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An integrated modelling framework to aid smallholder farming system management in the Olifants River Basin, South Africa

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ABSTRACT

Computerised integrated models from science contribute to better informed and holistic assessments of multifaceted policies and technologies than individual models. This view has led to considerable effort being devoted to developing integrated models to support decision-making under integrated water resources management (IWRM). Nevertheless, an appraisal of previous and ongoing efforts to develop such decision support systems shows considerable deficiencies in attempts to address the hydro-socio-economic effects on livelihoods. To date, no universal standard integration method or framework is in use. For the existing integrated models, their application failures have pointed to the lack of stakeholder participation. In an endeavour to close this gap, development and application of a seasonal time-step integrated model with prediction capability is presented in this paper. This model couples existing hydrology, agronomy and socio-economic models with feedbacks to link livelihoods of resource-constrained smallholder farmers to water resources at catchment level in the semi-arid Olifants subbasin in South Africa. These three models, prior to coupling, were calibrated and validated using observed data and participation of local stakeholders. All the models gave good representation of the study conditions, as indicated by the statistical indicators. The integrated model is of general applicability, hence can be extended to other catchments. The impacts of untied ridges, planting basins and supplemental irrigation were compared to conventional rainfed tillage under maize crop production and for different farm typologies. Over the 20 years of simulation, the predicted benefit of untied ridges and planting basins versus conventional rainfed tillage on surface runoff (Mm^3/year) reduction was 14.3% and 19.8%, respectively, and about 41–46% sediment yield (t/year) reduction in the catchment. Under supplemental irrigation, maize yield improved by up to 500% from the long-term average yield of 0.5 t/ha. At 90% confidence interval, family savings improved from between US$ 4 and US$ 270 under conventional rainfed to between US$ 233 and US$ 1140 under supplemental irrigation. These results highlight the economic and environmental benefits that could be achieved by adopting these improved crop management practices. However, the application of various crop management practices is site-specific and depends on both physical and socio-economic characteristics of the farmers.

1. Introduction

Agricultural development in the Olifants subbasin of the Limpopo River Basin, South Africa is severely constrained by low and erratic rainfall, high temperature, decreasing soil fertility and limited farmer access to increased productivity options. Availability of new and technically feasible farm production systems, supported by appropriate policies, is generally considered to enhance food security, especially in smallholder rainfed agriculture. However, local farmers, water management institutions including agricultural institutions have been slow in building both technical and policy related capacity to adapt to new crop management practices under both climate and market variability. Climate change, likely to increase the occurrence and intensity of water-related natural disasters (IPCC, 2001, 2007), compounded by political and socio-economic changes, has called to question the viability of traditional decision-making norms that are typically guided by experience and rules of thumb in achieving sustainable rural livelihoods.

In the design and selection of decisions related to effective agricultural policy and technological interventions over a range of practices from rainfed, field conservation to full irrigation (CAWMA, 2007), integrated systems modelling has proved to be a useful tool (RNAAS, 2005; Loevinsohn et al., 2002; Parker et al., 2002; Sibbald et al., 2000). In addition, a comprehensive approach to coordinated policy-making continues to be recognised internationally through major UN Conferences (Abaza and Hamwey, 2001). It is on this basis that a study was carried out to develop an integrated model, ICHSEA (innovative coupling of hydrological

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and socio-economic aspects), comprising hydrology, agronomy and socio-economic models in the B72A quaternary catchment of the Olifants subbasin in South Africa, as part of the Challenge Programme Water and Food Project PN17. ICHSEA simulates farmers' food security and productivity responses to changes in agricultural practices, crop and input prices relative to a base year. It serves as the main driver in evaluating policy and weather related impacts of identified farming systems in the quaternary catchment.

The main objective of this paper is to illustrate the application of ICHSEA tool to support rainfed agriculture strategies for improved productivity of the maize crop to meet family food security, while satisfying downstream water requirements. By employing an integrated approach through ICHSEA, ways for reducing human vulnerabilities were explored by assisting farmers understand their agricultural production systems.

The subsequent sections describe ICHSEA model framework and its application to B72A catchment where scenarios of four crop management practices and maize market price variations under smallholder farming systems are assessed.

2. Study area

The quaternary catchment, B72A, with an area of 534 km^2 and located in the lower Olifants subbasin, was chosen as the study area (Fig. 1). The catchment is situated about 60 km south of Tzaneen in the Limpopo province. This catchment falls under Maruleng local municipality, in Mopani district municipality and is part of the Ga-Sekororo and Letsoalo Tribal Authorities. A large percentage of the catchment (80%) falls under the former Lebowa homeland, with an estimated eleven thousand smallholder farmers, each with an average land size of 1.3 ha (Magombeyi et al., 2011). The topography of the basin varies widely with altitude (Fig. 1). The climate is largely controlled by the movement of air-masses associated with the Inter-Tropical Convergence Zone. Hence, the area experiences seasonal rainfall that largely occurs during the summer months, from October to April. The mean annual rainfall is 603 mm; with potential evapotranspiration above 1500 mm (actual evapotranspiration is around 840 mm) and the average maximum temperature of 27 °C (DWAF, 2004). Soils are shallow and of poor nutrient status (Raisuba, 2007). Groundwater recharge occurs in only 3 months of the year from late December to March. The main rivers in the catchment are Malomanye and Makhutsi rivers. Some of the catchment priorities are promoting sustainable development for poverty alleviation and introducing technologies to optimise water use efficiency.

3. Model framework

The ICHSEA model innovatively couples SWAT (hydrology; Neitsch et al., 2001a, 2001b; Arnold et al., 1993), PARCHED-THIRST (crop growth; Young et al., 2002) and OLYMPE (socio-economics; Penot and Deheuvels, 2007). The ICHSEA interface was developed in Avenues script language in ArcView 3.3, to take advantage of the mapping capability of ArcView.

The ICHSEA model framework, showing model connections, is shown in Fig. 2. The suite of models comprises hydrology, agronomy and socio-economic models. The integrated model time-step is seasonal, but each model runs on a temporal resolution appropriate for the processes being modelled, ranging from daily to seasonal. Detailed descriptions of these individual models are presented in Magombeyi (2010).

Firstly, a physically based distributed hydrological model (SWAT) was used to generate surface runoff and sediments in the catchment. This model uses the hydrological response unit method (assumes similar hydrological response from similar land use, soil and topography to the same meteorological conditions) to generate

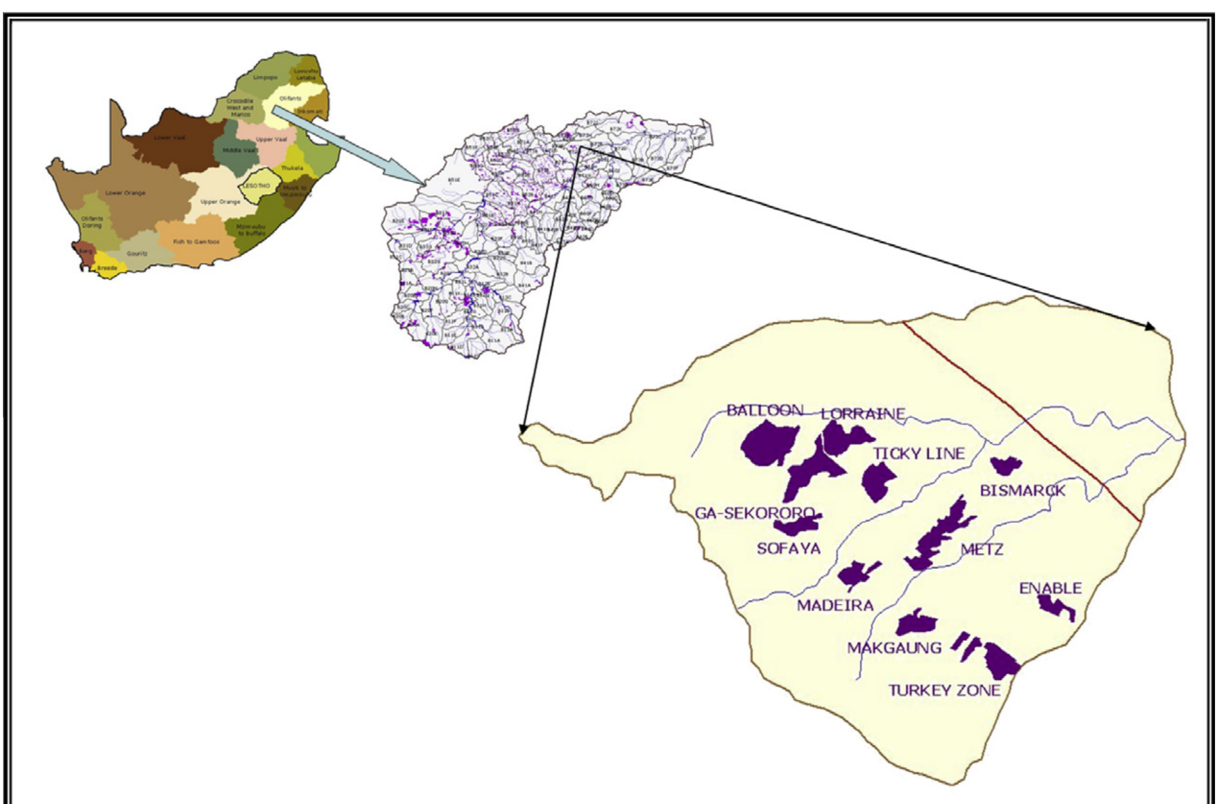

Fig. 1. Location of B72A quaternary catchment in Olifants River Basin, South Africa.