Development of an urban water requirement and return flow model

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Abstract

The Crocodile (West) River catchment, measuring approximately 29 300km² in extent, is a densely populated, substantially urbanised and industrialised catchment. Water requirements in the catchment exceed the yield of local water resources, and therefore require transfers from adjacent catchments to augment the supply. This has resulted in the volume of return flows being much greater than could be expected had the supplies in the catchment relied solely on local water resources. Development in the Crocodile (West) River catchment forms the largest economic contribution to the GDP. It is therefore expected that development will keep this momentum of growth to stimulate the economy. Associated to this pattern, it is expected that return flows in the Crocodile (West) River catchment area will in future play an important role in the quantity, quality and availability of water resources.

The study developed a water requirement and return flow model at a comprehensive level of detail, linking water requirements with return flows. The model in turn, was used to develop future scenarios of return flows up to the 2020 planning horizon, in 5-year intervals, for the study area. The conceptual model developed here has also subsequently been used in the development of a Reconciliation Strategy of the Vaal River System and is currently used in the development of a similar strategy for the Kwazulu-Natal Coastal Metropolitan Areas. The conceptual model as well as the outcomes from the study is described in more detail.

Keywords: *Crocodile (West) River System, urban water requirement and return flow model, future scenarios.*

1 Introduction

The Crocodile (West) River catchment is a densely populated, substantially urbanised and industrialised catchment and also contains a large component of irrigation agricultural development (see Figure 1). Water requirements in the catchment exceed the yield of local water resources, and transfers are required from adjacent catchments to augment the supply. Before the development of a detail return flow model, it was estimated that return flows accounted for 30% of the catchment yield. Furthermore the growth in requirements and return flows was always based on trends which made scenario analysis impossible.

Development in the Crocodile (West) River catchment forms the largest economic contribution to GDP. It is expected that this momentum of growth will continue. Associated to this pattern, it is expected that return flows in the Crocodile (West) River catchment area will continue to grow and will in future play an increasingly important role in the quantity, quality and locality of water resources. Return flows have been increasing with the increase in water use until now, but the future trend is unknown as it depends on a number of factors, which include population growth, land use planning, water conservation and demand management, re-use incentives, industrial and mining development, changes in irrigation practices, etc.

In 2002 a detail Water Requirement and Return Flow study was initiated. This study was the first phase of a multi-phase updating of the Water Resources Yield and Planning Models being used to model the availability, use and yield balances in the catchment. The need to quantify water requirements and return flows was identified as a priority in the process of updating the models.

The main objective of the study was to develop a return flow model linking water requirements with return flows, to calibrate the model by using existing information and to develop future scenarios of return flows, up to the 2020 planning horizon in 5-

year intervals, for the study area. The study included the analysis of return flows from urban, mining, industrial and agricultural land use activities at a comprehensive level of detail.

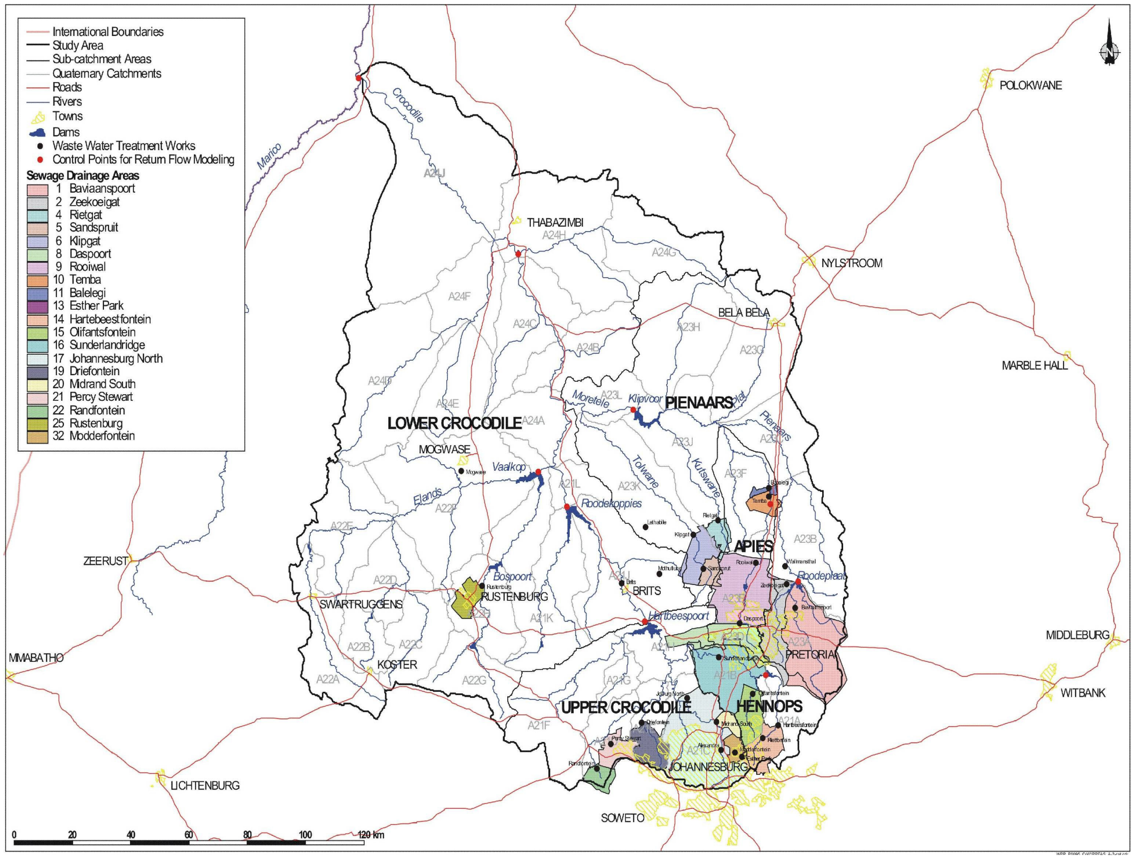

Figure 1. Location map with sewerage drainage areas

In order to achieve the study objectives the following methodology was followed:

- The current status of the return flows and water use in the catchment, as well as the land use characteristics that have an impact on the return flows under current and projected future conditions were established. Simultaneously a desktop investigation was conducted to assess the impacts of water conservation and demands management as well as tariffs on return flows;
- Return flow algorithms for the irrigation, mining and a combination of the urban and industrial sectors were developed. The status quo investigation however indicated that the mining sector does not contribute significantly to return flows due to a zero effluent discharge policy being practised by all mines in the study area;
- Once developed, these return flow algorithms were calibrated for the year 2001 using the existing historical information;
- The calibrated urban/industrial model was finally used to derive five return flow scenarios for planning purposes up to the 2020 planning horizon in 5-year intervals. These scenarios were developed to provide an indication of the impact of government policies with regard to poverty alleviation and service delivery as well as water conservation and demand management on water requirements and return flows. It is envisaged that the model and the scenarios will be of benefit to both Water Resource and Water Services related planning activities; and
- Since the general strategy in the catchment area is that irrigation development will remain at current levels, sensitivity analysis rather than deriving scenarios were undertaken with the irrigation model. These assessments investigated the potential impact that changes in irrigation applications systems and improved scheduling practices could have on the demands and return flows.

This paper describes in detail the conceptual Urban Water Requirement and Return Flow model as well as the outcomes from the study. More detail are available from the study reports (DWAF; 2004a to d).

2 Conceptual Urban Water Requirement and Return Flow Model

In the design of the conceptual Urban Water Requirement and Return Flow Model an attempt was made to achieve a balance between simplicity, availability of data and compatibility with models from previous studies. Figure 2 gives a schematic diagram of the conceptual Urban Water requirement and Return Flow Model. As indicated, Sewage Drainage Areas (DAs) are the main building block within which all the serviced land use activities are quantified. The land use is grouped firstly into two main categories, serviced housing related land use and other land uses that are serviced by water supply and or sanitation systems. The serviced housing land use is further split into seven Serviced Housing Categories. Land use other than housing, is defined in six categories namely, Business/Commercial, Industrial, Hospitals/Clinics, Parks, Education and Sport Stadiums.

Allowances are made for distribution losses in the supply network that occur between the bulk water supply meter and the user. Rainfall and groundwater infiltration into the sewer network are also taken into consideration. Losses during the treatment of the sewage are included as well as direct re-use usage, which could be for irrigation or other purposes. It is important to note that the urban return flow model was developed as a combined database/spreadsheet model.

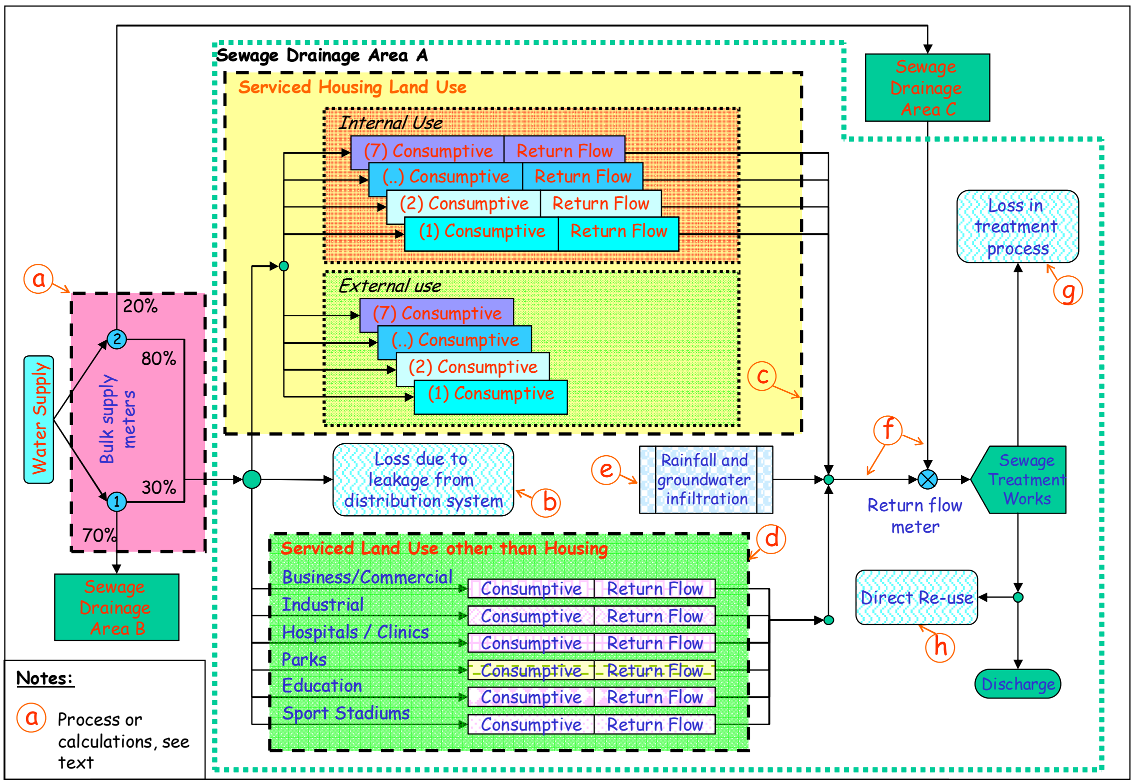

Figure 2. Conceptual Urban Water Requirement and Return Flow model

The following paragraphs describe in more detail each of the components of the conceptual model.

2.1 Split of water supply meter flows - (a) indicated on Figure 2

In cases where the water supply areas served by a bulk supply meter do not fall completely within a Sewage Drainage Area, an appropriate split was calculated to determine the total supply into each Sewer Drainage Basin. The split was calculated using land use data to establish an equivalent demand for the portions of each supply area that intersects with a Sewage Drainage Area. The ratio of the equivalent demands for all the intersecting areas served by a particular bulk meter was then used to split the recorded flow into each Sewage Drainage Area.

In the model the results of the split were used to calibrate the model. During the calibration it, however, became apparent that due to inter-linkage between the water supply systems, the results of the splitting of the water meter flows showed discrepancies in certain areas (the measured water flowing in the DAs did not tie up with the measured return flows flowing out). To overcome this problem some of the DAs were grouped together during the calibration process as follows:

- The southern part of Tshwane (Zeekoegat, Daspoort and Rooiwal DAs);
- The north western part of Tshwane (Rietgat, Sandspruit and Klipgat DAs);
- The north eastern part of Tshwane (Temba and Babalegi DAs); and
- The greater Midrand area including Centurion (Olifantsfontein, Sunderlandridge and Midrand DAs).

2.2 Loss due to leakage from the distribution system - (b) indicated on Figure 2

The loss due to leakages in the distribution system was calculated in accordance with method proposed in the WRC publication TT 109/99 (WRC; 1999), where the length of pipes and the number of connections are used to estimate the losses. Unit leakage values of 0.96 l/day/m (length of pipes) and 96 l/day/connection (connections) were used for all the DAs due to lack of information regarding leakage for most of the DAs. Although these unit values might be on the high side compared to the normal range of unit leakage values, when tested with available information it proved to be within an acceptable range as a lot of the distribution systems are already fairly old.

2.3 Serviced Housing - (c) indicated on Figure 2

The Serviced Housing Land Use was characterised into seven categories as presented in Table 1. This category definition originated from the National Water Resources Strategy (NWRS) Usage Database (DWAF; 2001), where population (current and future) was the main driver variable to determine the water requirements and return flows of the urban sector. In this study the same method was used, however, the urban areas in the Crocodile River (West) Catchment were defined at much higher resolution than was the case in the NWRS Usage Database.

a. Population database

The population database of the National Water Resources Strategy (DWAF; 2001) (at enumerated area level) was used as a basis for the population for the study. This database includes data for the 1995 base year and projections for 2005, 2015 and 2025. A separate spreadsheet was developed for the purposes of this study to determine the population of any other year between 1995 and 2025.

The base area of this population database, however, is Consumption Centers that does not correspond with the Sewage Drainage Areas used in this study. To overcome this problem the enumeration areas (EA) from the 1996 Census were attributed to Sewage Drainage Areas using GIS coverage. The population for each Sewage Drainage Area was determined using the 1996 Census EA population figures. These population figures were then normalized to correspond with the population database of the National Water Resources Strategy (DWAF; 2001).

b. Land use

The method that was used to determine the population residing in each category was done by quantifying the extent of the land use that falls into each of the seven housing categories. In each housing category area, the number of erven (households) was determined from information received from the different local authorities (DWAF; 2004b). The population in the model was calculated by assuming some unit values for the "persons per erven per category". Using this with the number of erven the population for each drainage area was calculated.

The population was checked against available data and adjustments were made to the “persons per household” factors until the population derived from the land use data was equal to the “known” population, (see the section above for a description of the population database).

Table 1. Housing category definitions and default per capita usage from National Water Resources Strategy

Serviced housing category	**Description**	**Default per capita usage ([1]) (l/c/d)**
Category 1	Fully serviced houses on large erven (erven > 500 m2)	320
Category 2	Fully serviced flats, townhouses or cluster homes	320
Category 3	Fully serviced houses on small erven (erven < 500 m2)	160
Category 4	Small houses, RDP type houses and shanties with water connection, but no or minimal sewage service	90
Category 5	Informal houses serviced only by communal taps and no water borne sewage	10
Category 6	No service from any water distribution system	6
Category 7	Other/Miscellaneous (Includes hostels, military camps, etc.)	90

Notes:

1. Defaults unit usage applied in the National Water Resources Strategy developed by the Department of Water Affairs and Forestry (DWAF: 2001). It is important to note that these unit consumption figures were changed in a calibration process for the different urban areas in the country.

c. Internal/external split

Serviced housing water use was split into internal and external use (internal and external refers to inside and outside of serviced housing respectively - an example of external use is water for gardening). For a schematic presentation of this split as well as the categories of internal use see Figure 3. The external use is assumed to be consumptive. The internal water use was further split into three categories:

- Plumbing leakage inside a housing unit;
- Consumptive use (which represents an extremely small percentage and is basically human consumptive use); and
- Return flows from internal use.

From Figure 3 it is also clear that any changes to the relationship between plumbing leakage inside a housing unit and the return flows from internal use will not have a significant influence on the total return flow from serviced housing land use due to the small nature of the consumptive internal use.

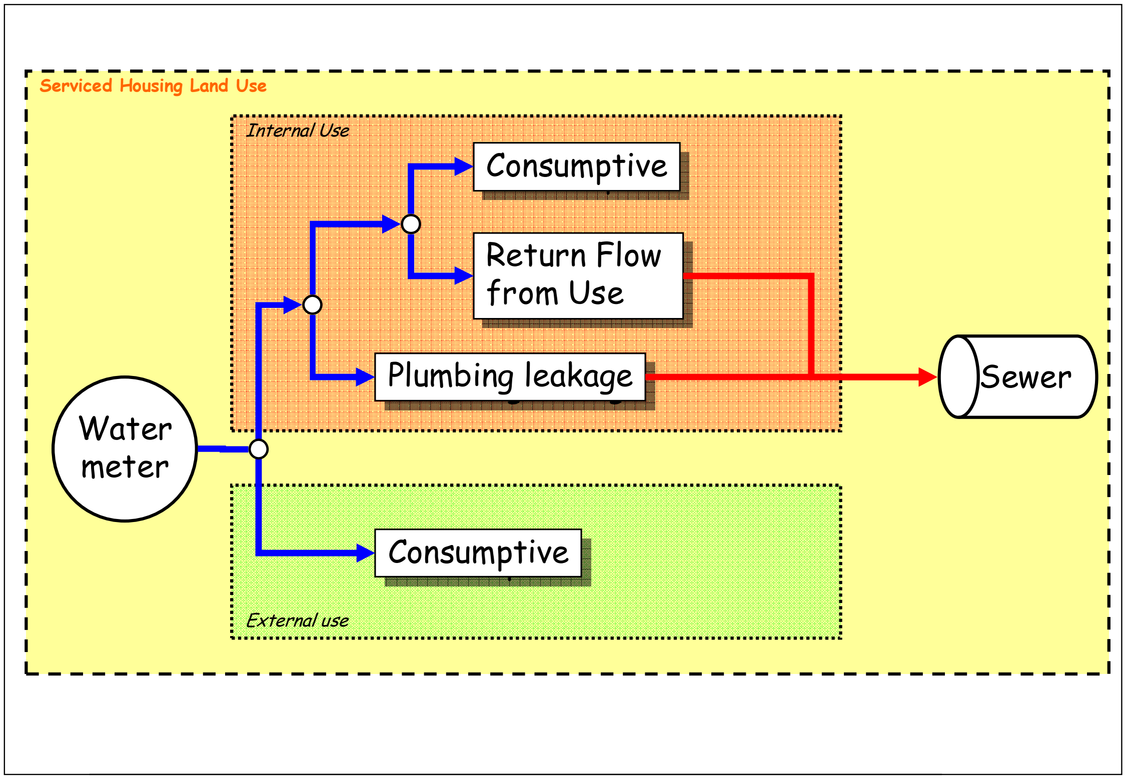

Figure 3. Conceptual model for serviced housing land use

2.4 Serviced Land Use other than for housing purposes – (d) indicated on Figure 2

Other urban land use that generates water demands and or return flows were identified as indicated in Figure 2. The water use and return flows for these areas were estimated through the land use cover multiplied by the unit usage and the unit return flow factors. The land use cover was determined from information received from the different local authorities. The unit usage for the different sectors is provided in Table 2.

Table 2. Non housing related unit usage in urban areas

Land Use Category	Default unit usage
Business / Commercial	4 l/m2/day
Industrial	4.8 l/m2/day
Hospitals	260 l/bed/day
Parks	2 l/m2/day
Educational	20 l/pupil/day
Sport Stadiums	21 l/seat/day

2.5 Rainfall and Groundwater Infiltration - (e) indicated on Figure 2

The infiltration of water into the sewer network could be quantified by using estimates obtained directly from Local Authorities or by applying infiltration parameters used for design purposes (l/day per length (km) of sewer pipeline). For the purposes of this study, actual values obtained from Tshwane (2000), which equated to 5.8 l/m/day, were used.

2.6 Contribution of different Sewage Drainage Areas - (f) indicated on Figure 2

It was required to allocate (split) the return flows generated in a single Sewage Drainage Area to different Sewage Treatment Works. In each of the cases that such a split was required, one of the Treatment Works had a fixed capacity. This fixed capacity was used to determine the ratio of the specific split.

2.7 Losses in Sewage Treatment Works - (g) indicated on Figure 2

The losses through the Sewage Treatment Works were based on a percentage of the inflow. These percentage loss data were however not available for all the Sewage Treatment Works. This necessitated the use of measured return flow values flowing into the Sewage Treatment Works and not the flows from the Sewage Treatment Works for the calibration. An average percentage of 4% were used for all the Sewage Treatment Works except for Baviaanspoort where it is known that the actual loss percentage is 8% (including some irrigation which normally is not part of the losses) and Percy Stewart where a loss of 100% was assumed due to seepage of the return flows into the dolomites resulting in no return flows into the river system .

2.8 Direct Usage - (h) indicated on Figure 2

In some Sewage Treatment Works direct usage for irrigation or other re-use takes place prior to discharging the water into the river system. This was quantified for each Sewage Treatment Works .

2.9 Total return flow discharged into river system

Finally, the single parameter that will be used the most in other water resources studies is the total return flow discharge from each Sewage Treatment Works into the river system. This is determined by using all the above-mentioned relationships.

3 Calibration

3.1 Calibration assumptions

The following calibration assumptions were used:

- The NWRS population database figures (with 1995 as base year) as well as the predicted population growth are correct;
- The water requirements of each Sewage Drainage Area are the same as the bulk measurements of water flow into each drainage area; and
- The return flows measurements (received from the different sewerage treatment work operators) at the entrance of each sewage treatment works are correct.

After an analysis of all the data collected, it was decided to use 2001 as basis for the calibration (DWAF: 2004c) for the following reasons:

- 2001 can be classified as an average hydrological year (not too wet or too dry);
- There were no water restrictions applied in the study area;
- Various developments have taken place since 1994 on the water resources as well as water services institutional and development scenes. The influence of these developments became identifiable by 2001; and
- Reliable Information was available for most of the important parameters in the majority of the Sewage Drainage Areas for 2001.

3.2 Modelling input

During the calibration process and through sensitivity analysis it was determined that the most important factors influencing the modelling results and therefore the calibration process are the population distribution, the unit water requirements, the split between internal and external housing use and the percentage return flow from other water requirements. These factors are discussed in more detail in the following paragraphs.

a. Population distribution

The population distribution was determined according to the water use categories defined in the National Water Resources Strategy (NWRS) (DWAF; 2001). It was done during the calibration process using the land use information (number of erven) and the total population figures per consumption centre from the NWRS determined for 2001.

A comparison between the population distribution determined during this study and that used in the NWRS showed some major discrepancies throughout the study area. Some of the discrepancies could be attributed to the scale of the areas for which the distributions were determined. In the NWRS the areas are much bigger than the drainage areas used in this study. The distribution in the NWRS would therefore be more of an average nature.

Another important issue is the fact that the categories are based on property size which in some cases does not provide a clear indication of the unit water use. A case in point would be in the northern areas of Tshwane and in particular, the Rietgat drainage area, where the majority of erven would be classified as Category 1 erven but the unit use for these erven is the same as Category 3 and 4 erven.

Finally, an assumption with regard to a shift in the population distribution in the Temba and Babalegi drainage areas had to be made during the calibration process, as it was impossible to calibrate the model with the information available. Available information showed the majority (more than 80%) of the population in these areas to be classified into Category 4, which by definition does not generate any return flows as there are no sewage connections for this category. To be able to calibrate the model it was assumed that in 2001, 50% of the population fell into Category 3 and 50% fell into Category 4. No other major discrepancies were experienced in the rest of the study area.

b. Water requirement

The water requirement was determined by calibrating the model's water requirement using the total inflows into the area. The different housing water requirements per capita used in the National Water Resources Strategy (DWAF; 2001) were used as starting point during the calibration process. It is important to note that in most cases the calibrated housing water requirements per capita are at least 30 % more than the values used in the National Water Resources Strategy as default values. There is no apparent explanation for this phenomenon.

c. Internal/external housing use

All the relations between the internal and external housing use per category for the different drainage areas are the same, except for the Temba, Babalegi, Johannesburg Northern and Rustenburg drainage areas, which required some changes to facilitate calibration. These relationships were determined from the calibration process accounting for the difference between inflows and outflows of each DA assuming that the calculated losses due to leakage from the distribution system and rainfall and groundwater infiltration into the sewer network to be correct.

d. Return flow from other water requirements

The percentage return flow from other water requirements is the same for all the different drainage areas except for the Hartebeestfontein drainage area, which required a change in the industrial percentage to facilitate calibration.

3.3 Calibration results

The calibration process was first carried out for the Sewage Drainage Areas that form part of the Apies and Pienaars River catchments as part of a pilot. The calibrated unit values were then successfully used with most of the other drainage areas. The following are the most important results from the calibration process:

- The calibration of the model could be achieved in most areas using similar inputs;
- The calibration results compare favourably with the available measured values for both the water requirements as well as the return flows for the majority of the DAs;
- On average, the percentage modelled return flow relative to the modelled requirement varied between 60% and 70% for the respective catchment areas. This ratio however varies to a much greater degree on a Sewage Drainage Area level (between 43% and 78%); and
- The results for the total catchment for 2001 was modelled as follows:
    - Water requirement - 495 million m^3/annum;
    - Return flow – 309 million m3/annum; and
    - Percentage return flow – 62.3% (compared to the generalised 70% previously used).

In addition, a total return flow into the river system of 359 million m3/a was estimated for the year 2001 from the calibration process from both the urban and irrigation sectors. The urban sector generates by far the larges portion of return flows (76%) compared to the irrigation sector (24%). The analysis further confirmed that the urban sector is mainly responsible for return flows in the upper part of the catchment whereas the irrigation sector is dominant in the main stem of the Crocodile (West) River downstream of Hartbeespoort Dam. Total water requirements for 2001 of 495 million m3/a and almost 600 million m3/a were estimated for the urban/industrial and irrigation sectors respectively. For the urban/industrial sector the total return flows into the river system represents 56% of the water requirement compared to 15% for the irrigation sector.

4 Scenarios

Five return flow projection scenarios were developed for the urban sector. These scenarios were developed to provide an indication of the impact of the government policies with regard to poverty alleviation and service delivery as well as water conservation and demand management on water requirements and return flows. The scenarios are as follows:

- Scenario A: Growth in population according to the National Water Resources Strategy with no other changes in water requirements or factors except for growth in water requirements of the other land use at the same rate as the population growth;
- Scenario B (Intermediate): The same as Scenario A except for increase in levels of service of Categories 4, 5 and 6 to at least Category 3 by 2020;
- Scenario C: The same as Scenario B except for the improvement of services in some previously disadvantaged areas mainly through infrastructure improvement that will have an influence on the unit water requirement;
- Scenario D: The same as Scenario B with water conservation and demand management measures being implemented through for example increased tariffs; and
- Scenario E: The same as Scenario B except for increase in levels of service of Categories 4, 5 and 6 to at least Category 3 already by 2010.

The return flow results for the different future scenarios for the total system (both urban/industrial as well as irrigation) are graphically presented in Figure 4. From the results it was proposed that Scenario B representing the improvement in service levels to at least fully serviced houses on small erven (Category 3) by 2020 be considered as the most likely (Intermediate) Scenario. It represents an increase of 51% in water requirements and 68 % in return flows released into the river system for the whole catchment area. The other scenarios would therefore represent either alternative High Scenarios (C and E) or alternative Low Scenarios (A and D).

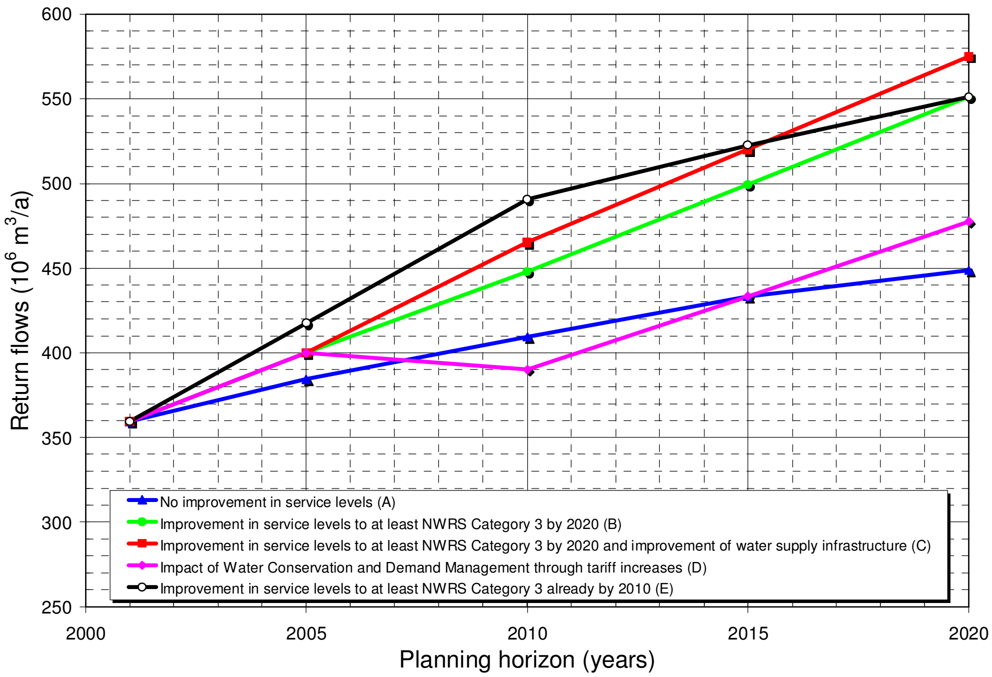

Figure 4. Scenario results: Total return flows into river system

5 Conclusions

The following main conclusions could be drawn from the results of the study:

- It was possible to develop an urban/industrial sector return flow model by linking water requirements with return flows in a combined modelling approach;
- The calibration results of the urban/industrial sector compare favourably with the available measured values for both the water requirements as well as the return flows for the 2001 base year used in the study;
- The availability as well as the format and spatial distribution of reliable water requirement and return flow data for certain areas proved to be a considerable problem. It was however possible to overcome this problem by comparing these areas with other areas for which information was available;
- The study results compare favourably over the long term with the presently used values of the Planning Analysis. In the short term however the difference between the two studies (this study and the Planning Analysis) borders on the significant (Planning Analysis is 16% lower). This difference should be considered when making decisions using the lower values;
- The urban sector is by far the dominant sector (76%) compared to the irrigation sector (24%) and analysis showed that the urban sector is mainly responsible for return flows in the upper part of the catchment whereas the irrigation sector is the dominant sector in the main stem of the Crocodile (West) River downstream of Hartbeespoort Dam; and
- The scenario results show that the effective implementation of water conservation and demand management would result in a significant decrease in the water requirements as well as the return flows. On the other hand, the policies of government for improved service delivery would result in a significant increase in the water requirements as well as the return flows.

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