Hydrological processes in the Middle Mohlapitsi Catchment/Wetland, Capricorn District of Limpopo Province, South Africa

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Abstract

The hydrology of the Middle Mohlapitsi Catchment/Wetland, Limpopo Province of South Africa was studied from November 2005 to April 2008, involving both fieldwork and laboratory analyses. This paper presents the results of an investigation of the hydrology of the catchment and wetland and its contribution to dry season flow in the Mohlapitsi and Olifants Rivers. Forty piezometers were installed along seven transects and water levels monitored in order to understand water table level characteristics with time. The river in the wetland environment is a gaining stream because the water table level elevation is above that of the river, indicating the wetland is feeding the river. Transects 2 is affected by artificial drains by farmers and most of the piezometers closest to the river channel showed the lowest variations. The relationships between rainfall, groundwater, and surface water at this research site shows that stream flow did not respond quickly to precipitation as expected. Furthermore, the groundwater levels did not show significant fluctuations, indicating that groundwater responds gradually to precipitation, and that the relationship between rainfall, groundwater and surface water is complex.

Keywords: wetlands, hydrology, piezometers, transects, rainfall, water levels, stream flow, groundwater, and surface water

1. Introduction

Wetlands provide many services such as crop production, grazing, timber production, flood protection/mitigation, carbon and nitrogen sequestration, flow regulation, water quality and etc [Mitsch and Gosselink, 1993;]. Wetlands have been recognized for their extremely important role in the environmental quality maintenance [Adekola, 2007]. Moreover wetlands have been identified as one of the environments most sensitive to physical and chemical changes. These changes may be due to changes in climate, water and land uses in adjacent surrounding catchments, chemical and nutrient incoming loads, ditching, draining, dredging, and filling [Carter, 1996; Troy et al., 2007].

Wetlands in Africa and in southern Africa play an important role in the livelihoods of rural communities [Masiyandima et al., 2006]. Naturally, wetlands store water during wet season and release it during dry time. Due to this reason, farmers, who live in semi-arid areas such as the Mohlapitsi wetland, are able grow crop all-year round thereby improving their food security and incomes [Bullock and Ackerman, 2003]. Besides crop production, wetlands provide other services that support peoples’ livelihoods such as dry season livestock and domestic water supply, fishing, and natural products (such as reeds for roofing and decorations) [Kotze, 2005].
However, wetlands have been threatened by anthropogenic activities [IUCN, 2008]. Alike other parts of the world, altering the Mohlapitsi wetland environment through conversion to croplands and other uses has the potential to degrade the wetland and undermine its capacity to provide services in the future [Dixon and Wood, 2003; Jogo and Hassan, 2010]. Wetlands have been threatened or at least affected by non natural causes. Anthropogenic activities in Africa and world-wide contributed to the loss of at least 50% of wetlands in the last 20th century [Jogo and Hassan, 2010]. The degree of recovery of these wetlands functioning shows uncertainty even though some attempts were made to restore ecology [Hughes and Munster, 2000]. Negative impacts in wetlands have resulted in natural resources degradation, which might not be reversed unless high investment is made for recovery planning. Much is not done in order to prevention and mitigate of such ecosystem degradation in Africa and elsewhere, as well the rehabilitation of these environments, have not been increasingly incorporated into projects for broader environmental quality enhancement [Kusler, 1987]. Such projects frequently rely on management plans, for which quality of ecosystems have been considered one of the major objectives [McCartney et al., 2005].

Several negative environmental impacts of human use of wetlands are reported, such as declining of soil fertility, reduction of biodiversity and declining of wildlife population, soil erosion leading to increased sediment downstream, water pollution due to use of agro-chemicals or to human and livestock waste, and impact on water quantity on-site (productivity of wells) and downstream (reduced flows and rapidly receding water levels during the dry season) [Kotze, 2005; Masiyandima et al., 2006].

A major cause of wetlands degradation all over the world, and more specifically in southern African countries, is precisely the lack of knowledge by government planners, natural resource managers and wetland users of the ecological processes by which wetlands provide [Ellery et al., 2005]. Even in the scientific community, there is a large gap in the understanding of the effects of land and water uses in the wetlands on hydrological processes in the catchments.

The Middle Mohlapitsi Wetland is experiencing threats such as overgrazing, surface water abstraction for irrigation, over fishing and domestic purposes, erosion, over exploitation of macrophytes, siltation, among others [McCartney et al., 2005]. Uncontrolled subsistence cultivation and grazing practices will further exacerbate the wetland degradation. These threats are worse during the dry spell because the community rush to reclaim land for agriculture and overgrazing [Riddle et al., 2008]. Despite these threats, the Middle Mohlapitsi Wetland still provides a substantial flow of ecosystem goods and services which forms the backbone of the wetland community livelihood [Sarron, 2005]. The value of this flow has however not been established deeply and as a result, management decisions have not considered the economic importance these goods and services provide to the local community and the national economy [Troy et al., 2007]. If hydrology and the value of the Middle Mohlapitsi Wetland goods are not established, management decisions will not sufficiently consider its economic value. This is likely to lead to misallocation of resources and may cause major ecosystem degradation.

One of limitations to sustainable wetland management by decision makers and wetland users in southern Africa has been insufficient understanding of the values and functions of wetlands and the consequences of alternative management and policy regimes on wetland functioning, ecosystem services and human well-being [Wood, 2000c]. To accomplish that goal, planners,
managers, and specialists should carry out effective multidisciplinary efforts; however further connectivity among related areas of knowledge is still necessary. Understanding the hydrology of a wetland is important to decisions involving its future and to evaluating trade-offs involved in protection, development, and mitigation. To address these questions and provide adequate wetland evaluations requires an understanding of why wetlands occur in a particular place and where the water comes from. Therefore, the main objective of this research paper is to improve and develop understanding of hydrological processes and wetland dynamics of wetland. The goal of this research project is to contribute to the development of advanced understanding of hydrological processes and dynamics of wetlands.

2. Study area

This study was conducted at the Middle Mohlapitsi Wetland, which lies in the former homeland area of Lebowa in the Capricorn District and in the middle part of the Limpopo basin. The wetland is a riverine system covering an area of 120 ha [Kotze, 2005]. The wetland is located in the B71C quaternary catchment and geographically on coordinates 24°6’0” South and 30°6’0” East. Agricultural activities have extensively modified the ecological status of the wetland system under study [Jogo and Hassan, 2010]. The study valley is narrow and confined; with steep hill slopes on the edges of the valley bottom.

The Mohlapitsi River is in Limpopo Province of South Africa and drains southwards from the Wolkberg Mountains into the Olifants River (Figure 2.1). The upper part of the Mohlapitsi Catchment in Olifants Catchment (in Limpopo Catchment) is mountainous with peaks above 2050m and mainly covered by natural forest, whereas the lower reaches are alluvial valleys [Kotze, 2005]. At the confluence with the Olifants River, the Mohlapitsi catchment is 49000 km$^2$ and upstream of the wetland it is approximately 263 km$^2$.

![Figure 2.1 Map showing the location of the study area within the Olifants catchment [Mekiso, 2011].](image)
2.1 Rainfall

The Mohlapitsi River basin is within the summer rainfall region of South Africa and receives rain between October and April. The mean annual rainfall in the uplands of the Mohlapitsi catchment exceeds 1000 mm, while the long-term average annual rainfall over the wetland [Nell and Dryer, 2005] is reported to be 511 mm, of which 440.8 mm, or 86%, falls from October to March. The wetland site is characterized by seasonal rainfall and experiences frequent drought and floods (for example, the devastating 2000 floods) [Jogo and Hassan, 2010]. Mean annual rainfall in the valley bottom, where the wetland is located, is typically 500-600 mm [Jogo and Hassan, 2010]. The mean annual potential evaporation for the B71C quaternary catchment is 8.33 mm/day.

2.2 Geology and soils

The geology of the region comprises sediments of the Transvaal Sequence and the study area is underlain by the Malmani Subgroup of the Chuniespoort Group [Nell and Dryer, 2005] which are Early Proterozoic dolomitic rocks of between 2,100 million years and 2,000 million years old [Mekiso, 2011]. The material in this subgroup consists of grey to grayish blue and pink, compact and poorly bedded dolomites and limestone with chert layers. The groundwater resources assessment (GRAII) database suggests that the mean annual recharge to groundwater for B71C is between 24.08 mm y⁻¹ and 86.50 mm y⁻¹ depending on the methods used to generate the estimates. Groundwater transmissivity is expected to be approximately 14.71 m² d⁻¹, while storativity have been estimated as 0.004 and aquifer thickness as 25 m [Nell and Dryer, 2005].

The soils in the wetlands are a mix of fine-textured, poorly drained areas away from the river bank, and less extensively sandy soils located close to the channel [Kotze, 2005. During floods, the Mohlapitsi River carries fine and coarse sediments from the steep catchment slopes with high velocity until it reaches the wetland with gentler slopes. A sudden reduction in flow velocity in the valley has created a changing pattern of braided channels, where it spreads and deposits coarse sediments or bed load (gravel, cobbles and boulders) during very high flood stages. These deposits are located near the base of the alluvium. Suspended load (fine materials or sediments
such as sands, clays and silts) are deposited at the surface as well as in the interstices of the deeper coarser sediments [Kotze, 2005]. Soils of the study area are hydric-wetland soils, which have grayish, dark brown to reddish brown, sandy loam top soils and strongly sub-angular structured, sandy clay loam sub soils because of the long periods of saturation [Nell and Dryer, 2005].

2.3 Streamflow

The river is gauged just below the Kudumela wetland, at station B7H013 and stream flow records are available for the periods 1970 to 2008. The flow shows both seasonal and inter-annual variation, with mean annual flow is 37.96 Mm$^3$, equating to about 144 mm of runoff [McCarty et al., 2005]. The coefficient of runoff for the catchment (i.e., the proportion of rainfall converted to runoff) is 0.18, which compares to an average of 0.06 for the whole of the Olifants catchment [McCarty et al., 2005].

Daily stream flow was measured at the only gauging station on the Mohlapitsi River (B7H013), located about 1 km downstream of the wetland. The gauging station weir is maintained by the Department of Water Affairs (DWA) and has been in operation since August 1970. Mean daily stream flow data available from the DWA website (www.dwaf.gov.za) were used in the analysis. For the current study, historical records from June 1990 – September 2008 were used for all calculations in the analysis. Due to a technical problem with the gauging station from 30 May 2006 were found unreliable. Starting in the dry season of 2006 river flow has been measured upstream of the wetland by using a C2 current meter (OTT instruments). Measurements were taken for the months of July and August 2006. Unfortunately, the gauge was washed away during the November 2006 flood after which, no data were collected. Moreover, attempts at performing more accurate fluorescent dye tracing failed as no suitable sections of river could be found along which the basic criteria for such tracing (complete mixing, no stagnant water, a single channel) could be satisfied. All field data were collected by the field assistants and sent to the author on a monthly basis. The data were processed and checked for errors and consistency using a spreadsheet. The rainfall (histogram), groundwater hydrographs of all transects as T1, T2, and T6 and stream flow at gauge B7H013 were plotted in order to compare and understand groundwater fluctuations and their relationships (Figures 4.1,4.2 and 4.3).

3. Methodology

3.1 Groundwater monitoring by piezometers

Piezometers were installed to gain a better understanding of subsurface-surface water interactions (Figure 3.1). Piezometers were made from PVC with an internal diameter of 65mm, and no bottom and top caps were provided (Figure 4.1). In November 2005, piezometer holes were made using a Dutch Auger (Figures 4.2 and 4.4) and all tubes were installed at different time. It was planned to install all piezometers at a spacing of 50m within a transect. The lateral distance between transects differs due to the wetland orientation (left bank and right bank position). The surface elevation of each piezometer was obtained from profile surveying using a dumpy level. Two benchmarks namely, one at T1 and the second and the last one at T7 were established on permanent structures. After the first surveying, the candidate carried out two more surveying on the same piezometers by starting the first round from benchmark (BM2) at T7 and the last check-up from first benchmark (BM1) in order to see any errors.
Initially it was planned to install a total of 47 PVC piezometers in the seven transects. However, the depth of each hole and the spacing were constrained by the occurrence of boulder beds beneath the surface and a few of the augers were broken during augering due to the presence of the impermeable layer. The spacing was adapted to accommodate this feature and until subsurface water was reached in each hole. Slots were drilled in the lower 300mm of the piezometer and the slotted part was installed as shown in Figure 4.1. The slots were covered with coarsely textured sandy material. None of the piezometers were capped. The backfill material around the tube was placed using a mason’s trowel. A gentle manual compaction was applied around the piezometer after pouring cement-sand mortar.

Groundwater monitoring started in November 2005 and water table levels were recorded daily following rain events. During other days (summer and winter seasons) recording was made every other day. Because water levels did not show significant difference during short time measurement, recording frequency was changed from 2 days to 8 days (4 times in a month). The water levels were recorded in cm. Water elevations and fluctuations were assessed and compared through time to determine the natural variability associated with seasonal and long term climatic changes.

In order to monitor water level in the piezometers, a water level indicator was used (Durham Geo Slope Indicator, http://www.slopeindicator.com - Figure 4.4). It consists of a probe, a cable with laser-marked graduations, and a cable reel. An LED located in the hub of the cable reel illuminates (and a beeper sounds) as soon as the probe contacts the surface of the water in the piezometer tube.
3.1 Rainfall

The duration of the records at five rain gauges operated by South African Weather Stations are variable and none of the stations are currently active and reporting data. The Fertilis Weather Station is located approximately 3 km upstream of the wetland, with a mean annual rainfall of 570 mm. Furthermore, in November 2005 five manual rain gauges were installed within the wetland (Figure 2.1) on transects T1, T2, T4 and T6, two gauges were installed on T4 because it is the largest transect. These gauges were read after each rainfall by the field assistants.

4. RESULTS

4.1 Rainfall and streamflow

Figure 4.1 illustrates the relationship between rainfall measured over the wetland and stream flow at the DWAF gauging station (B7H013) downstream. The accuracy of the measured flow data at the hydrological station B7H013 is expected to be about 5% in the range 0 – 5 m$^3$ s$^{-1}$ and 10% for flows higher than 5 m$^3$ s$^{-1}$. Moreover, when the water level exceeds 1 meter at the gauge (which corresponds to
12.8 m$^3$ s$^{-1}$), water overtops the weir and no stage-discharge relationship is available. Therefore, no high flow data are available and such a situation appears as observation gaps in the records (Troy et al., 2007).

The rainfall data plotted are obtained from the study area located at the 5 rain gauges installed as part of the project (Figure 2.1). There were very small differences between the rainfalls measured at the five gauges suggesting low spatial variability of rainfall inputs over the wetland area. The technical assistants indicated that no rainfall was measured for the periods before 29/11/2005 and after 28/02/2006; however, the stream flow response at the end of the study period suggests that rainfall did occur within the catchment of the wetland. However, there is a generally poor relationship between the rainfall measured in the valley bottom and the gauged stream flow (Figure 4.1), suggesting that rainfall patterns in the catchment area could be very different. Unfortunately, data for the South African Weather Service (SAWS) rain gauges referred to in chapters 3 and 4 were not available for the study period as they had been closed down.

![Figure 4.1 Rainfall over the wetland and daily streamflow observations at B7H013](image)

### 4.2 Groundwater monitoring

#### 4.2.1 Transect T1

After the water table was reached, augering continued for a further 50 cm in all piezometers in order to observe the water table fluctuations. Water table monitoring started 24 hours after the installation of the piezometers. All piezometer levels showed a rapid response at the start of the wet season (from 18/11/2005 until 28/01/2006). However, water levels in Piezometer MRB101 showed rapid response from 18/11/2005 to 16/01/2006 and undulating pattern was observed between 16/01/2006 and 29/03/2006. The water table surface elevation along T1 did not drop significantly during the dry episodes that followed (Figure 4.1). Again after 28/09/2006 until the end of measurement period (30/12/2008), water level elevations in all piezometers in T1
environment showed positive increase. However, there is very little correlation with the patterns of local rainfall during the main part of the wet season.

None of the piezometers responded to the large amounts of rainfall recorded during the first three weeks of February 2006 (74 and 103mm) (Figure 4.1). MRB103 and MRB105 show some response to the final stream flow event of the season (end of March 2006), but no clear responses to any of the other stream flow fluctuations during the wet season. Variations in groundwater levels in MRB101 (Figure 4.2) show the closest relationship with variations in stream flow, an expected result given that this piezometer is closest to the channel. The assumption is that the groundwater is draining towards the channel and that the wetland is probably contributing to stream flow, however, the source of the increments to wetland groundwater is not very clear from the available data.

Most of the piezometers in T1 do not show a great deal of variation at the end of the wet season and yet the groundwater levels (and hydraulic gradients toward the river) are substantially higher than at the start of the 2005/2006 wet season (Figure 4.2). On the other hand, water levels in all piezometers increased from the end of 2006 until the end of recording time (Figure 4.2).

![Figure 4.2](image)

**Figure 4.2**  Groundwater table fluctuations November 2005 to December 2008 for T1

### 4.2.1 Transect T2

In T2 the depth of the boulder bed was observed to be approximately 0.2m and water table measurements in all piezometers started on 30 November 2005 (Figure 4.3). Most of the piezometers in T2 show a relatively small response throughout the wet season, although MRB206 responds rapidly to the high rainfalls that started at the beginning of February 2006 and, as with the T1, the piezometer closest to the river (MRB201) approximately follows the patterns of stream flow variation (Figure 4.3). MRB206 also shows a response at the same time as the last flow event of the year (at the end of March 2006). If the increase in water elevation of 0.89m in MRB206 in early February is caused by local rainfall a ‘storage coefficient’ of 22.7% would be required. While this might seem reasonable for the type of soil, there is no explanation
for the lack of response in the other piezometers. Alike T1, water levels in all piezometers in T2 increased from the end of 2006 until the end of measurement date.

![Figure 4.3](image-url)

**Figure 4.3** Groundwater table fluctuations November 2005 to December 2008 for T2

### 4.2.3 Transect T6

Figure 4.4 indicates that the water levels across this transect fluctuate more so than other transects. These fluctuations are also quite well correlated with the variations in stream flow downstream at the gauging station, except at the start of the wet season. There is always a positive gradient towards the river channel and unlike some of the other transects the fluctuations in the piezometer closest to the channel are greater than further away. Figure 4.4 suggests that there may have been a wetting influence before the study started collecting data and this was followed by a drying period immediately after the first period of observed rainfall.

The response to the second rainfall period (early February) was more or less immediate with water levels rising between 0.4m in MLB601 and a little more than 0.2m in MLB603 (Figure 4.4). The responses to later events in the wet season are also relatively immediate, but not always as clear and there appears to be a gradual accumulation of groundwater during the whole period, despite frequent, but relatively short periods of drying. These are presumably caused by drainage or evaporation, or a combination of these two processes. The recession in groundwater levels at the end of the wet season also reflects the pattern of stream flow recession, a result that is not as evident in both the previous transects. The implication is that the groundwater in this transect has a greater connection to the channel than in the other transects.
5. DISCUSSIONS

At least 7 active springs were identified in the area in August 2005 in the middle of the dry seasons, 6 months after the last rainfall was observed. The springs indicate the presence of regional groundwater contributing to inflows to the Mohlapitsi wetland (Kotze, 2005; McCartney, 2006). Although the wetland is located in the channeled valley, the overflow from the river does not contribute significantly to the water balance of the wetland. Experienced local individuals we interviewed told us that over bank flow during flooding of the river is insignificant. The last known occurrence was during floods in 2000. Subsurface transfers from the wetland to the river occur but the magnitude of this transfer is unclear.

Groundwater monitoring on all piezometers did not commence on the same day due to the fact that drilling all holes manually could not be done the same day. In addition, boulders beneath the soil did not allow some holes to penetrate as deeply as others. However, these constraints have not affected the interpretation of the results as the main wet season groundwater response has been captured within all transects.

At the start of the 2005/2006 wet season the variation in water levels across some of the transects was relatively low, while the variation at the end of the season was much greater (T1 and T3). However, in other transects (T2, for example) the variations during the wet season were relatively minor. Most piezometers showed a gradual increase in water table level at the start of the wet season. Almost all transects show a flow gradient towards the river, while in some cases there are local gradients towards depressions in the wetland surface. The fluctuations in the water level varied from transect to transect as well as within transects. Transect 1 showed the greatest variations (between 1.1 and 2.0m, with the exception of MRB101 next to the channel). Most of the sites closest to the river channel showed the lowest variations. The soils near the river channel are sandy and well drained in nature (Kotze, 2005; Nell and Dryer, 2005) and these smaller variations in water level possibly reflect the presence of rapid lateral flow processes.
The fluctuations in water level appear to be more strongly associated with the stream flow variations reflected at the gauge (B7H013) located downstream of the wetland (Figure 4.1). The lower part of the wetland is characterized by sandy and more permeable soils, allowing for more rapid movement of water, both vertically and laterally (Nell and Dryer, 2005). In this part of the wetland, any increase in storage in the wetland due to rainfall may be lost shortly after the event through lateral flow to the river. A further possibility that is difficult to explore in more detail without more data is that the river flow from upstream is influencing the water tables in some of the transects.

Water levels in all piezometers showed undulating pattern until the end of 2006 and increased until the end of measuring period although rainfall did not impact these results. The main reason for the above results could be that the wetland is built on karst aquifer. Karst aquifers are characterized by caves, sinkholes and other geological heterogeneities created by dissolution of the parent carbonate or evaporitic rock. Worldwide an estimated 20–25% of the population largely depends on groundwater from karst aquifers (Mekiso, 2011). The mean water table surfaces in all transects (Figures 4.2, 4.3, and 4.4) show gradients in the water table along the transects towards the channel, suggesting inflow from the slopes. The upstream part of the wetland is affected by artificial drains (Figure 3.1), although the exact location of these with respect to the transects has not been recorded. The influence of these drains could be partly responsible for the relatively low degree of variation in most of the piezometers of T2.

This investigation has attempted to show whether there are relationships between groundwater, surface water and rainfall at the study site. Very few of the piezometers show any clear relationships with the measured local rainfall inputs, suggesting that other processes are playing equal or more important roles. These processes could include inflows from the adjacent hill slopes (either surface or subsurface or both), interactions with flow in the channel and the effects of artificial drains. There is some evidence within the data for all of these processes, but it is not conclusive.

One of the important observations that has been made is that the research resources required satisfactorily quantifying and understanding wetland processes are substantial. Many valuable lessons have been learned from this study. While the study site is relatively small, it is apparent that the hydrological processes within it are quite complex.

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