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DEPARTMENT OF WATER AFFAIRS
AND FORESTRY
DIRECTORATE OF WATER RESOURCES PLANNING

BREEDE RIVER BASIN STUDY

PAPENKUILS WETLAND

INTERMEDIATE RESERVE DETERMINATION

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DEPARTMENT OF
WATER AFFAIRS AND FORESTRY

BREEDE RIVER BASIN STUDY

PAPENKUILS WETLAND

INTERMEDIATE (ECOLOGICAL) RESERVE DETERMINATION
(LOW CONFIDENCE)

Final

MAY 2003

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BREEDE RIVER BASIN STUDY

PAPENKUILS WETLAND
INTERMEDIATE (ECOLOGICAL) RESERVE DETERMINATION
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EXECUTIVE SUMMARY

RESERVE DETERMINATIONS UNDERTAKEN FOR THE BREEDE RIVER BASIN STUDY

Environmental sustainability forms one of the cornerstones of the National Water Act. In recognition of this, and to provide the information that would be required to set Preliminary Reserves in the Breede Water Management Area, a considerable portion of study resources was directed toward determining the ecological water requirements of the aquatic ecosystems in the catchments of the Breede River.

Reserve determinations were carried out for the following components of the Reserve :

- The Papenkuils Wetland. (The subject of this report.)
- Riverine water quantity, documented in Report PH 00/00/1302 *Ecological Reserve Determination for Six Representative Sites using the Building Block Methodology.*
- Riverine water quality, documented in Reports PH 00/00/3402 *Ecological Reserve Determination (Water Quality)*, and PH 00/00/3602 *Ecological Reserve Determination (Water Quality) – Recalculation of the Water Quality Reserve.*
- The Breede River Estuary, documented in Report PH 00/00/1102 *Intermediate Determination of Resource Directed Measures for the Breede River Estuary.*
- Groundwater, documented in Report PH 00/00/1202 *Groundwater Reserve Determination.*

The geographical spread and confidence levels of the determinations were planned to deliver, as far as present knowledge and available resources permitted, Reserve determinations commensurate with the management needs of the Breede River catchments. The study findings represent scientific estimates of the ecological water requirements of the aquatic ecosystems. The socio-economic implications of the implementation of Reserves at the recommended levels (Ecological Management Categories) should be carefully considered prior to the setting of preliminary Reserves. Before a final Reserve can be adopted, a separate stakeholder consultation process must first take place.

Numerous interrelations exist between the different components of the Reserve in the Breede River Basin. These had to be taken into account to provide an accurate reflection of current and future water availability. This information will also be required when setting a Preliminary Reserve, and to manage the system accordingly. Relatively simple integration procedures were therefore developed during the course of the Study, and the findings of this work are reported on in the *Main Report* of the Study (Report PH 00/00/3102)

Very little experience has thus far been gained in the implementation and management of Reserves in South Africa, and little is known about the effectiveness of the ecological water requirements (EWRs) in achieving the recommended ecological management categories. In recognition of the limited experience available, further study work was approved to explore the implications that the system-wide implementation of recommended EWRs may have on water availability in the Basin. This work is also documented in the *Main Report*.

THE PAPENKUILS WETLAND

The Papenkuils Wetland is located next to Brandvlei Dam, downstream of the confluence of the Smalblaar (Molenaars) and Breede Rivers (Figure E1). The Smalblaar and Breede Rivers have their confluence directly to the north of the wetland, and bypass the wetland to the north-west and north-east, respectively. Both rivers may overflow into the wetland during high flow conditions. The Holsloot River drains into the wetland from the west, and provides most of the surface runoff to the wetland.

The Papenkuils is a rare and important example of a wetland that contains a variety of wetland and terrestrial flora that are worthy of conservation. Certain of the plant communities present in the Papenkuils Wetland are not conserved anywhere else. There are no other wetlands within the Breede River Basin Study (BRBS), nor any in a condition that would offset the total or partial loss of wetland functions provided by the Papenkuils. This wetland is presently negatively impacted upon by reduced water availability and retention, as a consequence of anthropogenic activities within the catchments of the influent rivers and within the wetland itself, and on account of redirection of flows from the Holsloot and Smalblaar Rivers to Greater Brandvlei Dam. The wetland's moderate to high (B/C) Ecological Importance and Sensitivity category is offset by a declining C-category Present Ecological Status, which implies the need for rehabilitation to mitigate this disparity. Any further reduction in the availability of water for the wetland, such as might be the result of additional upstream abstractions and impoundments, would bring about further drying and deterioration, as well as reducing the recharge of groundwater that is currently occurring via the wetland. Inundation of the wetland as a consequence of impoundment would lead to its complete loss.

In the absence of supporting hydrological and hydraulic information for the wetland, the Reserve can only be expressed as a combination of water level and frequency of attainment of this. The yields of possible future water resource developments were determined after allowing for provisional riverine Reserves, and are documented in Reports PH 00/00/2602 *Regional Yield Assessment* and PH 00/00/2702 *Regional Scheme Development Options and their Environmental Implications*. The volumetric requirements of the Papenkuils Wetland are not known at present, and were not taken into account in the determination of scheme yields. The Breede and Smalblaar Rivers do not flow directly into the Papenkuils, and only overflow into the wetland during high flow conditions. Possible schemes such as the Michell's Pass Diversion in the Upper Breede River, and the Molenaars Diversion rely on run-of-river abstractions, and are therefore not expected to reduce inflows to the wetland. This should be confirmed with further studies in the event that one, or both of these schemes be considered for implementation. Increased diversions from the Breede River to Greater Brandvlei Dam at the existing Papenkuils pump station would not impact on the wetland, as the diversion point is located downstream of the southernmost extent of the wetland.

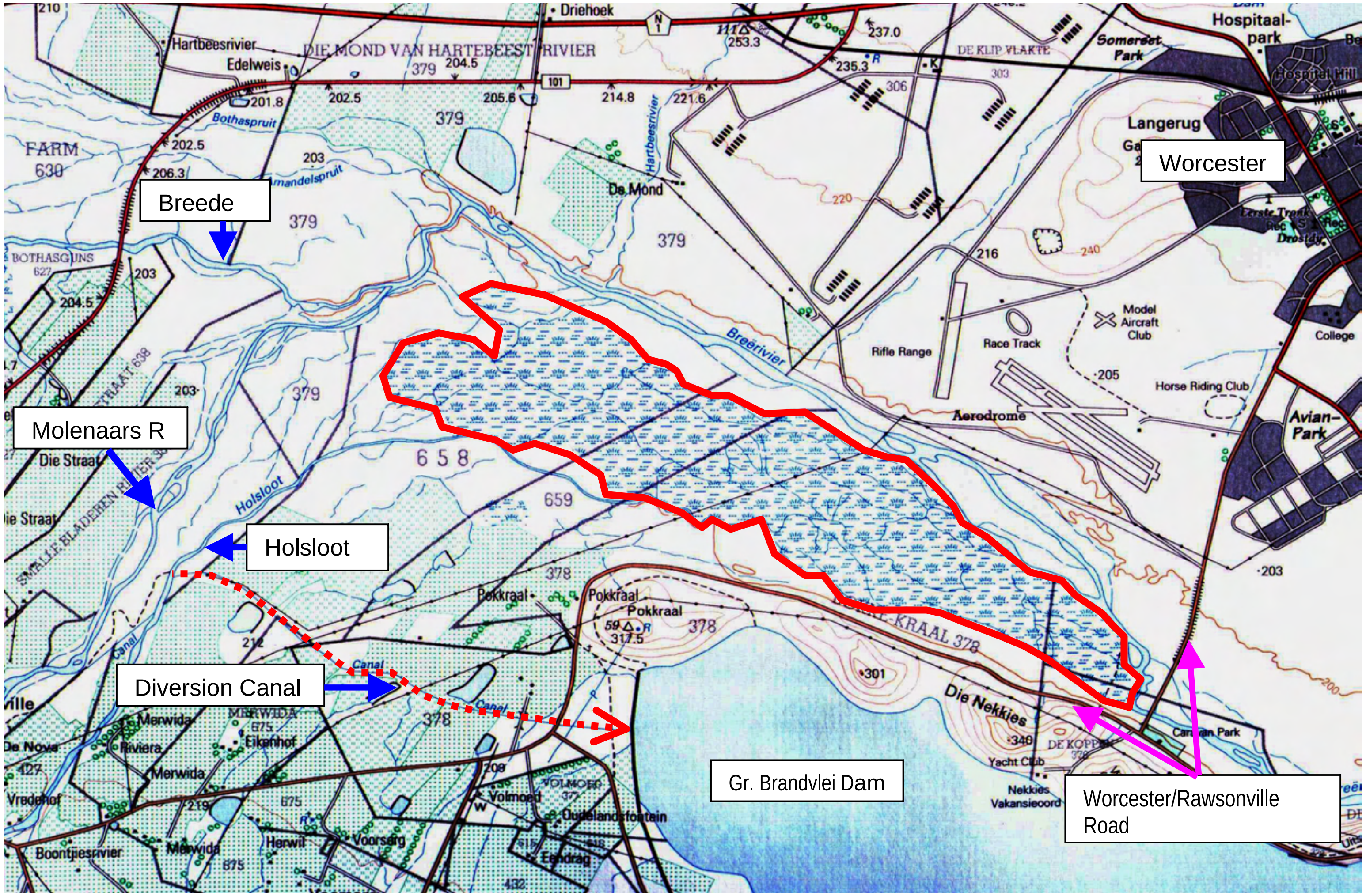

Figure E1: Extract from SA 1:50 000 3319CB Worcester showing the Papenkuils Wetland (red line); the major rivers associated with the wetland; the canal diverting water from the rivers to Greater Brandvlei (dotted red line).

On a preliminary basis, the Intermediate Ecological Reserve (Quantity) for the Papenkuils Wetland is defined as those conditions of flooding that result in the wetland being filled to a water surface level of about 199 m above mean sea level. During a hydrological year, all floods providing this level of inundation, as allowed by the existing hydraulic constraints between the Holsloot (Smalblaar), Molenaars and Breede Rivers, should be allowed to enter the wetland. It is provisionally estimated that complete inundation to the specified level should occur on 3 to 5 occasions during an annual hydrological cycle. The extant flooding cycle, as defined by the aforementioned constraints, is deemed to be the minimum acceptable flooding regime necessary to sustain the wetland in its present form. Any improvement in the extant condition of the wetland will require mitigation of the present physical restrictions limiting the flow of water between the river and the wetland, or drainage of the wetland via the man-made channels.

The preliminary Intermediate Ecological Reserve (Quality) is set as the maintenance of the extant identified riverine water quality for the wetland's feeder rivers.

Given the constraints, the level of confidence associated with this Reserve Determination is perforce Low.

Further studies should be undertaken to fully assess the potential impacts of future developments in the wetland feeder rivers, and to facilitate management of the system. The possibility of mechanical intervention to rehabilitate the system by, for example, diverting flows from the main channel of the Breede River into the wetland, should also be investigated.

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BREEDE RIVER BASIN STUDY

PAPENKUILS WETLAND INTERMEDIATE (ECOLOGICAL) RESERVE DETERMINATION

(LOW CONFIDENCE)

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ABBREVIATIONS

AMSL	above mean sea level
BRBS	Breede River Basin Study
ºC	degrees Centigrade
DTM	Digital Terrain Model
DWAF	Department of Water Affairs and Forestry
EIS	ecological importance and sensitivity
EMC	ecological management category
ha	hectares
IER	intermediate ecological Reserve
IFR	instream flow requirements
km^2	square kilometres
m	metres
mm	millimetres
%	percentage
PES	present ecological state
RDM	Resource Directed Measures
TMG	Table Mountain Group

PH 00/00/1402

BREEDE RIVER BASIN STUDY

PAPENKUILS WETLAND
INTERMEDIATE (ECOLOGICAL) RESERVE DETERMINATION
(LOW CONFIDENCE)

1. BACKGROUND TO THE DETERMINATION

The assessment of the Papenkuils Wetland (Breede River, Worcester; see Figure 1) forms a sub-component of the aquatic ecosystem assessment of the Breede River Basin Study (BRBS). The objectives of the parent study (Report PH 00/00/1302 : *Ecological Reserve determination for Six Representative Sites using the Building Block Methodology*) are to :

i. assess the present condition of the aquatic ecosystems within the BRBS study area;
ii. determine the Ecological Reserve for the key river reaches and principal wetlands;
iii. assess the possible impacts on the aquatic ecosystems associated with several identified water development options;
iv. recommend future action with respect to the sustainable utilization of the assessed aquatic ecosystems.

Although the Breede River system encompasses several wetlands, the Papenkuils Wetland lies within an area that could, potentially, be impacted upon by a number of developmental options intended to augment water supply to Greater Brandvlei Dam. Accordingly, this was the only wetland for which detailed assessment was carried out as part of the BRBS study.

At the first meeting of the Environmental Working Group which was held in June 2001, a concern was expressed that the wetlands in the Breede River Basin are poorly known, and that it is likely that a number of these wetlands could be negatively impacted on by the development options that have been identified during the course of the Study. The Working Group recommended that a mapping exercise be conducted to identify these wetlands, and that a preliminary assessment of their conservation importance and sensitivity be made.

Additional funds were made available for this purpose, and sixteen further wetland zones (excluding the Papenkuils Wetland) were identified in the remainder of the Basin. A preliminary assessment of the condition and ecological importance of these wetlands was carried out, and documented in Report PH 00/00/2702 : *Scheme Development Options and their Environmental Implications*.

2. SCOPE AND CONSTRAINTS

2.1 In order to inform the derivation of an Ecological Reserve for the Papenkuils Wetland, a **limited wetland assessment** was undertaken, based on existing information and the prevailing botanical characteristics, and supported by *ad hoc* geohydrological and avifaunal interpretation, i.e. no team-based assessment process, as was employed for the Pienaars River (Oryx Environmental, 1999) was possible. Within the scope of the budget provided, the wetland assessment was furthermore conducted as a stand alone component, i.e. **no allowance was made in the parent study for integration of the river and wetland components, particularly those pertaining to hydrology, hydraulics, geohydrology and water quality**. The lack of an opportunity to link the water requirements of the wetland to water availability in the feeder rivers was, at the outset, identified as a major constraint to this assessment. Assessment of the importance of the wetland in terms of the downstream river environment was precluded by the absence of instream flow requirement (IFR) sites proximal to the wetland.

2.2 There is an absence of appropriate wetland assessment methodologies provided for by the resource directed measures (RDM), particularly with regard to linking river and wetland hydrology and hydraulics. Compensation for this lack of appropriate methodologies, by integrating the river and wetland components of the study was not provided for in the study.

2.3 Timing of the detailed field assessment precluded identification of the geophytic elements and spring annuals, or indeed any seasonal appreciation over a full hydrological year. Furthermore, budget constraints limited the assessment to the eastern sector of the wetland (see Figure 2).

2.4 The wetland was assessed following several years of below-average rainfall and high ambient summer temperatures, i.e. during a period of atypical stress and consequently depauperate flora and fauna.

2.5 Accordingly, the wetland assessment is perforce supported by limited data collection and conceptual interpretation. The confidence with which the assessment is made is rated as Low.

It should be noted that this was one of the first assessments conducted with the intent of determining an ecological reserve for a wetland. In this regard the work served as a pilot investigation for future wetland assessments.

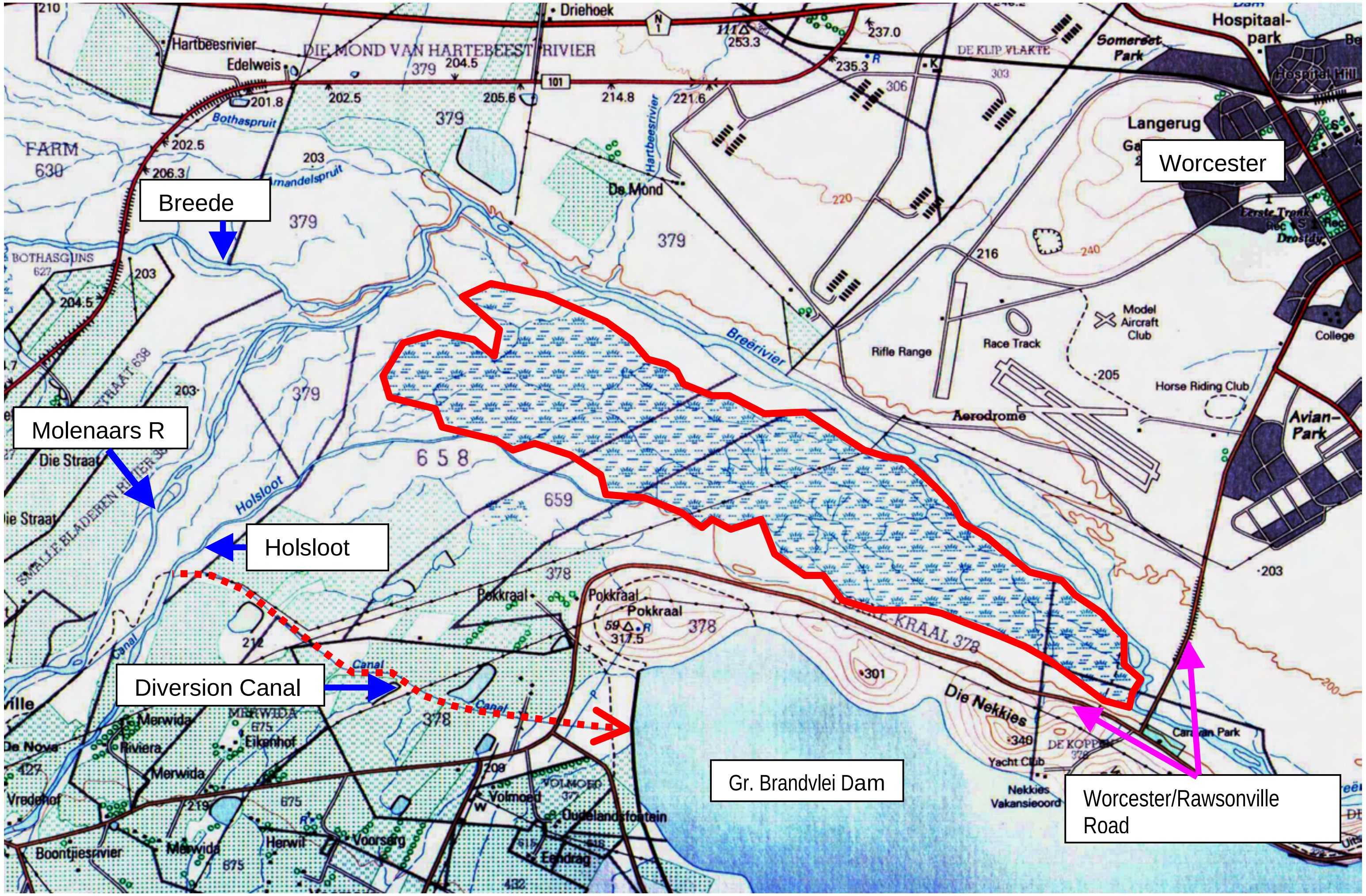

Figure 1: Extract from SA 1:50 000 3319CB Worcester showing the Papenkuils Wetland (red line); the major rivers associated with the wetland; the canal diverting water from the rivers to Greater Brandvlei (dotted red line).

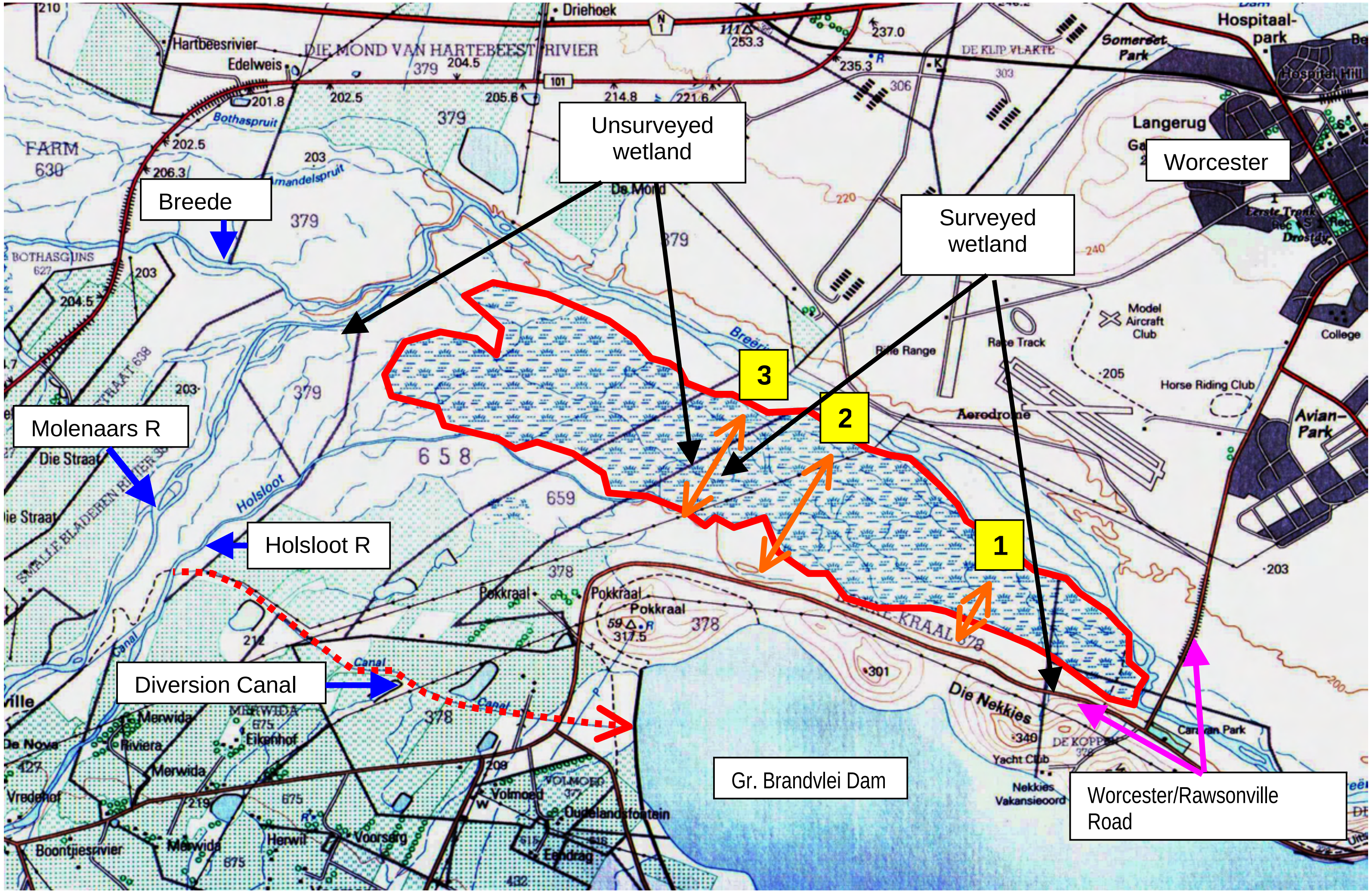

Figure 2: Extract from SA 1:50 000 3319CB Worcester showing the approximate location of the botanical survey transects (1 & 2), and the geohydrological transect (3) referred to in the text.

3. STUDY TEAM

The Papenkuils Wetland assessment team comprised the following:

- Dr W R Harding (Southern Waters; wetland ecology)
- Dr C Boucher (University of Stellenbosch, botany)
- Mr M C Briers (Surveyor)

The team was assisted by Mr G. Papini (Groundwater Consulting Services), and Dr J Turpie (Southern Waters; avifaunal specialist), who provided further input. Technical support was provided by Ms A. Rode (University of Stellenbosch), Mrs J.F. Ewart-Smith and Mr C. Pemberton (Southern Waters).

4. AVAILABILITY OF DATA

No previously collected data were identified for the Study Area. Historical and current aerial photography, spanning the period 1945-2000, provided substantial information pertaining to changes in the wetland in response to the development and utilization of water resources, in particular reduced water availability to the wetland as a consequence of the diversion of the Holsloot and Molenaars Rivers to Greater Brandvlei Dam. Various *ad hoc* items of information were sourced from local landowners.

5. PROCEDURE ADOPTED

This assessment followed the Final Procedure for the Intermediate Determination of Resource Directed Measures (RDM) for Wetland Ecosystems, i.e. an Intermediate Ecological Reserve (IER), as contained in the Department of Water Affairs and Forestry Reports (DWAF, 1999a,b). This methodology is still under development, and has not been tested or subjected to evaluation on an inter- or intra-wetland-type scale, or at local or regional scales (DWAF, 2001) (see also Section 2, Scope and Constraints). It should be noted that the confidence level of application of the methodology is not comparable with that for the riverine components of the BRBS.

The draft methodology as specified incorporates the following assessment steps relevant to this assessment:

Step 1: Delineate the boundaries of the wetland;
Step 2: Determine the eco-regional type of the wetland;
Step 3: Determine the reference conditions;
Step 4: Determine the Present Ecological Status;
Step 5: Determine the Ecological Management Category;
Step 6: Set the Reserve (quality and quantity);

Application of the procedure encompassed a three-day working site visit in January 2001, supported by seasonal visits to the wetland for the collection of photographic records of water levels and the degree of inundation of the system. In addition, low-level aerial photography was undertaken during several overflights between September 2000 and December 2002 to support the vegetation and topographical assessments. The detailed assessment was based on the botanical, substrate and topographical analysis of two transects that were surveyed in January 2000 (see Figures 1 and 2; and Appendix A), and one transect that was surveyed in April 2001 to determine hydraulic conductivity (see Figure 1, Appendix B).

6. RESULTS

STEP 6.1 : DELINEATION OF GEOGRAPHICAL BOUNDARIES

The Papenkuils Wetland is situated downstream of the confluence of the Holsloot (Smalblaar), Molenaars and Breede Rivers. The physical boundaries of the wetland are well defined by the geomorphological characteristics of the area, as follows (see Figure 1):

North:	Breede River (right bank);
South:	Ridge of hills between Greater Brandvlei Dam and the wetland;
East:	Breede River (right bank) and the Worcester/Rawsonville north-south road (eastern outlet of the wetland defined by the topographic constriction between Die Nekkies and the high ground south of Worcester;
West:	Holsloot and Molenaars Rivers (right banks).

STEP 6.2 : ECO-REGIONAL CATEGORIZATION

The Papenkuils Wetland is a 900 ha seasonal floodplain palustrine scrub-shrub wetland situated downstream of the confluence of the Holsloot (Smalblaar), Molenaars and Breede Rivers. The wetland is located in the upper mid-reaches of the Breede River catchment.

The following details pertaining to the eco-regional classification have been extracted from Report PH 00/00/1302 : *Ecological Reserve Determination for Six Representative Sites using the Building Block Methodology*.

The Cape Fold Mountains eco-region lies to the north of the Riviersonderend Mountains and the Langeberge and encompasses the bulk of the Breede River Basin (almost 70 % or 8458 km^2). Typical characteristics of this eco-region are table lands surrounded by high mountains with high relief, low mountains with high relief, closed hills with moderate relief and open hills with high relief.

Altitude varies from 200 – 1 750 m amsl. Rock types include shale, tillite, sandstone and quartzitic sandstone overlain with sand-clay-loam, clay-loam, sand-loam, and sand-clay soils. The natural terrestrial vegetation is a mixture of fynbos, Rhenosterveld and succulent karoo types. Rainfall varies from 100 - >1 200 mm a^{-1} and mean annual temperature is between 10 and 20 °C.

Five sub-regions have been identified within the Cape Fold Mountain Belt eco-region, namely mountain streams, foothill-cobble bed and foothill-gravel bed rivers, upland floodplains and rejuvenated cascades. Of these the latter two are rare, with the rejuvenated cascades being confined to gorges on the middle reaches of the Brak, Konings and Buffeljags Rivers, and upland floodplains occurring in the upper reaches of the Modder and Koekedouw Rivers near Ceres and the Brak River.

The underlying geology of the Breede River Basin comprises a diversity of metamorphic, igneous and sedimentary lithologies. Sediments derived mainly from quartz sands are transported via the high gradient river systems originating in the upper reaches of the catchment. Since geology is a primary determinant in both the distribution of natural vegetation and the crops, land use patterns in the Breede Basin reflect those of the natural vegetation. The Rhenosterveld vegetation, which would normally have been found on shales, mudstones and sandstones, has been almost entirely replaced by crops.

The water regime category is Category 2, i.e. seasonally (winter) flooded (wetness very severe) (Kotze *et al*, 1994). The wetland encompasses the distal facies of an alluvial fan, and is comprised of sand and mud (GCS, 2001).

STEP 6.3 : REFERENCE CONDITIONS

6.3.1 Pattern of Historical Change

Elucidation of the reference character of the Papenkuils Wetland was made using aerial photography (SA Trigonometric Survey) spanning the period 1942 to 1997. This analysis was supported by limited ground truthing. Severe dessication of the western zone of the wetland, and a reduced overall frequency of inundation, have been caused by:

- diversion of water from the Holsloot and Molenaars systems to Greater Brandvlei Dam;
- large scale abstraction of groundwater throughout the recharge area, especially to the west and south-west;
- deliberate internal drainage of the wetland;
- reduced rainfall. The rate of loss of original (pre-1940s) character, evident as reduced penetration of the major river (Holsloot) along the central and southern west to east axes of the wetland, appears to have increased post-1970.

Anecdotal evidence suggests that flooding of the southern and eastern zones of the wetland may be a function of backflooding caused by a combination of topographic and vegetation constrictions at the wetland outlet. Observations made during peak flood events during 2001 revealed, however, that inundation of these areas was due to water entering the wetland via the Holsloot channel.

The northern boundary of the wetland, adjacent to the Breede River, has become densely invaded with woody aliens, to the extent that almost impenetrable forest areas exist along the shoreline.

6.3.2 Reference Conditions

The Papenkuils Wetland formed the distal facies of an alluvial fan, having its source in the Table Mountain Group (TMG) mountains to the south and south-west. The wetland comprised a meandering and braided series of streams and channels, up to 2 m in depth and 50 m in width, modified by sedimentary deposits. These were principally fed by the Holsloot River, and to an undetermined extent by the Molenaars Rivers, and indirectly (overbank flooding) from the Breede. Relatively rapid draining of the wetland following flooding may be due to the existence of an underlying clay horizon. The annual inundation of the wetland is likely to have supported recharge of the shallow floodplain sediments, with this recharge augmented by groundwater from the TMG and Bokkeveld aquifers.

The wetland would have been completely inundated to a level of 198-199 m above mean sea level (m amsl) on an undetermined number of occasions during the winter. Water would have remained at or above the surface until early or mid-summer (November to January), and thereafter with groundwater expressions in the deep hollows, until the onset of the following seasonal rains. Flow regimes would have encompassed a wide range of variability, with this range of fluctuation constituting a major driving force in forming and maintaining the vegetation zonation.

The vegetation would have been dominated by a diverse assemblage of Rhenosterveld and Sand Plain Fynbos, with physiognomic elements of salt marsh and azonal riparian flora. Dominant vegetative characteristics would be grasslands (*Themeda* sp.) with palmiet (*Prionium serrulatum*)-lined permanent river channels, interspersed with elevated meadows and sedge zones.

The wetland would have been moderately important for waterfowl (Dr J. Turpie, Southern Waters, personal communication). Prior to the enhanced drainage of the wetland, the channels and deep pools may have provided a refuge for fish for several months.

The grassland areas of the wetland are utilized at a low level for grazing (cattle). The collection of *Apongogeton* ('waterblommetjies') is informally practiced during the spring, both in the wetland and in the isolated pools that form once the floodwaters recede.

STEP 6.4 : PRESENT ECOLOGICAL STATUS (PES)

6.4.1 Basis for the PES Evaluation

The Present Ecological State was determined on the basis of the type, location, botanical uniqueness (see Appendix A) and hydrological (groundwater recharge) importance (see Appendix B) of the wetland. Notwithstanding the fact that the wetland assessment was conducted at a time when the full floral assemblage (annuals and geophytes) could not be assessed, the wetland was found to contain in excess of 100 species encompassing four floral elements. This amounts to a very diverse and unusual assemblage of very different elements within a relatively small spatial footprint. Furthermore, the floral characteristics are unusual for the Fynbos Biome. The wetland is deemed to be richer than many other wetlands within the Fynbos Biome, and contains stands of *Themeda* sp. (rooigras) that are very rare in the south-western Cape. The patterns of vegetation zonation are related to a perceived high level of flow variability (temporal and spatial) (see Appendix A).

Reduced inundation and rapid drainage of the wetland will have limited the value of the system as a refuge for fish. No fish were observed in the isolated pools present during the summer of 2001, but shoals of barbel (*Clarias gariepinus*) were observed spawning in the strongly-flowing southern wetland channels during September 2001.

The Papenkuils Wetland is the only wetland of its size and type occurring in the Breede River system. This observation is made on the basis of expert opinion, and is not supported (see Section 2) by a comprehensive survey of the size and type of all wetlands within the catchment area of the Breede River.

6.4.2 Water Quantity

Examination of historical aerial photography clearly shows reduced penetration of both the Holsloot and Molenaars River channels into the central and southern wetland. This is a consequence of the diversion of said rivers to Greater Brandvlei Dam. Complete inundation of the southern wetland occurred during September 2001 as a result of strong flows entering the system from the Holsloot. While the absence of any hydraulic information precludes any assessment of the inter- or intra-annual frequency of such flooding, it is highly probable that this occurred on a much greater intra-annual frequency than is currently the case.

It should be noted that the Terms of Reference for this assessment precluded the crucial determination of water volumes and timing necessary to sustain the wetland environment, and the impact of these allocations on the downstream Breede River. Accordingly, the downstream IFR-based Reserve will require qualification once the quantity and timing component for the wetland has been quantified (see Section 6.7).

6.4.3 Water Quality Issues

The scope of this assessment did not include the collection of water quality data for the wetland. The establishment of a meaningful, once-off water quality assessment protocol would have placed punitive pressure on the limited budget available for the IER determination. Observations made within the wetland at various times throughout the period December 1999 to September 2001 did not reveal evidence of eutrophication attributable to extraneous sources of nutrient loading. Furthermore, the assessment of water quality for the river (Section 5 of Report PH 00/00/1302) indicates Category B water quality upstream of the wetland, i.e. posing limited risk of wetland impairment.

6.4.4 PES

The PES for the Papenkuils Wetland was determined using a modified version of the RDM methodology as described in DWAF (1999b) which incorporates a wider consideration of wetland functions and services as shown in Table 1 (Southern Waters, 2001). Derivation of the assessment is detailed in Tables 2 and 3. (**Note** : All tables appear at the end of the main text of this report).

The wetland was deemed to be in a Category C condition (Table 2 *vs* Table 3) i.e., moderately modified but with some loss of habitat. Although not quantified (see Section 2), it was clearly evident that the current pattern of hydrological/hydraulic impairment places the wetland PES on a downward trajectory towards a D category.

The assessment concurred with that applied for the associated reach of the Breede River, viz. a PES category of C/D, with a medium-term trajectory towards a Category D (Southern Waters, 2001b).

STEP 6.5 : ECOLOGICAL IMPORTANCE AND SENSITIVITY (EIS) AND ECOLOGICAL MANAGEMENT CATEGORY (EMC)

6.5.1 EIS

As for the PES (Section 6.4.4), the EIS was similarly determined using a modified version of the RDM methodology (Southern Waters 2001a). With respect to the scoring of ecological criteria, a precautionary approach was adopted by allocating a minimum score of 1 in all cases where no data or information was available. The deemed EIS was determined as a B category (see Table 4 for scoring of ecological, functional and socio-cultural criteria).

6.5.2 EMC

Given the botanical uniqueness and hydrological (recharge) roles of the wetland, and the need to sustain and conserve both, the Ecological Management Category for the Papenkuils Wetland is set as a C/B (see Table 5). This implies the need to mitigate the impairment of flow regimes other than those caused by inter-annual climatic variation.

STEP 6.6 : DETERMINATION OF THE RESERVE

6.6.1 Approach

This assessment sought to define the Ecological Reserve for the Papenkuils Wetland in terms of quantity. Currently no models or tools exist to link wetland structure and hydrology, or to define the links between wetland hydrology and function (DWAF, 1999b). Seasonal observations made during the course of this study allowed the high water mark (maximum inundation level) for the Papenkuils Wetland to be identified and captured as a contour height, viz., 198.97 m AMSL, thus facilitating the interim expression of the Reserve (quantity) as a water level.

6.6.2 Preliminary Reserve (Quantity)

On a preliminary basis, the Intermediate Ecological Reserve (Quantity) for the Papenkuils Wetland is defined as those conditions of seasonal flooding that result in the wetland being filled to a water surface level of 198.97 m AMSL (height based on Trigonometrical Beacon 207, X=3724351.84; Y=-39185.97; Z=289.5); and that, during a hydrological year, all floods providing this level of inundation, as allowed by any or all existing hydraulic constraints implemented on the Holsloot (Smalblaar), Molenaars and Breede Rivers, be allowed to enter the wetland. It is provisionally estimated that complete inundation to the specified level should occur on a minimum of between 3 and 5 occasions during an annual hydrological cycle. The extant flooding cycle, as defined by the aforementioned constraints, is deemed to be the minimum acceptable flooding regime necessary to sustain the wetland in its present form and pattern of change. Any improvement in the extant condition of the wetland will require mitigation of the present physical restrictions limiting the flow of water between the rivers and the wetland, as well as the drainage of the wetland via the man-made channels.

6.6.3 Preliminary Reserve (Quality)

It was not possible to develop a nutrient loading budget and water quality model for this wetland within the constraints of the assessment (see Section 2). Accordingly, and given the identified water quality for the river reach(es) upstream of the wetland (Section 5, Southern Waters, 2001b), the preliminary Reserve (Quality) for the Papenkuils is set as nil degradation of the extant water quality of the feeder rivers upstream of the wetland.

STEP 6.7 : RECOMMENDATIONS FOR FURTHER INVESTIGATION AND MONITORING

The following recommendations are made for further work and monitoring deemed necessary to support the refinement of the IER provided by this assessment. The following should be undertaken:

- Botanical re-assessment of the two transects surveyed for this study, together with the inclusion of two additional transects in the western (un-surveyed) sector of the wetland. This should be undertaken during late spring/early summer so as to capture the presence of annual and geophyte species;
- Elucidation of the hydraulic interface(s) between the rivers and the wetland, and the size and duration of flood flows necessary to inundate the wetland to the specified levels and frequency;
- Formulation and calibration of a digital terrain model (DTM) for the wetland;
- Development and expansion of the conceptual model of the interactions between groundwater and the wetland/river;
- Identification of those man-made drainage lines between the wetland and river, the closure of which would offset the present rate of wetland drainage;
- Comprehensive avifaunal, herpetofaunal and small mammal assessments;
- Fixed point photography (weekly intervals) to inform the understanding of the process and duration of filling and draining of the wetland. This could be readily undertaken from the vantage point of the high ground adjacent to the southern end of the wetland;
- Integration of the river and wetland disciplines in order to develop the understanding of the interaction between the two in terms of ecological functioning;
- Expansion of the wetland study to include preliminary assessment and ranking of the ecological and functional value of all of the wetlands within the Breede River Basin.

7. DISCUSSION AND CONCLUSIONS

The Papenkuils is a rare and important example of a wetland that contains a variety of wetland and terrestrial flora that are worthy of conservation. Certain of the plant communities present in the Papenkuils Wetland are not conserved anywhere else. There are no other wetlands within the Breede River Basin, in a condition that would offset the total or partial loss of wetland services provided by the Papenkuils. This wetland is presently negatively impacted upon by reduced water availability and retention as a consequence of anthropogenic activities within the catchments of the three influent rivers, and redirection of flows to Greater Brandvlei Dam. The wetland's moderate to high (B/C) Ecological Importance and Sensitivity category is offset by a declining C category Present Ecological Status, and implies the need for rehabilitation to mitigate this disparity. Any further reduction in the availability of water for the wetland, such as would be the result of additional upstream abstractions and impoundments or the construction of additional drainage channels within the wetland, will bring about further drying and deterioration, as well as reducing the recharge of groundwater that is currently occurring via the wetland. Inundation of the wetland as a consequence of impoundment would lead to its complete loss.

In the absence of supporting hydrological and hydraulic information for the wetland, the Reserve can only be expressed as a combination of water level and frequency of attainment of this. The yields of possible future water resource developments that were investigated as part of the BRBS, were determined after allowing for provisional riverine Reserves, and are documented in Reports PH 00/00/2602 *Regional Yield Assessment* and PH 00/00/2702 *Regional Scheme Development Options and their Environmental Implications*. The volumetric requirements of the Papenkuils Wetland are not known at present, and were not taken into account in the determination of scheme yields. The Breede and Smalblaar Rivers do not flow directly into the Papenkuils, and only overflow into the wetland during high flow conditions. Possible schemes such as the Michell's Pass Diversion in the Upper Breede River, and the Molenaars Diversion rely on run-of-river abstractions, and are therefore not expected to reduce inflows to the wetland. This should be confirmed with further studies in the event that one, or both of these schemes be considered for implementation. Increased diversions from the Breede River to Greater Brandvlei Dam at the existing Papenkuils pump station would not impact on the wetland, as the diversion point is located downstream of the southernmost extent of the wetland.

On a preliminary basis, the Intermediate Ecological Reserve (Quantity) for the Papenkuils Wetland is defined as those conditions of flooding that result in the wetland being filled to a water surface level of 198.97 m amsl (height based on Trigonometrical Beacon 207, X=3724351.84; Y=-39185.97; Z=289.5). During a hydrological year, all floods providing this level of inundation, as allowed by any or all existing hydraulic constraints between the Holsloot (Smalblaar), Molenaars and Breede Rivers should be allowed to enter the wetland. It is provisionally estimated that complete inundation to the specified level should occur on a minimum of between 3 and 5 occasions during an annual hydrological cycle. The extant flooding cycle, as defined by the aforementioned constraints, is deemed to be the minimum acceptable flooding regime necessary to sustain the wetland in its present form. Any improvement in the extant condition of the wetland will require mitigation of the present physical restrictions limiting the flow of water between the river and the wetland, or drainage of the wetland via the man-made channels.

The preliminary Intermediate Ecological Reserve (Quality) is set as the maintenance of the extant identified riverine water quality for the wetlands' feeder rivers.

The level of confidence associated with this Reserve Determination is Low.

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TABLE 1 : SUMMARY OF FUNCTIONS AND VALUES PROVIDED BY WETLANDS

All of the listed services are provided by the Papenkuils Wetland to a greater or lesser degree

FUNCTION	SERVICE PROVIDED	SOCIETAL VALUE	INDICATOR
Hydrologic			
Short-term water retention	Flood peak attenuation	Protection from flooding	River corridor floodplain
Long-term water retention Groundwater discharge	Maintenance of base flows	Habitat maintenance during dry season; Water supply Climate modification	Floodplain
Maintenance of water table	Groundwater recharge; Maintenance of hydrophytic community	Water supply; Maintenance of biodiversity	Presence of aquifer; Hydrophytes
Hydraulic			
Erosion protection	Bank and shoreline protection, energy dissipation, flow and discharge attenuation		
Biogeochemical			
Element transformation and cycling	Nutrient transformation	Vegetative production	Reeds, trees and shrubs
Retention, removal of dissolved substances	Reduced downstream transport of nutrients	Water quality enhancement	Reduced nutrient levels in outflow
Accumulation of peat	Retention of nutrients, trace metals and other elements	Water quality enhancement	Accretion of peat layer
Accumulation of inorganic sediments	Sediment and nutrient retention	Water quality enhancement	Sediment accumulation
Habitat and food chain (life) support			
Maintenance of characteristic plant communities	Food, refuge and nesting sites for birds and animals	Support for waterfowl	Mature and robust wetland vegetation
Maintenance of characteristic energy flows	Support for populations of vertebrates	Maintenance of biodiversity	High biodiversity
Production	Generation of human use products	Economic or subsistence resource	Yield
Socio-cultural			
Open space and aesthetics	Outdoor recreation; environmental education; Research opportunities; Heritage preservation	Cultural resource	Level of recreational use

TABLE 2 : PRESENT ECOLOGICAL STATUS ASSESSMENT PROCEDURE FOR WETLANDS (PALUSTRINE, LACUSTRINE)

WETLAND NAME : Papenkuils
POSITION : Lat : Long :

MAP REFERENCE : SA 1:50 000 : 3319CB Worcester
SIZE (ha) : 900

ASSESSMENT

CRITERIA AND ATTRIBUTES	RELEVANCE	SCORE	CONFIDENCE
HYDROLOGIC		**One score or mean per criterion**	
Flow Modification	• flows reduced by abstraction (surface and/or groundwater, upstream or within wetland) or impoundment (dams, weirs or spillways), alien plant infestation or silviculture; • increased runoff from hardened catchment, agricultural drains, effluent disposal or change in watershed:wetland ratio; • alteration in flow regime (timing, duration, frequency, volume or velocity); • outflows constricted by vegetation; • altered inundation pattern of wetland habitats resulting in floristic changes or incorrect cues to biota.	2	
Permanent Inundation	• impoundment or water level regulation resulting in destruction of natural wetland habitat	N/a	
Water Quality			
Water Quality Modification (nutrient loading and/or toxics and/or faecal pollution)	• from surface or groundwater point and/or diffuse sources (agricultural activities, human settlements, industrial or wastewater effluent); • internal loading from accumulated sediments; • aggravated by volumetric decrease in flow delivered to the wetland (scored under flow modification); • change in ambient (desired) salinity as a consequence of altered freshwater or marine intrusion.	3	
Sediment Load Modification	• reduction due to upstream retention by impoundment; • increase due to land use practices such as overgrazing, unnatural rates of erosion or in-filling, and resulting in atypical accretion and/or turbidity.	2	
Hydraulic/Geomorphic			
Canalisation/culverts	• desiccation, shrinkage, altered inundation patterns and changes in habitats; • point discharges as opposed to broad or sheet flows.	2	
Topographic Alteration/ Habitat Fragmentation	• consequence of infilling, ploughing, dykes, causeways, trampling, bridges, roads, railway lines and other substrate disruptive physical changes that alter wetland habitat either directly or through changes in inundation patterns.		
Biotic			
Terrestrial Encroachment	• desiccation of wetland and/or encroachment of terrestrial plant species due to changes in hydrology, geohydrology or geomorphology, resulting in a change from wetland to terrestrial (upland) habitat and associated loss of wetland function.	3	
Loss of Shoreline (riparian) and/or fringing Vegetation (indigenous)	• loss or reduction in herbaceous or woody vegetation cover, and/or increased distance between upland vegetation and permanent water; • switch from macrophyte to algal dominance; • loss of critical riparian or upland vegetation as a consequence of development, farming activities, grazing or firewood collection affecting wildlife habitat, overland attenuation of flows, input of organic matter or increased potential for erosion; • loss of shading.	1	
Invasive Plant Encroachment	• altered habitat characteristics through changes in community structure and/or water quality (oxygen reduction and shading), (lacustrine only)		
Faunal Disturbance/ Alien Fauna	• faunal disturbance due to human presence, domestic animals, noise, light, footpaths, roadways, airports, electricity servitudes; • presence of alien fauna affecting faunal community structure (e.g. top down imbalance due to coarse fish, excessive zooplankton grazing etc; bird predation; gerbils); • atypical fauna due to human presence.	3	
Over-utilisation of biota	• overgrazing, fishing, mowing, burning or harvesting leading to alterations and imbalances in community structure and foodweb interactions.	4	
TOTAL SCORE **MEAN** (determined as Total Score / number of attributes evaluated)		24 2.7 (Class C)	1 (see text)
Scoring guidelines per attribute : Natural, unmodified = 5; Largely natural = 4; Moderately modified = 3; Largely modified = 2; Seriously modified = 1; Critically modified = 0. (please refer to definition of "reference condition", Section 8.4.1.1) **Relative confidence of score :** Very high confidence = 4; High confidence = 3; Moderate confidence = 2; Marginal/low confidence = 1.			

TABLE 3 : INTERPRETATION OF PRESENT ECOLOGICAL STATUS SCORE

SCORE	WETLAND DESCRIPTION	PES CATEGORY	
>4	Unmodified or approximates natural condition	**A**	**Acceptable Condition**
>3 <=4	Largely natural with few modifications, minor loss of habitat	**B**	
>2 <=3	Moderately modified with some loss of habitat	**C**	
= 2	Largely modified with loss of habitat and wetland functions	**D**	
>0 < 2	Seriously modified with extensive loss of habitat and wetland function	**E**	**Unacceptable Condition**
0	Critically modified. Losses of habitat and function are almost total, and the wetland has been modified completely.	**F**	
Note : Should any criterion (Table 8.1) be scored as < 2, then this criterion is to be taken as being the PES score, and not the mean.			

TABLE 4 : SCORING OF WETLAND IMPORTANCE (ECOLOGICAL, FUNCTIONAL AND SOCIO-CULTURAL CRITERIA)

CRITERION (SCORE ONLY RELEVANT CRITERIA)	SCORE	CONFIDENCE
Ecological	1	
1. Rare and endangered species	1	
2. Populations of unique species	1	
3. Species/taxon richness	3	
4. Diversity of habitat types or key physiognomic features	3	
5. Migration route node/breeding/feeding site for wetland species	2	
6. Sensitivity to changes in natural (prevailing) hydrology	3	
7. Sensitivity to changes in water quality	2	
8. Ecological integrity	3	
Sub-total (Ecological criteria)	19	1
Functional		
9. Groundwater storage/recharge	3	
10. Natural or created flood storage/energy dissipation	3	
11. Sediment and/or toxicant retention	3	
12. Food chain support	3	
Sub-total (Functional criteria)	12	1
Socio-cultural		
13. Protected status considerations (nature reserves, conservancies)		
14. Production (human use values other than recreation)	1	
15. Recreation/tourism/education (other than embodied in 13)		
Sub-total (Socio-cultural criteria)	1	1
WETLAND IMPORTANCE VALUE (carry forward to Table 5): [85% (Ecological sub-total/no. of criteria scored) + 10% (Functional sub-total no. of criteria scored) + 5% (Socio-cultural sub-total/no. of criteria scored).	2.4 (Class B)	1 (see text)
Score guideline Very high = 4; High = 3; Moderate = 2; Marginal/Low = 1 Confidence rating Very high = 4; High = 3; Moderate = 2; marginal/Low = 1		

TABLE 5 : RECOMMENDED WETLAND MANAGEMENT CATEGORY

IMPORTANCE CLASS (ONE OR MORE ATTRIBUTES MAY APPLY)	RANGE OF MEDIAN	RECOMMENDED WETLAND MANAGEMENT CATEGORY
Very high Representative of wetlands that : • support key populations of rare or endangered species; • have a high level of habitat and species richness; • have a high degree of taxonomic uniqueness and/or intolerant taxa; • provide unique habitat (e.g. salt marsh or ephemeral pan; physiognomic features, spawning or nursery environments); • is a crucial avifaunal migratory note (e.g. RAMSAR wetlands); • may provide hydraulic buffering and sediment retention for large to major rivers that originate largely outside of urban conurbations; • have groundwater recharge/discharge comprising a major component of the hydrological regime of the wetland; • are highly sensitive to changes in hydrology, patterns of inundation, discharge rates, water quality and/or human disturbance; • are of extreme importance for conservation, research and education.	>3 < = 4	A
High Representative of wetlands that : • support populations of rare or endangered species, or fragments of such populations that are present in other similar and geographically-adjacent wetlands; • contain areas of habitat and species richness; • contain elements of taxonomic uniqueness and/or intolerant taxa; • contain habitat suitable for specific species (e.g. physiognomic features); • provide unique habitat (e.g. salt marsh or ephemeral pan; spawning or nursery environments, heronries); • may provide hydraulic buffering and sediment retention for rivers that originate largely outside of urban conurbations, or within residential fringes of urban areas; • have groundwater recharge/discharge comprising a component of the hydrological regime of the wetland; • may be sensitive to changes in hydrology, patterns of inundation, discharge rates, water quality and/or human disturbance; • are of importance for conservation, research, education and eco-tourism.	> 2 < = 3	B
Moderate Representative of wetlands that : • contain small areas of habitat and species richness; • provide limited elements of habitat that has become fragmented by development (e.g. salt marsh, ephemeral pan; roosting sites and heronries); • provide hydraulic buffering for rivers that originate within urban areas; • are moderately sensitive to changes in hydrology, patterns of inundation, discharge rates and/or human disturbance; • perform a moderate degree of water quality enhancement, but are insensitive to sustained eutrophication and/or pollution; • are of importance for active and passive recreational activities.	> 1 < = 2	C
Low/marginal Representative of wetlands that : • contain large areas of coarse (reeds) wetland vegetation with minimal floral and faunal diversity; • have a high urban watershed:wetland area ratio; • are important for active and passive recreation; • provide moderate to high levels of hydraulic buffering; • may be eutrophic and generally insensitive to further nutrient loading; • are generally insensitive to changes in hydrology, patterns of inundation, discharge rates and/or human disturbance; • have regulated water levels and limited seasonal water level variation; • contain large quantities of accumulated organic and inorganic sediments.	> 0 < = 1	D

Appendix A

Vegetation Assessment

THE VEGETATION OF PAPENKUILS WETLAND, WORCESTER

Contents

TABLES

1. INTRODUCTION

The Papenkuils Wetland is sandwiched between Greater Brandvlei Dam and the Breede River, west of Worcester. The wetland is probably fed from water originating from the Breede River and its tributaries, the Holsloot and the Molenaars Rivers. The groundwater contribution is unknown at present. These rivers originate in the surrounding Table Mountain Group (TMG) sandstone mountains and generally contain a high quality water low in dissolved salts.

Water from both the Holsloot and Molenaars Rivers is diverted into Greater Brandvlei Dam from upstream of the Papenkuils Wetland. This diversion, together with large-scale extraction from the Breede and from the groundwater of the Holsloot and Molenaars Rivers, in particular, have a major reducing effect on the flows in these rivers adjacent to the wetland.

This study intends to describe and categorise the general vegetation, to highlight the ecological importance of the wetland, and to comment on the sensitivity of the vegetation to changes in wetland character, including comments on changes discernable from aerial and other photographs over the period 1939 to 1997.

2. METHODS

This description is based on the detailed study of the vegetation, in relation to the topography, along two, approximately north-south orientated transects through the wetland undertaken in January 2001. Each change in vegetation observed along the transects was recorded using a Leica GPS “total station” system. Altitudes were recorded at each community boundary. Perceived variations in the vegetation along the transects were sampled periodically using 1 x 1 m sample plots to record the species present in the different plant communities. Percentage cover values were ascribed to each species recorded in the sample plots.

After the vegetation was analysed using the Braun-Blanquet phytosociological method (Werger 1973), the plant communities derived were compared to known riparian vegetation zonation patterns occurring along the banks of the Breede River (Section 6, Southern Waters, 2001). The altitudes determined for each zone in the wetland are related to each other and to the adjacent Breede River to determine whether there is any direct correlation between these systems or whether the wetland water levels function independently of each other.

3. RESULTS

3.1 DESCRIPTION OF COMMUNITIES IDENTIFIED

The following descriptions of the communities are presented in the order they appear in Table 1. The communities have been named on the basis of differential or characteristic species, or using species that are particular distinctive for a particular community (i.e. they are often dominant species).

3.1.1 Spergularia Media – Sporobolus Virginicus Halophytic Grassland

The community is identified as Community A in Table 1. It is a halophytic (salt tolerant) community that occurs in the Back Dynamic Zone of the Wetland on Bokkeveld Group shales. It was recorded at altitudes of 196.84 −197.64 m along Transect 2. Water leaking through an adjacent fill area in the Greater Brandvlei Dam and run-off from the road could contribute to the presence of this community.

The community is typified by the differential species: *Lampranthus* sp. (Boucher 6669), *Panicum schinzii, Spergularia media* and *Sporobolus virginicus.* The dominant species are an unidentified vygie (mesem) *Lampranthus* sp. (Boucher 6669), the sedge *Juncus kraussii,* the grasses *Cynodon dactylon*, *Panicum schinzii* and *Sporobolus virginicus*.

The community has two strata with 0.35 m tall patches of either sedge (*Juncus kraussii*) or grass (*Panicum schinzii*) forming the upper stratum interspersed through a dominant 0.15 m tall short grass stratum of *Cynodon dactylon* and *Sporobolus virginicus*.

3.1.2 Aspalathus spinosa – Athanasia trifurcata Renosterveld Shrubland

The community is identified as Community B in Table 1. It was recorded at altitudes of 198.18 −198.09 m along Transect 1 in the Back Dynamic Zone.

The community is typified by the differential species: *Aspalathus spinosa* subsp. *flavispina, Athanasia trifurcata* and *Tetraria compar*. The dominant species is *Athanasia trifurcata. Elytropappus rhinocerotis* occurs sporadically in the community and indicates the affinities of this community to the rare Renosterveld Shrubland vegetation type. Geophytes are generally common in Renosterveld Shrublands, and, judging from dried remains, this area is no exception.

The community has three strata with the exotic *Acacia saligna* (port jackson willow) forming the emergent 2.0—3.0 m tall shrub stratum. *Athanasia trifurcata* forms a 0.80 m tall shrub stratum while *Aspalathus spinosa* subsp. *flavispina* and *Tetraria compar* form a 0.45 tall dwarf sedge and shrub stratum.

3.1.3 Pentaschistis airoides – Lachenalia sp. Geophytic Grassland

The community is identified as Community C in Table 1. It was recorded at altitudes of 197.36 –196.46 m along Transects 1 and 2 in the Lower Dynamic Zone.

The community is typified by the 0.20—0.30 m tall differential and dominant grass *Pentaschistis airoides.* A sporadic stratum of the 0.60 m tall sedge *Juncus punctorius* and an 0.80—1.50 m tall emergent shrub stratum of exotic *Acacia saligna* has developed in places.

Leucadendron brunioides is fairly common at the interface between this community and the *Aspalathus spinosa – Athanasia trifurcata* Shrubland community.

3.1.4 Themeda triandra Flats Grassland

The community is identified as Community D in Table 1. It was recorded at altitudes of 196.82 –197.19 m along Transects 1 and 2 in the Lower Dynamic and Tree-Shrub Zones.

The community is typified by the differential and dominant species *Themeda triandra*.

Occasionally the shrub *Diospyros* glabra can be a co-dominant species.

The community has two strata with *Themeda triandra* together with *Hyparrhenia hirta* forming the dominant 0.90 m tall emergent grass stratum in which *Watsonia* sp. is common with *Ficinia indica* and *Lotus subbiflorus* being conspicuous in the geophyte rich 0.40 m tall sedge dominated herbaceous stratum.

3.1.5 Cliffortia strobilifera – Pennisetum macrourum Wetland Shrubland

The community is identified as Community E in Table 1. It was recorded at altitudes of 195.92 –198.06 m along Transects 1 and 2 in the Lower Dynamic Zone. This community occupies a similar position along the middle reaches of the Breede River.

The community is typified by the differential species *Cliffortia strobilifera* in association with *Rhus angustifolia*. *Pennisetum macrourum* is usually dominant in this community.

The community has three strata with *Cliffortia strobilifera* and *Rhus angustifolia* forming the emergent 2.20 m tall shrub stratum, *Pennisetum macrourum* is dominant in the 1.00 m tall grass stratum with *Eragrostis curvula, Lotus subbiflorus* and *Zantedeschia aethiopica* forming a 0.30—0.40 m tall grassy herb stratum.

3.1.6 Juncus scabriuscula – Pennisetum macrourum Sedgeland

The community is identified as Community F in Table 1. It was recorded at altitudes of 195.69 –196.90 m along Transect 1 in the Upper Wetbank Zone.

The community is typified by the differential species *Juncus scabriuscula* and *Agrostis lacnantha*. The dominant species are *Juncus scabriuscula, Pennisetum macrourum* and in places *Acacia saligna.*

The community has two strata with the 1.0 m tall grass *Pennisetum macrourum* dominant in the upper herb stratum and 0.20—0.40 m tall grasses and sedges *Agrostis lacnantha, Hemarthria altissima* and *Juncus scabriuscula* dominant in the lower herb stratum.

3.1.7 Pennisetum macrourum – Hemarthria altissima Wetland Grassland

The community is identified as Community G in Table 1. This is a widespread basic community found through most of the wetland where other specialist communities are absent. It was recorded at altitudes of 195.30–197.10 m along Transects 1 and 2 in the Upper Wetbank and Lower Dynamic Zones.

The community is typified by the presence and often by the dominance of *Eleocharis limosa, Eragrostis curvula, Hemarthria altissima, Lotus subbiflorus, Pennisetum macrourum* and the absence of differential species typifying the other communities described here.

The community typically has two strata with 1.0 m tall *Pennisetum macrourum* dominant in the upper grassy herb stratum and 0.30–0.40 m tall grass, *Hemarthria altissima* and herb *Lotus subbiflorus* dominant in the lower herb stratum.

3.1.8 Paspalum distichum – Hemarthria altissima Wetland Grassland

The community is identified as Community H in Table 1. It was recorded at altitudes of 195.19 –196.30 m along Transects 1 and 2 in the Lower Wetbank Zone.

The community is typified by the differential species *Leersia hexandra* and *Paspalum distichum*. *Eleocharis limosa* is dominant on occasions while *Hemarthria altissima* occurs quite regularly in the community.

The community has two strata with the 0.50 m tall sedge *Eleocharis limosa* dominant emergent herb with the grass *Paspalum distichum* generally forming a low 0.10 m tall mat through the community.

3.1.9 Eragrostis sarmentosa – Hemarthria altissima Wetland Grassland

The community is identified as Community I in Table 1. It was recorded at altitudes of 194.92–195.85 m along Transects 1 and 2 in the Aquatic and Lower Wetbank Zones.

The community is typified by the differential and dominant species *Eragrostis sarmentosa*. *Hemarthria altissima* is regularly found in the community.

The community has two strata with *Hemarthria altissima* forming the 0.40 m tall emergent grassy herb stratum and *Eragrostis sarmentosa* forming a 0.10 m tall grassy mat beneath.

3.1.10 Nymphoides indica Aquatic Herbland

The community is identified as Community J in Table 1. It was recorded at altitudes of 194.67 –195.73 m along Transect 1 in the Aquatic Zone.

The community is typified by the presence of the differential and dominant species *Nymphoides indica*.

While this aquatic community dries out completely now during the late summer months, the upper fringes of the Aquatic Zone in particular appear to be under stress, drying out for longer periods than in the past, judging from the condition of *Myriophyllum aquaticum,* for example, which was found to be dying from exposure and the lily-like *Nymphoides indica*, that is usually found growing in water with long leaf-stems, was found to be surviving in areas without water, with leaves being carried only up to 0.02 m off the ground.

3.1.11 Isolepis prolifer – Salix mucronata Riparian Fringing Scrub

The community is identified as Community K in Table 1. It was recorded at altitudes of 195.54 –197.03 m along Transects 1 and 2 in the Lower and Upper Wetbank Zones in the Papenkuils Wetland and along the banks of the Breede River adjoining the wetland.

The community is typified by the presence of the differential and dominant species *Isolepis prolifer* and *Salix mucronata*.

The community has three or four strata with *Salix mucronata* and *Morella integra* forming a 4.00 — 5.00 m tall tree stratum. A 2.00 m tall shrub stratum frequently occurs where invasions by the exotic *Sesbania punicea* has taken place. *Persicaria serrulata* forms a 0.60 tall herb stratum, with a second 0.15 — 0.25 m tall herb layer underneath with *Isolepis prolifer* and *Paspalum distichum* being dominant in it.

3.1.12 Myriophyllum aquaticum – Persicaria serrulata Aquatic Herbland

The community is identified as Community L in Table 1. It was recorded at altitudes of 194.87 –196.58 m along Transects 1 and 2 in the Aquatic Zone.

The community is typified by the differential species *Myriophyllum aquaticum* and the absence of the species differential to the *Nymphoides indica* and the *Isolepis prolifer – Salix mucronata* Communities. The dominant species are *Myriophyllum aquaticum* and sporadically *Digitaria* eriantha and *Xanthium stromarium*.

The community has two herbaceous strata with *Persicaria serrulata* and *Xanthium stromarium* forming a 0.60 tall stratum, with *Isolepis prolifer* and *Paspalum distichum* forming a second 0.15 — 0.25 m tall herb layer underneath.

3.1.13 Prionium serrulatum – Persicaria serrulata Fringing Herbland

The community is identified as Community M in Table 1. It was recorded at altitudes of 195.09 –197.33 m along Transects 1 and 2 in the Lower and Upper Wetbank and Lower Dynamic Zones.

The community is typified by the presence of the differential and dominant species *Prionium serratum* accompanied by *Mentha aquatica. Persicaria serrulata* is usually co-dominant.

The community generally has one dominant dense monotypic 1.50 — 2.00 m tall stratum of *Prionium serratum,* but where it is more open, particularly near the margins of the stands, *Persicaria serrulata* forms a 0.60 m tall herbaceous stratum.

3.1.14 Helichrysum cymosum – Conyza canadensis Secondary Sandplain Herbland

The community is identified as Community N in Table 1. It was only sampled on a single occasion on the disturbed banks of the Breede River at an altitude of 197.20 –197.21 m along Transect 1 in the Lower Dynamic Zone.

The community is typified by the presence of the 0.20 — 0.30 m tall weedy species such as *Conyza canadensis* and *Helichrysum cymosum* and the absence of most of the species characterising all the other communities. This community is probably an early succesional stage following removal of exotic shrubs such as *Acacia longifolia.*

3.1.15 Willdenowia incurvata Acid Sandplain Fynbos

This community did not occur along either of the two transects through the wetland. It occurs on accumulations of windblown sand from the Breede River.

Typically the community has a 1.2 m tall dense aphyllous restioid stratum with abundant herbs and geophytes beneath. The community is dominated by the common tussock-forming Restionaceae, *Willdenowia incurvata.* Low growing annuals and geophytes are normally conspicuous in Spring.

Large parts of this community have become overgrown by the exotic invasive tree *Acacia saligna.* Patches of sand with similar vegetation occur sporadically near the Breede River between Worcester and Robertson. A number of rare and endangered species are associated with this community elsewhere in the Breede Valley.

3.2 LIST OF PLANT COMMUNITIES IN EACH RIVER BANK ZONE

Back Dynamic Zone

Community A; 196.84 –197.64 m; Transect 2
Community B; 198.18 –198.09 m; Transect 1

Tree-Shrub and Lower Dynamic Zones

Community D; 196.82 –197.19 m; Transects 1 and 2

Lower Dynamic Zone

Community C; 197.36 –196.46 m; Transects 1 and 2
Community E; 195.92 –198.06 m; Transects 1 and 2
Community N; 197.20 –197.21 m; Transect 1

Lower and Upper Wetbank and Lower Dynamic Zones

Community M; 195.09 –197.33 m; Transects 1 and 2

Lower Dynamic and Upper Wetbank Zones

Community G; 195.30–197.10 m; Transects 1 and 2

Upper Wetbank Zone

Community F; 195.69 –196.90 m; Transect 1

Upper and Lower Wetbank Zones

Community K; 195.54 –197.03 m; Transects 1 and 2

Lower Wetbank Zone

Community H; 195.19 –196.30 m; Transects 1 and 2

Lower Wetbank and Aquatic Zones

Community I; 194.92–195.85 m; Transects 1 and 2

Aquatic Zone

Community J; 194.67 –195.73 m; Transect 1
Community L; 194.87 –196.58 m; Transects 1 and 2

Direct comparison between the wetland and the river wetland zone altitudes did not produce clear results because the river bank has extensive stands of exotic species that disrupt and suppress the natural flora and this causes "fuzzy" boundaries to zones. These exotic plants increase where natural systems are disturbed or are stressed, as is the case in this instance through considerable water extraction sand mining and untimely fires. Comparison suggests that there are overlaps within a general trend, however, these overlaps can be caused by retarded reactions by different species to a general lowering in flow regimes, particularly during the dry period, that has taken place in this system over a number of years in the recent past.

It is therefore not possible to state unequivocally from this survey that the vegetation in the Papenkuils Wetland is directly correlated to different flow regimes in the Breede River and that both systems react to simultaneous cues. Probably, flows from the tributaries, the Molenaars and particularly the Holsloot, were the major driving forces in the maintenance of the Wetbank Zone vegetation until relatively recently when the combined effects of abstractions and lower rainfalls started to allow the wetland to dry out from the west and the Breede became more important in maintaining the Drybank vegetation during flood events in this wetland than in the past. More recently the Breede has dominated the lower wetland, but this may reduce if the current alien clearing actions reduce the constrictive effect downstream of the roadbridge. The maintenance of water levels during the dry season is now reduced considerably through the diversion of the Molenaars and Holsloot tributaries into Greater Brandvlei Dam.

The Wetbank Zone vegetation requires two or more inundation episodes during each winter with fluctuating water levels during the dry summer months to maintain the vegetation and associated processes (Table 2). The Drybank Zone of south western Cape rivers are generally completely inundated on a five to twenty year cycle. This cycle probably holds for the Papenkuils Wetland as well given its location alongside the Breede River.

3.3 COMMENTS ON THE FLORA

Some 100 odd plant species were identified during this study that took place during the summer months when most of the geophytic and annual components are unrecognisable. This makes this a fairly rich wetland, comparable and in fact richer than many in lowland areas in the Fynbos Biome in the Western Cape.

A plant (*Senecio* sp. 6662) could not be identified by taxonomists at Kirstenbosch and has been sent to the National Botanical Institute at Pretoria for examination. *Juncus kraussii* is the only species listed in the Red Data List of Southern African plants (Hilton-Taylor 1996). It is categorised as 'not threatened', a category used for taxa which are no longer in one of the other threatened categories due to an increase in population sizes or to the subsequent discovery of more individuals or populations.

Phytogeographically this wetland contains Renosterveld elements (for example, *Elytropappus rhinocerotis, Themeda triandra*), Sand Plain Fynbos elements (for example, *Willdenowia* *incurvata*), Azonal riparian elements (for example, *Salix mucronata* and *Morella integra*) and halophytic or saltmarsh elements (for example, *Sporobolus virginicus*). This is a diverse mixture of different elements in a single wetland, and is very unusual for the Fynbos Biome.

A number of listed invasive exotic species occur in the wetland, including *Acacia longifolia, A. mearnsii, A. saligna, Eucalyptus camaldulensis, Eichhornia crassipes, Myriophyllum aquaticum* in addition to some exotic weeds such as *Briza minor, Rumex acetosella* and *Xanthium stromarium*. The presence of these species is related to disturbances such as sand mining as much as from the vegetation being under stress because of low water levels that appear to be associated with water extraction from the Holsloot, Molenaars and Breede Rivers, particularly during the dry summer months. Nutrient pollution might also contribute to the presence of *Eichhornia* and *Myriophyllum.*

4. DISCUSSION AND CONCLUSIONS

This is the only wetland of its size and type, based on its combination of plant communities, along the Breede River Floodplain. This makes the Papenkuils Wetland very important biologically. It is fairly rich in wetland plant species (some 100 odd plant species were identified during this study) and it contains many geophytes (bulbous plants). It is comparable to and in fact richer than many other wetlands in lowland areas in the Fynbos Biome in the Western Cape. It has combinations of freshwater and saline wetland communities, as well as extensive *Themeda triandra* (rooigras) stands that are very rare in the South Western Cape. This Wetland serves as a type area for this community in the area. Sand accumulations blown out of the Breede River, containing an inland form of the Sand Plain Fynbos found sporadically in the Worcester Valley, are also present. They are not conserved anywhere. This Wetland provides an ideal opportunity to conserve this vegetation type in addition to the wetland flora.

If the flow regimes influencing the wetland are left as they are at present, a continuing drying out of the substrate would take place given that extensive summer extraction is already taking place and that a natural dry cycle is currently being experienced in the Western Cape. The Wetbank Zone would migrate downwards, where it can, while the Drybank Zone would invade the Lower Dynamic Zone and the vacated upper part of the Wetbank Zone. The *Themeda triandra* Grassland community would deteriorate through the drier conditions, because grazing pressures would increase through lengthened access periods (less flooding) and generally because of more concentrated attention by stock because the dry conditions would result in less natural grazing being available in the general veld. *T. triandra* veld deteriorates rapidly under long periods of heavy grazing.

The fluctuations in flow regimes suggested above (Table 2) are a major driving force forming and maintaining the vegetation of the Papenkuils Wetland. The natural variability determines the zonation patterns present. If this variability is lost, such as through the construction of a low impoundment immediately downstream of the wetland, it would result in some species disappearing from the wetland and in the width of zone bands changing. A large impoundment would result in the total destruction of this important wetland.

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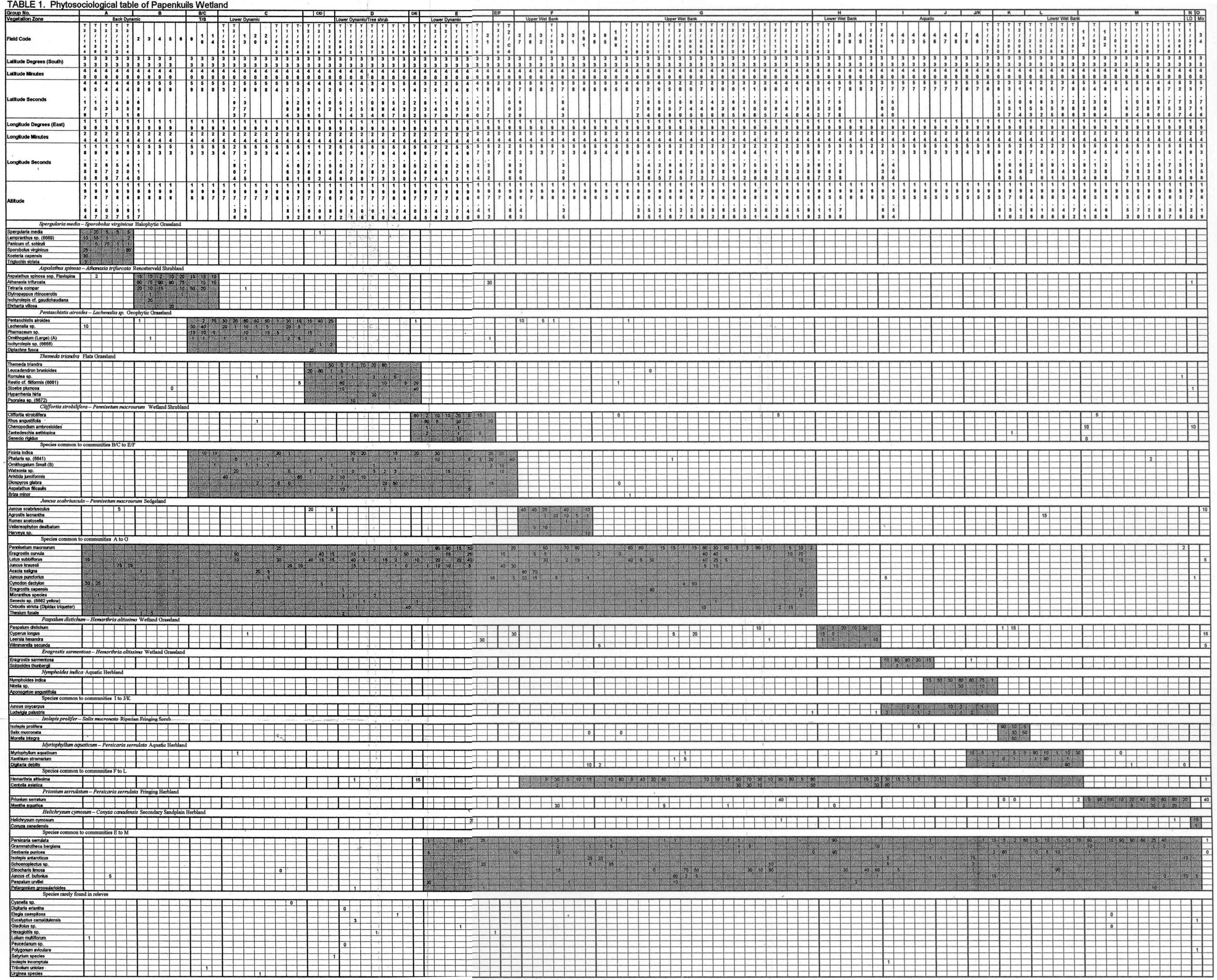
TABLE 1. Phytosociological table of Papenkuils Wetland



Group No.: A, B, B/C, C, C/D, D, D/E, E, E/F, F, G, H, I, J, J/K, K, L, M, N, O

Vegetation Zone: Back Dynamic, T/S, Lower Dynamic, Lower Dynamic/Tree shrub, Lower Dynamic, Upper Wet Bank, Upper Wet Bank, Lower Wet Bank, Aquatic, Lower Wet Bank, LD, Mix

Field Code

Latitude Degrees (South)

Latitude Minutes

Latitude Seconds

Longitude Degrees (East)

Longitude Minutes

Longitude Seconds

Altitude

Spergularia media – Sporobolus virginicus Halophytic Grassland

Spergularia media
Lampranthus sp. (6669)
Panicum cf. schinzii
Sporobolus virginicus
Koeleria capensis
Triglochin striata

Aspalathus spinosa – Athanasia trifurcata Renosterveld Shrubland

Aspalathus spinosa ssp. Flavispina
Athanasia trifurcata
Tetraria compar
Elytropappus rhinocerotis
Ischyrolepis cf. gaudichaudiana
Ehrharta villosa

Pentaschistis airoides – Lachenalia sp. Geophytic Grassland

Pentaschistis airoides
Lachenalia sp.
Pharnaceum sp.
Ornithogalum (Large) (A)
Ischyrolepis sp. (6666)
Diplachne fusca

Themeda triandra Flats Grassland

Themeda triandra
Leucadendron brunioides
Romulea sp.
Restio cf. filiformis (6661)
Stoebe plumosa
Hyparrhenia hirta
Psoralea sp. (6672)

Cliffortia strobilifera – Pennisetum macrourum Wetland Shrubland

Cliffortia strobilifera
Rhus angustifolia
Chenopodium ambrosioides
Zantedeschia aethiopica
Senecio rigidus

Species common to communities B/C to E/F

Ficinia indica
Phalaris sp. (6641)
Ornithogalum Small (B)
Watsonia sp.
Aristida junciformis
Diospyros glabra
Aspalathus filicaulis
Briza minor

Juncus scabriuscula – Pennisetum macrourum Sedgeland

Juncus scabriusculus
Agrostis lacnantha
Rumex acetosella
Vellereophyton dealbatum
Harveya sp.

Species common to communities A to G

Pennisetum macrourum
Eragrostis curvula
Lotus subbiflorus
Juncus kraussii
Acacia saligna
Juncus punctorius
Cynodon dactylon
Eragrostis capensis
Micranthus species
Senecio sp. (6662 yellow)
Onixotis stricta (Dipidax triqueter)
Thesium funale

Paspalum distichum – Hemarthria altissima Wetland Grassland

Paspalum distichum
Cyperus longus
Leersia hexandra
Wimmerella secunda

Eragrostis sarmentosa – Hemarthria altissima Wetland Grassland

Eragrostis sarmentosa
Scirpoides thunbergii

Nymphoides indica Aquatic Herbland

Nymphoides indica
Nitella sp.
Aponogeton angustifolia

Species common to communities I to J/K

Juncus oxycarpus
Ludwigia palustris

Isolepis prolifer – Salix mucronata Riperian Fringing Scrub

Isolepis prolifera
Salix mucronata
Morella integra

Myriophyllum aquaticum – Persicaria serrulata Aquatic Herbland

Myriophyllum aquaticum
Xanthium stromarium
Digitaria debilis

Species common to communities F to L

Hemarthria altissima
Centella asiatica

Prionium serrulatum – Persicaria serrulata Fringing Herbland

Prionium serratum
Mentha aquatica

Helichrysum cymosum – Conyza canadensis Secondary Sandplain Herbland

Helichrysum cymosum
Conyza canadensis

Species common to communities E to M

Persicaria serrulata
Grammatotheca bergiana
Sesbania punicea
Isolepis antarcticus
Schoenoplectus sp.
Eleocharis limosa
Juncus cf. bufonius
Paspalum urvillei
Pelargonium grossularioides

Species rarely found in releves

Cyanella sp.
Digitaria eriantha
Elegia caespitosa
Eucalyptus camaldulensis
Gladiolus sp.
Hexaglottis sp.
Lolium multiflorum
Peucedanum sp.
Polygonum aviculare
Satyrium species
Isolepis incomptula
Tribolium uniolae
Urginea species

TABLE 2 : VEGETATION ZONES FOR RIVERS

Location	Vegetation Zone	Inundation interval	Abb.	Marker
				Debris Line
Dry Bank	Back Dynamic Zone Transitional	approx. >20 year floods	BD	
	Tree/Shrub Zone	2- approx. 20 year floods	TS	
	Lower Dynamic Zone Transitional	Within year floods	LD	Bottom Dry Bank Top Wet Bank
Wet Bank	Shrub Zone	Wet Season Freshets	WS	
	Sedge Zone	Wet Season base flow	WE	
Aquatic	Rooted Aquatic Macrophyte Zone Transitional	Dry Season Freshets	AM	Perennial Free Water
	Algae	Dry Season base flow Free Water throughout the year	AA	

Appendix B

Groundwater Conceptualisation

TABLE OF CONTENTS

Tables and Figures:

1. BACKGROUND

This investigation has been carried out on behalf of Southern Waters to provide conceptual understanding of the role groundwater plays in maintaining water levels in the Papenkuils Wetland and to assist with the Wetland Reserve determination as part of the Breede River Basin Study (BRBS). The fieldwork was carried out on the 23rd and 30th of April 2001. On the 23rd a site orientation and interviews with local farmers was conducted and hydraulic conductivity tests were carried out on the 30th of April. This work has been carried out at the end of summer before any major rains and after 3 years of below average rainfall in the Breede Valley. The measured groundwater levels are therefore representative of low-flow conditions.

The aquifer underling the Papenkuils Wetland can be considered as part of the alluvial fan that makes up the Rawsonville aquifer. The cultivated areas south of Rawsonville comprise the proximal facies of the fan and consist largely of gravel and boulders beds whereas the wetland comprises the distal facies made up of sand and mud. The sedimentology and morphology of the wetland has, however, been influenced by the Breede River which flows perpendicular to the axis of the fan. The Holsloot and Smalblaar Rivers flow from south to north across the upper part of the fan and then turn eastward to flow sub-parallel with the Breede River.

Groundwater use from the Rawsonville area has been estimated at around 20 Mm^3 / annum and is used primarily for irrigation (BRBS study – groundwater component). The water table is usually less than 4m below surface and in lieu of drilling boreholes, many farmers excavate pits several metres deep and pump directly into their irrigation systems. A major source of recharge to the Rawsonville alluvial aquifer is thought to take place via the permeable streambeds and banks of rivers like the Holsloot and Smalblaar. These rivers rise in the Table Mountain Group Mountains to the south and, prior to diversion of their courses to the Greater Brandvlei Dam, supplied perennial flow to the wetland and the Breede River. The fractured rock aquifer underlying the alluvial aquifer is also thought to contribute to recharge of the alluvium, however, the Bokkeveld Formation is present directly underneath Papenkuils Wetland. This formation usually has less storativity and transmissivity compared with the Table Mountain Group rocks which comprise the recharge area to the south of Rawsonville. The saturated thickness of the alluvial aquifer around Rawsonville is estimated at 25m (Rosewarne, 1981), however, in places like the Voorsorg area the alluvium can be as thick as 45m.

Information provided by Southern Waters of relevance to the role of groundwater includes:

- The Holsoot River used to have a meandering course parallel to the main stem of the Breede but now cuts an additional channel directly across the western end of the wetland to the Breede River.
- The Western half of the wetland is drying out whereas the eastern (outlet) section is congested with alien vegetation, which attenuates the flood peaks and pushes flood waters back up the wetland.
- A large proportion of the eastern wetland is submerged several times per annum but rapidly drains away.
- Transects undertaken in late January by Southern Waters revealed that the level of the Breede River is slightly above the levels in a pond (approximately 20cm) thought to be groundwater close to the Rawsonville-Worcester road (Pan 1) suggesting the Breede loses water to the wetland.

2. FINDINGS

Groundwater use in the area between the Hosloot diversion channel and the Papenkuils Wetland (Pokkraal) is limited and confined to domestic and livestock consumption. A single well (co-ordinates +3727450X, -34000Y) supplies the farmstead closest to the wetland at Pokkraal. The well is comprised of a 3m caisson sunk into the ground in the vineyard with a water level of 1.6m below surface. The water level reportedly does not vary much between summer and winter nor does the water level decline when the well is pumped suggesting high storage and transmissivity in the aquifer.

Streams that rise in the Voororgs Berg approximately 10 km south of the Papenkuils Wetland have been diverted by the construction of the Greater Brandvlei Dam. These streams now flow into a canal that runs parallel to the Greater Brandvlei Dam wall and reportedly supply irrigation water for the Pokkraal vineyards. Prior to construction of the Greater Brandvlei Dam these streams drained eastward but now flow north into the Papenkuils Wetland and join the meandering and overgrown channel of the Holsloot River.

The meandering main channel of the Holsloot River in the wetland is clearly visible in the ortho-photo of 1979 (Figure 1). More recent aerial photographs indicate that this easterly meandering channel has been abandoned and the river now flows due north to the Breede River. This is considered to be a result of the diversion of the Holsloot to the Greater Brandvlei Dam; the Holsloot's river channel below the diversion receives only peak flow, which takes the shortest route to the Breede River.

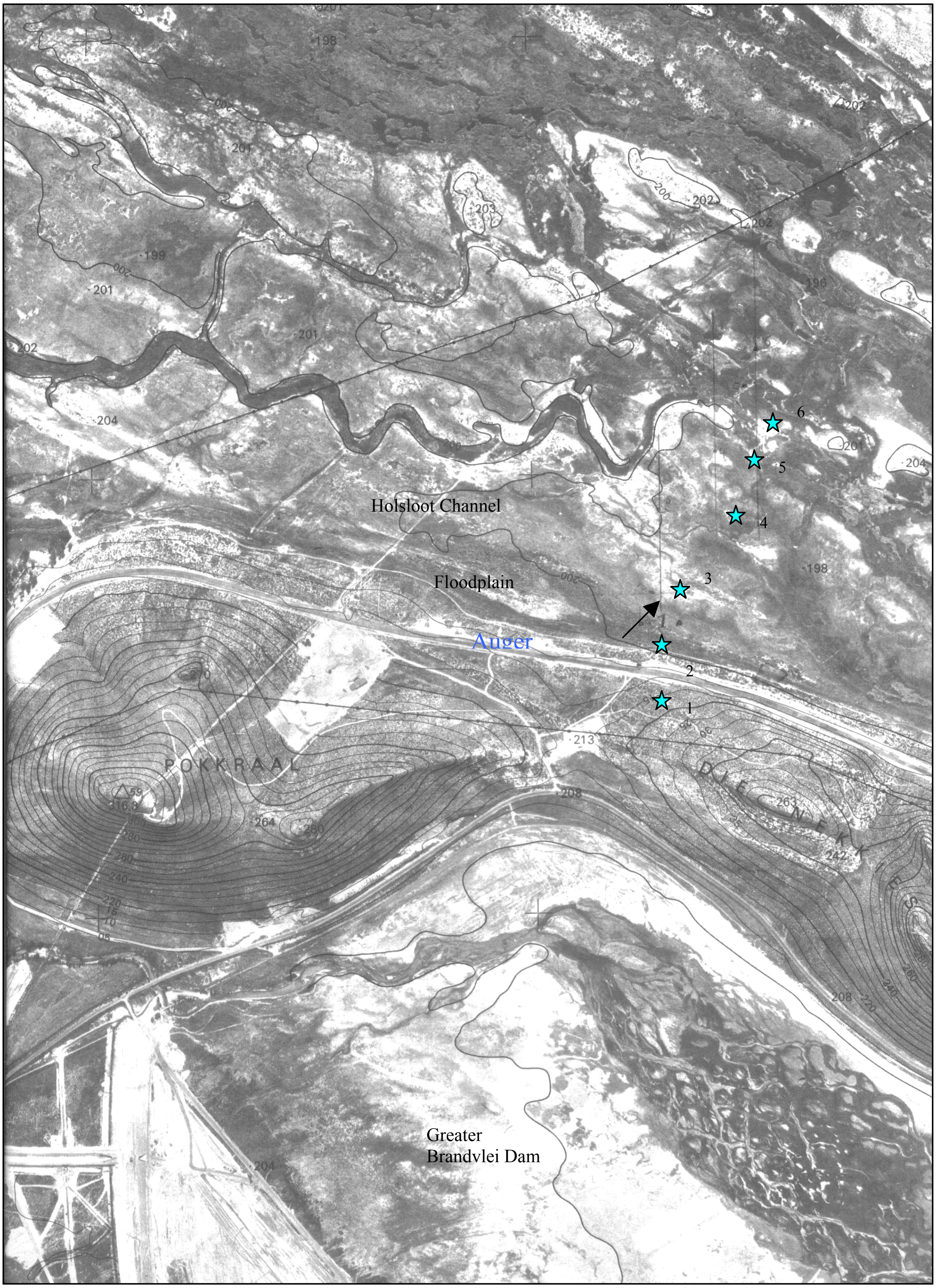


Figure 1: Positions of auger holes used in hydraulic conductivity tests.	**Groundwater Consulting Services** Consultants in Water Resources and Earth Sciences	**May 2001** 1:10 000 Papenkuils

3. MEASUREMENT OF HYDRAULIC CONDUCTIVITY

To gain an understanding of the occurrence of groundwater in the wetland, holes were augered on a northerly traverse across the wetland commencing near the Rawsonville – Worcester road and terminating adjacent to the Holsloot channel (Figure 1). Every 100 m across the wetland, the sediment was excavated to a depth of around 2m and the sediment type and the depth of the water table noted (in metres below ground level (mbgl)). The co-ordinates of these points are provided in Table 1.

TABLE 1 : CO-ORDINATES OF PIEZOMETER SITES

Latitude	**Longitude**	**Lat**	**Lon**	**Y**	**X**	**Site**
D M S	D M S					
33 40 32	19 23 25.5	33.675500	19.390417	-36,206.486	3,727,458.166	Car Stop
33 40 29	19 23 26.3	33.674694	19.390639	-36,227.432	3,727,368.898	Auger 1
33 40 25	19 23 26.8	33.673667	19.390778	-36,240.744	3,727,254.952	Auger 2
33 40 21	19 23 28.3	33.672361	19.391194	-36,279.934	3,727,110.296	Auger 3
33 40 14	19 23 34.3	33.670611	19.392861	-36,435.242	3,726,916.785	Auger 4
33 40 12	19 23 38.6	33.670083	19.394056	-36,546.242	3,726,858.669	Auger 5
33 40 9.6	19 23 39.9	33.669333	19.394417	-36,580.051	3,726,775.612	Auger 6

A 2m long by 60mm wide PVC pipe was inserted into the auger holes to approximately 10cm below the invert level of the hole. This pipe was filled with water and the rate of decline of the water level in the pipe recorded. The hydraulic conductivity (K) of the sediment was determined using the Inversed Auger Method. Although this method provides a vertical hydraulic conductivity, the value is assumed to be similar to the horizontal permeability. The hydraulic conductivity is determined with Darcy's law in the form:

$$K = 2.3 \frac{L}{(t_1 - t_0)} \log \frac{h_0}{h_1}$$

where L is the length of the sample (i.e. ~10 cm) and (t_1-t_0) is the time required for the head to fall from h_0 to h_1. Six tests were carried out and the results are presented in Table 1.

TABLE 2 : SATURATED PERMEABILITY, WATER LEVELS AND SEDIMENT TYPES IN AUGER HOLES

	Hydraulic Conductivity	Approximate groundwater level (mbgl)	Locality and description of sediment
Piezo 1	0.2 mm / day	2	Flood plain. Pale orange SAND. Increase in clay content with depth and pebbles noted about 2.1 m below surface.
Piezo 2	7 cm / day	1.9	Flood Plain. Coarse-grained pale orange SAND to 2 m below surface. Clay layer from 0.3 – 0.5 m.
Piezo 3	<0.1 mm / day	1.8	Flood Plain Pale orange, loose SAND to 0.5m. Dark brown, damp, sandy CLAY to 2.2m.
Piezo 4	6 m / day	1	Dry river channel. Very coarse-grained SAND to 1.5m.
Piezo 5	<0.1 mm / day	1	Adjacent to river channel. Dark brown stiff CLAY to 1.5m becoming moist at 0.5m
Piezo 6	<0.1 mm / day	1	Dry river channel Dark brown CLAY to 1m followed by saturated coarse-grained SAND to 1.5m

A small increase of the clay content in the sediment significantly reduces the hydraulic conductivity. The hydraulic conductivity data for the different sediments are summarized as follows:

• Clean, coarse grained channel sands:	1 – 10 m /day
• Silty floodplain sands:	1 – 10 cm / day
• Clay-rich floodplain sands:	0.1 – 1mm day
• Channel clay:	< 0.1 mm /day

The groundwater velocity (V) can be calculated from the modified form of Darcy's equation:

$$\mathbf{V = KI / n}$$

where K = hydraulic conductivity, I = hydraulic gradient and n = porosity.

The groundwater velocity can be estimated for the area between Pokkraal and the wetland. This area is approximately 2 km west of the auger traverse indicated in Figure 1. Here, several shallow holes were augered in the wetland and intersected coarse-grained sands with a water table similar to the auger traverse: i.e. approximately 2m below surface. Approximately 700m south of these auger holes a water level of 1.6m was measured in a well on the farm Pokkraal. The well has an elevation approximately 1m higher than the auger hole giving an hydraulic gradient of 1:500. Using a hydraulic conductivity of 10 cm/day for the 'floodplain' sand similar to that tested in Piezometer 2 (Table 2) and a porosity of 30% (US Geological Survey Water Supply Paper 1839-D), we can calculate an approximate groundwater velocity between Pokkraal and the wetland:

$$V = 0.10 \text{ m/day} \times (2 \times 10^{-3}) / 0.3 = 7 \times 10^{-3} \text{ m/day} \quad \text{(or 1 mm /day)}$$

This groundwater velocity represents low flow conditions and one would expect this value to increase substantially in winter when the hydraulic gradient (I) increases from recharge. Groundwater velocity in the silty sands of the floodplain can be compared to that of the clean coarse-grained river channel sands (Piezometer 4, Table 2). If we assume a porosity of 40% for the clean channel sands and the same hydraulic gradient, we see that the groundwater velocity is significantly higher:

$$V = 6 \text{ m /d} \times (2 \times 10^{-3}) / 0.4 = 9 \times 10^{-3} \text{ m/day} \quad \text{(or 30 mm/day)}$$

These low groundwater velocities indicate somewhat ‘stagnant’ conditions in the aquifers in late summer. In the case of the river channel, however, the gradient (I) is significantly greater than that estimated for the Pokkraal area because surface streams are continuously recharging the channel alluvium. Groundwater velocity in the channel alluvium is therefore expected to be several orders of magnitude greater than that presented above even in late summer. In depressions in the channels, groundwater 'daylights' as ponds but disappears where sand banks or elevated areas are present. The shallower groundwater levels in the channel deposits compared to the floodplain silty sands suggests that recharge of the floodplain aquifer from the meandering channel is likely to occur although this may be restricted by the clay sediments bordering the meander channel.

4. DISCUSSION AND CONCLUSIONS

The Papenkuils Wetland can be thought of as the distal facies of an alluvial fan having its source in the TMG mountains to the south. Sedimentary deposits created by meandering and braided rivers have modified the wetland. Meandering streams generally produce linear shoestring sand bodies that are aligned parallel to the river course, and these are normally bounded below and on both sides by finer materials (Cant, 1982 in Domenico and Schwartz, 1998). These coarse-grained channel sand bodies comprise preferential conduits for groundwater in the Papenkuils Wetland and are recharged by surface streams. The finer deposits surrounding these shoestring sand bodies maintain groundwater elevations above the surrounding floodplain. Braided rivers, on the other hand, frequently produce sheet-like sands that contain beds of clay enclosed within them. The floodplain deposits may be underlain by clay rich horizons below a depth of 2m. The extent of these clay horizons is uncertain but their presence may explain the rapid draining of the wetland after flooding. The findings and their interpretation are summarized below:

- The diverted surface streams discussed above are believed to constitute a major source of recharge to groundwater, at least in the drier western part of the wetland.
- The hydraulic conductivity of the channel sand (1-10 m /day) and impermeable clay (<0.1 mm / day) associated with the edges of the alluvial channel suggest that groundwater flow occurs preferentially along the channels and ‘daylights’ in topographic lows in the channels.
- The elevated water table in the channel compared to the floodplain area indicates groundwater recharge occurs through river channels.
- Clay deposits associated with the meandering channels limit the rate of groundwater flow from the alluvial channel deposits to the floodplain sands.
- Groundwater recharge of the floodplain sands may occur from underlying aquifers (i.e. the TMG and Bokkeveld) and via channels recharged from surface streams, but the annual inundation of the wetland from over-topping of the banks of the Breede River is likely to constitute a major source of recharge to the shallow sediments of the floodplain.
- The slightly greater elevation of the Breede River compared to the groundwater levels in the 'pans' encountered in the transects carried out by Southern Waters suggests that the Breede River does not gain significant inflows (baseflow) of groundwater from the wetland.
- The lower elevations of the 'pans' in the wetland also reflect the diminished surface flow and recharge of the wetland from the Holsloot and Smalblaar as a result of their diversion to the Greater Brandvlei Dam.
- Between the Holsloot channel and the Breede River additional dry channels occur.
- Toward the Breede River, landowners attempting to create dams have modified the river channels.
- Rock outcrop, possibly excavated by dam construction was observed close to the Breede River suggesting limited development of alluvium.
- Numerous north-south ditches traverse the wetland and were presumably dug by landowners to drain the wetland.
- Prior to agricultural development in the catchment, the wetland must have been a lot wetter: channels would have been deeper, groundwater levels higher and baseflow to the Breede River greater than appears to be the case at present.

A G PAPINI (*Pr. Sci. Nat)*

GROUNDWATER CONSULTING SERVICES

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