CATCHMENT MANAGEMENT IN THE SEMI-ARID AREA OF CENTRAL SOUTH AFRICA: IMPLICATIONS FOR RIVER BASIN MANAGEMENT

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ABSTRACT

In the semi-arid part of central South Africa, population growth and industrial development are the driving forces for an increased demand for water. This accentuates the need for wise decisions by catchment management agencies (CMAs), especially in water scarce semi-arid areas. These decisions become more and more complex as the range of demands widens over the spectrum of water consumers, i.e. municipal, industrial, irrigation and rainfed farming. A study was conducted in the Upper Modder River catchment which is situated in the semi-arid area of central South Africa, where crop production in the catchment using conventional production technique is currently not suitable due to marginal and erratic rainfall. Moreover, the area is characterised by low precipitation use efficiency as a result of large runoff and evaporation losses on clay and duplex soils. A labour intensive in-field rainwater harvesting (IRWH) technique recently introduced into a part of the basin occupied by small scale farmers has been shown to increase maize and sunflower yields by 30 to 50% compared to conventional tillage, making it a feasible option for the these farmers in the catchment. The area of land suitable for the IRWH located in the communal land is estimated to be 23 000 ha. Two catchment management options presented in this paper are: option-1: allowing the IRWH suitable land in the communal farming area to remain under grassland and utilizing the runoff downstream for irrigating maize; option-2: utilizing the IRWH suitable land for maize production in the basin, using the IRWH technique. Results showed that the expected maize production from option-2 was higher than from option-1. A financial analysis also showed that gross margin, expressed as Rand per m^3 of rainwater utilized, was between 0.0234 to 0.0254 under option-1 and 0.0354 for option-2. This clearly shows that use of rainwater where it falls has high socio-economic benefits for the communal farmers who are currently struggling to achieve sustainable livelihoods.

Keywords: catchment management, river basin, rainwater, water productivity

1. INTRODUCTION

In a new paradigm shift related to integrated water resources management in the context of a river basin, attention is being drawn to consider the upstream influences on the various water use entities, as well as the downstream impacts arising from them. Along the path of water flowing in a river basin are many water-related human interventions, such as water storage, diversion, regulation, pollution, purification, etc. and 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 (Sunaryo, 2002).

In rainfed agriculture water productivity will have to increase dramatically over the next generations if food production is to keep pace with human population growth (Rockström et al., 2002). In Sub-Saharan Africa, over 60% of the population depends on rain based rural economics, generating about 30 - 40% of the regions GDP (World Bank, 1997). However, in many parts of the water scarce countries, yields from rainfed agriculture are low, oscillating around 1 $t.ha^{-1}$ (Rockström, 2001). Many researchers, however, suggest that the low productivity in rainfed agriculture is more due to sub-optimal performance related to management aspects than to low physical potential. For instance, Bennie et al. (1994) reported that in arid and semi-arid areas between 60 and 85% of the rainfall evaporates from the soil surface without making any contribution to production.

In the semi-arid part of central South Africa, population growth and industrial development are the driving forces for an increased demand for water. This accentuates the need for wise decisions by catchment management agencies (CMAs), especially in water scarce semi-arid areas. These decisions become more and more complex as the range of demands widens over the spectrum of water consumers, i.e. municipal, industrial, irrigation and rainfed farming. Due to its location which is close to the relatively densely populated and industrialised greater Mangaung Municipal area that includes Bloemfontein, Botshabelo and Thaba Nchu, the the Modder River catchment is of strategic importance, with the widest possible range of competing stakeholders.

In the Modder river basin irrigated agriculture is the main sector with the highest water requirement. Based on estimation by BKS (Pty) Ltd (Rossouw, undated) the total water requirement for both irrigation and urban use and the available water supply in the Modder river basin is given in Figure 1. It is estimated that 74% of the total water requirement is for irrigation purpose compared with 26% for urban water need. So, it can be seen that irrigated agriculture puts a large demand and pressure on water resources of the basin. However, given the limited availability of water resources in the basin it appears that only a portion of the irrigation demand, estimated at 55.5%, can be met by the existing water supply (see Figure 1), whereas 97.7% of the urban water requirement does seem to be met. It is therefore important that the CMA's decision for this and other similar river basin be based on reliable information. The objective of this paper is to provide essential new information relevant to the use of rainwater in rainfed crop production by small scale farmers in the Modder river basin.

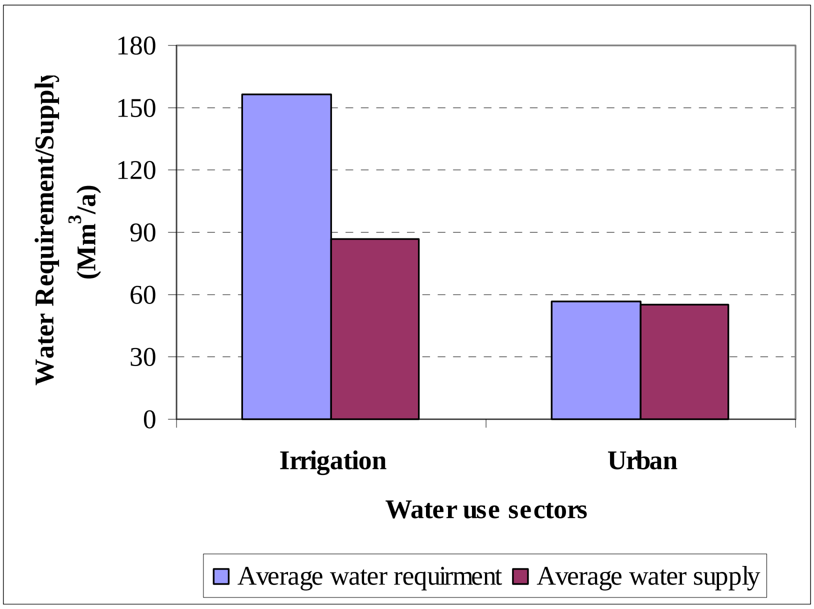

Figure 1. Water requirement and supply for irrigation and urban use in the Modder river basin (*data source*: BKS Pty Ltd).

The Upper Modder river basin is characterized as marginal for crop production due to low and erratic rainfall combined with clay and duplex soils, and high water losses by runoff and evaporation. As water conservation alternative an Infield Rainwater Harvesting technique (IRWH) was developed to improve yields (Hensley et al., 2000). The field layout of the IRWH technique is described in Figure 2. The main aspect of the IRWH technique is that it reduces runoff to zero. If this technique is widely adopted, a possible change in catchment hydrology needs to be considered and evaluated by CMAs in relation to the many other demands for water in this important catchment. Woyessa et al. (2006a and b) provide valuable information in this regard highlighting the comparison in economic terms of the two strategies, namely (1) no IRWH in the catchment and using the runoff for irrigation below the storage dams, and (2) all suitable land in the catchment under IRWH. They concluded that in purely economic terms the later was found to be the best strategy. The aim this paper was to present the result of a study on the different catchment management options for efficient use of rainfall at the river basin scale.

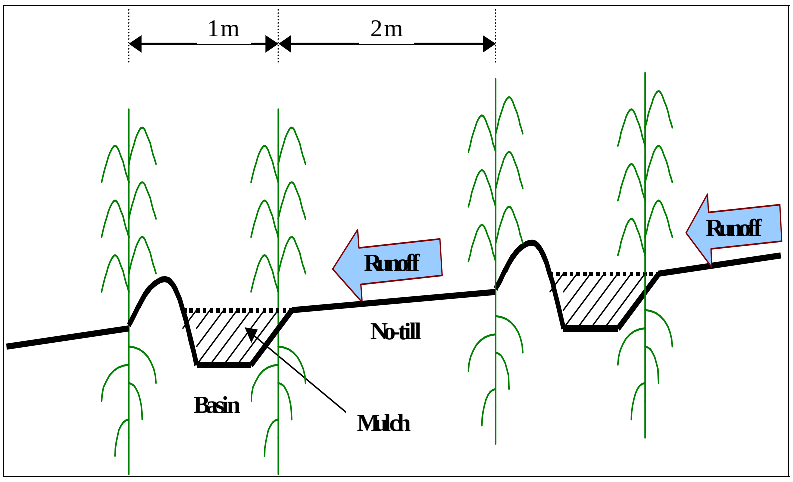

Figure 2. Diagrammatic representation of the Infield Rainwater Harvesting (IRWH) technique (adapted from Hensley et al., 2000).

2. METHODOLOGY

The Modder River basin (Figure 3) is a large basin with a total area of 1.73 million hectares. It is divided into three sub-basins, namely the Upper Modder, the Middle Modder and the Lower Modder. It is located within the semi-arid Upper Orange Water Management Area to the east and north of the city of Bloemfontein, central South Africa. A detailed description of the Upper Modder River catchment is given by Woyessa et al. (2006a and b). The area is 295 766 ha, mean annual precipitation of 537 mm and average runoff coefficient of 5.95%. The mean annual runoff from the total area is estimated at 94.42 x 10^6 m^3. Included in the catchment is around 70 000 ha of communal land occupied by subsistence farmers with a low standard of living.

2.1 Estimating the area of communal IRWH land in the catchment

Different land types have been identified in the catchment. Land Type Dc17 (Land Type Survey Staff, 2002) occupies 76% of the UMR catchment. Ellof (1984) estimated that 10% of Dc17 is arable. Assuming that this fraction is fairly uniformly distributed over the whole area of the land type, and that “arable” is equivalent to “suitable for IRWH”, this percentage can be used as a first approximation of IRWH land in the communal area component of the catchment. Tekle (2004) investigated the soilscapes procedure in an attempt to refine the evaluation of Dc17 for IRWH. The procedure used was also described by Tekle et al. (2004). It involves subdividing a land type into carefully selected smaller areas, termed soilscapes, with similar topography and geology. Because of the very important role which these two factors play in soil genesis in this semi-arid area, soil distribution in a soilscape can be assumed to be more homogenous than in its parent land type. Due to this, estimates of IRWH land based on soilscapes should be better than those based on the parent land type.

2.2 Estimating the economic benefit of IRWH to the subsistence farmers

The enterprise budget for maize production complied by Kundhlande et al. (2004) was used in the analysis of the economic benefit of IRWH to the subsistence farmers. This includes land preparation, maintenance (repair of basins) and harvest and post-harvest labor.

2.3 Estimating the decrease in runoff from the UMR catchment due to the IRWH

The amount of runoff that could be retained by IRWH was estimated from the total estimated runoff and the amount of land suitable for this technique. The total area of suitable land for IRWH was estimated to be 22% of the total area of the land in the catchment. The mean annual total runoff and the amount of runoff retained by the IRWH were then estimated from the mean total rainfall of 537 mm and a runoff coefficient of 5.95%.

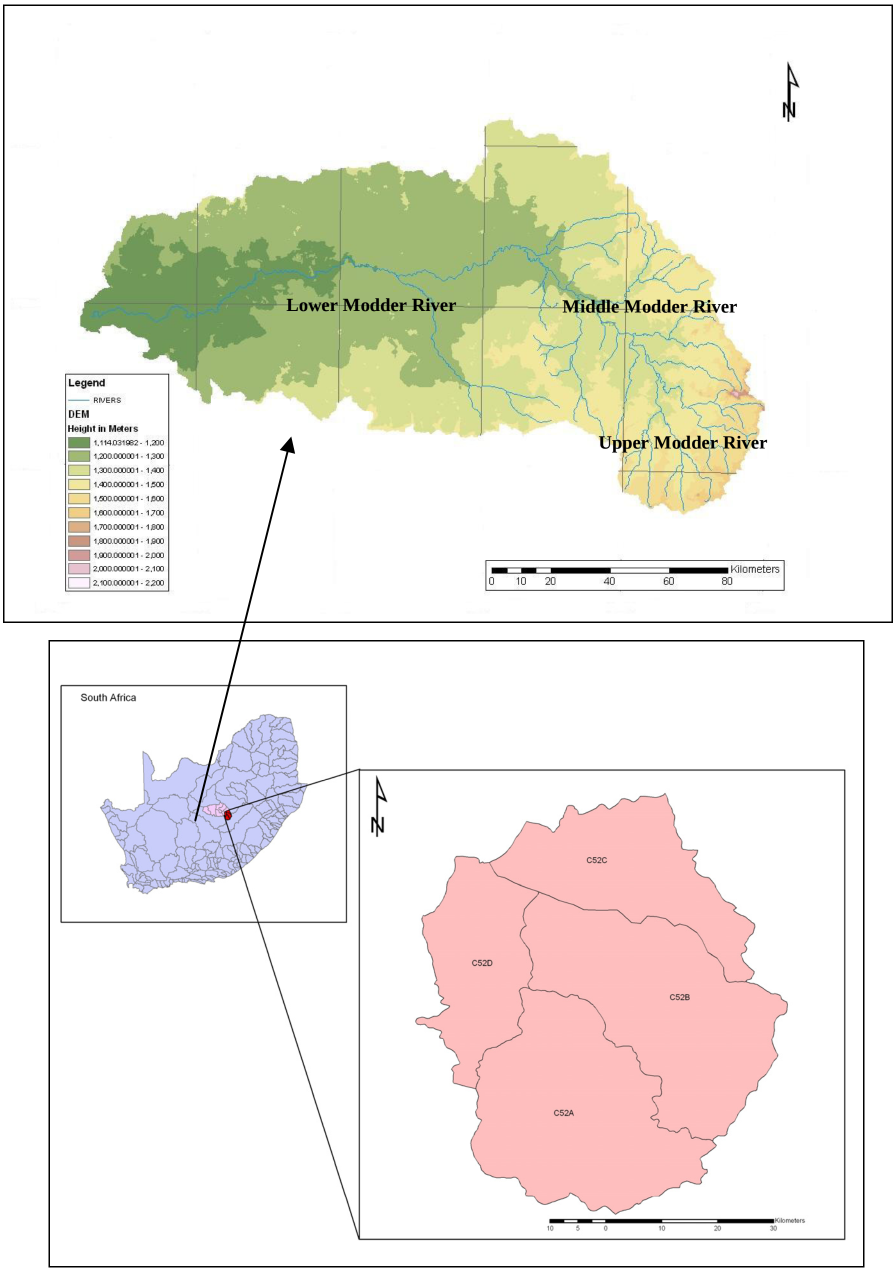

Figure 3. (a) The Modder River Basin showing the three catchments, namely the Upper, Middle and Lower Modder River catchment and (b) location map of the study site and the sub-catchments within the Modder river basin.

3. RESULTS AND DISCUSSION

Tekle (2004) presents a table with the total area of each of the 66 components of the land type Dc17 and a map showing the boundaries of each soilscape. The original boundaries were drawn on maps with a scale of 1:50 000. By transforming these boundaries to a map with a scale of 1:250 000 and superimposing it on a map of similar scale showing the boundaries of the communal land, it is possible to identify the whole soilscape, or portions of soilscape, that are located on the communal land. Using these results together with the estimate by Tekle (2004), it was possible to obtain what is considered to be a reasonable final estimate of IRWH land in the communal area of the UMR catchment. The result is 23 000 ha or 22% of the total area. Recent soil surveys in the area indicate that this estimate may be somewhat too high. Using the procedure of Eloff (1984), i.e. 10% arable land, would give 10 000 ha It is necessary to note here that there would be a danger of disturbing the ecological balance in the catchment if more than 30% of the area was used for IRWH (Van Collar, 2004: Personal communication).

Based on detailed economic analyses Kundhlande et al. (2004) concluded that by adopting the simplest form of infield rainwater harvesting – without the use of mulches in the basins and runoff area, farmers can increase their income by R800 per hectare per annum in the case of maize production. The values presented for gross margin above the total allocatable costs vary depending on the type of IRWH employed for maize production, but are generally around R1200 per ha per annum. It needs to be kept in mind that, apart from food grown in home gardens, crop production in the communal land is currently almost negligible. Farmers have an allocation of about 1-5 ha of cropland. It is therefore clear that employing IRWH efficiently on that sort of area would have a significant beneficial effect on their livelihood.

3.1 Possible impact of the rainwater harvesting technique on runoff

The mean annual runoff and the amount of runoff expected to be retained in the IRWH suitable are within the communal lands in the catchment are presented in Figure 4. If runoff from this portion of the catchment is captured for on-site use for crop production using the IRWH technique, it is estimated that it will retain a mean annual runoff of 9 mm, decreasing the mean annual runoff from 32 mm to 13 mm (Figure 4). It should be noted that, in this part of the country, mean annual evaporation (Class A pan) is 2198 mm (Botha et al, 2003) which can cause a tremendous amount of water loss from dams, rivers and other storage reservoirs. For instance it is estimated that 25.5 million cubic meters of water can be lost annually through evaporation from Rustfontein Dam, located in the catchment, with storage surface area of 1158.5 ha. This is one of the losses of water that can be avoided by the on-site use of rainwater at upstream level for food production.

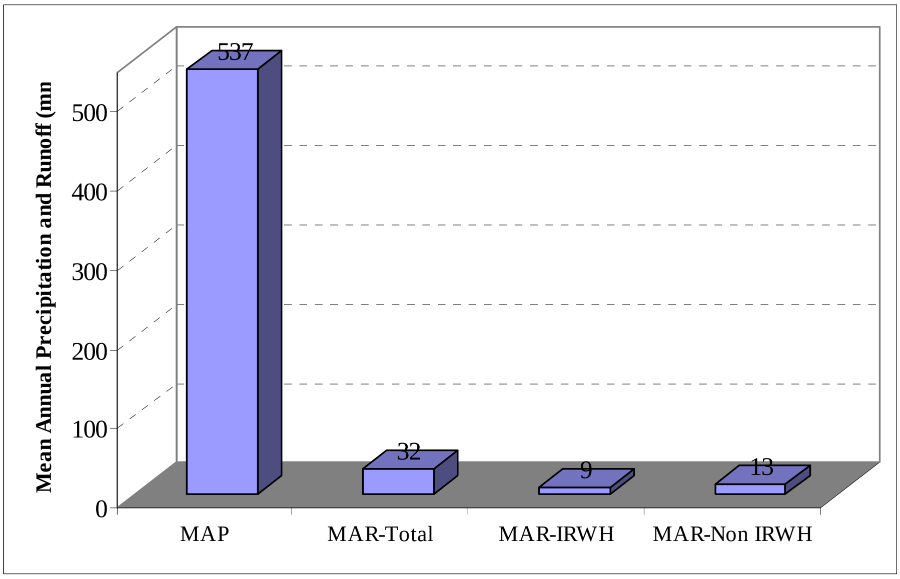

Figure 4. Mean annual runoff from the total area of the catchment and the amount of runoff that can be retained by the IRWH in all the suitable land in the Upper Modder River catchment. *Note*: MAP = Mean Annual Precipitation; MAR-Total = Total Mean Annual Runoff; MAR-IRWH = Mean Annual Runoff retained by the IRWH; MAR-Non IRWH = Mean Annual Runoff available from non IRWH lands.

However, the assumption of the scenario of all the suitable land for IRWH being put under cultivation using the IRWH technique should be seen in relation to the following factors. Firstly, the current form of the IRWH technique has been designed for implementation using hand labor, and therefore only suitable for the relatively small areas expected to be developed initially by communal farmers living in the catchment area. The estimated area of suitable land for the IRWH technique inhabited by communal farmers is 23 000 ha. At present the IRWH technique is employed almost exclusively by large numbers of the communal farmers in their backyard gardens. The rate of expansion into the 23 000 ha of communal cropland is expected to be determined by the extent and rate at which certain socio-economic constraints can be overcome. Secondly, research is currently being planned to mechanize the IRWH technique and make it suitable for commercial production. If this proves to be successful, expansion would probably be accelerated. However, it is useful to see the implications for river basin management decisions in terms of the possible impact of the different scenarios of rainwater use, namely on-site versus off-site, in relation to water productivity and some economic factors. These are discussed in the following sections.

3.2 Implications for River Basin Management

There is a growing need for wise catchment management decisions that will lead to improved river basin management in the whole of South Africa in general and the Modder River basin in particular, because water is such a limiting factor. This need has been recognized in the new National Water Act by the creation of catchment management agencies (CMA's) (DWAF, 2004). The question regarding the catchment management decision that need to be addressed are: allowing the IRWH suitable areas to remain under grassland and utilize the runoff which occurs from it to flow via storage dams and be used downstream for irrigation or utilize all the rainfall on the IRWH suitable land for growing maize (or sunflower) using the IRWH technique on site. These two catchment management options are illustrated using schematic representation in Figure 5. The detailed calculations and discussion on these two options have been reported by Woyessa et al. (2006a and b). Here, these two options are summarized under the following two sections.

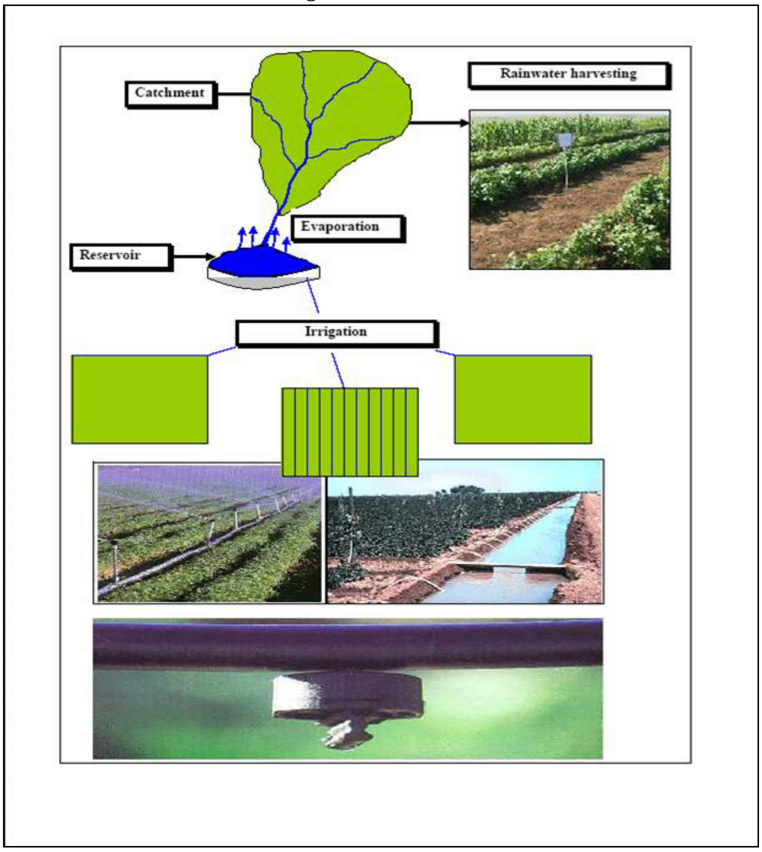

Figure 5. Diagrammatic representation of the two catchment management strategies.

3.2.1 Crop production and water productivity in the catchment

In sub-Saharan Africa, rain-fed agriculture is practiced on approximately 95 percent of agricultural land, with only 5 percent under irrigation (Rockström et al. 2002). This shows that rain-fed agriculture will remain the dominant source of food production for the foreseeable future in the region. Thus, increasing the productivity of water in agriculture will play a vital role in easing competition for scarce resources, prevention of environmental degradation and provision of food security (Molden et al. 2003).

Using the procedure described by Woyessa et al. (2006a and b), the mean annual runoff retained in the 23 000 ha of IRWH land is estimated to be 7.34 x 10^6 m^3. It is reasonable to assume long term average maize yields of 1.7 and 0.8 tons per hectare with the IRWH and CON production techniques respectively. These results can be read from the graph in Figure 6, using 80% probability of achievement (or 20% probability of non-exceedance). It can therefore be calculated that the increase in yield of 0.9 tons ha^{-1} is due to the water which did not runoff the IRWH lands, i.e. 7.34 x 10^6 m^3 from an area of 23 000 ha. The water productivity of this runoff water can therefore be estimated as follows:

$$\frac{0.9\times10^{3}\,kg\;ha^{-1}}{\left(7.34\times10^{6}\,m^{3}\big/23\times10^{7}\,m^{2}\right)} = 28.2\;\;kg\;\;ha^{-1}\,mm^{-1}.$$

This value shows a high water productivity indicating a large benefit that could result from using the IRWH in terms of meeting the food security as well as preventing erosion and sedimentation of downstream rivers.

It has been reported that crop production in the study area under dryland and conventional tillage is very marginal because of relatively low and erratic rainfall and predominantly duplex and clay soils on which the precipitation use efficiency is low due to large runoff and evaporation losses from the soil surface (Hensley et al, 2000). Because of this, maize production using conventional tillage in the UMMRB is currently almost negligible. The two catchment management strategies given in Figure 6 are, firstly, veld grass in the catchment and using the runoff for centre pivot irrigation downstream; and secondly the application of the IRWH technique in the catchment.

Included in the calculations are the losses from the original runoff water which occur due to: (1) evaporation from the storage dams, and (2) transmission downstream to the hypothetical site of irrigation. Reliable values for these parameters are currently not available. As a preliminary solution to this difficulty, two scenarios are presented in Figure 6, using two fairly extreme values for storage and conveyance losses, i.e. 35% (scenario A) and 60% (scenario B). For irrigation a centre pivot system with 75% efficiency was assumed. The total water requirement of a target yield of 10 $t.ha^{-1}$ maize was estimated to be 735 mm (Bennie et al., 1988).

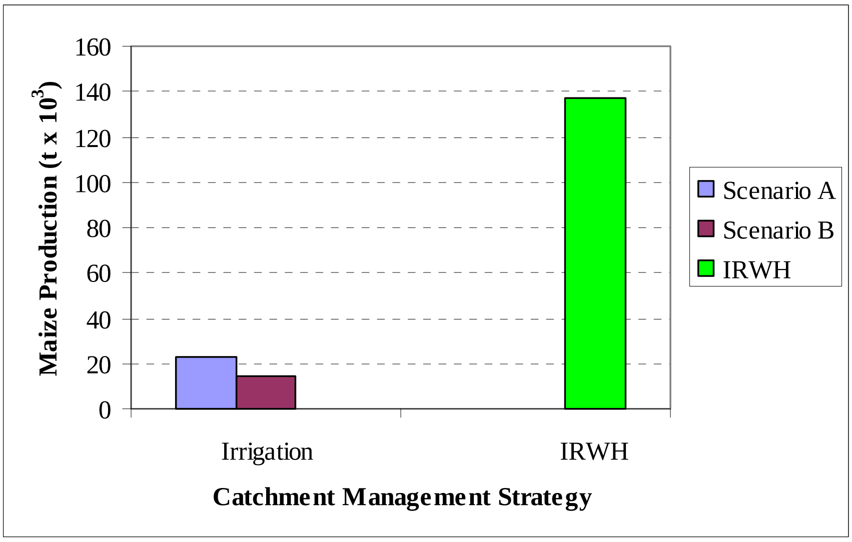

Figure 6. Comparison of use of rainwater under upstream (IRWH) and downstream (Irrigation) for agricultural production (in case of irrigation, storage plus conveyance losses are assumed to be 35% and 60% for scenario A and B respectively).

The results presented in Figure 6 show the expected total production under the two production strategies. The monetary benefit derived from these different strategies will be dealt within the financial analysis (Figure 4). The comparison of total maize production under the two production strategies shows that using rainfall where it falls in the catchment with the IRWH technique results in the production of six times more maize than the downstream irrigation strategy. This information makes it quite clear that the on-site use of rainwater as described constitutes the best catchment management decision. It should also be noted that investment in the development of irrigation systems for a viable farming business is far from being accessible to small scale farmers who are struggling to meet their daily food requirement. The IRWH technique therefore offers an attractive option at this moment towards meeting household food security in the communal farming area. This, however, will require a concerted effort on the part of the Department of Agriculture and other stakeholders to promote the technique and to develop the skill of the small scale farmers to make the system sustainable.

3.2.2 Financial assessment of the catchment management strategies

A preliminary financial assessment of the two strategies, presented in Figure 7, shows that the combined irrigation plus veld grazing strategy is shown to yield a combined gross margin of 0.0254 and 0.0234 $R.m^{-3}$ (Rand per cubic meter of rain-water), for scenarios of A and B respectively. The detailed calculation of the gross margin for the two catchment management strategies is reported in Woyessa et al. (2006a and b). The comparable figure for the use of the IRWH technique to produce maize is 0.0354 $R.m^{-3}$. In monetary terms, the estimated IRWH advantage compared to irrigation plus veld grass amounts to R4.3 million and R5.2 million per year for scenarios A and B respectively.

The results in Figure 8 provide additional economic support for the conclusions. It is clear that it would be a wise catchment management decision to allow maize production using the IRWH technique to be developed in the UMR catchment. It is of value to include here relevant information presented by Kundhlande et al. (2004) i.e. that among the communal farmers a family of five needs about one ton of maize per annum to supply their staple food. Therefore, the estimated maize production on the approximately 23 000 ha of the IRWH suitable land in the communal farming area within the UMR catchment would be sufficient to supply the staple food for about 39 100 families or 195 500 people.

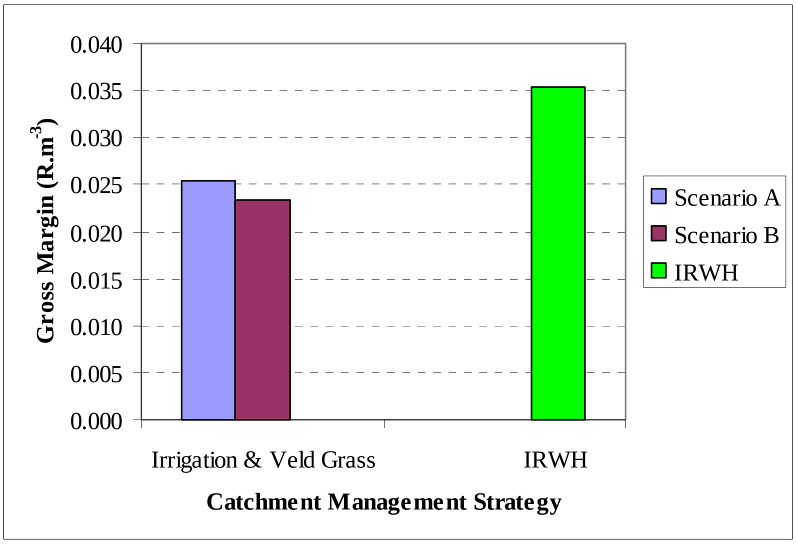

Figure 7. Financial assessment of the two management strategies for maize production (Scenarios A & B are as described in Figure 6).

4. CONCLUSION

The ultimate goal of water resources policy in a catchment management is to increase the beneficial utilization of the rainwater falling in the catchment through reduction of non-beneficial losses and water pollution. Infield rainwater harvesting together with appropriate farming practices can contribute towards achieving this goal. The IRWH technique introduced to the subsistence communal farmers in the UMR catchment is one such practice designed to increase crop yields under dryland production compared to conventional tillage, and hence increase water productivity.

The result of this study shows clearly that from all points of view, i.e. water productivity, social considerations and economics, it would be a wise decision to allow the IRWH technique to be expanded in the UMR catchment. However, this does not imply that downstream irrigation farming should be scaled-down in favour of the application of the IRWH technique at the upstream level. Nevertheless, the challenges faced by these farmers in the application of the IRWH technique are such that it could affect the expansion thereof, and should be addressed by the concerned governmental departments and non governmental organizations operating in the area. However, a regulating factor in the future will be the growing need for more water for municipal and industrial purposes in the ever growing Bloemfontein, Botshabelo and Thaba Nchu areas. Thus, it should be emphasized that water loss reduction and management are considered to be part of a basin-wide integrated water resource management, which gives an essential role to institutions and policies in ensuring that upstream interventions are not made at the expense of downstream water users. These principles apply at all scales, from field to basin levels, but the associated options and practices require different approaches at different spatial scales. Therefore, there is a need to identify the types of policies and incentives that will work best in promoting adoption of new production techniques and cultural practices which increase water productivity at all levels.

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