Impacts of agricultural use of the GaMampa wetland on the hydrology of the wetland and the Mohlapetsi River

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Abstract

Wetlands in southern Africa support the livelihoods of many poor people through agriculture for both food production and income. They are used to mitigate the problem of low crop yields associated with low rainfall and droughts. However, wetlands are complex and sensitive ecosystems, and they fulfill important environmental functions. Conversion of wetlands to agriculture has potential impacts not just within the wetland but also in downstream areas. While further development of wetlands for agriculture is difficult to prevent when alternative livelihood opportunities are lacking, it is important to ensure that this does not compromise the provision of goods and services by the wetlands. This paper investigates the possible contributions by the GaMampa wetland to stream flow in the Mohlapetsi River, a tributary of the Olifants River during low flow periods and the impact of the wetland use for agriculture on the hydrological functioning of the wetland. The GaMampa wetland comprises less than 1 % of the Mohlapetsi catchment and an even smaller portion of the Olifants catchment. Yet hydrological records show that the Mohlapetsi River contributes a significant amount of the Olifants flow particularly during the dry season. Because of the connectivity between wetlands and their surrounding catchments, hydrological processes upstream of wetlands impact the water balance of the wetlands, and processes within the wetlands impact on areas down stream. The results presented in this study are based on ongoing hydrological investigation focusing on rainfall, groundwater, and stream flow monitoring and analysis to understand hydrological processes within the GaMampa wetland. Further study is required to confirm them, but the preliminary results indicate that groundwater is a significant contributor to the dry season flow in the Mohlapetsi River, but there is little contribution directly from the wetland.

Target Sub-Theme: Water and Land (Oral presentation)

Introduction

Inland wetlands that cover more that 20% of the landscape in southern Africa are an important resource. They play provisioning, regulatory, and habitat roles in the landscape. Many of these wetlands are utilized by local communities for crop production, fish production and fishing, livestock production, harvesting natural products, and provision of domestic water. Wetland ecosystems, including rivers, lakes, marshes, rice fields, and coastal areas, provide many services that contribute to human well-being and poverty alleviation (Millennium Ecosystem Assessment, 2005). They also play a role in conservation and management of freshwater resources (Ne´gre et al., 2003), maintaining environmental quality, supporting immense biodiversity (Mitsch and Gosselink, 1993) and sustaining livelihoods and providing employment for many people. They have recreational and aesthetic qualities, and play an important role in local and regional hydrology by serving as water-storage areas that reduce flooding by retaining water excess and releasing it to streams (Ne´gre et al., 2003)

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Due to connectivity between wetlands and the surrounding catchment areas, some land uses within the wetlands have the potential to impact surrounding areas. Similarly, processes and land uses in the surrounding areas potentially impact the wetland. Understanding flow generation process in wetlands is important for determining the role of the wetland in relation to river flows as well as for managing land uses, particularly agriculture-related, that impact on the functioning of the wetland. If wetlands are to be used in a sustainable manner, knowledge of wetland hydrology and quantification of water inputs and outputs are necessary prerequisites to understanding wetland environments and determining their vulnerability to changes resulting from man's activities.

Inland wetlands are hydrologically complex as they are influenced by processes within them as well as those in the surrounding catchments. In many of these wetlands the boundary between the wetland and the surrounding area is not well defined. There are exchanges of material, including water, between the wetland and upstream and downstream areas. Many argue about the role that wetlands play in such exchanges. In the case of small inland wetlands, their role in stream flow generation and sustaining downstream flow remains unclear (Bullock and Acreman, 2003). The hydrological processes of groundwater storage and flow generation determine the extent of the inundation of the wetland, and land use changes that modify the wetland can modify these processes (Wolski and Savenije, 2006). This paper presents preliminary results from a study of the hydrology of the GaMampa wetland in South Africa, and its contribution to dry season flow in the Mohlapetsi and Olifants Rivers. A conceptual model has been developed that will be used to assess the possible impact of increasing cultivation within the wetland on its hydrological functioning.

Description of the study area

The GaMampa wetland is located in the Mohlapetsi river catchment in the B71C quaternary catchment (DWAF delineation of catchments) within 24° 05' and 24° 20' S and 30° 00' and 30° 25' E (Figure **1**). The Mohlapetsi River, a tributary of the Olifants River, originates in the Wolkberg mountains. At the confluence with the Olifants River the catchment is 490 km^2 and the catchment area to the wetland is approximately 263 km^2. The wetland covers approximately 1 km^2 of the catchment. The catchment is predominantly rural, with a low population density. The upper catchment comprises relatively natural grassland vegetation, contained within a national reserve (Sarron, 2005). All villages are located, and agricultural activities occur, close to the valley bottom and in the wetland. Although only a small tributary, the Mohlapetsi is said to be important for the hydrology and hence water resources of the Olifants River. The general perception is that this tributary makes a significant contribution to the flow of the lower Olifants particularly in the dry season.

The Mohlapetsi catchment is characterized by seasonal rainfall that largely occurs during the summer months, from October to April. The mean annual rainfall for the catchment is 771 mm, but varies significantly with altitude and aspect. Mean annual rainfall in the higher parts of the catchment exceeds 1,000 mm (with a maximum of 1,433 mm); whilst in the valley bottom where the wetland is located rainfall is typically 500 – 600 mm (Table 1; Figure 2). Averaged across the catchment mean annual open water evaporation (i.e. A-pan) and potential evapotranspiration (i.e., Penman-Monteith) are 2,014 mm and 1,428 mm respectively (Table 2; Figure 3).

The Mohlapetsi is a perennial river, with peak flows generated during the rainy season between December and April. The river is gauged just below the GaMampa wetland, at station B7H013. 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 (McCartney, 2006). 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 (McCartney *et al*., 2004).

Chiron (2005) carried out a soil survey of the study area. This is the basis for the following soils description. Because of the underlying geology in the upstream areas this area has predominantly sandy soils. These are also found in the upstream portion of the valley bottom. Lower in the floodplain sandy loam soils are dominant, with organic soils in the valley floor. On the valley floor the clay and silt content of the soils increase from upstream to downstream

The GaMampa wetland

The wetland occurs in the channeled valley bottom section of the Mohlapetsi River below the Wolkberg mountains. The valley is narrow and confined, with steep hill slopes on the edges of the valley bottom (Figure 4). The wetland is approximately 120 hectares in area. It occurs along the valley floor, extending about 4 – 5 km downstream on both sides of the river as well as within the river in some sections. The hydrogeomorphology of the wetland is described in detail in Kotze (2005). The soils in the wetland are a mix of fine-textured, poorly-drained areas away from the river channel, and less extensive sandy soils located close to the channel.

The wetland is heavily utilized for agriculture and currently natural vegetation (mainly *Phragmites australis* and *Phragmites mauritanus)* is limited to about 30% of the wetland area, in the wetter parts of the wetland (Kotze, 2005). Livestock grazing takes place in the areas of natural vegetation, some of which is subject to moderately heavy grazing (Kotze, 2005). The cultivated area has progressively increased over the last 10 years, accompanied by decreasing natural vegetation and grazing area. Drainage canals are a major feature of the croplands as the crops grown in the wetland (maize and coriander) do not perform well under saturated or flooded conditions.

The wetland can be divided into four main poorly drained areas of about 25 ha each (Figure 5). Portion 1 is on the western side of the river channel, and Portion 2 and Portion 3 on the eastern side of the channel. All of these areas contain extensive organic (peat) soils maintained by permanent saturation and are surrounded by seasonally to temporarily saturated areas with predominantly mineral soils. Portion 4 has is less inundated than the areas upstream and has less organic soils. The inundation of portions 1 to 3 described here seems to be maintained by lateral subsurface inputs from the surrounding catchments. More than 7 active springs were identified in the area in August 2005 in the middle of the dry season, 7 months after the last rainfall was observed. The springs indicate the presence of regional groundwater contributing to inflows to the GaMampa wetland (Kotze, 2005; McCartney, 2006). Although the wetland is located in the floodplain, the overflow from the river does not contribute significantly to the water budget of the wetland. Local people say that over bank flow during flooding of the river only occurs rarely. 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.

The uplands of the Mohlapetsi catchment above consist of dolomite, well known for its high groundwater storage capacity and the wetland and its local catchment are underlain by banded ironstone and chert, which are likely to have an intermediate capacity for groundwater storage (Kotze, 2005). The lower permeability material underlying the wetland and immediate catchment favours the accumulation of water from both rainfall and the surrounding areas, and seem likely to maintain the wet conditions in the valley bottom.

A functional assessment of the wetland (Kotze, 2005) showed that the wetland provided important ecosystem services, including provision of land for cultivation, natural resources (grass for livestock grazing and reeds for making crafts), provision of water, and carbon storage. These services continue to be provided, although some to a lesser extent, in the current transformed state of the wetland.

Agriculture in the wetland

The GaMampa settlement is in the enclosed valley on the edges of the GaMampa wetland. There are limited resources in this enclosed valley, providing limited options for livelihoods. Previously the communities depended on irrigated agriculture practiced on government water schemes. There were three such schemes: Mashushu, Fertilis, and Valis (see Chiron, 2005 for detailed descriptions of the irrigation schemes). With the collapse of the irrigation schemes in 2000 as a consequence of damage caused by the floods that year, the community intensified crop production activities in the wetland to complement the loss of production in the irrigation schemes. With abundant moisture in the wetland, it is a natural alternative to the irrigation schemes. Many community members have cultivated plots in the wetland, producing maize in the rainy season and coriander and vegetables during the dry winter season. Early conversion of the wetland to croplands took place in the downstream section of the wetland with less organic soils (Portion 4, Figure 5). More recently, extension of the cultivated area into the peat and organic soils has taken place. With the widely held perception (by stakeholders outside the wetland communities) that the wetland contributes to flow in the Mohlapetsi river and hence the flow of the Olifants River (Darradi, 2005) there is concern that conversion of the wetland to croplands endangers the hydrological functioning of the Mohlapetsi River. There are opposing views about the role of the wetland and the impacts of converting the wetland to agricultural fields resulting in conflict among stakeholders (Darradi, 2005; Darradi et al., 2006).

Methodology

To determine whether or not the wetland contributes to the Mohlapetsi flow, the following observations and analyses were carried out.

Historical rainfall data measured at five stations located in, or just outside the catchment boundary (Figure 6) were obtained from the South African Weather Service. The duration of the records is variable (Table 2) and as such multiple data sets were used to produce a continuous time series from 1971 to 2005 (see Sarron (2005). Most of the data used were from the Wolkberg station. The Fertilis station located closest to the wetland has a mean annual rainfall of 570 mm (Figure 6). Since 2005 (November) five manual rainfall stations were installed in the wetland. Rainfall observations were made twice a day, starting in November 2005.

In November 2005 a network of piezometers was installed in the valley bottom in 7 transects (T1 up to T7) across the valley bottom and extending towards the hill slopes. The depth of the piezometers was determined by the occurrence of an impermeable layer below the wetland. In all locations piezometers depth was less than 3m. Groundwater level monitoring started in November 2005. Groundwater level observations were made daily following rain events, and every other day during dry periods in the summer and during the dry season. A dip meter was used to measure the depth to groundwater. For this paper we analyzed groundwater levels observed in 14 piezometers in 4 transects, two in the upper part of the wetland (T1 and T2) in Portion 1 (Figure 5) and two in the downstream part of the wetland (T6 and T7). Four piezometers were monitored along T1. These are T100RB, T102RB, T103RB and T105RB located adjacent to the river right bank, 100m, 150m, and 250m from the river right bank respectively. Along T2 on the right bank of the river these are T200RB, T201RB,T204RB, and T206RB located adjacent to the river right bank, 50m, 200m, and 300m from the river right bank respectively. In the lower part of the wetland T6 comprises T602LB, T603LB, and T604LB located 100m, 150m, and 200m from the river left bank and T7 comprises T702LB, T703LB, and T704LB also located 100m, 150m, and 200m from the river left bank. The lateral distance between transects is about 500m between transects T1 and T2; 2,000m between T2 and T6; and 500m between T6 and T7.

Daily streamflow was measured at the only gauging station on Mohlapetsi River (B7H013), located about 1 km downstream of the wetland. The gauging station is maintained and operated by the Department of Water Affairs and Forestry (DWAF). Average daily flow data for this station (available from 1970 to May 2006) were used in the analysis. The gauging station accuracy is low for very high flows as water overtops the station and the stage-discharge relationship becomes invalid (Sarron, 2005). Due to a technical problem with the gauging station no flow measurements were available from 30 May 2006. Consequently for the current study, historical records (1990 – 2005) for the period June to September were used to estimate, based on recession flow characteristics, the likely flow in July and August 2006. Starting in the dry season in 2006 river flow has also been measured upstream of the wetland, in an attempt to determine whether the river gains water from, or loses water to the wetland. A C2 current meter (OTT instruments) was used to measure the flow. Gaugings were done for the period July – August. Measurements will continue in the wet season to establish the high flow rating curve for the station.

Based on the observations made in conjunction with the historical data, a conceptual model for the GaMampa wetland was constructed.

Results

Surface water

The flow of the Mohlapetsi River is seasonal in nature, with high flows observed between December and April, and low flows during the rest of the year. The average daily flow measured at the B7H013 gauging station for the 1990/91 – 1999/2000 and 2000/01 – 2005/06 periods and the flow observed in 2005/06 is shown in Figure 7. Visual comparisons of the hydrographs for 1970 – 2005 show correlation of flow with rainfall. The flow is characterized by hydrographs with steep rising and falling limbs, indicating limited infiltration and retention in the catchment.

During the 2005/06 period the first flood peak was observed after the first three storms observed in the valley bottom, indicating that at the start of the wet season there is an initial wetting up period in the catchment.

Starting in the dry season of 2006 between 6 July and 22 August, 14 river inflow measurements were made immediately upstream of the wetland. The low flow measured during this period ranged from 0.27 – 0.41 m^3s^{-1} (Table 3). From the historical observations, low flows occur between August and December. As would be expected, the observed low flows were lower during years of low rainfall (Figure 8). The average daily low flows observed between 1990 and 2000, and again between 2000 and 2005 ranged from 0.3 – 2 m^3s^{-1} and 0.4 – 1.3 m^3s^{-1} respectively. Low flows during low rainfall years (e.g. 1991/92 and 2002/2003) were generally less than 0.5 m^3s^{-1} (Figures 9 and 10). Considering the observation period for flow, 2005/2006 was a dry year, with annual rainfall below 500mm; the current meter measurements in August 2006 are consistent with the historical flow record from below the wetland for dry years. Analysis of the historical flow recession from 30th May would perhaps provide a very good estimate of the likely flow in July-August 2006. The historical average low flow measured downstream of the wetland was higher than the inflow observed in July and August 2006. This indicates that the river gains flow along the wetland.

Groundwater

The period of records for groundwater levels is currently 10 months. It includes the 2005/2006 wet and dry seasons. These data show the short term variation in the water levels in the shallow aquifer associated with the wetland.

Figure 11 shows the hydrological fluxes in the wetland, and the possible linkages between groundwater and the river. Groundwater hydrographs for piezometers along T1, T2, T6, and T7 are shown in Figures 12 to 16. The changes in the groundwater levels correlate well with periods of rainfall, with groundwater level increases observed immediately after rainfall. Rapid response by groundwater was observed in piezometers close to the river (e.g. T100, T200 in Figures 13). In piezometers located further away from the river and closer to the hill slopes (e.g. T102RB, T103RB, T105RB, T201RB, T204RB, and T206RB) rapid increases in the water levels were observed following rainfall. These piezometers maintained the higher levels of groundwater beyond each rainfall event, an indicator of lateral flow from the hill slope maintaining groundwater levels (Figures 13 and 14). In all the piezometers there was a gradual recession in the dry season between May and September 2006. Figures 17 to 20 show the daily changes in groundwater levels. After May no significant changes of groundwater levels were observed at all locations.

Water table profiles across transects T1, T2, T6, and T7 indicate groundwater flow from the wetland to the river during periods of high groundwater levels. The profiles for T1 and T6 are shown in Figure 21. The profiles for T1 and T2 in the upstream part of the wetland, with organic soils and peat, showed a large response to rainfall between December and January at 100m, 150m, and 250m from the river bank. Adjacent to the river bank (T100RB), the water level did not increase as much as further upslope at T102RB, T103RB, and T105RB. The water table surface elevation along T1 did not drop significantly during the dry episodes that followed. In the downstream section T6 and T7 showed a different response pattern of the water table surface (e.g. T6 in Figure 21).

The changes in the level of the water table surface were more intense in the downstream area with less organic matter content and peat. The water table surface indicates a hydraulic gradient towards the river. It follows that groundwater flow towards the river occurred during the rainfall season and for a short time after the rainfall season. The slope of the water level surface along the transect T1 at the end of the dry season in 2005 was much lower than during the rainfall season (Figure 21); again indicating reduced flow towards the river. In the lower part of the wetland, the hydraulic gradient was similar (~0.006) in both dry and rainfall seasons. It did not change with the changes in the level of the surface (Transect 6, Figure 21), indicating flow in both the rainfall and dry seasons.

GaMampa wetland flow generation conceptual model

The understanding of groundwater and surface water flow into and out of the wetland derived from analysis of the piezometer and flow data (described above) enabled a conceptual model of the wetland to be constructed. Figure 11 is a schematic representation of the GaMampa wetland and its main components (the hill slopes of the upper catchment, the wetland, and the river). In analyzing the results some assumptions are made about the functioning of the wetland. We assume that the hydrology of the GaMampa wetland is influenced by

1. Rainfall and runoff and groundwater recharge processes in the upper catchment.
2. Groundwater outflow from the hill slopes: Much of the upper catchment consists of dolomite. It is likely that there is significant recharge to groundwater in the upper catchment. This (regional) groundwater flows into the shallow groundwater in the wetland. Many springs at the foot of the hills support this.
3. River flow from the upper catchment is not redistributed in the wetland. Therefore changes in river flow between upstream and downstream of the wetland measured at B7H013 are due to wetland processes.

These assumptions are further explained in the following section.

The Mohlapetsi River forms the drainage channel for the wetland. There is no evidence of the river contributing to the wetland inflows. Local people indicated that overbank flow (i.e. water moving from the river to the wetlands surface during flooding) is relatively uncommon, only occurring every few years (i.e., the last time was the floods of 2000). During the dry season, the period that this analysis focused on such lateral flow did not occur. Thus current understanding suggests that the wetland hydrology is likely to be dominated by precipitation, evapotranspiration, groundwater inflow from the surrounding hills, and lateral flow between the wetland and the river.

We make the assumption that surface inflow from the upper catchment is not redistributed in the wetland and valley bottom, thus the diversion for irrigation does not in any way influence the water budget of the wetland directly, except if a proportion of diverted flows contributes to the wetland through groundwater inflow.

Following the above, the changes in surface flow downstream of the wetland are due to runoff from the wetland and valley bottom, groundwater outflow from the wetland into the river, evapotranspiration losses by crops in the wetland and natural wetland vegetation, and domestic and livestock water use. Runoff from the bare soil on the valley bottom is insignificant and it is likely that it all infiltrates into the wetland before reaching the river (ref. Sarron). The peat soils in the wetland suggest that direct runoff from the wetland to the river does not occur, leaving groundwater flow from the wetland to the river as the only lateral transfer between the wetland and the river. Although it is possible that some runoff may occur when the soils are saturated in the wet season, this is more likely to occur if the land is cultivated and if the soils are compacted.

The changes in the water balance of the wetland caused by the different crops and the change from natural vegetation to crops still needs to be investigated. Evapotranspiration by the crops or the natural vegetation depends on crop selection – rooting depth etc. However, for the crops grown at GaMampa, maize and coriander, losses by evapotranspiration can be assumed to be similar. The agronomic practices in the wetland are expected to impact on the outflow from the wetland. The wetland is intersected by a number of drainage canals intended to create an environment suitable for the production of maize. The drains accelerate outflow from the wetland. The increased outflow associated with drainage will reduce groundwater levels. Some of the cultivated land is bare during the dry season. This results in changes in the loss rates from the wetland which would be dominated by evaporation from the bare soil and no transpiration.

The flow of the river upstream of the wetland is mostly generated from the catchment upstream in catchment B71C (Figure 6) that is predominantly natural vegetation. Most of the area in the hills is classified as a Nature Reserve. Other than livestock grazing in this area land use in the mountains has not changed significantly over time. Livestock can have a major impact on vegetation and soils (e.g. compaction), but in this case it is low density and it can be assumed that the livestock has not had significant impacts. The inflow is not expected to change over time. For the river section through the wetland therefore, the change in the volume of flow observed below the wetland is a result of rainfall over the valley bottom (dry land, wetland, and river section and groundwater discharge (LF) from the wetland.

The links between the components described above are shown in Figure 11**.** The water balance of the GaMampa wetland can therefore be presented as:

$$\Delta Sw = P - E \pm OF \pm GWi + SWi$$

Where:

ΔS_w = change in storage in the wetland
P = rainfall
E = evapotranspiration (crop and wetland vegetation)
OF = overland flow
GW_i = groundwater inflow from the surrounding catchment
SW_i = surface water inflow from the hill slopes

Following the previous sections, the following assumptions were made:

- $SW_i = 0$
- OF (from the wetland to the river) is negligible
- OF (from the river to the wetland) is only observed during extreme rainfall events, and is considered negligible for this dry season analysis.

The water balance for the period from July to August 2006 when flow upstream of the wetland was estimated following the assumptions above was estimated. The wetland area was taken to be 120ha, including both the cultivated and natural areas. Evapotranspiration estimates for the same period from Sarron (2005) were used. During this period there was no precipitation. As shown in Figures 17 to 20, the change in wetland storage, for which the change in groundwater levels is a proxy, was negligible. Average inflow was taken as the average of the gaugings between 6 July and 22 August of $0.35 m^3 s^{-1}$ (15.6 mm). It was assumed that outflow for the period would be similar to the average outflow of a similar dry year for the same period. The average outflow was computed from July to August of the year 2002/03, the most similar year. The average outflow was $0.41 m^3 s^{-1}$ (18.3mm). The groundwater inflow from the surrounding catchment was estimated to be 179.7mm, almost the same as the calculated potential evapotranspiration (Penman-Monteith). This suggests that only about 3 mm reaches the river by way of lateral flow from the wetland (Table 4).

Discussion:

Groundwater level changes

The two distinct groundwater responses observed in the upper and lower parts of the wetland indicate complex processes in the wetland, and different, possibly time-dependent flow generation processes. In the upper part of the wetland (Portion 1 in Figure 5) the water table rises quickly but does not recede significantly in the dry periods following rainfall. Initially the water table continues rising, even between rainfall events (Figures 13 and 14), indicating lateral inflow. However, adjacent to the river bank (Figure 12) the water level response was consistent with rainfall, showing rapid increases when it rained and rapid decreases immediately following rainfall. This rapid recession observed in the piezometers next to the river bank was indicative of lateral flow from the wetland area adjacent to the river bank. The soils near the river channel are sandy and well drained in nature (Kotze, 2005) and allow such lateral flow.

As shown in Figures 15 and 16 the groundwater level responses in the lower wetland were more rapid, and directly related to rainfall for piezometers near the river bank as well as away from the river bank. 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. In this part of the wetland, any increase in storage in the wetland due to rainfall is lost shortly after the event through lateral flow to the river, explaining the rapid water table surface elevation changes observed for transect 6 (Figure 21).

The water table surfaces (for example Figure 21) show a gradient in the water table along transects, suggesting groundwater inflow from the slopes. The data available indicates such flow during the wet season, when groundwater levels are high, and does not show continued flow. The groundwater levels do not change much after April (Figures 17 to 20), and if flow does continue it would be limited due to smaller head differences between points along the transects. The contribution to river flow from the upper part of the wetland (Portion 1, Figure 5) is difficult to ascertain as it is evident from the piezometers next to the river channel but not away from the channel. This part of the wetland seems to act like a storage reservoir, losing water largely through evapotranspiration (particularly when the groundwater levels are high during the rainfall season) but also through some lateral transfer. However, this needs to be explored further using reliable evapotranspiration and lateral flow estimations.

Surface water flow

There are two main reasons why the surface flow observed at B7H013 during the dry season will be assumed not to be generated directly by the wetland. First the similarity of surface flow recession in all years including dry years is indicative of the fact that surface flow during the dry season does not originate from the wetland. If it originated from the wetland, there would be no flow measured. Even in a dry year such as 2005/2006, inflows lower than outflow from the wetland were observed, indicating inflow to the river along the wetland. In the absence of groundwater level changes after May as shown in Figures 17 to 20, the flow does not originate from the wetland. It is possible that the wetland simply acted as a conduit and flow comes through the wetland from the surrounding catchment. However B7H013 flows were nearly the same as upstream flows indicating marginal impact of the wetland on flow. There is a strong possibility of groundwater inflow from the surrounding catchment. Additional data is required to show the relationship between groundwater inflow and outflow.

Conclusion

The intermediate results presented in this paper indicate that the Mohlapetsi contributes to the dry season base flow of the Olifants River. The results to date do not show the role of the wetland in runoff generation for the river. Despite common perception to the contrary, the wetland per se appears to make only a very small contribution to dry season flows, certainly in comparison to the amount of water that is evaporated from it. It seems more likely that the base flow is generated in the upper catchment and is high, because of the underlying geology and the fact that the catchment is only disturbed very slightly.

The dry season water balance estimate shows that groundwater inflow from the surrounding catchment is the largest inflow to the wetland. However, only a small proportion of this flow seems to contribute to lateral flow to the river. Most of the inflow into the wetland is lost through evapotranspiration, either by agricultural crops or natural vegetation. However, the wetland, through it's functioning, may play a role in the processes that affect flow in the river. With the present level of understanding it is not clear how modifying land-use in the wetland will affect dry season flows in the river. From the above it is possible this would be relatively little and if it reduced evaporation it might actually increase the dry season flow.

Because of it's linkage with the regional groundwater system, the GaMampa wetland is a complex hydrological system. Detailed water balance analysis is required to ascertain the contribution of the wetland to downstream flow in the Mohlapetsi River. This would require more accurate estimation of the evapotranspiration component of the water balance. Remote sensing technologies, such as the use of the Surface Energy Balance Algorithm for Land (SEBAL) can be explored to estimate seasonal evapotranspiration for inclusion into the water balance and more accurate determination of the unknown component of groundwater inflow from the hill slopes.

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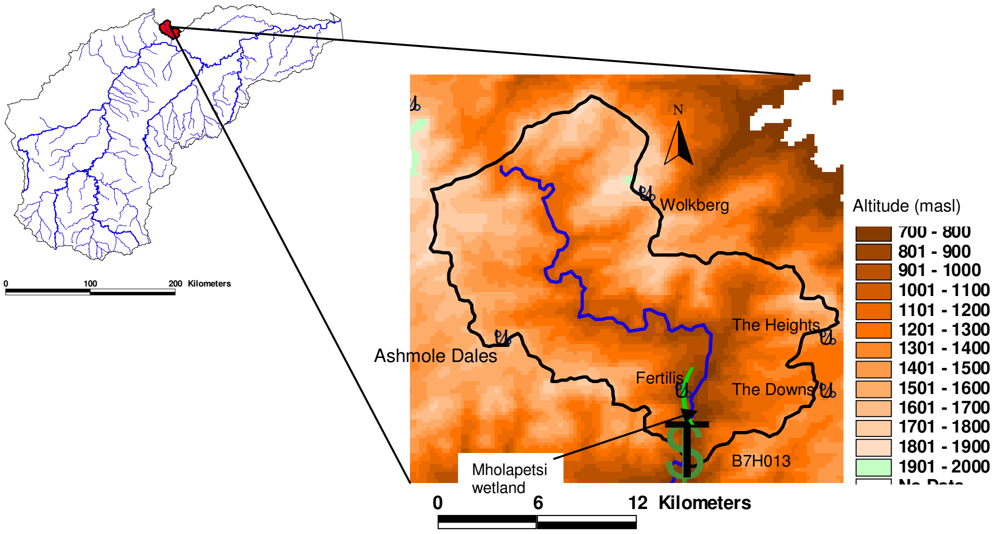


Figure 1. Map showing the location, altitude range (from Schulze *et al*., 1997) and position of the flow gauging station, raingauges and wetland in the Mohlapetsi River catchment (Source:

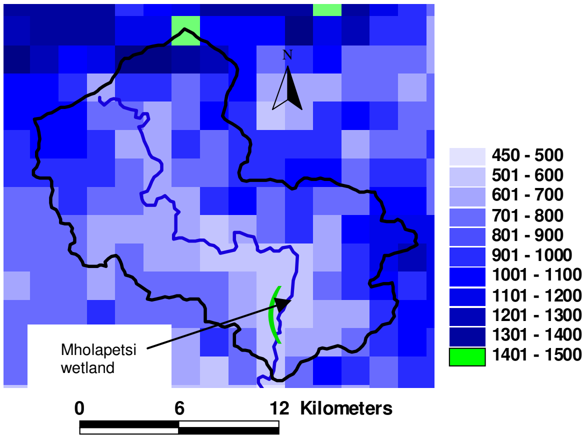


Figure 2. Mean annual precipitation across the Mohlapetsi catchment (developed from data in Schulze *et al*., 1997)

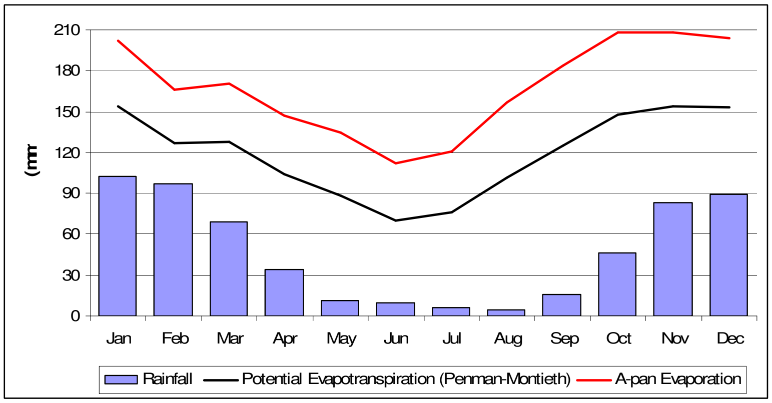


Figure 3 Mean monthly rainfall measured at the Fertilis rain gauge (1959-1988) and Penman-Monteith evapotranspiration and A-pan evaporation computed from data in Schulze *et al.* (1997).

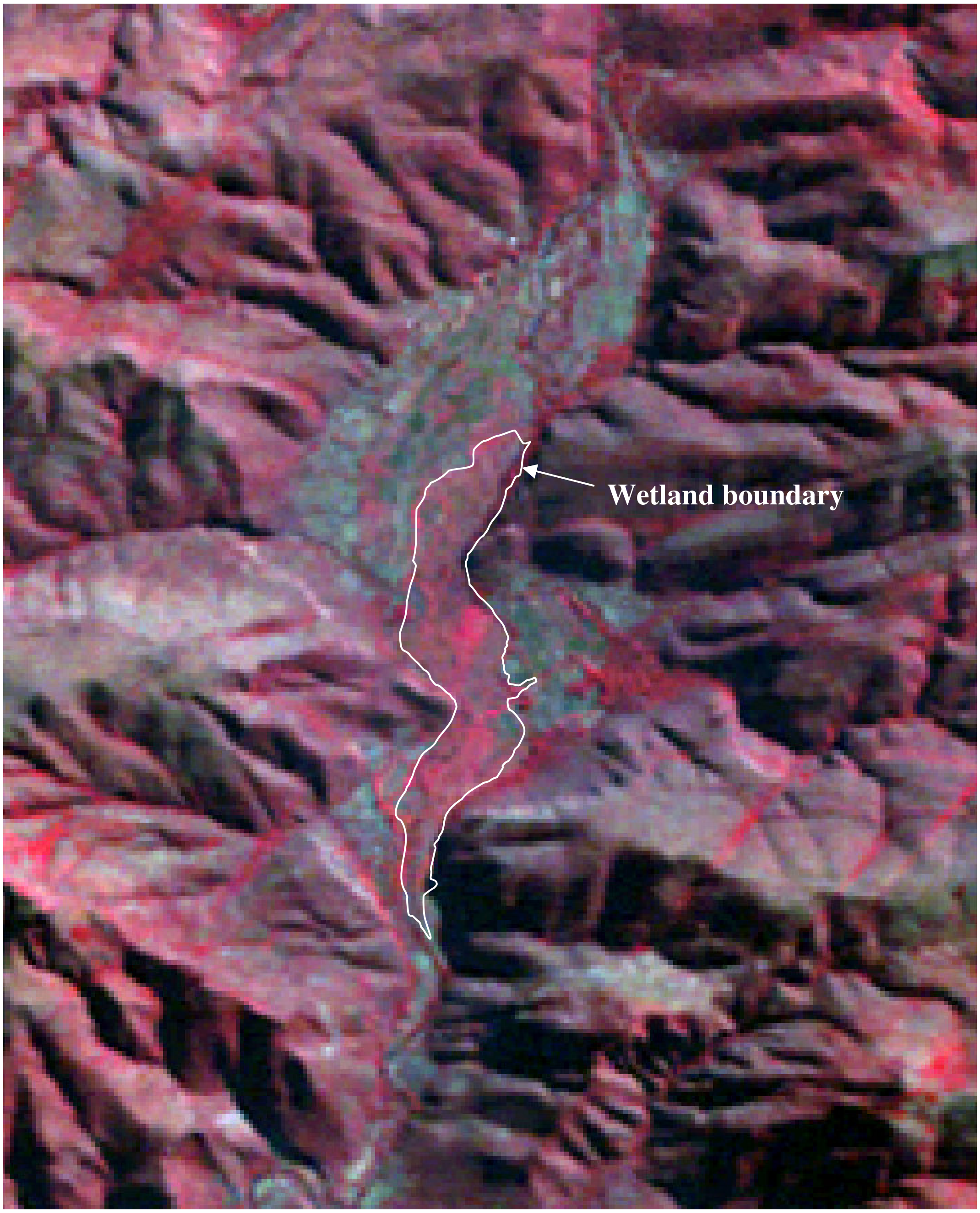


Figure 4. Landsat 7 ETM satellite image extracted from the 169/077 area, July 1996, bands 1 to 5 and 7 (Source: DWAF in Sarron, 2005) showing the valley floor surrounded by steep hillsides

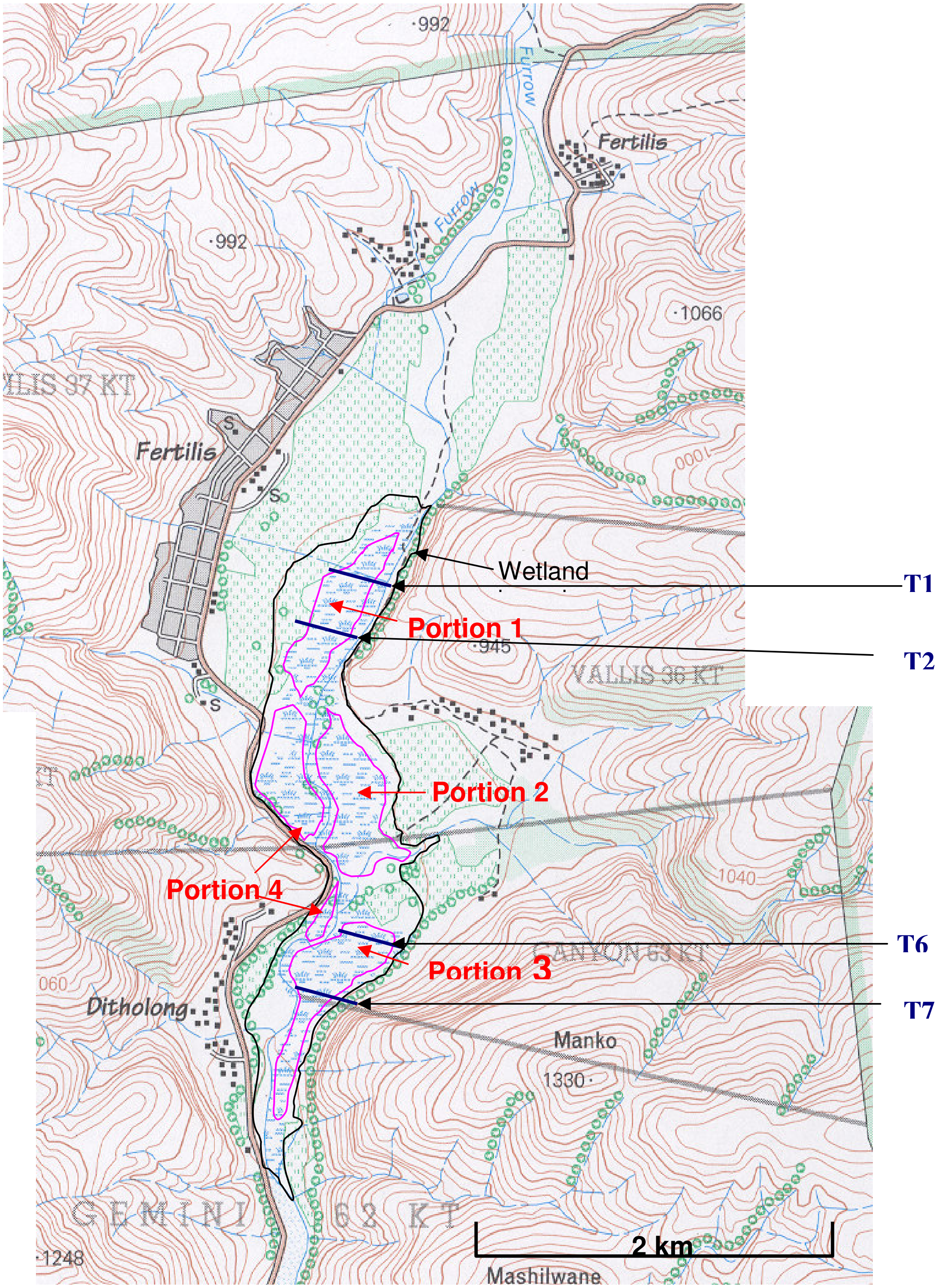


Figure 5. Map of the Mohlapetsi wetland, showing the location of the four valley floor portions of the wetland and groundwater monitoring locations (T1, T2, T6, and T7)

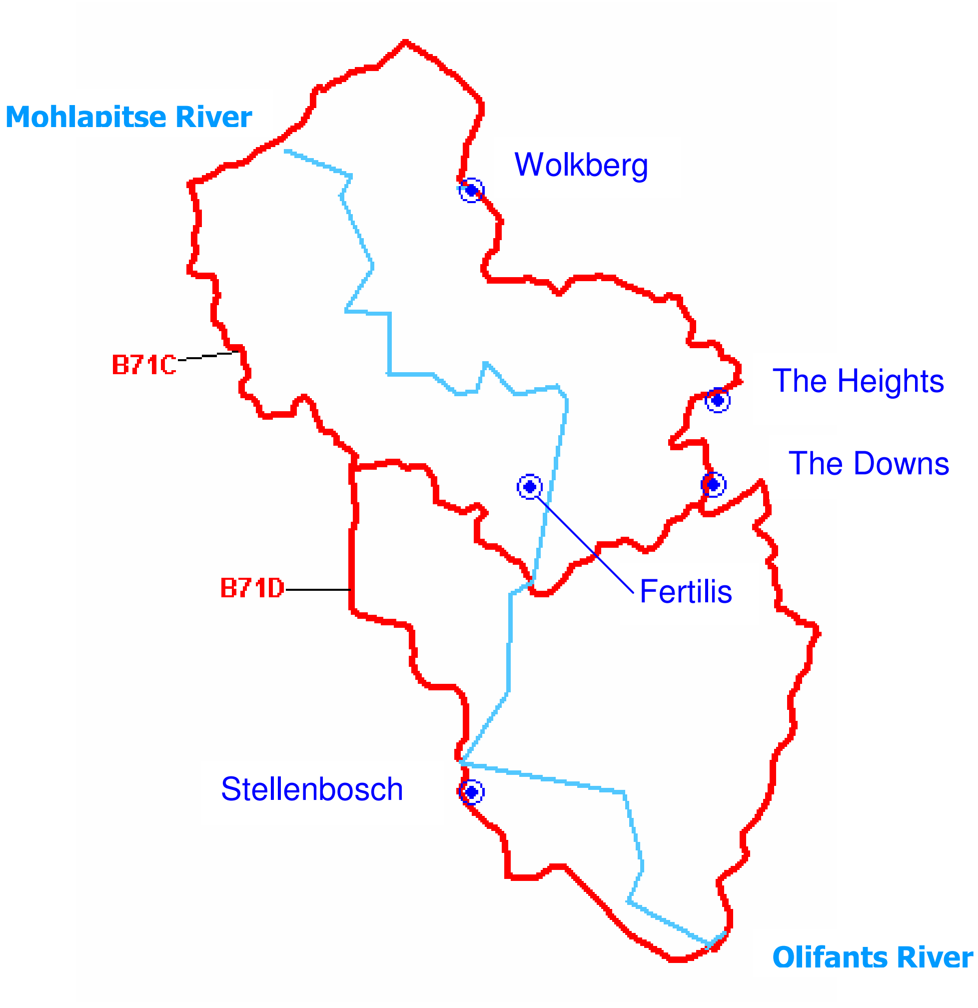


Figure 6. Location of rain gauges in the Mohlapetsi catchment

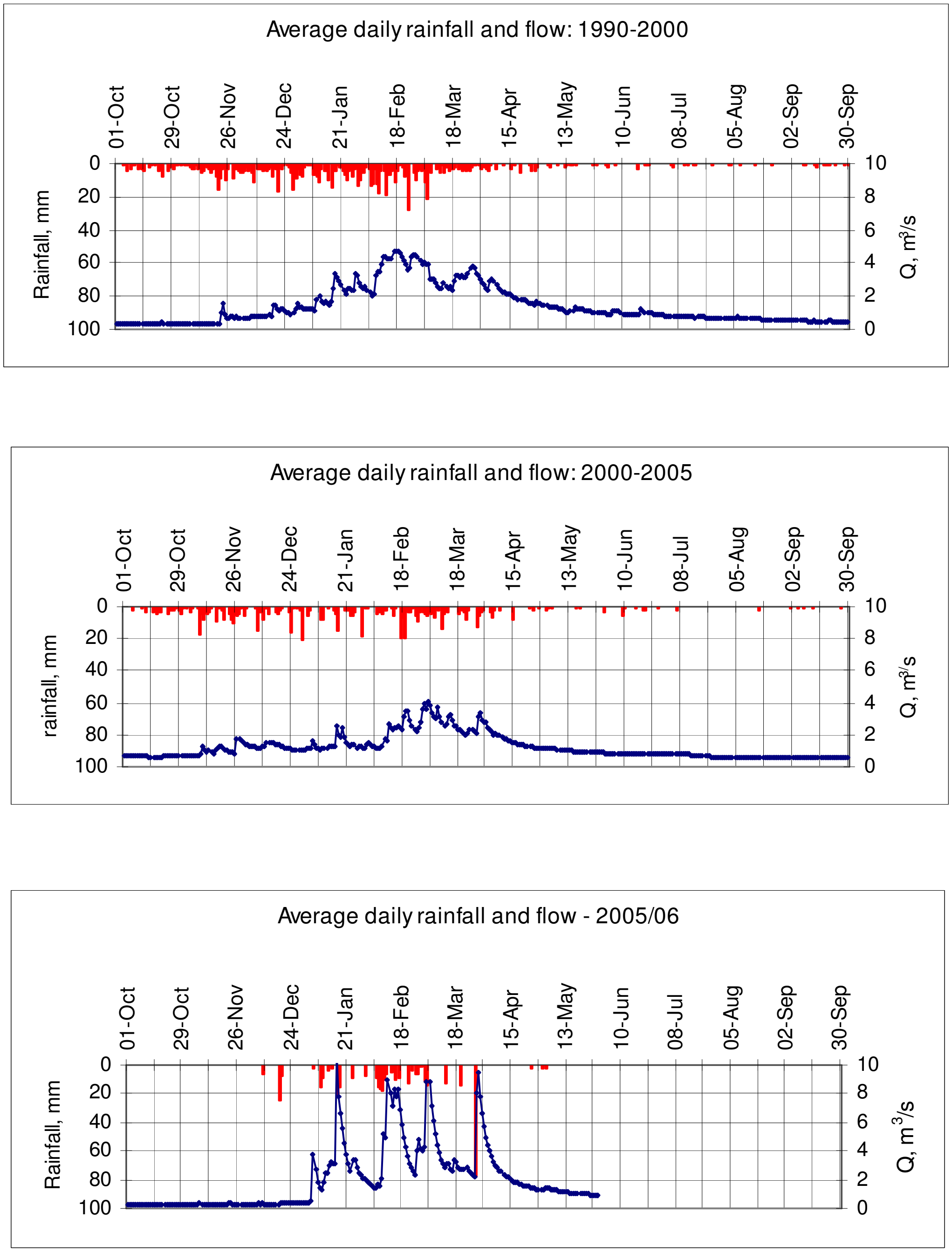


Figure 7. Average daily flow and rainfall for 1990 to 2000 (top); 2000 – 2005 (middle); and for 2005/2006 (bottom)

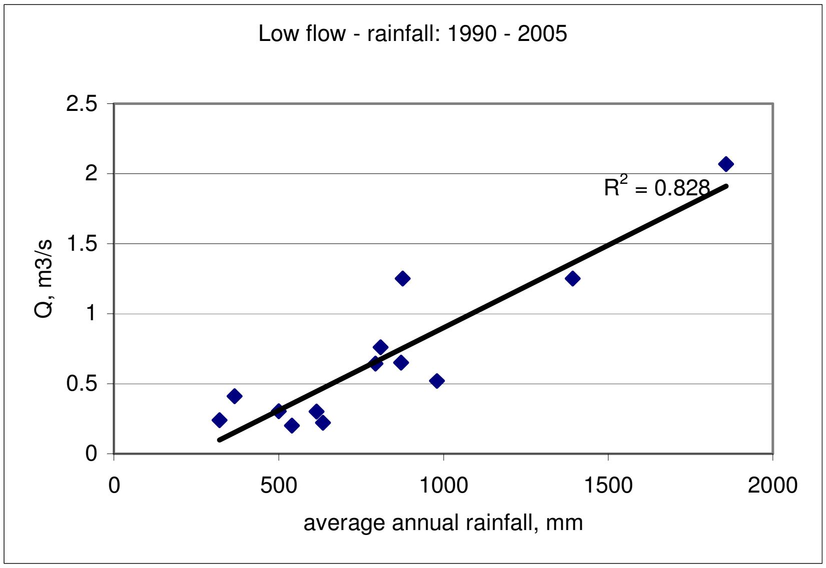


Figure 8. Rainfall and low observed at B7H013 (1990 – 2005)

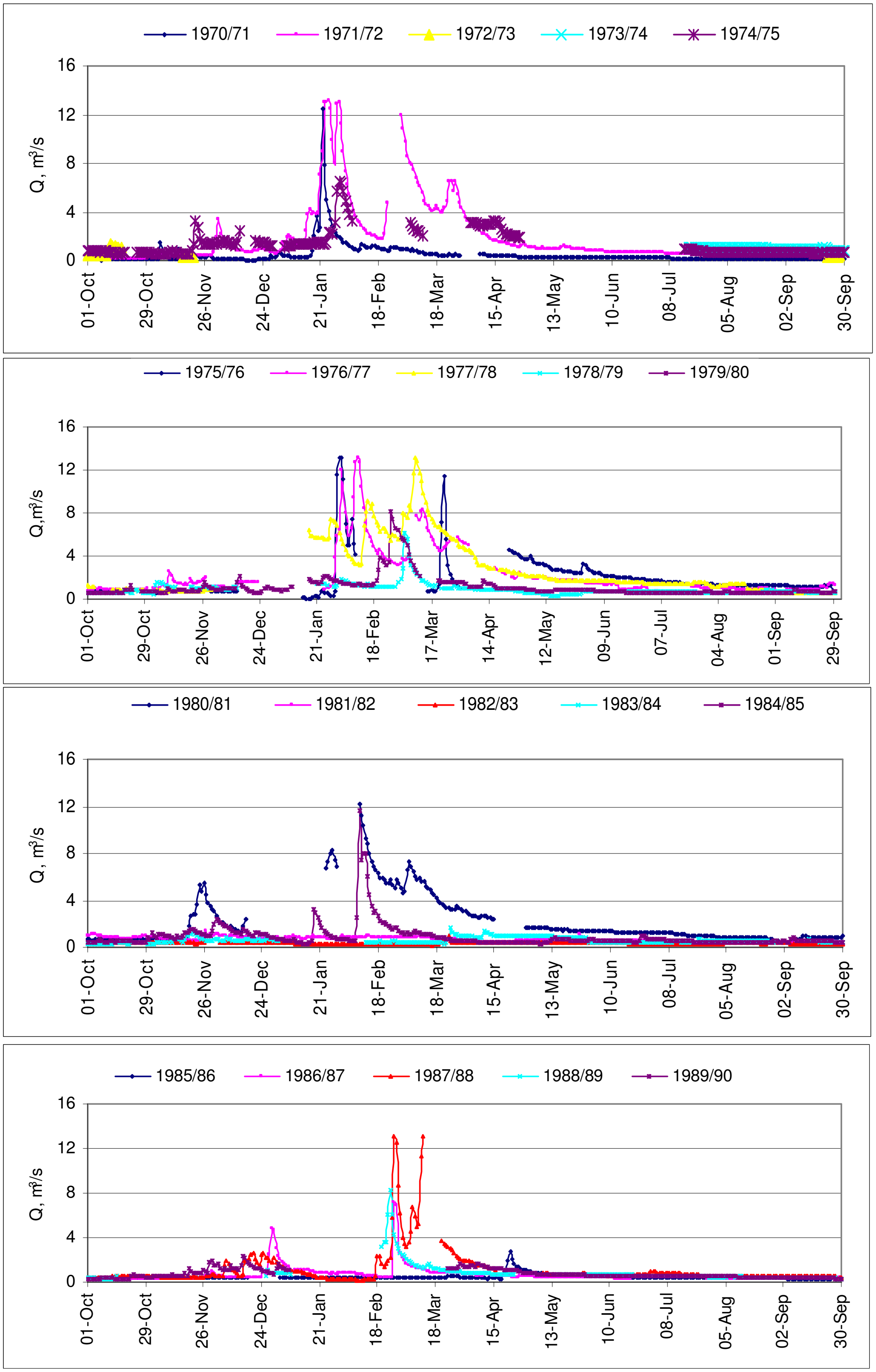


Figure 9. Five year average daily flows (from top: 1970 – 75, 1975 – 1980, 1981 – 1985, and 1985 - 1990

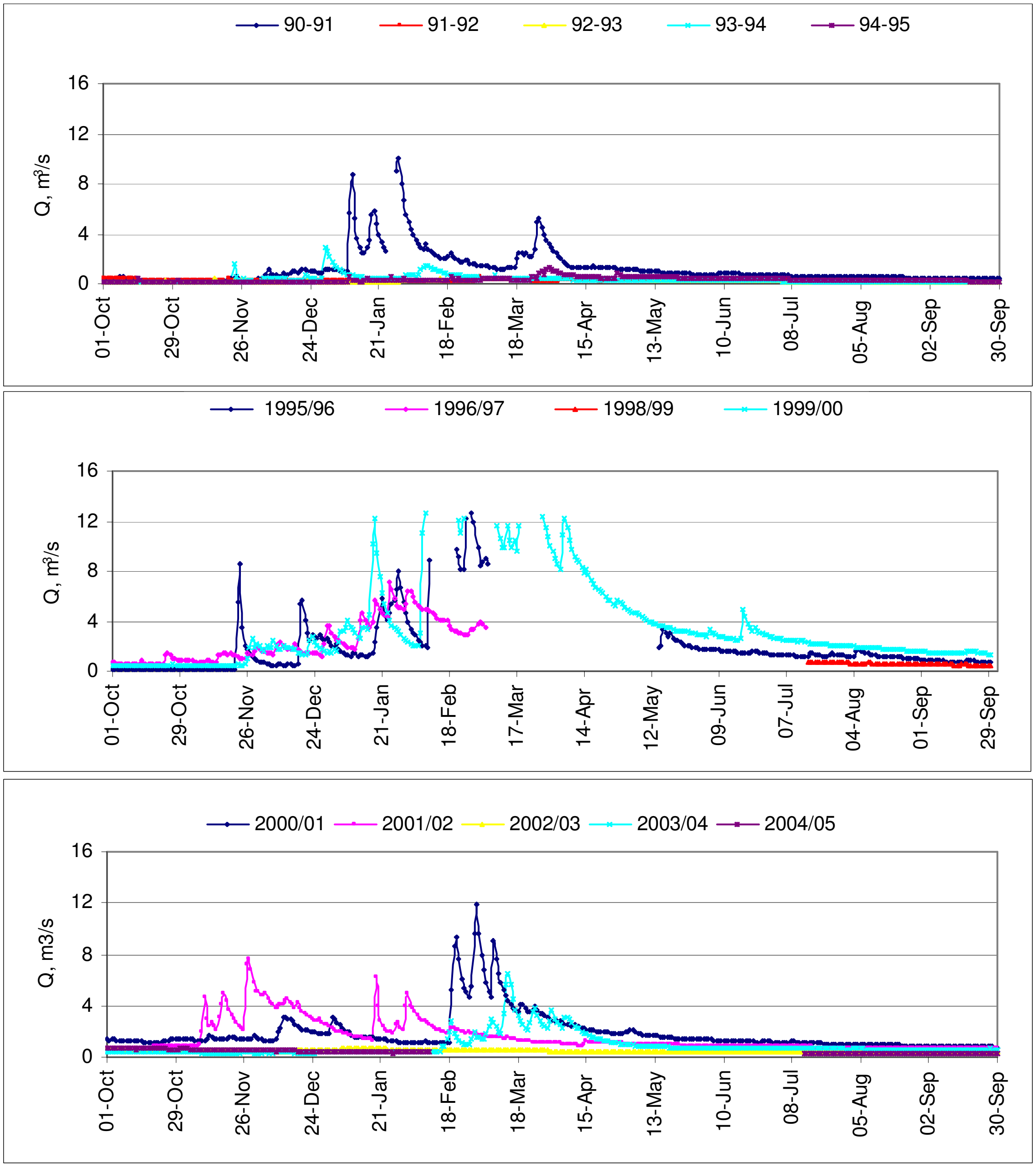
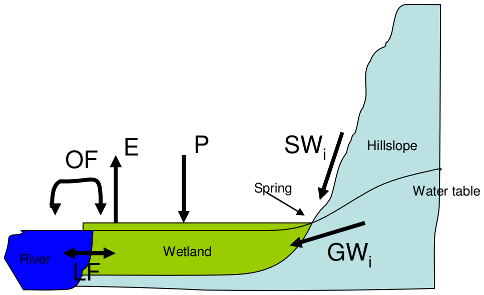


Figure 10. Five year average daily flows (from top: 1990 – 1995; 1996 – 2000; 2000 – 2005)



P = rainfall
E = evapotranspiration
LF = subsurface lateral flow to/from the river
OF = surface water moving to/from the river
SW_i = surface runoff moving into the wetland
GW_i = groundwater moving into the wetland

Figure 11. Picture of the hydrological fluxes in the Mohlapitsi wetland (McCartney 2006)

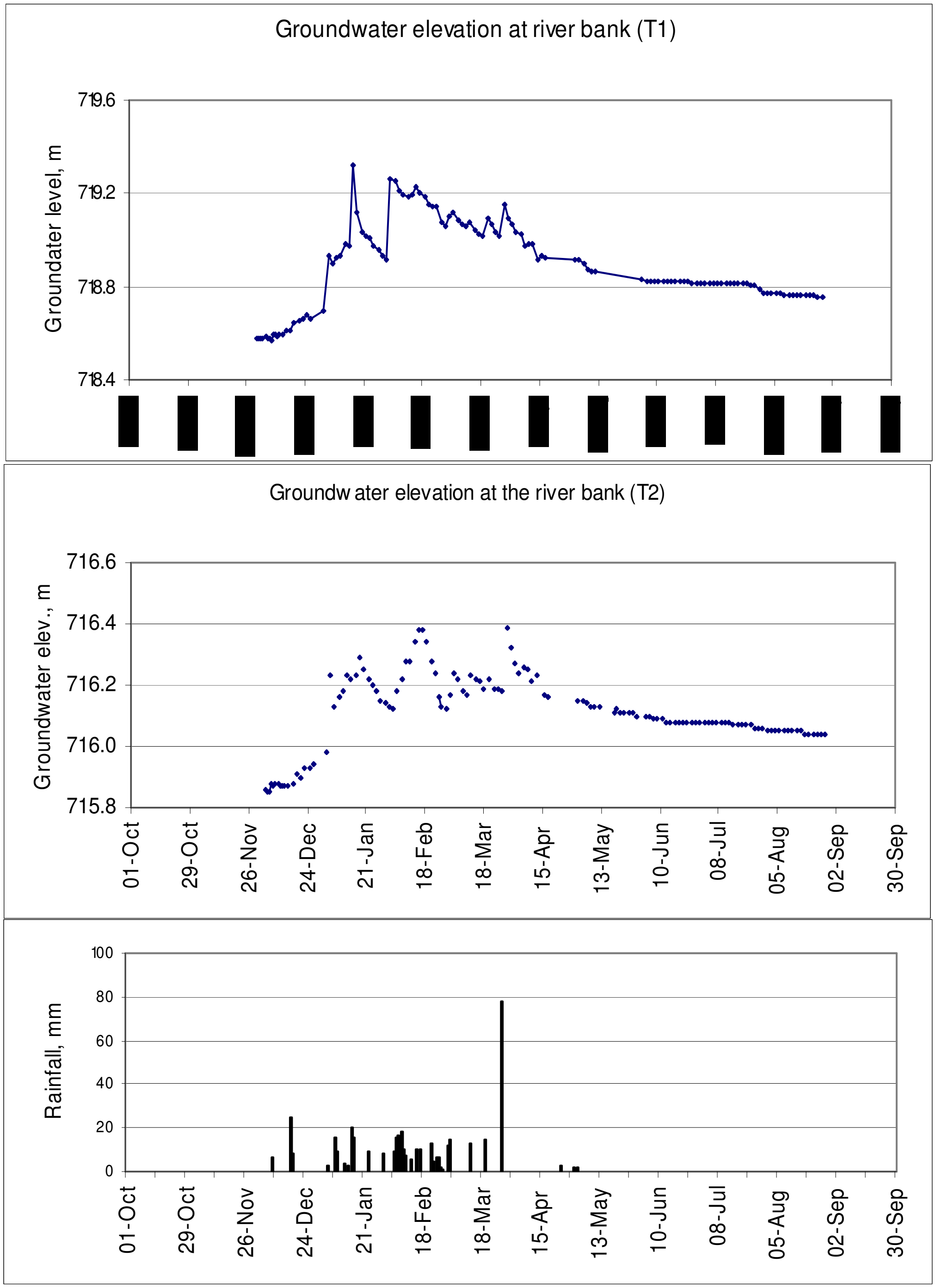


Figure 12. Groundwater elevation next to the river bank for T1 (top) and T2 (middle) from November 2005 to August 2006

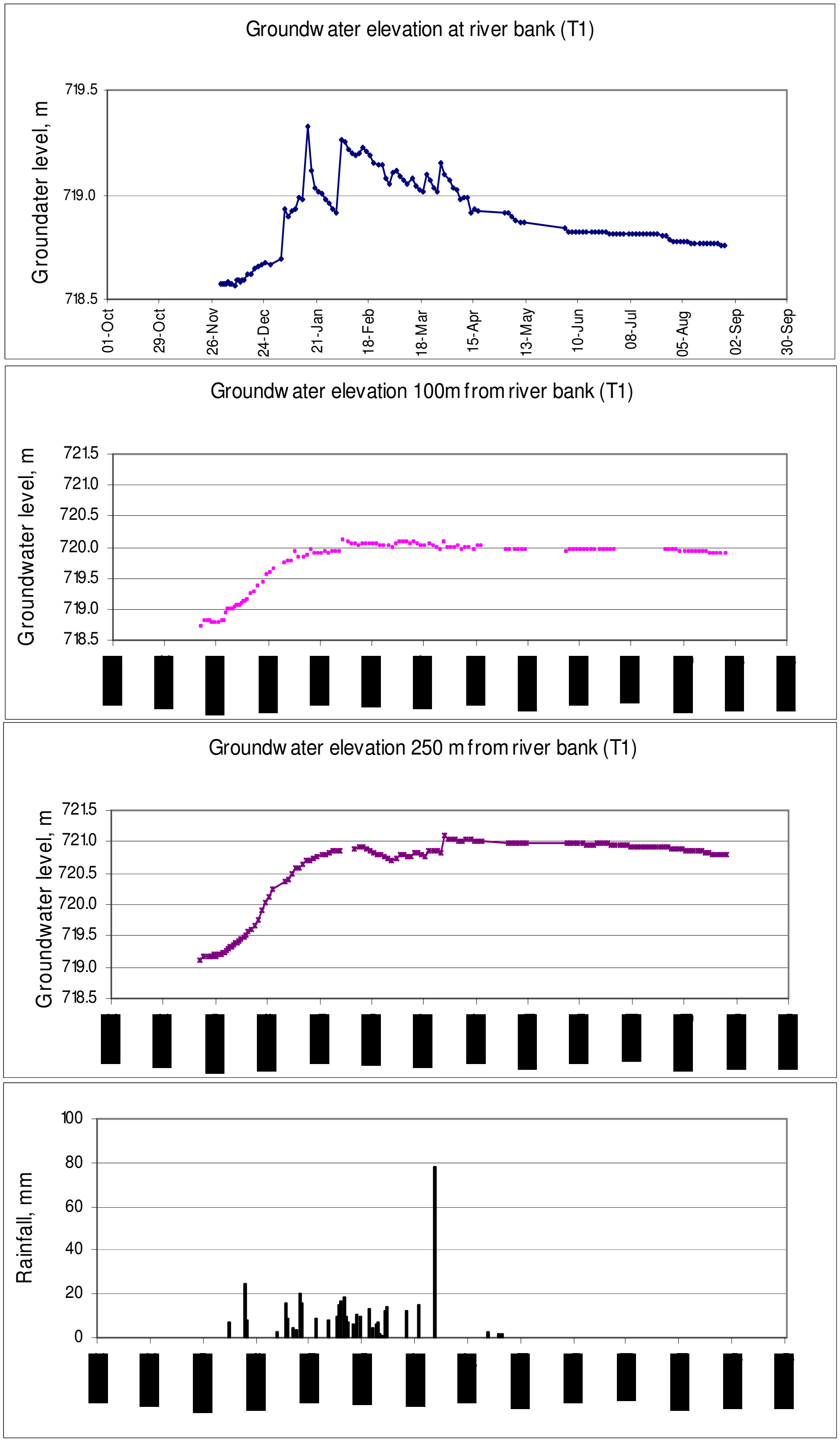


Figure 13. Groundwater elevation along T1 from November 2005 to August 2006

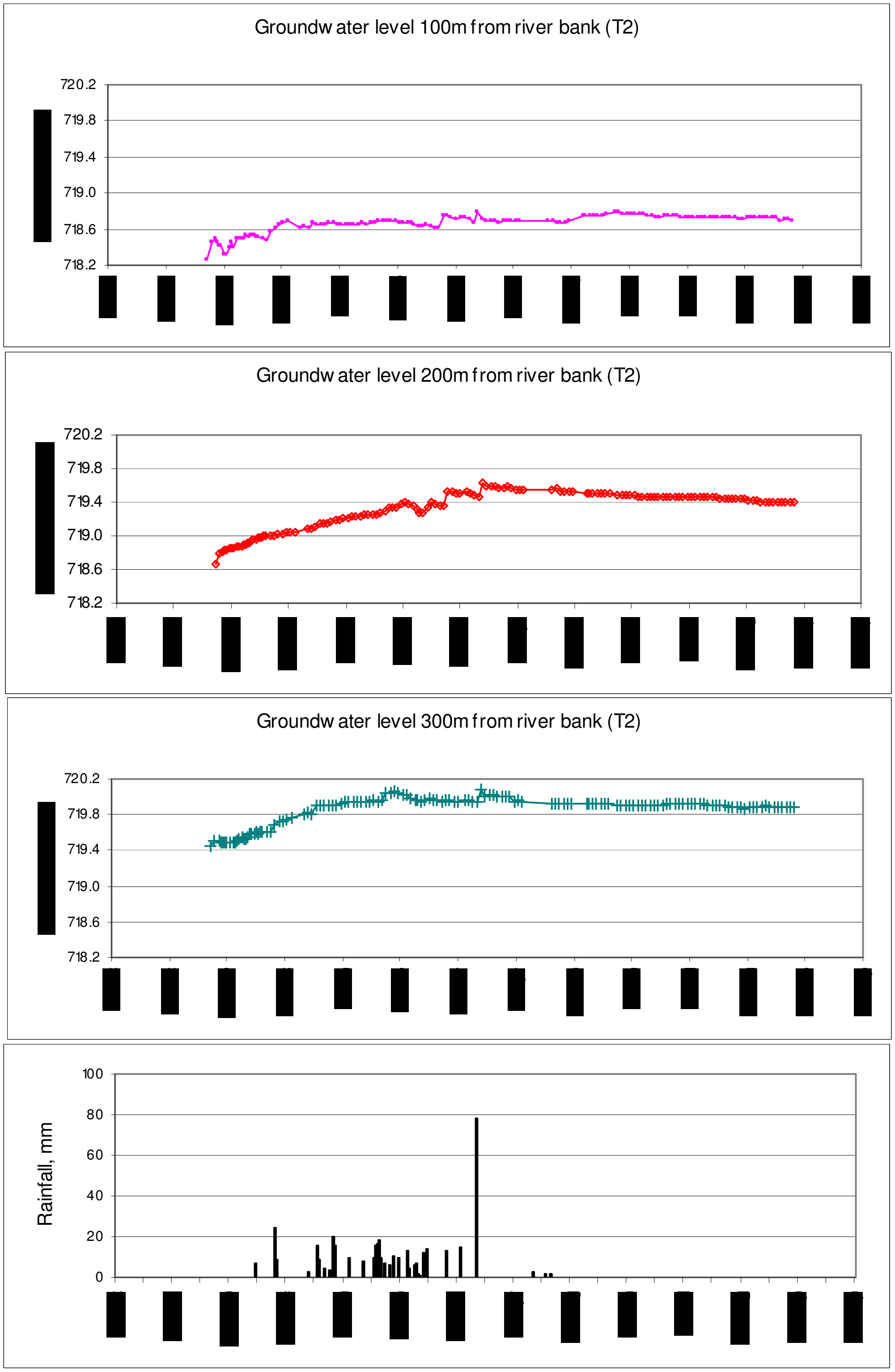


Figure 14. Groundwater elevation along T2 from November 2005 to August 2006

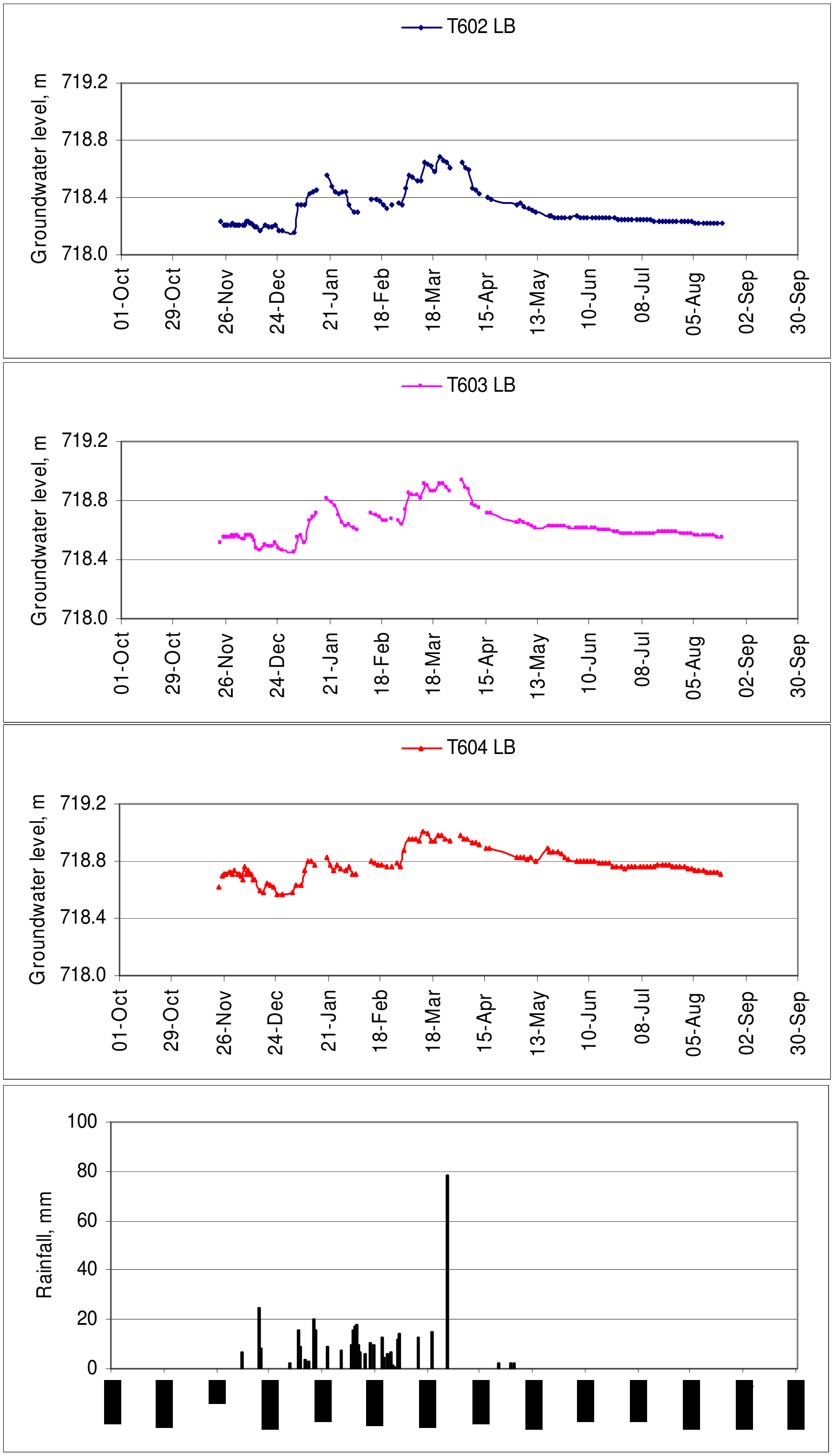


Figure 15. Groundwater elevation along T6 (from top: 100m, 150m, and 200m from river bank respectively) from November 2005 to August 2006

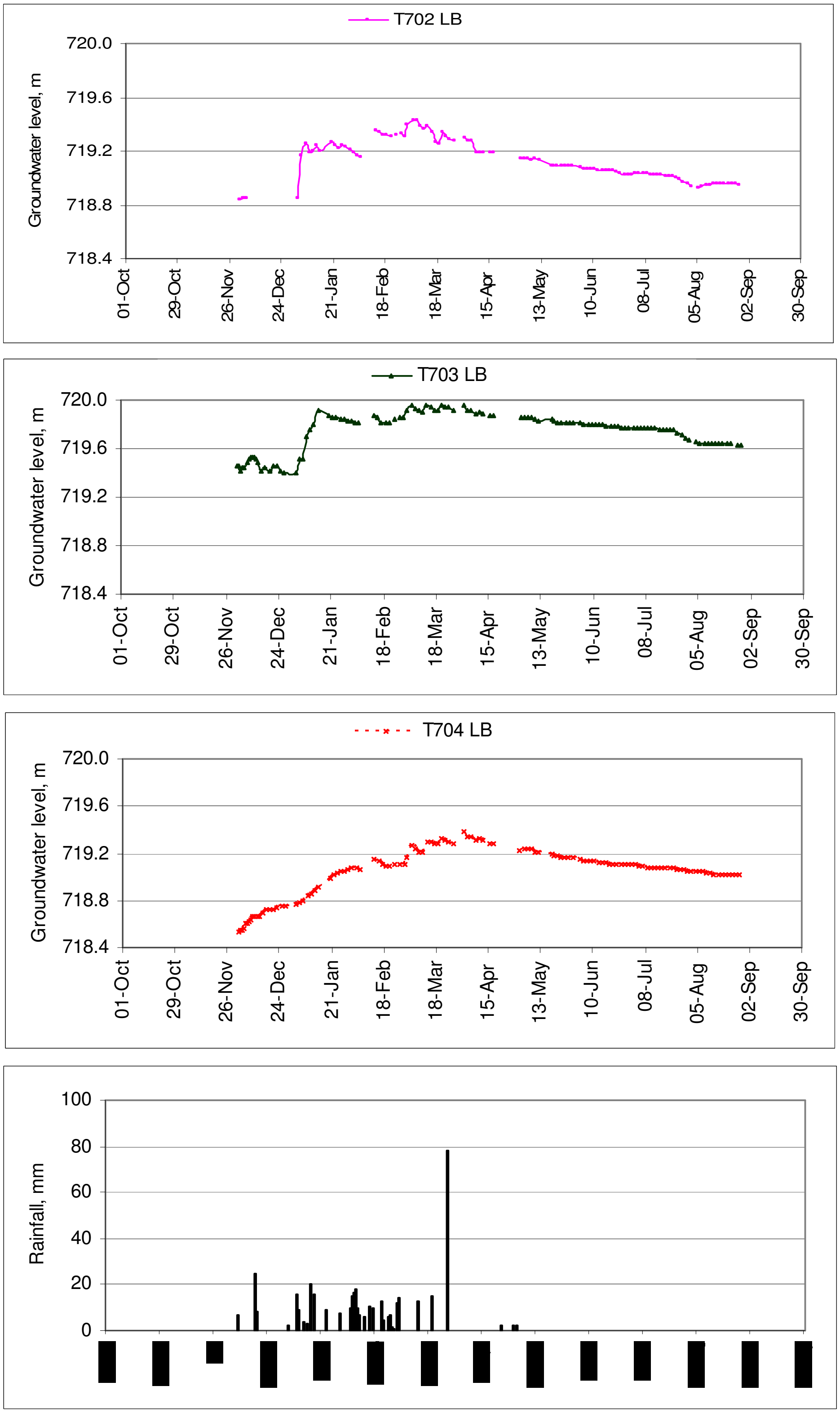


Figure 16. Groundwater levels along T7 (from top: 100m, 150m, and 200m from river bank respectively) from November 2005 to August 2006

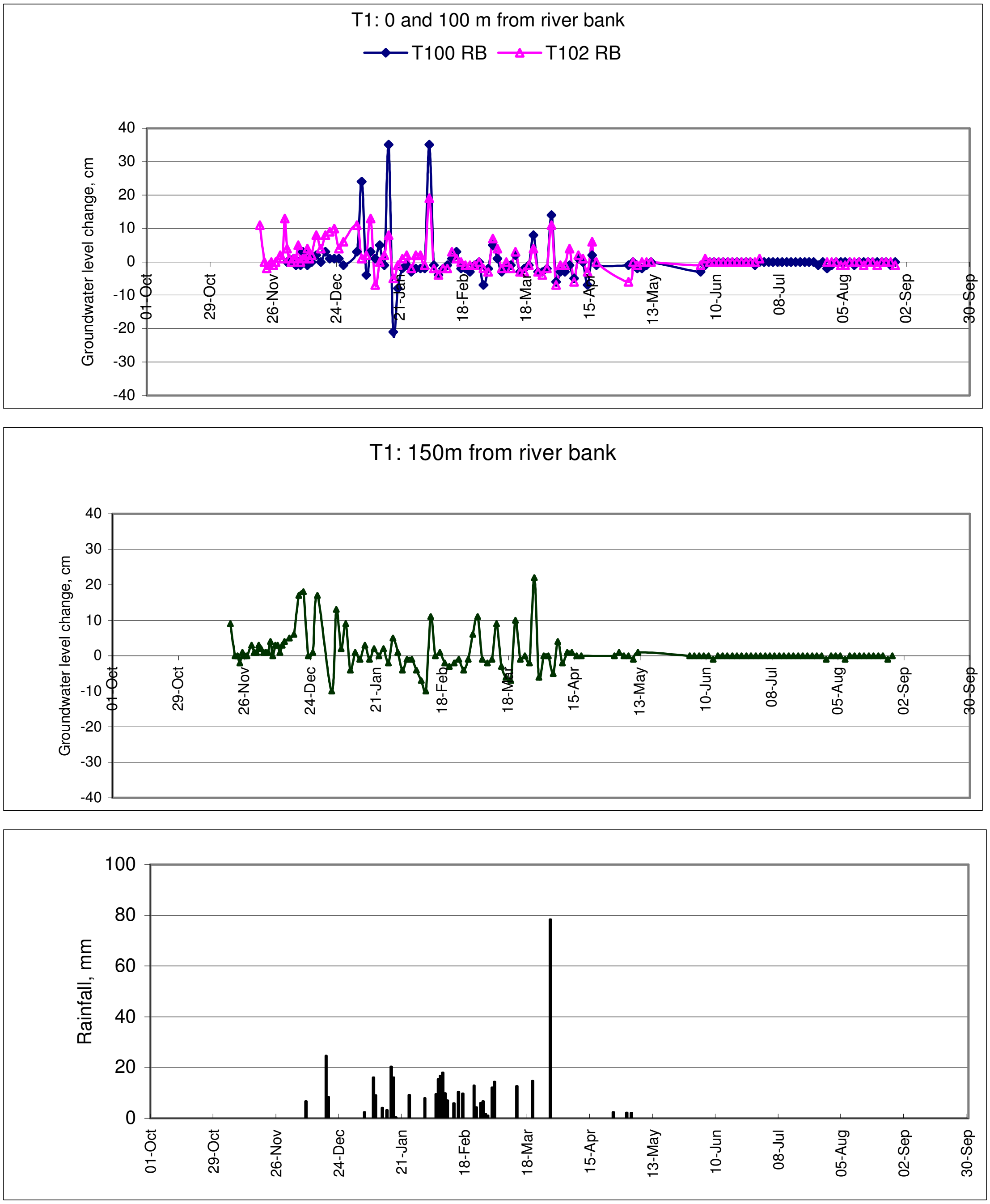


Figure 17. Groundwater level changes at piezometers locations along T1

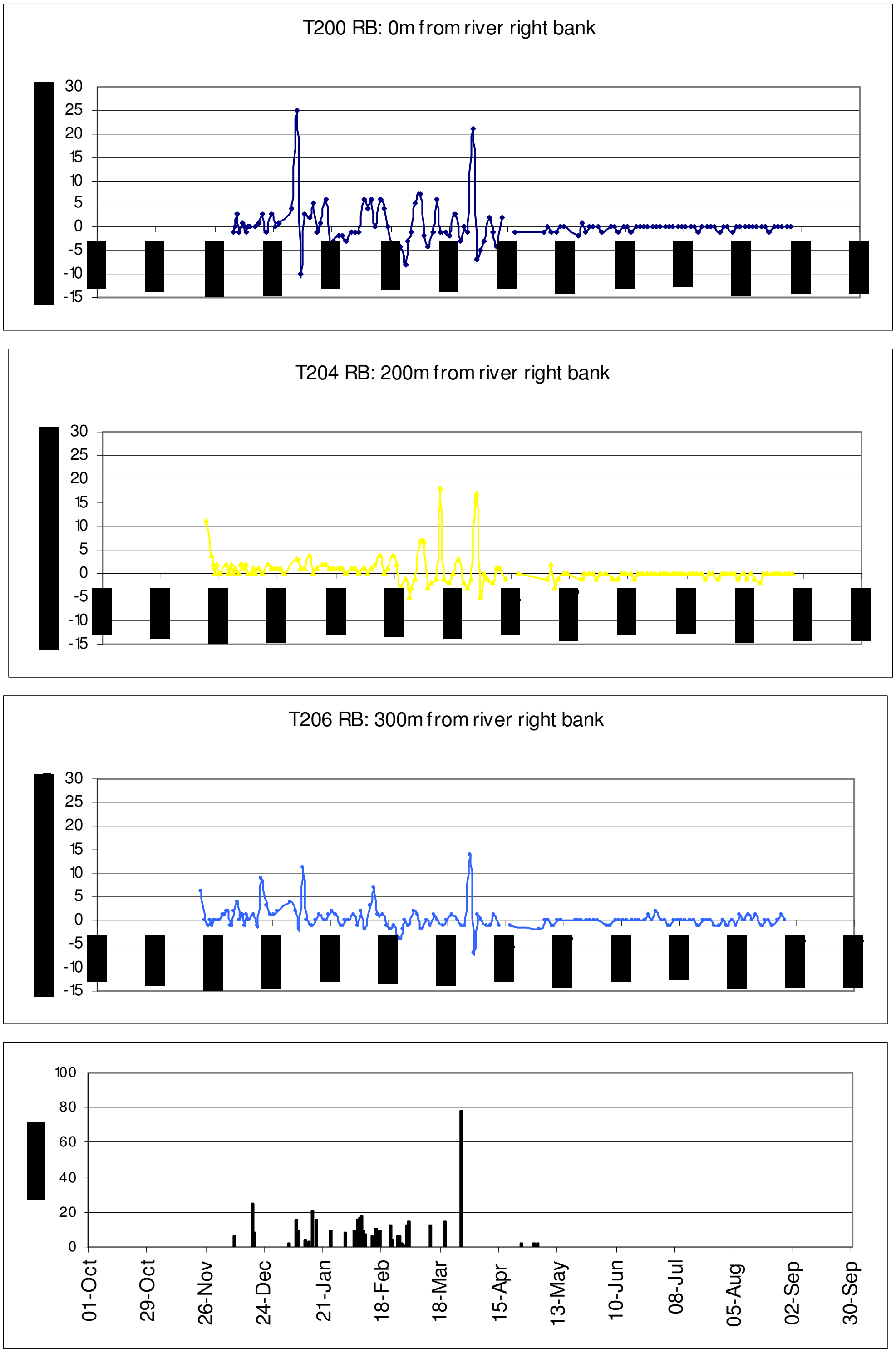


Figure 18. Groundwater level changes at piezometers locations along T2 (from top: 0m, 200m, and 300m from river bank respectively) from November 2005 to August 2006

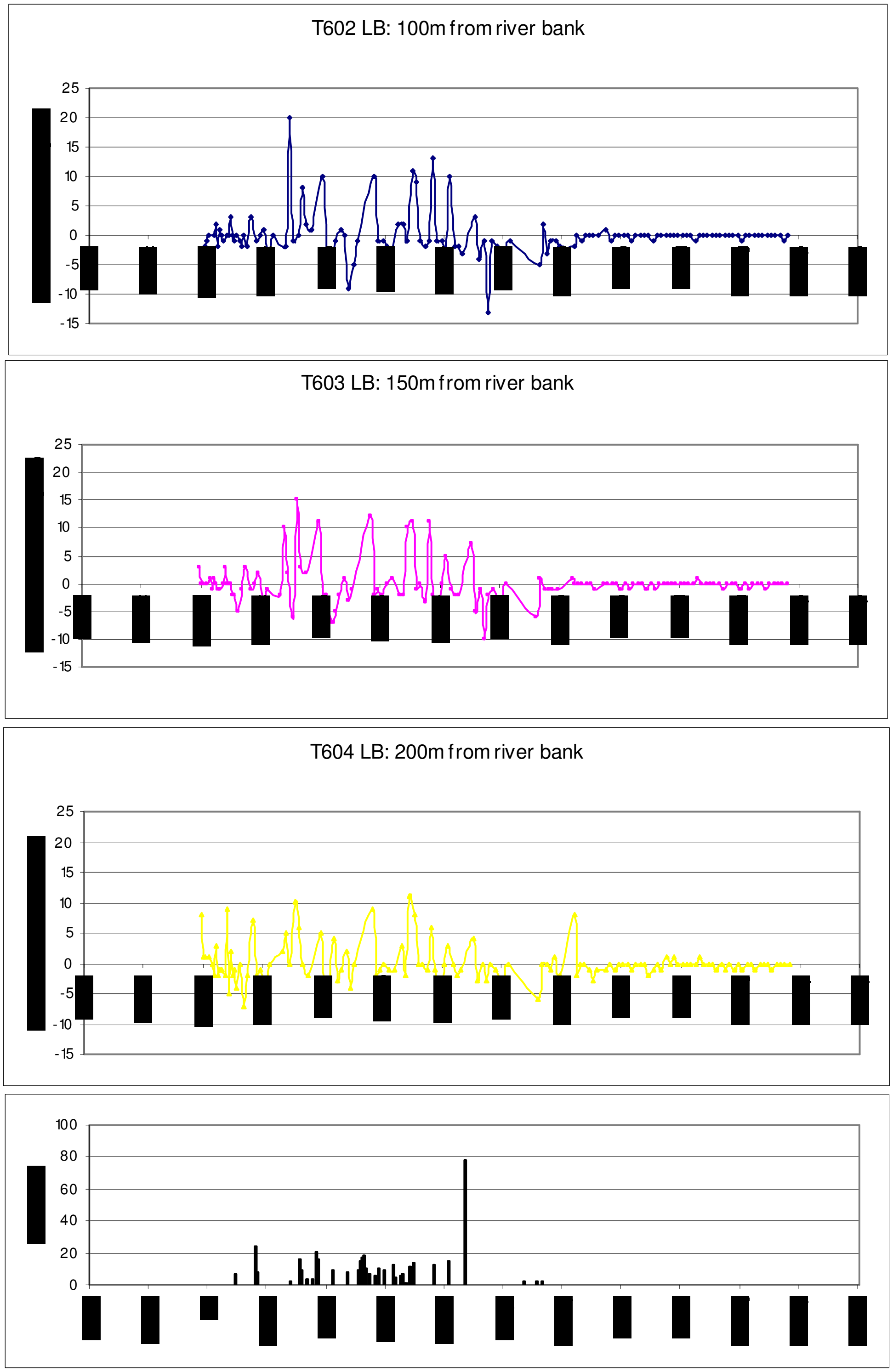


Figure 19. Groundwater level changes at piezometers locations along T6 (from top:100m, 150m, and 200m from river bank respectively) from November 2005 to August 2006

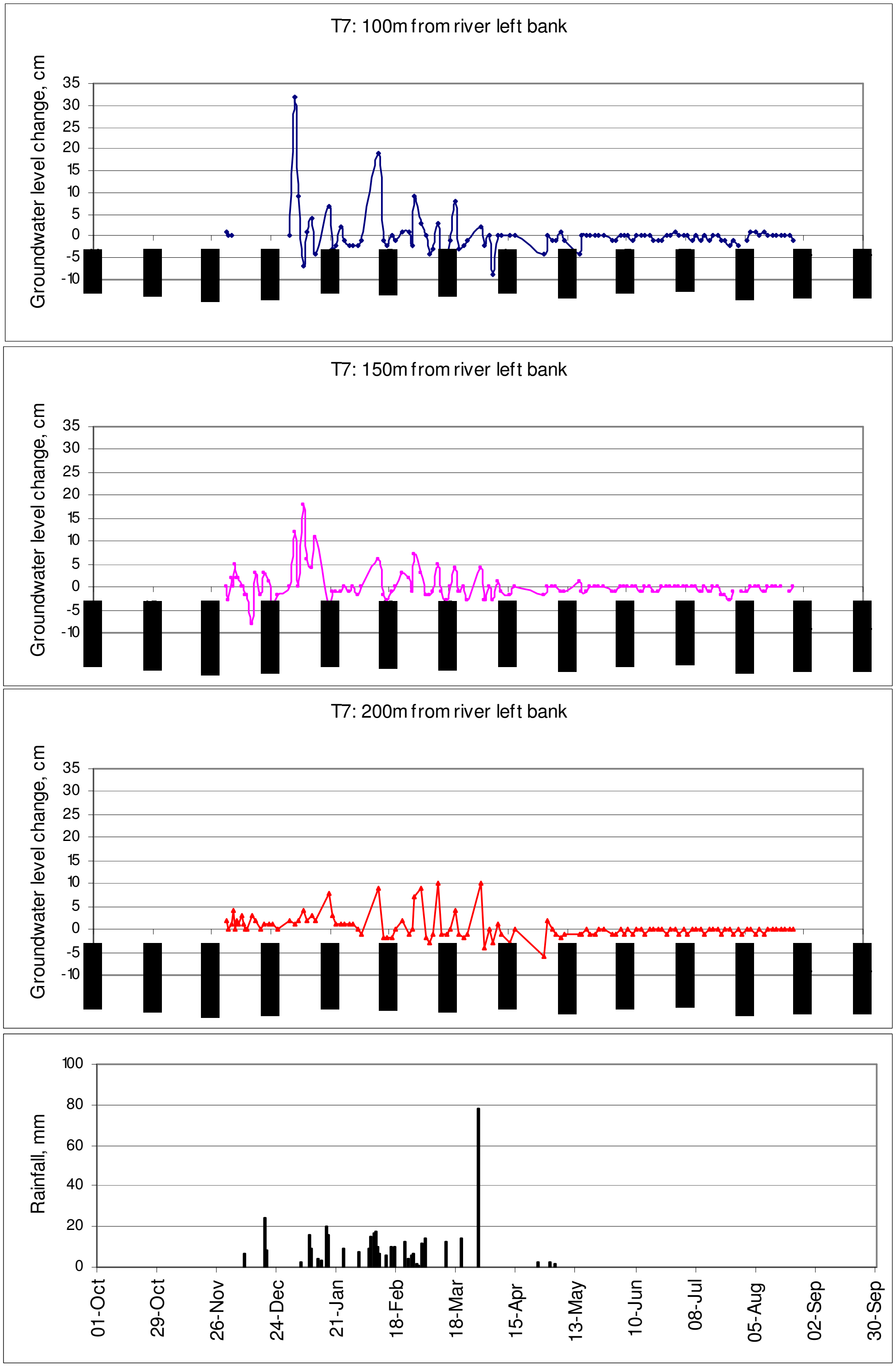


Figure 20. Groundwater level changes at piezometers locations along T7 (100m, 150m, and 200m from river bank respectively) from November 2005 to August 2006

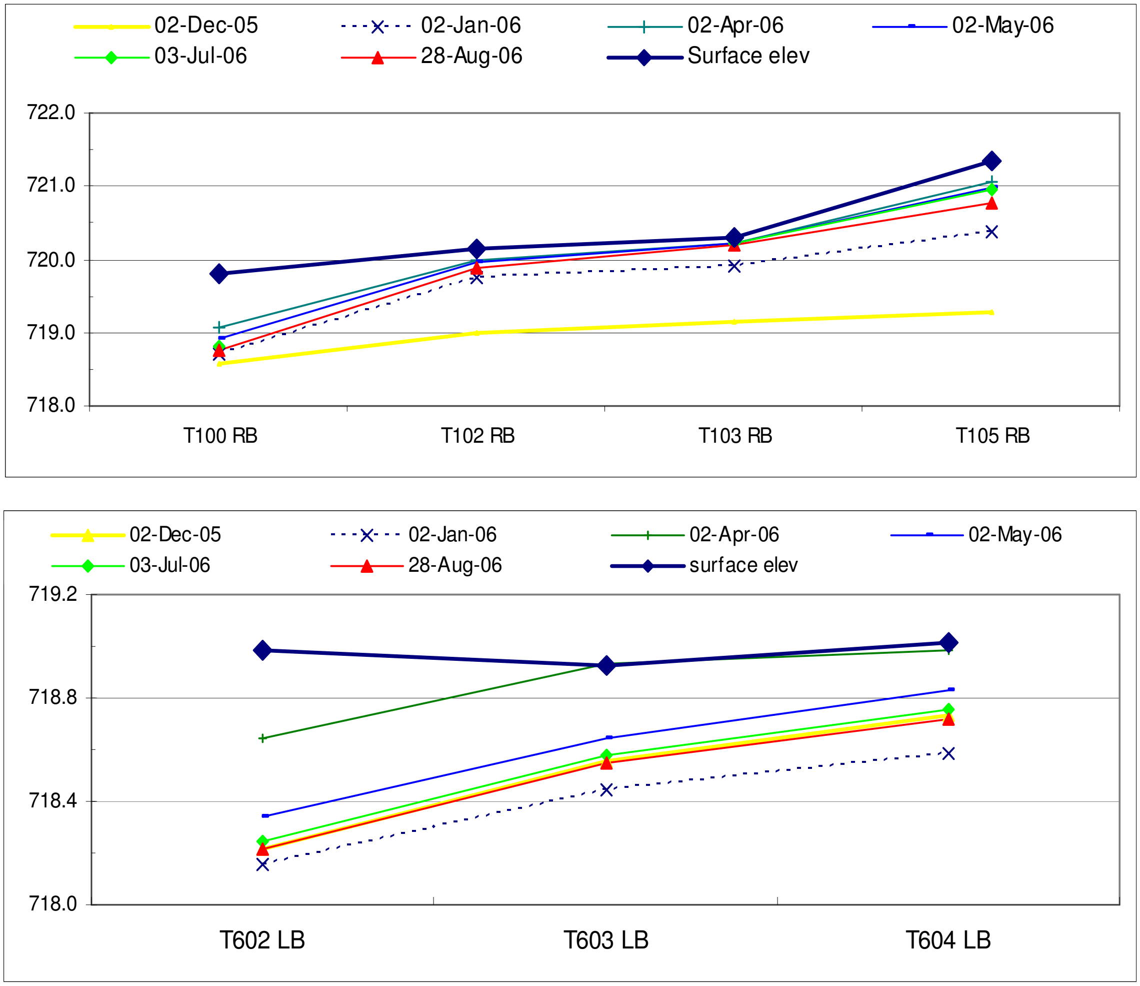


Figure 21. Changes in the elevation of the water table surface along T1 (top) and T6 (bottom)

Table 1. Rainfall gauges located in, and close to, the Mohlapetsi catchment

Station number	Station name	Location		Altitude (masl)	Length of record	Mean annual rainfall (mm)
		South	East			
0635873	Wolkberg	24.02	30.08	1580	1972-1989	844
0635845	Ashmole Dales	24.06	29.60	1524	1917-1921	N/A
0636157	Fertilis	24.13	30.10	780	1959-1988	570
0636276	The Heights	24.10	30.18	1250	1929-1972	1,067
0636308	The Downs	24.13	30.18	1350	1913-1973	941.2

Table 2. Mean monthly and annual A-pan and Penman-Monteith potential evaporation (mm) for the Mohlapetsi catchment

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
A-pan	202.4	166.3	171.0	147.1	134.6	111.6	102.7	156.5	184.1	208.1	208.2	203.8	2014
Penman-Monteith	153.7	126.7	128.1	104.3	88.7	70.1	75.9	101.6	125.0	147.6	153.9	152.8	1428

Source: Computed from data in Schulze *et al*., 1997

Table 3. Inflow measured above the wetland between 06/07/2006 and 22/08/2006). A C2 current meter was used for flow measurement.

Current meter gauging #	Flow (Q, m^3s^{-1})
1	0.27
2	0.33
3	0.37
4	0.40
5	0.41
6	0.37
7	0.38
8	0.40
9	0.39
10	0.31
11	0.28
12	0.33
13	0.33
14	0.36

Table 4. Water balance for the wetland and river section for July to August 2006

	Inputs (mm)	Outputs (mm)
Precipitation	0	
ΔS_w	0	
Evapotraspiration		177
Inflow above the wetland	15.6	
Outflow (B7H013)		18.3
GW_i	179.7	