Impact of rainwater harvesting on catchment hydrology: case study of the Modder River basin, South Africa

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Abstract

The river basin is increasingly acknowledged as the appropriate unit for the analysis and management of water resources, especially as water availability at the basin level becomes the primary constraint to agriculture. The Modder River basin is located within the Upper Orange Water Management Area in central South Africa. The irrigated agriculture in the basin draws water mainly by pumping out of river pools and weirs, whilst the rural small-scale farmers rely on rain-fed agriculture for crop production. In the past few years the Institute for Soil, Climate and Water of the Agricultural Research Council has been developing water harvesting techniques for small farmers in the basin with the objective of harnessing rainwater for crop production. This technique has resulted in a significant increase in crop yield compared to conventional practices and it is therefore expected that this practice will be adopted on a wider scale in the Modder River basin. The purpose of this project is to investigate and determine the impact of wider use of this practice on watershed hydrology and also the impact downstream of the river basin if the technique is applied on a wider scale.

Keywords: rainwater harvesting, watershed management, crop production, hydrological modelling.

1 Introduction

In a new paradigm shift related to integrated water resources management (IWRM) in the context of a river basin, attention is being drawn to consider the upstream “off-site” influences on the various water use entities, as well as the
downstream “off-site” impacts arising from them. Along the path of water flowing in a river basin there are many water-related human interventions, e.g. water storage, abstraction, regulation, distribution, application, pollution, purification and other associated acts to modify the natural systems. All of these have one common effect, and that is that they impact on those who live downstream [5]. This concept of river basin analysis of water would enhance the common understanding of the issues on overall productivity of water and related strategies.

With the recognition of significant reuse of water, the river basin is increasingly acknowledged as the appropriate unit for the analysis and management of water resources, especially as water availability at the basin level becomes the primary constraint to agriculture. Growing scarcity of good-quality water in most river basins results in intense inter-sectoral competition for water. The efficiency of water use can be seen in a more comprehensive manner if the allocation of water in a basin among various users is considered. Similarly, a more comprehensive analysis requires that the adverse effects of the rapid degradation of the environment and the ecological problems arising from severe competition for water to be studied, including the irrigation-induced environmental problems. It also tends to highlight the importance of equity and sustainability issues related to IWRM [1].

An integrated approach to water resources management in a river basin would enhance both productivity and sustainability of natural resource use. Sustainability means that the concerns about resources use should transcend short-term “on-site” gains, and should necessarily focus on an environmentally sensitive use of resources including many possible “off-site” implications. For instance, in many irrigation systems, the act of water use is limited to achieving system objectives, such as obtaining highest crop yields, and is rarely concerned with downstream drainage problems or pollution caused by fertilizer and other chemical inputs. The off-site influences on a water use system, as well as the off-site impacts arising from a water use system, can both be systematically studied to identify the factors that affect the performance of the water use system.

The project focuses on understanding the impact of infield rainwater harvesting (IRWH) on the general water balance of the Modder river basin. The Modder River basin is located within the Upper Orange Water Management Area to the west, north and east of the City of Bloemfontein (central South Africa). The irrigated agriculture in the basin draws water mainly by pumping out of river pools and weirs. The Krugersdrift Dam, which is located west of the City of Bloemfontein, acts as a buffer for stabilising the water supply to the lower reaches of the Modder River. However, many of the rural developing farmers rely on rain-fed agriculture for crop production. In the past few years the Institute for Soil, Climate and Water (ISCW) of the Agricultural Research Council (ARC) has been developing water harvesting techniques for small farmers in the basin with objective of harnessing rainwater for crop production [3]. They found that, with the use of the water harvesting technique developed at the centre on an area of 1m², the surface run-off was reduced to zero and that evaporation from the soil surface was reduced considerably, resulting in a
significant increase in crop yield compared to conventional practices. Moreover, this practice was also reported to reduce soil loss significantly, which otherwise would run into the river system. The researchers expect that many developing farmers in the river basin with limited access to irrigation water will be able to adapt this practice for crop production. The research question arising from this scenario is: what will be the consequences of wider use of this practice on the river water balance, and what will be the off-site impact of this practice on the downstream of the river basin if used on a wider scale?

2 Hydrological modelling

To arrive at an answer for the question as stipulated above, a hydrological simulation model needs to be employed. Hydrological modelling systems perform processes on sequences of time-dependent data. Such systems must also be flexible in terms of the temporal and spatial resolution of the processes being modelled. The most important key functional element of an installed modelling system is therefore a top class time series management system. The modelling system and the service utility shell, which serves as an interface between most of the beneficiaries of the system should be able to operate in an optimised client server environment in which both shared and local information and processing are possible. The system should be able to model both quantity and quality on the land and in the stream. It should be able to model both point and non-point sources of conservative and non-conservative pollutants. The system should be able to inter-operate with the functional modules of other systems where sensible in terms of the science involved. The networks of flows, abstractions, return flows, pumping and release regimes within a catchment are most often complex. Keeping track of all these, a functional, flexible and robust manner is an essential requirement of an installed modelling system framework. Installed systems should be capable of modelling the responses to conditional interventions by humankind. The service utility shell which serves it should, ideally have a graphical user interface (GUI), make use of geographical information systems (GIS), have links to hypertext help files, pictorial data bases and be able to produce appropriate reports. It should act as a client platform to shared software on a central server, which is accessible by all major stakeholders.

HSPF is a key component of a number of successful installed modelling systems in the world today and the rationale for deciding to use HSPF as hydrological model for this project is described as follows: The HSPF system was designed so that the various simulation and utility modules can be invoked conveniently, either individually or in tandem. HSPF follows a top down approach, emphasising structured design. The overall framework and the time series management system were designed first. Work progressed down the model structure from the highest, most general level to the lowest, most detailed one. Structured design has made the system relatively easy to extend, so that the user can add modules with relatively little disruption of the existing code. This functionality of the model was important for the researchers in order to keep up with the variety of factors to be considered when investigating the impact of
infield rainwater harvesting on the catchment hydrology. Therefore the first step to determine the consequence of infield rainwater harvesting on the water balance of the catchment will be to simulate the natural conditions of the catchment after which parameter estimation and calibration of the model will take place. The parameters will then be adjusted taking rainwater harvesting into consideration and the impact of the technique will be determined through simulation.

3 Study Area

3.1 Delineation of sub-catchments

The South African classification of drainage systems is such that primary river systems, which make up the primary catchments, are major rivers that open into the sea or cross the boundary. Secondary rivers, which define secondary catchments, are tributaries of primary rivers. Tertiary rivers are tributaries of secondary rivers, and have tertiary catchments. Quaternary rivers are the next tributaries that define the last drainage unit, i.e. quaternary catchments, referred to here as sub-catchments.

Four sub-catchments have been selected for this study, i.e. C52A, C52B, C52C and C52D. They are located in the Upper and Middle Modder River basin (Figure 2). The areas (in ha) of each of these sub-catchments are: C52A = 93671, C52B = 94935, C52C = 47129 and C52D = 60031, and with a total area of 295766 ha.

![Figure 1: Delineated sub-catchments in the Upper and the Middle Modder River basin.](image-url)
3.2 Land cover/land use

It is mainly grassland which covers approximately 80% of the total area, of which 10% is degraded grassland. About 70% of the area is covered by unimproved natural grassland. Cultivated land in the study area covers only about 10% of the total area, of which 9% is commercial dryland crop production and less than 1% under crops by subsistence farmers.

3.3 Climate

The average annual rainfall in the area is about 540 mm. The average rainfall distribution based on the means of the weather station records within this climatic zone is given in Figure 2. Much of the summer rainfall occurs as high intensity storms which promote runoff.

![Figure 2: Long-term average rainfall for the study area (Source: Land Type Survey Staff, 2000).](image)

4 Area suitable for infield rainwater harvesting

The recently completed land type survey of South Africa, at a scale of 1:250 000, was designed as a first step towards evaluating the natural agricultural resources of the country. A land type is defined as an area of land in which the macroclimate, terrain morphology and soil pattern are reasonably homogenous. The survey provides valuable information for the present study.

The land type covering most of the study area is called Dc17. Its total area is 239080 ha, which is about 80% of the study area. The land type is characterized by a specific climate, soil pattern and topography. The symbol Dc defines the soil pattern as being dominated by duplex soils with greater than 10% upland margalitic soils (i.e. high in clay of the smectite type). The number 17 merely
differentiates this particular land unit from all other Dc land units which occur in South Africa.

The land type inventory of Dc17 [4] provides the following information regarding the characteristic terrain/soil pattern: (Standard geomorphological symbols that are used to describe terrain units (TU’s), are 1 = crest; 2 = scarp; 3 = hillside; 4 = foot slope; 5 = valley bottom; Soil names are according to “Soil Classification: a Taxonomic System for South Africa” Soil Classification Working Group [6].

About 15% of the area on slopes greater than 5%, with shallow soils, are covered by rock, and are located on TU’s 1, 2 and 3; the remainder of the area is on TU’s 1, 3, 4 and 5, with slopes less than 4%, and on which the potentially arable soils occur, i.e. mainly of Swartland and Valsrivier forms (both duplex soils), with limited areas of soils of Bonheim and Arcadia forms (margalitic soils).

It will be possible to obtain a more accurate assessment of the area of land suitable for IRWH in the study area by conducting a detailed soil survey, preferably at a scale of 1:10,000. Although ortho-photo maps at this scale are available for the study area, such a survey would be costly and time consuming and therefore far beyond the scope of the present project. The assessment will therefore have to depend on estimates based on expert knowledge.

Dc17 was defined and characterized by soil scientists J.F. Eloff and A.T.P. Bennie in the early 1970s [4]. Eloff [2] estimated that 10% of the land type Dc17 was arable, and assessed the crop growing potential as being “low”. A very recent attempt has been made by Tekle et al. [7] to estimate the arable area suitable for IRWH in Dc17. They subdivided the land type into 67 smaller more homogenous units called soilscapes. Based on a considerable amount of field work and computer aided studies they then estimated the arable area suitable for IRWH of each of the soilscapes separately, concluding with 56875 ha or about 24% of the total area of Dc17. This is considered to be the most reliable estimate available at present. For this study it is intended to review the assessment made by Tekle et al [7] and also to expand the procedure to include that part of the catchment which is not part of Dc17.

5 Discussion and conclusion

Several problems were experienced in trying to simulate the natural conditions of the catchment. As standardized data sets (climatic and digital) for South Africa are not readily available, it was quite an effort to obtain the necessary data. Data received from governmental agencies had gaps and it took several months to obtain most of the data and fill the gaps. The digital data obtained was in the form of a set of contour maps of the study area. After conversion of these poly lines in ArcView 3.3, a 50m cell size DEM was created for the study area using the Quaternary drift Kiriging interpolation method. This DEM were then converted into an integer grid for use in BASINS 3.1. After rectifying the DEM grid with BASINS a digitized stream network was overlaid and automatic
watershed delineation was applied with the streams and the catchment boundary created. 

To be able to accomplish the above several software packages had to be obtained. A few months after receiving Environmental Systems Research Institute (ESRI®) software packages, such as ArcMap Desktop 8.3 (ArcInfo, ArcView 3.3), ESRI launched an upgraded version, ArcMap Desktop ArcInfo 9.0® which took another three months to obtain.

Currently compatibility problems are experienced between Windows XP and ArcView 3.3. This has to be sorted out in order to add a shape file theme on land cover and soil type. This is a necessary step before an attempt can be made to simulate the natural conditions of the catchment. After this has been done, accomplished tests can be run and the necessary calibrations be done.

Even though no simulations have been done and the impact of infield rainwater harvesting have not yet been determined, this study have the potential to indicate what effect this technique, if any, would have on downstream farmers and communities, and would also indicate the boundaries within which practices like water harvesting could take place and still ensure enough water for use by downstream farmers and communities.

The results of the study should also provide guidelines for future management of the Modder River Basin by the Water Management Authority (to be implemented). Presently the Department of Water Affairs and Forestry assumes this responsibility.

References