Estimation of environmental flow requirements at the Orange River Mouth using an improved spatial interpolation approach

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Abstract

In the context of a lack of information, the share of river flows that enables to maintain the equilibrium of aquatic ecosystems is often difficult to estimate due to (1) the definition of actual environmental needs and (2) missing or incomplete observed flow time series at the sites concerned. To address the hydrological component of this issue at the Orange River Mouth site (South Africa / Namibia), which shelters endangered wetlands of international importance (RAMSAR site), a spatial interpolation approach was applied to estimate daily flows at ungauged sites. This paper describes improvements to the original method used to estimate daily flow time series at an ungauged site, which resulted in better matches with observed water levels than the original method. These results allowed to estimate the frequency of flooding at the mouth required to support conservation of the wetlands. These generic methodological improvements could easily be included in future applications of this spatial interpolation approach.

Keywords: environmental flows, flow duration curves, Orange River Mouth, Ramsar site, spatial interpolation approach, wetlands.

Estimation des débits environnementaux requis à l'estuaire du fleuve Orange par l'utilisation d'une méthode d'interpolation spatiale améliorée.

Résumé

En conditions d’information déficiente, les débits nécessaires à la satisfaction des besoins environnementaux sont souvent difficiles à estimer en raison (1) de la méconnaissance des besoins environnementaux de l’écosystème et (2) du fait que les séries chronologiques de débits peuvent être incomplètes voire absentes au site considéré. Une méthode d'interpolation spatiale des débits a été utilisée pour simuler le régime hydrologique journalier pour de tels sites non jaugés. Cet article présente des améliorations apportées à cette méthode qui est appliquée au site de l’estuaire du fleuve Orange (Afrique du Sud et Namibie) qui abrite une zone humide d’importance internationale (classée RAMSAR). Cette méthode d’interpolation spatiale modifiée a permis de calculer des séries temporelles de débits journaliers qui sont mieux corrélées avec les hauteurs d’eau journalières observées que la méthode originale. Ces résultats ont ensuite été utilisés pour estimer une fréquence d’inondation à l’estuaire compatible avec la conservation des zones humides de l’estuaire. Ces développements méthodologiques sont génériques et pourraient être facilement réutilisés à l’occasion de futures applications de cette approche d’interpolation spatiale.

Mots clefs: courbe débit-fréquence, débits environnementaux, estuaire du fleuve Orange, interpolation spatiale, site Ramsar, zones humides.

INTRODUCTION

In the current context of increasing pressure on water resources, it is important for water resources managers to be able to quantify the flows that have been, or that will have to be, allocated to a given environmental need. However, their task is often complicated by deficiencies in the hydrological monitoring network on the watercourse concerned. The Orange River Mouth (ORM), located at the border between South Africa and Namibia, is a good illustration of such an issue. The Ramsar site includes wetlands of exceptional biodiversity, but although ecological conditions depend directly on inflows from the Orange River, there is no flow recording station at the inlet of the mouth which would enable estimation of the degree to which the freshwater requirements of the wetlands are fulfilled. We thus had to apply a spatial interpolation approach that allowed us to simulate daily flows at ungauged sites. This method was first designed by Hughes & Smakhtin (1996) and subsequently completed with additional features (Smakhtin, 2004). It was applied successfully in various contexts in South Africa, Sri-Lanka and Nepal, in particular to assess environmental flows at ungauged sites (Smakhtin, 2004; Smakhtin *et al.*, 2004 and Smakhtin & Weragala, 2005). Hughes & Forsyth (2006) designed a piece of software called SPATSIM which facilitates the implementation of the approach. However, it appeared that further improvements could be made to the method to deal more efficiently with contexts like the one of the ORM, where the nearest flow gauging stations are located in different tributaries of the same hydrological drainage network. The purpose of this study was thus to determine if improvements to the original method would enhance the quality of the hydrological model and thus the estimation of environmental flooding requirements at the ORM. After a description of the study area, the paper describes the application of a refined spatial interpolation approach to simulate time series of daily flows and water levels at the ORM. This is followed by the description of a simple hydraulic model to simulate the flood hydrograph required to ensure flooding of the most degraded part of the ORM wetlands.

DESCRIPTION OF THE STUDY AREA

Overview of the Orange River basin

The Orange River basin covers more than 1 000 000 km² in South Africa, Lesotho, Botswana and Namibia (Fig. 1). The Orange River originates in the Lesotho Highlands some 3 300 m above sea level where mean annual precipitation (MAP) can exceed 1 800 mm year^{-1}. The river courses run 2 300 km from the source to the mouth on the Atlantic Ocean, where the MAP is below 100 mm year^{-1} and the potential evaporation (A-Pan equivalent) is higher than 2 600 mm $year^{-1}$ (Schulze *et al.*, 1997; LORMS, 2005b).

The Orange River has a mean annual runoff (MAR) of approximately 4 743 hm^3 $year^{-1}$ (LORMS, 2005c). It is highly regulated by more than 30 dams having a storage capacity higher than 12 hm^3 (Turton *et al.*, 2004). In particular, the Van der Kloof Dam was built in the 1970s for purposes of irrigation, drinking water supply and production of hydro-electricity, approximately 1 400 km upstream of the mouth, with a storage capacity of 3 171 hm^3. It is currently the last main storage structure on the Orange River and in effect controls the flows from the dam to the mouth.

The Orange River Mouth and its wetlands

The ORM is located at the border between South Africa and Namibia. Wetland habitats cover a surface of 23 km^2 and are located in the river channels, in the river mouth, in a tidal basin and in a saltmarsh on the southern bank (South African bank) of the mouth (Fig. 2). The South African and Namibian parts of the Orange River Mouth Wetlands (ORMW) were classified as Ramsar sites in 1991 and 1995 respectively (Le Maître *et al.*, 2001; Bornman *et al.*, 2005).

The ORMW were highly impacted by (Bornman *et al.,* 2005):

(a) The change in the flow regime of the Orange River as a consequence of the construction of dams during the 1960s and the 1970s, in particular the Van der Kloof Dam, whose releases are mainly linked to production of hydro-electricity,

(b) A dyke constructed in the 1970s along the river channel at the mouth and a causeway crossing the saltmarsh towards the beach. These are major obstacles to the flooding of the wetlands by freshwater.

As a consequence of these changes, the soil and groundwater salinity in the saltmarsh increased and is at present too high for the existing vegetation, which threatens the maintenance of the biodiversity of the area (Bornman *et al.*, 2005).

CHARACTERIZATION OF THE HYDROLOGICAL REGIME AT THE ESTUARY AT A DAILY TIME STEP

Availability of hydrological data

There is no flow recording station at the mouth, but a water level recorder is operated at the Oppenheimer bridge (9.5 km upstream of the ORM). On the Orange River, the closest flow gauging station is located at Vioolsdrift, about 280 km upstream of the ORM (Fig. 3). The low flows measured at the Vioolsdrift site are known to be of poor quality, as the measurement site is a very wide concrete weir. Thus a minor inaccuracy in the recording of water levels during low flow periods can imply a significant difference in flows. On the Fish River, which is the major tributary of the Orange River in this part of the basin, the nearest flow gauging station is located at Ai-Ais (Namibia), about 65 km upstream of the Fish/Orange confluence, the confluence itself being about 120 km upstream of the ORM (LORMS, 2005c). The Konkiep River, a tributary of the Fish River, is not monitored by the Ai-Ais station, but its contribution to the Lower Orange system in terms of flows is considered to be negligible (source: Department of Water Affairs - DWA- Namibia). Therefore the hydrological stations we selected to characterize the flow regime at the ORM were Vioolsdrift and Ai-Ais, plus the water level recorder located at the Oppenheimer bridge (Table 1).

The original spatial interpolation approach

Hughes & Smakthin (1996) developed a spatial interpolation approach for time series of observed flows, which was successfully applied in various contexts in South Africa, Sri-Lanka and Nepal

(Smakhtin, 2004; Smakhtin *et al.*, 2004; Smakhtin & Weragala, 2005). Hughes & Forsyth (2006) designed a piece of software called SPATSIM that assists the implementation of the approach.

This method transfers hydrological time series (for example time series of daily flows) from one or several gauged sites (called "source sites") to an ungauged site (called "destination site") where hydrological time series are needed. Flow Duration Curves (FDC), which link a flow value to the frequency of occurrence of this flow, are a central tool in this method. The key assumption is that flows occurring simultaneously at two sites located reasonably close one to another have the same frequencies of occurrence in their respective FDC. The method is implemented in two main steps:

(a) Calculation of daily FDC at source and destination sites;

(b) Generation of time series of daily flows at the destination site.

In this study, the destination site was the Orange River at the Oppenheimer bridge, which corresponds to the inlet of the ORM. Vioolsdrift (Orange River) and Ai-Ais (Fish River) were selected as source sites. Two different periods were used in this study:

- Period 1: 1 November 1935 – 29 September 1960,
- Period 2: 1 October 1980 – 16 August 2005,

The two periods are of almost equal length but one occurred before and the other after the construction of the major impoundments on the Orange River, e.g. the Van der Kloof Dam. For the former period, observed data were only available at Vioolsdrift, whereas for the latter period, data were available both at Vioolsdrift and Ai-Ais (cf. Table 1).

A modified spatial interpolation approach applied at the Orange River Mouth

In this study, two modifications were made to the original spatial interpolation procedure. First, when several source sites are available (as is the case here with Vioolsdrift and Ai-Ais), the method recommends calculating the flows at the destination site with each source site separately, and then calculating a weighted average of the simulated flows (Smakhtin, 2004). However, as the flows from Vioolsdrift and Ai-Ais come together in the stretch of the river downstream of the confluence, we chose to create a synthetic source site (called “sum”), whose flows at day *N* were defined as the sum of the flows at Vioolsdrift and Ai-Ais at day *N* (when no observed value was available at one site, no value was calculated at the “sum” site). This method was applied only for period 2 as data were not available at Ai-Ais for period 1. The second modification was the addition of a time lag of one day in the time series of simulated daily flows at the ORM to take into account the time of transfer from Vioolsdrift and Ai-Ais to the mouth.

Estimation of daily FDC The time series of daily flows were available at Vioolsdrift and Ai-Ais, which enabled direct calculation of daily and monthly FDCs at the source sites. The SPATSIM software calculated a discrete representation of the FDC with the corresponding flow rates of 17 fixed percentage points ranging from 0.10% to 99.99% (0.10%, 1%, 5%, 10%, 15%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 85%, 90%, 95%, 99%, 99.90%), before interpolating these points to carry out a continuous FDC.

For the destination site, where hydrological time series were incomplete or missing, three different methods are proposed for the construction of daily FDCs (Smakhtin 2000a, b, 2004). In the present study, we applied the explicit ratio curve method. The main steps of this method were the following:

(a) Daily and monthly FDCs were calculated at source sites, namely Vioolsdrift for period 1 and “sum” for period 2,

(b) For each of the 17 fixed percentage points of the FDC of these source sites, we calculated the ratio of [the flow from the daily FDC / the flow from the monthly FDC]. These ratios were plotted against the percentage points and constituted the two ratio curves for periods 1 and 2.

(c) The ratio curves were used as conversion functions from monthly FDCs to daily FDCs at the destination site. As already mentioned, no daily flows time series were available in the vicinity of the mouth. Nevertheless, previous assessments simulated monthly flows at the mouth for the present state of the basin and for a previous more natural or "naturalised" state (LORMS, 2005c). These two time series were used to compute monthly FDCs at the mouth for periods 1 and 2. Then, for the 17 percentage points, the flow from the monthly FDC at the ORM was multiplied by the corresponding ratio from the ratio curve. We thus obtained daily FDCs at the ORM for the two periods concerned (Table 2 and Fig. 4).

Simulation of time series of daily flows The algorithm of calculation of daily flows from a daily FDC is illustrated in Fig. 5. As we knew the value of an observed daily flow at a specific source site on day *N*, the daily FDC enabled us to get the corresponding frequency of occurrence. Then we used this value of frequency on the daily FDC at the destination site, which had previously been calculated (see above). The corresponding value of flow was taken as the flow at day *N* at the destination site. This algorithm was applied automatically with SPATSIM for periods 1 and 2. Then a time lag of one day was applied in the flow time series at the destination site for the two periods.

Results

Time series of simulated daily flows at the ORM were compared to the daily water levels observed at the bridge (Fig. 6). The comparison was carried out over the period for which records of water levels existed i.e. from 27 October 1993 to 31 July 2005. Due to the poor accuracy of low flow measurements at Vioolsdrift, flows lower than 200 $m^3 s^{-1}$ and water levels lower than 1.5 m were not used. As water levels could not be measured for extreme flood events, these events were not used in the comparison either. It can be seen on Fig. 7 that, under these conditions, modifications to the original method resulted in a better correlation between simulated daily flows and observed water levels, with a correlation coefficient of 0.93 instead of 0.72, corresponding to the following relationship:

$$H = -1.849 \times 10^{-7} \times Q^2 + 1.394 \times 10^{-3} \times Q + 1.316 \qquad (1)$$

where H is the observed water level (m) and Q is the simulated daily flow ($m^3\ s^{-1}$), with H>1.5 m and Q>200 $m^3\ s^{-1}$.

As can be seen in Fig. 7**,** the addition of a one-day time lag contributes to reducing the dispersion within the full range of flows considered. Moreover it is likely that the modified method, based on time series of flows that correspond better to the actual volume of water entering the hydrographical network, tended to avoid outliers. This is visible for relatively high flows, which correlated poorly with observed water levels using the original method.

Changes in the daily flow regime at the ORM

Simulated daily FDC at the estuary, detailed in Table 2 and Fig. 4, allow the comparison of period 1 (1935-1960) and period 2 (1980-2005):

(a) The frequency of drying out of the Orange River at the estuary for one day was 5% in the 1935-1960 period and 0.1% in the 1980-2005 period,

(b) Medium flows were substantially reduced: the value of the flow exceeded 70% of time was 32.3 $m^3\ s^{-1}$ in period 1 and 18.6 $m^3\ s^{-1}$ in period 2. On the other hand, the value of the flow exceeded 20% of time decreased from 501 $m^3\ s^{-1}$ in period 1 to 121 $m^3\ s^{-1}$ in period 2,

(c) Concerning high flows, the value of the flow exceeded 10% of the time decreased from 824 to 329 $m^3\ s^{-1}$, i.e. the intensity of floods was more than halved during the current period.

ASSESSMENT OF POTENTIAL FLOODING OF THE ORANGE RIVER MOUTH WETLANDS

Presentation of the hydraulic modelling approach

First, equation (1) relating daily water levels to flows at the Oppenheimer bridge was used to extend the time series of water levels over periods 1 and 2.

Given the poor quality of topographic data available in the area of the ORM, a basic hydraulic simulation was carried out to assess potential flooding of the saltmarsh. A fictitious canal was used to model the conveyance of water from the Oppenheimer bridge to the saltmarsh, which is the most degraded part of the ORMW. The water level in the canal, determined by the water level at the bridge, was calculated at a daily time step assuming a uniform and permanent flow in the canal. If the water level at the bridge reached a certain threshold (fixed by the authors based on field observations), a flow entered the canal and its discharge Q was calculated using the Manning-Strickler formula (Chow, 1959):

$$Q = KSR^{2/3}i^{1/2} \tag{2}$$

where K is the roughness coefficient ($m^{1/3}$ s^{-1}), S the flow cross-section (m^2), R the hydraulic radius (m), i the slope of the canal (m/m). These parameters were roughly estimated by the authors from field observations and GPS measurements (altitudes, distances and surfaces).

The saltmarsh was modeled as a reservoir. When water flowed into the canal, the discharge was spread over the surface of the wetlands and a daily evaporation rate, computed from monthly values taken from Schulze *et al.* (1997), was applied. Infiltration had very limited influence during flooding events and was thus ignored. The water level in the saltmarsh $H(N)$ was then calculated with the following formula:

$$H(N) = \left(\frac{Q(N) \times 86400}{S} \right) - E + H(N-1) \quad (3)$$

where $H(N)$ is the water level in the saltmarsh at day N (m), $Q(N)$ is the discharge in the canal at day N ($m^3\ s^{-1}$), S is the area of the saltmarsh (m^2) and E the daily potential evaporation (m).

This approach modelled the flooding of the saltmarsh but did not take into account the influence of local developments (e.g. the causeway crossing the saltmarsh), thus allowing only the impacts of the change in the flow regime of the basin to be estimated.

Results

This model allowed us to calculate a time series of potential water levels in the saltmarsh for the two periods. Then potential flooding events leading to at least 5 cm of water in the saltmarsh (the threshold was arbitrarily fixed) were selected, as it was assumed that only such events could significantly flood the marsh. This allowed us to define an average flood hydrograph at the bridge, under which the saltmarsh would be flooded. This hydrograph corresponded to a mean daily flow of 1 270 $m^3\ s^{-1}$ over a period of seven days.

In order to assess the frequency of occurrence of such a hydrograph, we generated a time series of daily flows calculated over a 7-day average period at the bridge. In this time series, the flow value at day N was the mean of the daily flows over the 7-day period *centered* on day N. The corresponding flows were named $\tilde{Q}_7$. The annual maximum values of the flows $\tilde{Q}_7$ were selected for each year of the time series and compared to the value of 1 270 $m^3\ s^{-1}$. The annual maximum value of $\tilde{Q}_7$ exceeded 1 270 $m^3\ s^{-1}$ 19 years out of the 24 years of period 1, and only 7 years out of 25 for period 2 (the year 1939 in period 1 could not be included in the calculation because of major gaps in the time series of measured flows at Vioolsdrift). This implies that potential flooding events were approximately between twice and three times more frequent under the previous “more natural” conditions of period 1. It is likely that this decrease substantially contributed to the degradation of the ORMW. Nevertheless, these results must be considered with caution given the basic hydraulics model applied. No calibration of the model was possible due to the absence of water level values recorded in the saltmarsh.

According to Bornman (personal communication, 2006), a frequency of flooding of once every 3 years could support partial rehabilitation of the saltmarsh, provided that water could circulate freely within it, i.e. the causeway is removed. This is in the same magnitude than the calculated present potential frequency of the saltmarsh flooding (7 years out of 25) and therefore the current hydrological regime should be able to rehabilitate and maintain the ecological state of some parts of the wetland, provided the causeway is removed. And in fact, removal is currently (2007) underway, thanks to a project of the “Working for Wetlands” organization.

DISCUSSION AND CONCLUSION

In many parts of the world, integrated water resources management is often limited by the inadequacy of the design of hydrological monitoring networks, or by gaps in data series, or by the poor quality of the time series (gaps, inaccuracy). In the face of such problems, the purpose of this study was to propose improvements of a spatial interpolation approach to simulate the daily hydrological regime at the ungauged site of the ORM. Observed flow time series from neighbouring gauged sites of the same hydrological network were summed rather than averaged in the simulation algorithm and a time lag was added between the gauged sites and the ORM. These improvements significantly enhanced the quality of the model compared to the original approach. Then, using a simple hydraulic model, we simulated the occurrence of flooding events in the wetlands area of the ORM under present and previous conditions corresponding to a more natural state of the Orange River basin.

However, the calculation of the time series of daily flows at the estuary could only be validated with a rather short time series of observed water levels. Extreme events (low and high flows) could not be taken into consideration due to the poor quality of observed data (flow and water levels). As far the hydraulic modelling is concerned, no observed water levels were available in the wetlands area and it was thus not possible to validate the results of the flooding simulation. This study thus identified additional measurements and monitoring needed to produce the refined environmental knowledge required for the sustainable management of the ORMW. In a similar way, assessing floods for rehabilitation of the wetlands in the Mauritanian parts of the delta of the Senegal River, Duvail & Hamerlynck (2003) showed that the use of a hydrodynamic model with detailed hydraulics data and measurements, in particular cross sections of the channels, enabled precise simulation of the spatial distribution of the level and duration of floods in selected flood plains of ecological interest. Despite these limitations, the hydrological tool described in this paper was able to deal with very limited hydrological information and produced initial results that are usable for integrated water resources management.

Modelling showed that the frequency of flooding of the ORMW was dramatically reduced compared to the situation prior to the construction of the major dams on the Orange River. These results are in accordance with the general findings of the World Commission on Dams, which highlighted that flooding of wetlands downstream of dams diminished or disappeared as a result of damming, and thus led to significant degradation (Bergkamp *et al*., 2000). Among different possible solutions to mitigate this degradation, managed flood releases proved to be efficient in maintaining the ecosystems functions in several specific areas (Acreman, 2003). In the case of the ORM, the nearest major impoundment (the Van der Kloof Dam) is located 1 400 km upstream of the ORMW, which implies that, apart from any economic considerations, hypothetical flood releases would not reach the mouth at sufficient intensity to flood the wetlands (i.e. flood hydrographs will be “laminated” during their transit from the dam to the mouth). However, the construction of a smaller dam at Vioolsdrift is currently under consideration and this could enable such management alternatives. With this option in view, assessment and management of environmental flows should be performed within the framework of a broader river basin plan that integrates the different water uses at catchment and sub-catchment scales (Dyson *et al.*, 2003 ; Hamerlynck & Duvail, 2003).

Further, the generic methodological developments of this study could be used to calculate environmental flow requirements in different contexts. Indeed, four main types of methods are currently used to estimate flow requirements for the environment, ranging from the simple calculation of a fraction of the MAR to more complex habitat modelling (Dyson *et al.*, 2003). Most of the time they aim to link hydrological and ecological characteristics and can thus be strongly limited by a lack of detailed hydrological data at a particular site of major environmental interest. The method proposed here is an appropriate and easy way to tackle this issue.

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Tables

Table 1 : Selected hydrological stations in the vicinity of the Orange River Mouth (Source: computed from Department of Water Affairs and Forestry - DWAF- South Africa and Department of Water Affairs - DWA- Namibia).

Station	River- Location	Data type	Record start-end	MAR (hm^3 $year^{-1}$)
D8H003	Orange River at Vioolsdrift	Mean daily flow	October 1935-present	8376
0499M02	Fish River at Ai-Ais	Mean daily flow	October 1975-present	221
D8H012	Orange River at Alexander Bay-Oppenheimer bridge	Mean daily water level	October 1993-July 2005	-

Table 2: Simulated daily FDC at the ORM for the two periods.

% time exceeded	0.10%	1%	5%	10%	15%	20%	30%	40%	50%
***Q* (m^3 s^{-1}) 1935-1960**	6790	3450	1500	824	637	501	285	184	110
***Q* (m^3 s^{-1}) 1980-2005**	6470	2910	710	329	187	121	66.4	48.2	39.5

% time exceeded	60%	70%	80%	85%	90%	95%	99%	99.90%
***Q* (m^3 s^{-1}) 1935-1960**	68.3	32.3	11.7	8.10	2.57	0.00	0.00	0.00
***Q* (m^3 s^{-1}) 1980-2005**	23.6	18.6	17.6	15.4	14.4	9.95	6.11	0.00

Figure captions

Fig. 1: Location of the Orange River Mouth in the Orange River basin (modified from LORMS, 2005a).

Fig. 2: Aerial view of the ORM in 1998.

Fig. 3: Location of the selected hydrological stations in the vicinity of the ORM.

Fig. 4: Simulated daily FDC at the ORM for the two periods.

Fig. 5: The spatial interpolation algorithm (modified from Smakhtin *et al*., 2004).

Fig. 6: Time series of observed daily water levels and simulated daily flows at the ORM. Top: original spatial interpolation approach. Bottom: modified spatial interpolation approach.

Fig. 7: Observed daily water levels versus simulated daily flows at the ORM (with $H > 1.5$ m and $Q > 200$ m^3 s^{-1}). Left: original spatial interpolation approach. Right: modified spatial interpolation approach.

Figures

Fig. 1

Fig. 2

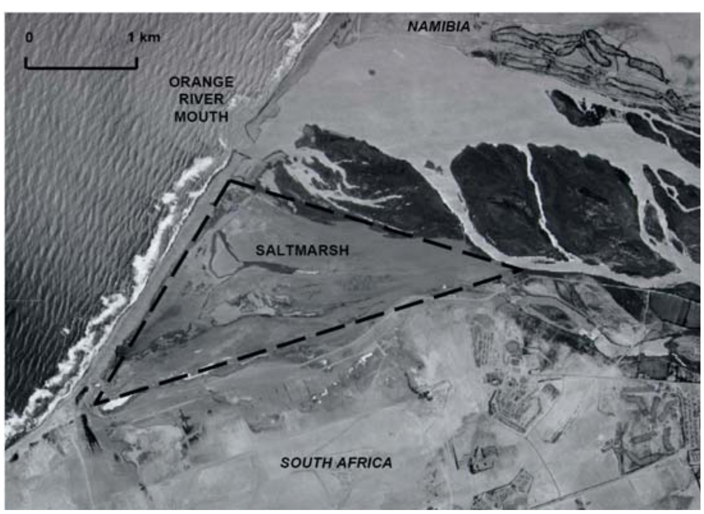


Fig. 3

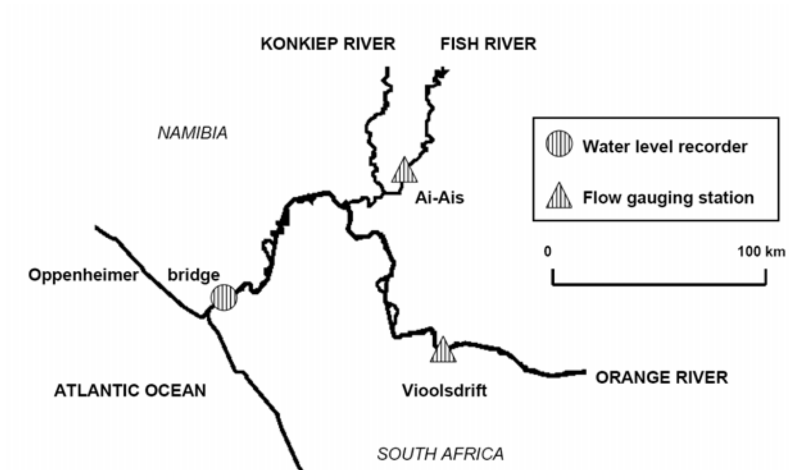


Fig. 4

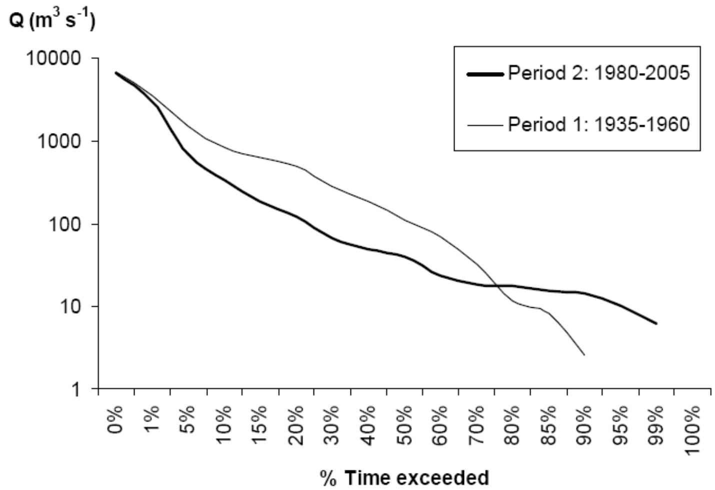


Fig. 5

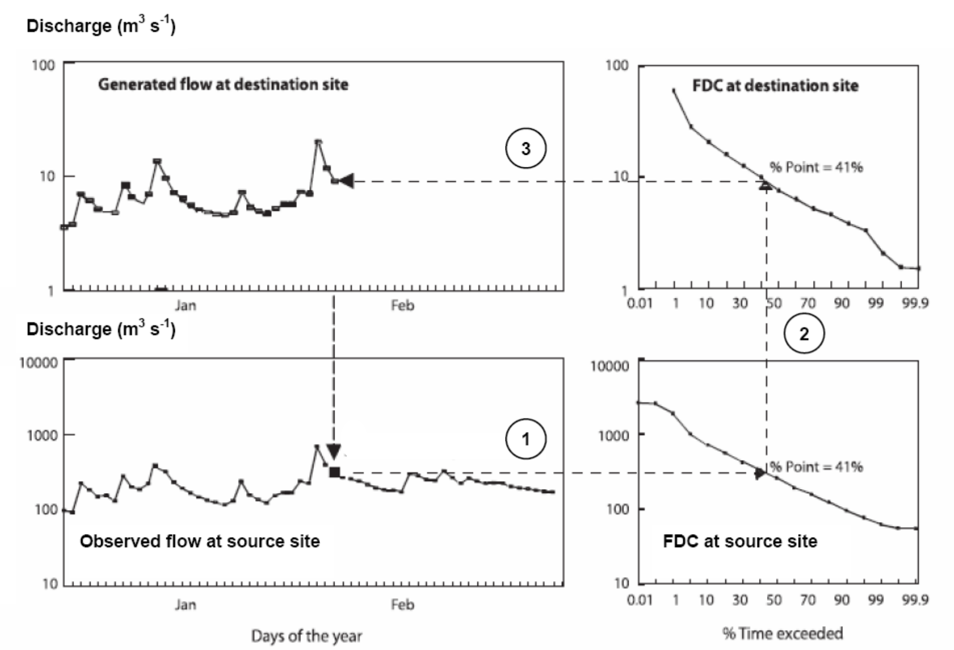
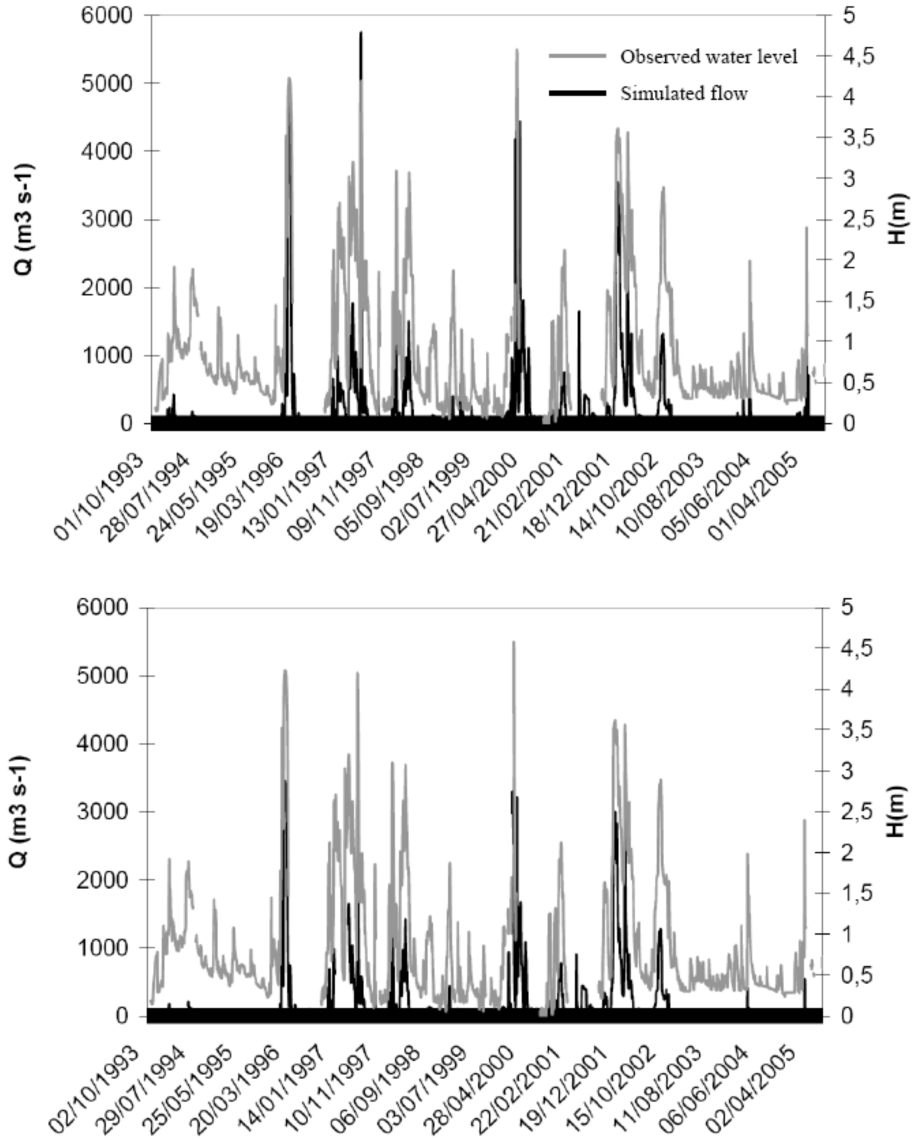
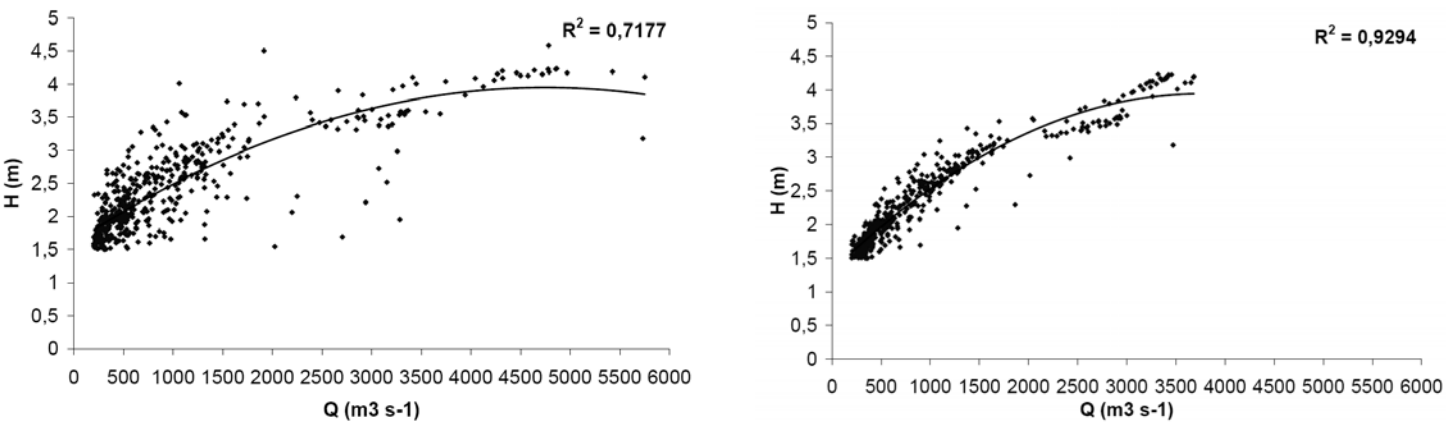


Fig. 6



Observed water level
Simulated flow
Q (m3 s-1)
H(m)
6000
5000
4000
3000
2000
1000
0
5
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
01/10/1993
28/07/1994
24/05/1995
19/03/1996
13/01/1997
09/11/1997
05/09/1998
02/07/1999
27/04/2000
21/02/2001
18/12/2001
14/10/2002
10/08/2003
05/06/2004
01/04/2005
02/10/1993
29/07/1994
25/05/1995
20/03/1996
14/01/1997
10/11/1997
06/09/1998
03/07/1999
28/04/2000
22/02/2001
19/12/2001
15/10/2002
11/08/2003
06/06/2004
02/04/2005

Fig. 7



R^2 = 0,7177
R^2 = 0,9294
H (m)
Q (m3 s-1)
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000