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Physics and Chemistry of the Earth 28 (2003) 779–786

PHYSICS and CHEMISTRY of the EARTH

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Testing water demand management scenarios in a water-stressed basin in South Africa: application of the WEAP model

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Abstract

Like many river basins in South Africa, water resources in the Olifants river basin are almost fully allocated. Respecting the so-called "reserve" (water flow reservation for basic human needs and the environment) imposed by the Water Law of 1998 adds a further dimension, if not difficulty, to water resources management in the basin, especially during the dry periods. Decision makers and local stakeholders (i.e. municipalities, water users' associations, interest groups), who will soon be called upon to work together in a decentralized manner within Catchment Management Agencies (CMAs) and Catchment Management Committees (CMCs), must therefore be able to get a rapid and simple understanding of the water balances at different levels in the basin. This paper seeks to assess the pros and cons of using the Water Evaluation and Planning (WEAP) model for this purpose via its application to the Steelpoort sub-basin of the Olifants river. This model allows the simulation and analysis of various water allocation scenarios and, above all, scenarios of users' behavior. Water demand management is one of the options discussed in more detail here. Simulations are proposed for diverse climatic situations from dry years to normal years and results are discussed. It is evident that the quality of data (in terms of availability and reliability) is very crucial and must be dealt with carefully and with good judgment. Secondly, credible hypotheses have to be made about water uses (losses, return flow) if the results are to be meaningfully used in support of decision-making. Within the limits of data availability, it appears that some water users are not able to meet all their requirements from the river, and that even the ecological reserve will not be fully met during certain years. But the adoption of water demand management procedures offers opportunities for remedying this situation during normal hydrological years. However, it appears that demand management alone will not suffice during dry years. Nevertheless, the ease of use of the model and its user-friendly interfaces make it particularly useful for discussions and dialogue on water resources management among stakeholders; it can also be used to promote greater awareness and understanding of key issues and concerns among the public.

Keywords: Water allocation; WEAP model; Water demand management; River basin management; Water resources management; Olifants river

1. Introduction

The progressive South African water law (RSA, 1998) is expected to bring about fundamental changes in the way in which water is used and shared among different users. A major aim is to ensure a better balance between efficiency, sustainability and equity needs in water allocations (Lévite and Sally, 2002). Water must be guaranteed for all, especially to meet the basic human needs of poor people in rural areas who have been disadvantaged for so long. Furthermore, water cannot be simply allocated to meet the increased demand from agriculture, industry and other productive sectors but must also satisfy the requirements of aquatic ecosystems and the ecological reserve. Finally, responsibility for decision-making in respect of water allocations will be decentralized to the level of the future Catchment Management Agencies (CMAs). A system of authorizations for water abstractions is foreseen, with compulsory licensing when the basin is water stressed.

Such is the case of the Olifants river basin, which flows from the highly populated and industrialized Gauteng Province of South Africa to Mozambique. Water resources have already been largely developed in the Olifants basin. Water demand management, especially in the agricultural sector, which is the biggest user, is one of the possible solutions being considered by the South African Department of Water Affairs and Forestry (DWAF). In order to quickly assess alternative water allocation scenarios at basin level, technicians and policy makers will need practical and user-friendly tools.

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1474-7065/$ - see front matter © 2003 Published by Elsevier Ltd.
doi:10.1016/j.pce.2003.08.025

This study sets out to test the usefulness of the Water Evaluation and Planning (WEAP) model in this regard, particularly in assessing scenarios of water demand management, through an application to the Steelpoort sub-basin of the Olifants River.

2. Generalities and presentation of the WEAP model

The WEAP model was developed by the Stockholm Environment Institute (SEI). It operates at a monthly step on the basic principle of water balance accounting. The user represents the system in terms of its various sources of supply (e.g. rivers, groundwater, and reservoirs), withdrawals, water demands, and ecosystem requirements.

WEAP applications generally involve the following steps (SEI, 2001):

- Problem definition including time frame, spatial boundary, system components and configuration;
- Establishing the 'current accounts', which provides a snapshot of actual water demand, resources and supplies for the system;
- Building scenarios based on different sets of future trends based on policies, technological development, and other factors that affect demand, supply and hydrology;
- Evaluating the scenarios with regard to criteria such as adequacy of water resources, costs, benefits, and environmental impacts.

The scenarios can address a broad range of 'what if' questions, such as: What if population growth and economic development patterns change? What if ecosystem requirements are tightened? What if irrigation techniques and crop patterns are altered? What if various demand management strategies are implemented?

An intuitive graphical interface provides a simple yet powerful means for constructing, viewing and modifying the system and its data. The main functions—loading data, calculating and reviewing results—are handled through an interactive screen structure. WEAP also has the flexibility to accommodate the evolving needs of the user: e.g. availability of better information, changes in policy, planning requirements or local constraints and conditions.

The present application of the WEAP model forms part of ongoing research at the International Water Management Institute (IWMI) to develop, test and promote management practices and decision-support tools for effective management of water and land resources. WEAP has been described as being "comprehensive, straightforward and easy-to-use, and attempts to assist rather than substitute for the skilled planner" (University of Kassel, 2002).

3. The Steelpoort sub-basin

The Steelpoort River is an important tributary of the Olifants River, contributing useful inflows of fresh water during critical periods; the Olifants itself is one of the reference (or benchmark) basins where the IWMI focuses much of its research effort in South Africa. The Steelpoort was chosen to pilot-test this application of WEAP also because: (a) IWMI has already worked there extensively (Stimie et al., 2001; Thompson et al., 2001) and (b) it is a relatively simple basin with no large dam and no inter-basin transfers. Fig. 1 shows the location of the Steelpoort sub-basin in relation to the Olifants river basin and major cities in South Africa.

The Steelpoort sub-basin has a total area of 7130 km^2 with a rather elongated shape. Its altitude is between 1500 and 2400 m above sea level in a mountainous landscape. The vegetation can be divided into two categories: grassland, covering the southern half of the area, and savanna, extending northwards from the town of Lydenburg (Stimie et al., 2001). The basin is densely populated (117 inhabitants/km^2) with a few small towns and a very crowded rural population in the former homeland of Lebowa. The GDP per capita was US$ 130 in 2000, which is less than one sixth of the national average. There is a high incidence of unemployment with the main job opportunities in the mining, agriculture, forestry and tourism sectors.

Fig. 2 shows the main rivers and the quaternary basins, which are the basic hydrological units considered in this study. The prospect of major platinum mines being developed in the basin has led DWAF to recently conduct specific hydrological studies in this regard. A major feature of this basin is that its Mean Annual Rainfall (MAR) is relatively high (397 million m^3/year) compared with the other sub-catchment of Olifants river basin but is also very variable, ranging from 147 to 769 million m^3/year (Bruinette, Kruger and Stoffberg, BKS, 2000). The available water resources for the basin are around

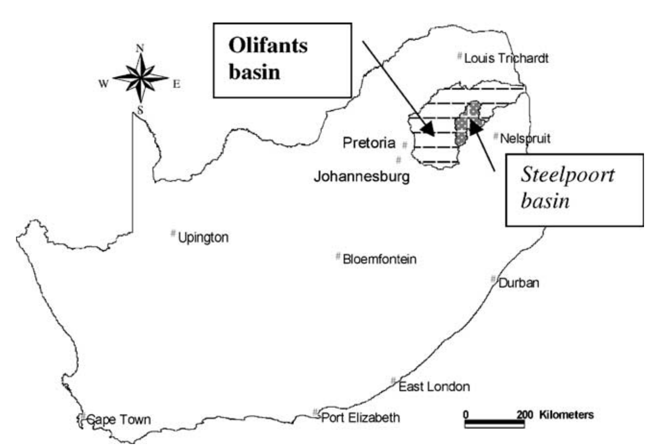


Fig. 1. Location of the study area in South Africa.

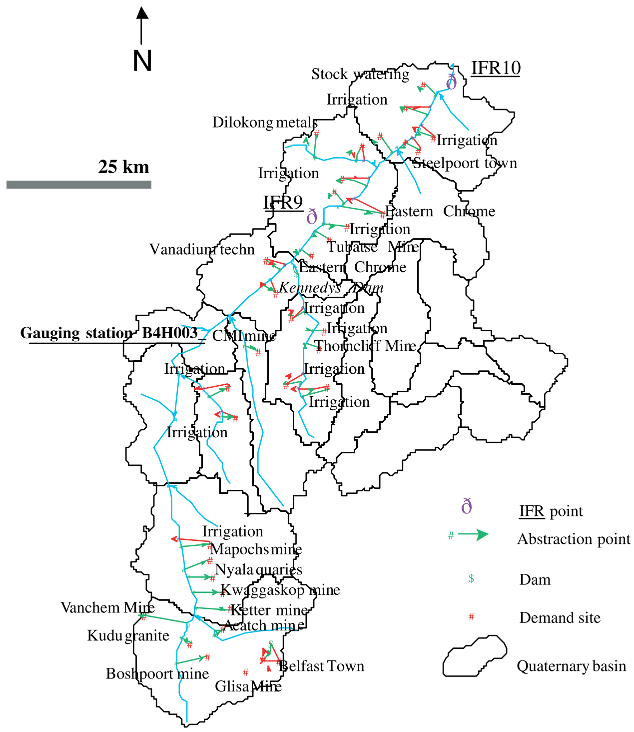


Fig. 2. Schematic representation of the Steelpoort basin for WEAP analysis showing quaternary basin sub-divisions and main abstractions.

56 millions m^3 (DWAF, 2002a) with a 15% contribution from groundwater and 85% from surface water.

4. Setting up the WEAP application for Steelpoort

As mentioned earlier, data collection is a critical step in setting up WEAP. The characterization of the water system involved collecting and entering in WEAP the following data:

- water uses (demand sites),
- reservoirs: location, capacity and operation rules,
- flow gauging station (flow requirement and ecological reserve),
- river headflows.

4.1. Demand

The description of the demand proved to be very tricky. Even with the existence of reports from DWAF and BKS, field visits were necessary for ground-truthing purposes. The 1998 water law has brought about a complete shift in water authorization. Before the introduction of this law, water users had a relatively large degree of freedom in respect of utilization of water. Now, they are expected to register but they do not always know how much water they really abstract and use. On the other hand, many users do not declare the real figures as they have their own strategies to obtain rights to water or are reluctant to pay the fees.

Only the major water users were described (33 in total: 14 irrigation schemes, 2 towns, 16 mines and 1 stock watering). The demand coming from minor users was neglected due to inadequate information (the process of registration of users is still underway). It is believed that when lumped together, their total demand could amount to a significant quantity. However, as will be shown later, neglecting this demand is a conservative assumption because any difficulty in satisfying the major water users will only be exacerbated by the addition of the minor users, driving home the need for even greater efforts on the demand management side.

For each major user, the activity level, the annual water demand (net values after accounting for losses), the monthly variation as well as a return flow (generally 20% for irrigation schemes in accordance with DWAF-BKS observations in South Africa) were introduced (see Fig. 3). For several mines, the water consumption values were not available, so this information was estimated in the course of field visits. The evolution of the demand is based on studies carried out by DWAF and BKS (BKS, 2000). Growth rates between 1995 and 2010 are as follows: domestic 10%, livestock 25%, irrigation 7% and mining 10%.

4.2. Hydrology

In WEAP, rivers are considered to be made up of nodes connected by river reaches, that have to be drawn. A river node has been introduced at the mouth of each quaternary basin as well as when a new tributary meets the Steelpoort river. Naturalized monthly flows at each node were provided in an electronic format directly utilizable in WEAP by BKS/Consultburo (1999), based on a study carried out of the hydrology of the Steelpoort river basin. With 10 gauging stations including 2 on the Steelpoort River, the hydrology is well described. One must note that the adjoining Spekboom sub-basin has been taken into account in WEAP as a flow entering directly into the system.

The role of groundwater was neglected since there was little knowledge concerning this. Fig. 4 shows an example of the flows in the Steelpoort river (average, minimum, and maximum monthly flows).

In WEAP, it is possible to quickly create different climatic situations ranging from very wet to very dry. Based on the analysis of 76 years of observation (1920–1995), the flow during the year 1994 was found to be the closest to the mean annual flow in the middle of the basin, and was thus chosen as the year of reference.

4.3. Ecological reserve

The National Water Act of South Africa accords an absolute priority to meeting basic human needs and the

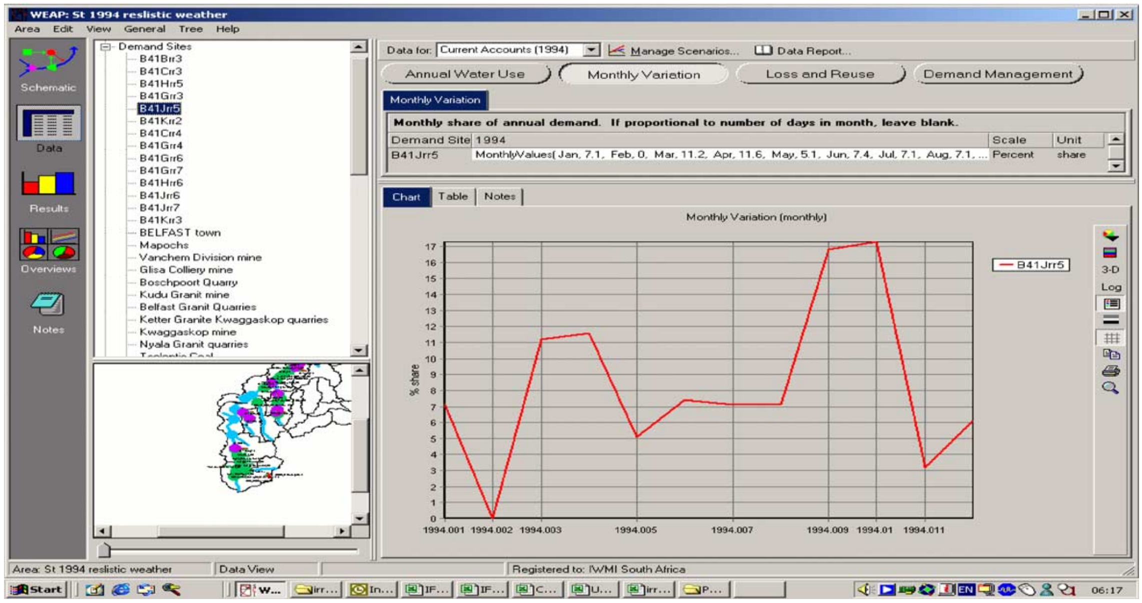
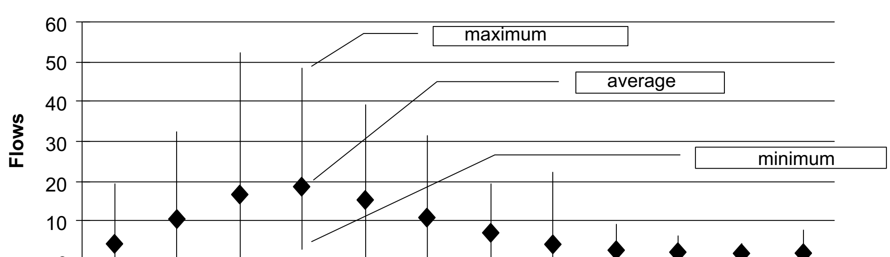


Fig. 3. WEAP model interface: a water user description.



	Oct	Nov	Dec	Jan	feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Max	19.53	32.44	52.13	48.57	39.06	31.65	19.38	22.05	9.09	6.12	4.42	7.57
Min	0.04	0.2	0.27	2.8	0.98	0.39	0.13	0.16	0.14	0.12	0.18	0.09
◆Average	4.030625	10.560313	16.969688	18.752813	15.309375	10.895313	7.00125	4.1153125	2.724375	2.3578125	1.59625	1.744375

Month

Fig. 4. Monthly variation of flow in Steelpoort (station B4H003, average 1963–1988) in million m^3.

ecological reserve. Figures on this have recently been released following special studies carried out for determining the Reserve (DWAF, 2002b). Points of control referred to as In-stream Flow Requirement (IFR) points are established and in this present study, we focus on IFR control point 9, situated on the Steelpoort River (upstream of Steelpoort town).

The IFRs have been defined for dry years (drought flow) and for normal or wet years (maintenance flow). It is important to note that there are two components in the reserve: low flow and floods/freshets. Floods and the small summer flow events known as freshets are essential to the ecological functioning of the river for a variety of reasons (Jewitt et al., 1997). Consequently they have been considered in the determination of IFRs. For the IFR 9, in normal years, the total is about 37 million m^3, that is, 21.5% of the Mean Annual Runoff (MAR) (Table 1).

In the WEAP model, any specific constraint can be introduced in the flow requirement component as shown in the printout of the corresponding interface screen in Fig. 5.

4.4. Water demand management options

Water demand management options can be included in WEAP either at specific sites (for example, by studying the possibilities for saving water by individual users) or globally. This study chose to consider the effect of the overall efforts of all users. Three options (at 10%, 20%, and 30%) were considered as reasonable after consultation with knowledgeable local professionals

Table 1
Instream flow requirements at control point 9 in normal years (in million cubic meters)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Vol	%MAR
Low flow	1.23	2.18	2.57	3.35	3.12	2.73	2.67	1.80	1.37	1.26	1.15	1.11	24.54	14.3
Floods/freshets	0.55	0.50	1.41	5.19	2.13	2.17	0.48	0	0	0	0	0	12.43	7.2
Sum	1.78	2.68	3.98	8.54	5.25	4.90	3.15	1.80	1.37	1.26	1.15	1.11	36.97	21.5

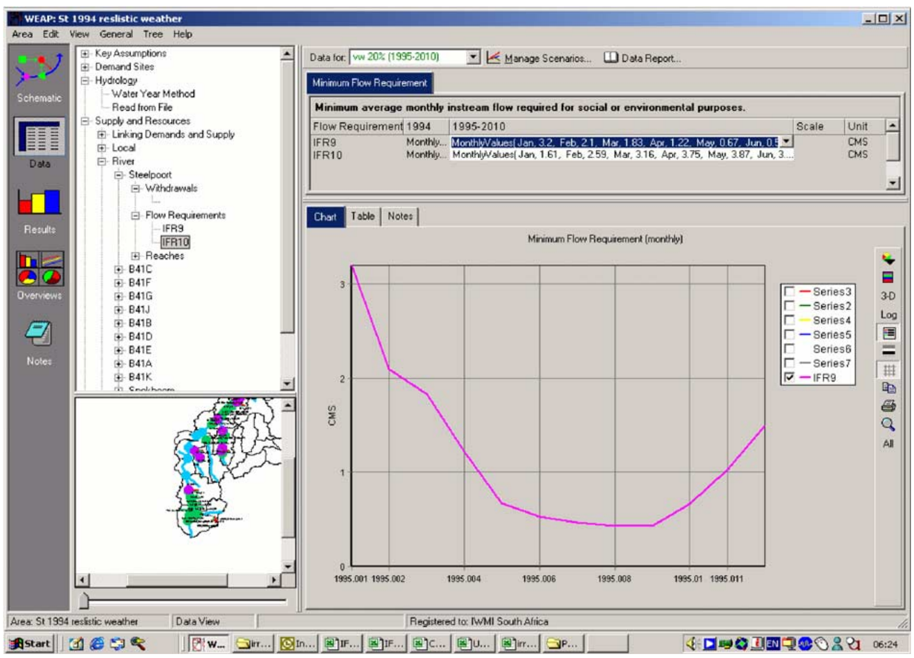


Fig. 5. Description of an IFR during normal years.

(Crosby, 2002). The efficiency of water use by agriculture in South Africa is estimated by FAO to be 21% (FAO, 2002). Even it is a global figure it suggests room for improvement.

These 'targets' could be achieved through a variety of means such as: licensing, pricing, collective awareness, fines and surcharges during crisis periods. In the National Water Resources Strategy (DWAF, 2002a), water demand management is recognized as a major undertaking (DWAF, 2000; Rothert, 2000).

5. Results and discussion

5.1. First simulations

Water users experience periods of unmet demand—Even during normal years, it appears that some users (15 out of 33) already experience unmet demands as shown in Fig. 6. Unmet demand is defined as the quantity of water that cannot be physically delivered from the river during a part of the year. This situation is likely to deteriorate in the future due to the progression of water demand if no measures are taken to address them.

This result merits careful analysis as it contradicts earlier work on the Olifants river basin (BKS, 2000). But in more recent studies (DWAF, 2002a), DWAF does consider a negative balance for the Steelpoort basin, suggesting the possibility of problems in the future.

It has been observed that many users have devised their own strategies to cope with shortages: e.g. using boreholes or developing their own storage systems. These "shortages" sometimes represent half of the demand in some cases (e.g. Eastern Chrome Mine Lannex). But, in general, they are of limited magnitudes (e.g. 20% in the case of irrigation schemes). It is therefore necessary to carefully verify these results through further field surveys in order to ascertain the possible effects of data uncertainties and the extent to which water-users adopt alternative coping strategies.

In some years the reserve will be difficult to achieve during certain periods—For the IFR point 9, which is in the middle of the basin, the simulation with WEAP suggests that the requirements for the months of

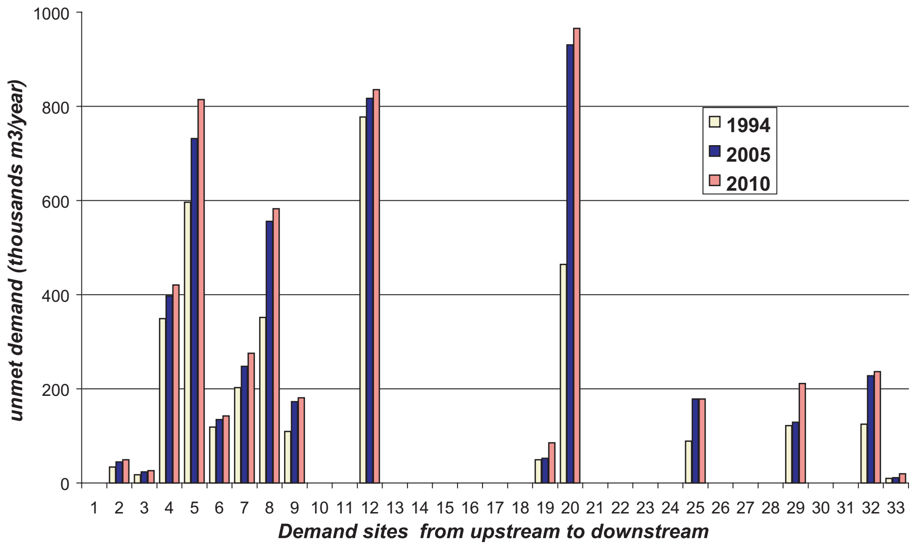


Fig. 6. WEAP simulation results: annual unmet demand (in thousands m^3) during normal years.

December and January will be difficult to be met in years that have hydrographs similar to that of 1994 where precipitation occurs late in the season and the peak flows appear in March or April with flows still quite low in December and January. The ecological reserve will therefore not be met during these months unless water demand management is promoted even at a limited level (e.g. 10 %).

5.2. Water demand management scenarios

The simulation results shown in Fig. 7 demonstrate that with normal years and no water demand management efforts, the requirements of up to 15 users would not be met. Moreover, for certain users, even extreme water demand management efforts (30%) would not be enough. This is possibly a consequence of their position in the basin, and merits further investigation. On the other hand, at certain other locations, limited efforts appear to be sufficient to meet local requirements.

Demand management can help achieve reserve requirements—Fig. 8 shows that without water demand management efforts (grey pattern), some IFR 9 targets cannot be met, even during normal hydrological years. However, the WEAP simulations show that with just 10% water demand mnagement effort, the reserve targets could all be achieved (black pattern).

Demand management alone will not suffice during dry years—In the case of dry years, the simulation results (Fig. 9) show that 19 users would experience problems instead of the 15 during normal years. Even water demand reduction of 30% would resolve only a few cases. This suggests that demand management alone would not be enough and that, probably, other measures (such as compulsory licensing or further development of water resources) would also have to be envisaged.

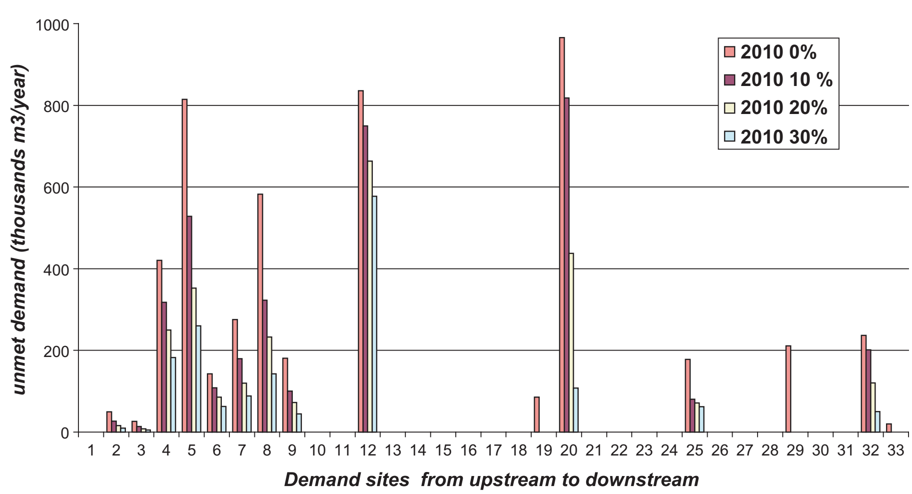


Fig. 7. Annual unmet demand (in thousands m^3) from WEAP simulations over 15 normal years with Water Demand Management (WDM).

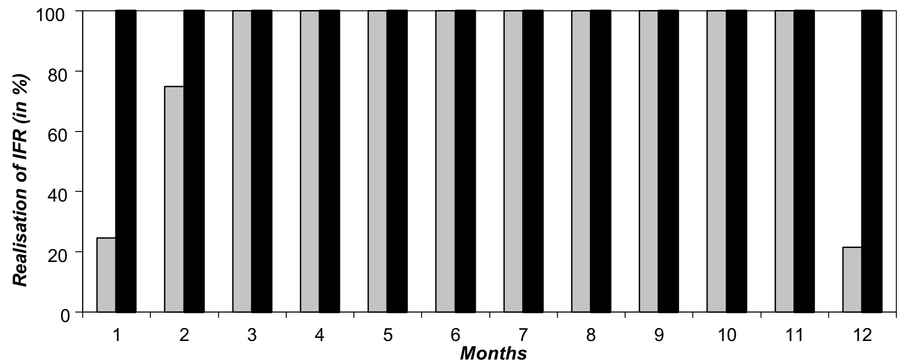


Fig. 8. Achieving the Reserve at IFR 9 in two cases, WEAP simulations over 15 normal years (defined as type 1994): without WDM (in grey); with 10% WDM (in black).

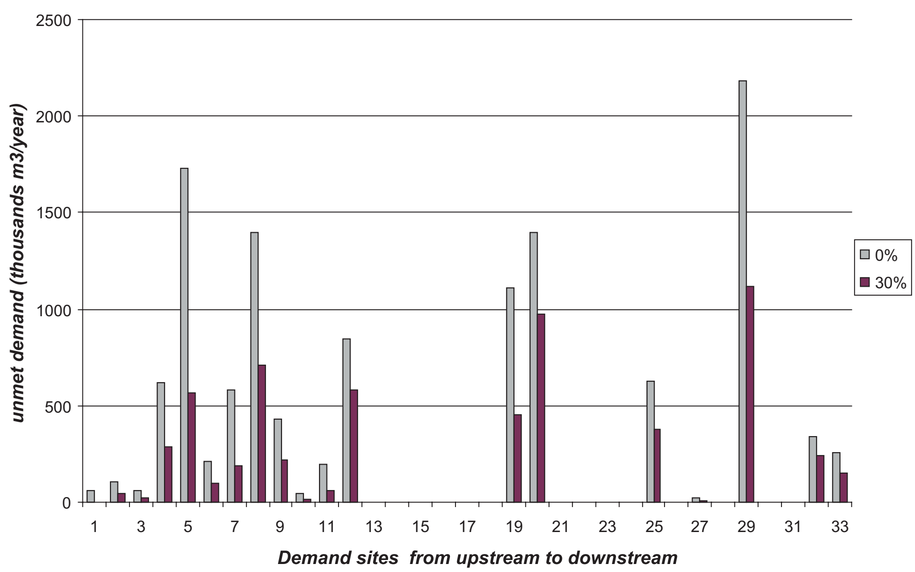


Fig. 9. Annual unmet demand (in thousands m^3) from WEAP simulations with dry years.

6. Conclusion

This study represents a first attempt at applying and testing the WEAP model as a means of addressing water allocation questions in a water-stressed river basin in South Africa. Additional water needs in such a basin can be met through creation of storage facilities, gains in water productivity, by reallocation, or by augmentation from an outside source. IWMI has begun using WEAP as a research tool to simulate and analyze water allocation scenarios in river basins, taking into account variations in abstractions, demands, and ecosystem requirements.

At this early stage we are not yet in a position to make firm recommendations with regard to the management of the Steelpoort river basin, which was used as our study example. A number of assumptions need to be verified and some of the data and hypotheses require refinement in consultation with the principal actors in the basin such as the Department of Water Affairs and Forestry. It is hoped that the collection and availability of data will also be improved with the establishment of the Catchment Management Agency (CMA) for the Olifants river basin in the near future.

For example, the assumption that groundwater does not play a major role (as a source of water for users and also as a source of water for the base flow in the river) could influence the results of the study. It was also observed that, in the absence of large storage dams in the basin, water users and water management were very dependent on river flows and levels. Water users appear to have developed their own strategies to confront such circumstances—farmers who dig pools in the river, mines that sink boreholes or develop their own storage facilities. Careful verification of declarations made by users in this regard is indicated. Incorporating groundwater use and carrying out simulations to assess the impact of the behavior of different users and uses should provide further insights and guidance regarding the management of water resources in the Steelpoort sub-basin.

This study so far has also brought to light some limitations of the model. In particular, the options of dry, normal and wet years available in WEAP, though very simple and easy to use, may not adequately capture the large variability of hydrologic phenomena in the South African context where extremes are very common, even when working with a monthly time-step.

Nevertheless, one clear lesson that has emerged is that the WEAP model is potentially a useful tool for a rapid assessment of water allocation decisions in a river basin, in particular to locate geographically where the problems are likely to occur. Its user-friendly interface gives it the added capability of facilitating dialogue among the various stakeholders with an interest in water allocation and management in the basin.

Follow-up action is being undertaken in all these respects. Further investigations and dialogues in the field with water users have been embarked upon. Data and results are being shared in order to stimulate debate and discussion with a view to refining this work and coming out with meaningful results that are useful for decision makers and all stakeholders alike.

Acknowledgements

The authors are thankful to the South African Department of Water Affairs and Forestry (DWAF) and Bruinette, Kruger and Stoffberg (BKS), one of the main consulting companies in South Africa for their assistance in data sharing. They also thank Annette Huber-Lee of the Stockholm Environment Institute (SEI) for her support in unraveling some of the mysteries of WEAP and the anonymous reviewers of an earlier version of this paper for their very helpful comments and suggestions.

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