

# Modelling the Flooding Regime of the Nylsvlei Floodplain

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## Abstract

Nylsvlei is an internationally recognized wetland in Limpopo Province, South Africa. A proposal for a dam in the catchment in 1993 highlighted the lack of knowledge of the behaviour of the hydraulics of the floodplain and hydrology of the catchments. A hydrological model of the floodplain's catchments and a hydraulic model of the floodplain have been constructed and used to demonstrate the effects of various catchment scenarios. The construction of the Olifantspruit Dam as proposed in 1993 would have caused a reduction in flooded areas of 25 days duration (necessary for the wild rice grass species on the floodplain to grow optimally) of between 35% in dry years and 1% in wet years in the Nylsvley Reserve.

## Introduction

Nylsvlei is a floodplain situated in Limpopo Province between Modimolle (previously Nylstroom) and Mokopane (previously Potgietersrus). The floodplain is a RAMSAR site, and plays host to some 60% of South Africa's breeding water birds (Morgan, 1996). Evidence suggests that the Nyl River was historically a perennial river, at least in its upper reaches but since the 1980s it has become a periodic river due to developments upstream (Theron Prinsloo Grimsehl & Pullen, 1993).

In the late 1980s Modimolle was forced to look at ways of augmenting its water supply during a severe drought and the Modimolle town council proposed construction of a new dam on the Olifantspruit, a tributary of the Nyl River. The TPA Directorate: Nature Conservation objected to the proposed implementation of the scheme until its likely impact on the Nylsvlei could be investigated. A conference was held in Modimolle in 1991, where it became clear that the hydrologic and hydraulic behaviour of the floodplain was not sufficiently understood. The Mogalakwena Basin Study completed in 1992 included attempts to model flows through the floodplain but these were found to be inadequate for impact assessment as there was a lack of calibration data (Pitman *et al*, 1997). In 1993 it was decided to rather supply water to Modimolle from Roodeplaat Dam, as the effects of the proposed Olifantspruit Dam on the floodplain could still not be quantified.

It was with this background that the present study of the floodplain was born in 1996. This study consisted of two parts, hydrological modelling of the catchments of the floodplain and hydraulic modelling of the floodplain itself. The hydrological model provides the boundary inflows necessary to run the hydraulic model. The input into the hydrological model is rainfall and the output from the hydraulic model is the extent, depth, timing and duration of floods on the floodplain. This information

provides an important link between water resources development in the contributing catchments and the ecological response of the floodplain. Many water bird species on the floodplain require a minimum flooding duration to breed and the wild rice grass (*Oryza longistaminata*) that grows on the floodplain also has a minimum flooding duration, depth and timing requirement to grow optimally.

## Hydrological Modelling

A hydrological model of the Nylsvlei Floodplain catchments was constructed by Stewart Scott Consulting Engineers, using their in-house programs WRSM2000 and Dayflow. WRSM2000 can produce flows on a monthly basis and Dayflow can produce flows on a daily basis. Flows were produced by the model at the various Department of Water Affairs and Forestry (DWAF) flow gauges in the catchments and calibrated using the historical flow data for these gauges at a daily time step. The modelled flows from these gauges were then routed downstream to the points where the rivers enter the floodplain at the floodplain margin. The hydrological model took into account impoundments, afforestation, urbanization and irrigation developments in the catchments. Modelled flow data were provided from 1973 to 2001 by the model at the floodplain margin.

## Hydraulic Modelling

As the Nylsvlei floodplain covers a large area and runs from Modimolle to Mokopane, a distance of some 90km, only the most sensitive and ecologically important portion was modelled. This portion extends from the N1 freeway crossing of the floodplain to the Naboomspruit – Crecy Road crossing near the farm Mosdene, a distance of some 35km (Fig. 1). As even this reduced area was still very large for a hydraulic model, it was divided into three manageable sections. Each then provides its outflow as the next section's inflow downstream. The sections chosen are bounded by road crossings of the floodplain. The upstream section extends from the N1 freeway to the provincial road bridge at the upstream end of the Nylsvley Nature Reserve. The middle section then spans the reserve, from this bridge down to the provincial road that crosses the floodplain at the farm Vogelfontein, the downstream boundary of the reserve. The downstream section then extends from this road crossing to the Naboomspruit – Crecy road crossing near the farm Mosdene.

Flow and stage data as well as rating curves were required for boundary conditions and calibration purposes for a model, so in 1996, the Centre for Water in the Environment (CWE) at the University of the Witwatersrand set up stage gauges which were manually recorded at least once a week depending on flows. DWAF also set up additional stage



Figure 1: Map of the Nylsvlei area showing the study area and the site of the proposed Olifantspruit Dam

gauges at various sites on the floodplain to provide automatically logged continuous stage data. These data are still being collected. Rating curves were derived through regular measurement of stage and flow (by stream gauging) at five sites mainly in the summer months between 1997 and 2001.

The floodplain topography was surveyed using an airborne laser mapping system from a helicopter. This system is capable of penetrating vegetation and mapping the “bare ground” underneath, but it cannot penetrate water (Birkhead et al, 2003). The absolute accuracy of the elevation data is 15cm and the system is able to produce elevation point densities high enough for a grid spacing of 1 metre or less. Due to the rapid rate of data collection, this method is also cost effective. The floodplain from the N1 in the south to the Naboomspruit – Crecey road was mapped in this way.

The survey data was thinned and imported into a commercial digital terrain model (DTM) program called QuickSurf (marketed by Boss International), where a contour map of the floodplain was drawn at a contour interval of 20cm. The contour map was imported into a commercial river modelling program called RiverCAD (also marketed by Boss International) where cross-sections were cut from the contour map.

The floodplain hydraulics was modelled in one dimension using the US Army Corps of Engineers freeware program HEC-RAS (Hydrological Engineering Centre - River Analysis System). The cross section data were imported into HEC-RAS from RiverCAD and a one dimensional unsteady hydraulic model of the floodplain was constructed.

Losses due to evapotranspiration, ponding and infiltration and the addition of water through rainfall on the inundated area were taken into account. Evapotranspiration losses were found using monthly averaged daily evapotranspiration values applied to the inundated area. As part of this study, an investigation into evapotranspiration on the floodplain was conducted by Blight (2002) using an energy balance method to measure actual evapotranspiration over the course of several distinct days during 2000 and 2001. These data were then used to find a suitable model for monthly averaged daily evapotranspiration on the floodplain. A field study of infiltration rates in the floodplain soils was conducted using a Guelph Permeameter. It was found that on the floodplain alluvium, which makes up most of the floodplain soil, infiltration rates were too low to measure with the Guelph Permeameter used (less than 0.036mm/hour).

Inundated area is highly correlated with inflow from the main channel for each model section and thus inundated areas were determined using an empirical equation describing inundated area as a function of inflow (one of the inputs to the model and already known), obviating the need for an iterative method to find inundated area and associated losses and rainfall input for the model. Infiltration and ponding losses are taken as a lumped term and were first determined as cumulative annual amounts using a water balance for the years where there was gauge data. An empirical equation was derived that described annual cumulative loss as a function of annual cumulative inundation area for each year. Daily losses could then be found by subtracting the day's cumulative losses from the previous day's cumulative losses. As infiltration rates were found to be so low

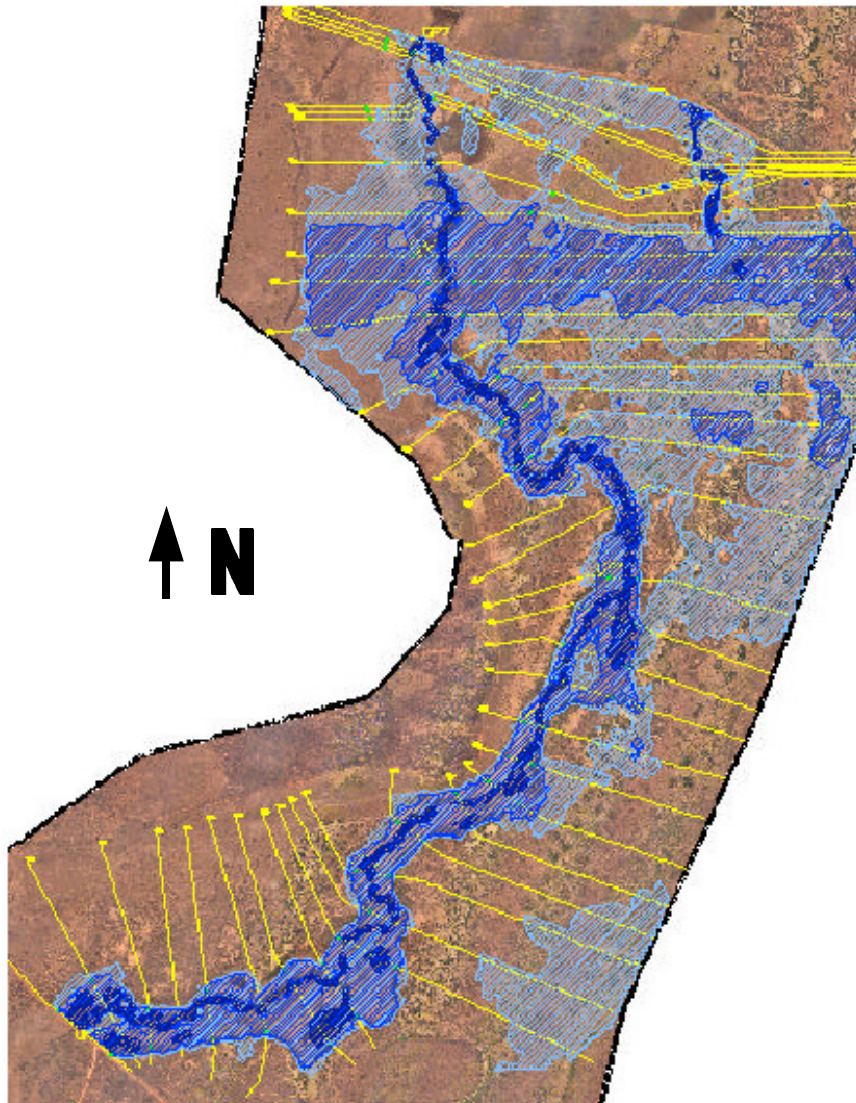


on the floodplain, it was assumed that the majority of the lumped ponding and infiltration loss is through ponding and subsequent evaporation.

The model was calibrated by adjusting the Manning's resistance coefficients of the floodplain and channel, the position of the bank stations which separate the floodplain from the channel, and by defining ineffective flow areas where water is ponded but does not contribute to the cross sectional area of flow. The model was calibrated for unsteady flow using observed inflows at the Nyl River boundary for the 1999/2000 hydrological year. The inflows used for the tributaries flowing directly onto the floodplain had to be modelled due to a lack of observed flow data for these rivers at the floodplain margin.

The model was verified for 1998, 1999 and 2001 using the balance of the available observed inflow data for these years. Once the verification and calibration were acceptable, the model was applied to historical hydrological inflow data generated using observed historical data collected from flow gauges upstream in the Nyl River catchment and routed to the floodplain margin. This model application was also a verification run of sorts since stage data were available for a few gauges on the floodplain from as early as 1922.

RiverCAD has an add-on module for floodplain mapping. This module allows the importation of stream profile data from other programs such as HEC-RAS and then uses this data and the contour map in RiverCAD to map flooded areas. Flooded areas were mapped using this tool to provide a final graphical output (Fig. 2).



**Figure 2: Modelled progression of a floodwave through the Nylsvley Reserve using the RiverCAD floodplain mapping module, plotted for 15, 18 and 21 January 2000 in reducing shades of blue. River flow is from south to north and yellow lines denote cross-sections used in the HEC-RAS analysis.**

## Scenario Modelling

Once the hydraulic model was up and running, various catchment scenarios were run to quantify the effects these different developments would have on flooding extent, depth, duration and frequency on the floodplain. The following scenarios were considered:

- A virgin catchment with no development of any sort.
- The historical catchment from 1973 to 2001 with growth in irrigation, dams, urban areas and afforestation taken into account over that period.

- The development of the Olifantspruit Dam with a capacity of  $5.2 \times 10^6 \text{ m}^3$ , draught of  $2.1 \times 10^6 \text{ m}^3/\text{annum}$  and environmental base flow release of 30 l/s as proposed in 1993 to augment Modimolle's water supply (Theron, Prinsloo, Grimsehl & Pullen, 1993) in the context of the historical catchment scenario above.
- The development of a dam on the Olifantspruit large enough to prevent any flow from this river from ever reaching the floodplain within the context of the historical catchment scenario, thus demonstrating the sensitivity of the floodplain to flows from this tributary.

These scenarios were all run for the period 1973 to 2001 with the historical rainfall for this period used as the input.

Once these scenarios had been run through the hydrological model and the inflows to the floodplain had been found, these inflows were run through the hydraulic model.

The effects of flooding were quantified in terms of parameters that would affect the growth of wild rice (*Oryza longistaminata*). The wild rice is an important food source for animals that inhabit the floodplain, both domestic ones on the farms along the floodplain and wild ones in the Nylsvley Reserve, and for the fish species that thrive on the floodplain when it is flooded. The fish population in turn affects the bird population, being an important food source. The wild rice has also been extensively studied by Marneweck (2003) and the effects of flooding on its growth are fairly well understood. It has been found that wild rice on the Nylsvlei floodplain requires flooding for at least 25 days in January or February, longer in other months, to flower and set seed. It was also found that it grows optimally at a water depth of between 10 and 50cm.

As a preliminary indication of the ecological impact of the scenarios, the largest area flooded for 25 continuous days for each hydrological year was determined from the hydraulics. A larger area would have been flooded for shorter periods, but it is this critical 25-day period that determines the growth of the wild rice.

## Results

The maximum areas flooded for 25 continuous days for each hydrological year in the Nylsvley Reserve are shown in Figure 3. The effects on flooding in the reserve section only are considered here, as this is the most sensitive area and is ecologically in a more pristine state than the rest of the floodplain. Selected inundated area results for a drought year (1985/1986), an abnormally wet year including a large flood (1995/1996), the 1983/1984 hydrological year and the average flooded areas for the period from 1973 to 2001 are shown in Table 1. The historical and development scenarios are compared to the virgin scenario in Table 2 and the development scenarios are compared to the historical scenario in Table 3.

**Table 1: Maximum areas inundated for 25 days (km<sup>2</sup>) for three selected hydrological years and the average over the period 1973-2001.**

	<b>Virgin Scenario (km<sup>2</sup>)</b>	<b>Historical Scenario (km<sup>2</sup>)</b>	<b>Olifantspruit Dam Scenario (km<sup>2</sup>)</b>	<b>No flow from Olifantspruit Scenario (km<sup>2</sup>)</b>
<b>Average for 1973 - 2001</b>	3.66	3.39	3.13	2.82
<b>1983/1984 Hydro Year</b>	3.87	3.47	2.25	2.20
<b>1985/1986 Hydro Year</b>	1.24	0.97	0.98	0.96
<b>1995/1996 Hydro Year</b>	8.77	8.68	8.60	7.22

**Table 2: Comparison of maximum areas inundated for 25 days for three selected hydrological years and the average over the period 1973-2001 as a percentage of the virgin scenario.**

	<b>Historical Scenario</b>	<b>Olifantspruit Dam Scenario</b>	<b>No flow from Olifantspruit Scenario</b>
<b>Average for 1973 - 2001</b>	93%	85%	77%
<b>1983/1984 Hydro Year</b>	90%	58%	57%
<b>1985/1986 Hydro Year</b>	78%	79%	77%
<b>1995/1996 Hydro Year</b>	99%	98%	82%

**Table 3: Comparison of maximum areas inundated for 25 days for three selected hydrological years and the average over the period 1973-2001 as a percentage of the historical scenario.**

	<b>Olifantspruit Dam Scenario</b>	<b>No flow from Olifantspruit Scenario</b>
<b>Average for 1973 - 2001</b>	92%	83%
<b>1983/1984 Hydro Year</b>	65%	63%
<b>1985/1986 Hydro Year</b>	101%	99%
<b>1995/1996 Hydro Year</b>	99%	83%

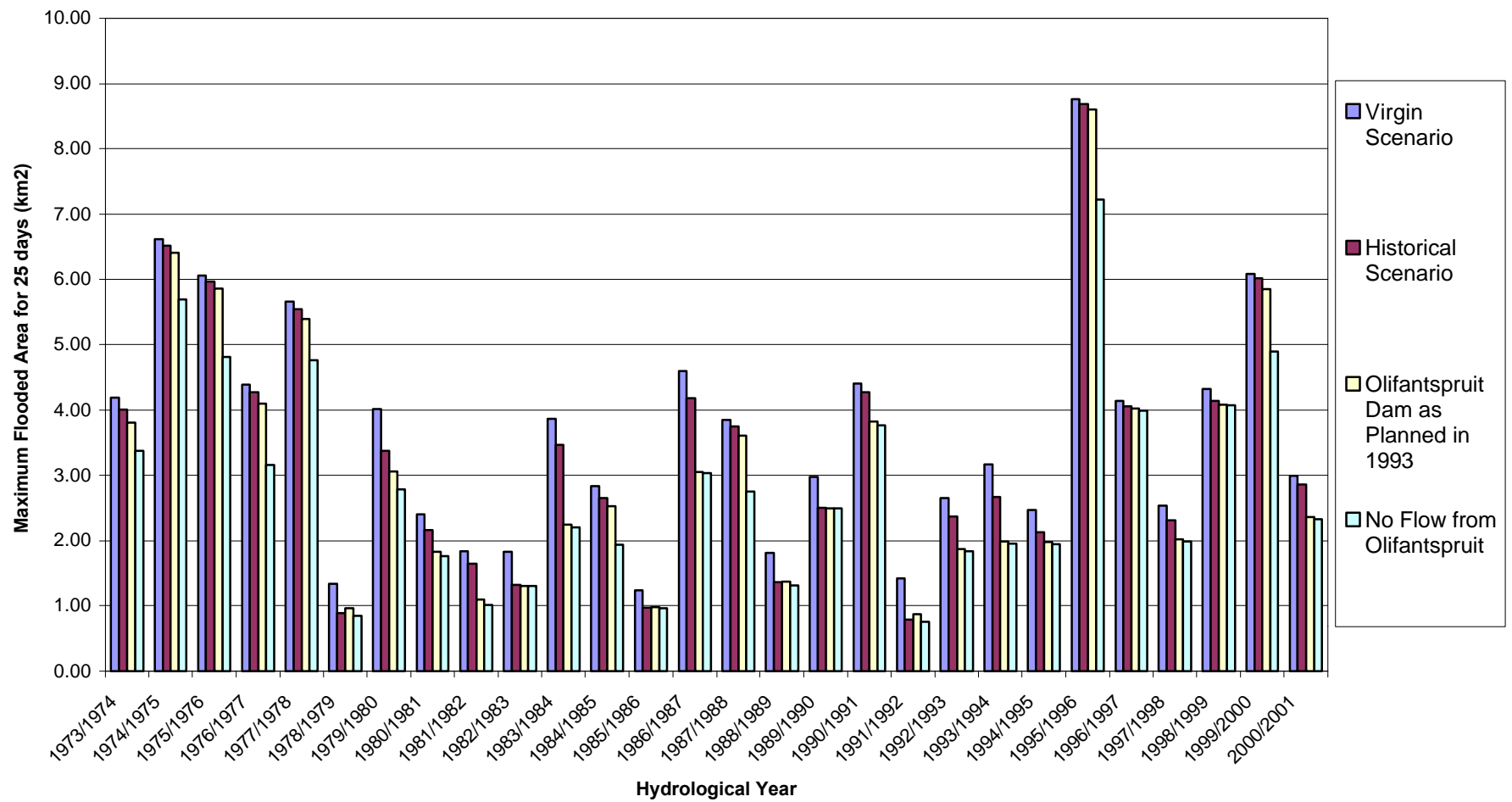


For the virgin scenario the Olifantspruit contributes on average 23% (0.84 km<sup>2</sup>) to the area flooded over 25 days. In the historical scenario the Olifantspruit contributes on average 17% to the areas flooded, which shows that the Olifantspruit is an important tributary to the Nyl River. The dam as proposed in 1993 would have reduced the areas flooded (as an average over the 28 hydrological years) by 8% (0.26 km<sup>2</sup>) over that flooded in the historical situation. The MAR of the Olifantspruit catchment upstream of the dam site was  $6.26 \times 10^6 \text{ m}^3$  and of the entire catchment to the downstream end of the Nylsvley Reserve approximately  $37.5 \times 10^6 \text{ m}^3$  according to the Dayflow simulations from 1950 to 2000 (Bailey, 2003). The Olifantspruit contributes approximately 17% of the MAR at the downstream end of the Nylsvley Reserve, a very similar proportion to the contribution to the inundated area with the historical scenario.

In the abnormally wet year of 1995/1996 the Olifantspruit contributed roughly 18% to the flooded area, yet the dam as proposed in 1993 made only a 1% difference to the area flooded. The dam was full for most of this year and so had very little effect on the floods passing through.

For the drought year of 1985/1986, the flooded areas are very similar for the historical and two development scenarios, and all these scenarios have a flooded area more than 20% less than the virgin scenario. This suggests that runoff in the Olifantspruit catchment that would contribute to the flooding in the floodplain is being caught by the farm dams upstream of the Olifantspruit Dam site. It would seem that in this drought year the damage has already largely been done by the construction of farm dams in this catchment. The reason for the flooded area being larger for the Olifantspruit Dam scenario compared to the historical scenario is that the Olifantspruit Dam was modeled to release an environmental base flow of 0.03m<sup>3</sup>/s, the flow recommended at the time of the planning of the dam (Theron, Prinsloo, Grimsehl & Pullen, 1993). The inflow to the dam during this period was 0.01m<sup>3</sup>/s, the additional 0.02 m<sup>3</sup>/s adding enough flow to inundate the additional 0.01km<sup>2</sup>. The positive effects of this base flow on flooded areas is apparent again in 1978/1979 and 1991/1992.

The years when the Olifantspruit Dam seemed to have the largest impact on the areas flooded over 25 days was in 1983/1984 and 1986/1987. In 1983/1984 the Olifantspruit Dam prevented a large portion of the flood from reaching the floodplain from this catchment and had a very significant impact on flooding on the floodplain. The flood occurred in early December 1983 when the Olifantspruit Dam was still filling, being no more than 85% full during this time. The dam was releasing the 0.03m<sup>3</sup>/s base flow over the period and the inflows were of the order of 1.5m<sup>3</sup>/s into the dam.



**Figure 3: The effects of four catchment scenarios on flooding areas over 25 continuous days in the Nylsvley Nature Reserve**

## Conclusions

The construction of the Olifantspruit Dam would have had a notable impact on the Nylsvlei Floodplain, reducing the areas flooded over the 25-day period investigated by 8% on average compared with the historical conditions. The Olifantspruit is an important tributary to the Nyl River contributing 23% on average for the virgin scenario and 17% for the historical scenario to the areas flooded over the 25-day period investigated. The impact of the dam on flooding areas was far less in wet years (such as a 1% decrease in flooded area in 1995/1996) when the dam was full initially, than in drier years when the dam was not full during a flood (such as a 35% decrease in flooded area in 1983/1984). The results also suggest that in certain years, the existing farm dams affect the flooding far more than the Olifantspruit Dam would have and that the base flow release had a positive impact on the flooding areas such as in 1985/1986. The Olifantspruit contributes approximately 17% of the MAR for the Nylsvley Reserve catchment, a very similar proportion to the contribution to inundated areas.

In this paper only the effects of catchment developments on flooding areas of 25-days continuous duration are shown, which gives a useful indication of ecological impact but is insufficient for effective planning and management. However the hydraulic model can easily be used to produce additional information, such as areas flooded to within specified depth ranges or minimum flooding frequencies, which may be the requirement of certain species to breed or grow optimally.

## Acknowledgements

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