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PHYSICAL HYDROLOGY OF THE MIDDLE MOHLAPITSI WETLAND, CAPRICORN DISTRICT, SOUTH AFRICA

FA Mekiso[*1], J Snyman[*1] and GM Ochieng[2]
Department of Civil Engineering, Faculty of Engineering and the Built-Environment, Tshwane University of Technology, Pretoria 0001[*1]
Department of Civil Engineering & Building, Faculty of Engineering and the Built-Environment, Vaal University of Technology, Vanderbijlpark – 1911[2]

ABSTRACT

Anthropogenic intervention in wetlands water dynamics is thought to have created significant changes in water table fluctuations in the Middle Mohlapitsi Wetland. For example, clearing or drainage of wetlands can lead to losses of stored organic carbon (C) to atmospheric carbon dioxide (CO2). By doing this, wetlands mitigate climate change. Changes from flooded to drained conditions in soils stimulate changes from aquatic to terrestrial vegetation and decrease the algal contribution to total primary production. The objective of this paper is to analyse and quantify the dynamics of water generation and retention within the wetland. The study involved both fieldwork and laboratory analyses. Twenty (20) piezometers made from 65 mm diameter PVC tubes were installed along three transects namely T4, T5 and T6. T4 is the widest transect (596.50m); with nine piezometers that were kept in place until the end of 2012. T5 is the second widest transect (450.70 m) with a total of eight piezometers and is located in the left bank of the river. Among this group of transects, T6 is the narrowest (198.90m) with only three piezometers. Long-term groundwater table (GWTL) levels were monitored in order to understand water table fluctuations. GWTL fluctuations were measured by an electronic water level recorder and the readings were sent to the authors for desktop analyses.
Five funnel-shaped rain gauges were installed in 2005 within the wetland and readings were taken after every rain events until 2012. These readings were used for all calculations. Streamflow readings from 1970 through 2012 were taken from Department of Water Affairs (DWA) weir, located 1 km downstream of the wetland. Between 10/02/2010 and 02/04/2010, the study wetland received some 214 mm of rainwater, and it was observed that GWTLs in all three transect increased. Thereafter, all piezometers did not show any increase or decrease until the end of study period. Statistical analysis showed that there is a significant moderate positive correlation between rainfall and streamflow. However, there is no relationship between rainfall and groundwater. Such complex situations between in groundwater table and rainfall could be caused by rainfall far from the study area. Hydrological processes in the upper and surrounding catchments impact water balance of the wetland under study.

Keywords- Mohlapitsi Wetland, water table, transect, piezometer.

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1. INRODUCTION

Wetland ecosystems cover at least 6% of the earth's land surface and contain approximately 12% of the global carbon pool, playing an important role in the global carbon cycle (Fiona et al., 2010; Ferreti et al., 2005). Wetlands provide many other services such as crop production, grazing, timber production, flood protection/mitigation, nitrogen sequestration, flow regulation, water quality (Heimann and Femmer, 1997; Mitsch and Gosselink, 1993). Wetlands have been recognized for their extremely important role in the environmental quality maintenance (Adekola, 2007; Troy et al., 2007; Carter, 1996).

Wetlands in southern Africa play an important role in the livelihoods of rural communities (Masiyandima et al., 2006). Wetlands are crucial for pollution control, nutrient recycling, soil formation, ground water recharge, climate regulation, and erosion control (Bullock and Acreman, 2003). In addition, they provide other services that support peoples' livelihoods such as domestic water supply, fishing, reed (Phragmites mauritanus) harvesting for roof construction (Kotze, 2005).

However, wetlands have been threatened by anthropogenic activities (IUCN, 2008). Altering the wetland environment such as conversion to croplands, residential area, road construction activities has the potential to degrade the wetland and undermine its capacity to provide services in the future (Jogo and Hassan, 2010; Dixon and Wood, 2003). Most wetlands in the world are stressed by both animal and crop farming activities. Human interventions in Africa and world-wide contributed to the loss of at least 50% of wetlands in the last 20th century (Holland et al., 1995).

Negative impacts in wetlands have resulted in natural resources degradation, which might not be reversed unless recovery planning is made (Hughes and Munster, 2000; Hook, 1988). Much is not done in order to prevention and mitigate of such ecosystem degradation in Africa and elsewhere, as well as 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 (Liang and Ding, 2004).

Furthermore, two major negative environmental impacts of human use of wetlands are point and non-point source pollutions. Point sources, such as municipal industrial sites, and non-point sources, such as agricultural lands and urban runoff, add materials to ground water and surface water that upset the balance of wetland water chemistry and the biogeochemical cycling of materials in wetland ecosystems (Dahl, 2005).

Moreover, global climate change is being recognized as a threat to species survival and the health of ecosystems. Wetlands are vulnerable to changes in quantity and quality of their water supply, and it is becoming real more than ever that climate change is having a pronounced effect on wetlands through alterations in hydrological regimes (Anderson and Emanuel, 2008; Conly and van der Kamp, 2001). Wetland habitat responses to climate change and the implications for restoration will be realized differently on a regional and large area groundwater-bearing geological environment.

The Middle Mohlapitsi Wetland is experiencing threats such as overgrazing, surface water abstraction for irrigation, over fishing, 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 communities rush to reclaim land for agriculture and overgrazing (Riddel et al., 2008). 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 the 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). 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 adequate wetland evaluations requires an understanding of why wetlands occur in a particular place.

Lon-term groundwater table level monitoring in a wetland catchment is an essential element for water resources management decisions. Monitoring provides important data that can serve as input into the appropriate decision process (Combalicer et al., 2008). Furthermore; they demonstrated that monitoring of groundwater can enable water resources managers, policy makers and engineers to:

i) track changes in GW levels to understand the long-term sustainability of an aquifer,

ii) identify and obtain GW contamination information and better understand water quality problems impacting public and ecosystem health, and address the problem,

iii) enable decision makers to assess the effects of climate change on GW table levels to issue timely warnings,

iv) help water resources managers understand potential changes in flow due to GW withdrawal, and

v) assist wetland managers and agricultural extension workers to monitoring artificial drainage ditches in the wetland.

This paper illustrates the importance of long-term monitoring of GW table levels in the wetland environment and highlights the applicability of monitoring data to water resources issues. The goal of this research project is to contribute to the development of advanced understanding of hydrological processes and dynamics of wetlands inferred from water table level fluctuations in the wetland.

2. METHODOLOGY

2.1 Study area

This study was conducted at the Middle Mohlapitsi Wetland, in the Capricorn District and in the Limpopo basin. The study site is a palustrine wetland covering an area of 120 ha (IUCN, 2008). It comprises predominantly reed beds (*Phragmites mauritanus*). The wetland is located in the B71C quaternary catchment within Oliphants catchment and geographically on coordinates $24^0$06'0" South and $30^0$06'0" East. Agricultural activities have extensively modified the ecological status of the wetland system under study (Holland et al., 1995).

The Mohlapitsi River is in Limpopo Province of South Africa and drains southwards from the Wolkberg Mountains into the Olifants River (Figure 1). The upper part of the Mohlapitsi Catchment in Oliphants Catchment is mountainous with peaks above 2050m and mainly covered by natural forest, whereas the lower reaches is alluvial valley. The river drains approximately 490 km^2.

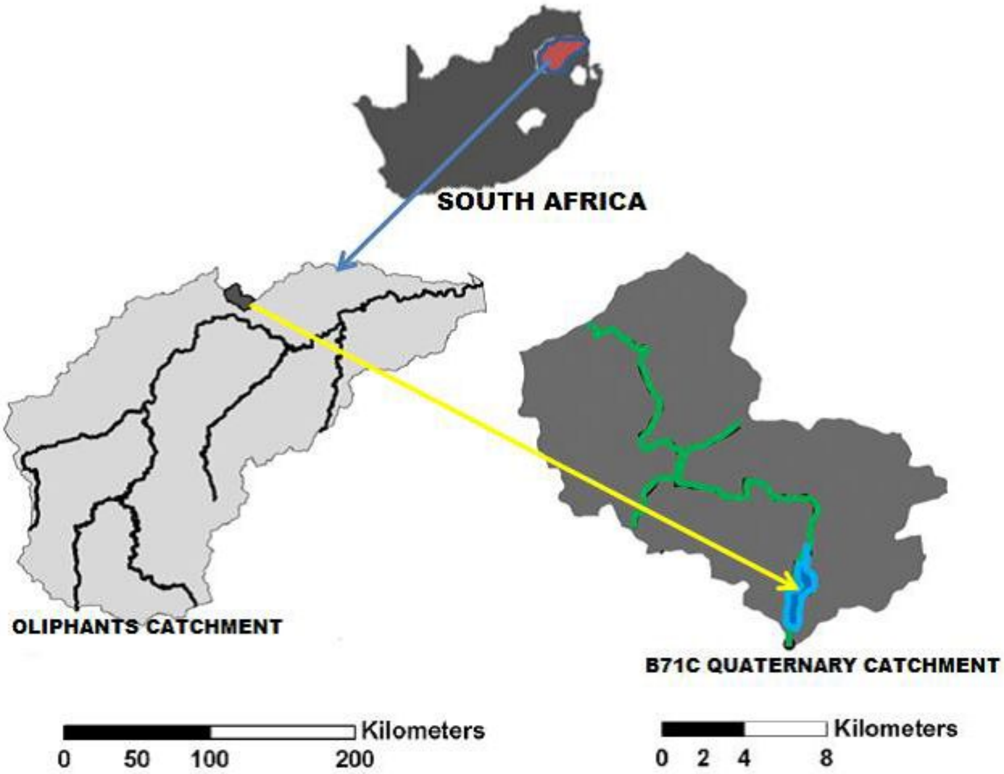


Figure 1: Map showing the location of the study area in B71C Quaternary Catchment within the Olifants Catchment (Mekiso, 2001).

The Mohlapitsi wetland experiences semi-arid climate, although summer starts in October and ends in April; while winter season begins in May and ends in the month of September. Due to its low elevation of 720m, the study catchment enjoys moderate climate throughout the year. Mohlapitsi and its surroundings receive moisture from Indian Ocean. The study valley is narrow and confined; with steep hill slopes on the edges of the valley bottom (Figure 2).

Figure 2: The Middle Mohlapitsi Wetland in the valley bottom

The Mohlapitsi River basin is within the summer rainfall region of South Africa and receives rain between October and April. The wetland site is characterized by seasonal rainfall and experiences frequent drought and floods (Holland et al, 1995). Mean annual rainfall in the valley bottom, where the wetland is located, is 550 mm (Mekiso, 2011; Nell and Dreyer, 2005) of which 86%, falls from October to March. The mean annual potential evaporation for the B71C quaternary catchment is 8.33 mm/day (Midgley et al., 1994).

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 (Figure 3). 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.

Figure 3: Sediments at T1 environment transported by the river during severe flood

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 (IUCN, 2008). 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 soils (Nell and Dreyer, 2005).

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 which are Early Proterozoic dolomitic rocks of between 2 100 million years and 2 000 million years old (Mekiso et al., 2013; Mekiso, 2011; Miyano and Beukes, 1996). 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 m^2 d^{-1}, while storativity have been estimated as 0.004 and aquifer thickness as 25 m (Nell and Dreyer, 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. During flood time, the Mohlapitsi River carries fine and coarse sediments from the steep catchment slopes with high velocity until it reaches the wetland with gentler slopes (Figure 3). 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.

2.2 Streamflow

No gage was installed at the head of the valley and flow measurement was achieved by using float and stopwatch. The river is gauged approximately one km below the end of the Middle Mohlapitsi Wetland, at station B7H013.The total runoff from the study was estimated by McCartney (2011) as 103 mm. 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 Oliphants catchment.

The gauging station weir (Figure 4) is maintained by the Department of Water Affairs (DWA) and has been in operation since August 1970. For the current study, historical records from November 2005 – December 2012 were used for all calculations in the analysis. All field data were collected by the field assistants and sent to the authors on a monthly basis. The data were processed and checked for errors and consistency using a spreadsheet. The rainfall histogram, groundwater hydrographs of T1 and T7 and stream flow at gauge B7H013 were plotted in order to compare and understand groundwater fluctuations and their relationships.

Figure 4 Department of Water Affairs weir site

2.3 Study design and procedure

This study was designed to provide the scientific community, water resources managers and policy makers with current, scientifically valid information on the status and extent of wetland resources and to measure change in those resources over time. Simple random sampling design was used to run statistical analyses.

2.4 Piezometer installations

A total of 20 piezometers made from 65 mm diameter PVC tubes were installed along three transects perpendicular to the river (Figure 5). The purpose of using PVC tubes as piezometers was that PVC pipes were easily transported, cheap, easy for cutting and installing. Monitoring piezometers was the easiest means of determining depth and movement of water tables within and below the soil profile. Piezometers were manually perforated only at the bottom of the pipe. They were installed with an impermeable mixture of bentonite, sand and cement to seal the hole around the piezometer so that water could not flow down the outside of the pipe. Water levels inside the pipe result from the water pressure over the narrow zone of perforation at the bottom of the pipe.

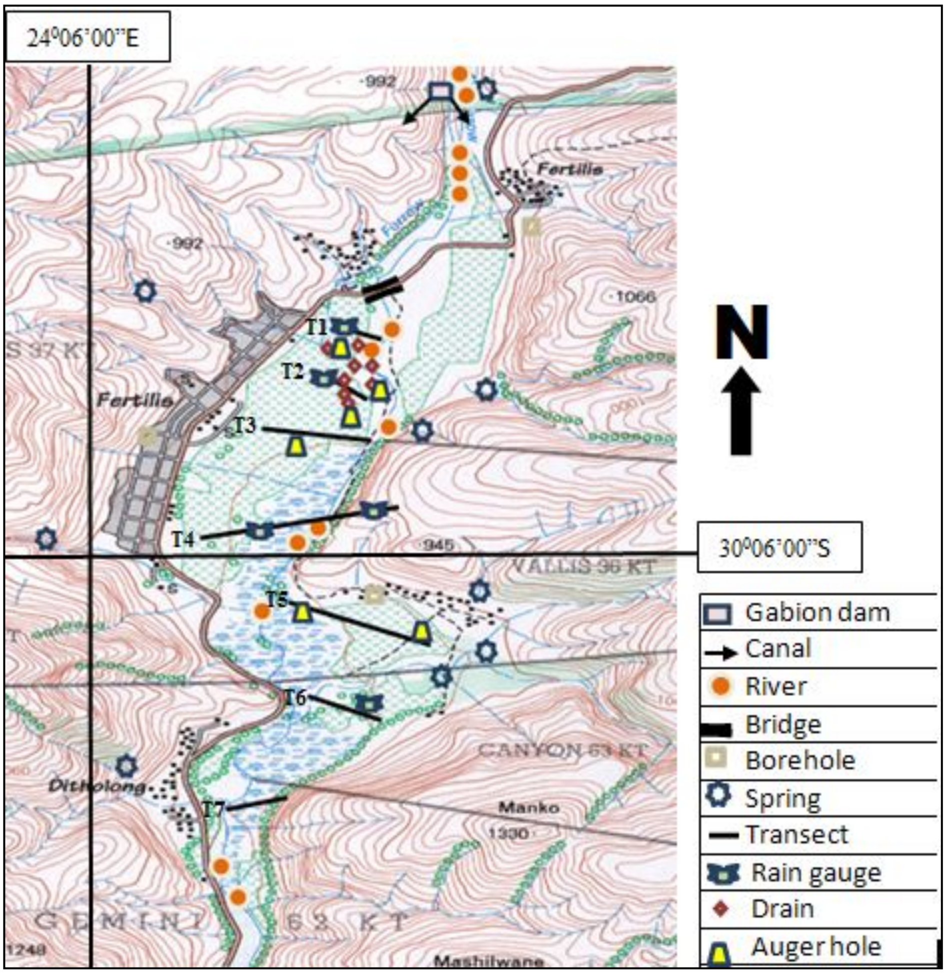


Figure 5 Locations of water sampling points in the study wetland during 2007 through 2013

Boreholes for piezometer installations were drilled by means of Dutch Auger and mud was cleaned before piezometer tubes were installed. Backfilling the bottom of the borehole with clean fine sand was done to a point 180 mm below the piezometer tip position. GW levels fluctuations with time were measured by electronic water level recorder.

Wetland water balance calculation was attempted by using equation described by Mekiso (2011) and McCartney et al (2011) as

$$\Delta Sw = P + GWi + SWi - E - SWo - GWo \qquad (1)$$

where ΔSw is change in storage in the wetland; P is rainfall; GWi is groundwater inflow from the surrounding catchment; SWi is surface water inflow from the hill slopes or river; E is evapotranspiration (crop and wetland vegetation); SWo is surface water outflow; and GWo is groundwater flow to the river.

2.4 Rainfall data

Long-term rainfall data were obtained from five stations (Figure 6) of the South African Weather Service (SAWS) in the vicinity. Among the five daily rainfall stations that are available to characterize the rainfall over the basin, three are located on the top of the mountain near the watershed (Wolkberg, The Heights and The Downs); while the Fertilis station is located at the top of the Middle Mohlapitsi Catchment/Wetland and Stellenbosch is in the valley immediately downstream from the B71C catchment.

Figure 6 Location of rain gauges in the Mohlapitsi catchment (Mekiso, 2011)

The duration of the records is variable and none of the stations are currently active and reporting data. The highest rainfall was recorded at The Heights while Wolkberg Station is at the greatest altitude. In November 2005 a further five manual rain gauges were installed within the wetland and gauges were read after each rainfall by the field assistants.

3. RESULTS AND DISCUSSIONS

3.1 Rainfall and streamflow

The rainfall data plotted are obtained from the study area located at the five rain gauges installed as part of the project (Figure 5 above). There were very small differences between the rainfalls measured at these gauges suggesting low spatial variability of rainfall inputs over the wetland area.

Figure 7 depicts the relationship between rainfall measured over the wetland and stream flow at the DWA gauging station B7H013 downstream. The accuracy of the measured flow data at the hydrological station is 5% for flow lower than 5 $m^3 s^{-1}$ and 10% for flows higher than 5 $m^3 s^{-1}$. Moreover, when the river flow exceeded 12.8 $m^3 s^{-1}$, water overtopped the weir and no stage-discharge relationship was available. Therefore, no high flow data were available and such a situation appeared as observation gaps in the records (Troy et al., 2007).

Figure 7 Rainfall over the wetland and daily streamflow observations at B7H013

3.2 Piezometer responses

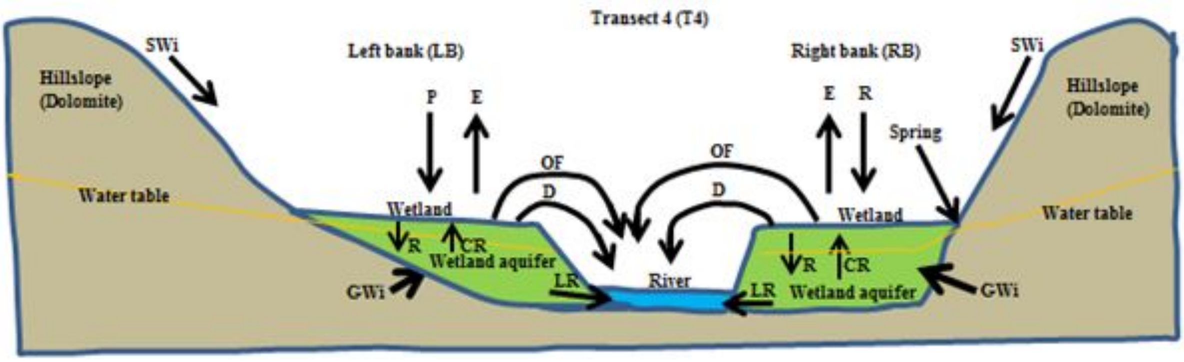
3.2.1 Transect T4

A total of 2175 measurements were taken and analysed during the entire study period. Figure 8 depicts that all piezometers responded to 102 mm rainfall recorded from 17 February 2010 until the first week of June 2010. All GW levels in piezometers except MLB406 and MLB407 showed undulations, but a rapid response was experienced between 15 February 2010 and 03 June 2010. Water levels in piezometer MLB406 showed rapid response from 30 January 2010 to 23 February 2010 and remained horizontal until the end of study period. Similarly, water levels in piezometer MLB407 experienced rapid response between 30 January 2010 and 02 April 2010 and remained horizontal until the end of study time (Figure 8). Therefore, there was a relationship between groundwater surface elevations and precipitation during February 2010 monitoring dates. In addition, there was no correlation among groundwater surface elevations, rainfall and river gauge heights throughout the study period, indicating river flow is influenced by baseflow contributed from surrounding mountains, caused by precipitation event occurred far from B7H013 gauge. Nearly all piezometer levels showed the same trend. In general, there was insignificant correlation with the patterns of local rainfall during the main part of the wet season.

Figure 8 Groundwater table fluctuations November 2005 to December 2012 for T4

T4 is the widest of all transects and its left bank is dominated by reeds. Most of the piezometers in T4 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 9 depicts wetland in T4 environment contributing flow to river, the groundwater is draining towards the channel and that the wetland is probably contributing more flow to stream channel. In addition, wetland elevation is higher than that of the river. The river's discharge at approximately 3 km north of the wetland was measured as $2.5m^3s^{-1}$, while in the wetland environment (T1-T7) it was $1.8m^3s^{-1}$, indicating the river is effluent stream. In gaining streams, groundwater seeps out into the streams.



EXPLANATIONS:
GWi=groundwater inflow
SWI=Surface water inflow
OF=overland flow to river
CR=Capilary rise
LR=seepage from wetland to river
P=rainfall
E=evapotranspiration
R=recharge
D= drainage from wetland to river

Figure 9 **The middle Mohlapitsi wetland flow generation conceptual model representing T4, located both sides of the river**

3.2.2 Transect 5

T5 site is located at the left bank of the Mohlapitsi River and just at the foot of the mountain, where it is fed by numerous springs originating from the dolomite hill. About 20 hectares of it is marshy area and at least 150mm of water was observed ponded. Farmers created artificial drainage close to the river. There is no much agricultural practice due to groundwater seeps all over the site.

A total of 2037 measurements were taken and analysed during the whole study time. The water table level with respect to the groundwater level of the piezometers in T5 is shown in Figure 10 to highlight the seasonal pattern of the water table behaviour during the period of study. From November 2005 until the end of 2006, water table levels in all piezometers showed increase with undulations. All piezometers showed distinct increase from January 2010 after receiving a total of 292 mm rain water during 10, 14, 20, 30 January, 10 and 17 February 2010. Piezometer MLB505 stopped increasing early and showed neither increasing nor decreasing 20 February 2010. During 46 days the groundwater level in this piezometer increased 0.93 m. Groundwater level in piezometer MLB508 started to increase towards the end of January 2010 (26/01/2010) and did not show any change until the entire study period. During 25 days the piezometer showed 0.57 m increase. Whereas, groundwater level in piezometer MLB507 started to increase in 01 January 2010 and showed neither increase nor decrease after 26 February 2010. During 56 days the piezometer showed 0.49 m increase. Groundwater levels in piezometers MLB504 and MLB506 began to increase on 06 January 2010 until March 2010, although the former one stopped neither increasing nor decreasing after 03 March 2010. Groundwater level in piezometer MLB506 continued increasing until 27 March 2010. Before they remained horizontal, groundwater level increase in both piezometers was nearly similar (MLB504=1.06 m and MLB506=1.00 m).

Furthermore, groundwater levels in piezometers MLB502 and MLB503 showed increasing in 06 January 2010. However, the latter piezometer did show neither decrease nor increase in 16 April 2010, whereas, the former one continued increasing until 28 March 2010. During this time, groundwater levels in MLB502 and 503 increased 0.76m and 1.91m respectively. Groundwater level in piezometer MLB501 started increasing late (after 20 January 2010 rain event) and stopped increasing early (20 March 2010). During 61 days groundwater levels in this piezometer increased 1.44m before it remained neither increasing nor decreasing until the end of study period.

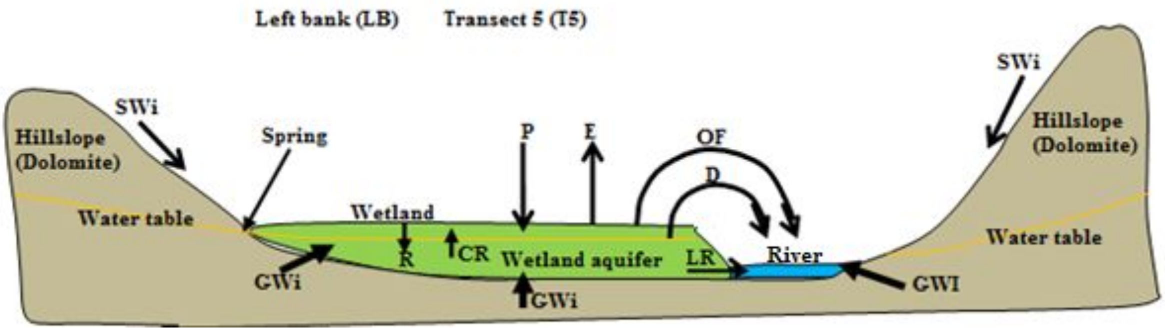
Figure 10　Groundwater table fluctuations November 2005 to December 2012 for T5

Several springs were identified within T4, T5 and T6 environments in September 2010 dry season. The springs indicate the presence of regional groundwater contributing to inflows to the Mohlapitsi wetland (McCartney et al., 2011; McCartney, 2006). Although the wetland is located in the channelled valley, the overflow from the river does not contribute significantly to the water balance of the wetland.

At the start of 2005/2006 wet season the variation in water levels across transects was relatively low, while the variation during January to May 2010 was much greater. 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 4 showed the greatest variations (between 1.0 m for MLB406 and 2.47 m for MLB404), while T6 showed the least variations (between 0.82 m for MLB603 and 1.34 m for MLB601). Most of the sites closest to the river channel showed the highest variations. The soils near the river channel in T4, T5 and T6 are loamy clay and not well drained in nature.

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). There are several observations leading to this situation. For example, at the head of the valley, rough flow measurement suggested that there was a reduction of river flow rate approximately 700 m south of gabion dam. In addition, during 2005, the river had stopped flowing altogether about 250m south from where the river flow reduced and that flow recommenced only about 900m north of T1. Furthermore, in 2005 only a single drain with little flow was observed, while during 2006 to the end of study period (30 December 2012) four springs with significant amount of flow was observed, indicating the river upstream initially contributed to groundwater table rise. This result is similar to what Dixon (2002) demonstrated in his wetland drainage cultivation in western Ethiopia.

Alike T4, wetland in T5 environment (Figure 11) keeps water from rainfall and groundwater and slowly releases to the natural channel. Furthermore, water surface elevation in the river is much lower than that of wetland. Hence, there is no reason to show in the conceptual model that there is seepage from river to wetland as Masiyandima et al. (2011) and McCartney (2004)



EXPLANATIONS:
GWi=groundwater inflow
SWI=Surface water inflow
OF=overland flow to river
CR=Capilary rise
LR=seepage from wetland to river
P=rainfall
E=evapotranspiration
R=recharge
D= drainage from wetland to river

Figure 11 The middle Mohlapitsi wetland flow generation conceptual model representing T5, located at left bank

3.2.3 Transect 6

During the entire study period 764 measurements were taken from piezometers MLB601, MLB602 and MLB603. Groundwater table levels in T6 (Figure 12) showed fluctuations until the beginning of January 2010 and revealed distinct increase during 17 February - 05 May 2010. The highest rainfall - 102 m that occurred on 17 January 2010, 01 and 05 March 2010 could impact these results. The mean water table surfaces in all transects within T4, T5 and T6 (Figures 8, 10 and 12) show gradients in the water table along transects towards the channel, suggesting inflow from the slopes.

Figure 12 Groundwater table fluctuations November 2005 to December 2012 for T6

Figure 13 depicts that piezometers in T6 are elevated in relation to the river. The river is fed by groundwater in the wetland environment; hence the river is an effluent stream. Even when the river rises suddenly due to flood, ground water levels are higher than the river and groundwater flow further from the river would to move toward the river while water in the river would begin moving into bank storage. Hence, seepage, overland flow and drainage are shown from wetland to the river.

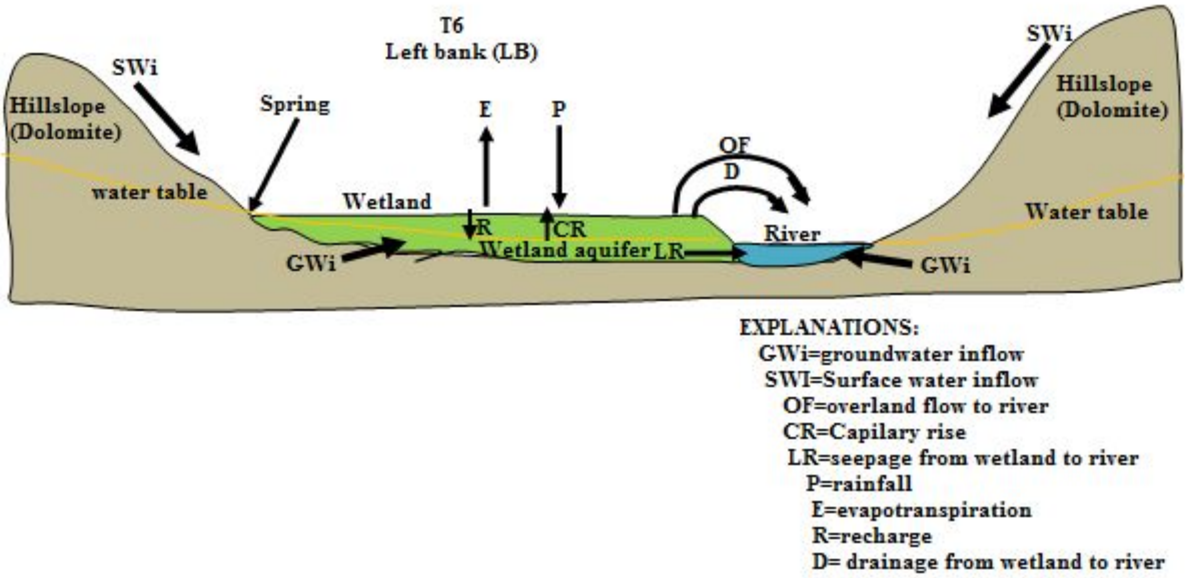


Figure 13 **The middle Mohlapitsi wetland flow generation conceptual model representing T6, located left bank of the river**

3.3 Wetland water balance and conceptual model

Based on the information available to quantify the water balance of the wetland, a number of observations can be made, which are illustrated in Figure 14. In the upstream parts of the wetland some water is almost certainly contributed from the artificial diversion of upstream stream flow onto the wetland surface for agricultural purposes, as well as flow from the channel into the upstream parts of the wetland through boulder beds (shown as C-W in Figure 14).

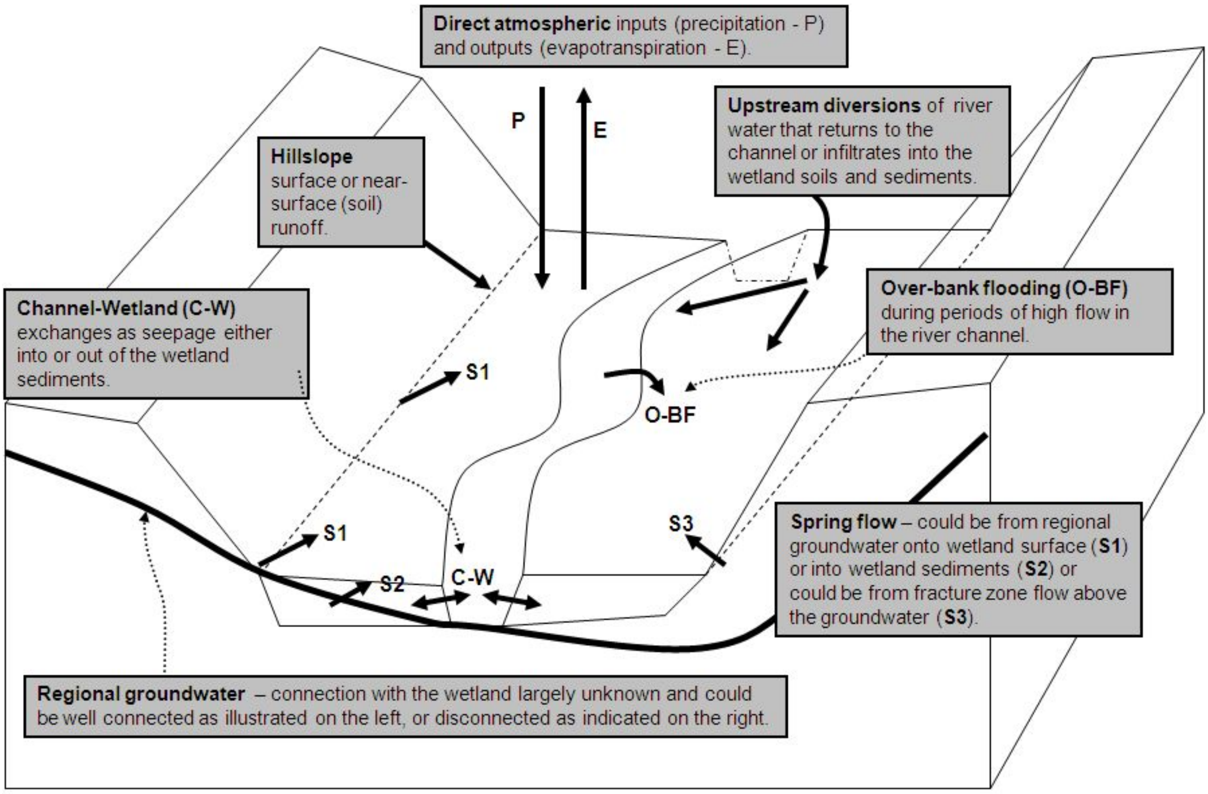


Figure 14 The middle Mohlapitsi wetland water balance of conceptual model (Mekiso, 2011).

Drainage from the wetland is contributing to river flow and that the variation in the amount of drainage closely follows patterns of runoff generation in the rest of the catchment (both processes labelled as C-W in Figure 14).

Over-bank flooding (O-BF) from the main channel contributes negligible amount of flow to the water balance of the study wetland and inundation is not a common occurrence. This may be related to the relatively small size of the catchment, which together with the steep topography suggests that flood events are relatively short lived.

While several valley springs contribute to the water balance of the wetland. Figure 13 offers three conceptual possibilities for different spring types. S1 type represents springs occurring at the topographic gradient change between the valley slopes and the flatter wetland surface and sourced from the regional groundwater. S2 represents spring flow rising into the lower sediments of the wetland and therefore not visible. S3 represents springs occurring as flow from fracture zones, or perched water tables, above the general level of the regional groundwater table (Hughes, 2010). The evidence suggests that at least S1 and S3 types are present in the middle Mohlapitsi wetland.

Reports from local people and observations by the authors indicate that in November 2005 the river had stopped flowing altogether in the northern part of the study area and that flow recommenced approximately 800m above T1. It was assumed that the river water was infiltrating to the wetland under boulder beds, but no significant flow was observed in the drains at the right bank side. However, in 2007-2012 the volume of flow in drains increased significantly and more drains were observed than 2005.

For the nine months of the dry season when the upstream flow was measured (March–November 2012), flow downstream of the wetland was significantly lower at gauge B7H013. During this period downstream flow varied from 0.30 to 3.13 $m^3 s^{-1}$

The present understanding suggests that the wetland hydrology is likely to be dominated by local rainfall, surface runoff from the valley sides, and spring flow from recharge on the surrounding hills, evapotranspiration and lateral flow from the wetland to the river.

Based on the above information, attempt was made to quantify water balance of the wetland. There was no rainfall during March 2012-November 2012. Estimating groundwater inflow and outflow was not easy to achieve although attempts were made from springs. Therefore, the groundwater at this moment is negligible. Data for surface runoff and evapotranspiration were obtained from McCartney et al. (2011) and Schultz et al. (1997) as 103mm and 1428 mm/year respectively. For the nine months period, evapotranspiration is estimated as 1071 mm/year. Therefore, the available data and other details of the study wetland are shown in Table 1.

Table 1 Details of the middle Mohlapitsi Wetland and available components for the development water budget

Watershed	Area (km^2)	Gaging station	Station number	Station drainage area (km^2)	Station period of record	Average Runoff (mm)	ET (mm)
Middle Mohlapitsi wetland	1.83	Mohlapitsi River	B7H013	263.0	1970-2012	103.0	1071.0

4. SUMMARY/CONCLUSIONS

This investigation has attempted to reveal 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 could be contributing to the study site. 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. One of the important observations that have been made is that the research resources required satisfactorily quantifying and understanding wetland processes are substantial. Although the study area is relatively not large, it is apparent that the hydrological processes within it are quite complex. The relationships between rainfall and water table levels are not always simple; however, there are some examples where water table levels do not closely follow rainfall fluctuations (Dixon and Wood, 2002; Conly and Wood, 2000; Meinzer, 1943; Theis, 1935).

It is difficult to make water resources decisions without GW table levels information. Long-term monitoring provided important data that can serve as input into the future appropriate decision process. The importance of long-term monitoring of GW table levels in the study wetland must be encouraged to:

- ✓ understand the long-term sustainability of an aquifer,
- ✓ address the health of the wetland ecosystem,
- ✓ aware the wetland farmers use the resource wisely,
- ✓ aware all stakeholders that climate change can affect the sustainability of the wetland and
- ✓ aware the wetland users stop or artificial drainage systems.

Long term water-table measurements confirm that the hydraulic gradient is generally towards the river, in both the wet and the dry seasons, indicating that groundwater moves from the wetland to the river. The existing knowledge for the specific wetland showed that there is seepage from river to wetland. For example, the conceptual model by McCartney et al. (2011) and McCartney (2004) demonstrated that the river contributes flow to the wetland. These demonstrations are not true for the following reasons. Firstly, water table in the wetland is higher than the river, hence ground water moves downward toward the river's lower elevation. When the river rises, the water surface elevation in T1 environment could become almost equal to the ground water surface close to the river only and water could move into the bank for few hours, creating bank storage. Groundwater far from the river continues to move toward the river since its surface elevation is higher than that of the river. Even until the river returns to its previous level, seepage (LR) from river to the wetland is negligible. Therefore, the rise in the level of the river may not cause a rise in ground water level. Secondly, there was significant flow reduction (1.86 $m^3 s^{-1}$) in the entire wetland environment compared to measurement taken upstream (2.58 $m^3 s^{-1}$), indicating the river in the wetland environment is effluent.

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