The hydrologic and hydraulic study of the behaviour of the Nyl River floodplain

C. F. B. Havenga[1], A. Jeleni[1], W. V. Pitman[2] & A. K. Bailey[2]
[1]*Department of Water Affairs and Forestry, South Africa*
[2]*Stewart Scott International, South Africa*

Abstract

The main purpose of this study is to model accurately the hydrologic and hydraulic behaviour of the Nyl River floodplain. It is envisaged that the model will not only provide a means whereby possible impacts on the floodplain system can be predicted, should upstream developments in the catchment be undertaken, but will also complement other investigations that have thus far been undertaken in the biological and ecological fields. Two rainfall-runoff models with different time scales, namely monthly and daily were used for the hydrological analysis. The monthly analysis was carried out using WRSM2000 as a means of comparison and for more broad scale planning, whereas the daily analysis was carried out using DAYFLOW in order to provide the required input to the hydraulic model. Hydrological model calibration was achieved on ten gauged catchments. Further tests on the daily model's ability to simulate daily flows indicated the model to be adequate for the study, notwithstanding the shortcomings in the distribution of rain gauges, particularly in the middle reaches of the study area. Hydraulic modelling and four modelling tools are used for developing the hydraulic models, viz Quicksurf, RiverCAD, HEC-RAS and HEC-DSSVue. The topography surveying is carried out using an aerial laser scan, and the data is processed using the Quicksurf and RiverCAD software packages. The hydraulic behaviour of the floodplain is shown to be well replicated by the models, with predicted peak stage levels generally agreeing to within 20 cm of observations.
Keywords: hydrologic, hydraulic, WRSM2000, water resource management, flood plain, Nyl River.

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1 Introduction

The Nyl River floodplain, including the Nylsvlei area, is a unique and highly biologically productive ecological system. Because of its large size and the variety of wildlife it supports, including several Red Data bird species, the area is recognised internationally as an important wetland habitat and proclaimed as a RAMSAR site [1]. It is also a tourist attraction and identified as such by the Limpopo Department of Tourism. In 1986 the Nylstroom Municipality (now the Modimolle Local Municipality) undertook an investigation into the augmentation of its water supplies, which recommended the construction of a storage dam on the Olifantspruit [3], a tributary of the Nyl River. This proposal was initially rejected on environmental grounds and the following important conclusions were arrived at:

- The augmentation of the Nylstroom water supplies needed immediate attention. The proposed Olifantspruit Dam, although the most attractive option, would only be sufficient for 10 to 15 years. Thereafter alternative sources of water would have to be developed. Implementation of the scheme would depend on the findings of a thorough environmental impact assessment.
- The hydrologic and hydraulic behaviour of the Nyl River floodplain was only imprecisely understood and no entirely satisfactory methodology was available to enable a more accurate assessment to be undertaken. Development of a refined model capable of predicting floodplain response to variable flood scenarios was considered to be essential to support the required investigations.
- The Nyl River floodplain system was already stressed due to water abstractions in the catchment. The relatively pristine Olifantspruit River sub-catchment appeared to be the most consistent and often largest contributor of floodwater.

However, by 1993 the issue of environmental impact of the proposed Olifantspruit Dam was still unresolved and a decision was taken to investigate the possibility of augmenting water supplies to Nylstroom from the existing Roodeplaat Dam as an interim measure. This option was approved and the project was implemented in 1995. The proposed Olifantspruit Dam however, is still considered as a potential water supply source for the communities in the Modimolle area, and the Nyl River floodplain could once again in the near future be targeted for further development [3]. It was therefore imperative for the study to be implemented to enable the timeous setting-up of the hydrologic and hydraulic model to provide a means whereby possible impacts on the floodplain system could be predicted, should upstream development in the catchment be undertaken.

2 Objective

The main objective of the study was to accurately model the hydrologic and hydraulic behaviour of the Nyl River floodplain. Two rainfall-runoff models were therefore developed with the hydrological model output used as input for the hydraulic model from which various scenarios were determined. It is envisaged that the models will not only provide a means whereby possible impacts on the floodplain system could be predicted, should upstream development in the catchment be undertaken, but would also complement other investigations that had thus far been carried out in the biological and ecological fields.

3 Study area

The study area is 2 793 km^2 in extent and comprises the Nyl River and its tributaries from the headwaters down to (but not including) the Rooisloot, which enters the Nyl near the town of Potgietersrust (now Mokopane) [1]. The main tributaries are the Groot Nyl, Klein Nyl, Olifantspruit, Middelfonteinspruit, Bad se Loop, Tobiasspruit, Andriesspruit and Dorpspruit (see Figure 1 for study area and flow gauges).

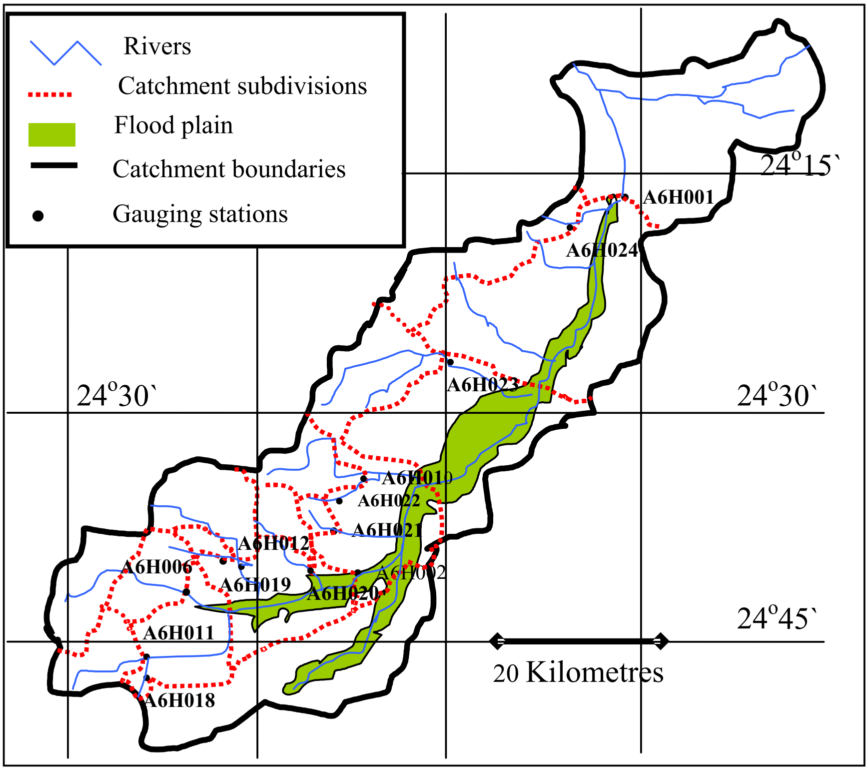

Figure 1: Study area and location of steam flow gauges.

4 Calibration and modelling

The hydrological model calibration was possible on ten gauged catchments. Two rainfall-runoff models were calibrated, namely; WRSM2000 on monthly time step (Updated Windows version of WRSM90) [3] and DAYFLOW [2] on daily time step. Although the hydraulic model requires daily stream-flows, the monthly model was considered to be useful for purposes of comparison and for broader planning of the Mogalakwena Basin as a whole. The performance of both the daily and monthly models was similar with respect to the simulation of annual flows, but the daily model was superior in the generation of monthly flows. Further tests on the daily model's ability to simulate daily flows indicated the model to be adequate for the study, notwithstanding the shortcomings in the distribution of rainfall gauges. Additional model verification was achieved by simulating natural stream-flows for the various sub-catchments of the Nyl and estimating the long term mean annual runoff (MAR). Table 1, lists MAR (in million cubic metres) at various locations along the Nyl River and compares both daily and monthly model results with MARs obtained during previous hydrological studies.

Table 1: MAR along the Nyl River.

	DAYFLOW (1950-2000)	WRSM2000 (1950-2000)	WRSM2000 (1920-2000)	Previous studies (1910-1995)
Location	(10^6 m^3)	(10^6 m^3)	(10^6 m^3)	(10^6 m^3)
Down stream of Groot/Klein Nyl confluence	20.1	18.8	19.6	-
Gauge A6H002 (Deelkraal)	32.1	31.2	31.8	34.1
Down stream of Bad se Loop/Nyl confluence	42.9	41.7	42.5	44.9
Down stream of Tobiasspruit/Nyl confluence	49.8	49.1	51.2	51.1
Gauge A6H001 (Moorddrift)	57.9	58.5	61.1	59.9
Up stream of Rooisloot confluence	65.7	70.5	75.8	72.6

Hydraulic modelling was undertaken by transforming floodplain input hydrographs provided by the hydrological models into ecologically relevant flood characteristics. It was shown by previous ecological studies carried out by Centre for Water in the Environment of the University of the Witwatersrand (CWE), Johannesburg that in general, these characteristics are the depth, area, duration and timing of inundation [1].

The Hydraulically modelled floodplain area is bounded by the N1 road crossing of the Nyl River at the upstream end and the Naboomspruit-Roedtan road crossing at the downstream end (see Figure 2). To enable the large amount of survey data generated for this study to be managed and processed, this area was modelled in three contiguous sections, viz the Nylsvlei Nature Reserve and the areas upstream and downstream of the reserve. A separate Hydraulic model was developed, calibrated and verified for each section. Each model accounts for inflows, local rainfall, evapotranspiration, infiltration and pondage losses.

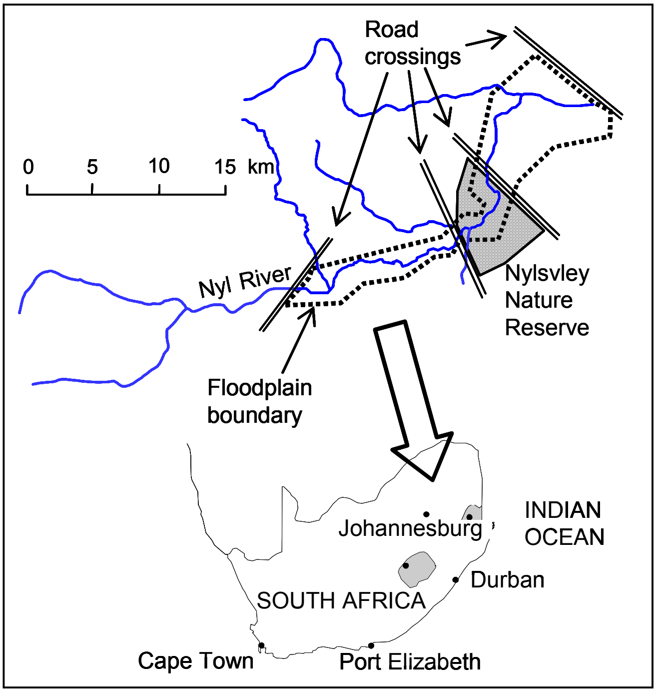

Figure 2: Location of modelled floodplain area.

A suite of four modelling tools was used for developing the hydraulic models, viz Quicksurf, RiverCAD, HEC-RAS and HEC-DSSVue [1]. These allow for surface mapping, unsteady one-dimensional flow analysis, and graphical representation of output, including plan plots of inundation areas and depths, rating curves, hydrographs and plots of other relevant hydraulic information. Introducing the digital contour map prepared in Quicksurf into RiverCAD, where computational cross-sections were defined, set each of the three floodplain section models up. The changing inundated area (required for computing evapotranspiration losses) was modelled using a correlation between inflow and instantaneous inundated area, as determined by HEC-RAS, and displayed through RiverCAD. Infiltration, evapotranspiration and ponding losses were accounted for using the extraction pumping facility in HEC-RAS.

The modelling scale and resolution were defined by previously observed spatial distributions and temporal responses of vegetation communities and species [1]. An extensive data collection programme was carried out to provide information for the development, calibration and verification of the models. The very flat topography of the floodplain necessitated high resolution surveying, which was carried out by airborne laser mapping and colour digital photography using a new surveying technology called an aerial laser scan. This technology however, could only be applied at a specific "window of opportunity" i.e. when the flood plain was dry (laser beam does not "see" under the surface of water). The survey produced 1.9 million data points over the study area, and the data were processed using the Quicksurf and RiverCAD software packages.

Water levels were monitored at a number of sites along the floodplain using gauge plates and autographic and auto-digital recorders installed by the Department of Water Affairs and Forestry. Within the Nylsvlei Nature Reserve, water levels were recorded periodically at six cross sections using gauge plates previously installed by CWE. Discharges were measured during flood events at the four road crossings bounding the three separate hydraulic model areas, enabling rating (stage-discharge) relationships to be established. The hydraulic information derived from this monitoring is stored in the HEC-DSSVue data storage system. Rainfall data for the floodplain were obtained from the suitable gauge, situated in the Nylsvley Nature Reserve, infiltration was measured using a Guelph permeameter at a number of locations within the reserve, and evapotranspiration was measured using an energy balance method in each of the four seasons daily. These daily values were converted to average monthly rates for the floodplain using pan evaporation data from the Donkerpoort Dam weather station.

Model application was carried out sequentially, starting with the most upstream of the three floodplain sections, and using the modelled output hydrograph as the primary input for the next downstream section. The models were calibrated by adjustment of local Manning flow resistance coefficients, using the wettest season (1999-2000) of the six-year (1996-2001) monitored period, and verified using the remaining data. Measured stage and discharge hydrographs at the inflow and outflow of each modeled section were used for model calibration and verification. The downstream boundary condition for each model is defined by the rating relationship developed from stage (water level) and discharge measurements at road crossings. Additional stage hydrographs were available from four locations monitored within the Nature Reserve and at the Deelkraal gauge upstream of the reserve. It was necessary to use hydrological data in the form of extrapolated recordings from gauges in upstream catchments to account for lateral inflows from three tributaries that drain the Waterberg Mountains. Hydrological modelling provided flow data for an ungauged tributary flowing from the Springbok flats.

5 Conclusion

The hydraulic behaviour of the floodplain was shown to be well replicated by the models, with predicted peak stage levels generally agreeing to within 20cm of observations. Estimated losses for the upper, reserve and lower floodplain sections account for between 16-35%, 13-50% and 26-100% of the total inflows, respectively.

The models were applied, to assess changes in the hydraulic behaviour of the floodplain in response to water resource developments in the upper catchments of the Nyl River and for predicting ecological consequences. These applications show that the models are able to simulate, with sufficient sensitivity, the floodplain response in terms of depth, area, duration and timing of inundation, to a modified hydrological regime. It is envisaged that the hydrologic and hydraulic models will not only provide a means to predict potential ecological impacts of upstream developments on the Nyl River floodplain system, but also complement related investigations in the biological and ecological fields. The hydraulic analysis involved an investigation on hydraulic models and methods for hydraulic analysis, and the calibrated models and experience gained will be of benefit in analysis of other wetland regions.

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