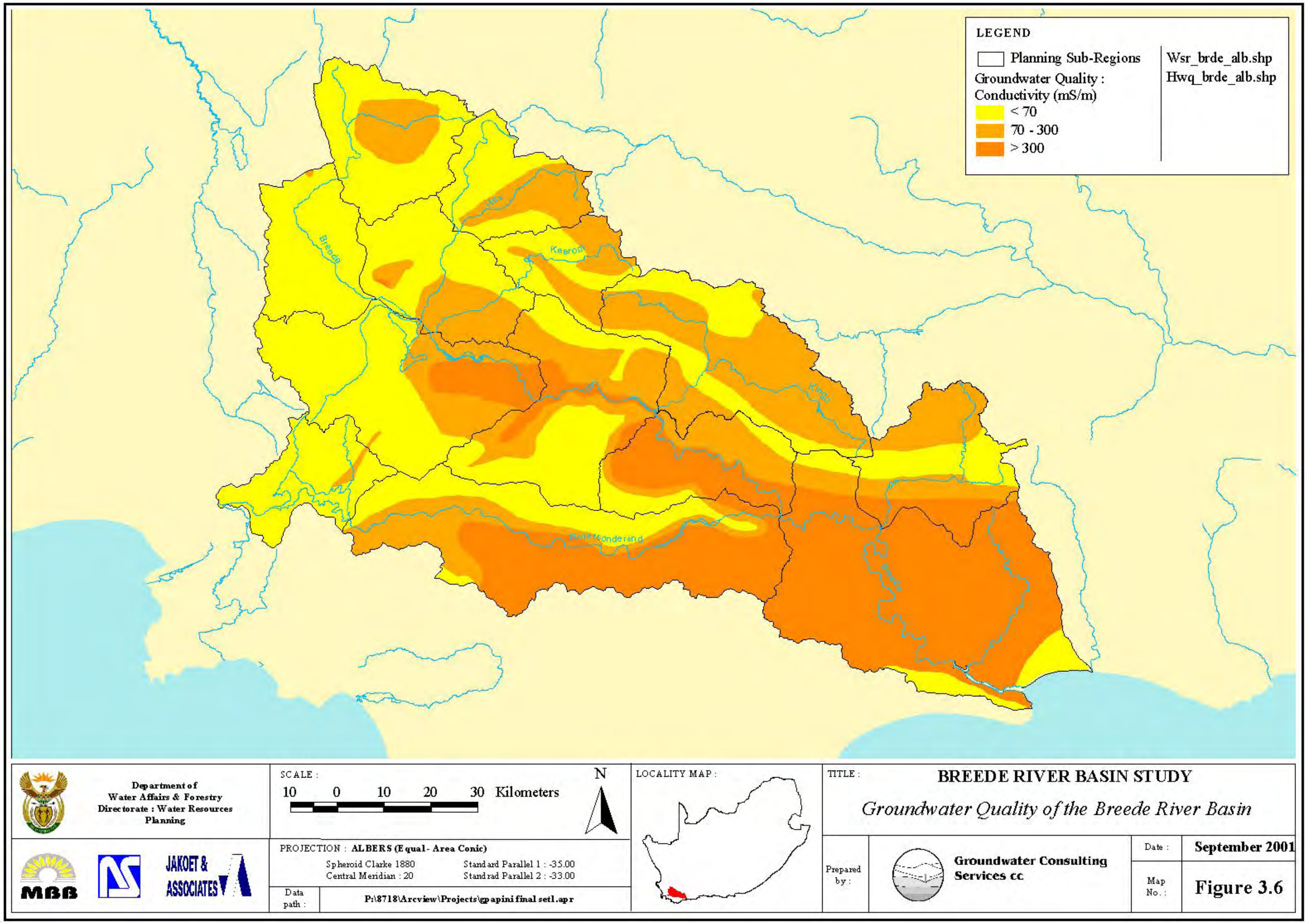
Figure 3.5: Comparison of groundwater quality in Bokkeveld and TMG boreholes

Downstream quality changes in alluvial aquifers

Alluvial groundwater quality changes with distance downstream: the alluvium from Wolsley to Rawsonville being of significantly better quality than in the Robertson area. The salinity (measured as the water's electrical conductivity -EC) is less than 30 mS/m between Wolsley and Brandvlei Dam (Rosewarne, 1981) but around Robertson the EC varies from 600 – 1200 mS/m. The deterioration in the quality of alluvial groundwater is partly from salts (primarily Na and Cl) contained in the Bokkeveld and Karoo rocks which leach out with the groundwater as it flows from the fractured aquifers to the alluvial aquifer. The alluvial aquifers are vulnerable to pollution and the main source of salinity in the alluvium is thought to originate from return flows from irrigated land.

Quality deterioration with time

In the Hex River valley, an intrusion of brackish groundwater (EC up to 300 mS/m) extends roughly parallel to and south of the Hex River (Rosewarne, 1984). This encroachment of poor quality water is attributed to heavy groundwater abstraction in the valley, which allowed lateral migration of brackish water into the pumped aquifer (Vandoolaeghe, 1984). Groundwater intersected in Bokkeveld Group rocks during the construction of the Hex River Railway Tunnel in 1983 had an EC of approximately 250 mS/m (Vandoolaeghe, 1984). This groundwater drained from the west portal of the tunnel at a rate of around 14 ℓ/s and into a tributary of the Hex River. This water is unsuitable for irrigation of vines and at the time there was considerable concern from the farming community about the impact on surface and groundwater quality in the valley.


LEGEND
Planning Sub-Regions
Groundwater Quality :
Conductivity (mS/m)
< 70
70 - 300
> 300
Wsr_brde_alb.shp
Hwq_brde_alb.shp
Department of Water Affairs & Forestry
Directorate : Water Resources Planning
MBB
JAKOET & ASSOCIATES
SCALE :
10 0 10 20 30 Kilometers
N
PROJECTION : ALBERS (Equal - Area Conic)
Spheroid Clarke 1880
Central Meridian : 20
Standard Parallel 1 : -35.00
Standrad Parallel 2 : -33.00
Data path :
P:\8718\Arcview\Projects\gpapini final set1.apr
LOCALITY MAP :
TITLE :
BREEDE RIVER BASIN STUDY
Groundwater Quality of the Breede River Basin
Prepared by :
Groundwater Consulting Services cc
Date :
September 2001
Map No. :
Figure 3.6

3.3.6 Potential Sources of Groundwater Pollution

Figure 3.6 illustrates average groundwater salinity ranges (EC in mS/m) for the fractured rock aquifers of the Breede Basin. These aquifers are, generally speaking, less vulnerable to pollution when compared to alluvial aquifers because of the shallow depth to groundwater and permeability of the aquifer material of the latter.

Developments of groundwater resources have to take into account the potential contamination, which could result from activities in the wellfield capture zone. Activities, which could potentially alter the suitability of groundwater resources in the Breede Basin, include:

- agricultural irrigation and saline return flow,
- application of fertilizers and pesticides in agricultural areas,
- areas of concentrated livestock activity (i.e. chicken farms),
- effluent irrigation from wineries,
- wastewater disposal from sewerage treatment plants,
- wastewater disposal by the fruit processing industries by land application,
- poorly sited waste sites and uncontrolled dumping,
- poor waste management practices at industrial sites,
- informal settlements.

Agricultural activities may be described as regional pollution sources whereas the remaining activities are localised point sources of pollution. The impacts of the latter on groundwater vary considerably and are site specific being dependant on the contaminant type, local geology, depth to water table, groundwater gradient and proximity to water users. Agricultural activities are considered to contribute significantly to the salinisation of shallow groundwater and surface water in the Breede Basin and are discussed in more detail.

Groundwater contribution to river salinity

When groundwater is within a few meters of the ground surface in an arid climate, evapotranspiration can result in concentration of whatever salts were originally present in the water. The same process occurs with irrigation water that infiltrates below the root zone and migrates back toward streams as return flow. Minerals may precipitate from the return flow (essentially shallow groundwater) with sparingly soluble minerals precipitating first (e.g. calcite and gypsum). When there is insufficient irrigation water or poor quality water, there is potential for salinisation of soil and damage to crops. Rainfall or irrigated water is required to flush accumulated salts from the root zone of plants into streams and rivers to prevent reduced crop yields and damage to plants. The need for flushing of salts concentrated in return flow by evapotranspiration as well as leaching from soils and rocks contributes to the salinisation processes in rivers.

Salt accumulation is an obvious result of irrigating in dry regions. The need for a leaching fraction (the ratio of water leaving the root zone against that applied by irrigation) in irrigation management is to prevent the accumulation of salts as well as to limit sodicity (measured by the Sodium Adsorption Ratio) of the soil. With a leaching fraction of 0.1, the salinity of the water draining the irrigated area is 10 times that of the applied irrigation water. For example, irrigation of 1 hectare with 30 m^3 of water per day with an EC of 70 mS/m will result in 3 m^3 draining the root zone and having an EC of 700 mS/m.

The increase in the salinity of soil described above is a result of evapotranspiration only and does not include leaching of salts from soil or rock. In general, irrigation of alluvium does not generate significant salinity when compared to irrigation of soils on clay-rich formations such as those found on the Bokkeveld and Malmesbury Group rocks. Irrigation of these soils has reportedly contributed significant salt loads in the middle Breede (Greef, 1994; Flugel, 1987). In soils formed on these geological formations, the clays (and mobile salts) have leached from surface and accumulated in the lower part of the soil profile. Deep ripping of these soils followed by irrigation flushes salts into streams, which are tributaries of the Breede River. Sharp increases in the salinity levels of the Breede River have been reported downstream of the confluences with the Poesjenels, Vink and Kogmanskloof Rivers (Flugel, 1987).

Groundwater salinity increases with flow path and/or residence time in the aquifer. Therefore aquifers with low permeability and those distant from recharge areas can be expected to have elevated salinity. There is also an evolution from Ca-HCO_3 type to a Na-Cl type groundwater with distance (or time) from recharge zones as a result of natural geochemical processes. Groundwater zonation is unlikely to be evident in the alluvial aquifers, because the groundwater is a mixture of irrigation water and groundwater. In the typical geological setting of quaternary catchments in the Breede catchment, where generally poorly transmissive rocks occupy the valleys (where there is low recharge) and permeable rocks occur in the uplifted mountainous areas, increase in salinity with length of flow path is enhanced.

Irrigation return flow quality

Considerable research has been conducted into the salinisation of the Breede and the role of irrigation return flow versus the contribution of groundwater to the salt load. Irrigation in the Breede River catchment started in the 18^{th} century and was limited to the sandy alluvial sediments. Recently, due to expansion of irrigation agriculture away from the Breede River, soils with a high potential for leaching of salts are under irrigation. Research carried out in the catchment of the Poesjesnels River (Greef, 1994) found that heavy salt loads were contributed by return flow seepage after irrigation of deeply ripped, thin soils, which overlie decomposed shale. Salt leaching rates of about 15 – 18 kg/ha/day have been reported (Kienzle, 1989 in Flugel, 1990). A salt and water balance for a 2 870 ha, irrigated area around Robertson estimated that a salt load of 22.7 t/day (in 11 420 m^3 of water) enters the Breede River (Lautner, 1989). The irrigation return flows have the potential to salinise the alluvial aquifers adjacent to the Breede River.

A study by Murray, Biesenbach & Badenhorst (1988) on a 1 064 Ha area near Robertson estimated an irrigation return flow volume of 5,2 Mm^3 over a 200-day irrigation period with average quality of 1 200 mg/ℓ. The irrigation-return flow volume estimated by MBB appears excessive and gives a very high leaching fraction of 0.8 (leaching fraction = quality of irrigation water divided by quality of return flow). The irrigation demand for vineyards is around 6 500 m^3/ha/annum giving a required irrigation volume would amount to 6,4 Mm^3. For most soils, a leaching fraction of 0.1 is adequate to flush salts from the root zones of crops. Applying this leaching fraction for irrigation water with a TDS of 800 mg/ℓ (126 mS/m) gives an irrigation return flow concentration of 1000 mg/ℓ (800/0.8), which is similar to that estimated by MBB. However, the median EC value of water in the Poesjenels, Vink and Kogmanskloof Rivers varies from 300 – 400 mS/m (~1950 – 2 600 mg/ℓ) suggesting a somewhat higher concentration of salts (i.e. lesser volumes of return flows but higher salinity).

The difference between the estimated irrigation-return flow quality (1 000 mg/ℓ) as a result of evpaotranspiration only and the measured water quality m (~1950 – 2 600 mg/ℓ) in the above-mentioned rivers is believed to indicate the potential salt load derived from the (recently developed) soils in these catchments where vineyards have been fairly recently developed on shale formations (e.g. Bokkeveld shale).

The MBB report estimates that for the irrigated areas between DWAF gauges H4H017 to H5H004 (Le Chasseur, Goree, Robertson, Angora and Zanddrift), an irrigation-return flow volume of 55,3 Mm^3/annum and a salt load of 65,8 x 10^6 kg is produced from a total irrigated area of approximately 11 300 hectares.

Comparative roles of groundwater and irrigation return flow in river salinisation

Flugel (1990), Jolly (1990), Kirchner (1994) and Greef (1994) have investigated the role of groundwater in contributing to river salinisation in the Middle Breede. The general consensus is that groundwater originating from recharge in the surrounding mountains and flowing through fractured formations of the Breede Valley plays a relatively minor role in river salinisation when compared to irrigation return flows to rivers, which take place largely via thin horizons of unconsolidated sand and silt.

Flugel's mass balance calculations estimated the groundwater contribution to the flow in the Breede River between DWAF gauges H4H017 and H5H004 at 135 000 m^3/day whereas groundwater flow calculations by others varied from 50 000 m^3/day (Jolly, 1990) to 4 000 m^3/day (Kirchner, 1994). Although the recharge estimates for the Robertson region (H40G, J, K, L and H - preliminary phase) is approximately 90 000 m^3/day, as much of this groundwater provides baseflow to streams and undergoes losses to evapotranspiration and abstraction. By only subtracting the estimated abstraction of 11 000 m^3/day in the Robertson region, we arrive at a groundwater contribution of approximately 3% of average annual surface flow (2,8 x 10^6 m^3/day).

Kirchner (1994) used strontium isotope ratios to differentiate groundwater from river and irrigation return flows and revised his groundwater contribution to river flow in this area to 6 500 m^3/day from Bokkeveld aquifers or, alternatively 80 000 m^3/day from TMG aquifers. The

6 500 m^3/day flow from Bokkeveld aquifers represents from 5 – 15% of average summer baseflow. From an average groundwater TDS of 600 mg/ℓ (EC ~90 mS/m) for Bokkeveld aquifers (Table 3.7), which is the predominant aquifer in this area, the salt load between DWAF gauges H4H017 and H5H004 would amount to 780 000 kg over a 200-day irrigation period. This is equivalent to approximately 1% (or 2% for TMG) of the total salt load entering the Breede River between H4H017 and H5H004 estimated by MBB.

The groundwater component of the salt load in the Breede River is likely to increase during winter because of the flushing effect that precipitation and recharge has on soils and aquifers. Dilution by surface flow will reduce this effect however. Flushed salts are more likely to originate from alluvium and soils since relatively constant water levels in the fractured aquifers of the Middle Breede Valley (Kirchner, 1994) indicate slow response to recharge. Discharges to streams in this part of the Breede are believed to remain relatively constant throughout the year.

4. GROUNDWATER CONTRIBUTION TO RIVER FLOW

4.1 THEORETICAL CONSIDERATIONS

Understanding the interaction of surface water and groundwater in watersheds is crucial to optimising water resources, controlling pollution, and understanding hydrologic processes like sediment and contaminant transport (Yu *et al*, 1998). The hydrologic system is complex, from the climate system that drives it, to the earth materials the water flows across and through, to the modifications of the system by human activities. Much research and engineering has been devoted to the development of water resources for water supply in South Africa. However, most past work has concentrated on either surface or groundwater without much concern about their interrelations. The need to understand better how development of one water resource affects the other is particularly relevant in a setting like the Breede catchment where agriculture-driven development, with its high demand for irrigation water, is likely to intensify.

4.1.1 The Interaction of Groundwater and Surface Water in Mountainous Terrain

A generalised concept of water flow in mountainous terrain includes several pathways whereby precipitation moves through the hillside to a stream. Between rain events, stream flow is sustained by discharge from the groundwater system. During intense storms, most water reaches streams very rapidly by partially saturating and flowing through highly conductive soils (termed storm interflow). On the lower parts of the hill slopes, the water table sometimes rises to the land surface during storms, resulting in overland flow when the rate of rainfall exceeds the infiltration capacity of the soil.

Near the base of some mountainsides, the water table intersects the steep valley wall above the base of the slope. This results in perennial discharge of groundwater (springs) and, in many cases, the presence of wetlands. A more common hydrologic process that results in some mountain valleys is the upward discharge of groundwater caused by the change in slope of the water table from being steep on the valley side to being relatively flat in the alluvial valley (Figure 4.1).

Small streams receive groundwater inflow primarily from local flow systems, which usually have limited extent and are highly variable seasonally. Therefore, it is not unusual for small streams to have gaining or losing reaches that change seasonally. Streams flowing from mountainous terrain commonly flow across alluvial fans at the edges of the valleys. Most streams in this setting lose water to groundwater as they traverse highly permeable alluvial fans. Where streams like the Molenaars, Holsloot and Amandel flow across alluvial deposits (e.g. south of Rawsonville), they are considered to recharge the alluvial aquifer during winter (i.e. they become 'losing streams' from being 'gaining' streams in the mountainous areas). In arid and semi-arid regions, seepage of water from streams can be the principal source of aquifer recharge and is considered as a significant means of recharge for the alluvial aquifers of the Breede Valley (e.g. Rawsonville aquifer).

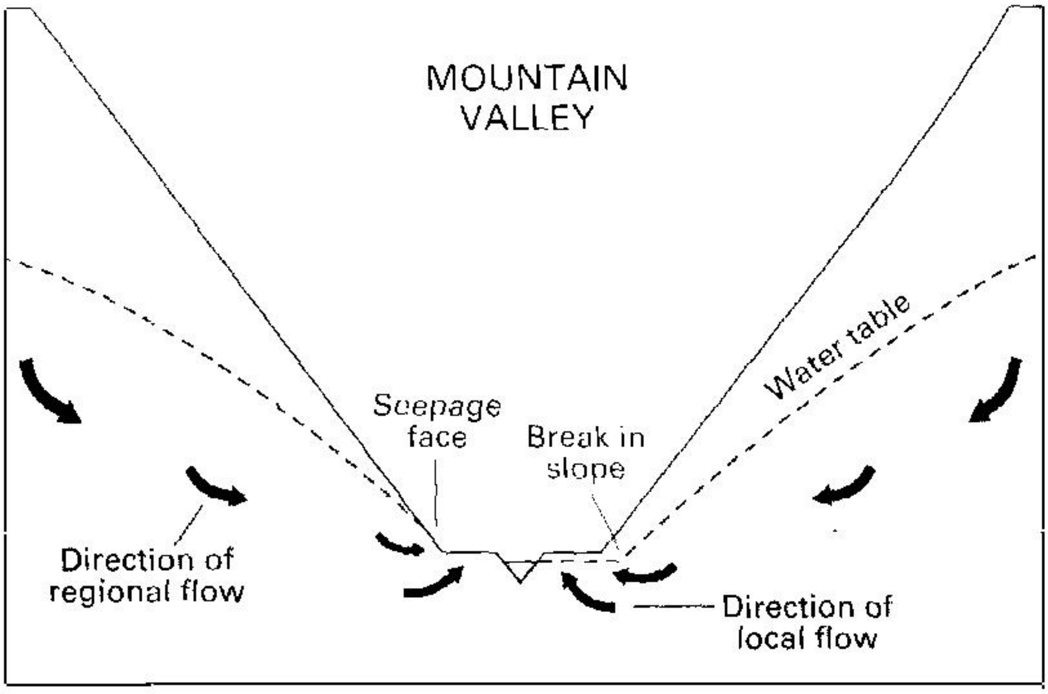


Figure 4.1 : In mountainous terrain, groundwater can discharge at the base of steep slopes as springs or seeps (left side of valley), within floodplains feeding wetlands or lakes (right side of the valley) and directly into rivers (USGS Circular , 1998)

Two routes for groundwater flow from recharge to discharge areas are considered to operate in the Breede catchment. The first is that component best described as interflow, which comprises from 75 – 90% of infiltrating precipitation (Toth, 1963 in Domenico and Schwartz, 1998). This groundwater rapidly becomes surface water in the mountainous catchments that form tributaries to the main stem of the Breede River. However, as the gradients of these mountain streams decreases where they flow into the Breede Valley the streams recharge, at least at the onset of the rain season, the extensive alluvial aquifer that occupies significant parts of the valley floor.

The remaining 10 – 25% of infiltrating precipitation in recharge areas is believed to infiltrate fracture systems to depths of up to several hundred meters and gravitates at a significantly slower rate down gradient towards rivers where it contributes to baseflow. Where there is a lateral change in the flow path to a lower permeability formation (e.g. from quartzite to shale), groundwater may rise to the surface as springs. Where there is a lateral increase in permeability, for example, where alluvium overlies quartzite, deeper groundwater will have an upward component of flow and recharge alluvial aquifers in the valley. This groundwater ultimately flows into adjacent streams and rivers as baseflow. The estimated recharge volumes made in this study comprise both modes of groundwater flow described above.

4.1.2 The Interaction of Groundwater and Surface Water in Riverine Valley Terrain

Fluvial sediments, which include the active floodplain, (the area adjacent to the channel that is flooded frequently) and higher river terraces that flood infrequently if at all, often have higher hydraulic conductivity than the adjacent bedrock (uplands). Both equipotential and groundwater flowlines are refracted at the alluvial/upland interface and groundwater flow is focused down valley (Woessner, 1998).

River channels are features that are cut into the fluvial plain. When the stream level is lower than the adjacent floodplain (alluvial aquifer) water table, the stream receives groundwater discharge and the stream gains flow (a gaining or effluent stream). In contrast, when the stream level is higher than the floodplain watertable, stream flow is lost to the groundwater system and the stream is classified as losing or influent. A third interaction or lack thereof occurs when the stream stage and adjacent water table are at the same elevation; a situation that can be termed a zero exchange channel. No gain or loss would occur along this reach of channel. Finally a flow-through stream channel exists where the floodplain water table is higher than the river stage on one side of the channel and this condition is reversed on the opposite side of the channel (Figure 4.2). This feature can occur in a meandering stream when the stream channel swings more perpendicular to the sloping floodplain, cutting across groundwater flow paths. Overall, conceptually, the stream channel acts to siphon off excess fluvial plain groundwater, leaks surface water back into the floodplain system, or exists in balance with the floodplain groundwater system (Woessner, 1998).

The interaction of groundwater and surface water in river valleys is affected by the interchange of local and regional groundwater flow systems with the rivers and by flooding and evapotranspiration. During times of high river flows, surface water may move into the groundwater system as bank storage. Groundwater flow takes place as lateral flow through the riverbank or, during flooding, as vertical seepage over the flood plain. Rising floodwaters cause bank storage to move into higher alluvial terraces.

The water table is usually not far below the land surface in the alluvial valley and vegetation on floods plains commonly have root systems deep enough to transpire water directly from groundwater. This is particularly the case in groundwater discharge areas, where the vegetation can transpire water near the maximum potential transpiration rate, resulting in the same effect as if the water were being pumped by a borehole. This large loss of groundwater can result in drawdown of the water table such that groundwater no longer flows into the river. In some settings it is not uncommon for the pumping effect of transpiration to be significant enough that surface water moves into the subsurface to replenish the transpired groundwater. Water consumption by alien vegetation along riverine stretches of the Breede and its tributaries may account for a significant reduction in baseflow during the critical low flow summer months. This may mean that although water balance calculations indicate a certain surface flow remaining in a river after development of a wellfield, the effect of alien vegetation may significantly reduce this flow.

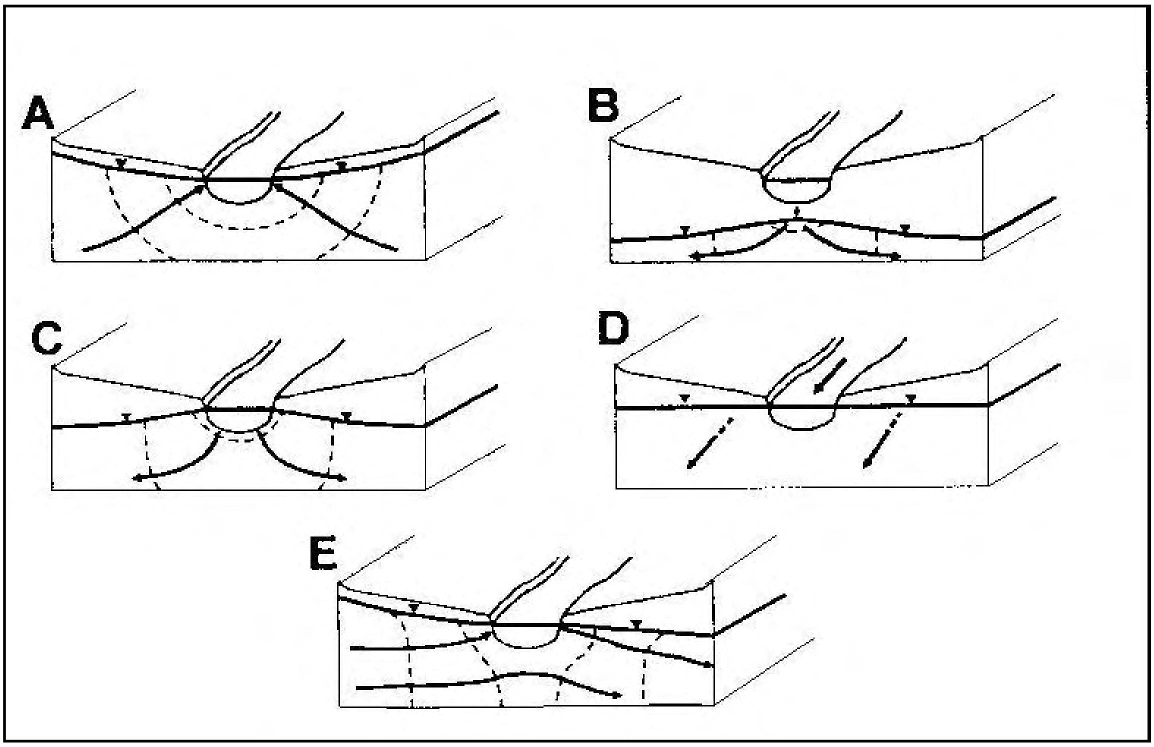


Figure 4.2 : Fluvial plain groundwater and river interactions showing channel cross-sections classified as: A – Gaining; B and C – Losing; D – Zero exchange and E – Flow-through. The water table and stream stages are shown by thicker lines with inverted triangles, groundwater flow direction by arrows and equipotential lines by dashed-lines (after Woessner, 1998)

4.1.3 Groundwater/Surface Water Interactions during Abstraction

Surface features of groundwater flow include springs, seeps, and saline soils, permanent or ephemeral streams, ponds or bogs in hydraulic connection with underground water. Withdrawing water from shallow aquifers near surface water bodies can diminish the available surface water supply by capturing some of the groundwater flow that otherwise would have discharged to surface water or by inducing flow from surface water into the surrounding aquifer system.

The nature of the hydraulic connection between stream and alluvial aquifers is a major factor controlling groundwater – surface water interactions. Traditionally, interaction parameters are estimated from simplified analytical models that assume full penetration of the aquifer by the stream and perfect hydraulic connection. As a rule, such models are far from reality because the penetration of the stream into the aquifer is often insignificant relative to the saturated thickness, and the hydraulic conductivity of streambed sediments is often drastically different from that of the aquifer material (Zlotnik and Huang, 1998). The abstraction of groundwater will decrease the baseflow of streams where there is hydraulic connection between the two and may lead to the reversal of groundwater – stream interaction in situations of excessive abstraction.

There will be a time lag between commencement of pumping in a wellfield and reduction in river flow. The lag will depend on numerous factors including: hydraulic gradient, transmissivity and storativity of the aquifer and streambed permeability. The time lag in river flow reduction in a stream adjacent to a wellfield in an alluvial aquifer is expected to be less than that for a fractured aquifer. This is essentially because in settings like the Rawsonville area, the average transmissivity of alluvium is typically 2 orders of magnitude greater than that of fractured aquifers.

4.1.4 Water Balance Calculations – Basin Yield Example

Some authors have suggested that the safe yield of a basin or aquifer be defined as the annual extraction of water that does not exceed the average annual groundwater recharge. However, this concept is incorrect as major groundwater development may significantly change the recharge-discharge regime as a function of time (Bredehoeft and Young, 1970 in Freeze and Cherry, 1979). Basin yield depends both on the manner in which the effects of withdrawal are transmitted through the aquifers and on the changes in rates of groundwater recharge and discharge induced by the withdrawals (Freeze and Cherry, 1979).

In the form of a transient hydrologic budget for the saturated portion of a groundwater basin, the following equation applies

$$Q(t) = R(t) - D(t) + dS/dt$$

Where $Q(t)$ = total rate of groundwater withdrawal
$R(t)$ = total rate of groundwater recharge to the basin
$D(t)$ = total rate of groundwater discharge from the basin (including baseflow and abstraction)
dS/dt = rate of change of storage in the saturated zone of the basin

An application of this equation can be made for the Rawsonville aquifer, which represents the largest and most studied alluvial aquifer in the Breede catchment. A water balance for the aquifer was conducted by Rosewarne (1980), in which a discharge rate from the aquifer of 20 Mm^3 (or 1 500 ℓ/s) was estimated from gauges in the Breede River upstream and downstream of the aquifer for the months of April to September 1980. The change in storage *(dS/dt)* brought about by a 2m rise in water levels in the aquifer accounted for a volume of 10,2 Mm^3 over the recharge period. This provided an *R(t)* of 30,2 Mm^3 for an aquifer of 170 km^2. This is unlikely to represent all recharge because of evapotranspirative losses underestimating the discharge rate.

Several simple scenarios using the above formula and parameters can be modelled to provide estimates of the change in storage (or water level decline) resulting from increased abstraction from the aquifer. For example, by increasing annual groundwater abstraction *Q(t)* to 20 Mm^3 and with recharge to and discharge from the basin remaining constant, the additional abstraction will result in a change of storage that will correspond to an average decline in water table of approximately 4m. In reality, however, the abstraction will be balanced not only by a decline in water levels but also by an increase in groundwater flow velocity (as a result of increased hydraulic gradients) to the wellfield and by a decrease in discharge from the basin (seen as a decline in baseflow).

Freeze (1971) examined the response of recharge and discharge due to an increase in abstraction in a hypothetical basin where water tables were close to surface. The responses were modelled with the aid of a three dimensional transient analysis of a complete saturated-unsaturated system. Figure 4.3 shows the time dependent changes that might be expected.

The initial condition (t_0) is steady-state flow system in which recharge equals discharge. At times t_1, t_2, t_3 and t_4, new boreholes tap the system and the pumping rate Q undergoes a series of stepped increases. Each increase is balanced by a change in storage, which in an unconfined aquifer takes the form of an immediate water-table decline. At the same time, the basin sets up a new equilibrium under conditions of increased recharge, R. The unsaturated zone will now be induced to deliver greater flow rates to the water table under the influence of higher gradients in the saturated zone. Concurrently, the increased pumping may lead to decreased discharge rates, D. In Figure 4.3, after t_4, all natural discharge ceases and recharge is induced from a stream that had previously been receiving its baseflow component from groundwater. At time t_5, the recharge, R and the induced recharge, D, are feeding Q; and there has been a significant decrease in the water table. Recharge attains a maximum between t_3 and t_4. At this rate, the aquifer is accepting all the infiltration that is available from the unsaturated zone under the lowered water table conditions.

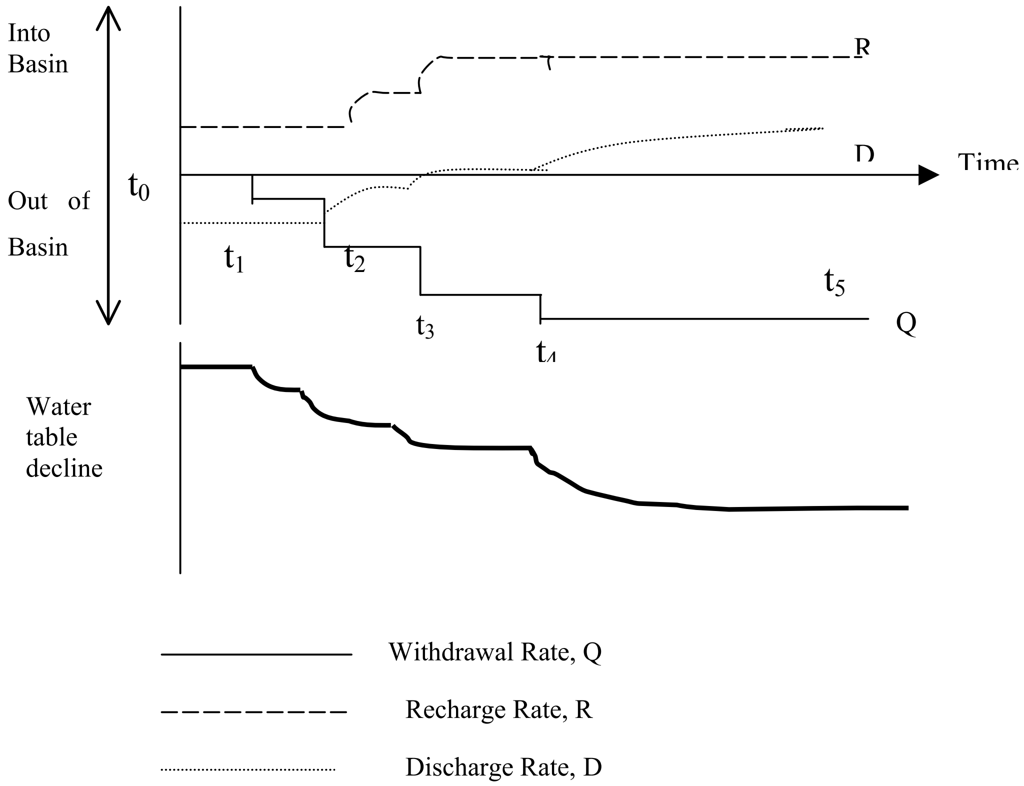


Figure 4.3 : Schematic diagram of transient relationship between recharge, discharge and withdrawal rates (after Freeze, 1971)

In Figure 4.3, steady state equilibrium conditions are reached prior to each new withdrawal rate. In a situation where pumping rates are allowed to increase indefinitely, an unstable situation may arise where the declining water table reaches a depth below which the maximum rate of groundwater recharge R can no longer be sustained. After this point, the same annual precipitation rate no longer provides the same percentage of infiltration to the water table. Evapotranspiration during soil-moisture redistribution takes more of the infiltrated rainfall before it has a chance to percolate down to the groundwater zone. Once the maximum rate of induced recharge is reached, the only means by which the increased rates of withdrawal can be maintained is through an increase rate of change in storage that manifests in rapidly declining water tables. Pumping rates can no longer be maintained at their original levels.

Freeze (1971) defines the value of Q at which instability (defined as the water table depth below which no stable recharge rate can be sustained) occurs as the maximum stable basin yield. This concept does not allow for the recent concept of the 'Reserve' which when considering Figure 4.3, would imply a curtailment to groundwater development in the basin around time t_3. To develop a basin to its limit of stability would be foolhardy as one dry year might cause an irrecoverable water-table drop. Production rates must allow for a factor of safety and must therefore be somewhat less than the maximum stable basin yield. The concept of 'Harvest Potential' is similar to the concept of stable basin yield although both do not incorporate the 'Reserve' concept, which requires consideration of environmental needs.

4.1.5 Evaluation of Evapotranspiration as a Percentage of Recharge

Evapo-transpiration of baseflow, particularly in riparian zones and wetlands, can account for losses in surface water systems when compared to groundwater storage. In other words, the ratio of the volume of groundwater released to streams and surface flow in a groundwater discharge area may not be 1 and to generate 1 m^3 of stream flow may require an amount in excess of 1 m^3 of groundwater. This relationship could be used to argue that groundwater abstraction, particularly during the summer, conserves water resources that would otherwise be subject to evapo-transpiration. Evapo-transpiration rates vary for climatic region and plant type but for exotic plantations in the Western Cape reportedly range from 9 – 12 m^3/ha/day (pers. comm. D. Le Maitre, CSIR).

In a 'worst-case' scenario where we assume that all riparian zones in the catchments around Rawsonville are infested with alien trees, we can estimate a maximum evapotranspiration rate of up to 5 Mm^3 /annum (using the CSIR rate and assuming a maximum evapotranspiration rate for half the year and half the rate for the remaining 6 months). The estimated recharge rate for these catchments is 66 Mm^3/ annum and therefore the evapotranspiration factor may account for up to around 10% of the annual groundwater recharge. In reality, riparian zones are unlikely to be completely infested with alien vegetation and the evapotranspiration rate is likely to be less than 10% of recharge.

Other land-uses (e.g. vineyards and orchards) may utilise shallow groundwater in some areas, however, irrigation normally meets these water requirements and therefore vineyards and orchards are not considered to decrease groundwater flow rates. Large non-indigenous trees that are situated away from riparian zones (e.g. blue-gums) may also evapotranspire groundwater; however, their extent is limited in the Breede Basin. A groundwater to surface water ratio of 1.1 is believed to represent a 'worse-case' scenario for heavily infested catchments.

4.1.6 Environmental Effects of Abstraction

In a quaternary catchment, assumed to be a closed groundwater unit, significant groundwater abstraction must result in a decline in surface water flow. The decline in surface flow will be particularly noticeable where there is close hydraulic connection between the aquifers and streams as is believed to be the situation for the alluvial aquifers and mountainous TMG catchments in the upper Breede Basin. In a situation of a gaining stream (groundwater supplying baseflow), abstraction will result in a decrease in flow reaching the stream. This baseflow is particularly critical for biota in the late summer months when low flow conditions are experienced in most rivers in the catchment. With increased abstraction, streams may change from gaining to a losing situation whereby they recharge aquifers. This will ultimately result in streams running dry in areas where there is hydraulic connection with underlying alluvium.

The environmental effects of abstracting groundwater from deep fractured aquifers are likely to be less noticeable in the vicinity of a wellfield and may only be noted by reductions in catchment yields after several years of monitoring if at all. Where there is insignificant connection between fractured aquifers and streams, groundwater abstraction is unlikely to have any influence on stream flow. The effects of natural climatic variability also need to be taken into consideration before attributing flow reduction to groundwater abstractions.

4.1.7 Increasing Catchment Yield

Increasing catchment yield implies reducing winter surface water 'losses' either by retaining this run-off in dams or alternatively, by abstracting groundwater in winter thereby utilising the storage capacity of aquifers. In early winter, groundwater recharge replenishes aquifers that have been depleted by discharge (baseflow) and abstraction. Near the end of winter, it is assumed that most aquifers, particularly the alluvial aquifers, have been recharged to the extent that streams may switch from a 'losing' to a 'gaining' situation with regard to groundwater flow. The switch from a stream losing flow to groundwater to gaining flow from groundwater demarcates the commencement of the groundwater recession.

The conjunctive use of groundwater and surface water implies that groundwater be abstracted during the recharge period which will prolong the period in which winter stream flow recharges the aquifer. In this way, increasing recharge of and abstraction from aquifers will reduce surface water 'losses' during winter. Clearly, allowing for adequate recharge prior to the end of winter to provide baseflow and water supply for the following summer will be essential.

4.2 THE THEORY OF THE CALCULATIONS OF GROUNDWATER CONTRIBUTION TO STREAMFLOW

Groundwater contributes to stream flow in most physiographic and climatic settings. Even in settings where streams are primarily losing water to groundwater, certain reaches may receive groundwater inflow during some seasons. The proportion of stream flow that is derived from groundwater inflow varies across physiographic and climatic settings. The amount of water that groundwater contributes to streams can be estimated by analysing stream flow hydrographs to determine the groundwater component, termed baseflow.

Stream flow hydrographs depict two very different types of contribution from the watershed. Peaks are delivered to the stream by overland flow and subsurface storm flow, and sometimes by groundwater flow, and are the result of a fast response to short-term changes in the subsurface flow system in hill slopes adjacent to channels. The baseflow, which is delivered to the stream by deeper groundwater flow, is the result of a slow response to long-term changes in the regional groundwater flow systems (Freeze and Cherry, 1979). For hydrographs indicating intermittent flow (i.e. non perennial streams) we can assume that there is minimal connection between surface and groundwater and/or groundwater storage is limited and aquifers rapidly depleted.

The United States Geological Survey has estimated baseflow by analysing streamflow hydrographs from 54 streams in 24 regions (USGS, 1998). The regions were delineated on the basis of similar physiography and climate, believed to have common characteristics with respect to the interactions of surface and groundwater. The analyses indicated that an average of 52% of steamflow was contributed by groundwater (ranged from 14 – 90% and median of 55%). River basins underlain by poorly permeable geological formations have a low percentage (<20%) of average annual flow contributed by groundwater whereas basins underlain by highly permeable sand and gravels were found to have up to 90% of flow contributed by groundwater.

4.3 BASEFLOW SEPARATION TECHNIQUES

The baseflow component of streams represents the withdrawal of groundwater from storage and is termed a groundwater recession. As this recession is determined from stream hydrographs, the hydrograph must be separated into its component parts, which normally consist of overland flow, interflow and baseflow. The interflow component is often ignored so that a two-component system is considered. Whatever the assumptions, methods employed in hydrograph separation are complicated by difficulties (Domenico and Shwartz, 1998) related to the estimation of timing and rate of baseflow rise and identification of the point on a hydrograph at which surface run-off is assumed to cease (Smakhtin, 1999). The baseflow separation methods (Figure 4.4) used by Vegter (1995) in his explanation of a set of National Groundwater Maps included:

- the semi-log plot (exponential recession equation) method, which requires the calculation of a recession constant for a particular baseflow recession from which the baseflow Q at a time t after the start of the recession (Q_0 and t_0) can be determined

- Herold's model (spread-sheet based using a groundwater decay and growth factor from the previous months flow)

- A linear interpolation method, which allocates the lowest proportion of river flow to groundwater as it joins lowest monthly flows on the hydrograph.

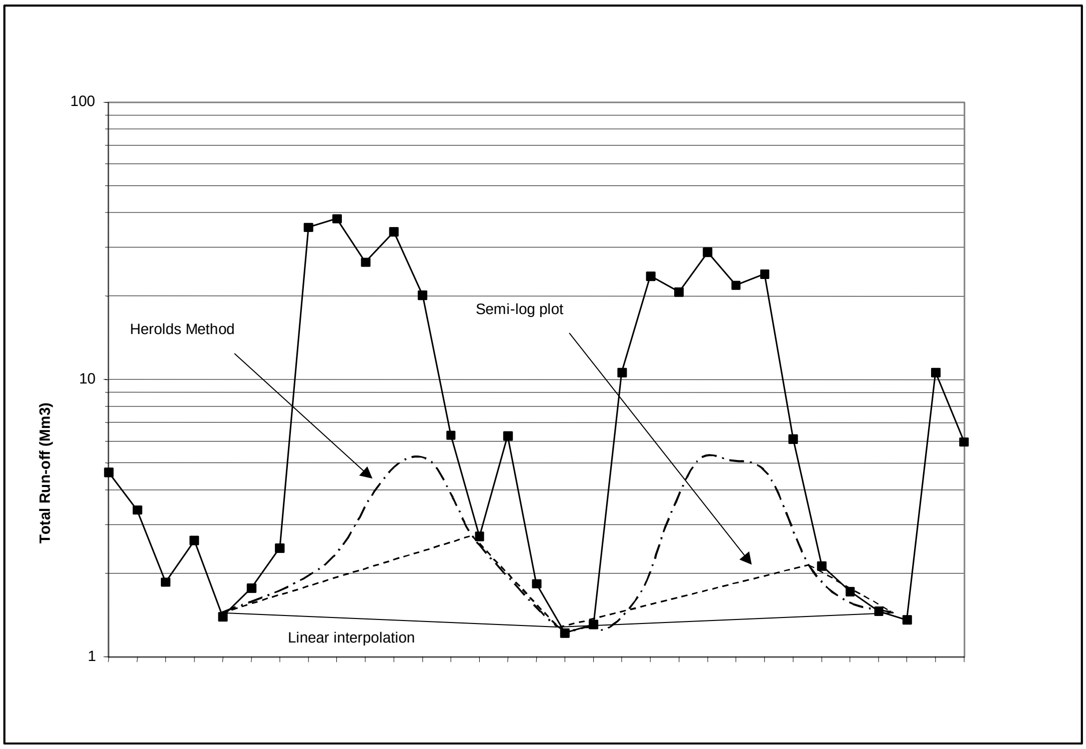


Figure 4.4 : Baseflow separation methods

The semi-log method is one of the more accepted methods of hydrograph separation (Domenico and Shwartz, 1998). Herold's model was used in Vegter's baseflow determinations and calibrated against the semi-log method using data from DWAF gauge X3H001 on the Sabie River. For the Sabie River, the semi-log and Herold's methods gave baseflow as 43% and 47% of MAR whereas the linear interpolation method gave a value of 37% of MAR. A brief description of each method and examples of hydrograph for each technique are provided in Appendix A. According to Vegter (1995), the groundwater component of mean-annual run-off (MAR) in the Breede catchment under current abstraction conditions is:

- 20 – 30% in the upper Breede catchment
- 0 –10% in the Hex River Valley
- Negligible in the middle Breede Valley
- 10 – 20% of MAR in the lower Breede catchment.

In the following section, comparison is made between the techniques of baseflow separation for a number of selected catchments. This is done with the purpose of indicating catchments in which groundwater plays an important role in contributing to surface flow and/or where there is a significant connection between surface and groundwater.

4.4 COMPARISON BETWEEN THE DIFFERENT TECHNIQUES

The results of hydrograph separation based on the methods described above are presented in Table 4.1. The columns in the table indicate the mean annual run-off (MAR) for selected catchments and the volumes and percentages of MAR believed to be supplied by groundwater. Both the measured monthly stream flows (DWAF gauges) and the naturalised mean annual run-off (sequences derived for the "Surface Water Resources of South Africa - 1990" (WR90) Study) have been used. The latter are based on Pitman's run-off model and represent run-off from undeveloped catchments whereas the DWAF data are measured.

TABLE 4.1: COMPARISON OF BASEFLOW IN SELECTED CATCHMENTS (1980-1990)

CATCHMENT	DATA SOURCE*	MAR	BASEFLOW					
			SEMI-LOG PLOT		Linear Interpolation		Herold's Model	
		Mm^3/a	Mm^3/a	% MAR	Mm^3/a	% MAR	Mm^3/a	% MAR
Wit H10E	H1H007	115	24	21	6	5	32	28
	WR90	101	16	16	6	6	28	28
Molenaars H10J	H1H018[1]	182	38	21	21	11	50	28
	WR90	206	32	16	11	5	58	28
Holsloot H10K	WR90	125	22	17	7	6	35	28
Sandriftkloof H20D	H2H004	38	11	28	6	15	10	28
	WR90	39	9	23	1.2	3	11	28
Amandel H20E	WR90	55	7	13	2	4	15	28
Hex H20A – G	H2H001	100	25	25	10	10	28	27
	WR90	140	24	17	6	4	39	28
Poesjenels H40G	H4H018	5.9	1.4	24	0.6	10	2	41
	WR90	23	5	24	0.5	10	6	28
Riviersonderend H60D – L	H6H009	365	90	25	19	5	100	28
	WR90	524	100	19	38	7	148	28

* H1H are DWAF gauges whereas WR90 are naturalised, simulated, long-term data.
1: H1H018 is not comparable with WR90 data, as the DWAF gauge does not monitor flow from the entire quaternary catchment.

The difference in MAR between the DWAF measured flows and WR90 data may give an indication of hydrological changes brought about by water abstraction and/or storage and irrigation return flows. However, direct comparisons are usually not possible because of incomplete records for gauged data (particularly during high flow) and non-coincidence of quaternary catchments with DWAF monitoring stations. The following comments can be made relating to the baseflow separation techniques:

- Herold's method gives an indication of the baseflow component of stream hydrographs. This incorporates the interflow as well as the groundwater contribution to stream flow. Herold's method provides a baseflow volume of approximately 30% for most sub-catchments in the upper Breede Basin for both gauged DWAF and WR90 data.

- The semi-log plot method gives an estimate of the interflow component and groundwater contribution to baseflow but incorporates a greater component of the groundwater recession as baseflow (Figure 4.4). The baseflow as a percentage of MAR resulting from baseflow is 5% – 10% less than that using Herold's method.

- The linear interpolation method provides a low estimate baseflow (3% – 15% of MAR) and is thought to constitute the groundwater contribution to stream flow when compared to other hydrograph separation methods. The linear interpolation therefore provides a more realistic indication of the groundwater component to surface flow.

- There is no marked difference in the groundwater contribution to stream flow between predominantly Bokkeveld catchments (Poesjenels and Riviersonderend) and TMG catchments (Wit and Molenaars), at least in the upper Breede catchment. These catchments have TMG in their recharge areas and alluvium overlying Malmesbury or Bokkeveld rocks in the valleys and there is probably a high degree of hydraulic connection between surface and groundwater. This situation is unlikely to prevail in the middle and lower catchments where the degree of hydraulic connection between surface and groundwater is thought to be less than in the upper catchment.

- The greater percentage of baseflow attributed to the gauged flow when compared to the WR90 data may indicate that a greater component of MAR occurs during low-flow periods and may be attributed to both natural groundwater flow and that arising from irrigation return flow. In the Hex River valley where groundwater comprises about 50% of total irrigation water use, the greater baseflow % for gauged data compared to WR90 data may indicate inputs from irrigation return flows.

5. GROUNDWATER EXPLOITATION POTENTIAL

5.1 GROUNDWATER RECHARGE

Sustainable groundwater abstraction depends on adequate recharge to replace the water being abstracted. Recharge to the bedrock aquifers may differ from recharge to the alluvial aquifers. Recharge to alluvial aquifers may take place by a combination of the following mechanisms:

- Direct rainfall infiltration on the surface.
- Infiltration of irrigation water.
- Influent seepage from rivers entering the alluvial plain from the bordering mountains.
- Upward leakage into alluvial aquifers from the underlying bedrock and lateral flow of groundwater from the mountain fronts.

Conditions for rainfall infiltration to the alluvium are favourable over large areas of the middle and upper Breede catchment, which have high groundwater-levels, and permeable surface horizons. Recharge to the valley bottom bedrock aquifers being exploited (mainly Bokkeveld Group rocks) is effected by:

- Infiltration of rainfall into the bedrock in the higher lying mountainous areas (mainly the Table Mountain Group sandstone). This water gravitates down gradient and feeds the valley bottom aquifers. Conditions for the infiltration of rainfall on the high mountains surrounding the Breede Valley are favourable as the TMG has a fractured, 'blocky' surface, with limited soil cover resulting in quick seepage through the unsaturated zone.

- Downward leakage of groundwater from overlying saturated alluvium. Downward leakage of groundwater in the alluvium to the bedrock is likely to be of most importance in those areas where large-scale abstraction takes places from the bedrock aquifer (e.g. Hex Valley, Jan DuToit and Wabooms areas).

- Lateral movement of groundwater already in storage into areas dewatered by pumping.

Historically most South African aquifers have estimated recharge of less than 10% of annual precipitation. Very rarely are double figures mentioned, with the Cenozoic sands being regarded as exceptional at 15 – 25%. Comparison of Cl and $\delta^{18}O$ for rainfall and groundwater from boreholes in mountains indicates recharge of 50% (Weaver *et al*, 1998). However, not all this recharge will reach aquifers in the valleys as it will daylight to springs and streams (baseflow), before reaching the valley floor. Finite element modeling of the Rawsonville - Goudini alluvial aquifers (Gilding and Orpen, 1978) established that under steady state conditions the natural rate of recharge to the aquifer is approximately 31,5 M m^3/year (using S of 0,08). Around 38% was estimated as infiltration from rainfall and the remaining 62% recharge from surface streams.

For the current investigation, estimates of annual groundwater recharge volumes were made using recharge based on a number of different rainfall scenarios. GIS software was used to overlay rainfall data on the catchment area, producing recharge maps based on 5% of rainfall and 10% of rainfall, using variable recharge contribution in different rainfall areas (see Table 5.1) and on a combination of variable rainfall and geology. In the case of variable recharge for different MAPs, the recharge percentage varied from 2 - 3% of MAP in areas with an MAP of 125 - 250 mm and up to 24-33% in areas with a MAP of 2250 - 3250 mm/annum. In the case of variable geology, the recharge values in Table 5.1 were multiplied by a weighted factor according to the underlying geology. The factors compared the expected recharge (under similar rainfall conditions) of different geological formations to recharge in TMG rocks. For example, in areas covered by alluvium, the recharge was multiplied by a factor of 1,5 indicating enhanced recharge potential whereas for the Bokkeveld, the recharge was multiplied by 0,7 indicating reduced recharge potential.

In the estimation of aquifer recharge, there are other issues which effect recharge other than rainfall and geology. These factors have not been incorporated into the results presented in Table 5.1. These factors included the type and thickness of the soil, vegetation effects, slope angle and aspect, rainfall intensity and wind effects. Although there may be disagreement over the factors used, alteration of the factors will not have a dramatic effect on the final results produced.

TABLE 5.1 : FACTORS USED IN CALCULATING RECHARGE BASED ON VARIABLE RAINFALL AND VARIABLE GEOLOGY

RAINFALL (mm/annum)	RECHARGE %
< 300	3
300-600	6
600-900	9
900-1200	12
1200-1500	15
1500-1800	18
1800-2100	21
2100-2400	24
2400-2700	27
2700 –3000	30
3000-3300	33
3300-3600	36
3600-4000	40
>4000	42

GEOLOGY	VARIABLE RECHARGE FACTOR
Table Mountain Group	1.0
Bokkeveld Group	0.7
Witteberg Group	0.6
Alluvium	1.5
Malmesburg and Klipheuwel Groups	0.6
Ecca Group	0.6
Uitenhage and Dwyka Group	0.5
Granites	0.7
Any other	0.6

The GIS system ARC-INFO was utilised to calculate the recharge for the total catchment and the quaternary catchments. The estimated recharge volumes (Table 5.2) suggest that for the catchment as a whole that recharge is slightly less than 10% of MAP, with the total recharge calculated from the variable rainfall/variable geology map showing a total annual recharge volume of ~ 650 Mm^3/annum.

TABLE 5.2 : TOTAL CATCHMENT RECHARGE ESTIMATES

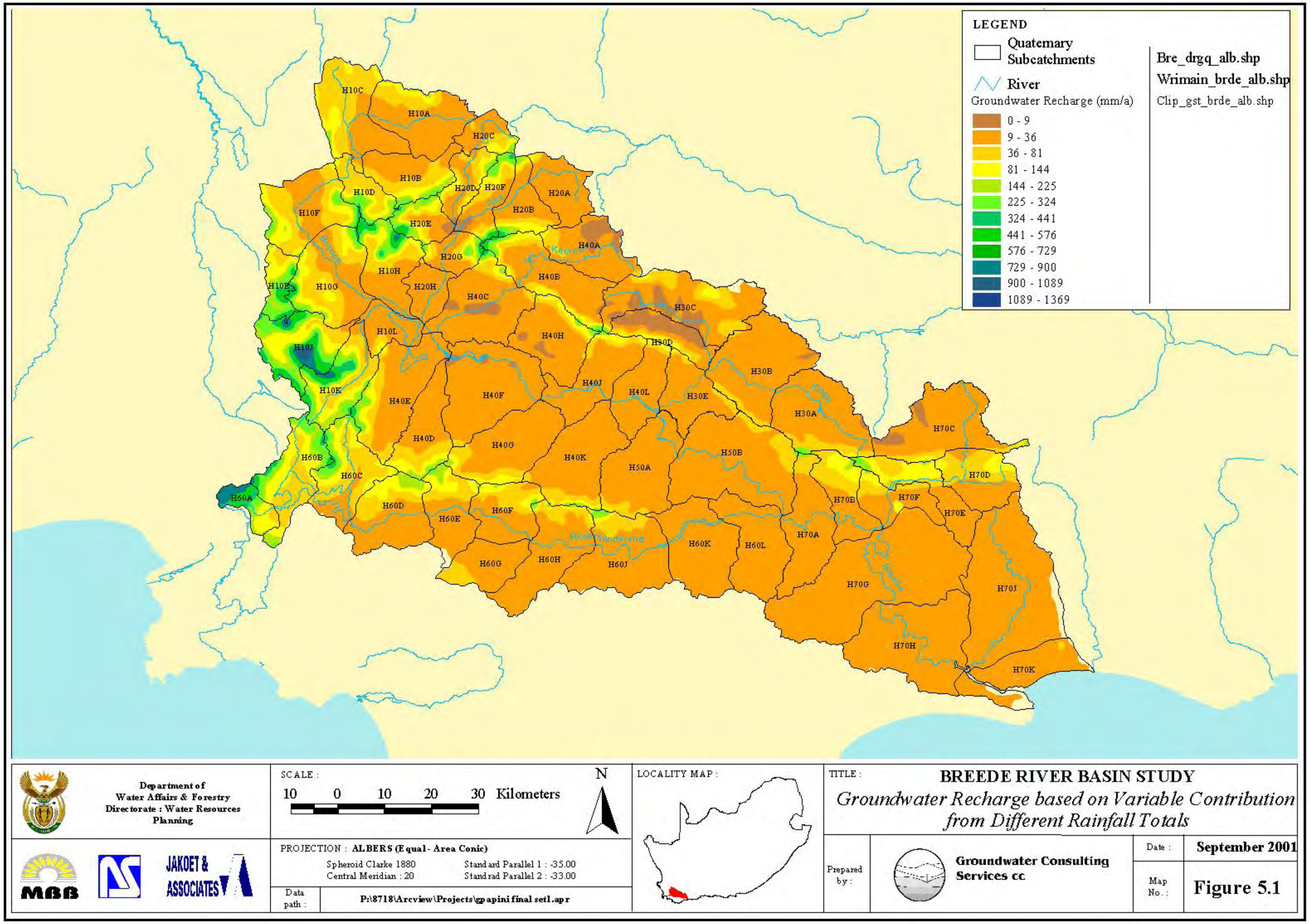
RECHARGE ASSUMPTIONS	RECHARGE VOLUME
5% of rainfall	359 Mm^3/annum
10% of rainfall	719 Mm^3/annum
3-40% based on variable rainfall	705 Mm^3/annum
3-40% based on variable rainfall and geological influences	648 Mm^3/annum

The two recharge maps for the variable rainfall and variable rainfall/geology are presented below as Figures 5.1 and 5.2 respectively. The figures are very similar except for the increased contribution made to recharge in the alluvium and sands around Wolseley, Goudini, Rawsonville and east of Witsand in Figure 5.2. The recharge figures for 5% and 10% of MAP are not shown as they are similar to Figures 5.1 and 5.2.

The maps indicate the high recharge areas being the mountainous regions in the west (Du Toits, Stettyns and Hottentots-Holland ranges) and north (Hex and Kwadouw ranges) of the Breede River catchment. In these areas, the recharge varies from 162 mm - 1072 mm per annum and comprises approximately 40% of the total volume of groundwater recharge in the basin, even though these areas comprise only 6% of the total catchment area. Areas of moderate recharge (40 to 136 mm per annum) indicated in yellow in Figures 5.1 and 5.2, correspond to the base of the mountainous areas in the west and north of the Breede catchment (including the alluvial valleys around Rawsonville and north of Goudini) as well as the Riviersonderend and Langeberg ranges.

In Figure 5.2 the coastal alluvial deposits and a narrow strip in the Potberg range are also attributed to have moderate recharge potential. Areas of moderate recharge account for approximately 35% of annual recharge and comprise 23% of the catchment area. The high and moderate recharge areas combined make up 29% of the surface area of the catchment but receive 75% of the total basin recharge. Areas of low recharge (0 – 35 mm/annum) are depicted in orange and brown on the maps and represent the valley areas. Although comprising around 71% of the catchment area, only 25% of the total recharge is estimated to occur in these areas.

The estimated groundwater use in the whole catchment is approximately 100 Mm^3/annum. This is about 16% of the total recharge to the catchment (640 Mm^3/annum). It must however be remembered that the remaining 84% is not necessarily all available for abstraction.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Quaternary Subcatchments
River
Groundwater Recharge (mm/a)
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36 - 81
81 - 144
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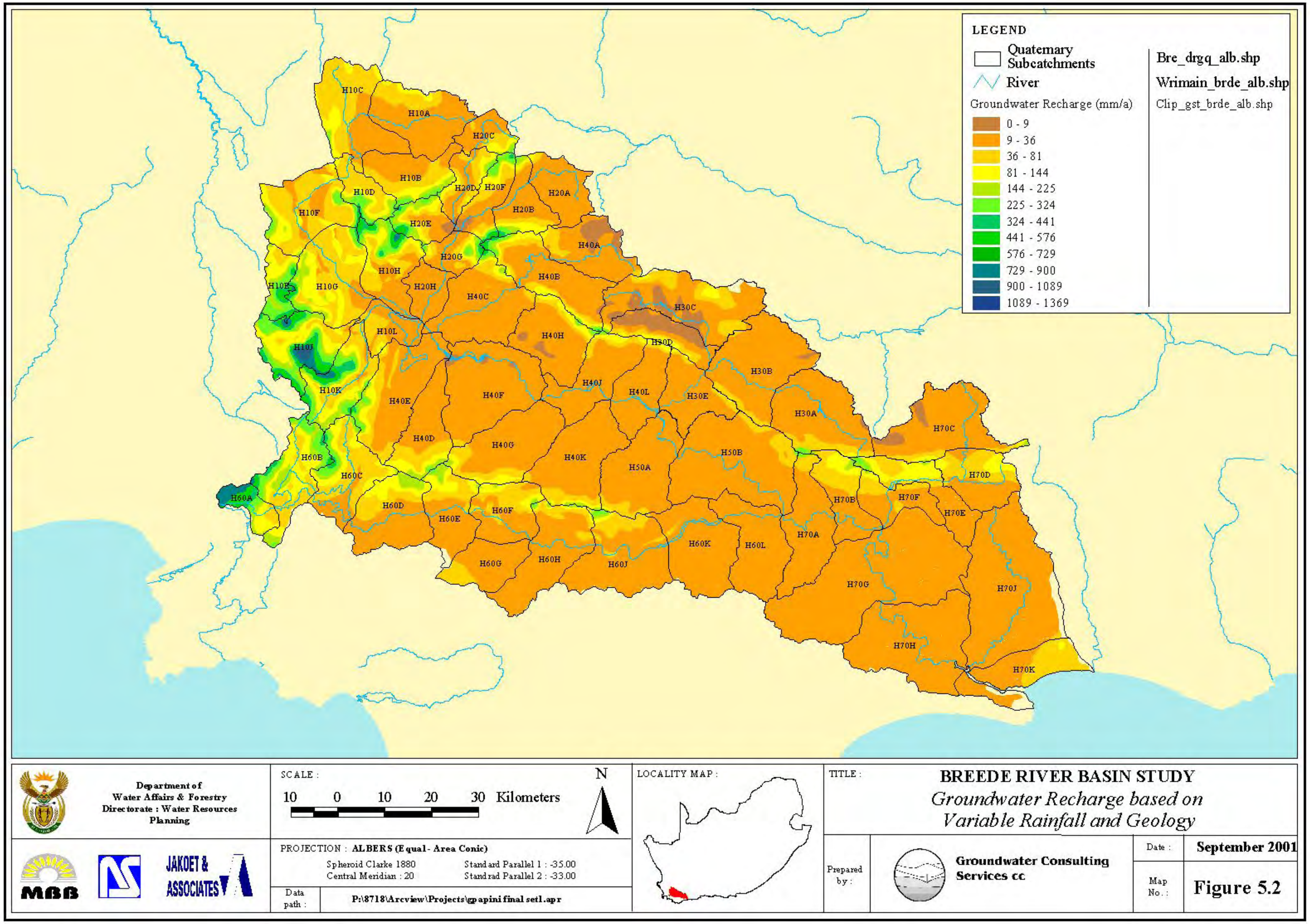
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Groundwater Recharge based on Variable Rainfall and Geology
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PROJECTION : ALBERS (Equal - Area Conic)
Spheroid Clarke 1880
Central Meridian : 20
Standard Parallel 1 : -35.00
Standard Parallel 2 : -33.00
Data path :
P:\8718\Arcview\Projects\gpapini final set1.apr
Prepared by :
Groundwater Consulting Services cc
Date :
September 2001
Map No. :
Figure 5.2

Average annual recharge per quaternary catchment (per km^2/a) in the Breede catchment is presented in Tables 5.3 and 5.4.

TABLE 5.3: RECHARGE VARIABILITY IN THE UPPER BREEDE CATCHMENT

UPPER BREEDE		AREA km^2	RECHARGE Mm^3/a	RECHARGE 10^3 m^3 PER km^2/a
H10A	North Ceres Valley	235	6,6	28
H10B	South Ceres Valley	163	11,1	68
H10C	Prince Albert/Ceres	261	13,9	53
	TOTAL	**659**	**31,6**	
Wolseley Goudini				
H10D	Tierhokkloof	97	12,6	130
H10E	Wit	85	20,7	244
H10F	Wolseley	250	20,1	80
H10G	Rawsonville (N of Breede)	77	7,2	93
H10H	Jan du Toit	189	23,4	124
	TOTAL	**698**	**84,0**	
Rawsonville				
H10G	Goudini	195	18,2	93
H10J	Molenaars	215	67,1	312
H10K	Stettynskloof (Holsloot)	195	37,5	192
H10L	Brandvlei	96	3,3	34
	TOTAL	**701**	**126,2**	
Hex				
H20A	Upper Hex	141	2,6	18
H20B	De Doorns	125	7,7	62
H20C	Lakenvallei	81	4,3	53
H20D	Sandrifkloof	101	6,8	67
H20E	Amandel	96	12,8	133
H20F	Sandhills	117	10,7	91
	TOTAL	**661**	**44,9**	
Worcester				
H20G	Glen Heatlie	86	7,0	81
H20H	Worcester	90	2,4	27
H40C	Nuy Nonna	273	8,8	32
H40D	Doring	183	8,8	48
H40E	Hoek Modder	287	13,8	48
H40F		341	4,7	14
	TOTAL	**1 260**	**45,5**	
Villiersdorp				
H60A		73	27,7	379
H60B		211	33,8	160
H60C		218	20,2	93
	TOTAL	**502**	**81,7**	
TOTAL UPPER BREEDE			**414**	

TABLE 5.4: RECHARGE VARIABILITY IN THE MIDDLE AND LOWER BREEDE CATCHMENT

MIDDLE BREEDE		AREA km^2	RECHARGE Mm^3/a	RECHARGE 10^3 m^3 PER km^2/a
H30A		285	8,2	29
H30B	Montagu	316	7,0	22
H30C		329	10,5	32
H30D		128	3,9	30
H30E	Ashton	154	3,9	25
	TOTAL	**1212**	**33,5**	
Keerom				
H40A		185	4,5	24
H40B		242	13,9	57
	TOTAL	**427**	**18,4**	
Robertson				
H40G	Poesjenels	265	8,8	33
H40H	Vink	209	6,1	29
H40J	Robertson	205	6,1	30
H40K	Keisersriver	272	8,1	30
H40L		160	3,7	23
	TOTAL	**1 111**	**32,8**	
Bonnievale				
H50A		266	5,6	21
H50B		432	8,7	20
	TOTAL	**698**	**14,3**	
Riviersonderend				
H60D		228	12,2	54
H60E		171	9,1	53
H60F		166	7,7	46
H60G		142	3,8	27
H60H		254	7,2	28
H60J		294	9,3	32
H60K		263	4,7	18
H60L		231	3,6	16
	TOTAL	**1749**	**57,6**	
LOWER BREEDE				
Swellendam Suurbrak				
H70C		288	7,1	25
H70D		171	8,6	50
H70E		157	10,5	67
H70F		121	3,8	31
	TOTAL	**737**	**30,0**	
Malgas				
H70A		225	4,8	21
H70B		154	7,4	48
H70G		654	10,0	15
H70H		400	7,0	18
H70J		552	8,3	15
H70K		146	5,7	39
	TOTAL	**2131**	**43,2**	
MIDDLE AND LOWER BASIN RECHARGE			**230**	

5.2 GROUNDWATER RESERVE

In terms of Chapter 3, part 3 of the Water Act (36 of 1998), the Reserve is defined as the quantity and quality of water required to satisfy basic human needs by securing a basic water supply, and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of the relevant water resource. Satisfaction of basic human needs usually accounts for such small volumes that it is immaterial to the overall Reserve determination. The in-stream flow requirement to meet ecological requirements has significant implications for groundwater abstraction since groundwater abstraction is likely to diminish the baseflow to rivers in most of the catchments of the Breede catchment, where there is groundwater – surface water interaction. In terms of the Water Act, the Minister of Water Affairs and Forestry must make a preliminary determination of the Reserve before authorising the use of water. Until such time as a reserve determination is made for the Breede Basin, the exploitable water potential of the catchment cannot be finalised.

5.3 GROUNDWATER HARVEST POTENTIAL

Harvest Potential can be defined as the maximum annual volume of groundwater that is available for abstraction on a long-term (i.e. sustainable) basis without exhausting the resource. It is determined from groundwater recharge and aquifer storage conditions, without consideration of socio-economic factors (cost, legal and environmental) or water quality. The Harvest Potential does not necessarily imply that all this groundwater is available for abstraction. Constraints to the exploitation potential of an aquifer include the availability of groundwater (as controlled by transmissivity), the cost of groundwater development and the desirability of using groundwater (Smart, 1998). It is important to note that Harvest Potential cannot simply be added to surface water availability to obtain a number for total water resources.

The units of Harvest Potential are cubic metres per square kilometre per annum. Rainfall to recharge relationships and typical aquifer storativity ranges from the literature (Bredenkamp *et al*, 1995) were used in the development of the South African Harvest Potential Map (Seymour and Seward, 1996) as published by DWAF. This map indicates that in the Breede catchment area, the Harvest Potential varies from 10 000 – 15 000 $m^3/km^2/a$ for the lower Breede (i.e. south of Swellendam to the coast but excluding the Potberg), from 15 000 to 25 000 $m^3/km^2/a$ in most of the valley areas of the central and upper Breede River catchment to greater than 50 000 $m^3/km^2/a$ for most of the mountainous areas. The Harvest Potential (taken from the map by Seymour and Seward, DWAF, 1996) and the recharge estimates determined in Table 5.3 are similar, although the recharge estimates are slightly higher than the harvest potentials.

The TMG provides the highest Harvest Potentials within the catchment. The harvest potential of the TMG of the Hexriviersberge, the Langeberg and the Slanghoekberge/Dutoitsberge/ Stettynsberge ranges are estimated to exceed 100 000 $m^3/km^2/a$ (0,1 $Mm^3/km^2/a$). In spite of these high values, Rosewarne (1981) concluded that the 'safe yield' of the Hex River Valley has been exceeded and that brackish water intrusion occurs. The very high recharge rates in the mountainous areas do not imply that all of this water is available to groundwater users adjacent to the mountains – the majority of this water daylights into the mountain streams long before the groundwater reaches the valley floor.

5.4 AVAILABLE GROUNDWATER SUPPLIES

In all of the sub-regions, the recharge is far greater than the usage, suggesting that available groundwater resources exist. However, total recharge in a sub-region is not always available for exploitation, especially when the highest recharge is taking place in inaccessible mountainous areas. Further, recharge figures need to be adjusted, taking into account the environmental Reserve, before the Harvest Potential of an area can be calculated. Notwithstanding the above comments, the total recharge in the upper Breede catchment areas (~410 Mm^3/annum) is still far greater than the estimated usage (~80 Mm^3/annum) in the same areas. It is these upper basin areas, which have the best quality water, the highest recharge and, even given the high current usage, the greatest potential for future development.

5.5 FUTURE GROUNDWATER EXPLOITATION

Groundwater exploitation in the Breede Basin can be undertaken on different levels – either for local supply, or as part of larger scale regional supply systems.

5.5.1 Regional Scale Aquifers

Large-scale groundwater abstraction for regional supply projects will have to take place in areas where recharge is high, thus allowing sustainable utilisation at high abstraction rates. This limits large-scale abstraction projects to the mountainous western and northern parts of the basin. The TMG aquifers have long been seen as potential aquifers suitable for regional water supply projects in the Western and Southern Cape (Weaver *et al*, 1998). The exploitation of these aquifers will however have to take place taking into account difficulties of access into the mountainous areas and potential impacts of abstraction on the environment. Table 5.5 lists potential areas where large-scale groundwater abstraction schemes could be implemented and Table 5.6 lists potential local schemes.

All of these aquifers are in areas of higher recharge and therefore are the areas with the highest potential for sustainable development. Any abstraction schemes would however have to be carefully managed to make certain that over-abstraction does not take place.

TABLE 5.5: REGIONAL SCALE AQUIFERS FOR FUTURE EXPLOITATION

SUB-CATCHMENT	POTENTIAL REGIONAL SUPPLY AQUIFERS
Hex River Valley	Large-scale groundwater abstraction from the TMG aquifer to supply water to Hex River and Worcester and De Doorns. An estimated 10 Mm^3 could be exploited in the catchment below the Roode Elsburg Dam and a further 25 Mm^3 from the Amandel River catchment (SRK, 1997). SRK (1997) also identified 16 Mm^3 of storage available in alluvial fans for artificial recharge of which possibly 7 Mm^3 could be recovered directly from alluvial boreholes or indirectly by leakage into the underlying bedrock aquifer.
Rawsonville and Slanghoek	TMG of Du Toitskloof- and Slanghoekberg mountains and the alluvial aquifers of the Rawsonville area could be utilised to supplement the Brandvlei Dam scheme. The TMG aquifer below the Rawsonville alluvium is also an under-utilised aquifer.
Villiersdorp	TMG of Du Toitskloof Mountains can be utilised to supplement the Theewaterskloof Dam.

TABLE 5.6: LOCAL SCALE AQUIFER FOR FUTURE EXPLOITATION

SUB-CATCHMENT	POTENTIAL AQUIFERS
Ceres Basin	Bokkeveld and Table Mountain Group (TMG) aquifer to the south and west can be utilised by the towns of Ceres and Prince Alfred Hamlet and the surrounding farmers.
Hex River Valley	River alluvial and TMG along the Hex River and Langeberg mountains can be utilised by agriculture and De Doorns although careful management is required.
Koo Valley	TMG of the Langeberg mountains is a potential aquifer to the Koo agricultural community, with a small scale rural water supply scheme being a possibility.
Wolsley – Goudini	River alluvial and TMG of the Slanghoekberg- and Witzenberg mountains can be utilised by farmers and the settlements of Wolseley, Goudini, Bree River and Bothashalt.
Riviersonderend	TMG of the Riviersonderendberge and River alluvial to supply water to Greyton, Riviersonderend, Stormsvlei and farmers.
Robertson	TMG of Langeberg to the north and Riviersonderendberge to the south, could be utilised for McGregor, Robertson and farming community.
Montagu	TMG of Langeberg Mountains as a supply to Ashton, Montagu and farmers.
Bonnievale	TMG of Riviersonderend mountains to supply Bonnievale town and farmers.
Swellendam	TMG of Langeberg Mountains to supply towns of Barrydale, Slangrivier, Suurbrak, Buffelsjags and farmers.
Malgas	TMG of Langeberg and Potberg Mountains to supply water to Nature Reserves, Malgas, Infanta and Witsand. Coastal aquifers also potential supplies.

6. GROUNDWATER USE IN THE BASIN

6.1 WATER RIGHTS AND REGISTRATION OF WATER USE

Sections 9 and 10 of the Water Act of 1956 did not require that farmers have a permit where water consumption did not exceed a flow of 110 ℓ/s. In the case of water storage, a dam wall with a height of 5 m or capacity of 250 000 m^3/annum did not require permitting. Interviews with DWAF personnel suggest that most water use, outside of government water schemes and that provided by irrigation boards, is done without DWAF permits. This means that, without a detailed census of water users and volumes abstracted from streams and boreholes (or registration in terms of the Water Act of 1998), estimates of volumes of water used by the agricultural sector are likely to be of low confidence. Until the DWAF has concluded their registration of water users, any estimates of groundwater use based on existing licenses will have low confidence attached. Groundwater use in the catchment also varies from year to year with consumption likely to be greater in years of below average precipitation.

6.2 GROUNDWATER USE IN THE BREEDE CATCHMENT

Significant groundwater abstraction takes place in the upper Breede catchment and approximately 95% is for irrigation. In quaternary catchments H10A - K (Ceres to Brandvlei Dam) approximately 44 Mm^3/annum is abstracted from aquifers compared to a recharge volume of 245 Mm^3 whereas in the quaternary catchments H20A – H (Hex Valley to Worcester including Nuy and Noona – H40C), abstraction is approximately 20 Mm^3 and recharge estimated at only 63 Mm^3. In the Middle and Lower Breede areas annual groundwater abstraction is not as significant when compared to the upper catchments although is approximately 20 Mm^3/a.

Approximately 30% of farmers' irrigation requirements are estimated to come from groundwater in the upper Breede. In the Hex River and Rawsonville areas, the percentages are around 50 and 32% respectively. The report 'Beskrywing van Water-Infrastruktuur en Bedryfsreels' (DWAF, 1995) estimates groundwater use in the upper Breede Catchment as comprising from 60 – 70% of the total irrigation needs.

The data available from the NGDB do not provide a representative record of groundwater use in individual catchments as only a small number of the boreholes (10 – 20%) that exist have been captured on this database. At best, the NGDB provides a patchy indication of groundwater yields although most of these are airlift yields, which can over-estimate the actual yield by up to 200%. The registration programme currently underway for groundwater users in the Breede should improve the lamentable status of the NGDB. The data used by Haupt (1995) for the Groundwater Harvest Potential Map of South Africa have been used to provide estimates of groundwater use in the middle and lower Breede catchment. These data, it is felt, do not adequately reflect groundwater use in the upper catchment as there are significantly fewer boreholes recorded than are known to exist, for example, in the Rawsonville area and Hex River Valley.

6.2.1 The Upper Breede River Catchment

The upper Breede catchment is indicated in Figure 1 and Table 1. The following section provides a summary of groundwater properties (numbers of boreholes, average depths, yields, water levels etc.) and use in the upper Breede catchment. Table 6.1 gives estimates of groundwater consumption from various sources. An updated estimate is provided at the end of this section.

TABLE 6.1: ESTIMATES OF GROUNDWATER USE IN UPPER BREEDE CATCHMENT (VARIOUS SOURCES)

SOURCE	IRRIGATION DEMAND	ESTIMATED GROUNDWATER USE		
	MBB	SPILHAUS.	NGDB*	DWAF, (1995)
CATCHMENT	Mm^3/a	Mm^3/a	Mm^3/a	Mm^3/a
Ceres (H10A-C)	66	10.9	3.95	~15**
Wolseley H10F	29	3.4	0.05	17
Jan du Toit H10H	6	3.6	0.34	3.6
Rawsonville	69	22	0.39	41
H100 (total)	**170**	**40**	**4.7**	**76.6**
Villiersdorp	-	-	-	4.7
Hex Valley H20A – F	36	-	1.28	23
Worcester H20G, H and H40C, D, E, F	51	-	>0.2	32

* Based on a third of the sum of yields in each catchment multiplied by pumping for 12 hours a day, 7 months a year.

** Result of DWAF registration initiatives (October 2000).

Ceres (quaternaries H10A – C)

The Ceres Basin has a reported 7 020 hectares under irrigation and incorporates orchards (83%), pastures (8%), vineyards (8%) and cash crops (1%). This equates to a projected water demand of approximately 66 Mm^3 / annum of which irrigation boards supply about 24 Mm^3/a. Private schemes therefore account for up to 42 Mm^3/a. of which groundwater is believed to supply around 40%.

A total of 165 boreholes are recorded in the NGBD and this is similar to the number of boreholes (150) estimated by pump and irrigation specialists, Spilhaus for this region. Most of the boreholes (84%) are situated in the H10C quaternary catchment. The remaining boreholes are distributed evenly between H10A (11) and H10B (13). Sixty eight percent of boreholes have reported yields in excess of 5 ℓ/s and 44% of boreholes have reported yields in excess of 10 ℓ/s. The Western and Bella Vista Wellfields that augment the Ceres Municipality's water supply have average yields of 11 ℓ/s and 25 ℓ/s respectively. Approximately 50% of boreholes are in the depth range of 60 – 120 m. In quaternary sub-catchments H10A and H10C, between 90 and

100% of water level measurements were less than 10 m from surface. In sub-catchments H10B, only 67% of water levels were less than 10m and the remaining 33% of measurements were from 10 – 30 m below surface.

Recent registration of water use by DWAF suggests that abstraction may be as much as 18 Mm^3/a. This does not necessarily represent actual groundwater consumption as the estimates are based on registered water use. Landowners may be registering their current abstractions at elevated volumes to ensure retention of rights. The Ceres catchment is believed to have potential for further groundwater development although this will have to be confirmed against the Reserve requirements.

Wolseley (quaternary H10F)

A total of 3406 ha is irrigated in this quaternary catchment requiring approximately 29 Mm^3/annum; approximately ⅔ are orchards and ⅓ vines. Irrigation boards supply approximately 60% (18 Mm^3 / annum) of the water needs which means an amount of 11 Mm^3/annum must be provided by own schemes (both surface and groundwater). A significant percentage (~70% or 8 Mm^3/a) of the water requirements not supplied by irrigation boards is believed to be supplied by groundwater.

Estimates in the DWAF report "Beskrywing van Water Infrastruktuur en Bedryfsreels", (1995) suggests that 60% of irrigation demand originates from boreholes, which amounts to 17 Mm^3 whereas the estimates of Irrigation and Pump specialists Spilhaus suggest an amount of only 3,4 Mm^3/annum. There are only 20 borehole records in the National Groundwater Database for this quaternary catchment and of those, only 5 have yield records (all less than 2,5 ℓ/s). Most of the boreholes are in the 60 – 120 m depth range and 70% of water levels are in excess of 40 m depth. There may be considerable abstraction of groundwater from the Breede riverside alluvium not accounted for by the Spilhaus estimate.

Jan du Toits (quaternary H10H)

The agricultural area in this catchment incorporates the area around Goudini Station and the Jan du Toits River Valley. The total irrigation area is 856 hectares, of which irrigation boards (Waaihoek, Jan du Toits and Olifantsberg) supply 574 hectares. The irrigation water requirements are approximately 6 Mm^3/annum, of which approximately half are provided by Irrigation Boards. Groundwater is believed to account for the other 3 Mm^3/a.

Spilhaus's estimate 3,6 Mm^3/annum (from approximately 40 boreholes) is of a similar order to the 4,8 Mm^3 (or 60%) of total water use supplied from groundwater suggested by H. Aab (DWAF, 1995). The NGDB contains 22 borehole records with 50% of borehole depths in a 60 – 120 m depth range and 60% of water level records greater than 30 m.

Rawsonville (quaternaries H10G, J, K and L)

The Rawsonville agricultural area is situated within four quaternary catchments, and therefore the data on agricultural areas and water use have been combined for all these areas. Quaternary catchment H10G incorporates the areas from train stations 'Breede River - Goudini', which is north of the Breede River and the Slanghoek River Valley, which is separated by mountains from Rawsonville. The former areas are also geologically different from the Rawsonville area as Malmesbury Group rocks underlie them instead of TMG/Bokkeveld/Karoo and the alluvium cover is not as thick here as at Rawsonville. The total irrigation area is over 10 000 hectares (about 90% vines) and the total water needs are 69 Mm^3/annum. Irrigation boards reportedly supply around only 14 Mm^3/annum with own schemes making up the remaining 55 Mm^3. Abstraction from the Rawsonville alluvial aquifer is believed to supply approximately 46% (32 Mm^3/a**)** of this demand.

In this area around 70% of irrigation needs (or 41 Mm^3) is reported (H Aab, 1995) to originate from groundwater. This would appear high as the Spilhaus estimate is only 22 Mm^3/annum (from 260 boreholes), although this estimate did not include shallow excavations in alluvium. Near Rawsonville many farmers pump from shallow trenches because of the shallow water table in this area. The NGDB contains 78 borehole records for the quaternary catchments comprising the Rawsonville area. There is little data for borehole yields although most yields are greater than 5 ℓ/s. There are also a significant number of shallow (30% < 30 m) boreholes in the area suggesting that adequate yields for irrigation are encountered in the alluvium. Although the natural water table is high around Rawsonville (2 – 3m below surface), pumped boreholes will have a cone of depression around them resulting from groundwater abstraction. The limited data indicate water levels greater than 20 m in more than ⅔ of records. This suggests significant use of groundwater.

Hex Valley (quaternaries H20A – F)

The Hex River Valley contains some 5200 hectares of irrigated land of which about 86% is used for grapes. Although the area supplied by Irrigation Boards is approximately 4 200 hectares, the boards do not supply all the needs for this area and only supply about 16 Mm^3/annum out of a requirement of 36 Mm^3/annum. Groundwater is believed to supply the remaining 20 Mm^3/a.

Although there are an estimated 450 boreholes in the Hex River Valley (Rosewarne, 1990) there are only 122 records in the NGDB. These data suggest that average borehole yield is below 5 ℓ/s. In catchment H20F approximately 40% of boreholes are less than 30 m deep (possibly because they are situated in alluvium close to the Hex River) whereas higher in the catchment (H20A and B) the average borehole depth ranges from 60 – 120 m (mainly in the Bokkeveld). Most water level measurements exceed a depth of 40 m.

Worcester, Nuy and Moordkuil (quaternaries H20G, H & H40C,D,E,F)

These catchments are considered under the Upper Breede Catchment even though H20G and H and H40C form part of the Middle Breede Catchment (Figure 1). There are limited data for groundwater catchments H40D, E and registration to date indicates abstraction at around 6 Mm^3/a. Abstraction in H20G, H and H40C is approximately 3 Mm^3/a. Groundwater abstraction is estimated at approximately 9 Mm^3/a.

Villiersdorp (quaternaries H60A – C)

In the Villiersdorp there are 121 boreholes which, if assumed to be used for irrigation at an average yield of 4 ℓ/s, would abstract approximately 4.7 Mm^3/annum. Annual groundwater abstraction is estimated at 5 Mm^3/a. The NGDB indicates that around 80% of boreholes have yields (air-lift) greater than 5 ℓ/s, are drilled to depths greater than 80m and have water levels of less than 10m below surface.

6.2.2 The Middle Breede

For the purposes of this report, the middle Breede catchment excludes the Hex River Valley, and Worcester/Nuy, Moordkuil quaternary catchments (i.e H10H, H20G, H and H40C, D, E, F). The database used by Haupt (1995) to determine exploitation potentials provides numbers of boreholes per quaternary catchment and their average yields. Assuming that these boreholes are utilised for irrigation and abstract groundwater for 12 hours a day over 7 months of the year and that the actual yields are only 50% of the reported yields, estimates of groundwater abstraction in the middle Breede can be made (Table 6.2).

TABLE 6.2: ESTIMATED GROUNDWATER USE IN THE MIDDLE BREEDE CATCHMENT (AFTER HAUPT, 1995).

QUATERNARY CATCHMENTS	NAME	NUMBER OF BOREHOLES	CORRECTED YIELD (ℓ/s)	ESTIMATED ANNUAL ABSTRACTION (Mm^3)
H30A – D	Montague	67	2	1,3
H40A – B	Keerom	13	3	0,4
H40C – L*	Robertson	191	3	4,5
H60D – L	Riviersonderend	87	0.5	0,4
H50A – B	Bonnievale	13	1.5	0,2
TOTAL				**6,8**

* Excludes H40C, E which are grouped with Worcester/Nuy area.

The results of aerial photographic mapping show that in the Montagu catchment (H300), approximately 5600 hectares are under irrigation. According to recent registration of water users, groundwater makes up around 50% of irrigation demand (similar to the Hex Valley). Based on an irrigation rate of 5000 m^3/ha/a, the annual estimated abstraction is approximately 14 Mm^3/a (see Table 6.4). The number of boreholes, particularly in areas like Keerom, appear too few and the estimate in Table 6.2 too low.

Groundwater quality is likely to limit use for vine and orchard irrigation in many of the quaternary catchments indicated in Table 6.2 (e.g. Bonnievale and Robertson) unless it is mixed with surface water. The estimated abstractions in Table 6.2 may also be too low and it is estimated that as much as 18 Mm^3 per annum may be abstracted in the middle Breede catchment.

6.2.3 The Lower Breede

Small volumes of groundwater are abstracted in the lower Breede catchment with the exception of quaternary catchment H70C. The town of Barrydale is situated in this catchment and there are approximately 100 boreholes with an average yield of 8 ℓ/s (or 4 ℓ/s used in Table 6.3 below). There are no borehole records in the NGBD for quaternary catchments H70D, E and F.

TABLE 6.3: ESTIMATED GROUNDWATER USE IN THE LOWER BREEDE CATCHMENT (AFTER HAUPT, 1995)

QUATERNARY CATCHMENTS	NAME	NUMBER OF BOREHOLES	CORRECTED YIELD (ℓ/s)	ESTIMATED ANNUAL ABSTRACTION (Mm^3)
H70C	Barrydale	99	4	3,8
H70A,B,G – K	Swellendam and Malgas	55	0,1	0,05
TOTAL				**3,85**

Haupt (1995) was a major contributor to the DWAF map 'Groundwater Harvest Potential of South Africa' (Seymour A and Seward P, 1996). The Harvest Potential is the maximum amount of groundwater that can be abstracted per square kilometer per annum without depleting aquifers. The Harvest Potential is comparable with recharge and does not include socio-economic issues (like the cost of abstraction) and environmental needs for which the term exploitation potential was developed. Exploitation potential volumes have been included in Table 6.4 for comparison with current use and recharge estimates.

TABLE 6.4 ANNUAL GROUNDWATER CONSUMPTION RATES COMPARED WITH RECHARGE VOLUMES AND EXPLOITATION POTENTIAL IN THE BREEDE BASIN

SUB-REGION	QUATERNARY CATCHMENTS	GROUNDWATER CONSUMPTION	RECHARGE PER ANNUM	EXPLOITATION POTENTIAL*
		Mm^3/a	Mm^3/a	Mm^3/a
Ceres	H10A – C	15	32	22,7
Wolsley-Goudini	H10D,E,F,G,H	17	102	44,7
Rawsonville	H10,J,K,L	15	108	50,4
Hex Valley	H20A- F	20	45	26,8
Worcester/Nuy/Moordkuil	H20G, H, H40C, E	9	32	21,7
Villiersdorp	H60A – C	5	82	29,4
Upper Breede	**As above**	**81**	**401**	**196**
Middle Breede[2]	**H30A-E, H40, H50, H60D-L**	**18**	**166**	**130**
Lower Breede	**H70**	**4**[1]	**73**	**31**
TOTAL		**103**	**640**	**357**

1: Haupt (1995. 2: excluding H20 G, H; and H40C, D, E, F.

Recharge and exploitation potential are not directly comparable as recharge includes groundwater that may not be available for abstraction for a number of reasons. For example, transmissivity of the aquifer is too low for economic exploitation, groundwater quality is not suitable for irrigation or the groundwater has a relatively short residence time in the aquifer and is not available when required (i.e. in summer). The recharge estimates from the preliminary phase are approximately double the Haupt's exploitation potential although in the middle Breede the exploitation potential is almost 80% of the recharge estimate suggesting that the recharge estimate is too low or the exploitation potential too high in this area.

Table 6.4 indicates that in the Hex River valley, the consumption rate is close to Haupt's exploitation potential whereas in the remaining sub-regions of the upper Breede catchments, consumption is approximately 50% of exploitation potential (except for Villiersdorp where it is only 17%).

In the middle Breede the estimated consumption rate is approximately 15% of the exploitation potential. In the lower Breede (H70), groundwater use for irrigation is limited by quality and most of the estimated abstraction of approximately 4 Mm^3/a is from the Barrydale area.

The annual groundwater volume abstracted in the Breede Basin is estimated at approximately 103 Mm^3. Estimated groundwater use in South Africa was 3 360 Mm^3 in 1999 (Vegter, 2000) for which irrigation accounted for approximately 16% or 540 Mm^3. This means that the Breede Basin accounts for around only 3% of total groundwater consumption but almost 20% of groundwater used in irrigation.

7. GROUNDWATER ABSTRACTION EXAMPLES

This section investigates four examples of areas where further groundwater abstraction potential is believed to exist. The section is aimed at providing a feeling for costs and volumes associated with groundwater abstraction schemes. Numerous other areas where abstraction schemes could be implemented exist and even in the examples provided, other options related to the method of abstraction exist.

The potential wellfields are all within single quaternary catchments except for the Rawsonville aquifer, which is situated across four quaternary catchments. Two examples consider abstraction from alluvial aquifers and two from hard rock aquifers that are closer to recharge areas. The examples suggest an abstraction configuration (number of boreholes, spacing, pumping rates and duration) and the potential lowering of water table as well as the capital costs of wellfield development. The areas are:

- The Alluvial Aquifer south-east of Rawsonville,
- The Stettynskloof (Holsloot River catchment) – TMG Aquifer,
- The Amandel River catchment – combined Alluvial / TMG Aquifer,
- Breede River Alluvium (south of Worcester).

Current groundwater use in the Breede catchment is primarily for the augmentation of irrigation water when farm dams supplied by run-off from streams and from irrigation schemes run dry toward the end of summer. This abstraction can result in a significant fall in water level, which usually recovers after recharge during the following winter (e.g. in the Hex River Valley). There is scope to increase this summer pumping/winter recharge aquifer management (Weaver *et al*, 1998) in areas where the Reserve is not already exploited and demand exists. Increased summer abstraction can result in greater storage volumes in the dewatered aquifer that will, theoretically, allow for higher rates of recharge during winter thus reducing catchment losses during stream flow peaks. However, as was discussed in Section 3.5, if the maximum stable basin yield is exceeded, a stable recharge rate cannot be sustained. All schemes need to take account of drought conditions of several years duration.

The close relationship between surface and groundwater, particularly in the upper Breede catchment, suggests that the quaternary sub-catchment be taken as the fundamental management unit when assessing groundwater potential. Groundwater flow between quaternary catchments does take place via deep fractures and faults (as indicated by the thermal springs in the catchment). The effect of high rates of abstraction from deep boreholes that intersect these major regional geological structures, on adjacent quaternary catchments is difficult to evaluate. However, it is likely that abstraction from boreholes sited on these regional features could affect water levels and stream flow in a number of adjacent quaternary catchments. Where saturated alluvium occurs above a fractured aquifer, abstraction from the latter can result in dewatering of the alluvium and leakage to the deeper aquifer.

Opportunities for further groundwater abstraction only exist in sub-catchments where there is surplus water over and above the requirements of the Reserve and current use, since increased groundwater abstraction rates ultimately reduce run-off volumes. Desktop estimates for ecological Reserve volumes in streams in the upper Breede (Hughes, 2000) indicate that between 23% and 27% of MAR is required to maintain the present ecological status of these tributaries.

There may be scope to enhance recharge to aquifers in winter by abstracting groundwater during this period. This type of scheme will only be of relevance where there are dams in the vicinity of the wellfield so that groundwater can be stored. However, careful monitoring is required to ensure that water levels recover to their normal post-winter levels to ensure that stream levels are not adversely affected in summer. High-rate, continuous abstraction is still likely to have significant environmental impacts, the major effect being a delaying or perhaps even stopping of surface flow in the vicinity of the wellfield area or sub-catchment. This type of abstraction is proposed in sub-catchments where there is an abundance of surplus water that would be expected to rapidly recharge the alluvial aquifer (e.g. in the Rawsonville area).

The sub-catchments that have been selected as examples are all in the upper Breede catchment and have been selected because of their proximity to recharge areas. In the folded and highly fractured mountainous terrain of the upper Breede valley, aquifer storativity is not expected to pose a constraint to groundwater development, as it is in the middle and lower parts of the Breede catchment.

7.1 ALLUVIAL AQUIFER SOUTH-EAST OF RAWSONVILLE

A 64-borehole wellfield operated from May to October to deliver 5 Mm^3.

7.1.1 Introduction

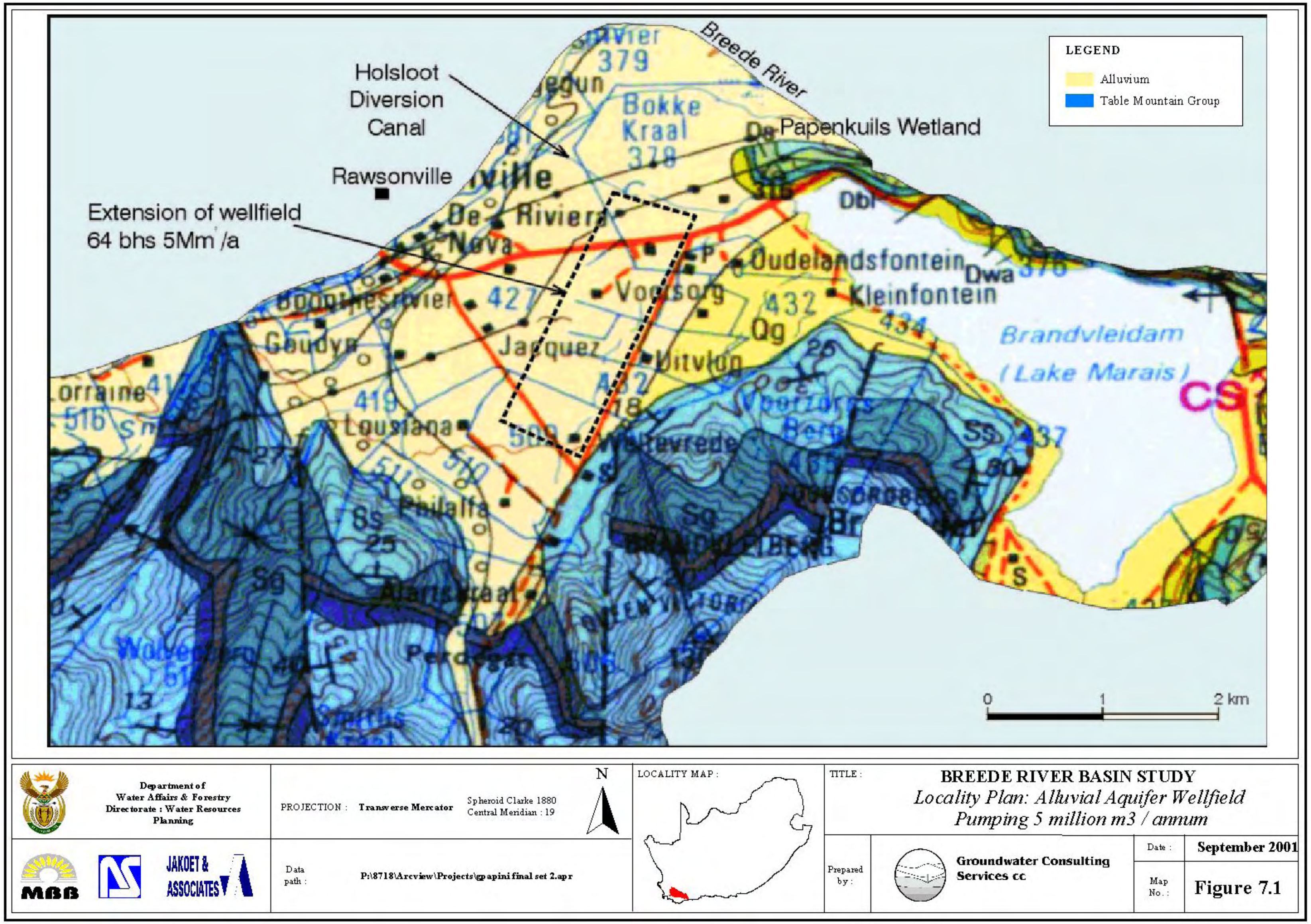
The Rawsonville alluvial aquifer covers an area of approximately 170 km^2 out of which current groundwater abstraction has been estimated at 20 Mm^3/annum (Rosewarne, 1981). The groundwater storage in the aquifer, based on a saturated thickness of 25 m (and an area of 75 km^2) is estimated at 56 Mm^3 and therefore there is potential for further abstraction. The northern limit of the proposed wellfield is approximately 3 km east of Rawsonville (Voorsorg area) where the alluvium has maximum thickness of up to 40m in a NNE-SSW trending trough (Figure 7.1). Groundwater abstraction is from the alluvium and average borehole depths are from 30 - 40m.

Following from an investigation of the area by the CSIR and French Geological Survey (BRGM) in 1976, Rosewarne (1981) calculated an average transmissivity (285 m^2/day) and specific yield (3%) for the aquifer (based on 12 tested boreholes). Recharge (via direct rainfall, influent seepage from rivers and upward leakage from underlying bedrock) to a 170 km^2 area of alluvial aquifer has been estimated at approximately 30 Mm^3/annum by Rosewarne (1981). Pumping in winter, thereby creating storage for infiltrating surface flow and precipitation, could enhance the recharge volume. The scheduling of pumping is over winter when there is currently limited abstraction. This scheme could continue into summer and integrate with existing boreholes; supplying irrigation farmers from a better-managed wellfield and augmenting dam storage in winter.

7.1.2 Wellfield Development

A 1 km x 4 km wellfield is proposed 3 km east of Rawsonville (Voorsorg) extending southward toward the mountain fronts (Brandvleiberg). The proposed wellfield is situated approximately 4 km south of the Breede River and Papenkuils wetland. The wellfield is predominantly within the H40L (Brandvlei) quaternary catchment but will abstract water primarily from the Holsloot catchment (H10K). Groundwater would be abstracted from 64 boreholes drilled to a maximum depth of 50m in the alluvial aquifer. The alluvial aquifer has an average thickness of 30m and a saturated thickness of 25m. The groundwater level is approximately 5 meters below surface and 25m above the level of the Breede River.

The area east of Rawsonville has around 200 shallow boreholes, which are used in summer for irrigation of vineyards and approximately 10,5 Mm^3 is abstracted (Whittingham, 1976). Sixty-four boreholes are proposed with an average borehole yield assumed at 12 ℓ/s per borehole. Four lines with 16 boreholes per line spaced 250 m apart give a 4 km north-south dimension for the wellfield and 1 km dimension in an east-west direction. An average yield of 12 ℓ/s per borehole (Figure 7.2) may be too optimistic, as Whittingham (1976) noted an increase in the proportion of low to moderate yielding boreholes, i.e. 3 – 7 ℓ/s in the area east and south east of Rawsonville.


Holsloot Diversion Canal
Rawsonville
Extension of wellfield
64 bhs 5Mm³/a
Breede River
Papenkuils Wetland
Bokke Kraal
Oudelandsfontein
Kleinfontein
Brandvleidam
(Lake Marais)
Jacquez
Uitvlug
Lousiana
Philalfa
LEGEND
Alluvium
Table Mountain Group
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Department of Water Affairs & Forestry
Directorate : Water Resources Planning
PROJECTION : Transverse Mercator
Spheroid Clarke 1880
Central Meridian : 19
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LOCALITY MAP :
Data path : P:\8718\Arcview\Projects\gpapini final set 2.apr
MBB
JAKOET & ASSOCIATES
TITLE :
BREEDE RIVER BASIN STUDY
Locality Plan: Alluvial Aquifer Wellfield
Pumping 5 million m3 / annum
Prepared by :
Groundwater Consulting Services cc
Date : September 2001
Map No. : Figure 7.1

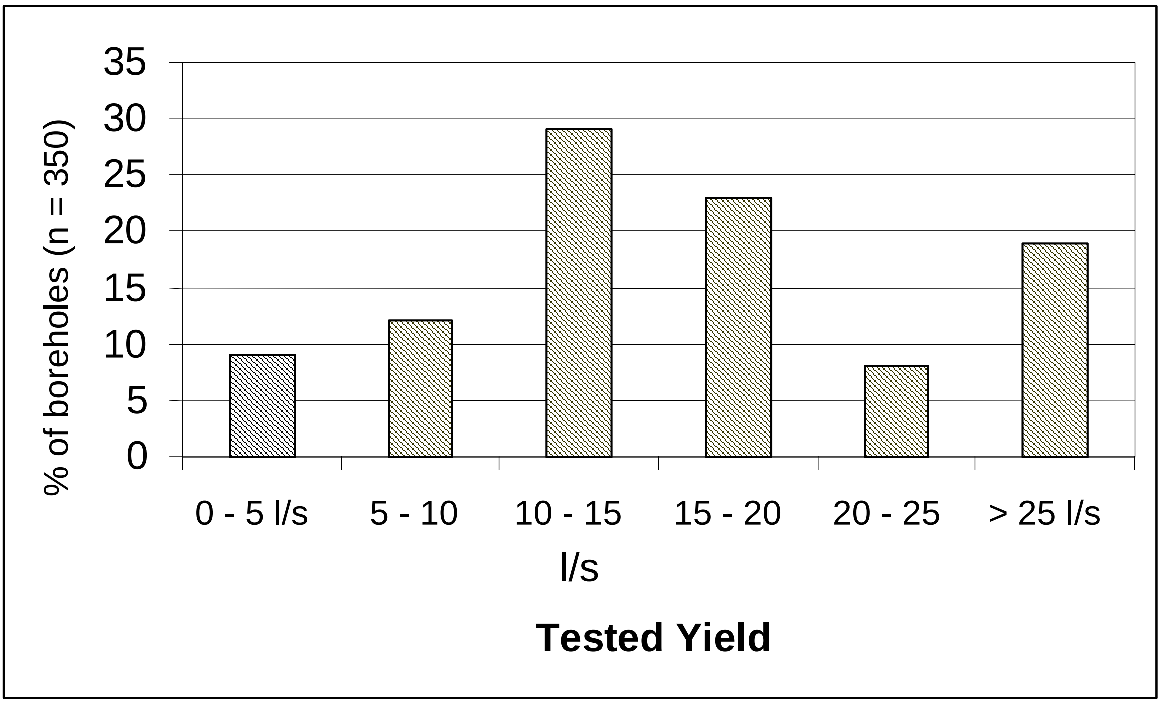


Figure 7.2 : Tested capacities of 350 boreholes in the Rawsonville area (Rosewarne, 1981)

Pumping may be reduced in the lower flow months of May, June, September and October but increased in July and August (Figure 7.3) to provide an anticipated yield of 5 Mm^3. Rosewarne (1981) estimated annual recharge to the alluvium at 30 Mm^3 over an area of 170 km^2 using an average annual fluctuation in water level of 2 m. Abstracting an additional 5 Mm^3 does not appear excessive, however, the abstraction will take place in an area of approximately 4 km^2 and result in a considerable cone of depression within and around the wellfield. The Papenkuils wetland receives recharge from the Holsloot and other smaller streams in the area and therefore abstraction of groundwater may result in reduction of flows to the wetland. However, abstraction in this conjunctive-use scheme will take place during winter months when the Papenkuils is likely to receive flood flow from the Breede River. With this abstraction schedule, the likelihood for the scheme to affect the wetland is considered low. Some other potential impacts of the scheme include:

- Flow reduction in the Holsloot River in spring and autumn some of which flows to the Brandvlei Dam via the current diversion.

- A potential lowering of the water table and reduction in borehole yields of existing groundwater users with shallow wells. However, the proposed wellfield should reduce abstraction prior to summer irrigation pumping to allow water levels to recover.

The operation of the scheme will need to be based on the conditions pertaining to the year in question to avoid depletion of the Reserve; in other words, commencement of pumping could be based on a flow threshold in the Holsloot. Figure 7.3 assumes that all abstracted groundwater is derived from the Mean Annual Run-off (WR90 data).

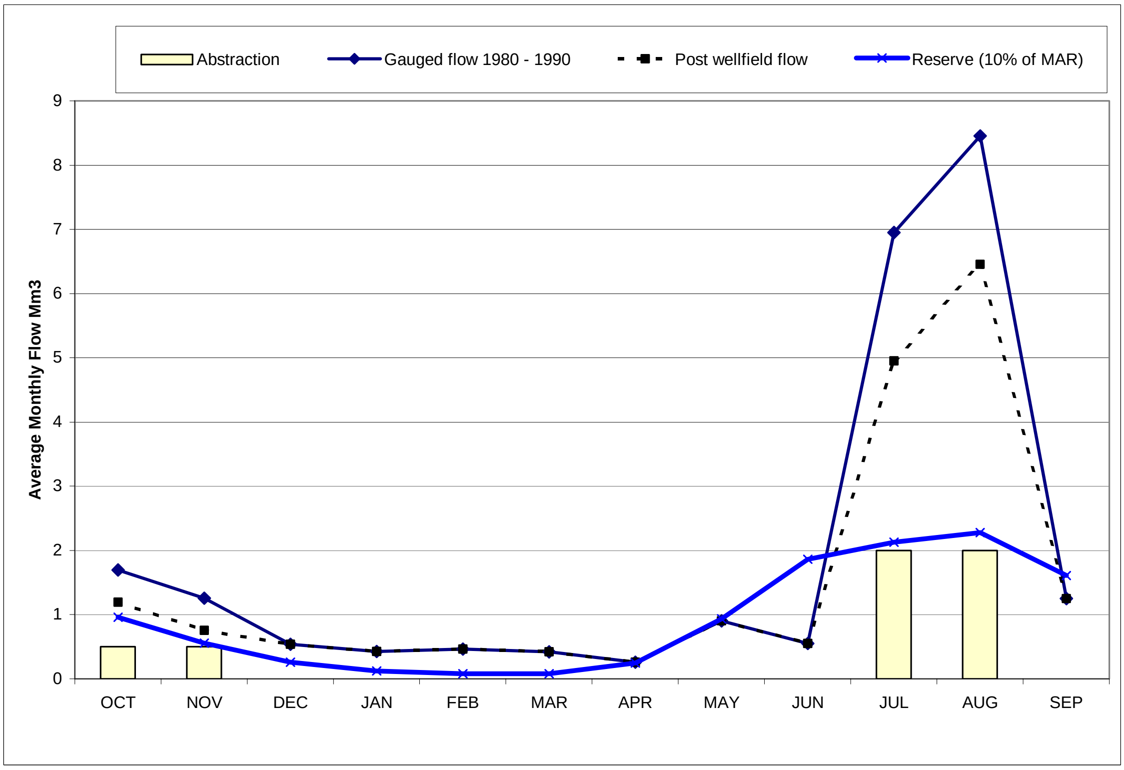


Figure 7.3 : Potential reduction in the flow in the Holsloot River (dashed line) as a result of wellfield pumping (at 5 Mm^3) in June and July and October/November at DWAF monitoring point H1H009. The median monthly flow data since 1992 has been used because of high variability of monthly flows

Although a significant component of the groundwater will come from river infiltration, it is thought that the underlying TMG aquifer will also recharge the alluvial aquifer. This implies the predicted reduction in stream flow in Figure 7.3 may be less pronounced. In addition, there may also be a delayed response in the reduction in river flow resulting from aquifer pumping, meaning that lower flows may occur in September and October rather than in July and August as indicated in Figure 7.3. Abstracted volumes should be controlled based on a combination of precipitation and groundwater levels in and around the production wellfield.

The possibility of supplying the scheme with groundwater sources from the underlying fractured-rock aquifers of the TMG and Bokkeveld Group as well as from the alluvium is also a possibility. This would entail deeper boreholes of up to 120m, which would increase the cost but also, the potential yield of the scheme. Zones of enhanced permeability are thought to exist in the bedrock beneath the alluvium where N-S trending faults (whose continuations are seen in the mountains to the south of Rawsonville) occur. However, the probability of drilling successful boreholes (> 10 ℓ/s) in the fractured-rock aquifers is reduced when compared to the alluvium.

7.1.3 Development Costs

The boulder layers in the upper reaches of the Rawsonville aquifer are likely to increase the costs of wellfield development because of the need for ODEX drilling. Groundwater would be pumped via a pipeline straight to the diversion canal in the Holsloot River and to the Brandvlei Dam. Costs for the scheme are presented in Table 7.1:

TABLE 7.1: COSTS FOR 64-BOREHOLE WELLFIELD DEVELOPMENT SOUTH-EAST OF RAWSONVILLE TO ABSTRACT 5 Mm^3/a

ACTIVITY	DESCRIPTION	COST (R)
INFRASTRUCTURE COSTS		
Wellfield Development	Drilling and test pumping 64 boreholes (203mm ODEX) to 50m depth	3,200,000
	Equipping: Super D T38/6 11 kW Franklin Motor	1,500,000
Pipeline to Diversion Canal	16 km (400mm) and 1 km (800mm)	9,775,000
P&G, Design and Management, Contingencies, VAT.		12,750,000
Total Capital Cost		**27,225,000**
ANNUAL OPERATING AND MAINTENANCE COSTS		
Wellfield pumping costs	1 267 200 kWh from 64 boreholes	228,000
Maintenance	Civil, pipelines, mechanical and electrical	241,000
Administration	Salaries, wages and transport	273,000
Repayment of Loan	Interest at 17,5% over 20 years	5,068,000
Total Annual Cost		**5,810,000**
UNIT COST OF WATER		**R1.16/m^3**

7.2 UPPER HOLSLOOT RIVER CATCHMENT (STETTYNSKLOOF)

A 10 borehole wellfield pumping throughout the year to deliver 3.8 m^3 / annum

7.2.1 Introduction

The Holsloot River catchment is primarily composed of the TMG Mountains of the Du Toits Berg and Stettynsberg. Mean annual precipitation varies from 800 mm to 3 000 mm and the mean annual run-off (WR90) is 111 Mm^3. The Holsloot River has been dammed (Stettynskloof Dam) in its upper reaches and this water is used to supply the town of Worcester at a capacity of 16 Mm^3 per annum. Groundwater recharge is estimated at 20 Mm^3 per annum and occurs predominantly in the mountainous areas in the south. Groundwater use is concentrated mainly in the Rawsonville area and comes almost exclusively from the alluvial aquifer, which is situated in the northern, low-lying part of the catchment. There is thought to be considerable groundwater potential in the southern mountain areas of the catchment where TMG and Malmesbury rocks occur in juxtaposition along a faulted contact in the Stettynskloof Valley.

The Holsloot River valley follows the NE – SW trending fault mentioned above for 10 km below the Stettynskloof Dam before deviating to an N-S direction (probably also along a fault line) for approximately 5 km before it reaches the Rawsonville area. The NE-SW section of this faulted valley is proposed as a suitable zone from which to abstract groundwater from the TMG and underlying Malmesbury Group aquifers. Boreholes would need to be sited using geophysics to exploit zones of enhanced transmissivity associated with the fault zone. The groundwater could be released to the Holsloot River and subsequently diverted to the Brandvlei Dam.

7.2.2 Wellfield Development

Borehole spacing is important in wellfield development as optimization results in the minimal drawdown of water level, which improves efficiencies and reduces pumping costs. Drawdown in the water level of anisotropic aquifers is often greater in the main structural trend of the formation. Borehole spacing becomes a major constraint to wellfield development in many of the smaller catchments like the Holsloot unless drilling rigs can access mountainous areas (e.g. by constructing access roads) or if inclined boreholes are drilled. A linear 10-borehole wellfield is proposed parallel to the fault zone of the Stettynskloof with boreholes spaced approximately 500 m apart (Figure 7.4).

It has been shown that borehole yields increase with depth of the borehole (Weaver *et al*, 1998 p3.8), however, the incremental yield increase per meter drilled does not generally warrant the increased drilling and pumping costs. This thinking has recently been challenged by the results of deep drilling (>400m) in the TMG, often below a cover of Bokkeveld rocks, which has indicated increasing groundwater yields with depth provided the borehole is sited on a suitable geological structure (pers. comm. R Hay). Successful boreholes reportedly had air-lift yields of up to 80 ℓ/s. In this exercise, however, the drilling depth is set at 120m with average pumping yields of 12 ℓ/s (or approximately 1 000 m^3/day) per borehole.

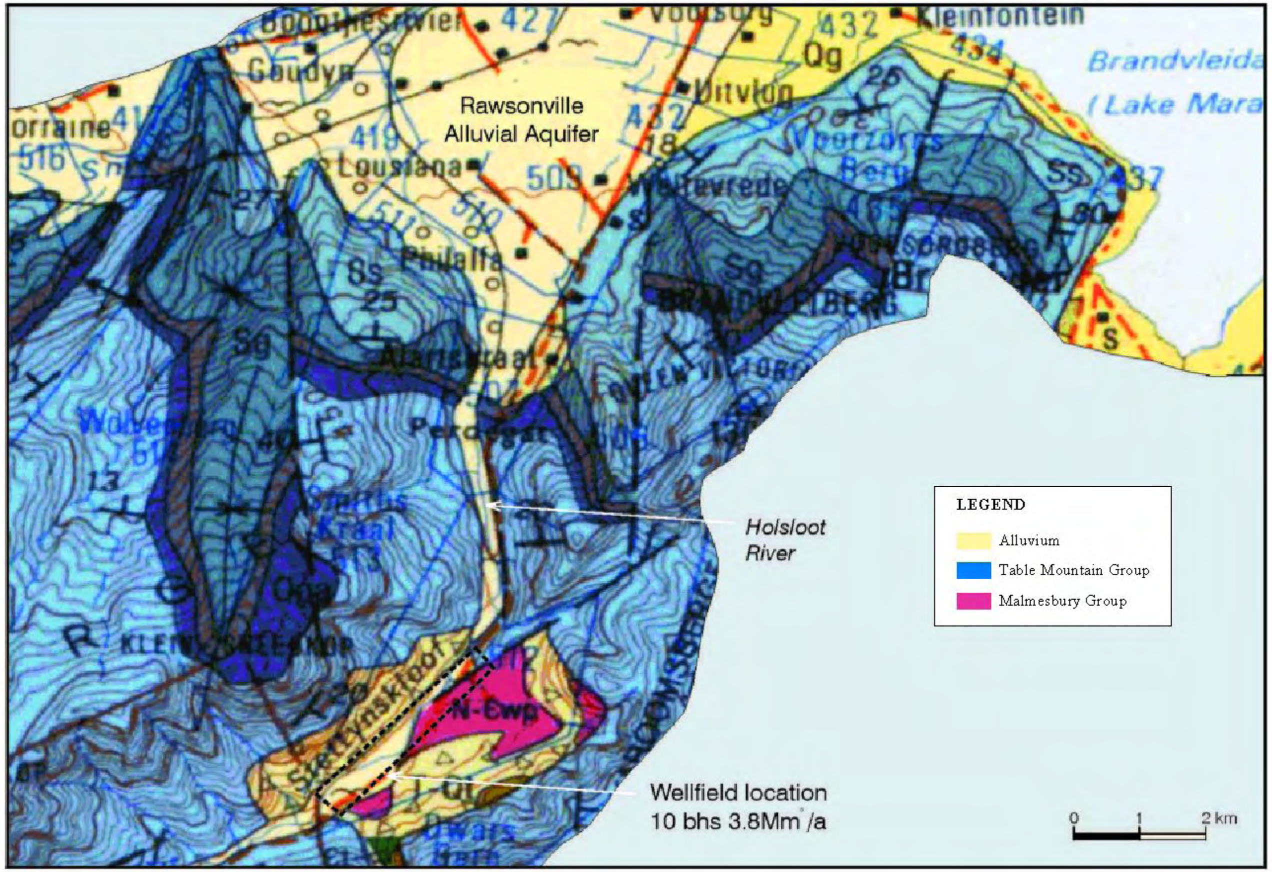
The effects of pumping at 3,8 Mm^3/annum on water levels (piezometric level) has been modeled and predicts that after a year of continuous pumping, the drawdown in the center of the wellfield would be approximately 20m, and 9m on the periphery. The aquifer is assumed to be confined and the average aquifer transmissivity is assumed to be 50 m^2/day and storativity 0,01 (or 1%). The aerial extent of the aquifer is 5 km x 10 km and the hydraulic parameters given above are assumed more representative of this 50 km^2 area than the fault zone where the hydraulic parameters are anticipated to be greater. The drawdown of the piezometric level may result in leakage from the overlying saturated alluvium to the hard rock aquifers, or more likely, a reduction in flow from the hard-rock aquifer to the alluvium and ultimately baseflow to the Holsloot. The destination of the abstracted groundwater is the Brandvlei Dam. Most of this groundwater, if pumped directly into the Holsloot River, will ultimately reach the Brandvlei Dam via the diversion canal in the Holsloot River.

7.2.3 Development Costs

The boreholes would be drilled deep into the hard rocks aquifers in the TMG and Malmesbury. Shallow groundwater in any saturated alluvium intersected in the boreholes would be sealed off. The boreholes would require test pumping to optimize pumping rates and pump settings. The boreholes would be equipped with an 18,5 kW electrical submersible pumps capable of pumping to depths of 120m below surface.

TABLE 7.2: COSTS FOR WELLFIELD DEVELOPMENT IN THE STETTYNSKLOOF TO ABSTRACT 3,8 Mm^3/a

ACTIVITY INFRASTRUCTURE COSTS	DESCRIPTION	COST (R)
Wellfield Development	Drilling and test pumping 10 boreholes (200mm) to 120m depth	865,000
	Equipping: Super D T38/6 11 kW Franklin Motor	700,000
Pipeline to Diversion Canal	5 km (400mm)	2,625,000
P&G, Design and Management, Contingencies, VAT.		3,110,000
Total Capital Cost		**6,665,000**
ANNUAL OPERATING AND MAINTENANCE COSTS		
Wellfield pumping costs		180,000
Maintenance	Civil, pipelines, mechanical and electrical	75,000
Administration	Salaries, wages and transport	67,000
Repayment of loan	Interest at 17,5% over 20 years	1,239,000
Total Annual Cost		**1,561,000**
UNIT COST OF WATER		**R0.41**



Department of Water Affairs & Forestry
Directorate : Water Resources Planning

PROJECTION : Transverse Mercator — Spheroid Clarke 1880, Central Meridian : 19

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LOCALITY MAP :

TITLE : **BREEDE RIVER BASIN STUDY**

Locality Plan: 10 Borehole Hard-rock Aquifer Wellfield Pumping Throughout the Year to Deliver 3.8 million m3/annum

Prepared by : Groundwater Consulting Services cc

Date : **September 2001**

Map No. : **Figure 7.4**

7.3 AMANDEL RIVER CATCHMENT

A 20 borehole wellfield abstracting 4.3 Mm^3 / over 7 month irrigation period

7.3.1 Introduction

The Amandel River catchment has an area of 96 km^2 and is relatively undeveloped as a result of the mountainous terrain; there are only 157 ha of vineyards. A large part of the catchment's usable land is reportedly infested with alien vegetation (121,5 ha or 41%). Almost the entire surface area is comprised of TMG Group rocks with some alluvial deposits occupying lower-lying areas near the confluence with the Sandrifskloof River. The upper catchment is comprised of Peninsula Formation quartzite of the Hex River Mountains whereas the Goudini and Skurweberg Formations occupy the lower parts. Two aquifer systems are believed to occur and are separated by the Cedarberg shale: the Peninsula and the Nardouw aquifers. The Amandel's catchment occupies the upper part of a plunging syncline which strikes in an ENE – WSW direction. The predominant component of groundwater flow is expected to be in ENE direction. A NE-SW regional fault bounds the southern boundary of the catchment.

The mean annual run-off (WR90) from the Amandel River catchment is 40 Mm^3 and groundwater recharge is estimated at approximately 7 Mm^3 per annum. Rosewarne (1997) estimated recharge at 14 Mm^3 however, much of this is considered as interflow, which reaches streams rapidly and is not considered available during the summer months. Current groundwater abstraction is 1,2 Mm^3/ annum to irrigate 100 ha of citrus. There is clearly potential for further development of groundwater resources in this catchment although this is relatively small local use. The impact of excessive abstraction, particularly in summer, may deplete water resources for the Worcester-East farmers (i.e. in quaternary catchments H20G and H20H).

7.3.2 Wellfield Development

A 20-borehole wellfield is proposed to abstract groundwater from the TMG and alluvial aquifer (Figure 7.5). The first part of the wellfield would comprise 10 boreholes that exploit groundwater from the Peninsula Formation in the Keurhoekkloof. The boreholes would be drilled to a depth of approximately 140m and spaced 500m apart in an E-W orientation adjacent to the Amandel River. The second part of the wellfield would comprise 10 boreholes drilled to a depth of 140m west of the Sandrifskloof River (vicinity of Kanevlei and Klipheuwel) and would abstract groundwater from the alluvium and underlying fractured aquifers of the Goudini and Skurweberg Formations. Anticipated borehole yields are approximately 12 ℓ/s and both wellfields would provide, based on a 7-month pumping schedule, approximately 4,3 Mm^3/a.

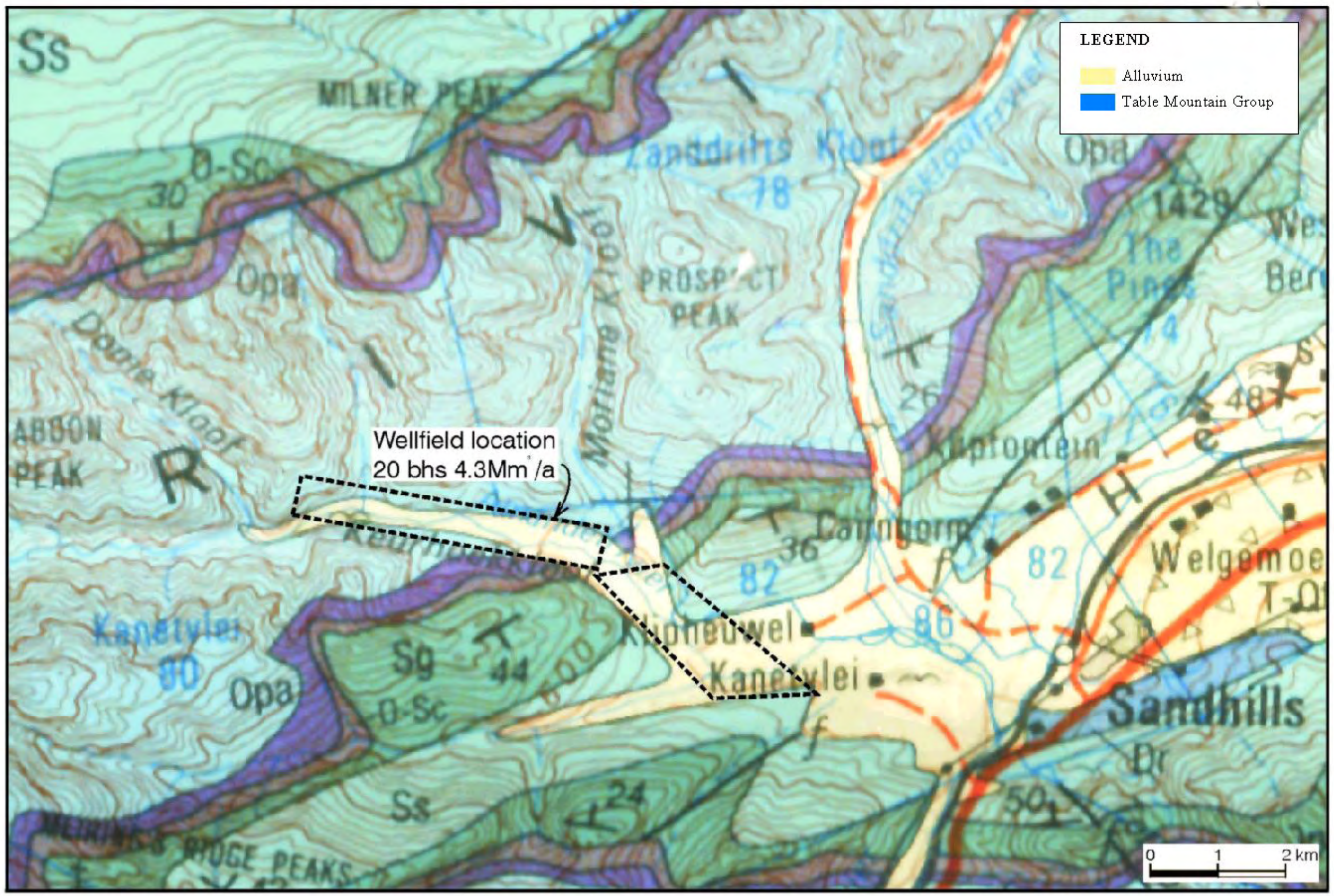
The effect of pumping 4,3 Mm^3 of groundwater over the summer months on flow in the Amandel River may result in the river running dry from January to March. This impact may be reduced by pumping in the months from June to October when there is significantly more flow in the Amandel River, however, the issue then becomes one of storage because there is no water demand in winter. One option may be to artificially recharge some of the alluvial fans in the Hex River Valley with this water.

7.3.3 Development Costs

The costs of the boreholes will vary according to the differing geology of the area. The areas underlain by greater thickness of alluvium are likely to require casing to depths of up to 50m because of the thickness of alluvium and potential weathered nature of the underlying Goudini and Skurweberg Formations. The casing in the alluvium should also be slotted to collect alluvial as well as fractured aquifer groundwater.

TABLE 7.3: WELLFIELD DEVELOPMENT COSTS IN THE AMANDEL RIVER CATCHMENT TO ABSTRACT 4,3 Mm^3/a

ACTIVITY	DESCRIPTION	COST (R)
INFRASTRUCTURE COSTS		
Wellfield Development	Drilling and test pumping 20 boreholes (200mm) to 140m depth	1,440,000
	Super D T38/14 18,5 kW Franklin Motor	800,000
Collector Pipeline and main pipeline	Main pipeline to convey water to current pipeline from Sandriftskloof Dam	11,097,000
Highlift Pumpstation	(see above)	1,372,000
Access roads and powerlines		1,100,000
P&G, Design and Management, EIA, Contingencies, VAT.		12,541,000
Total Capital Cost		**28,350,000**
ANNUAL OPERATING AND MAINTENANCE COSTS		
Wellfield pumping costs		657,000
Maintenance	Civil, pipelines, mechanical and electrical	145,000
Administration	Salaries, wages and transport	282,000
Repayment of loan	Interest at 17,5% over 20 years	5,180,000
Total Annual Cost		**6,264,000**
UNIT COST OF WATER		**R1.46**



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PROJECTION : **Transverse Mercator** Spheroid Clarke 1880 Central Meridian : 19

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LOCALITY MAP :

TITLE :

BREEDE RIVER BASIN STUDY

Locality Plan: 20 Borehole Wellfield Abstracting 4.3 million m3 / annum over 7 Month Irrigation Period

Prepared by : **Groundwater Consulting Services cc**

Date : **September 2001**

Map No. : **Figure 7.5**

7.4 BREEDE RIVER ALLUVIUM (SOUTH OF WORCESTER)

A 15 caisson (6m deep) wellfield parallel to the Breede River delivering 3,6 Mm^3 over a 6-month period at a cost of R1.5M.

The intention of developing a wellfield in proximity to the banks of the Breede River south of Worcester would be to exploit groundwater from the Breede River alluvium at the confluence of the Hex and Breede Rivers. The wellfield would be pumped in the winter, inducing recharge from the river (which would be at a relatively high level) into the alluvial aquifers. The groundwater could then be pumped to the Brandvlei Dam.

7.4.1 Wellfield Development

Groundwater would be abstracted from a linear array of caissons excavated in proximity to the Breede River and installed to a depth of approximately 6m below surface (Figure 7.6). The saturated aquifer thickness is estimated at approximately 4m. At the base of the caissons, six horizontal screens (150mm OD slotted PVC) radiate 5 meters into the surrounding alluvium material. Yields of at least 15 ℓ/s can be anticipated but are dependent on the permeability of the alluvium. Although the actual wellfield configuration would need to be determined by a more detailed survey of the site, a 15-caisson wellfield is proposed. A major constraint to the wellfield will be the effective transmissivity between the river and the adjacent aquifer. Transmissivity will also decrease with drawdown in the alluvium.

The proposed caissons would be spaced approximately 200m apart and operate from April to September. This would deliver an approximate yield of 20 000 m^3/day or 3.6 Mm^3 over a six month period. Without recharge from the Breede River, the drawdown in the water level around the caissons would rapidly limit yield. However, if we assume recharge from the Breede River over a 3 km river frontage, a river sediment permeability of 50 m/d and hydraulic gradient of 0,08 between the river and the caissons, up to 24 000 m^3/day of river water may flow to the alluvial aquifer. The impact of abstracting this volume of river water is not considered significant given that abstraction would occur during winter.

Expansion of this scheme to abstract larger volumes will be constrained by the extent and thickness of saturated alluvium adjacent to the Breede River in the vicinity of the Brandvlei Dam, the permeability of the river bed, the transmissivity and storage capacity of the alluvial aquifer and potential impact on the Papenkuils wetland. The abstraction of 30 Mm^3/annum (or approximately 1 m^3/sec) of groundwater from this aquifer with an eight-fold increase in the number of caissons is not considered feasible because of the constraints listed above.

7.4.2 Development Costs

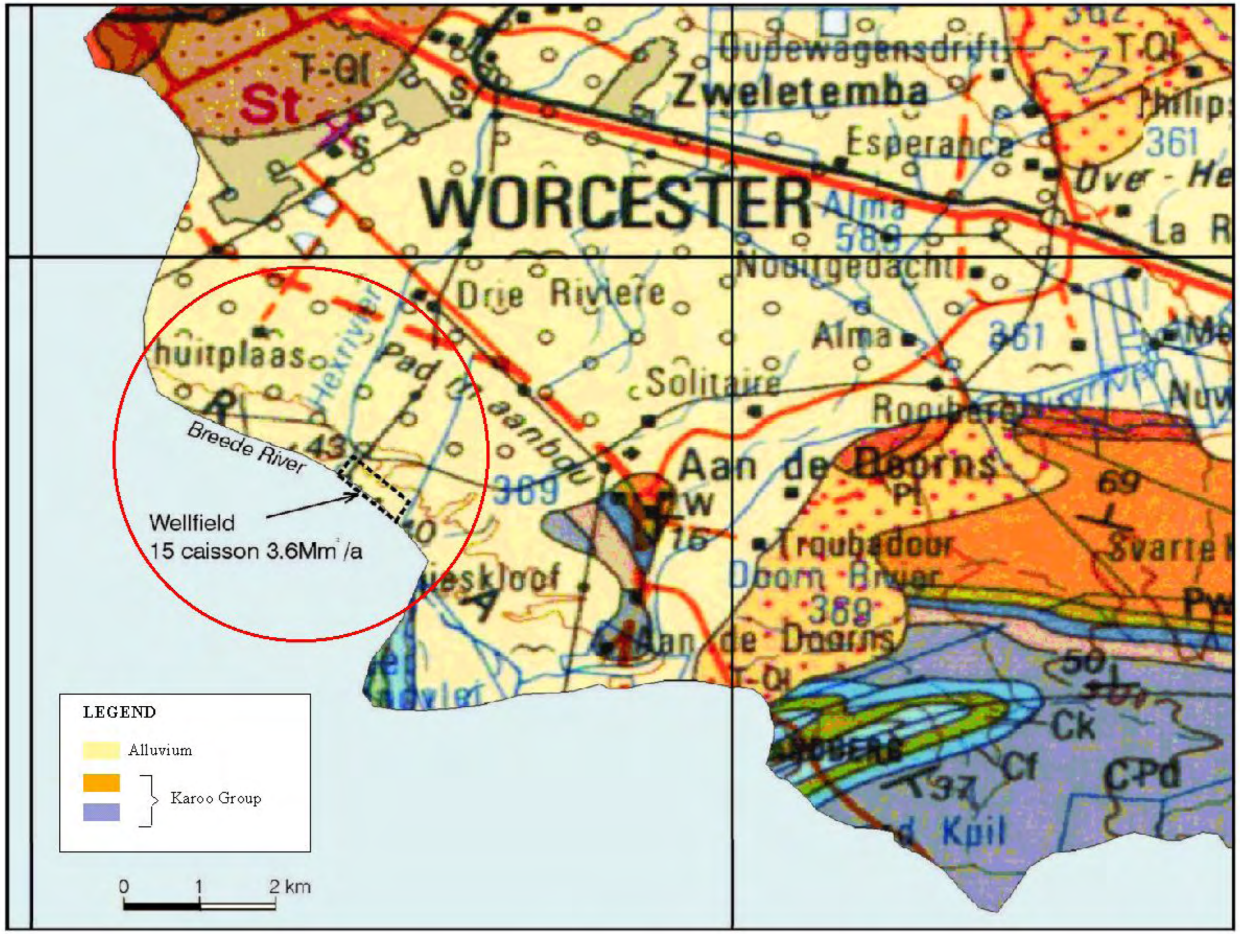
The development costs of the well field are determined in Table 7.4 and in Table 7.5 are compared with those of the other schemes investigated.

TABLE 7.4 : COSTS OF WELLFIELD DEVELOPMENT IN THE ALLUVIUM ASSOCIATED WITH THE BREEDE RIVER NEAR THE BRANDVLEI DAM TO ABSTRACT 3,6 Mm^3/a

ACTIVITY	DESCRIPTION	COST (R)
INFRASTRUCTURE COSTS		
Wellfield Development	Drilling and test pumping 20 boreholes (200mm) to 140m depth	1,050,000
	Super D T38/14 11 kW Franklin Motor	375,000
Collector Pipeline and main pipeline	Collect groundwater and pump to Brandvlei Dam	2,400,000
Highlift Pumpstation	(see above)	2,000,000
Powerlines		350,000
P&G, Design and Management, Contingencies, VAT.		4,991,000
Total Capital Cost		**11,266,000**
ANNUAL OPERATING AND MAINTENANCE COSTS		
Wellfield pumping costs		250,000
Maintenance	Civil, pipelines, mechanical and electrical	124,000
Administration	Salaries, wages and transport	114,000
Repayment of loan	Interest at 17,5% over 20 years	2,120,000
Total Annual Cost		**2,608,000**
UNIT COST OF WATER		**R0.72**

TABLE 7.5 : SUMMARY OF POTENTIAL GROUNDWATER ABSTRACTION SCHEMES

NAME	VOLUME	ABSTRACTION	NO. BHS	CAPITAL COST	COST OF WATER
	Mm^3	Period	No.	R Million	R / m^3
Rawsonville Alluvium	5	WINTER	64	R27	R1.16
Stettynskloof	3.8	12 MONTHS	10	R6.7	R0.41
Amandel	4.3	SUMMER	20	R27	R1.41
Breede Alluvium	3.6	WINTER	15	R11.4	R0.72



Department of Water Affairs & Forestry
Directorate : Water Resources Planning

PROJECTION : Transverse Mercator — Spheroid Clarke 1880, Central Meridian : 19

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LOCALITY MAP :

TITLE : **BREEDE RIVER BASIN STUDY**

Locality Plan: 15 Caisson Wellfield Parallel to the Breede Delivering 3.6 million m3 / annum Over a 6 Month Period

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Prepared by : Groundwater Consulting Services cc

Date : September 2001

Map No. : **Figure 7.6**

7.5 ADDITIONAL POTENTIAL CONJUNCTIVE USE EXAMPLES

Conjunctive use systems are constrained, in the case of those where abstraction is mainly in winter, by the need for nearby storage and in other cases by the cost of distribution if users are not located close to the wellfield. The potential volumes of groundwater are small when compared to surface water schemes but groundwater schemes have the advantage of being modular (i.e. can be scaled-up when and if the demand increases) at relatively low cost.

7.5.1 Other Valleys in the Table Mountain Group Mountains

The potential for groundwater abstraction schemes such as presented above is applicable in most of the major valleys in the TMG Mountains of the Breede catchment, including the Du Toitskloof (upper Molenaars), Michells Pass (Tierhokkloof), Wit River and the Sanddriftskloof. Clearly, level terrain on which to establish a wellfield is a constraint to groundwater development in these areas. Mobile rigs capable of traversing rugged terrain and drilling inclined boreholes or fewer, large diameter, deep boreholes are possibilities requiring further investigation. These schemes could be integrated with existing surface water schemes.

7.5.2 Artificial Recharge of Alluvium in the Sandhills Area

Groundwater from the Amandel and Sandrifskloof catchments or surface water from the Hex River could be artificially recharged into the alluvial fans of the Hex River Valley. There is an estimated 16 Mm^3 of storage available for artificial recharge (Rosewarne, 1997) of which about 7 Mm^3 could be recovered from shallow boreholes in the alluvium or indirectly by leakage into the underlying TMG/Bokkeveld aquifer. The recharged fans would also contribute to river baseflow, thus increasing stream flow during the summer months.

7.5.3 Tapping of Poorer Quality Aquifers to Mix with Surface Water

Poor quality groundwater could be available for mixing with surface water or good quality groundwater at a ratio that would ensure an EC of below 70 mS/m. Poor quality groundwater (>70 mS/m) is found in the middle Breede valley and the lower Breede area (excluding the Langeberg, and Potberg ranges and the Witsand alluvium. There is scope for this in the middle Breede and the Hex River Valley where groundwater could be mixed with surface water from the Brandvlei Dam. This may only be sustainable if carried out infrequently (e.g. during drought conditions) because of the generally poorer recharge of the more saline aquifers.

7.5.4 Deep Drilling (>250m) in the Table Mountain Group Aquifer

The structurally-controlled hot springs found in the Breede catchment provide evidence for the deep, regional (10 – 100 km-scale) flow of groundwater recharged in surrounding mountains, through confined 'aquizones' in the intermontane synclinal valleys, and along major fracture networks (hydrotects) transecting surface-water catchment boundaries (Hartnady *et al*, 1998). A borehole drilled deep into these structures in the Citrusdal area gave an air-lift blow yield in excess of 100 ℓ/s. Other deep boreholes have been drilled in the Kriedouwkrans area north of Citrusdal and the Verloren Valley area near Touws River and have delivered blow yields of ~80 ℓ/s.

There may be potential for intersecting high yielding TMG aquifers under a Bokkeveld cover in areas like the Riviersonderend Valley. Volumes of groundwater abstracted with these deeper boreholes should be greater than the traditionally shallower holes, but cost would be higher and an approximate cost for the siting, drilling, test pumping and equipping of a 400m deep borehole is at least R420 000 (April 2000 costs). Limited experience with deep drilling indicates that, if a deep borehole is successful, the cost per cubic metre is ~50% of that of shallow conventional boreholes.

The development of deep groundwater resources in the TMG begs the question of the potential impact on stream flows. However, the depth of these aquifers implies that they do not inter-act with streams in the conventional context of surface-groundwater interactions within quaternary catchments. Recharge of these deep aquifers is likely to be infrequent or at very low rates because of the intervening aquitard/aquicludes. However, Chris Hartnady of Umvoto Africa cc believes the deep aquifers are laterally connected through the fold structures to the high mountain exposures of TMG, where the dominant recharge takes place on a regular (winter season) basis. In other words, there is a sustained lateral inflow at depth from the up-gradient, near-surface, un- or semi-confined parts of the aquifer system. This deep inflow is balanced by outflow to down-gradient parts of the deep aquifer system, or to (thermal) springs in the same or other quaternary catchments, or to the ocean where TMG crops out at or below sea-level.

Much of the recharge may have occurred at wetter periods in the past although Verhagen's results from the Olifants/Doring and Gouritz catchments indicate mean residence times of >10 000 years or substantially less even for the hotter thermal springs, such as The Baths (^{14}C ~85% modern carbon, or ~2 000 years mean residence time), or Calitzdorp. As the recharge zones are tens of kilometers distant from the thermal spring discharges, e.g., ~40 km in the case of The Baths, minimum apparent velocities of >0.05 m/day are implied, depending on the actual tortuosity of the deep flow paths. The main constraint on sustainability is the hydraulic diffusivity of the deep confined aquifer, which governs the areal rate of expansion of the cone of depression around the borehole or well-field. This is independent of pumping rate (Hartnady, pers.com.). The drilling of deep TMG aquifers is receiving high priority by the Department of Water Affairs and Forestry.

8. CONCLUSIONS

The objectives of the groundwater component of the Breede River Basin Study was to:

- assess the significance and distribution of groundwater resources in the Breede River Basin study area
- estimate the extent and role of present groundwater abstraction and the degree of any stress it is causing
- indicate the scope for further development of groundwater resources and potential environmental impact this could have.

Groundwater is a significant resource in the upper Breede River basin but in the middle and lower Breede both the quantity and quality is reduced and use is often confined to livestock and irrigation of salt-tolerant crops. The source of groundwater is mainly the high rainfall mountainous areas ringing the upper basin. Most of the water percolating into the ground (recharge) emerges as surface water in tributaries of the main streams. In the drier summer months (November to March) groundwater supplies the flow in streams (baseflow) and underlying sediments, which is often critical for maintenance of aquatic organisms and sensitive vegetation.

Reliable information regarding the quantities of groundwater abstracted is lacking. This situation should be improved by DWAF's current registration of water users in the Breede River catchment, however, groundwater information has not been specifically collected. The number of boreholes per farm and estimated volume abstracted per annum is the only information that has been collected during the registration process. Useful information that could be collected in the registration process could include whether groundwater is abstracted for use in summer only (direct use) or whether dams/reservoirs are filled with groundwater during winter abstraction or both.

The total average annual abstraction for the whole basin is estimated at about 100 Mm^3. Groundwater constitutes approximately 30% of the total irrigation requirement in the upper Breede where approximately 80 Mm^3/a is abstracted. Only around 1 Mm^3/a is used for urban, rural domestic and stockwatering needs. In the middle Breede about 18 Mm^3/a is abstracted whereas in the lower Breede only around 4 Mm^3 is abstracted every year primarily in the Barrydale area. Irrigation boards do not abstract groundwater in general and groundwater for abstraction is almost exclusively by private farmers for use on their own lands.

The effect of groundwater abstraction can be to appreciably reduce baseflow of rivers, particularly when the abstraction is from alluvial aquifers where there is a significant degree of interaction between surface and groundwater. Reductions in baseflow caused by groundwater abstraction from alluvial aquifers have been partially compensated for by return flows from irrigation although these flows are of poorer quality than the natural baseflow. Groundwater abstraction from deep boreholes in fractured aquifers at distances of several kilometers from streams are likely to have less of an effect on baseflow than abstraction from alluvial aquifers. This is because there is likely to be a lag effect (between pumping and the development of a significant drawdown cone extending to the stream) whose period is longer than a normal irrigation season. Provided the aquifer is not being over pumped, winter recharge and recovery of the piezometric surface will mean that any impact on streams or springs in the vicinity is negligible.

There is scope for the expansion of groundwater use in the upper Breede basin and in limited areas near TMG outcrops in the middle and lower Breede basin. The quantities of groundwater that can be abstracted from the TMG and alluvial aquifers are limited primarily by the effective recharge to the aquifer in the locality of abstraction as the storage and transmissivity are generally high in these formations. In the remaining hard rock aquifers in the catchment, volumes available for abstraction are constrained by the storage capacity, which tend to be low. Average yields of successful boreholes in fractured aquifers are from 5 ℓ/s to 12 ℓ/s and up to 20 ℓ/s in alluvium.

Quantities that could be developed are small when compared with major surface water schemes. It is considered that volumes greater than 5 Mm^3/annum could not be abstracted from a practically sized wellfield without resulting in conflict with existing users (including the environment). In the conjunctive use or groundwater augmentation scenarios that have been investigated in this report, the need for reticulation and pumping to a surface storage reservoir significantly increase the cost of groundwater development. This makes it feasible to irrigate individual farms in the 20 – 40 hectare range, rather than supply communal schemes, from several boreholes, which is the current practice in many parts of the upper Breede.

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Appendix A

Method for evaluation of baseflow

1. Semi-log method

This method entailed plotting the hydrograph of monthly flow data that were averaged for the years 1980 to 1990. The flow data (on the y-axis) are plotted on a log scale and time on linear scale on the x-axis. The time for a complete log-cycle of discharge (e.g. from 1 Mm^3 to 0,1 Mm^3) is measured and multiplied by the discharge volume at the beginning of the groundwater recession. The groundwater recession generally commences in November as this is the month where the greatest change in gradient of most hydrographs occurs. This volume is divided by 2.3 according to the equation:

$$Vol = \frac{Q_0 t_1}{2.3} \qquad \text{(Domenico and Schwartz, 1998)}$$

This provides an estimate of the total potential groundwater discharge. The actual groundwater discharged is determined by evaluating the actual base flow over the period in which groundwater comprised the predominant flow in rivers (usually from November to end of March or 5 months) using the equation:

$$Vol = \frac{Q_0 t_1}{2.3} - \frac{Q_0 t_1 / 2.3}{(10^{t/t1})}$$

where t is the period of the groundwater recession and t1 the months to complete a log cycle of discharge.

The above calculation provides an indication of summer base flow and is presumed to originate exclusively from groundwater (although there may be an element of irrigation return flow in developed sub-catchments). Groundwater also contributes to base flow in winter and this amount is estimated by averaging the flow at the beginning and end of the groundwater recession and multiplying by the months over which surface run-off and interflow dominate the hydrograph. The summer and winter baseflow components are assumed to comprise the ‘deep seated’ groundwater contribution to river flow and attempts to exclude short-lived interflow.

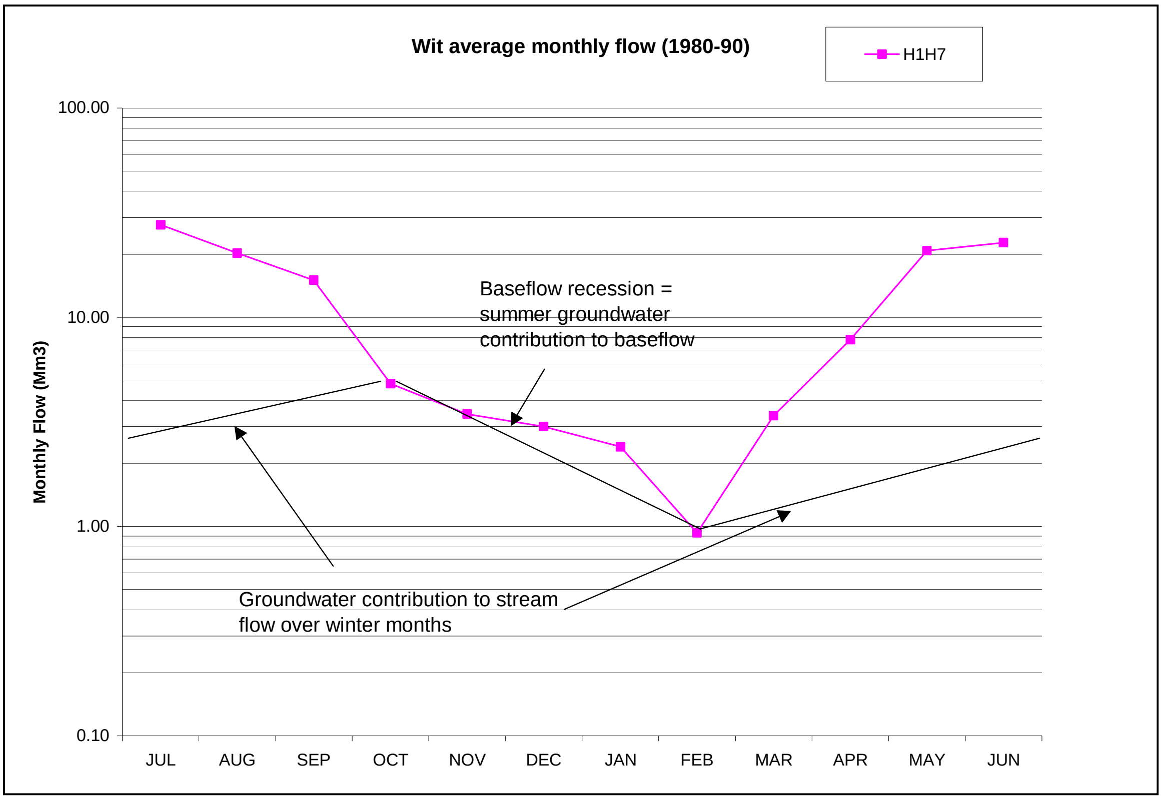

Figure A1: Graphical presentation of determination of groundwater contribution to river flow (Baseflow) using the semi-log plot method

2. Straight line interpolation

This method entails joining the annual low flows on a hydrograph over the period 1980 – 1989 and calculating the average annual. There is no distinction between summer and winter and it is therefore a conservative method of base flow estimation.

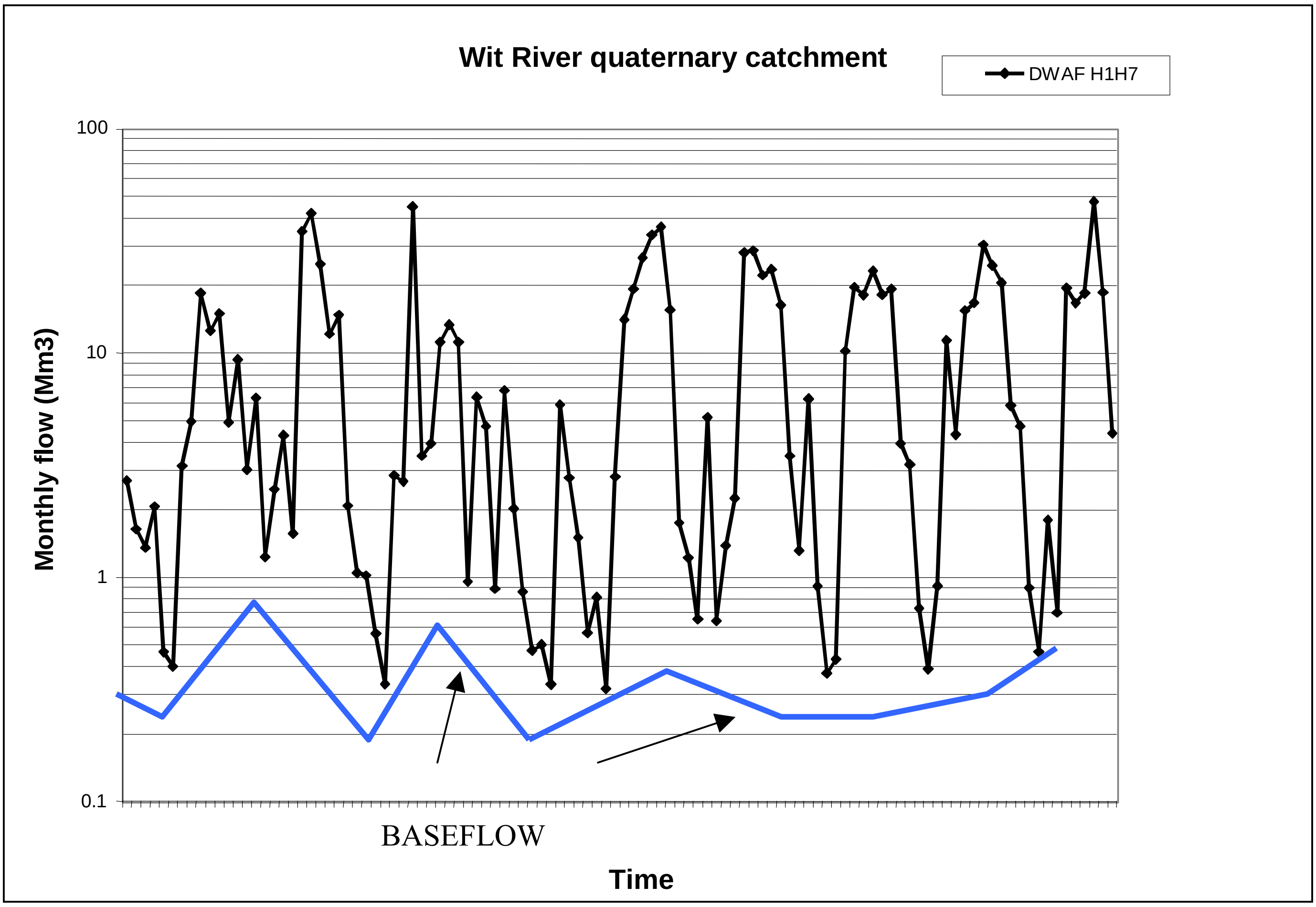

Figure A2: Graphical presentation of determination of groundwater contribution to river flow (Baseflow) using the linear interpolation method

3. Herolds Method

The total flow in a river in any month is due to surface run-off (Qs) and groundwater (Qg). An assumption is made that all flow below a certain value (Gmax) all flow originates from groundwater. The value of Gmax is adjusted each month according to the run-off from the preceeding month and assumed to decay with time according to the following equation:

$$Gmax_t = K_d \text{ x } Gmax_{t-1} + K_g \text{ x } Qs_{t-1} / 100$$

Where the subscripts t and t-1 refer to the current and preceding months and K_d is a groundwater decay factor ($0 < K_d < 1$) and K_g is a groundwater growth factor (%). Calibration of the model is achieved by selecting appropriate values of K_d and K_g. Both of these constants are likely to be high given the steep nature of the hydrographs in the mountainous catchments of the Breede study area. A value of $K_d = 0.5$ and $K_g = 20\%$ was selected in the examples.

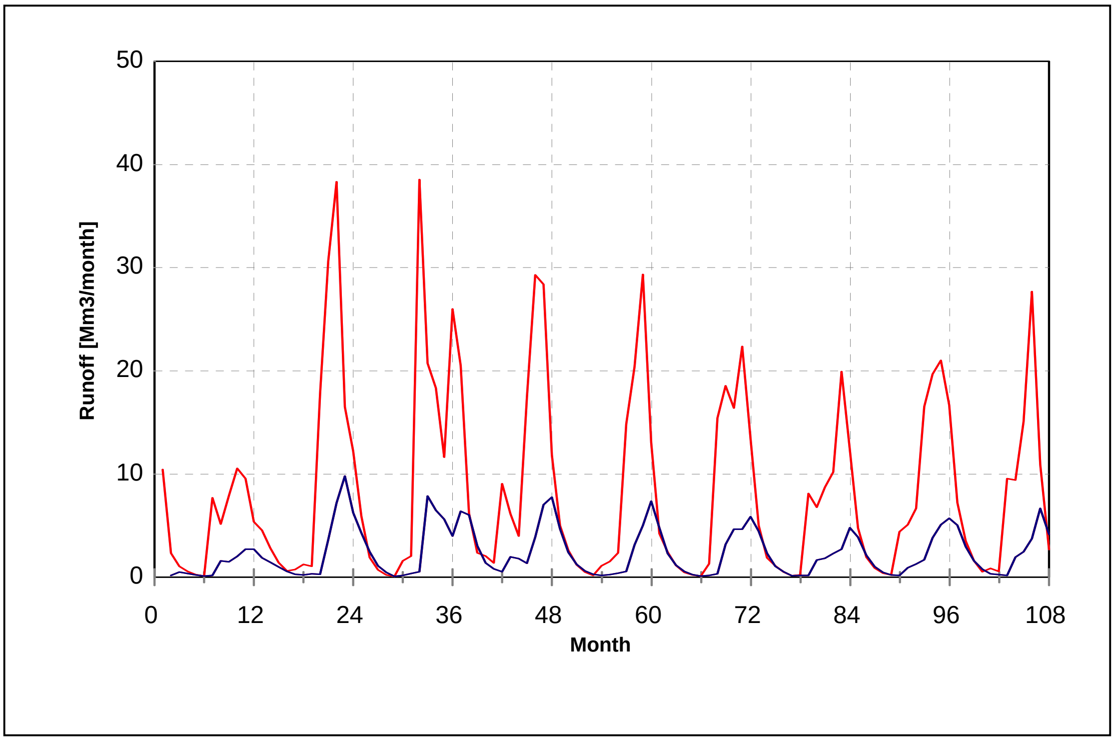

Figure A3: Graphical presentation of determination of groundwater contribution to river flow (Baseflow) using Herold's method