THE IMPACT OF LAND USE CHANGE ON THE HYDROLOGICAL DYNAMIC OF THE SEMI ARID TSITSA CATCHMENT IN SOUTH AFRICA

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ABSTRACT

In this study, GIS and remote sensing tools were combined with hydrological modelling to identify the impact of afforestation on basin hydrology in the Tsitsa basin, South Africa. Initially, hydrological characteristics such as long-term rainfall and temperature pattern as well as basin runoff dynamics were delineated analyzing available hydro-meteorological time series. Additionally, double mass plots of the runoff of the Tsitsa and its tributary Mooi were analysed in order to evaluate runoff dynamics with regard to spatio-temporal rainfall pattern. These efforts revealed a significant reduction of the Tsitsa runoff beginning in the 6th year after the first plantations. Furthermore, water balance was simulated using the process oriented, hydrological model JAMS/J2000 [1] to quantify the impact of these land use changes on runoff dynamics. Addressing the distributive concept of the J2000 model, the Tsitsa catchment has been divided into Hydrological Response Units (HRUs). Since a thorough hydrological system analysis has shown that slope, soil type, land use, geology and aspect are the hydrologically most relevant components, these input layers were used for a GIS-based overlay analysis to provide spatial model entities for the modelling. The model was parameterized using field data and literature values. Thus, it shows that GIS and remote sensing techniques provide proper methods and data for environmental modelling, particularly in large scale applications.

Keywords: land use change, afforestation, hydrological modelling, HRU derivation, South Africa

1 INTRODUCTION

Addressing the increasing demand on water for domestic, industrial, and agricultural use, prognostic hydrological modelling applications are required aiming to support and assess land management strategies and to analyze their impacts on the water balance, in particular in semiarid areas of South Africa. The north Eastern Cape Province is economically a less developed area in South Africa. For economic reasons, more than 60 000 ha of former grassland have been planted with pine and eucalypt species in the headwaters of the Umzimvubu catchment (19 845 km²) since 1989. Because little attention has been given regarding the effects of such land use

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changes on the basin hydrology, a research project has been initiated to analyze, simulate, and evaluate the impact of afforestation on hydrological process dynamics at different scales. Ref. 2 has shown, that forest activities will noticeably affect wetland and basin hydrology at both microscale (Weatherley catchment: 1.2 km²) and mesoscale (Mooi catchment: 307 km²). This study focuses on results achieved from impact analysis and assessment for the macroscale Tsitsa catchment (4 281 km²).

Especially for macroscale applications, GIS analyses and remote sensing data are essential to provide spatial data for a sufficient stream flow prediction. Based on the analysis of long-term hydro-meteorological time series and spatial data, a comprehensive hydrological system analysis was performed aiming to identify the hydrologically relevant processes and parameters for the parameterization of the catchment model.

2 STUDY AREA

The Tsitsa catchment is located in the south-east of South Africa, see Figure 1. Regarding its physio-geographic conditions, climatic and hydrologic dynamics as well as wetland characteristics, it represents the region of the south-eastern slopes of the Great Escarpment. The altitude ranges from about 782 m asl. at the Xonkonxa weir up to 2 700 m asl. at the catchment boundary along the border to the Kingdom of Lesotho. The study area with its major cities Maclear and Ugie belongs to the Eastern Cape Province. In the headwaters the relief is dominated by steep slopes with narrow floodplains while the majority of the study area is formed by a hilly landscape.

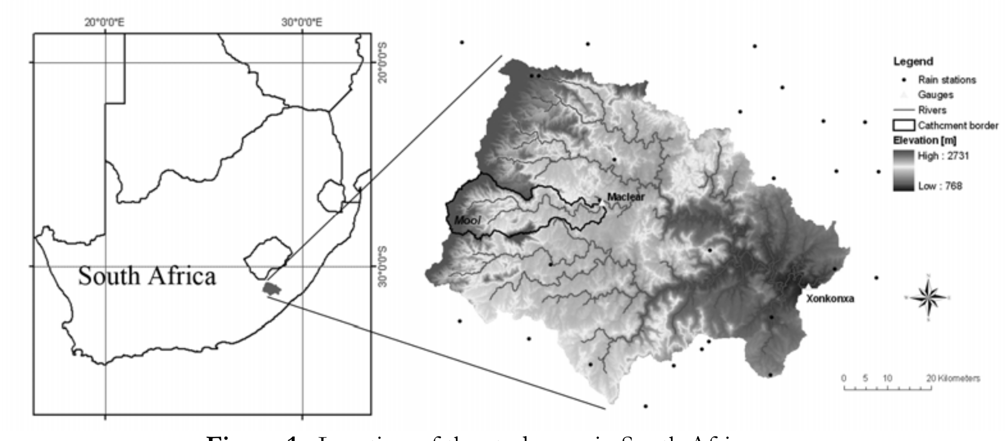

Figure 1. Location of the study area in South Africa.

According to Ref. 3 and [4], the geology of the study area is dominated by Triassic sediments belonging to the Karoo sequence, intruded in places by sills and dykes of Jurassic dolerite. The formations of the Karoo sequence are mainly characterized by changing layers of sandstone and mudstone, which are in places intruded by siltstone layers and horizons of coal or carbonaceous shales. Depending on local climate, relief and parent material, soil distribution shows a high variability. The plateau areas are mainly dominated by shallow Cambisols and Luvisols. In contrast, poorly developed, very shallow Regosols with very unconstrained textures are predominant on upslopes areas [4], while stagnic Cambisols and Luvisols can be found at footslopes. As shown by Ref. 5, the floodplains are dominated by Gleysols.

The climate of the study area is classified as temperate-subtropical and is characterized by summer rainfall, with about 75 % of the Mean Annual Precipitation (MAP) falling between November and March. The spatial-temporal rainfall variability is closely associated with macro- and mesoscale topography and its distance to the coast [6] (see also chapter 4.2). As presented by Ref. 7 the Mean Annual Temperature (MAT) of the Eastern Cape Province is 16.1 °C. The vegetation is characterised by a grassveld type namely Highland Sourveld in the upper parts and Dohne Sourveld in the warmer and drier lower elevations.

3 DATA BASE

For the hydrological system analysis and modelling of the Tsitsa and Mooi catchments several hydro-meteorological time series and GIS data were available. Daily data of temperature, relative humidity, sunshine duration and wind speed were available for the period from 1970 to 2006 from stations in Umtata, Ugie, Port St. Johns and Matatiele. Daily rainfall was given for the same period for 26 stations for the Tsitsa catchment and by five stations for the Mooi catchment. Measured daily runoff data (1970-2006) from the gauges in Maclear (Mooi river) and Xonxonka (Tsitsa river) were used for runoff analysis and modelling. All time series were reviewed and statistically corrected.

A variety of GIS data were available from previous studies for the HRU delineation. Multi-scale and multi-temporal land use information has been provided by land use classification from Landsat ETM/TM data and several mapping campaigns [8]. Additionally, data from the forest data base provided by the forest industry including specific stand information have been used to parameterize the model. Digital Elevation Models (DEM) were derived from SRTM data (Mooi: 25 m^2, Tsitsa: 100 m^2) and have been used to calculate topographic-related data such as catchment boundaries, river network, slope, exposition and aspect [9]. A soil map with a resolution of 100 m^2 grid size was provided from the SOTER Data Base for South Africa [10] while regional geology was digitized from 1:250 000 geological maps [11].

4 HYDROLOGICAL SYSTEM ANALYSIS

4.1 LAND USE CHANGE

Based on two classified Landsat TM/ETM scenes from 1989 and 2001, land use change detection was carried out for both catchments using GIS analysis. From this effort, absolute and percentage changes were computed for each land use class. Comparing land use changes between 1989 and 2001, a significant increase of forest areas was identified with a simultaneous decrease of all other land uses. In the forest areas, the main increase took place in pine plantations, i.e. about 94 % of the planted area are pine species. Indigenous forest loss is addressed to the clearing of wattle tree areas resulting from an initiative to reduce the prevalence of alien vegetation [5]. Primarily, grassland (Tsitsa: - 4 %, Mooi: - 12 %) received areal losses followed by agricultural lands (- 2.15 % and - 2.39 %) (Table 1). This is explained because trees have been usually planted on abandoned farm land which was primary used for rangeland or crop farming. The wetland loss (Tsitsa: - 0.28 %, Mooi: - 1.81 %) is addressed to planting trees in either transition areas between wetlands and uplands or in wetland areas directly. In addition, it is assumed that areas which are surrounded by afforestation are affected by the reduction of water inflows. Continuous monitoring of soil wetness at selected wetland sites leads to the assumption that individual slope wetlands surrounded by eucalyptus stands receive less water than in the past. Thus it is indicated that the lateral water inflow was reduced as a consequence of planting the wetland uplands. The change within the bare soil/rock class can be explained by the preparation of former rangeland for afforestation by contour ripping, burning etc.

Table 1. Absolute and relative land use changes within the Tsitsa and Mooi watersheds between 1989 and 2001.

Land use class	1989				2001				Total Change	
	Tsitsa		Mooi		Tsitsa		Mooi		Tsitsa	Mooi
	Km²	%	Km²	%	Km²	%	Km²	%	%	%
Forest plantations	15.41	0.36	8.08	2.64	303.40	7.09	59.25	19.30	6.73	16.67
Indigenous forest	159.25	3.72	2.49	0.81	173.51	4.05	1.63	0.53	0.33	-0.28
Grassland	3216.32	75.13	235.85	76.70	3041.65	71.06	198.79	64.77	-4.08	-11.95
Agricultural land	358.75	8.38	10.04	3.38	266.71	6.23	3.06	0.99	-2.15	-2.39
Water	0.43	0.01	0.04	0.01	0.43	0.01	0.05	0.01	0	0
Wetlands	232.46	5.43	38.67	12.61	220.47	5.15	33.11	10.79	-0.28	-1.81
Bare soil/rock	298.38	6.97	11.83	3.85	274.83	6.42	11.11	3.61	-0.55	-0.24
total	4281	100	307	100	4281	100	307	100	0	0

4.2 RAINFALL DISTRIBUTION

As shown in Figure 2, rainfall regionalization was performed in order to analyze the spatial variability of precipitation. Using the inverse distance weighting (IDW) [12], MAP was computed for the period 1985 – 1998. In addition, spatial rainfall distribution was calculated for the driest (1992, MAP 763 mm) and the most humid (1989, MAP 1015 mm) years of this period. All rainfall maps showed a similar pattern of rainfall distribution. The comparison to the relatively homogenous rainfall distribution of the Mooi catchment revealed that the Tsitsa catchment shows a significant higher spatial variability. However, the increase of MAP with altitude due to orographic effects [13] was not confirmed by these efforts.

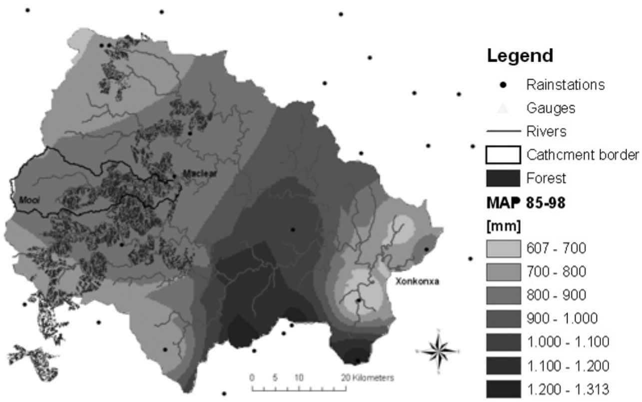

Figure 2. Spatial variability of precipitation in the study area between 1985 and 1998.

4.3 RUNOFF ANALYSIS

The runoff analysis focused on the runoff variability with regard to the rainfall behaviour. Therefore runoff coefficients were calculated for the Tsitsa and Mooi catchments. Additionally, double mass curves of cumulated daily runoff between the Tsitsa River and its tributary Mooi River were analyzed for evaluating the runoff dynamics. Moreover, the temporal variability of extreme events was analyzed and trends were calculated. Analyzing records to identify long-term trends, rainfall and runoff of the 35-year record received from the Tsitsa and Mooi basin were plotted with their percentage deviation from the long-term averages (Figure 3). Both rainfall and runoff show a high variability compared to their annual means. As shown in Figure 3, the parameters widely are highly coincident, i.e. runoff increases when rainfall increases. Moreover, it is concluded that small variations in rainfall dynamics may affect runoff response remarkably with implications for runoff generation processes and wetland functioning in the catchment.

In particular, attention has been given to the time after the establishment of plantation forestry (1989). Assuming a closed canopy cover in the forest stands since 1996 [5], the relationship between rainfall and runoff seems to be affected since this time. With the exception of the relatively dry 1999, the increase of runoff compared to rainfall is less significant than before the afforestation. For example, the area received its highest rainfall measured during the 35- year record, i.e. 35 % higher than the average, but runoff increased only by 80 %. A similar relationship regarding the increases is found for 1998, but it needs to be noted that the year before was characterized by drier conditions. In 2003 rainfall was reduced by 30 %, but runoff surprisingly only decreased by 55 %. In 1999 runoff was higher than the long-term mean, although rainfall was lower than the average resulting from intense rainfalls and an overall positive balance in 1998. Summarizing this analysis it is concluded that inter-annual rainfall-runoff relations are very complex. Nevertheless, it is indicated that the main drivers of the hydrological system are the spatio-temporal rainfall dynamics (system input) and the storage behaviour of the wetlands [2].

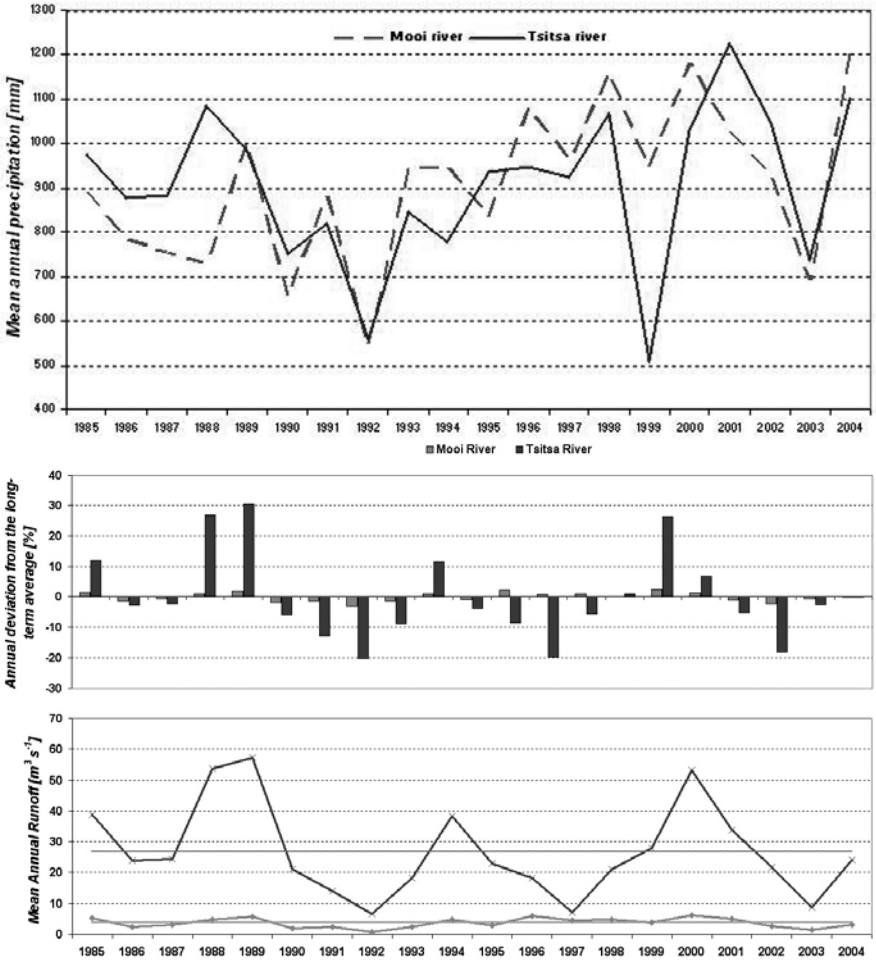

Figure 3. Comparison of inter-annual rainfall and runoff dynamics between the Mooi (dashed) and the Tsitsa (dark) Rivers from 1985 – 2004. Top: Mean annual precipitation. Middle: Annual deviation of runoff from its long-term averages in percent. Below: Mean annual runoff plotted against its long-term average (25.7 m^3 s-1 and 3.31 m^3 s-1).

The assessment of afforestation impacts based on measured runoff was done by plotting the cumulated runoff data from the Mooi River against cumulated data from the Tsitsa River located farther downstream. Comparing data given by the double mass curve for the period from 1970 – 2005 (Figure 4 left) it is shown that cumulated runoff generally shows a good correlation when compared to the 45° line, but also reveals a significant change starting in 1996. In addition, the dynamic of inter-annual variability (Figure 3) for the two rivers also shows a good agreement with the exception of 1996, 1997 and 1998, whether the Tsitsa curve shows a generally higher variability than the Mooi. Taking this into account, a system change is indicated resulting in a significant runoff reduction of the Tsitsa River between 1996 and 1998, even though 1996 and 1998 showed a positive water balance (i.e. higher rainfall values than the long-term average). Consequently, it is assumed that the Tsitsa tends to be more sensitive to system changes compared to the Mooi.

The significant change of runoff dynamics is mainly addressed to the dynamics of canopy closure of the predominant pine species. As shown by field studies in pine plantations, Pinus patula (Figure 4 right) show their highest increase of the Leaf Area Index (LAI) 6 years after planting indicating highest evapotranspiration and interception rates at this time.

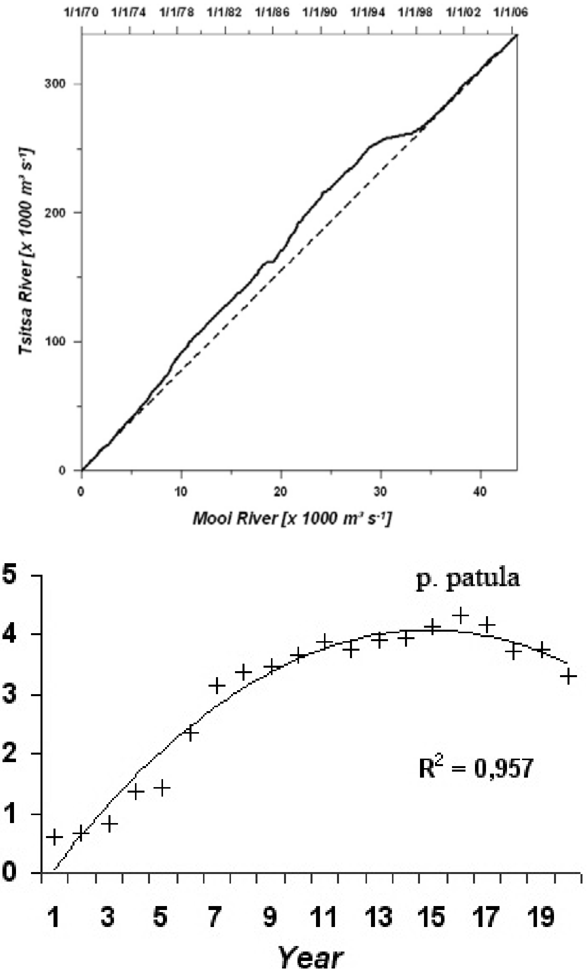

Figure 4. Double mass curve of Tsitsa river and its tributary Mooi as a result of the runoff analysis (left) and LAI development of Pinus patula, the mainly planted species in the study area (right).

4.4 HRU DELINEATION

A further important part of the system analysis and system representation is the delineation of HRUs. As defined by Ref. 14, HRUs are distributed, heterogeneously structured model entities representing specific landscape units of similar response in terms of their hydrological process dynamics. Criteria that are used for definition of the homogeneity are based on the hydrological system analysis of the respective basin. The delineation methodology is schematically illustrated in Figure 5.

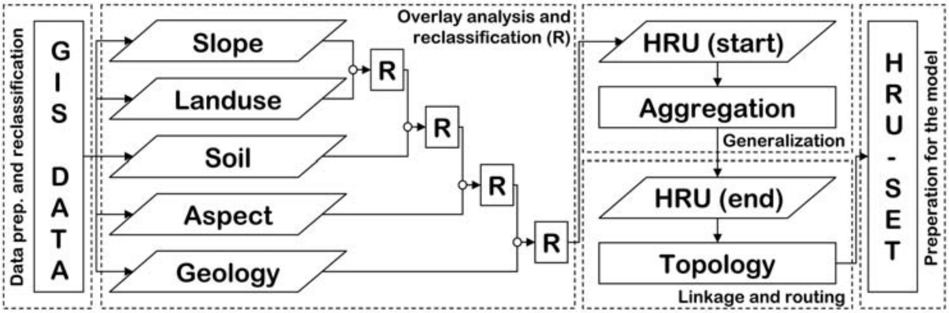

Figure 5. Flow-chart of the delineation of Hydrological Response Units (HRUs).

Initially, all GIS-layers were resampled in order to provide grids of the same spatial resolution. Grid sizes of 100 m² were considered as being appropriate to retain basin characteristics of both watersheds. The GIS-layers, than, were reclassified to receive classes to address their hydrological relevance and model needs. For generalization purposes each class was labelled with a unique number representing its associated attributes.

The GIS ArcView was used for the overlay analysis. Thereby the order of combining the GIS-layers was chosen regarding both the data quality and hydrological relevant criteria addressing major hydrological processes and dynamics (see Fig. 5). The overlay analysis was done by combining GIS layers sequentially in order to provide class layers with a unique layer-combination. Following each overlay, each class layer was reclassified to obtain different classes of hydrological significance. In general, classes representing less than 1 % of the total area were merged with classes of similar hydrological response. Exceptions were made when small classes were assumed to be affective for the hydrological process dynamics. For example, wetlands have been identified as ecosystems fulfilling essential hydrological functions such as flood flow attenuation, baseflow control and groundwater recharge, even though wetland areas may be very small. As a result of the overlay analysis, a class layer with 49 classes incorporating 8 031 HRUs was created for the Mooi basin, and 70 classes with 72 604 HRUs for the Tsitsa catchment.

Following the reclassification the overall HRU number was further reduced by eliminating HRUs with less than 4 pixels (aggregation) in order to eliminate sliver polygons and to improve model performance. Using this approach, the overall HRU numbers could be reduced to 1 741 (Mooi catchment) and 20 984 (Tsitsa catchment).

In particular for large river systems, the topological routing of HRUs is a prerequisite for distributed hydrological catchment modelling [15]. In this study, neighbourhood relations were calculated on the base of DEM parameters using ArcInfo-Macro Language routines (AMLs). This results in a topological linkage for each polygon (HRU) to i) a downward HRU or ii) a river reach. Additionally, the flow length of each HRU and the river width were derived using AMLs and catchment characteristics. Finally, the HRU sets were used to provide input parameter files addressing the needs of J2000 [1].

4.5 HYDROLOGICAL MODELLING USING JAMS/J2000

The hydrological model J2000 [1], [16] was applied to investigate effects of land use changes on runoff dynamics of the Tsitsa and Mooi rivers and for the prognostic modelling of different land use scenarios. The J2000 model is a conceptual, fully distributive hydrological modelling system, which uses the topological HRU approach introduced by Ref. 14 for catchment discretization. Its system structure considers the main processes, components and storages of the hydrological cycle (evapotranspiration (ETP), snow, soil water, groundwater, lateral routing between the HRUs and channel routing) as encapsulated process modules implemented in JAVA environment and the Jena Adaptable Modelling System (JAMS) [17].

The J2000 model was primarily developed to be used in macro-scale catchments like the Mulde, Unstrut, and Elster basins in Germany [1], [16], but it was also successfully applied in meso-scale watershed like the Wilde Gera subcatchment (Germany) [18].

As a consequence of the high number of HRUs in the Tsitsa catchment, the Mooi catchment was used for calibration (1983-1987) and validation (1987-1990) of the model parameter settings. First results of the model calibration are represented by Figure 6. The hydrograph shows a good fit of the runoff dynamic which is confirmed by statistical measures such as the Nash-Sutcliffe efficiency (NSE) (0.63) and the logarithmic Nash-Sutcliffe efficiency (logNSE) (0.61) for the hydrological year 1986. Moreover the analysis of the hydrograph shows, that the great peak flow events are underestimated what makes an additional calibration necessary. The difficulties in fitting the peak flow are partly caused by the coarse resolution of rainfall stations, i.e. local events could not be reflected by the regionalization very well. Model behaviour during the calibration process showed also, that the storage characteristic of wetlands has to be taken more into account. Especially in the beginning of the rain season an overestimation can be observed, what might be caused by the filling of the wetland storage. Additionally, the temporal shift in increase and decrease of some peak flow events are affected by the buffering behaviour of the wetlands.

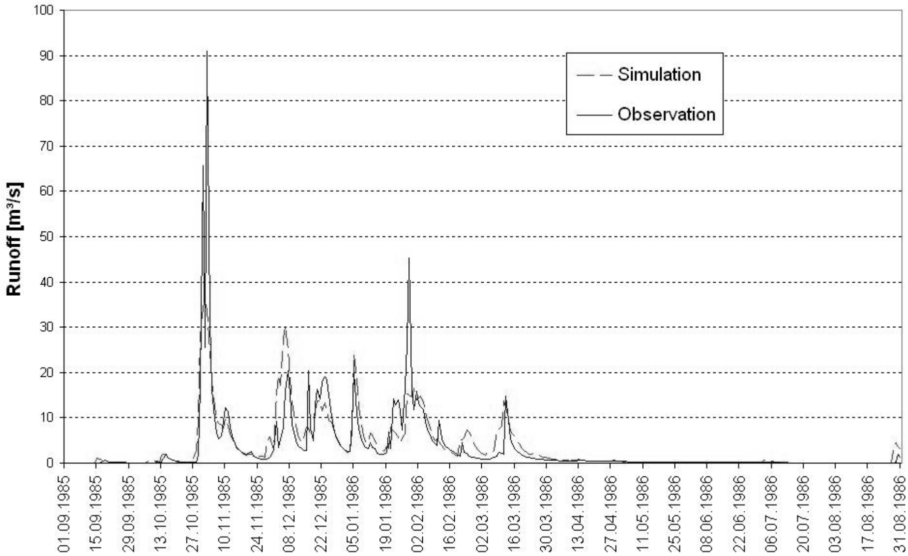

Figure 6. Simulated vs. observed runoff of the Mooi catchment in the hydrological year 1985/86.

5 CONCLUSION AND FURTHER NEEDS

This study has shown, that the combination of a comprehensive hydrological system analysis, GIS and remote sensing tools and distributed hydrological modelling can be used to evaluate the impact of afforestation on basin hydrology. The study was carried out in two headwaters (Tsitsa, Mooi) in the Umzimvubu basin, South Africa.

According to the previous system analysis, the Tsitsa catchment is assumed to be more sensitive to land use changes than the Mooi basin. Land use analysis has shown that proportions of land use vary between the Tsitsa and Mooi catchment. For example, the size of afforested areas in the Mooi basin is twice as the planted areas in the Tsitsa catchment, but it also has twice as much the size of wetland areas and therefore a much higher storage capacity. As a result of a sound rainfall-runoff analysis, it is indicated that the rainfall distribution also affects runoff dynamics. In particular, in the northern and southern subcatchments of the Tsitsa basin, a lower MAP was observed. Due to increased interception storage and ETP in these areas, runoff dynamics are stronger affected than in the Mooi basin. Moreover, the analysis of runoff data showed an abrupt change in the Tsitsa runoff record approximately six years after the establishment of large-scale plantation forestry in 1989/90. This is associated with the time when the predominant pine species reached canopy closure and the strongest increase of LAI which in turn indicates high evapotranspiration and interception rates reducing river runoff. The assumptions made from the hydrological system analysis explain the more sensitive behaviour and the significant reduction of the Tsitsa runoff in the year 1996.

Especially for delineating HRUs GIS analyses and remote sensing data are essential for a representative reflection of the catchments characteristics. Due to the high number of HRUs the physiographic heterogeneity of the catchments could be obtained. A first run of the parameterized subcatchment Mooi provided a good fit of the observed and simulated runoff dynamics. The result obtained by the first application of J2000 in semiarid areas on the southern hemisphere shows that the hydrological processes are well represented in the model. Since the parameter set used for the modelling of Mooi catchment provided reliable results, model parameters addressing the hydrological processes can be transferred to the Tsitsa catchment.

Further studies will focus on the validation and transferability of the model to the Tsitsa catchment as well as a quantitative assessment of the runoff behaviour after land use change. Additionally the analysis of different realistic land use scenarios and their effects to water resources are planed. Addressing the increasing water demand also different water management scenarios will be taken into account. Depending on further developments of JAMS/J2000 the display of the single runoff components for every single HRU and every time step will help to point out the most important areas for runoff and ground water generation.

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REFERENCES

1 Krause, P., 2001: Das hydrologische Modellsystem J2000. Beschreibung und Anwendung in großen Flußgebieten. In: Schriften des Forschungszentrums Jülich, 29.
2 Helmschrot, J., Lorentz, S., Flügel, W.A., 2005: Integrated wetland and landscape modeling. A case study from the Eastern Cape Province, South Africa. In: Zerger, A., Argent, R.M. (eds.): *MODSIM 2005 International Congress on Modelling and Simulation.* Modelling and Simulation Society of Australia and New Zealand, pp. 1382-1388.
3 Karpeta, P., Johnson, M.R., 1979: The geology of the Umtata area. Explanation to the geological map, sheet 3128, scale 1:250 000. Geological Survey, Pretoria, 16 pp.
4 Herbert, M., 1997: Report on a site evaluation study of the estates Glen Cullen and Chillingly, Maclear District. Presentation of field data on topography, lithology, soils vegetation and climate from a sire transect survey, and discussion on findings and recommendations for optimal silvicultural operations for forestry production. Private Report prepared for North East Cape Forest, 88 pp. (unpubl.).
5 Helmschrot, J., 2006: An integrated, landscape-based approach to model the formation and hydrological functioning of wetlands in semiarid headwater catchments of the Umzimvubu River, South Africa. Friedrich-Schiller-Universität Jena, Dissertation, pp. 278.
6 Smakhtin, V.Y, Hughes, D.A., Creuse-Naudin, E., 1997: Regionalization of daily flow characteristics in part of the Eastern Cape, South Africa. *Hydrological Sciences* 42, pp. 919-936.
7 Schulze, R.E, 1997: South African Atlas of Agrohydrology and -Climatology. Water Research Commission, Pretoria, South Africa, WRC Report TT82/96, pp. 276.
8 Helmschrot, J., Flügel, W.A. 2002: Land use characterization and change detection analysis for hydrological model parameterisation of large scale afforested areas using remote sensing. *Physics and Chemistry of the Earth 27*: 711-718.

9 Dahlke, H., Helmschrot, J., Behrens, T., 2005: A GIS-based terrain analysis approach for inventory of wetland in the semi-arid headwaters of the Umzimvubu basin, South Africa. In: Erasmi, S., Cyffka, B., Kappas, M. 2005: Remote Sensing and GIS for Environmental Studies. Göttinger Geographische Abhandlungen 113, pp. 78-86.
10 Dijkshoorn, J.A., 2003: SOTER Data Base for South Africa (SOTERSAF). Technical Report, International Soil Reference and Information Centre. Wageningen,
11 Department of Mines, 1977: 1:250 000 Geological Series, 3128 Umtata, Pretoria.
12 Watson, D.F., Philip, G.M., 1985: A Refinement of Inverse Distance Weighted Interpolation. In: Geo-Processing 2, pp. 315-327.
13 Forsyth, G.G., Versfeld, D.B., Chapman, R.A., Fowöes, B.K., 1997: The hydrological implications of afforestation in the North-Eastern Cape. WRC Report No 511/1/97, Water Research Commission, Stellenbosch, pp. 134.
14 Flügel, W.A., 1995: Delineating hydrological response units (HRUs) by GIS analysis for regional hydrological modelling using MMS/PRMS in the drainage basin of the River Bröl, Germany. *Hydrological Processes* 9, pp. 423-436.
15 Staudenrausch, H., 2001: Untersuchungen zur hydrologischen Topologie von Landschaftsobjekten für die distributive Flussgebietsmodellierung. Friedrich-Schiller-Universität Jena. Dissertation.
16 Krause, P., 2002: Quantifying the impact of land use changes on the water balance of large catchments using the J2000 model. In: Physics and Chemistry of the Earth, 27, pp. 663-673.
17 Krause, P., Kralisch, S., 2005: The hydrological modelling system J2000 - knowledge core for JAMS. In: Zerger, A.; ARGENT, R.M. (ed.): MODSIM 2005 International Congress on Modelling and Simulation Modelling and Simulation Society of Australia and New Zealand, December 2005, pp. 676–682.
18 Bäse, F., 2005: Beurteilung der Parametersensitivität und der Vorhersagesicherheit am Beispiel des hydrologischen Modells J2000. Friedrich-Schiller-Universität Jena. Diplomarbeit, pp.86. (http://www.geogr.uni-jena.de/fileadmin/Geoinformatik/Lehre/Diplomarbeiten/DA_Baese.pdf).