A REVIEW OF DEPRESSIONAL WETLANDS (PANS) IN SOUTH AFRICA, INCLUDING A WATER QUALITY CLASSIFICATION SYSTEM

Report to the
WATER RESEARCH COMMISSION

by

AR De Klerk[1], LP De Klerk[1], PJ Oberholster[2], PJ Ashton[1], JA Dini[3] & SD Holness[4]

Series Editors: AR De Klerk*[1], JA Dini[3], SD Holness[4] & PJ Oberholster[2]

[1]CSIR Natural Resources and the Environment, Pretoria
[2]CSIR Natural Resources and the Environment, Stellenbosch
[3]South African National Biodiversity Institute, Pretoria
[4]Nelson Mandela Metropolitan University

*email: ADKlerk@csir.co.za

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Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

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Reference Group

Jo Burgess	Water Research Commission
Bonani Madikizela	Water Research Commission
Ritva Muhlbauer	Anglo American
Johann Beukes	Coaltech Research Association
Elmien Webb	Glencore
Koos Smit	Exxaro
Meera Ormea	Eskom
Rod Schwab	Department of Water and Sanitation
Vik Cogho	Optimum / Glencore
Wietsche Roets	Department of Water and Sanitation
Graham Trusler	Digby Wells Environmental
Wendy Mey	BECSA / South32
Charles Linström	Exxaro
Gail Nussey	SASOL
Vicki Shaw	Xstrata

Others

Martin Platt	Anglo Coal
Reginald Mabalane	Chamber of Mines
Andre Beetge	South African National Biodiversity Institute
Pieter Viljoen	Department of Water and Sanitation
Clinton Lee	BHP Billiton / South32
Annalise van Zyl	Glencore

Institutions

Coaltech Research Association

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CONTENTS

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 WETLANDS

Wetland loss has been estimated to be around 50% globally, whilst in South Africa between 35% and 50% of wetlands have already been lost or severely degraded (Dini, 2004). Wetlands in South Africa are commonly impacted by unsustainable social and economic pressures, for example agriculture, industries, mining, overgrazing, water abstraction and the discharge or disposal of sewage waste (DWAF, 2004). This is problematic, because wetlands provide numerous important functions for natural organisms, the environment, and society (Richards, 2001).

Since the 1960s South African wetlands have been recognized as important aquatic ecosystems (DWAF, 2004). According to the National Water Act (NWA, 1998) a wetland can be defined as a "land which is transitional between terrestrial and aquatic systems, where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil". Generally, wetlands are characterized by one or more of the following attributes: firstly, it should at least periodically support predominantly hydrophytes; secondly, the substrate should predominantly consist of undrained hydric soils; and thirdly, the substrate should at some time during the growing season be saturated with water or covered with shallow water (Cowardin *et al*., 1979).

Based on these broad definitions of a wetland, many environments may be regarded as wetlands and a suitable system is therefore needed to classify wetlands in South Africa (Ferreira, 2010). Globally, the classification of wetlands is based on the system developed by Cowardin *et al*. (1979), while the system that is used most frequently in South Africa, is that of Dini *et al*. (1998). In South Africa, wetlands are divided into six classes: marine, estuarine, riverine, lacustrine, palustrine and endorheic systems. A pan is commonly classified as endorheic wetland system that could otherwise be categorized as palustrine or lacustrine, but also possess additional characteristics such as being circular, oval, kidney or lobed shaped, has a flat basin floor and does not have any outlet for water flows (Dini *et al*., 1998). The latest classification system proposed by Ollis *et al.* (2013) states that flat-bottomed depressions are often referred to as pans and subsequently grouped pans under the classification termed depressions. The definition of a depression is "a wetland or aquatic ecosystem with closed (or at least near-closed) elevation contours, which increases in depth from the perimeter to a central area of greatest depth and within which water typically accumulates".

1.2 PANS

1.2.1 Endorheic pans

Many terms such as sabkhas, vleis, pans, playas, playa lakes and saline lakes have been used to describe closed or endorheic basins. Usually the difference in name is related to culture or the country in which the depression is located. The term playa or playa lake is widely used in North America, while Spanish and/or Arabic speaking countries refer to these depressions as salenas or sabkhas, respectively. In southern Africa the term pan is most often used (Yechieli and Wood, 2002).

According to Shaw and Thomas (1989), pans can be described as arid zone basins that vary in size, were formed in several different ways and, while they are often located above the groundwater table, they are subjected to seasonal or perennial surface water inundation. In South Africa, pans and have been defined as having closed drainage basins and accumulating rainwater inflows (Richards, 2001). An important differentiation needs to be made between lakes and pans; lakes are often similar to pans, but are usually larger and have some form of defined outflow.

While pans are found throughout the world they are mostly concentrated in arid regions. These areas include: North America, Argentina, Brazil, southern and central Africa as well as southern and western Australia. Pans are present in three of South Africa's neighbouring countries – Namibia, Botswana and Zimbabwe (Goudie and Wells, 1995). In South Africa, the commonest wetlands found in dry regions are endorheic pans, although pans also occur in wetter areas, such as Mpumalanga (Allan *et al*., 1995).

Figure 1 shows that pans are spread across the interior of South Africa in a broad belt stretching from the Northern Cape Province across the North-West Province and into Mpumalanga Province (Goudie and Thomas, 1985; McCarthy *et al*., 2007). While this map is only a broad guide to the density of pans, the distributional pattern is widely accepted as accurate (Goudie and Thomas, 1985). Most of the pans in South Africa are situated in the arid north-western regions in areas with a mean annual rainfall of 500 mm or less (Goudie and Thomas, 1985); they are characterized by saline deposits and are usually ephemeral (McCarthy *et al*., 2007). The noticeable exception to this are the pans located in the eastern part of the country, which is characterized by a dense cluster of pans centred on Lake Chrissie (McCarthy *et al*., 2007). This area is known as the Mpumalanga Lakes District (MLD) and is subjected to warm, wet summer weather and cold, dry winters, but unlike other pan fields, the MLD is situated in a relatively humid area with a mean annual rainfall of approximately 800-1000 mm (Schulze, 1997). In the eastern Highveld region of South Africa a total of approximately 4628 pans occur, with the main concentration found in the MLD. Of these pans, approximately 2043 are perennial while 2585 are non-perennial pans (Allan, 1995). Here it is important to remember that the density of pans does not provide a reliable impression of their importance in a landscape because some areas may have many small pans (Goudie and Thomas, 1985).

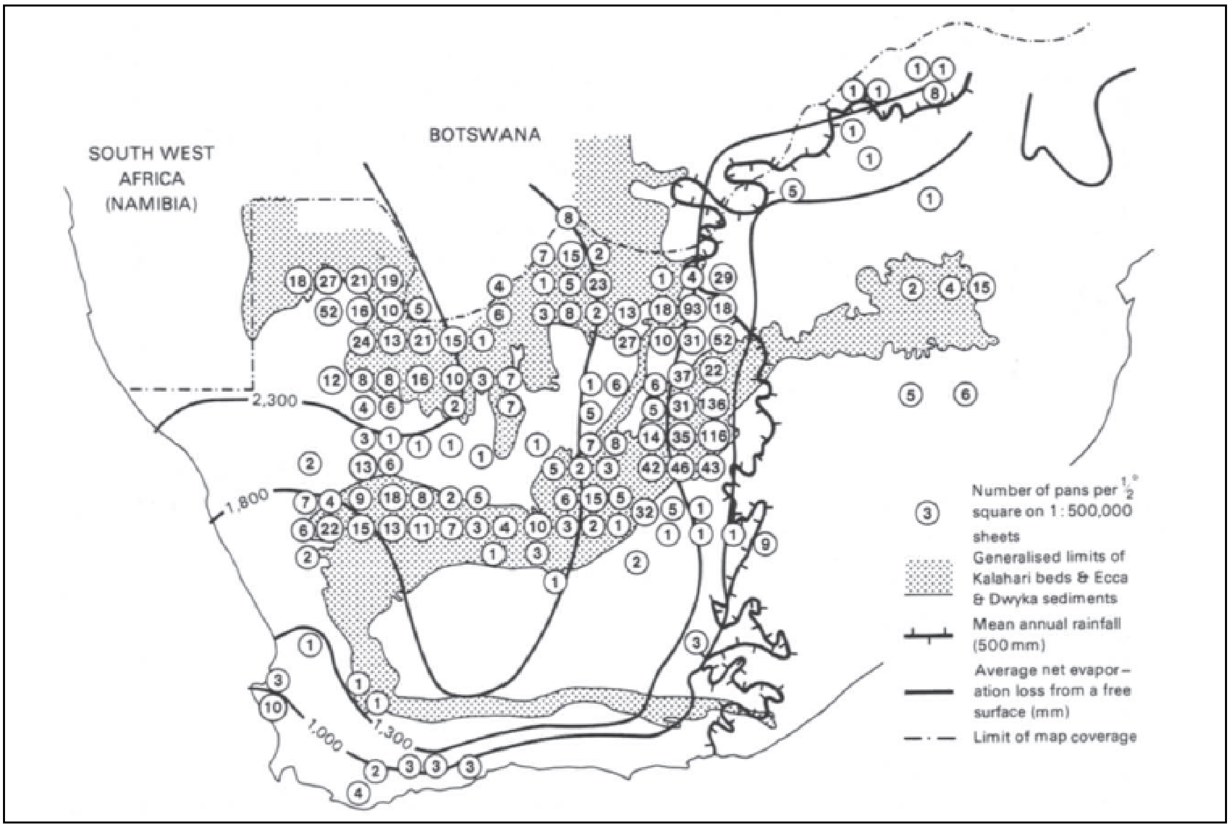

Figure 1 The recorded distribution of pans in South Africa derived from 1: 500 000 topographical maps, with the encircled values indicating the relative density of pans per quarter degree grid (from Goudie and Thomas, 1985)

1.2.2 Pan characteristics

Pans exhibit considerable variability because of changes in an assortment of characteristics that include origin, underlying geology or lithology, size, morphology (shape), and frequency of surface water inundation, as well as the relative importance of surface and groundwater inputs (Shaw and Thomas, 1989). Pans vary widely in size, from those that have a small surface area and are shallow to those that are more than a metre deep and have a relatively large surface area (Goudie and Thomas, 1985). On the whole, most pans are relatively shallow; this results in very little, if any, thermal or chemical stratification of the water column, which is generally well mixed due to wind action (Russel, 2008).

It is difficult to differentiate between perennial, non-perennial and dry pans, because pans range from wet to dry and the salinity of their water ranges from fresh (<3 g/ℓ) to saline. Pans in the western parts of the country tend to be large and dry, whereas those in the eastern parts are more perennially flooded (McCarthy *et al*., 2007). In contrast to pans found in the western parts of South Africa, those found in the Eastern parts (particularly the MLD) are usually perennial and relatively fresh. This area is also quite unique because no other region in South Africa has such a high density of perennial pans (McCarthy *et al*., 2007).

The shape of a typical pan is often difficult to interpret, but it is usually circular, elongated or oval, or a combination of the two, resembling a kidney shape (Goudie and Wells, 1995). The shape of a pan may also indicate its position along former drainage lines or the direction of the prevailing winds. Kidney-shaped pans are said to probably occur at stream confluences whereas round or oval pans most likely occur on straight courses (Wellington, 1955). A pan's shape may also be influenced by wind action, e.g., pans in the MLD are usually found to be elongated in a north to south direction, approximately perpendicular to the prevailing winds (Goudie and Thomas, 1985; Russel, 2008).

A characteristic of pans that has received relatively little attention in South Africa is the lunettes or crescentic dune features that occur on the leeward side of a pan. They are indicators of deflation, as well as the prevailing wind direction, and partially consist of materials such as clay aggregates that are derived from the pan floor (Goudie and Thomas, 1985). Lunettes may have a variety of forms, and not all pans have lunettes. More than one lunette may also be present at a single pan, indicating that various deflation processes have occurred (Goudie and Thomas, 1985).

Whilst there is a great deal of variability between pans, pans tend to share a number of common characteristics, including: occupying regional and local topographic lows, absence of surface outflows, relatively flat surfaces, a hydrological budget where evaporation exceeds input, etc. (Shaw and Thomas, 1989). Hydrological inputs may be by direct precipitation onto the pan surface, surface or subsurface inflows of water or a combination thereof (McCarthy *et al*., 2007). The topographic position within a landscape influences the groundwater regime, which can dominate hydrological processes (Sengupta, 1993). The areal extent, frequency and length of time that surface water occupies a pan are dependent on climatological and hydrological regimes and are a major source of variation between pans. Recent research has highlighted to growing importance of groundwater as well as its role in pan formation and function (Friedman *et al*., 1982; Torgersen *et al*., 1984; Torgersen *et al*., 1986; Osterkamp and Wood, 1987; Fryberger *et al*., 1988).

1.2.3 Origin or formation of pans

No consensus has been reached on precisely how pans originated (Marshall and Harmse, 1992). This may be because there is no single explanation for the origin of pans and it should not be assumed that a single factor was responsible for their development. While several hypothesis have been put forward to explain the origin of pans, including the removal of salts and clay by animals (Alison, 1899; Du Toit, 1954), drainage derangement (Wellington, 1945; Geyser, 1950) and wind erosion (Du Toit, 1954; Van Eeden, 1955; King, 1967), none of these can by themselves explain the complex distribution of pans. A number of studies have indicated that different types of mechanisms or combinations of mechanisms can account for the existence of pans (Shaw, 1988, Marshall and Harmse, 1992). These include the availability of susceptible surfaces, the subsequent disturbance of such surfaces through salt-weathering and/or trampling by animals, a lack of integrated fluvial systems and the subsequent effect of deflation processes (Goudie and Thomas, 1985). Such an integrated approach (Figure 2) is probably the most widely acceptable process to explain the origin of pans, and includes:

1.2.3.1 The biogenetic model:

This model suggests that pans were frequently visited by hoofed animals to obtain water and salt. The model also proposes that the depression was caused by the removal of mud adhering to the hooves and bodies of these animals (Alison, 1899; Laloy, 1909; Passarge, 1911). Le Roux (1978) also suggested that this process may have prepared the pans for deflation through the loosing of the substrate. At present, it is widely accepted that these methods could not have been the primary reason for the origin of pans, although they could have contributed to the formation of pans (Marshall and Harmse, 1992), because animal activities have been observed to contribute to depression development (Weir, 1969; Ayeni, 1977).

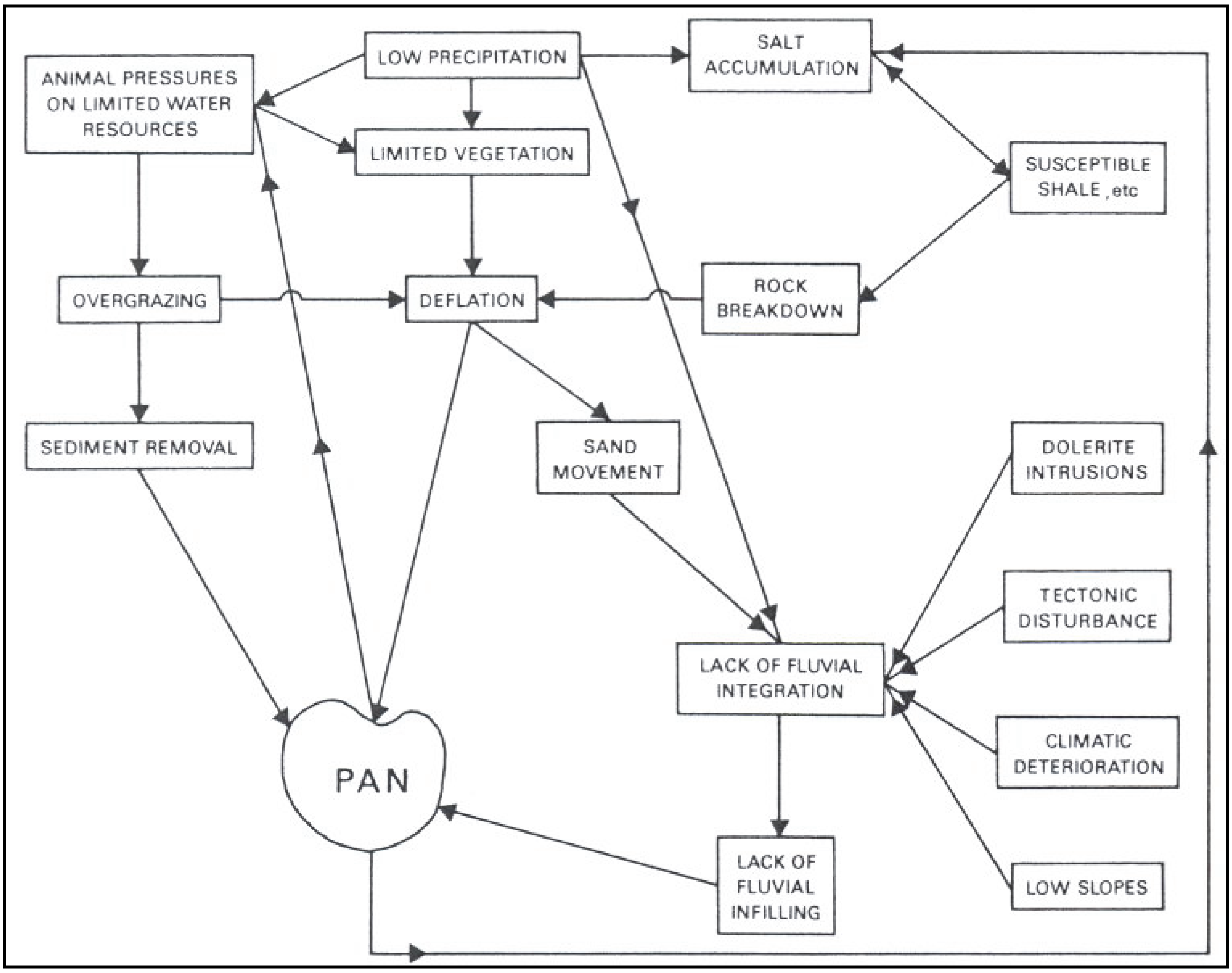

Figure 2 A widely quoted model of pan development by Goudie and Thomas (1985)

1.2.3.2 The deflation model:

This model considers wind deflation as the main factor in the formation and propagation of pans (Rogers, 1934), if other favourable conditions are present (Van Eeden, 1955). However, current opinion suggests that this is probably a mechanism by which pans are enlarged or propagated and not initiated (Marshall and Harmse, 1992).

1.2.3.3 Drainage derangement:

The choking of drainage lines is associated with wind-blown sand, the presence of dolerite intrusions across the drainage line and river capture (Wellington, 1955; Marshall and Harmse, 1992). Wellington (1943) stated that it is the position of pans along ancient river courses that determined their shapes. According to Wellington (1943), the pans in the MLD were previously linked together to form a flowing river in the area. The river was later on captured by the migration of the Vaal River headwaters. The previous river courses became choked with accumulated sediment causing the formation of kidney shaped pans where two tributaries were joined, as well as round and oval shaped pans on the straight sections

1.2.3.4 The lithological model:

This model suggests that the underlying lithology is the decisive factor in pan formation. De Bruiyn (1971) states that there is a correlation between the occurrence of dolerite dykes and sills and the occurrence of pans. This explanation may be satisfactory in his study area (western Free State) where many dolerite sills and dykes occur, but does not appear to explain the occurrence of pans elsewhere.

1.2.3.5 The ecological model:

This model (Verhagen, 1991) incorporates the principles of excavation by hoofed animals and deflation and states that these depressions continued to be excavated until there was an absence of animals, which then allowed the depression to be re-colonized by vegetation. The resulting soil formation and humus production caused the soil water to become more acidic and leach into the pan floor and flanks, allowing perched water to infiltrate. This reduced the depression's salinity and stimulated further plant development. Gradually the depression becomes increasingly filled with sand and soil until it is again frequented by animals. Where animals are absent, the depression may disappear when it is completely filled with plants and soil. This model needs a more thorough review and its applicability should be tested in different areas.

Recently, it has become necessary to distinguish between initiating mechanisms and propagating mechanisms in pan development. The former, mainly geological features, induces pan formation and results in the localization of certain pans / pan fields, whilst the latter (mainly erosion or depositional cycles) is involved in the evolution of pans (Marshall and Harmse, 1992). Tectonic processes (e.g., faulting and down warping) and climatic disruption of pre-existing drainage systems, and the presence of susceptible substrates, are now accepted as the main reasons for the initiation of a pan. Thus, the most suitable loci for pans are most likely joints, fractures, faults or dyke intersections because the rock is already weakened at these areas and is thus susceptible to further weathering. At these sites groundwater flows are concentrated, which enhances erosion and decomposition. This accelerated weathering promotes additional weathering through the release of salts (Shaw and Thomas, 1989; Marshall and Harmse, 1992). In addition, drainage derangement may be the main initiating agent for those pans that are located in ancient drainage channels. Deep weathering along subsurface flow paths may also contribute to pan formation (Marshall and Harmse, 1992). Once a pan / pan-field has come into existence, the pans might be eliminated by being in-filled with sediment or propagated and continue for a long period of time through various mechanisms such as deflation, physical and chemical weathering, etc.

The origin of the pans in Mpumalanga appears to have been subjected to a complex interplay of tectonic disruption and susceptible substrates (Shaw, 1988; Marshall and Harmse, 1992). Hence, in this area the following three factors appear to be necessary for the development of a pan, although one or more of the processes may dominate at a particular time.

First, there has to be a suitable substrate (Marshall and Harmse, 1992) that is easily weatherable (De Bruiyn, 1971), or susceptible to karstification (Marshall and Harmse, 1992) and can contribute to the formation of pans. Lithological sequences that are most susceptible to pan formation are those that contain a high concentration of salts which may be chemically leached and mechanically removed (De Bruiyn, 1971). The lithology on its own is not the only prerequisite for pan formation because a complex interplay of flowing water and geological structure is important (Marshall and Harmse, 1992). Pans have been observed to be associated with a relatively flat (level) ground surface where there is a hollow or depression present with a suitable gradient that allows rainwater and groundwater to drain into the hollow (Wellington, 1955). The distribution of pans in South Africa appears to correspond with the presence of rocks of the Ecca Group of the Karoo Supergroup (Le Roux, 1978; Goudie and Thomas, 1985) and the remnants of the Ancient African landsurface (Partridge and Maud, 1987). In the MLD the bedrock of pans belong predominantly to the Vryheid Formation, which is a part of the Ecca Group. The Vryheid Formation is a coal-bearing sequence of rocks of the Karoo Supergroup that hosts the Ermelo Coalfields (Johnson *et al*., 2006). Karoo shales have little resistance to chemical weathering and weather quickly on exposure, hence the dispersion of clay colloids by sodium ions may be of more importance than weathering by exudation. This is because saline soils (with a high sodium content) are structurally weaker and less well vegetated, making them more susceptible to wind erosion (Russell, 1961; Le Roux, 1978). In South Africa, approximately 23% of the time pans occur on tertiary and quaternary sediments, 21% on Dwyka shale, 14% on Ecca shale, 12% on Dwyka series (which includes tillite), 10% on dolerite and the remaining pans (approximately 20%) occur on various other types of rock. Therefore, most pans occur on shales or unconsolidated surficial sands (Hugo, 1974; Allan *et al*., 1995).

Once a pan has formed, several processes may cause it to be filled with sediment or become enlarged. These include factors such as wind action, which can enlarge pans by removing material; this material is often deposited on the leeward side of the pan and the process is called deflation (Wellington, 1955; Le

Roux, 1978). The erosional driving force (wind) is only able to operate within the given character of the landscape. Hence, the bedrock properties – including the extent of weathering, precipitation characteristics and drainage characteristics play important roles in the formation, localisation and development of pans (Le Roux, 1978). The presence of soils with increased salinity, where the resulting sparsely vegetated area is more easily affected by wind, may attract more larger mammals that could loosen soil through trampling, which will then help deflation processes and enhance pan formation (Russel, 1961; Le Roux, 1978) This is because physical weathering increases the surface to volume ratio of the applicable material which allows chemical weathering to be more efficient (Eby, 2004).

Secondly, there needs to be a poor drainage system, which can cause pans to form as a result of river choking. It has been recognized for a long time that certain pans may be the remains of disrupted drainage lines in the MLD (Figure 3) (Wellington, 1955). Studies have proposed that the pans can be linked, which may in turn be derived from a former tributary of the ancient uMpuluzi (Rodgers, 1922). The headwaters of the Vaal River may also have started headward migration, which would have deprived the river of water and breaking up the uMpuluzi River that flowed to the east. As mentioned earlier, the drainage line might then have been divided by wind-blown sand at a rock barrier (Wellington, 1955; Ferreira, 2010). This may, in part, explain one of the most obvious associations with pan formation, namely poor drainage. Rainfall in these regions forms static pools that provide the beginning of a typical pan. Water loss from these depressions is mainly through evaporation (Allan *et al*., 1995). Suitable climatic conditions are therefore essential for pan formation, in particular the balance between water accumulation and percolation or evaporation (Wellington, 1955).

Thirdly, certain geological structures such as fractures or faults could play an important role in the formation of pans because these are points of weakness that can be more easily weathered (Marshall and Harmse, 1992). Most of the Eastern Highveld is underlain with rocks of the Ecca group of the Karoo Supergroup, which has been locally intruded by dolerite dykes and sills. The host rocks are made up of mainly sandstones, and to a lesser extent siltstone and shale (McCarthy *et al*., 2007). The MLD is also thought to be one of the last remnants of the original African surface, which is an ancient land surface that was first described by King and King (1959) and later on by Partridge and Maud (1987). Because of the fact that little vertical denudation has taken place in the interior of South Africa, the MLD has remained one of the oldest land surfaces in the country (Russell, 2008). In the MLD, pan substrates are composed of coarse felspathic sandstones intercalated with thin layers of shale and coal (Goudie and Thomas, 1985). The Ecca sandstones vary in hardness and in various places have weathered rapidly. Dolerite provides a sufficient barrier to water whereas felsphatic sandstone and grifts are easily eroded and are often associated with pan-formation (Wellington, 1955). It seems likely to be the case that the formation of different pan types is greatly influenced by the presence of faults and fractures (Whitlow, 1994). Dolerite outcrops also seem to be influential in the formation of pans in the MLD, because a dolerite dyke would have prevented sand drift (Wellington, 1955). In Southern Africa pans are preferentially found on rocks, i.e. Ecca Shales, because it readily breaks down to fine-grained materials (Goundie and Thomas, 1985; Shaw and Thomas, 1989). These lithologies may also be a major source of the salts found in these depressions (Goundie and Thomas, 1985). In Mpumalanga, a geological origin for pans can be ruled out as there is also no known significant difference between the strata beneath the pan field and surrounding areas (Le Roux, 1978; McCarthy *et al*., 2007; Russell, 2008). It appears to be more a case of the specific topographical position (fractures, faults, flat surfaces, etc.) associated with these easily erodible substrate that results in different pan types.

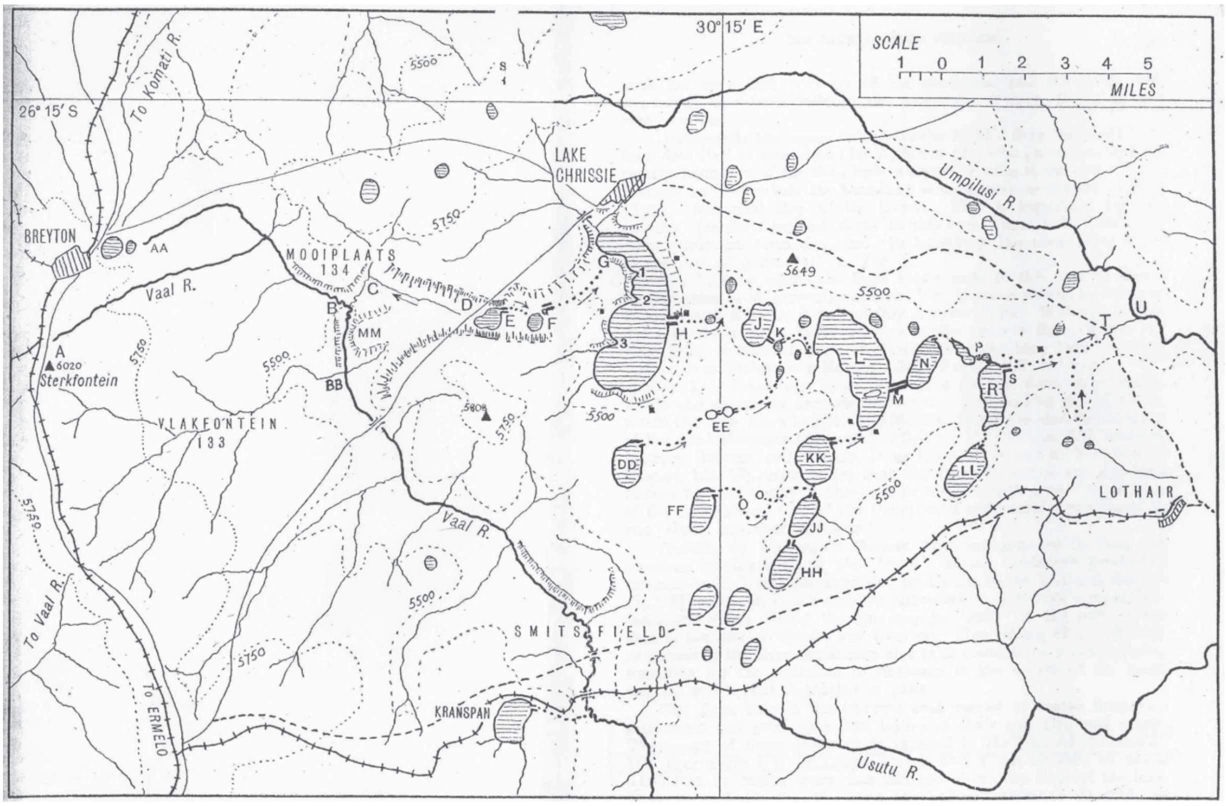

Figure 3 Some of the major pans in the MLD and their possible former drainage linkages (Wellington, 1955)

1.2.4 The classification of pans

Classification systems should not be devised arbitrarily, but need to be designed with some purpose in mind. Therefore numerous attempts to classify endorheic pans have been postulated by sedimentoligists, botanists, and others, and all of these systems differ widely (Allan et. al., 1995). Early attempts were made by Du Toit (1927), who classified pans as either inland or coastal, after which Hutchinson *et al*. (1932) built on this classification and added a further three classification levels for inland pans in the then Transvaal Province (part of which is now the Gauteng Province). Leistner (1967) later proposed a system based on the geology of various pans in the Kalahari, whilst Noble and Hemens (1978) classified pans into seven categories based on their physical appearance. Geldehuys (1982) used vegetation to distinguish between six types of pans in the Free State and several classification proposals have focussed on the vegetation associated with pans (Müller, 1975; Geldenhuys, 1982; Kooij *et al*., 1990; Du Preez and Bredenkamp, 1991; Kooij *et al*., 1991; Smit *et al*., 1992; Eckhardt *et al*., 1993; Bezuidenhout, 1995; Kotze and O'Connor, 2000; Perkins *et al*., 2000; Dingaan *et al*., 2001; Cilliers and Bredenkamp, 2003; Janecke *et al*., 2003; Collins, 2011).

Because of the sometimes complex and highly scientific nature of these classification systems, they are seldom regarded as “user-friendly” by non-technical specialists. For this reason the simplified classification system proposed by Allan (1987) is considered to be the most useful for this study, given the extent of our available knowledge. This classification system (Allan, 1987) is based on the larger heterogeneity patterns of the vegetation associated with pans in Mpumalanga. This allows pans to be classified as reed pans, sedge pans and open pans, based on their vegetation or the lack thereof. Two other types of pans have also been included with these, namely salt pans and grass pans (Allan, 1987; Allan *et al*., 1995; Cowan and Van Riet, 1998).

1.2.4.1 Open pans:

These are depressional wetlands that are most often associated with vegetation (mainly grasses and sedges, for example *Cynodon dactylon*, *Scirpus* and *Cyperus* species) that are limited to the fringing shoreline. These pans typically consist of open water without any vegetation and the substrate often consists of shallow soils or exposed bedrock (Allan, 1987). Where the bedrock is close to, or outcrops at the pan surface, high rates of evaporation may favour their breakdown by salt weathering.

Figure 4 An example of an open pan showing the characteristic rock outcrops and vegetation limited to the shoreline (Photo: A.R. de Klerk)

1.2.4.2 Salt pans:

These are a type of open pan which has an exceedingly saline substrate. They are mostly restricted to the more arid western parts of South Africa and have a white coloured substrate when dry due to the presence of precipitated salts. They are often surrounded by *Schoenoplectus triqueter* – a plant that is relatively well adapted to survive in these conditions (Allan, 1987). The substrate of salt pans is usually at or near the level of the water table and usually consists of highly saline clays or mud with little or no vegetation (Hugo, 1974). The most commonly associated salts found in saltpans are sodium chloride, sodium carbonate, sodium sulphate, calcium sulphate and, occasionally, magnesium sulphate (Wellington, 1955; Seaman *et al*., 1991). The bulk of salt pans in South Africa are underlain by Dwyka and Ecca shales, which are known sources of chlorides and sulphates of sodium, calcium and magnesium (Hugo, 1974; Seaman *et al*., 1991).

In Southern Africa salt pans tend to be shallow and non-perennial and occur within the major areas identified for pans (Seaman *et al*., 1991). South Africa has the most abundant and widely spread salt pans in Southern Africa (Seaman *et al*., 1991) and these first attracted attention because of the potential commercial value of their salt deposits (Seaman *et al*., 1991). These salt deposits usually form when evaporation exceeds precipitation and results in these closed basins becoming progressively more saline over time, especially if they receive inflows that are sufficient to maintain a standing body of water. When the receiving waters contain high solute loads, the process is accelerated, and when the salt concentrations become high enough, salt crystallization and deposition occurs (Ashton and Schoeman, 1983). The Pretoria Salt Pan is now classified as a saline lake located within a meteorite impact crater. This is the only crater lake in Southern Africa and is a good example of another mode of pan genesis, namely “dramatic” genesis. In contrast to the previously mentioned modes of pan genesis, these pans usually occur as a result of craters left by meteor impacts and volcanic activity (Ashton and Schoeman, 1983; Shaw and Thomas, 1989).

Figure 5 Aerial view of the Pretoria Salt Pan (Photo: P.J. Ashton)

1.2.4.3 Sedge pans:

These are usually small to moderately sized pans with a black, clayey soil as substrate; they are usually perennial but have been known to dry up during periods of drought. They usually contain a diverse amount of fringing vegetation in combination with extensive areas of vegetation within the pan basin. The vegetation in the pan can be emergent or submerged, or a mixture of these types. Typical species of plants found, include *Schoenoplectus corymbosus* and *Eleocharis palustris*. *Odontelytrum abyssinicum* has also been recorded from these pans in South Africa (Allan, 1987).

Figure 6 A sedge pan showing aquatic vegetation extending into the basin itself (Photo: A.R. de Klerk)

1.2.4.4 Reed pans:

These pans are unique and usually defined as containing a dense central reed bed (*Phragmites* sp.) within the pan, with a narrow fringing strip of open water between the shoreline and the reedbed. The central reedbed is usually floating above a loose layer of organic material and peat while the fringing water usually contains a rich diversity of other aquatic vegetation types (*Lagarosiphon* sp. and *Potamogeton* sp.). Reed pans are the most perennial type of pan and retain high water levels throughout the year. They have also been found to be much deeper (sometimes their depths exceed 5 m) than other pans (Grundling *et al*., 2003; De Klerk, 2009). There are approximately nine reed pans in the MLD and two other examples that are less well developed in the Eastern Highveld (Allan, 1987). Reed pans have also been confirmed to contain peat deposits (Grundling *et al*., 2003), which adds to their uniqueness.

Figure 7 A reed pan with its dense floating reedbed inside the basin (Photo: A.R. de Klerk)

1.2.4.5 Grass pans:

These pans are usually small, often temporary and only contain water for short periods. They typically contain fresh to slightly saline water and they have been found to be important breeding sites for the near-threatened bullfrog. They have been reported to be mainly covered by various sedges and grasses, i.e. *Schoenoplectus* sp. Grass pans are usually overlooked and are seldom seen because of their non-perennial nature, while the appearance of the pan differs during wet and dry periods.

Figure 8 A typical grass pan found in Mpumalanga, with the floor of the basin covered with various emergent grasses and sedges (Photo: A. Hoffman)

CHAPTER 2: METHODOLOGY AND RESULTS

2.1 METHODOLOGY

While most of the pans in South Africa are situated in the arid western regions of the country, there are unique and distinct pans in the Eastern parts of South Africa. This eastern region is the focus area for this study and it is unique because of its relatively high rainfall and the high density of perennial pans. It has been stated elsewhere that limited data are available on the physical and chemical properties of surface waters in various types of endorheic pans and that, until now, pans have been relatively neglected in terms of hydrological studies. It has also been noted that pans in the arid north-western regions of South Africa show a lot of instability in terms of abiotic variables, whilst the pans in Mpumalanga (in particular in the MLD) are much more distinct. It was with this in mind that an effort was made to produce an easy to use identification system for different kinds of pans in the MLD and link these to characteristic changes in abiotic variables. To achieve this, all the available information on abiotic data were obtained and examined. Only the data that could be assigned to a specific pan type without any uncertainty were used. Depending on the availability of the data for the specific abiotic variables, the number of data points used per abiotic variable differed. For open pans between 25 to 48 data points were available per variable (Russel, 2008; Hendry and Van Vuuren, 2009; Ferreira, 2010), for saltpans six to 62 data points were available (Ashton and Schoeman, 1983; Seaman *et al*., 1991; Day, 1993; Ashton, 1999), whilst 19 to 27 data points were obtained for sedge pans (Hendry and Van Vuuren, 2009; Ferreira, 2010; Oberholster *et al*., 2010) and 24 to 26 data points were obtained for reed pans (Russel, 2008; De Klerk, 2009; Ferreira, 2010). Between four and 65 data points for grass pans were obtained from Hoffman (2012). Significant differences between the different pan types were determined using a two-way analysis of variance (ANOVA). A Dunnette's T3 post hoc multiple comparison test was performed with significance being assumed as a probability level of $p \leq 0.05$.

2.2 RESULTS

Of the five different types of pans identified, salt pans showed the highest median pH level (~9.50) and highest median electrical conductivity values (EC ~50.9 mS/cm) (Figure 9A and B). The median pH levels in salt pans differed significantly from those of open pans (~9.10), reed pans (~7.47) and grass pans (~6.13). The median pH levels of sedge pans (~9.07) only differed significantly from reed and grass pans, whilst they were relatively similar to those found in open pans and not significantly different from salt pans. On the other hand, open pans were also found to differ significantly from all of the pans except sedge pans. The median pH levels found in reed and grass pans were found to be distinct from the other pans to which they were significantly different. The median EC values in salt pans (~50.9 mS/cm) differed significantly from sedge pans (~2.02 mS/cm), open pans (~4.30 mS/cm), reed pans (~1.34 mS/cm) and grass pans (~0.055 mS/cm), whilst the other pans were not found to have differed significantly from each other.

The concentrations of various nutrients were also evaluated to determine whether or not there were any possible differences in nutrient concentrations between the different types of pans (Figure 10A, B and C). With regard to nitrates, no significant differences were found between the different pan types and all of these different types had relatively similar median nitrate values. In salt pans the median ammonium concentrations varied significantly to those found in sedge, reed and open pans. The same trend was noticed with regard to phosphate concentrations in salt pans, where the median phosphate values in salt pans differed significantly from those in the other four types of pans. In terms of their ammonium and phosphate concentrations, sedge pans and open pans were very similar to each other, but they were different (although not significantly) from reed and /or grass pans.

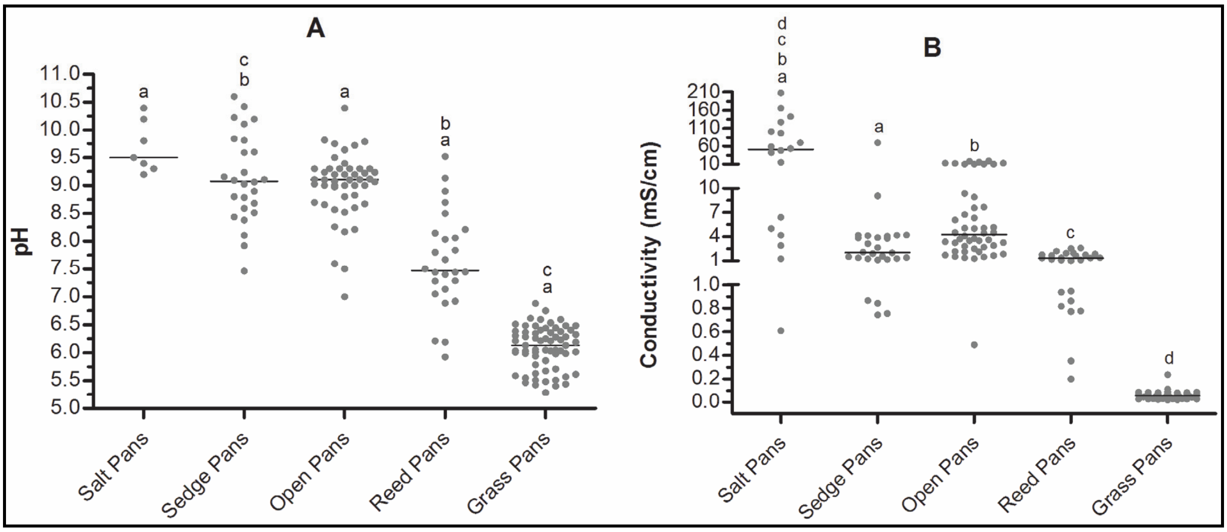

Figure 9 Physical characteristics of different types of pans: (A) pH; and (B) electrical conductivity, with their respective median values indicated. Pans with similar superscripts are significantly different from each other.

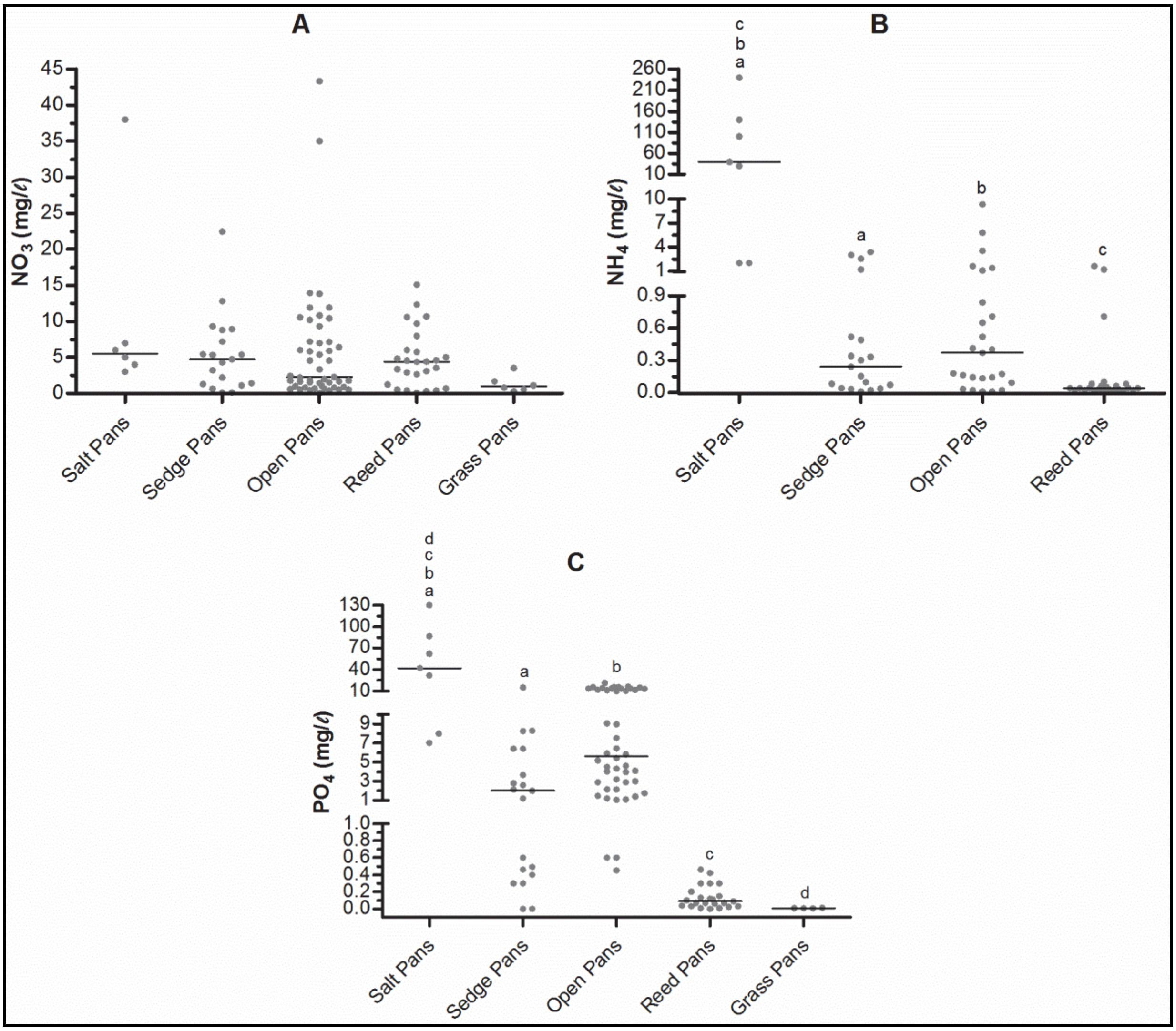

Figure 10 Concentrations of various nutrients in different types of pans: (A) nitrate; (B) ammonium; and (C) ortho-phosphate. Pans with similar superscripts are significantly different from each other.

The sulphate and chloride concentrations in salt pans differed significantly from the respective concentrations recorded for sedge, open and reed pans (Figure 11A and B).The chloride concentrations found in sedge and open pans were similar to each other but were slightly different (non-significantly) from reed pans.

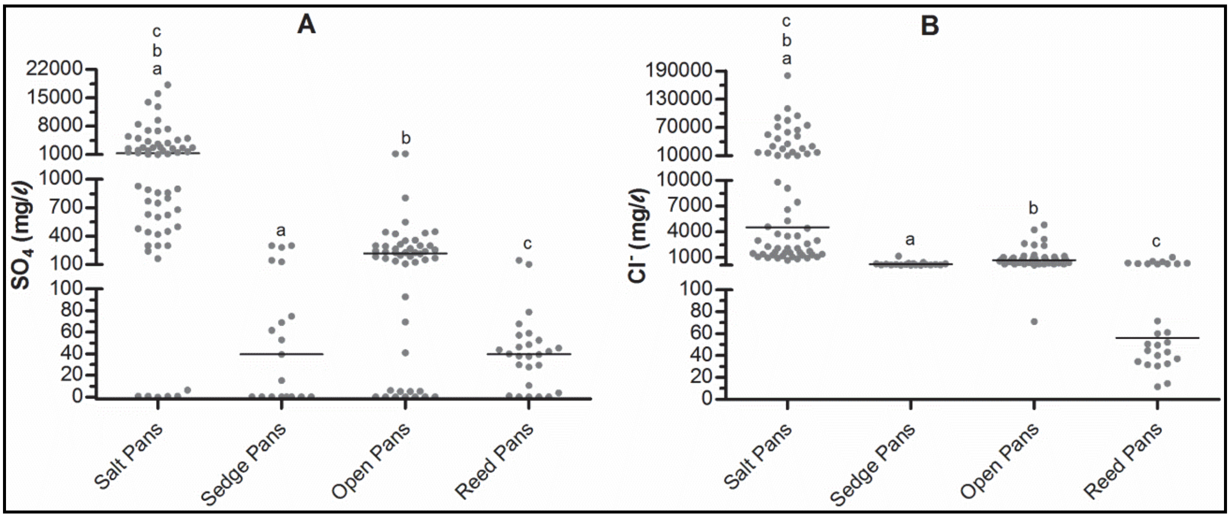

Figure 11 Changes in salt concentrations in different types of pans: (A) sulphate; and (B) chloride. Pans with similar superscripts are significantly different from each other.

CHAPTER 3: DISCUSSION AND RECOMMENDATIONS

3.1 DISCUSSION

3.1.1 Salt pans

Surface waters found in closed basins are greatly influenced by the mineralogy of the surrounding rocks as well as chemical fractionation caused by mineral precipitation (Rosen, 1994). During our analysis of the available data it became evident that salt pans are distinctly different from the other pan types in terms of the pH levels and EC values, as well as their salt and nutrient concentrations. Most salt pans have a minimum salinity of 5 000 mg/ℓ (Shaw and Thomas, 1989), though lower salt concentrations have been reported in the literature for a few cases. Nevertheless, these systems are significantly more saline than the other types of pans evaluated in this study. This is mainly because of the underlying geology and lithology which are known sources of chlorides, sulphates, sodium, calcium and magnesium (Hugo, 1974; Seaman *et al*., 1991), as well as the degree to which evaporation exceeds precipitation. Thus, most salt pans are mainly restricted to the more arid western parts of South Africa, and do not occur in the wetter eastern parts of the country. This pan type was still included in this present study because it is a well-known pan type in South Africa, and provides a good benchmark against which the other pans can be evaluated. Overall, the data show that the pans with higher EC values also had higher pH levels, and vice versa. The high levels of nutrients found in these types of pans can be attributed to the relative lack in vertical mixing of the waters within these saline waters. A more saline, anoxic layer forms near the bottom of the pan and does not mix with upper water of the pan (Ashton, 1999). This allows for the formation of a so-called mixolimnion and monimolimnion, which is separated by a chemocline (Hutchinson, 1957). Most of the nutrient cycling takes place within the mixolimnion, whilst the monimolimnion forms a nutrient “sink” where material accumulates over time in ℓ the absence of oxygen. Horizontal mixing (at low wind speeds) may also allow for the liberation of large amounts of nitrogen and phosphorous into the anaerobic monimolimnion from decaying algae (Ashton, 1999).

3.1.2 Open pans and sedge pans

Open pans and sedge pans are considered to be the more “traditional” type of pan found in South Africa. Both these types of pans have a relatively open body of water and most of the vegetation is limited to marginal areas. The most noticeable difference between these two types of pans are the presence of emergent or submerged aquatic vegetation. It appears that the main reason why vegetation is present in the one pan type and not in the other is the difference in substrate. Open pans usually occur on bedrock (with or without rock outcrops) and almost always have shallow soils (Allan, 1987). Because of this, the environment is less suitable for the propagation of aquatic vegetation in an open water pan. In contrast, sedge pans usually have a dense, black, clayey soil substrate (Allan, 1987) which seems to be more favourable for the development of aquatic vegetation. Pans with these types of substrates tend to have a relatively low groundwater input (Shaw and Thomas, 1989). It can thus be deduced that both of these types of pans occur either on or relatively close to a bedrock layer or thick clay layer which has a relatively low permeability for water. This trend have also been found by Sengupta (1993) who states that when depressions are relatively shallow, the confining layers underneath them are relatively close and this results in groundwater becoming perched on the land surface and very little, if any, deep ground water enters the pan depression (Figure 12). Russell (2008) also stated that the pans in her study were influenced to a large extent by seepage of shallow groundwater rather than deeper groundwater. Based on the available information, it is our understanding that both these types of pans are relatively similar to each other. The only difference being that open pans are situated on bedrock and have very little soil substrate; this prevents the development of aquatic vegetation within the open water.

When considering the water quality results it became evident that these two pan types were relatively similar in terms of their water quality. None of the abiotic variables analyzed showed any significant differences between open pans and sedge pans. The pH and EC values of these pans were most often lower than those of saltpans, but were higher than the values recorded from reed pans and grass pans. The same trend was noticed for the ammonium, phosphate, sulphate and chloride concentrations found in these pans. We therefore contend that both of these pan types can be grouped together as a single pan type, namely: open pans, which refer to endorheic depressional wetlands with an open body of water which contains a bedrock or sediment type substrate and is relatively perennial (although they are able to dry up).

3.1.3 Reed Pans

Approximately 320 pans have been recorded for the MLD, of which approximately 2.3% are reed pans (Allan, 1985; Grundling *et al*., 2003). These reed pans usually have high water levels throughout the year and are relatively deeper (mostly greater than 3 metres) than other types of pans (Dini et. al., 1998; Grundling *et al*., 2003). The width of the open water fringe may vary from about 20 to 150 metres, with the reed bed floating in most places (Grundling *et al*., 2003). Russell (2008) suggested that the presence of reeds in these pans is caused by a cyclical process of them dying off during periods of high salinity and regenerating when conditions become favourable. Unfortunately, this does not explain the permanent nature of these pans, which is confirmed by the presence of peat, and thus does not seem to adequately explain the formation of these unique systems.

Sengupta (1993) stated that fractures and joints are present in most rock types. Thus, pans may differ in their mode of origin, shape and structure as a result of variations in the amount of groundwater infiltration, aquifer storage capacity, permeability and location. As can be seen in Figure 12, groundwater generally moves within 45 m of the land surface. The downward movement of water from the hills is slowed down by the low permeability of confining layers. When depressions are shallow, the confining layers underneath them cause groundwater to perch on top of the land surface and these form so-called springs or seeps. When depressions occur at greater depths, or if depressions are located at specific topographical position (which may have been initiated by tectonic action), a large aquifer unit is usually formed underneath such a depression. As a result, the hydraulic head of the groundwater is usually large enough so that vertical leakage can be forced through the confining layers and into an underlying aquifer unit which serves as a constant source of groundwater for the depression (Sengupta, 1993).

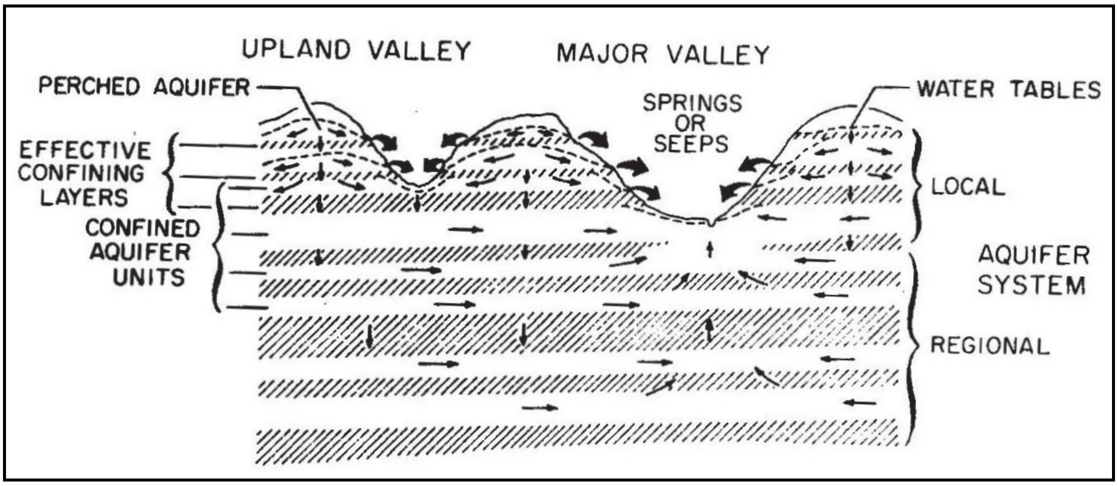

Figure 12 The movement of groundwater and its influence on deeper depressions (taken from Stoner, 1983)

This may provide insights into the formation of reed pans because they tend to be much deeper than other types of pans, and are the most perennial of all pan types (Allan, 1987, Grundling *et al*., 2003). It is their reliable source of fresh water that would have enabled these systems to support abundant vegetation, which over time has led to the formation of peat within this system. (Shaw and Thomas, 1989). According to Sahuquillo *et al*. (2006), the density of macroinvertebrates associated with reeds is greater in water bodies that contain fresh water instead of brackish water, again highlighting the importance of the fresh groundwater input for the continued existence of the unique invertebrate fauna of reed pans (De Klerk, 2009; Ferreira, 2010). Other pan types are subjected to evaporation, evolve over time and tend to become more saline, whereas reed pans are able to retain high water levels because of the inflows of fresh groundwater. The pH values recorded in reed pans are significantly different from those recorded in the other types of pans; reed pans are the only type of pan with a relatively neutral pH, compared to the relative alkaline or acidic nature of the other pans. The electrical conductivity values of the water in these pans is relatively similar to the values recorded from open pans and sedge pans, probably because of the geological features that influence the pans. Thus, no significant difference can be seen between the sulphate and chloride concentrations of reed pans compared to that of open and sedge pans. Most of the nutrients evaluated in this study are present in lower concentrations in reed pans than in sedge or open pans, probably also because of the greater influence of groundwater, but also influenced by the vegetation found in these systems. We therefore consider these pans are not only unique in terms of their water quality, but also in terms of their functioning, high dependence on groundwater and the availability of peat. These pans are considered to be sensitive and rare (seldom found) compared to the other pan types.

3.1.4 Grass pans

Grass pans are the least obvious type of pan and are often overlooked. They are generally covered with hygrophilous grasses and sedges and are often regarded as important breeding grounds for the near-threatened bullfrog (Allan, 1987; Cowan and Van Riet, 1998; Hoffman, 2012). These pans have also been found to contain fresh to saline waters (Cowan and Van Riet, 1998) and, based on the results in this study, the median electrical conductivity is approximately 0.05 mS/cm. This relatively fresh water may be a result of the highly seasonal nature of these pans, with a dilution effect during inflows after rainfall as well as high amounts of vegetation which may reduce salt loads (Marneweck, 2004). The pH levels found within these systems are also quite low, with a median pH of 6.13 and pH values also appear to be depressed as a result of the seasonal nature of these pans. Increased pH levels recorded in the other types of pans are mainly as a result of increased photosynthesis of the aquatic vegetation (including algae) which increases the pH of standing water (Barkay *et al*., 1989; Mason *et al*., 1995; DWAF, 1996; Ravichandran, 2004). Such an effect is not possible in grass pans, resulting in a lower pH level.

Grass pans also had the lowest nutrient concentrations when compared to the other types of pans – probably a result of nutrient uptake by the high amount of vegetation. Surface runoff, containing dissolved nutrients, tends to be the main contributor of nutrients, especially in depressional systems. The intermittent nature of grass pans results in nutrient concentrations often being at their highest during high rainfall. (Carpenter *et al*., 1998; McNaught and O'Keefe, 2005; De Villiers and Thiart, 2007). The plants will then be able to regulate sediment transport (Osborne and Kovacic, 1993) as well as nutrient and salt inputs during these periods (Lowrance *et al*., 1984; Raskin *et al*., 1997). The available evidence suggests to us that, although these pans are more numerous than reed pans, they are often overlooked as a result of their non-perennial nature; this may also be the reason why very little work has been carried out on these pan types. Ideally, these pans should be studied further, especially because they provide important refuge for certain species (e.g., the bullfrog).

3.2 CONCLUSIONS AND RECOMMENDATIONS

Although pans tend to be regarded as relatively insignificant in respect of the total surface area that they occupy, they are important interfaces between surface water and groundwater processes. Pans are often viewed as "unproductive" areas, which is in contrast to the extensive coal reserves which underlie much of these depressions (Allan, 1987). These types of wetlands are quite unique in form, function, sensitivity, as well as in the types of biota they attract and harbour. This is because geomorphological uniqueness frequently results in related biological uniqueness and is often associated with endemism (McCarthy *et al*., 2007). Based on the currently available literature, we feel that all the types of pans should be properly studied, in terms of their water quality, hydrological functioning, substrate composition, and species composition, so as to properly understand each type independently. This type of information will allow the compilation of a reference document on pans so that all stakeholders can be properly informed about these systems.

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