COMPREHENSIVE Assessment of water management in agriculture

Research Report 12

Impact of Land Use on River Basin Water Balance: A Case Study of the Modder River Basin, South Africa

Y.E. Woyessa, E. Pretorius, P.S. van Heerden, M. Hensley and L.D. van Rensburg

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Comprehensive Assessment of Water Management in Agriculture

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Cover photograph by Francois Carstens shows an Infield Rainwater Harvesting Plot with harvested maize in one of the villages in the Modder River basin.

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Summary

The study was conducted in the Upper and Middle Modder River Basin (UMMRB) which is located in the semi-arid area of central South Africa. About 35 percent of the basin consists of a communal-farming area where subsistence farmers have difficulty in growing enough food for themselves because of the marginal conditions for crop production. The limiting factors are low and erratic rainfall and excessive water losses due to runoff and evaporation from the predominantly duplex and clay soils. In an attempt to improve the crop production potential of the area the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC-ISCW) introduced a crop production technique called the Infield Rainwater Harvesting (IRWH), which increased the yields of maize and sunflower by around 30–50 percent compared to the yield obtained through conventional tillage. Runoff is reduced to zero where this technique is employed. Because of this fact it was realized that widespread application of IRWH in the UMMRB could reduce runoff from the catchment significantly. The main aim of this project was to investigate to what extent this was a possibility and, furthermore, to elicit information to "improve the management of scarce water supplies available for agriculture" in the UMMRB.

The first step in the project was to identify the area of land suitable for the IRWH technique in the UMMRB, based on the soil type and topographical features, which was estimated to be 27.2 percent of the total area, consisting of approximately 15,000 ha in the communal-farming area and another 65,667 ha, which is currently operated by commercial farmers. A socioeconomic survey was conducted in the communal-farming area, using a participatory approach, to assess to what extent the application of the IRWH technique could be expanded there. Results showed that a fairly rapid expansion within home gardens could be expected, but the expansion into large areas of croplands would be subject to finding solutions to socioeconomic constraints such as poverty, lack of appropriate tools and implements, and lack of crop-farming skills.

Assessment of the impact of the IRWH technique application on the suitable land in the UMMRB showed that the estimated mean annual runoff would be reduced by 25.75×10^6 m^3 from a total of 94.42×10^6 m^3. Calculations were then made to compare the use of rainfall under on-site (upstream) versus off-site (downstream) conditions. The two strategies compared in this study are: (1) allowing the 80,667 ha (the area suitable for IRWH) to remain under grassland and utilizing the runoff downstream for irrigating maize; and, (2) utilizing the 80,667 ha for maize production using the IRWH technique. The comparison of the total production of maize under the two production strategies indicates that the use of rainwater harvesting presents an ample opportunity for the small-scale farmers to increase crop yields. The financial analysis conducted also made it possible to compare the benefits of grazing from the grassland plus irrigation strategy (option-1) to that of the IRWH technique (option-2). The gross margin on the runoff from 80,667 ha of land in the catchment used for downstream irrigation plus the financial benefit derived from the grazing land amounts to 0.0254 R.m^{-3}. The comparable figure for the use of the IRWH technique to produce maize on-site (upstream) is 0.0354 R.m^{-3}. In economic terms, use of the IRWH technique is, therefore, shown to be superior to using the runoff downstream for irrigation. However, this does not imply that downstream irrigation farming will be scaled-down in favour of the application of the IRWH technique at upstream level. It should be noted that the overall impact of the IRWH technique in terms of runoff reduction to the downstream irrigation farmers is not significant at least in the short- to medium-term because of the limited

area of suitable land as well as the slow expansion rate of the IRWH technique. Hence, the IRWH technique will not have a significant effect on the existing downstream irrigation farmers in the short term.

What may become a regulating factor in the future is the growing need for more water for municipal and industrial purposes in the ever growing Bloemfontein, Botshabelo and Thaba Nchu areas. This is an issue that needs to be addressed using very reliable information to strike a balance between the relative importance of saving water to meet the growing urban and industrial demand expected in the future, and resolving the current dire situation of small-scale farmers who are struggling to meet their household food security in a more sustainable way.

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Introduction

Background

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 are many water-related human interventions, including water storage, diversion, 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 (Sunaryo 2001). 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 the adverse effects of a rapid degradation of the environment and other ecological problems arising from severe competition for water to be studied, along with the irrigation-induced environmental problems. It also tends to highlight the importance of equity and sustainability issues related to IWRM (Bandaragoda 2001).

The neglect of this type of wider consideration of the resources base has, up to now, clouded the inherent limitations of existing institutional arrangements to deal with irrigation systems. As countries experience growing water scarcity, water-sector institutions need to be reoriented to cater for the needs of changing supply-demand and quality-quantity relationships and the emerging realities (Saleth and Dinar 1999). It is inevitable that irrigated agriculture, the largest water user in many river basins, will be called upon to reassess its water requirements in view of the competition for water from other users. There is now wide acceptance of the necessity to focus on higher-level institutions, generally at the basin level.

The river basin is a geographical unit that defines an area where various users of the basin’s water interact, and where most of them live. A basin perspective helps include in the analysis the interactions among various types of water uses and users, and in the process, it helps in better understanding the physical, environmental, social and economic influences that impinge on the productivity of agricultural water management. In a basin context, interrelated issues of quantity and quality of surface water and groundwater, and the extraction, use and disposal of water resources can be more comprehensively analysed. Participation of a larger number of stakeholders can be sought, and water resources planning can be more effectively carried out. The broader view through a river basin is to be able to capture dimensions that are not normally included in an irrigation system management approach, such as the causes (and not only the effects) of water scarcity, water quality, water-related disputes and inequitable water distribution and use.

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 the use of resources should transcend short-term "on-site" gains, and should 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.

Water Management in Semi-arid Areas

The semi-arid areas of sub-Saharan Africa are characterized by the low annual rainfall, which is concentrated to one or two short rainy seasons (Ngigi 2003). The average annual rainfall varies from 400 to 600 mm in semi-arid zones and ranges between 200 and 1,000 mm from the dry semi-arid to the dry sub-humid zone (Rockström 2000). Water scarcity in semi-arid areas is attributed to poor rainfall distribution and poor partitioning leading to a large loss of water as non-productive water-flows, which is not available for crop production.

There is a growing understanding that the ever-increasing demand for food and water can only be achieved through an increase in biomass production per unit land and per unit water (Rockström 2001). Hence, there is a need to focus on opportunities of increasing efficiency of the use of limited water in rain-fed, smallholder agriculture in semi-arid areas. Rainwater harvesting is one such opportunity that is reported to contribute towards the efficient use of rainwater for crop and livestock production as well as for domestic purposes (Ngigi et al. 2005; Ngigi 2003; Rockström et al. 2004; Rockström et al. 2002). Water harvesting, defined in its broadest sense as the collection of runoff for its productive use, is an ancient art practiced in the past in many parts of the world, such as North America, Middle East, North Africa, China, and India. More specifically, in crop production, water harvesting is essentially a spatial intervention designed to change the location, where water is applied to augment evapotranspiration that occurs naturally. It is relevant to areas where the rainfall is reasonably distributed in time, but inadequate to balance the potential evapotranspiration of crops (Oweis et al. 1999). The role of rainwater harvesting in mitigating dry spells that occur during sensitive crop growth stages, is very significant when used as a supplemental irrigation.

Hydrological Impact of Up-scaling Rainwater Harvesting

Rainwater harvesting involves abstraction of water in the catchment upstream and, this may have hydrological impacts on downstream water availability (Ngigi 2003). Increased water withdrawal at the upstream level will have a bearing on the downstream water availability. However, it is assumed that there are overall gains and synergies to be made by maximizing the efficient use of rainwater at the farm level (Rockström 1999). Increased adoption of rainwater harvesting could have a hydrological impact on the river basin water resources management, and may have negative implications on the water availability to sustain hydro-ecological and ecosystem services.

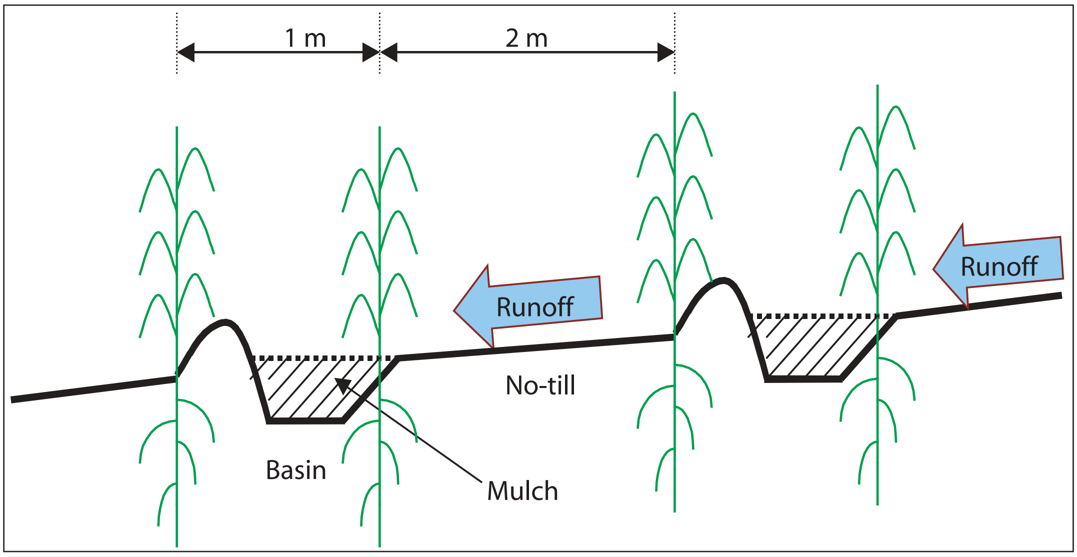
The expected upstream shifts in water-flows may result in complex and unexpected downstream effects, in terms of quantity and quality. In general, though, increasing the residence time of runoff flow in a watershed through rainwater harvesting may have positive environmental as well as hydrological implications/impacts downstream (Rockström et al. 2002). The Indian experience, where an Irrigation Department ordered the destruction of community rainwater harvesting structures, fearing that it would threaten the water supply located downstream for irrigation (Agrawal et al. 2001), indicates the need for further research on possible impact of wider adoption and for policies, legislations and institutions to manage rainwater harvesting, especially for agriculture.

Rainwater Harvesting in the Modder River Basin

The Modder River basin, located in the semi-arid regions of central South Africa, is experiencing intermittent meteorological droughts causing water shortages for agriculture, livestock and domestic purposes. 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 Bloemfontein, acts as a buffer for stabilizing the water supply to the lower reaches of the Modder River. However, many of 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 (ISCW) of the Agricultural Research Council (ARC) developed water harvesting techniques for small-scale farmers in the basin with the objective of harnessing rainwater for crop production (Hensley et al. 2000). It has been reported that with the use of the IRWH technique the surface run-off was reduced to zero and that evaporation from the soil surface was reduced considerably, resulting in a significant increase in the crop yield (30–50% yield increases) compared to that obtained through conventional practices (Botha et al. 2003). The IRWH technique is described in figure 1.

The low-infiltration rate of clay and duplex soil is employed as an advantage in the development of the IRWH technique.

FIGURE 1.
Diagrammatic representation of the IRWH technique.



Source: Adapted from Hensley et al. 2000

It increases the surface runoff from the collection area between crop rows, and this water is retained in basins that are covered with mulch between 1 m crop rows (figure 1). Furthermore, these types of soil have a high water-holding capacity and a dominant micro-pore flow. Thus, the surface runoff that is retained in the basins is not lost through drainage (Wiyo et al. 2000). Soil crusting occurs after the initial rains due to the “beating effect” of raindrops (Morin and Cluff 1980; Valentin and Stewart 1991; Botha et al. 2003). Crusted surfaces induce reduced infiltration rates, thereby generating more runoff, enhancing erosion and the consequent loss of organic matter and nutrients resulting from conventional tillage. With the IRWH technique this runoff is harnessed and used to enhance the crop yield (Botha et al. 2003).

Moreover, this practice was also reported to reduce soil-loss significantly, which otherwise would run into the river system. The researchers expect that many small-scale farmers in the river basin (with limited access to irrigation water) will be able to adapt this practice for crop production. The research questions arising from this scenario were: (a) what will the consequences be of a wider use of this practice on the river water-balance? (b), what will the off-site impact of this practice be on the downstream of the river basin, if used on a wider scale?

In fact, there are many activities that could possibly impact on the water-balance of the river basin, for example, recreational activities, public water consumption, etc. It is not possible to address all these issues within the time-frame and funding set for this project, but these could be subjects for further investigation. An attempt was thus made to assess the possible scenario of the impact of the land use practices aimed at rainwater harvesting for crop production by small-scale farmers on the river water balance.

The general objective of the study was to help improve the management of scarce water resources available for agriculture, within and responsive to a framework for IWRM in river basins. The specific purpose of this project was to investigate the possible impact of land use practices (aimed at harvesting rainwater for crop production) on the Modder River water balance.

Methodology

South Africa occupies the southern most part of the African continent and lies between latitude 22 S and 35 S and longitudes 17 E and 33 E. It comprises nine provinces and shares its boundaries with Lesotho, Swaziland, Mozambique, Zimbabwe, Botswana and Namibia. The country has a wide variety of climate, soil and topography, ranging from semi-desert to subtropical rainforest, from floods to sever droughts, from snow in the winter to heat waves in the summer, from barren sand dunes to soil of high productivity. Mean annual rainfall is 511 mm, but more than 60 percent of the country receives less than 500 mm. In the central high plateau of South Africa, which includes most part of the Free State Province, more than 75 percent of the rainfall occurs between November and March. Midsummer drought is a general phenomenon, coinciding with the flowering period of the summer crops, often causing poor flowering and consequent low yields (Beukes et al. 2004).

In view of the rapid growth of population and the increased use of water by several sectors of the economy, after a country-wide process of public consultation (DWAF 2004), the country was divided into 19 water management areas (figure 2) as primary geographic elements for water resources management, The number of water management areas and the location of

FIGURE 2.
Water Management Areas of South Africa.

Source: DWAF 2004

their boundaries were determined by considering factors such as:-

- The institutional efficiency of creating a large number of catchment management agencies, each managing a relatively small area, or a small number of agencies, each managing a larger area;
- The probability that the catchment management agency will become financially self-sufficient from water use charges;
- The location of centres of economic activity;
- Social development patterns;
- The location of centres of water-related expertise from which the agency may source assistance; and
- The distribution of water resources infrastructure.

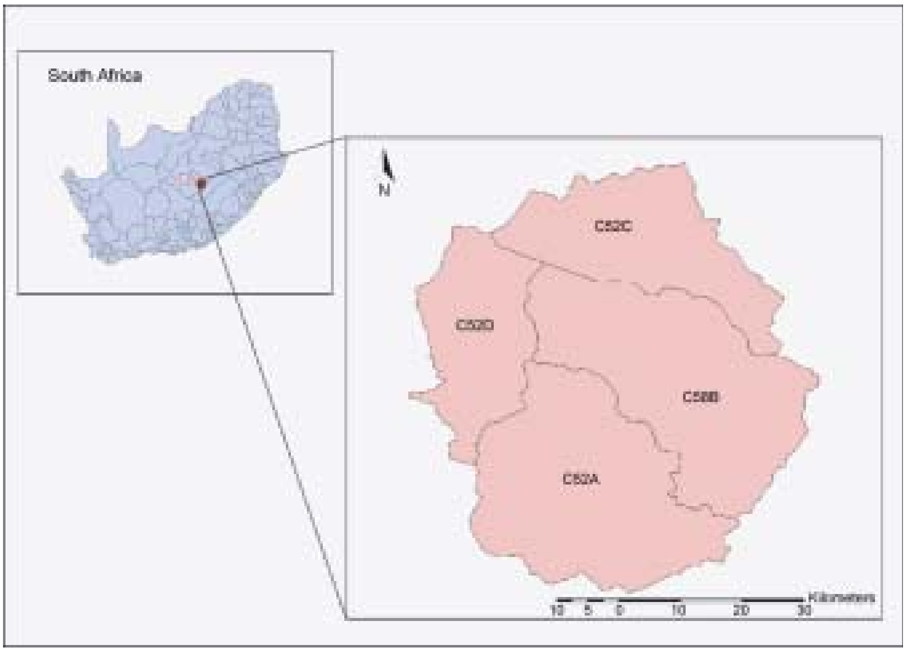
It is important to note that the boundaries of water management areas do not coincide with the administrative boundaries, which define the areas of jurisdiction of provincial and local government authorities. It is also important to note that the boundaries are not irrevocably fixed for all time. According to the Department of Water Affairs and Forestry (DWAF), if, in the light of operational experience, it proves necessary to change the boundaries to achieve greater efficiency or effectiveness, the changes will be made after consultation with all those who will be affected (DWAF 2004).

Based on this classification system, the Modder River basin is located within the Upper Orange Water Management Area to the north and east of the city of Bloemfontein in central South Africa.

Description of the Modder River Basin Area

The whole Modder River basin comprises 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 Upper Orange Water

FIGURE 3.
Location map of the study site showing the delineated sub-catchments in the UMMRB.



Note: Author's creation

Management Area to the east of the city of Bloemfontein. The irrigated agriculture in the basin is sustained by pumping out water from river pools and weirs. However, most of the rural small-scale farmers rely on rain-fed agriculture for their crop production. The water supply to the middle and lower reaches of the Modder River is stabilized by the Rustfontein and Mockes dams in the east, Krugersdrift Dam in the west of the city of Bloemfontein.

Four quaternary catchments, hereafter referred to as sub-catchments, located in the Upper and Middle Modder River basin (UMMRB) have been selected for this study (figure 3). These are C52A, C52B, C52C and C52D; together they comprise a total area of 296,570 ha.

Quantifying and Describing the Area of Land Suitable for the IRWH Technique

The natural agricultural resources of South Africa have been surveyed as land types at a scale of 1:250 000 (Land Type Survey Staff 2000). Variation in soil properties and the sensitivity of crops to these properties require detailed surveys for land-suitability evaluation. Conventional detailed soil surveys (scale 1:10 000) are useful for land-use planning on land units as small as one hectare. However, the cost of these surveys restricts their widespread application, particularly with regard to resource-poor farmers (Tekle et al. 2004).

The objective of the land-type survey in South Africa was to make a systematic inventory of the natural agricultural resources of the country. The survey was carried out on maps with a scale of 1:50, 000. The boundaries of the different land types were transferred from the 1:50, 000 maps to 1:250,000 maps and an inventory of each land type was compiled. The Land Type Survey Staff (2000) identified about 7,200 land types within 3,000 climate zones in South Africa. The land-type database contains profile descriptions and comprehensive soil analyses for approximately 2,400 modal profiles. This process has lead to a thorough register of the different types of soil in South Africa and their distribution.

In the past, crop production in the Free State region of central South Africa has, generally, been very marginal in areas with mean annual rainfall of less than 500 mm (Eloff 1984). Conventional crop production on sandy soils has increased since then due to improved soil-management practices and increased application of the advantages of sandy soil. However, the agricultural productivity of clay soil remained very low due to its low infiltration rate and high runoff coupled with a relatively low and erratic rainfall (Hensley et al. 2000).

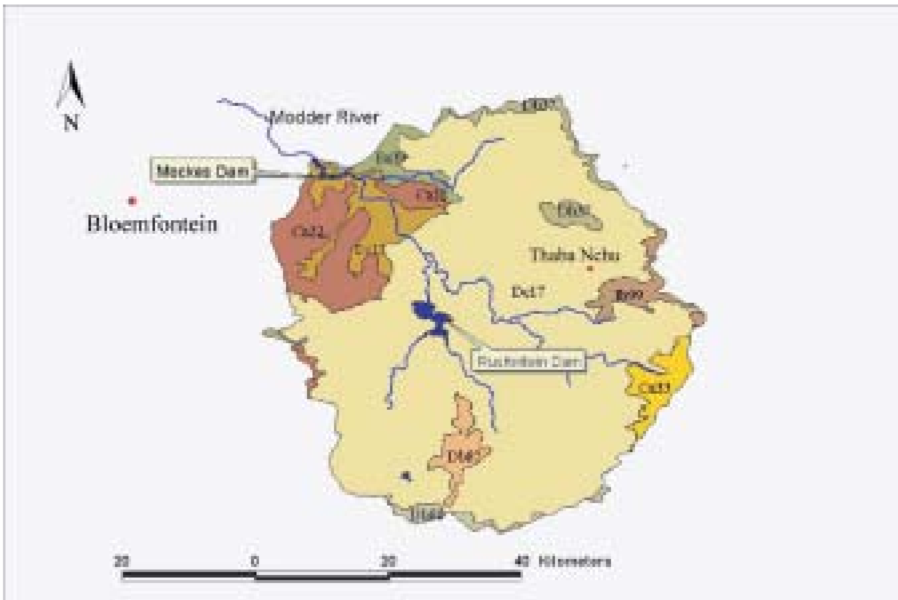
The development of the IRWH technique was aimed at efficiently utilizing the available precipitation in order to increase the agricultural potential of the clay soil. The restrictive features of clay soil and duplex soil are employed as advantages in the use of the IRWH technique. The low infiltration rate of these types of soil increases surface runoff from the runoff collection area between crop rows, and the runoff water is retained in basins covered with mulch between 1 m crop rows.

The land type covering most of the study area is called Dc17 (figure 4) with a total area of 226,177 ha, which is about 76 percent of the study area. It is considered to be marginal for commercial crop farming due to the low and erratic rainfall and unsatisfactory types of soil (Eloff 1984). 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 soil, which has greater than 10 percent of upland “margalitic” soil (i.e., high in clay of the smectite type). The number 17 merely differentiates this particular land unit from all other Dc land units that occur in South Africa. The characteristics of Dc17 are briefly described as follows:

Climate

The climate of Land Type Dc17 is characterized as semi-arid in which duplex soil with prismacutanic and pedocutanic diagnostic soil horizons are dominant, and in addition vertic, melanic and red structured diagnostic horizons occur. The impact of climate, time and vegetation on soil formation are relatively homogenous and, therefore, differences between the various types of soil are mainly due to the influence of parent material and topography (Land Type Survey Staff 2000).

FIGURE 4.
Map of the study area showing the land-type codes, such as Dc17, Ca22, etc.



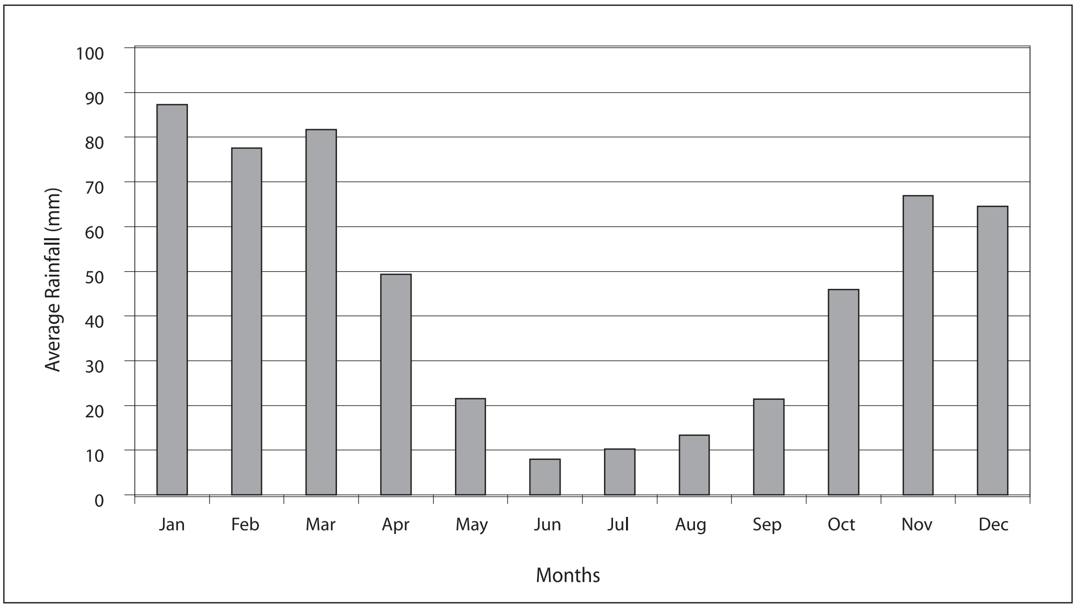
Note: Author’s creation

The average annual rainfall in the area is about 537 mm. The long-term average monthly rainfall distribution based on the means of the weather station records within this climatic zone is given in figure 5. Much of the summer rainfalls, which occur between November and March, are high-intensity storms that promote runoff. More detailed information about the climate of the region is available from the long-term records obtained from the nearby Glen meteorological station shown in table 1. The mean annual rainfall there is slightly higher (543 mm) than in the study area. The mean temperature during these 5 months is relatively high with a high evaporative demand, relatively low rainfall and low aridity index (table 1).

Terrain/Soil Pattern and Estimated Area Suitable for the IRWH Technique

The land-type inventory of Dc17 (Land Type Survey Staff 2000) provides the following information regarding the characteristic terrain/ soil pattern. Figure 6 shows standard

FIGURE 5.
Long-term average monthly rainfall for the study area.



Source: Land Type Survey Staff 2000

TABLE 1:
Long-term monthly and annual climate data from the nearby Glen meteorological station (ARC-ISCW data); rain and temperature data: 1922–2003; evaporation data: 1958–2000.

Climate variables*	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Mean annual
P (mm)	8.1	11.6	19.3	49.0	68.2	66.6	83.4	77.6	80.7	49.3	19.9	9.0	542.7
E_o (mm)	93.5	140.6	197.5	239.1	256.0	291.6	276.5	207.7	177.1	126.1	110.6	81.9	2,198.2
T_{max} (^{0}C)	17.8	20.6	24.4	25.4	28.3	30.2	30.8	29.5	27.4	23.9	20.5	17.9	24.8
T_{min} (^{0}C)	-1.6	0.9	5.2	9.2	12.0	14.0	15.3	14.8	12.6	7.8	2.8	-1.1	7.5
T_{ave} (^{0}C)	8.1	10.7	14.8	17.5	20.1	22.0	23.0	22.1	19.9	15.8	11.6	8.2	16.2
AI	0.087	0.083	0.10	0.21	0.27	0.23	0.30	0.37	0.46	0.39	0.18	0.11	0.23

Source: Botha et al. 2003

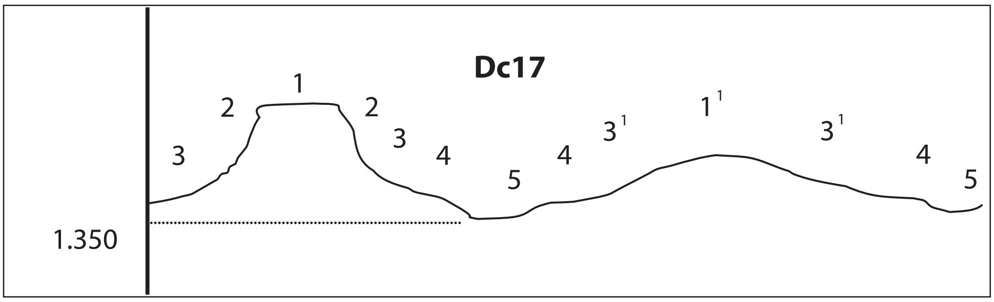
Note: *P = Precipitation, E_o = Class A pan, T_{max} = Mean maximum temperature, T_{min} = Mean minimum temperature, T_{ave} = mean monthly temperature; AI = Aridity index (rainfall/pan evaporation) geomorphological symbols that are used to describe terrain units (TU's), i.e., 1 = crest; 2 = scarp; 3 = hillside; 4 = foot slope; 5 = valley bottom. Soil names are according to "Soil Classification: A Taxonomic System for South Africa" (Soil Classification Working Group 1991).

About 15 percent of the area is located on slopes greater than 4 percent and has shallow soils covered by rock. These areas are located on TU's 1, 2, and 3. The remainder of the area has slopes of less than 4 percent and is located on TU's 1^1, 3^1, 4 and 5 (figure 7) with a potential arable type of soil, mainly Swartland and Valsrivier forms (both duplex types of soil), with limited areas of soil of "Bonheim" and "Arcadia" forms (both margalitic types of soil). Further information on the surface features of the study site is given in figure 8.

It will be possible to obtain an accurate assessment of the area of land suitable for the IRWH technique 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 was, therefore, made using estimates based on expert knowledge.

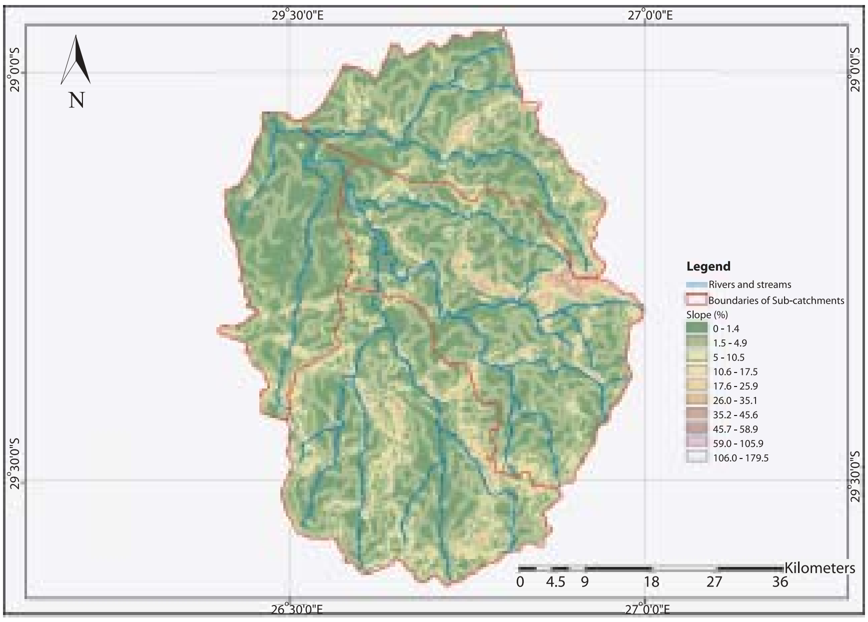
Dc17 was defined and characterized by soil scientists J.F. Eloff and A.T.P. Bennie in the early 1970s (Land Type Survey Staff 2000). Eloff (1984) estimated that 10 percent of the land type

FIGURE 6.
Characteristic terrain/soil pattern of the land type Dc17.



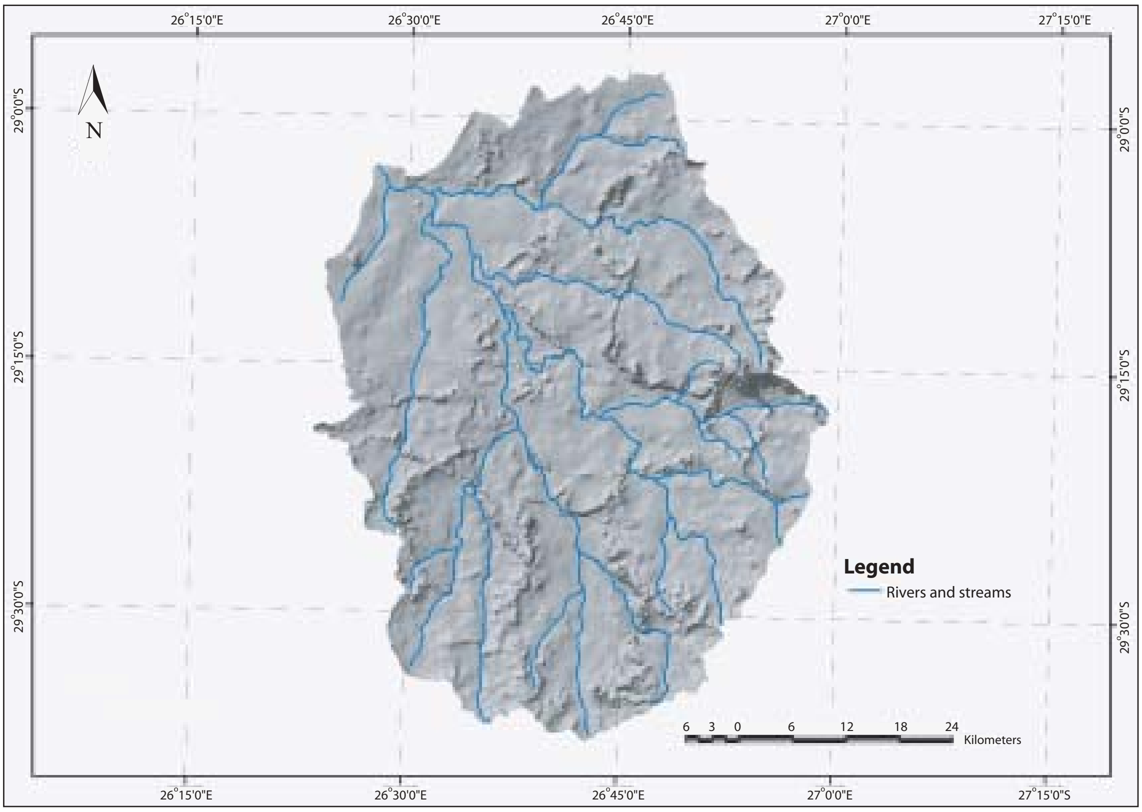
Source: Land Type Survey Staff 2000

FIGURE 7.
Map of the study area showing the average slope (%) of the study site, as computed from the Digital Elevation Model.



Note: Author's creation

FIGURE 8.
A map of the study area showing surface features, and rivers and streams.



Note: Author's creation

Dc17 was arable, and assessed the crop growing potential as being "low." A very recent attempt has been made by Tekle et al. (2004) to estimate the arable area suitable for the IRWH technique in Dc17. They subdivided the land type into 67 smaller and more homogenous units called "soil-scapes." Based on a considerable amount of field work and computer-aided studies, they estimated the arable area suitable for the IRWH technique of each of the "soil-scapes" separately. This amounted to 53,772 ha or about 24 percent of the total area of Dc17, and is considered to be the most reliable estimate available at present. In this study the assessment made by Tekle et al. (2004) was reviewed and the procedure expanded to include that part of the catchment which is not part of Dc17. The areas of land suitable for the IRWH technique for the main land types in the study area are given in table 2.

Land Cover/Land Use

The study area is characterized as marginal for crop production because of its dominantly clay soils (on which the precipitation use efficiency is low because of high losses due to runoff and evaporation from the soil surface) and the relatively low and erratic rainfall it receives (Hensley et al. 2000). The land cover in the study area is shown in figure 9. It is mainly grassland, which covers approximately 80 percent of the total area, of which 10 percent is degraded grassland. About 70 percent of the area is covered by unimproved natural grassland. Cultivated land in the study area covers only about 10 percent of the total area, of which 9 percent is utilized for dryland crop production and less than 1 percent is the area on which crops are grown by subsistence farmers.

TABLE 2.
Land types and area of land in the catchment suitable for the IRWH technique.

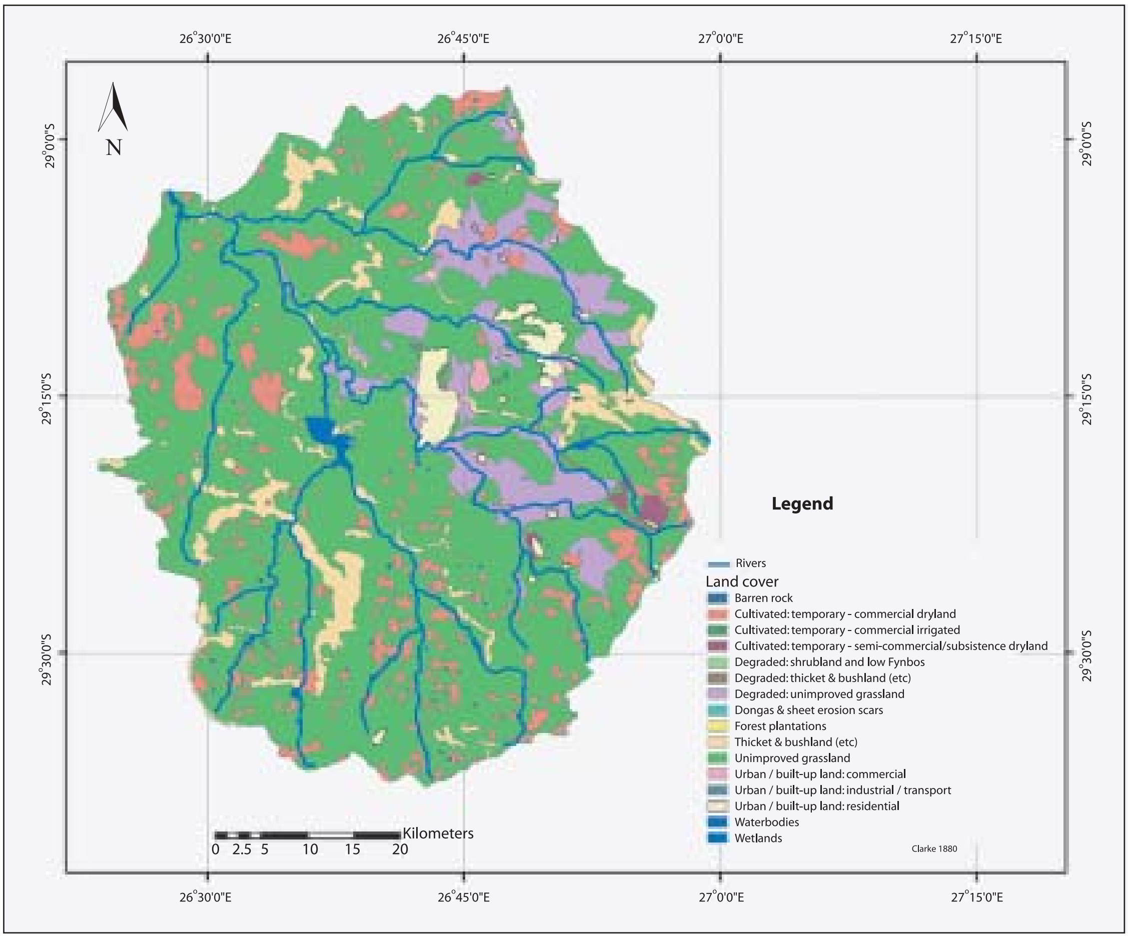
Land type	Total area	Estimated area for (ha)	Estimated area for IRWH (%)	Main soil types[a] IRWH (ha)
DC17	226,177	24	53,772	Sw, Se, Va, Ar, Bo,
Ca22	23,335	60	14,001	Va, We
Ca33	6,637	65	4,314	We, Ss
Db37	6,118	15	918	Va, Sw
Db87	5,418	35	1,896	Va, Sw, Ss
Dc13	13,499	25	3,375	Va, Oa
Ea39	6,528	20	1,306	Ar, Mw, Va
Ib99	5,759	0	0	Ms, Rock
Db88	3,099	35	1,085	Ss, Va, Sw

Notes: (a) Author's creation

(b) [a]Main soil types are: Va = Valsrivier, We = Westleihg, Ss = Sterkspruit, Oa = Oakleaf, Ar = Arcadia, Mw = Milkwood, Ms = Mispah, Bo = Bonheim, Sw = Swartland

[b]The total area given here is estimated using ArcGIS and is slightly different from the figure given under the section on Estimation of Runoff... (see page 20) which is obtained from Midgley et al. (1994)

FIGURE 9.
Land cover/land use in the study area.



Note: Author's creation

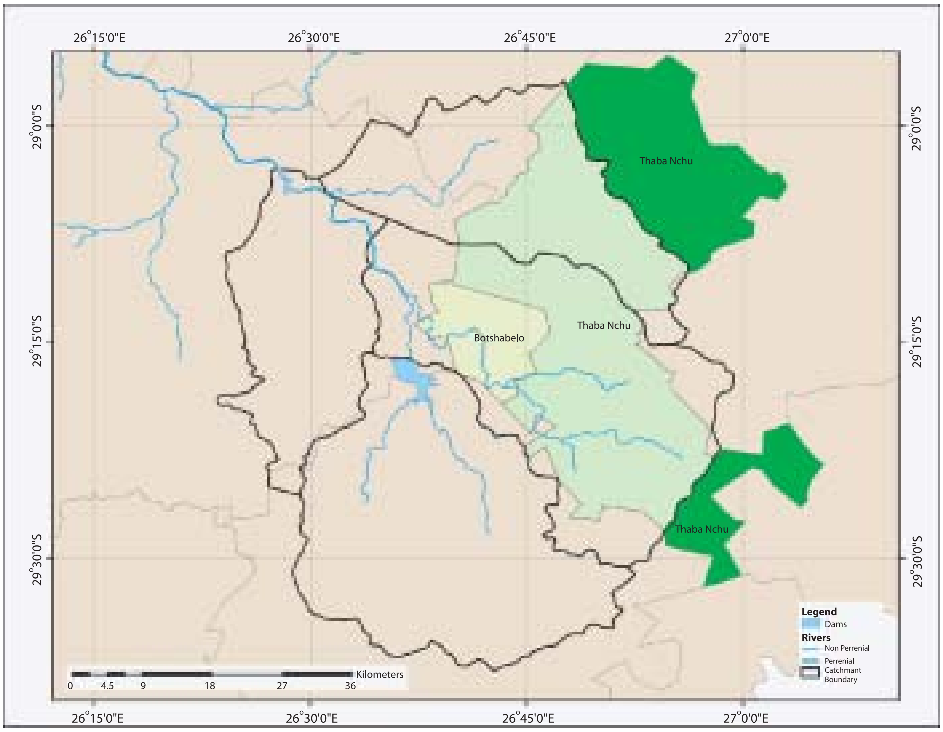
Runoff Estimation and Impact of the IRWH Technique

The introduction of the IRWH technique at the present moment is focused on the communal-farming areas, which are dominated by small-scale farmers with limited access to irrigation water. The widespread adoption of the technique is expected to result in:
(i) considerable benefit to the subsistence farmers in the communal-farming areas in the catchment with regard to food security; and
(ii) decreased runoff from the catchment in proportion to the area on which the IRWH technique is applied. Hence the need to obtain an estimate of the total area in the catchment that is suitable for the IRWH technique.
The part of the catchment occupied by the communal-farming area is shown in figure 10. It constitutes about 35 percent of the total area and contains about 18 percent of the land found suitable for the IRWH technique.

Long-term data on the hydrology of the catchment, such as precipitation and runoff were obtained from a database on surface water resources of South Africa (Midgley et al. 1994). With the identification of the suitable area of land for the IRWH technique in the study area, based on soil and topographical information, the mean annual runoff was estimated for the whole catchment and the possible impact of the IRWH technique on runoff generation was quantified.

In order to further highlight the impact of the IRWH technique, comparative analysis of the use of rainwater for crop production was made for "on-site" (upstream) and "off-site" (downstream) conditions using the total production from the mean annual rainfall amount and some financial indicators, such as gross margin in terms of an economic benefit from a unit amount of water.

FIGURE 10.
Part of the catchment occupied by the communal-farming area: Botshabelo and Thaba Nchu.



Notes: (a) Author's creation:
(b) Part of Thaba Nchu (dark green color) lies outside of the study area

Socioeconomic Survey on the Application of the IRWH Technique

To predict the possible changes in the application of the IRWH technique and its effects on local runoff, it was necessary to determine the present situation regarding the application thereof and determine factors (motivators or demotivators) that could either stimulate or constrain potential expansion of the IRWH technique. This information could then be used as a basis for formulating realistic scenarios of future expansion. Wide-scale application of the IRWH technique could have an impact on the hydrology of the UMMRB, if the total runoff from the IRWH technique was reduced to zero on suitable land in the communal-farming areas.

The methodology used was a participatory approach using semi-structured interviews and focus-group discussions as described by Salomon (1998) and Van Zyl (1999) in order to determine the perceptions and attitudes of the communities regarding the IRWH technique. The questionnaires were constructed in such a way that the presence of a concept and its perception by the community could be tested. A positive response or the mentioning of keywords or key concepts during discussions with the community would imply knowledge of IRWH technique or a positive perception of the same. The absence of a keyword or concept would indicate ignorance or disinterest in the technique. A non-leading question regarding the item to be discussed was put to the group and they were prompted to discuss it among themselves in the presence of a facilitator. The facilitator then noted or marked keywords and concepts mentioned by the group. There was also space to indicate negative perceptions, especially if these were emphasized.

The survey was conducted on samples of 21 villages that were selected randomly out of approximately 45 villages. A total of 335 people were involved in this survey-exercise. All these villages were visited during the week preceding the survey and a contact person was asked to organize a group for the forthcoming survey-visit. The groups interviewed were not of equal size, therefore a weighting factor, based on the group-size, was built into the analysis.

Results and Discussion

Application of the IRWH Technique in the Communal-farming Areas

In the process of investigating the possible expansion of the IRWH technique in the communal-farming areas, it is important to have an understanding of the land-tenure system. In the communal-farming areas of the study-site the land is owned as a communal property, where the traditional leader is responsible for distribution (allocation to community members) and the overall management of the land. Whether this land- tenure system encourages or discourages adoption of new or improved technologies needs to be investigated and is beyond the scope of this project.

The IRWH technology was rolled out to communities in the Thaba-Nchu area during Phase II of the ARC-ISCW water harvesting program. Phase I concentrated on the scientific development and testing of the technique against conventional tillage using on-station facilities at the Glen Agricultural Institute and on farmers' fields. The "ecotopes" used are representative of the target area. Summer crop yields were between 30 percent and 50 percent higher on the IRWH plots than those obtained through conventional tillage (Botha et al. 2003). Phase II was developed to educate potential farmers in the technical aspects of crop farming, specifically the application of the IRWH technique in the backyards. Much attention was given to the understanding of the water-related processes such as runoff, evaporation, storing of water in the soil, mulching, etc., by using an Interactive Physical Scale model (van Rensburg et al. 2003). The philosophy was that if they could understand the basic water processes involved they could spread the message (farmer to farmer exchange). Therefore, they could also adapt the technique to accommodate other crops than those studied. By fulfilling these objectives the main goal of improving food security at the household level would automatically be addressed.

The roll-out of the technique started during the 2001/2002 cropping season, at six homesteads (from four villages) and expanded to 400 homesteads (from 37 villages) by the end of the 2003/2004 cropping season. A recent survey done by the Institute for Soil, Climate and Water (ISCW) of the Agricultural Research Council (ARC) – (Botha 2005, personal communication) showed an exponential increase in the expansion of the technique, i.e., more than 950 households from 42 villages prepared the structures in the backyards during the fallow period. This implies that approximately 550 people are testing the technique for the first time, and can be regarded as inexperienced as they have not received full-training in planting, fertilizing, mulching etc.

According to the Water Harvesting Team of the ARC-ISCW at the Glen Agricultural Institute the third phase, i.e., roll-out of the technique on croplands, will be introduced fully after the national workshop on “Up-scaling of the in-field rainwater harvesting application.” Taking into account that the average household has access to between 1.5 and 3 ha of cropland, the potential is currently between 1,400 ha and 2,900 ha (depending on bio-physical and socioeconomical factors). The mean number of households per village is 110, hence giving a potential area between approximately 7,000 ha and 14,000 ha. It should be noted that some of these villages are situated outside of the selected catchments in the communal-farming area (see figure 5).

Field survey, conducted within the framework of this project using a participatory approach, helped the team to understand the general farmers’ perceptions and attitudes towards this technique, the extent of adoption of this practice among the subsistence-farmers and the potential for its expansion in the future, including the activity calendar and labor availability for this practice. These are given in the following sections.

Farmers’ Perceptions and Attitudes Regarding the IRWH Technique

The point of entry into the analysis of the adoption of a given innovation is to identify its sources of information. In this particular survey, the researchers were interested to know what might be the initial source of information and the initial routes of the information-flow regarding this technique. The results are depicted in table 3.

TABLE 3.
Sources of information on the IRWH technique.

Source of information	Percentage of the respondents
Family member	5
Neighbor	37
In a neighboring village	39
Research or extension workers	42
Field or demonstration day	33
Water harvest festival	0

Note: Author’s creation

The percentages in table 3 add up to more than 100 percent, as a group could indicate more than one source. What is noticeable is the relatively high rating of research and extension workers (technical assistants) as a source, an indication that the frequent visits by the ARC-ISCW team has been fruitful. High ratings are also given to neighbors, neighboring villages and field or demonstration days as sources. Remarkably low, is the rating of the water harvest festivals, as more than 200 people have attended such days. This could probably be due to some possible confusion of water harvest festival with field demonstration days.

The general perceptions of the groups' regarding the IRWH technique and mentioned more frequently were good yields, storage of rainwater, and free seed and fertilizer. The last one was with reference to the extension support system (incentive) that was provided by the ARC-ISCW, as most of the participants are ultra-poor with no capacity to buy their own inputs.

The villagers developed an understanding of the IRWH technique through either applying the technique or through observing the technique being applied in their vicinity. Their understanding of the technique is shown in table 4.

TABLE 4.
The groups' understanding of the IRWH technique.

Groups' understanding of the technique	Percentage of respondents
Stops running water	91
Water storage in the soil	59
More plant available water	53
More food for the household	86
Surplus produce for sale	43

Note: Author's creation

It is obvious that the concept of water harvesting and its related water-storage in the soil for plant use has been understood and accepted by most of the people included in the survey. With the use of the IRWH technique, 86 percent of respondents indicated that they have more food available for their families (household).

Ninety percent of the respondents indicated that they applied the technique in their home-garden, while 8 percent planted in both community- and home-garden and 2 percent planted in a community-garden only. The respondents who have indicated planting in community-gardens were mostly those respondents that lived in villages linked to the town of Thaba Nchu. The plots in these villages are smaller (±400 m^2) than those in the villages further away, where plot sizes are about 2,500 $m^{2.}$ Reasons given as to why a general expansion from home-garden to community-garden has not taken place were: (i) the lack of fencing around community gardens (resulting animal damage to crops; (ii) the non-affordability of cultivating bigger areas; and (iii) the prevalence of theft.

The respondents' reaction to what they have experienced in the application of the IRWH technique is shown in table 5. Table 5 shows that the majority of the respondents have experienced

TABLE 5.
Respondents' experience in the application of the IRWH technique.

Experience in the application of the IRWH technique	Percentage of respondents
Easy to understand	67
Have necessary tools to prepare the IRWH plots	25
Testing the idea on a small scale	13
Easy to prepare the IRWH plots	38
Experienced an increase in crop yield	78
Stable crop yield every year	40
More food security	67
Extra income from the sale of produce	50
Better feeling of producing own food	22
The results were easy to see	40
Easy integration of the technique with the existing methods of farming	14
Group or community pressure for adoption of the technique	14

Note: Author's creation

an increase in crop production, more food for the family, perceived the technique as being easy to understand and that they could make more money by selling the surplus produce. These strong positive factors could act as motivators for the expansion of the IRWH technique.

As shown in table 5, only 25 percent had their own tools and the rest had to borrow tools for the preparation of the IRWH plots. Analyzing the experience of the respondents against the influence of characteristics on the adoption of an innovation as described by Rogers (1962) and Bembridge (1993), one comes across a mix of both expected and unexpected results as discussed below:

- *Relative Advantage*: The technique is expected to give a higher yield for the same effort required when growing a crop. The perception is that, initial land preparation for IRWH requires more labor than conventional tillage, and for some people this might be a demotivator regardless of the higher yields obtained with the application of the technique. This perception seems to be grounded on fact, as Kundhandle et al. (2004) found out, that the members of a household might not be able to provide enough labor, particularly during critical periods. The results in table 5 show that 78 percent of the respondents experienced an increase in crop production, 67 percent had more food and 50 percent could sell the surplus produce. However, 38 percent perceived that the IRWH plots were easy to prepare, while 22 percent experienced a feeling of well-being by being able to produce their own food. This low response level regarding the feeling of well-being by producing one's own food is normally expected to be high under the present condition of the villagers who are struggling to meet their daily food requirement. This is a cause for concern because it implies that a lot needs to be done to create awareness and facilitate the adoption of the IRWH technique, or in the expansion of areas under the IRWH technique.
- *Complexity:* The technique was perceived as easy to understand by 67 percent of the respondents. This confirms the researchers' point of view that the IRWH technique is a simple one and could be applied by any community (Botha et al. 2003).
- *Visibility:* Forty percent (40%) said that the results were easy to fathom and interpret. This is a surprise outcome, as the method and result demonstrations showed an obvious difference between the results of conventional tillage and application of the IRWH technique. The fact that non-applicants could not see, or did not notice is that the good growth and higher crop yields are negative values for the adoption of the technique.
- *Divisibility:* This reflects the ease with which an innovation can be tested on a smaller scale than that on which it would eventually be applied. The IRWH technique is a very easily divisible technique. A potential adoptee needs to make one block of 2 meters by 4 meters and compare it with the results of conventional field preparation. However, only 13 percent of the respondents indicated that they see the technique as divisible.
- *Compatibility:* Only 25 percent indicated that they had the necessary tools to prepare the plots. Tools had to be borrowed from neighbors, and in one case it was indicated that tools were borrowed from the project team of ARC-ISCW. Only 14 percent could associate crop production techniques when applying the IRWH technique with that of conventional tillage. This implies that the majority of the applicators of the IRWH see the technique as completely new, from the way the soil is prepared to all aspects of crop farming.
- *Group Action:* Only 14 percent indicated that group pressure influenced their thinking about IRWH, which indicates a very low level of peer pressure or peer involvement in the adoption of the IRWH technique. In

itself, this indicates that the changeover from conventional tillage to the IRWH technique was done without reference to peer groups, which could speed up the process of adoption of the IRWH technique.

Table 6 shows that 37 percent of the respondents paid for help in the preparation of the basins and the runoff plots (IRWH plots). The cost was as high as Rand (R) 500 (6.5 Rand = US$1) per family garden, although costs of R 220 or less were usually indicated. Thirty two percent (32%) of those who have paid said the cost was expensive irrespective of what was paid for the preparation of the IRWH plots. Only 19 percent of those that have paid had money available from the sale of chickens and milk, while15 percent had to borrow money from friends for the preparation of the basins and runoff plots. This can be regarded somehow as a positive sign since the people seem to have recognized that a profit could be made on the money spent. This also indicates that the IRWH technique could be considered as a job creation activity where unemployment in the rural area is considered to be very high.

TABLE 6.
Cost of preparation of the IRWH plots.

Responses	Percentage of respondents
Did not pay to prepare plots	63%
Paid to prepare the plots	37%
• See it as expensive	32%
• Money available from sale of chickens and eggs	19%
• Borrowed money from friends	15%

Note: Author's creation

Some of the respondents indicated the existence of different forms of assistance with the preparation of the runoff plots and basins, IRWH plot (table 7). Table 7 shows that 66 percent of the preparation of the IRWH plots was done with help from other villagers, either as a community project or on a "I help you, then you help me" basis, or for payment in some cases. Eight percent (8%) indicated outside help, which have been specified as help given by ARC-ISCW during the preparation of the original demonstration plots.

TABLE 7.
Sources of labor for preparation of the IRWH plots.

Sources of labor for preparation of the IRWH plots	Percentage of respondents
Own labor	10
For free; by family members	9
For payment; by family members	7
For free; by members of the same community	13
For payment; by members of the same community	17
As a community project	36
With outside assistance	8

Note: Author's creation

Regarding the provision and availability of seed it can be seen from table 8 that 94 percent of the participants planted seed that was given to them. Only 10 percent said that seed prices are too expensive, the implication being that these respondents will not be able to buy seed unless they get external assistance. A general response at this stage was that the purchase of seed is an investment in the future; this perception is supported by the 38 percent who indicated that they will definitely buy seed if it is not given to them.

TABLE 8.
Means of obtaining seed for planting on the IRWH plots.

Means of seed provision	Percentage of the respondents
Given to the them	94
Bought own seed	4
Used own seed	2
Will buy seed, if it is not given	38
Seed prices are too expensive	10

Note: Author's creation

The respondents indicated that weed control is important (93%) and that fertilisation should also be part of the production inputs, where 82 percent applied artificial fertilizer, 31 percent animal dung, 18 percent compost and 7 percent used crop residue. These percentages total to more than a 100 percent because some respondents indicated combinations of fertilizer types. The extent to which the application of fertilizer that was provided by project team has boosted the adoption of this practice could not be determined.

The different types of crops grown by the villagers using the IRWH technique are depicted in table 9.

TABLE 9.
Crops grown using the IRWH technique.

Crop type	Planting dates	Percentage of respondents
Beans	1/10 – 1/12	86
Maize	1/10 – 15/01	81
Beetroot	1/10 – 15/01	71
Pumpkin	1/10 – 15/01	71
Spinach	1/09 – 15/01	57
Carrots	1/09 – 5/01	43
Watermelon	1/10 – 15/01	38
Onions	1/10 – 5/01	19
Tomatoes	1/10 – 1/11	19
Squash	1/12 – 15/01	19
Cabbage	1/12 – 1/01	14
Peas	5/01	5
Potatoes	5/01	5
Melon	1/10	5

Note: Author's creation

Activity Calendar and Labor Availability

Monthly time lines showed a general tendency to prepare and repair the plots during winter, planting in summer, looking after the crop during its growing season, which includes chasing birds and animals, and then reaping in autumn. Not much seems to be going on during the rest of the year. All the villages are supplied with electricity, therefore the fetching of firewood does not take up time and water is usually available at standpipes at street-corners, although some cases have been found where water taps are installed on the plots. Water is usually taken to the house by means of pails and the time required could be 30 minutes, sometimes longer but mostly shorter. In most cases there seems to be no limit to the quantity of water that can be used by a family. Some cases have been found where the little grey water that is produced in a household is used for watering fruit and shade trees, and flowers in some cases, around the house. In general, the time lines indicate that half a day, or less, would be available for the family to work in the fields.

Issues and Challenges of the IRWH Technique

With a rainwater harvesting technique such as the IRWH technique, where water is not stored in a container for later use in irrigation, the farmer is forced to plant when the best use of the soil water and rainfall could be made, which would be during the rainy season. In the study area the bulk of the rain falls in mid- and late summer, which should be the planting time for suitable crops. Unless enough rain has fallen in early spring, or unless water has been stored in the soil from the autumn rains, planting in September and October in this area is risky because of unreliable and low rainfall during those months. However, this happens in some cases, because of a lack of knowledge and skill of the IRWH technique by some of the villagers. Failure of yields from crops planted at the wrong time would be negative experiences, which could lead to rejection of IRWH as an innovation.

The villages are mostly small, with an average of about 110 households in each, but with a range from about 50 to about 900. The bigger communities (Ratau, Ratlou and Selosesha) form part of the town of Thaba Nchu. Except for these three villages, the population composition found in the villages are not normal, in most cases older women predominate; children are noticed in most of the villages and in some cases elderly men are also noticeable. Bembridge (1987) found similar patterns in rural areas of Eastern Cape and Kwazulu-Natal where men and women of working age were employed elsewhere. Older people who remained in the villages were not risk takers and therefore not necessarily prone to adopt innovations. Family size ranges from 4 to 12, with an average of about 6.5. In 68 percent of the cases family labor is available to help with the preparation of the IRWH plots, but this is an unqualified help, as it is mostly the children, and they can only help during weekends or holidays when there are no school activities. In cases where both father and mother work elsewhere and where grandparents are not available, one usually find that the elder children accept the responsibility for the housekeeping, sometimes under supervision of a neighbor. In this area the poverty level is very high. Botha et al*.* (2003) describes the living standards in the villages as: "extreme poverty, hardship and suffering, hunger, poor housing". In most cases people survive only on social grants and child support grants. A study by Steyn and Bembridge (1989) found that 94 percent of the income of rural families came from outside sources and the balance of 6 percent from farming, which corroborates this finding.

Leaders of the communities are positive in most cases about the IRWH technique, although the odd case of disinterest or absolute negativity was found. The people themselves seem to be demotivated by their lack of farming skills, lack of tools and theft that seems to be fairly prevalent in some places. A low level of cooperation was mentioned as well as a fair number of cases where the biggest problem was described as a lack of motivation. On the other hand, the research team was struck by the apparent supportive role that participants of the IRWH technique played to each other. The absence of fences around community gardens allowed livestock free access to whatever could be planted, and that seemed to be a big demotivator against the expansion of the IRWH technique to beyond garden size. The comment about the technique being too labor-intensive has also been made.

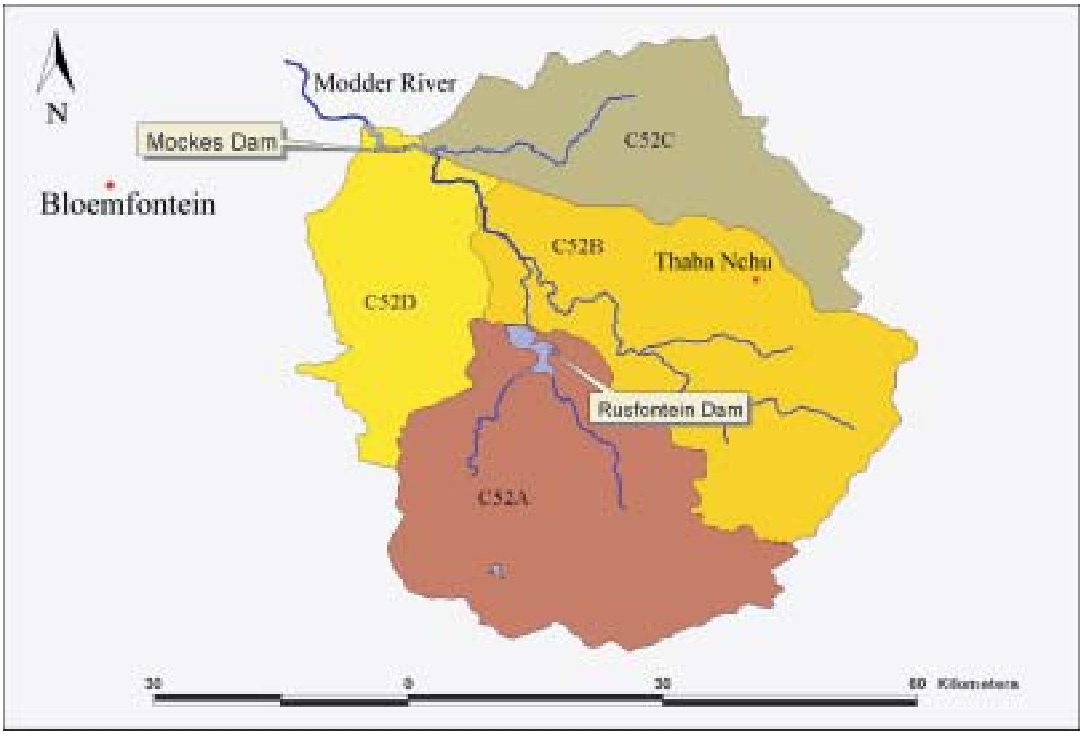
The survey result showed that the technique is expanding fast at home yard level. However, presently there is only a limited expansion to community croplands because of socioeconomic constraints. A large proportion (86%) of the subsistence farmers interviewed responded that this technique contributes to household food security, although there were some concerns on the high labor requirement for the preparation of the IRWH plots. The gap in the understanding of adoption criteria is very wide and should include issues like biophysical and socioeconomic conditions, market issues, land- tenure issues, and the critical issue of human capacity. During the field survey, market issues and lack of necessary farming skills have been repeatedly mentioned by the respondents, which suggest that the technology transfer should be accompanied by other necessary measures as well.

However, it is known that the IRWH technique will involve decreased runoff to some extent in the catchment which may impact downstream water availability. Therefore, one needs to understand the hydrological impact of increasing adoption of the IRWH technique and its influence on river basin water resource management. Moreover, one needs to keep in mind the fact that the IRWH suitable land in the communal-farming areas constitutes about 18 percent of the total IRWH suitable land in the UMMRB. The remaining 82 percent occurs on commercial farms on which the issues concerning possible expansion of the IRWH technique are not applicable.

Estimation of Runoff and Impact of the IRWH Technique

In South Africa, irrigated agriculture takes place on 1.3 million hectares of land (almost 10% of the total cultivated area) and uses an estimated 12.3 billion cubic meters of surface and groundwater per year, which is about 56 percent of the total annual water use (WRC 2000). Irrigated agriculture draws water mainly from dams and water transfer schemes between catchments that ensured the retention of sufficient runoff (Beukes et al. 2004). In the

FIGURE 11.
Location of Rustfontein and Mockes Dams in the study area.



Note: Author's creation

study area, there are two dams (figure 11), namely Rustfontein Dam (see figure 12 for partial view of the Dam) and Mockes Dam that store water for the supply of potable water to the cities of Bloemfontein, Botshabelo and Thaba Nchu and also for supply of irrigation water for the downstream commercial farmers.

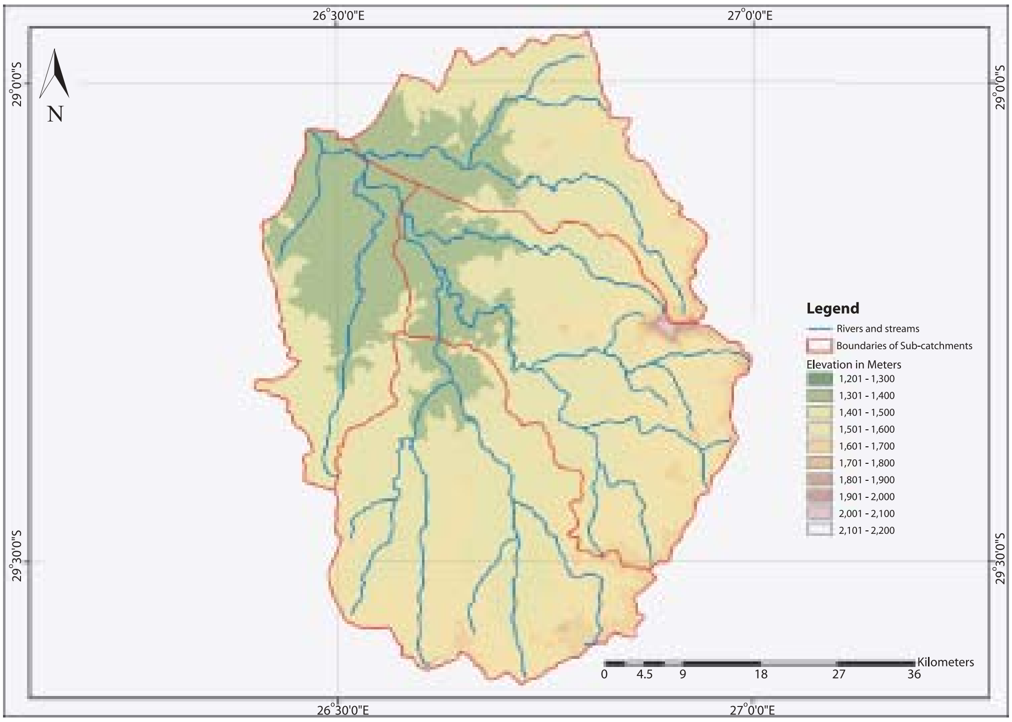
A reduction in runoff will result from practices that successfully increase the infiltration capacity of the soil, increase the contact time, and reduce surface sealing. It is commonly accepted that covering the soil with mulch, for example, with a crop residue, will achieve these goals (Unger 1990) and will also reduce evaporation from the soil surface. The IRWH technique, whereby runoff is captured in a micro basin, is found to reduce runoff from the field to zero by converting to stored soil water, and consequently to increased yields, compared with conventional tillage. The effect of the IRWH technique on retention of runoff being obvious, it is only suitable on certain type of soils and topographic conditions as discussed under the section on Application of the IRWH Techniques... (see page 13). Thus, it is worthwhile to see to what extent it can impact on runoff generation and inflow into the dams that are located in the study site.

The runoff generated from C52A, one of the sub-catchments in the study area, is captured by the Rustfontein Dam. The remaining sub-catchments, such as C52B, C52C and C52D drain into the Mockes Dam. Gauging stations placed at the vicinity of the two dams measure the incoming runoff water into the dams. Data are available for the Rustfontein Dam for 36 years giving the mean annual total runoff coming into Rustfontein Dam from a catchment area of 93,700 ha (i.e., area of C52A) as 27.9 million cubic meters (Midgley et al. 1994). The mean annual precipitation for the study area is 537 mm. Based on these values the mean runoff coefficient was calculated to be 5.945 percent, which is similar to the values obtained at experimental sites on conventional plots (total soil tillage) at Glen experimental station (Hensley et al. 2000).

FIGURE 12.
Partial view of the downstream side of Rustfontein Dam.

Source: DWAF 2004

FIGURE 13.
Digital Elevation Model of the study site.



Note: Author's creation

Using the above information, runoff amount draining into the Mockes Dam can be estimated. The catchment draining into the Mockes Dam (C52B, C52C, and C52D) have a total area of 202,000 ha. The estimated mean annual runoff flowing into the Mockes Dam is, therefore, estimated at 68.6 million cubic meters.

Table 10 shows possible scenarios of what may be expected if all the suitable land in the catchment is put under cultivation using the IRWH technique. The aim of this exercise is to see to what extent the inflow into the two dams may be affected under this extreme scenario. As shown in table 2, the area of land suitable for the IRWH technique is estimated to be 27.2 percent of the total area of the catchment (the study area). If all runoff from this portion of the catchment is retained for on-site use for crop production, it is estimated that it will reduce the mean annual runoff from 94.42 to 68.67 million cubic meters, i.e., a reduction of 25.75 million cubic meters. It should be noted that, in this part of the country, mean annual evaporation (Class A pan) is 2,198 mm (Botha et al. 2003), which can cause a tremendous amount of water loss from dams, rivers and other storage reservoirs. For instance, with the storage surface area of Rustfontein Dam which is 1, 158.5 ha, it is estimated that 25 million cubic meters of water is lost annually through evaporation. In this context, the on-site use of rainwater at upstream level for food production may contribute to the reduction of non-productive water loss due to evaporation.

However, the assumption of the scenario of all the suitable land for the IRWH technique being put under cultivation using the technique should be seen in relation to the following factors.

First, 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 15,000 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 15,000 ha of communal cropland is expected to be determined by the extent and rate at which certain constraints can be overcome (see section on Farmers' Perceptions... on page 14).

Second, 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. The technique may then even be employed by the commercial farmers on the remaining 65,667 ha of suitable land for the IRWH technique in the catchment.

So, it appears that, under present conditions, expansion of the technique into the whole suitable area is far from imminent. There is, therefore, no reason to believe that the water balance of the Modder River will soon be affected significantly as a result of the expansion of the IRWH technique. However, it is useful to study the possible impact of the different scenarios of use of this runoff water, “on-site” versus “off-site”, in relation to the comparative advantage in terms of yield, water productivity and socioeconomic factors. These are discussed under the following sections.

TABLE 10.
Estimated runoff and possible impact of the IRWH technique on the inflow of runoff into the dams.

Parameters	Unit	Values
Mean annual precipitation for C52	mm	537
Average runoff coefficient	%	5.945
Total area of the catchment (i.e., C52A-D)	ha	296,570
Total suitable area for IRWH	ha	80,667
Suitable area as % of the total area of the catchment	%	27.2
Estimated mean annual runoff from the total area	m^3	94.42×10^6
Mean annual runoff retained in IRWH area	m^3	25.75×10^6

Note: Author’s creation

Crop Production Scenarios and Water Productivity: 'On-site' versus 'Off-site'

Water productivity in rain-fed agriculture will have to increase dramatically over the next generations if food production is to keep pace with human population growth (Rockström et al*.* 2002). Furthermore, 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). In sub-Saharan Africa, over 60 percent of the population depends on rain-based rural economics, generating about 30–40 percent of the regions Gross Domestic Product (GDP) (World Bank 1997). 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 sub-Saharan Africa.

In many parts of the water scarce countries, yields from rain-fed agriculture are low, oscillating around one ton per hectare (Rockström 2001). However, many researchers suggest that the low productivity in rain-fed 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 percent and 85 percent of the rainfall evaporates from the soil surface before it could make any contribution to production.

With the use of the IRWH technique runoff and soil loss from the cropland were reduced to zero (Hensley et al. 2000). It is also reported that use of mulch in the basins reduced evaporation significantly, contributing to the increase in yield, on average 30–50 percent, compared to production under conventional tillage. On the other hand, it has been shown by several hydrological studies at watershed level that upstream shifts in water-flow partitioning may result in complex and unexpected downstream effects, both negative and positive, in terms of water quantity and quality (Vertessy et al. 1996; cited by Rockström et al. 2002).

The growing need for wise catchment management decisions is accentuated in the motivation for this project. There is a particular need for this in South Africa, and particularly in the UMMRB, 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). This project presents a question to catchment management authorities with a call for a wise decision. Although the question is currently only hypothetical, the timing is propitious in view of the importance of the UMMRB for supplying water for the growing needs of the relatively densely populated areas of Bloemfontein, Botshabelo, Thaba Nchu and the surroundings.

The catchment management question can be formulated as follows: Which of the following two strategies will result in the best use of the rainfall which falls on an important portion of the UMMRB?

(a) Allowing the 80,667 ha to remain under grassland and utilize the runoff which occurs from it to flow via storage dams and be used downstream for irrigation.

(b) Utilize all the rainfall on the 80,667 ha for growing maize (or sunflower) using the IRWH technique.

Data are presented in tables 10, 11 and 12 to facilitate the relevant catchment management decision making.

Values of critical importance in the calculations are the losses from the original runoff water which occur due to: (a) evaporation from the storage dams, and (b) transmission downstream between the two dams and downstream below Mockes dam 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 table 11, using two fairly extreme values for storage and conveyance losses, i.e., 35 percent (scenario A) and 60 percent (scenario B). For irrigation a centre pivot system with 75 percent efficiency was assumed. The total water requirement of a target yield of 10,000 kg.ha^{-1} maize was estimated to be 735 mm (Bennie et al*.* 1988).

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 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. This is confirmed by the information presented in figure 10. These facts eliminate the need to include maize production using conventional tillage as one of the options in table 11.

The two strategies given in table 11 are, firstly, veld grass in the catchment and using the runoff for centre pivot irrigation downstream; and secondly IRWH in the catchment. Two scenarios are presented, namely A and B, with storage plus conveyance losses of runoff water amounting to 35 percent and 60 percent, respectively.

The results in table 11 show expected total production under the two production strategies. The benefit derived from these different strategies will be dealt with in the economic analysis (table 12). The comparison of total maize production under the two production strategies indicates that the use of rainwater harvesting presents an ample opportunity for the small-scale farmers to increase crop yields compared with conventional methods. 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 even their daily food requirement. IRWH therefore offers an attractive option at this moment towards meeting household food security in the communal-farming area. This, however, requires a concerted effort from the part of the Department of Agriculture in the promotion of the technique and skill development of small-scale farmers for the sustainability of the system.

TABLE 11.
Water budget to compare how rainfall in a part of the UMMRB is utilized by the two strategies.

Production strategy	Parameters	Units	Values	
			Scenario A	Scenario B
Irrigation	- Total area of land suitable for IRWH	ha	80,667	80,667
	- Mean annual runoff retained by IRWH	m^3	25.75×10^6	25.75×10^6
	- Water losses (storage plus conveyance)	m^3	9.01×10^6	15.45×10^6
	- Water available at field for irrigation	m^3	16.74×10^6	10.30×10^6
	- Water demand for a target yield of 10 t maize ha^{-1}:			
	• Rainfall (50% effective) Nov-Mar	mm	190	190
	• Irrigation water (I)	mm	545	545
	• Total demand[a]	mm	735	735
	- Gross irrigation water demand with centre pivot system ([I x 100]/75) per ha:	mm	726.67	726.67
		m^3	7, 266.7	7, 266.7
	- Irrigable area with the available water	ha	2, 303.66	1, 417.42
	- Expected maize production at 10 t.ha^{-1}	kg x 10^3	23, 036.6	14, 174.2
Veld grass production	- Total grass[b] produced at 1.3 t.ha^{-1} from 80,667 ha	kg x 10^3	104, 867	104, 867
IRWH	- Maize production at 1.7 t.ha^{-1} from 80,667 ha	kg x 10^3	137, 134	137, 134

Notes: (a) Author's creation
(b) [a] Bennie et al. 1988
[b]Snyman 1998

Assessment of Financial Implications of the Different Options of Rainwater Use

A preliminary financial assessment of the different options is presented in table 12. The total allocatable cost for the use of IRWH technique was based on the work of Kundhlande et al. (2004). It was calculated for maize production using the IRWH technique with organic mulch in the basin and stone mulch on the runoff strip. The average value for three production years (1999/2000, 2000/2001, 2001/2002) was R986.71. The allocatable cost includes pre-harvest costs (seed, labor, fertilizer, pest and weed control, and maintenance of the basin) and post-harvest costs (labor, threshing, and removal of maize stems). For ease of calculation and also for the fact that the estimated value is based on data taken 5 years ago, we assumed the allocatable cost in this particular exercise to be R1000.00.

The gross margin on the runoff from 80,667 ha of land in the catchment used for downstream irrigation (assuming scenario A) plus the economic benefit derived from the grazing land from which the runoff occurred amounts to 0.0254 $R.m^{-3}$. The comparable figure for the use of the IRWH technique to produce maize is 0.0354 $R.m^{-3}$. The results provide economic support for the contention expressed in the previous paragraph in which social factors relating to the needs of the subsistence farmers are highlighted. It is clear that it would be a wise catchment management decision to allow the IRWH technique to be developed in the UMMRB. It is of value to record relevant information presented by Kundhlande et al. (2004), i.e., a family of five needs about one ton of maize per annum to supply their staple food, that the estimated maize production on the approximately 15,000 ha of the IRWH land in the communal-farming area within the UMMRB would be sufficient to supply the staple food for 127,000 people.

TABLE 12.
A financial assessment of the two production strategies and scenarios described in table 11.

Production strategy	Parameters	Unit	Scenario A	Scenario B
Irrigation plus veld grazing	- Irrigable area with the available water	ha	2,303.66	1 417.42
	- Expected maize production at 10 $t.ha^{-1}$	t	23 036.6	14 174.2
	- Gross income @ R700.ton^{-1} for maize	R	16.13×10^6	9.92×10^6
	- Allocatable cost @ R6,000.ha^{-1}	R	13.82×10^6	8.5×10^6
	- Gross margin from irrigation on 2,303.66 ha	R	2.31×10^6	1.42×10^6
	- [a]Gross margin from veld grazing on 80,667 ha by sheep plus cattle @R108.ha^{-1}	R	8.71×10^6	-
	- Gross margin for the downstreamirrigation plus veld grazing strategy	R	11.02×10^6	10.13×10^6
	- Gross margin on rainwater use forirrigation and grass $\left(\frac{GM_A \text{ or } GM_B}{0.537 \times 80667 \times 10^4}\right)^b$	$R.m^{-3}$	0.0254	0.0234
IRWH	- Maize produced on 80,667 ha at 1.7 $t.ha^{-1}$	t	137 134	-
	- Gross income @ R700.ton^{-1} for maize	R	95.99×10^6	-
	- [c]Allocatable costs @ R1,000.ha^{-1}	R	80.67×10^6	-
	- Gross margin from 80,667 ha	R	15.32×10^6	-
	- Gross margin on rainwater use for IRWH $\left(\frac{15.32 \times 10^6}{0.537 \times 80667 \times 10^4}\right)$	$R.m^{-3}$	0.0354	-

Notes: (a) Author's creation

(b) [a]The procedures used to obtain this data are from Snyman (1998), with adjustments for current conditions by Snyman (personal communication 2005), and Free State Department Agriculture Economist, van Rensburg (personal communication 2005). The data apply to commercial farmers

[b]GM_A = Gross Margin based on scenario A. GM_B = Gross Margin based on scenario B

[c]Khundhlande et al. (2004)

Conclusion and Recommendations

The ultimate goal of water resources policy in a river basin management is to increase the beneficial utilization of the rainwater falling in the catchment through reduction of non-beneficial losses and water pollution. Rainwater harvesting coupled with appropriate farming practices can contribute towards achieving the goal of increasing the beneficial use of water in a river basin management.

The IRWH technique introduced to the small-scale communal farmers in the Upper and Middle Modder River Basin (UMMRB) is one such practice designed to increase yields under dryland crop production compared to conventional tillage, and hence increase the water productivity. This study has showed relatively higher gross margin on rainwater use for maize production using the IRWH technique in the catchment compared to using the rainwater for downstream irrigation farming.
The contribution of this practice towards the household food security and increased income for the small-scale farmers, who do not have access to irrigation water, is significant if farmers are willing and capable of expanding it.
The majority (86%) of the small-scale farmers interviewed in this study reported that this technique contributes to their household food security. However, 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 nongovernmental organizations operating in the area.

The results of the socioeconomic survey among the communal farmers who occupy about 35 percent of the UMMRB revealed that leaders of the communities are positive in most cases about the IRWH technique, although the odd case of disinterest or absolute negativity was found. The people themselves seem to be demotivated by their lack of farming skills, lack of tools and theft that seems to be fairly prevalent in some places. A low level of institutional cooperation was mentioned as well as a fair number of cases where the biggest problem was described as a lack of motivation. On the other hand, the surveying team was struck by the apparent supportive role that participants of the IRWH technique played to each other. The absence of fences around community croplands allowed livestock free access to whatever could be planted, and that seemed to be a big demotivator against the expansion of the IRWH technique to beyond home garden size.

Indications are that a fairly rapid spread of the application of IRWH technique can be expected within the scope of the homestead size, but no significant spread to community crop lands and beyond is expected in the short term because of socioeconomic constrains. Factors that count for rapid expansion are, among others, the good understanding of the technique by the communities, the obviously higher production and more food per family, and the possibility of making some money by selling the surplus produce. The support services provided by the ARC-ISCW research group, such as free supply of seed and fertilizer and the intensive servicing of the communities do have a positive influence on future expansion. However, the high levels of poverty and the fact that the communities have to rely on limited family labor for the preparation and cultivation of these plots limits potential development in most of the cases to a level that can be handled within the frameworks of the available family labor. Furthermore, lack of tools and lack of fences around community crop lands can lead to theft and damage by animals, which can be considered as demotivators for the significant spread of the IRWH technique.

The key data for the focal point of this study are presented in tables 10, 11 and 12. It aims at providing the information needed for the relevant catchment management decision regarding wise use of rainwater falling on the 80,667 ha of land in the UMMRB considered being suitable for the IRWH technique. The data shows clearly that from all points of view i.e., precipitation use efficiency, social considerations and economics, it would be a wise decision to allow the IRWH technique to be expanded in the UMMRB rather than suppress development to the benefit of downstream irrigation. What may become a regulating factor in the future is the growing need for more water for municipal and industrial purposes in the ever growing Bloemfontein, Botshabelo and Thaba Nchu areas.

To complete this study it has been necessary to make a number of assumptions to provide the data for tables 11 and 12. In order to make the necessary improvements the research team wishes to recommend that further research and more detailed study be done with regard to the following:

- Obtaining reliable values for storage losses in the dams and runoff transmission losses;
- An in-depth study of the catchment water balance taking into account the current inter-catchment water transfer schemes;
- Completing the development of the hydrological modelling study using HSPF (Hydrological Simulation Program-FORTRAN), ACRU (Agro-hydrological Model), or Water Resources Yield Model (WRYM) in order to quantify the impact of IRWH on the water yield at the dams in the catchment;
- Disaggregation of the hydrological model so as to be able to compute runoff from each soilscape separately. This should provide more reliable information regarding runoff reduction due to IRWH, since application of the technique is only possible on specific topographical sites;
- Comparison of the total effect of irrigated agriculture versus IRWH on communities;
- Developing and testing of cultivation equipment that will enhance the expansion of the IRWH technique;
- Developing of accredited IRWH training material for farmers, and additional involvement of educational and tertiary Institutions to enhance the up-scaling process; and
- At this stage the identification of land suitable for IRWH in the UMMRB has been done in an extensive way, based on an expert system estimation procedure applied to each of the soilscapes separately. For efficient expansion of IRWH in the UMMRB and in other parts of the semi-arid regions of South Africa, a prerequisite is more detailed soil survey information at a scale of 1:10 000 to provide reliable soil boundaries for small-scale farmers. In view of the many new technologies (GIS Software and GPS instruments) available for facilitating such surveys, contributing towards fulfilling this need offers a valuable opportunity for research and extension.

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