

1 Managing water by managing land: Interactive land use planning using water productivity indicators

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Abstract

Many river basins in the world experience unprecedented pressures on -and increasing competition for- water resources. The availability and quality of water resources are, however, principally related to land use and land management. In the absence of specific land planning institutions at catchment level, river basin organizations should take up the responsibility to liaise with spatial planners and land users aimed at the better incorporation of land use planning and management in water management.

Land and water development and management strategies may serve multiple policy objectives, which can also vary from place to place. Examples of development targets are food security, income security, social security (employment), equitable water allocation and ecological integrity.

To facilitate stakeholders' discussions, policy dialogues and negotiations on land use planning and management Alterra, LEI and WaterWatch have developed an interactive open-source web-based discussion support tool, which can instantaneously generate spatially distributed information on tangible indicators on water consumption, (economic) water productivity, water-related employment and water availability. The tool can assist stakeholders to evaluate trade-offs between alternative land development scenarios and courses of (social) actions that may impact on water resources and –use. As the tool uses consistent, transparent, impartial and verifiable information, it stimulates open discussions among stakeholders and contributes to confidence building. The tool has been applied in stakeholders' meetings in the Inkomati basin in Southern Africa.

1.1 Introduction

1.1.1 Global water stress

Many river basins in the world experience unprecedented pressures on land and water resources. Main drivers are the population growth, socio-economical developments (such as the liberalization of the world food markets), socio-cultural developments (such as changes in lifestyles and diets) and the global climate change. These developments result in a rapid worldwide growing demand for fresh water. At the same time are water resources subject to increased variability in availability and quality, causing increasing imbalances between supply and demand.

The increased competition for water, which has social, agronomic, economic and environmental implications, is globally recognized as one of the most serious problems of this millennium. In

many river basins water resources are over-exploited, which causes tension or conflicts between water users and the degradation of important ecosystems.

1.1.2 Stakeholders and water management

To effectively deal with competing claims on water resources good communication between stakeholders within the river basin is crucial. Their active and genuine participation is imperative in the search for consensus on water management and for raising commitment to support and comply with decisions taken. This entails a legal and institutional setting which properly reconciles the interests of all stakeholders in the river basin. It also requires transparent and impartial information, particularly in the case of large river basins with stakeholders from various sectors, regions and countries.

1.1.3 Scope and objectives of research

In many water-stressed river basins tough decisions on water allocation, reallocation and/or prioritization are inevitable, as the scope for water supply management (e.g. transport and/or storage of water) and water demand management through increasing end-use efficiencies (e.g. water saving measures, water reuse) has often been fully exploited already. These decisions are generally the domain of water managers. This situation does however not sufficiently acknowledge the role of rainfall as the ultimate water resource, as will be shown in this article. As the fate of rainfall and the availability and quality of surface water and groundwater resources, including their spatial-temporal variability, primarily depends on land use and land management, spatial planning and land management are crucial for water management.

In this article the role of land use planning in water management will be elaborated and a tool will be presented that can support stakeholders in a river basin to identify and discuss feasible land development scenarios according to different policy priorities. The tool has been applied in the Inkomati river basin, within the framework of stakeholder discussions on trans-boundary water management issues.

1.2 *Rationale: Managing water by managing land*

Water management organizations, including River Basin Authorities, are usually -and to various degrees- responsible for the development, distribution and protection of surface water and groundwater resources. These water resources however cover only a small portion of the hydrological cycle and the overall water resources in a river basin. The surface water and groundwater can be referred to as “blue water” (Figure 1). Blue water is the traditional domain of water engineers and licensing authorities, as this water can be transported and manipulated through water infrastructures.

The soil moisture is referred to as the “green water” resource (Figure 1). Any manipulation of green water is principally done through land management practices (by the land user). The use of the soil water by the various possible land uses (e.g. agriculture, forestry, nature) causes a green water flow to the atmosphere. Soil water can be replenished naturally by precipitation, or artificially through irrigation (blue water). The green water flow may, therefore, (partially) originate from rainfall and from blue water resources.

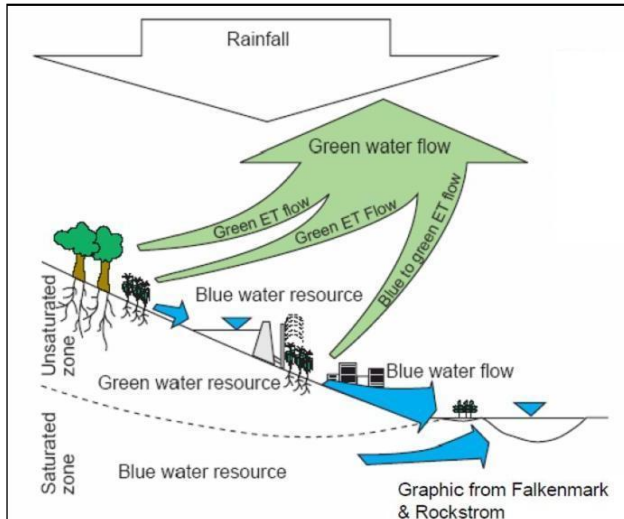


Figure 1. Blue and green water (after Falkenmark & Rockström)

On a global scale blue water constitutes only one third of the rainfall (Falkenmark and Rockström, 2006). In water-scarce river basins the blue water resources often represent an even lower percentage of the rainfall. It would, therefore, make sense to pay more attention to the management of the green water in relation to rainfall, as the manipulation of the green water flows can have huge impacts on the hydrology and water resources of a river basin. The planning and management of green water flows is principally the domain of spatial planners and land users, such as farmers.

1.3 Coping with competing claims on water resources

1.3.1 Green water flow management

Discussions on water allocation often highlight the stake of irrigated agriculture, which can be regarded as the portion of agriculture that uses blue water resources. In many river basins in semi-arid areas irrigated agriculture may indeed utilize most of the allocated blue water resources. It is, however, often ignored that the total consumptive water use in a basin by rain-dependent agriculture, forestry and ecosystems generally largely exceeds the water consumption by irrigated agriculture.

In this research the focus has, therefore, been on the investigation of options to manipulate the green water flows through spatial planning rather than manipulating blue water resources (e.g. by water saving or reallocation). An important implication of green water flow management is that the traditional distinction between rain-fed and irrigated agriculture becomes superseded, as irrigated agriculture can just be regarded as one of the many water uses that generates green water flow.

1.3.2 Constraints in land planning and management

A major constraint is that land use is generally not planned and managed at the level of river basins, despite of the huge impact of land use on the hydrology and water resources. As a result sub-optimal conditions have often emerged. Good economical or ecological prospects of downstream areas are often being infringed by water scarcity or pollution, while less favorable areas, located in the upstream portions, are using the water resources sub-economically or sub-ecologically. This is especially valid for trans-boundary river basins, where upstream countries tend to focus on their own interest rather than on the entire river basin.

In the absence of specific land planning institutions at catchment level river basin organizations should be encouraged to start dialogues and discussions with spatial planners and to incorporate -where possible- land use planning and management issues in their mandate. To be effective there should be a good understanding of the interaction between land and water, particularly in the consumptive water use of the various land uses.

1.3.3 Need for transparency

A frequently occurring problem in land and water management issues is that data and models are not transparent and objective, which obstructs their acceptance by stakeholders. The acceptance by stakeholders is often more critical than the accuracy of information. In this research the focus has, therefore, been on relatively simple, verifiable methods that generate consistent information throughout the river basin.

1.4 Policy objectives and prioritization

Any land and water development and management strategy should obviously follow policy objectives and priorities, which can serve single or multiple development goals. Policy objectives in land and water management can target:

- Food security
- Income security
- Social security (employment)
- Equitable water allocation
- Ecological integrity

Indicators can help to assess the current situation and to identify and evaluate proposed land and water development scenarios which best serve policy objectives and priorities. For this purpose the following set of indicators are used (Table 1):

Table 1. Indicators (see also Hellegers et al, submitted)

Policy objective	Indicator	Description
Food security	Crop water productivity	Beneficial biomass per unit of water consumed
Income security	Economic water productivity	Net private benefits per unit of water consumed
Social security	Job water productivity	Employment per unit of water consumed
Equitable water allocation	Water availability for downstream uses	Volume of water to downstream uses
Ecological integrity	Ecological returns on water	Various indicators for biodiversity possible

The policy objective to promote food security is aimed at maximizing the *crop water productivity*, which is the beneficial biomass (yield) per unit of consumed water. If income security should have the highest priority then land and water management scenarios should target maximum *monetary returns on water*. For agriculture this implies that the monetary value of the produced beneficial biomass (yield) per unit of consumed water should be maximized. The economic water productivity can be calculated if the prices of commercial (agricultural and forestry) inputs

and outputs are known. The economic water productivity is also referred to as the “*value of water*” or “*net return to water*”.

The policy objective to promote social security is here defined as maximizing the employment per unit of consumed water. The policy objective to promote equitable water allocation is aimed at ensuring that sufficient water is available to downstream uses. The water availability to downstream uses is an important indicator for the ecological reserve (environmental flow requirements) and water assurance commitments (water rights), including international agreements. Disaster management such as floods and droughts can also be regarded as aspects of water equity, but to adequately assess these phenomena additional, more specific indicators are required. The policy objective to prioritize on ecological integrity should focus on land and water management options that maximize the ecological benefits per unit of consumed water, for example through the creation of valuable nature areas.

1.5 Discussion support for policy development

1.5.1 Concept

Alterra, LEI and WaterWatch have jointly developed an interactive, web-based and GIS-based tool to assist land and water managers in identifying and assessing scenarios that best serve the policy objectives and priorities (the tool supports strategic management). As policy priorities may vary across the river basin while also multiple objectives may need to be addressed the tool does not optimize on land and water management, but rather support discussions. Stakeholders can interactively identify and evaluate land development scenarios and quickly assess whether or not envisaged policy priorities will be achieved. As ecological objectives and tangible biodiversity indicators can be very diverse across a catchment the tool does not incorporate information on the ecological returns on water. However, stakeholders can define environmental flow requirements through the water availability indicators.

The tool is based on a number of relatively simple concepts and assumptions, giving priority to objectivity, transparency and rapid assessments. These qualifications make the tool suitable to be applied in multi-stakeholder meetings, in workshops and by individuals to analyze (and jointly discuss) the current situation and identify alternative land development strategies. Promising alternatives may then be investigated by more detailed studies (Figure 2):

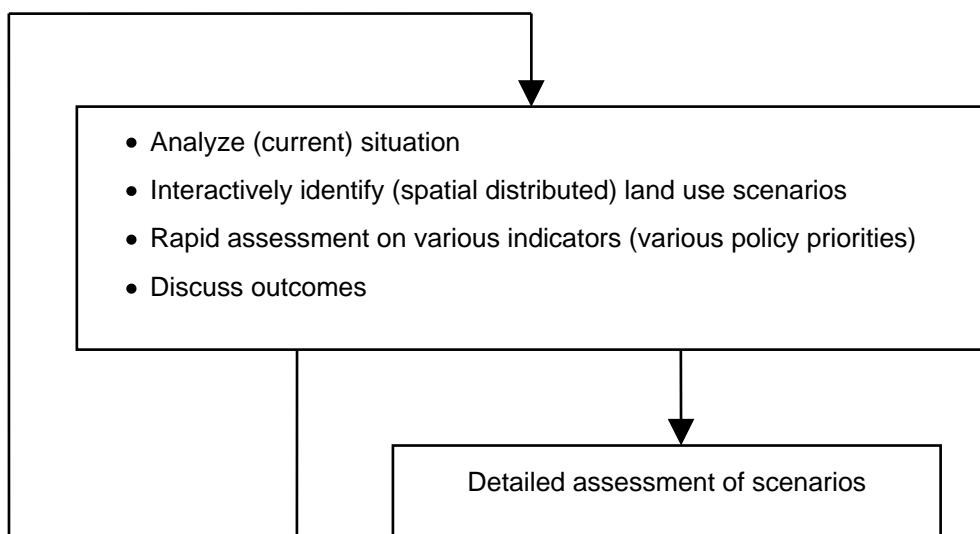


Figure 2. Scenario development

1.5.2 Data

To quantify the land and water indicators, land use data, climatic data, crop growth data and socio-economical data are required. Table 2 present a summary of the required data and data sources:

Table 2. Summary of data and sources

Indicator	Data required	Data source
Crop water productivity	Land use ¹⁾	Land use maps
	Actual evapotranspiration ³⁾	Satellite images & remote sensing
	Beneficial biomass or yield ^{3,4)}	Satellite images & remote sensing
Economic water productivity	See under Crop Water Productivity	
	Market price ³⁾	Surveys, statistical bureaus, farmers' organizations
	Variable financial production cost ³⁾	
Job water productivity	Land use ¹⁾	Land use maps
	Number of jobs required to manage the land	Surveys, statistical offices
	Actual evapotranspiration ³⁾	Satellite images & remote sensing
Water availability for downstream uses	Land use ¹⁾	Land use maps
	Rainfall ²⁾	Tropical Rainfall Measurement Mission (TRMM; radar) or meteostations
	Actual evapotranspiration ³⁾	Satellite images & remote sensing

¹⁾ Spatially distributed

²⁾ Spatially and temporally distributed

³⁾ Spatially and temporally distributed and for each land use

⁴⁾ Calculated from the gross biomass production and the harvest indices (which can be determined through historical yield data and/or literature)

It is assumed that the consumptive water use is represented by the actual evapotranspiration. The actual domestic and industrial consumptive water uses can be neglected, as most domestic and industrial uses are non-consumptive recoverable uses (Perry, 2007). The actual evapotranspiration is the green water flow in Figure 1. Both the actual evapotranspiration and gross biomass production were quantified with the Surface Energy Balance Algorithm for Land (SEBAL) applied on freely available MODIS images, which have a spatial resolution of 250x250 m and a temporal resolution of approximately 2 weeks.

The maps with the actual evapotranspiration and biomass production were combined with the land use map to obtain the consumptive water use for each land use on a pixel by pixel basis. The harvest indices can vary spatially, as certain areas are more suitable to grow a specific crop than other areas, and temporally, as climatic conditions and related yields vary from season to season. Socio-economical data such as the market prices of crops and the variable and fixed financial production costs also vary spatially and temporally. Rainfall, evapotranspiration and biomass production can be determined objectively through remote sensing techniques. The harvest indices and socio-economical data may however be subject to discussions and can therefore be specified by the user.

The water availability for downstream uses is calculated as the accumulated rainfall surplus in all upstream areas. Percolation losses (e.g. from irrigation systems), domestic and industrial waste waters are regarded as internal (recoverable) flows and volumes, as they remain within the system.

1.6 Example of application: The Inkomati basin

1.6.1 Rainfall and irrigation

The discussion support tool has been applied in stakeholders' meetings in the Inkomati river basin in Southern Africa, which is a trans-boundary river basin shared by South Africa, Swaziland and Mozambique. The Inkomati basin is a typical showcase of a river basin where many of the globally experienced problems are encountered:

- Competing claims on water resources (between sectors and areas/countries), over-allocation of water resources;
- (Increasing) water variability & scarcity, aggravated by the global climate change;
- Socio-economical developments and land reforms.

As in many other water-scarce river basins discussions on water management focus on irrigated agriculture. In the Inkomati basin approximately 80% of the allocated blue water resources are utilized by irrigated agriculture. However, irrigated agriculture accounts for less than 20% of the total consumptive water use by agriculture (Figure 3). By far most of the water is used by rain-dependent agriculture, forestry and ecosystems, which reconfirms that the hydrology and water resources in the basin are primarily determined by land use.

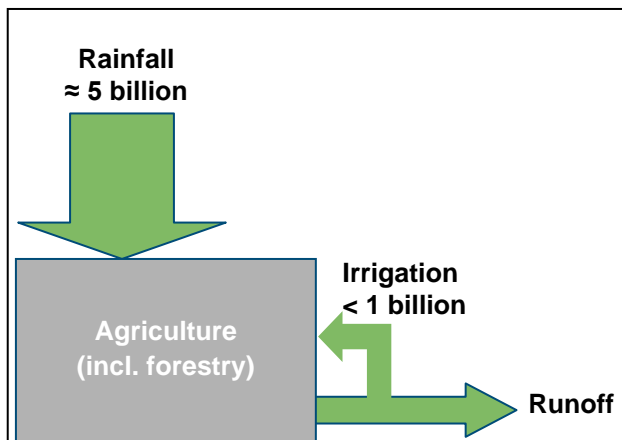


Figure 3. Rainfall and irrigation on agricultural lands in the Inkomati basin

1.6.2 Interactive land use planning

The discussion support tool can quantify (spatially and temporally) the consumptive water use by various land uses, provide on-line (instantaneous) spatial and temporal information on the impact of changes in land use on the water availability and on a number of water productivity indicators, which can be used to identify the most feasible land development strategies. Periods of one year can be assessed, which thus covers a hydrological cycle. The user can introduce and assess land use changes in 24 subareas, which can be considered as “land management areas” (Figure 4). For these subareas the market prices, production costs and harvest indices can also be specified and altered. After each adjustment the tool instantaneously recalculates the indicators, display them in tables and maps, and compare them with the current (reference) situation (Hellegers et al, submitted).

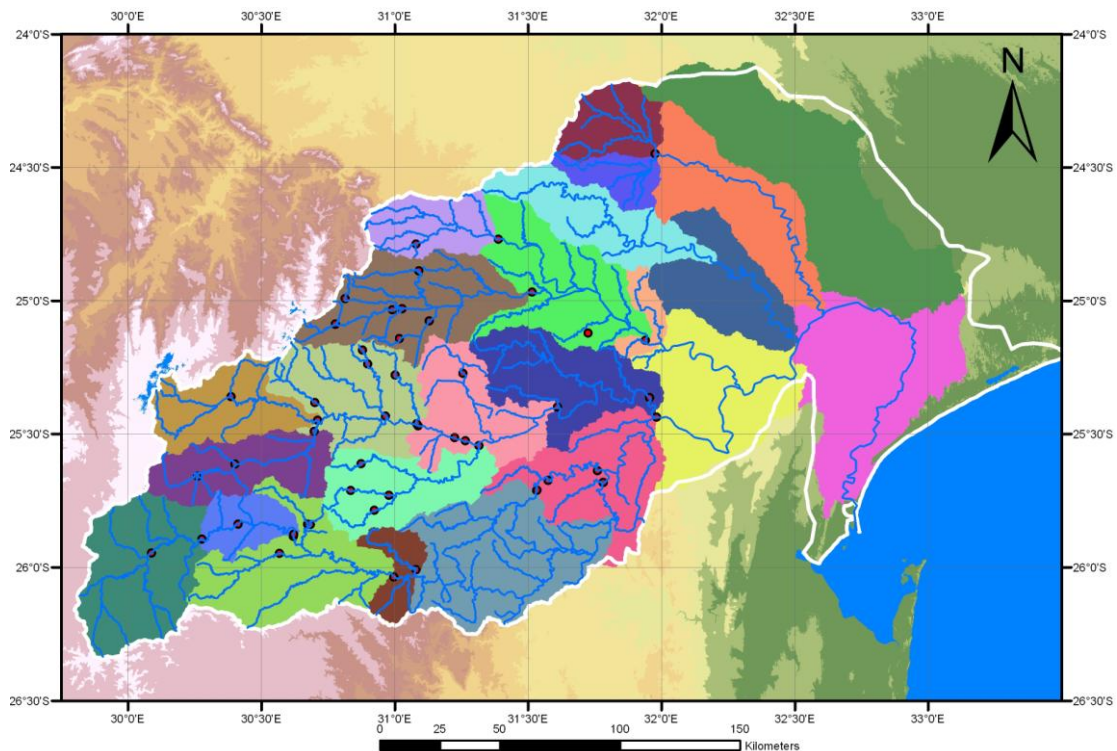


Figure 4. Subareas

In the stakeholder meetings representatives from the riparian states have identified and discussed land development scenarios. One of the plans that was brought forward was the conversion of 25,000 ha of bushland for biofuel production by sugarcane in Mozambique. Detailed results of these assessments are described in Hellegers et al, submitted.

The tool showed that the conversion of land for sugarcane production would cause a decrease in the rainfall surplus of approximately 50 million m³ in an average year, as sugarcane consumes more water than bushland. The water availability for downstream areas would then decrease by 3%. In dry years the already experienced shortages would aggravate, which means that this scenario is only feasible if provisions are made to cover water shortages. Arrangements need to be made with upstream water uses to release more water. Alternatively surface water reservoirs or boreholes can be constructed (provided that their impacts are acceptable).

The water availability to downstream uses will thus reduce, but the socio-economical indicators show positive effects: Both the crop water productivity and the economic water productivity will considerably increase. The economic water production value of the area increases by more than 300 million ZAR/year in an average year. The cultivation of sugarcane also creates about 17.000 additional jobs in the area. These economic and social benefits may provide space for negotiations and compensation schemes with less productive upstream water uses.

1.6.3 Other findings

It was found that the economic water productivity is not equated among the crops in an area. Such spatial variations in the subareas can be due to management practices, random, uncontrollable events and the natural productivity of the farm resources (Hellegers et al., 2010). Examples of management practices are irrigation application practices, weed control, seed selection, the use of nutrients and pesticides. Examples of random events are droughts, storms

and pest attacks. The natural productivity of farms depends on the climate, local hydrology and soil properties.

1.7 Conclusions

The hydrology, the availability and quality of surface water resources and groundwater resources are primarily determined by land use and land management. In the absence of specific land planning institutions at catchment level river basin organizations should take up the responsibility to liaise with spatial planners aimed at the better incorporation of land use planning and management in water management. Effective dialogues and discussions with spatial planners require good understanding of the interaction between land and water and the (spatial-temporal) consumptive water use of the various land uses. Moreover should information be consistent, transparent, objective and verifiable in order to be accepted.

Land and water development and management strategies may serve multiple objectives as policy objectives and priorities can vary across river basins. Examples of development targets are food security, income security, social security (employment), equitable water allocation and ecological integrity. Biophysical and socio-economical water (productivity) indicators can help to assess the current situation and to identify and evaluate proposed future land and water development scenarios.

The discussion support tool developed by Alterra, LEI and WaterWatch can instantaneously generate spatially distributed information on tangible indicators on water consumption, water productivity, and water availability. The tool can assist stakeholders to evaluate trade-offs between alternative land development options and courses of (social) actions that may impact on water resources and –use. It promotes open discussions among stakeholders and thus contributes to confidence building.

The tool is aimed at rapid assessments, which means that promising options should be investigated in more detail. The quality of the rapid assessments largely depend on the quality of the underlying data, particularly the land use map and the economic basic data such as the market prices and production costs. It should be noted that large changes in land use can affect market prices, especially if crops are produced for the local markets, since the supply will change.

1.8 Discussion and recommendations

Indicators

As information on biomass production is generated, it is possible to assess carbon sequestration policies, using the indicator “mass of carbon sequestration per unit of consumed water”. Ecological indicators may also be incorporated in the tool, but it should be noted that the assessment of ecological benefits from water would require that the land use map would be more specifically directed to ecosystems.

Operational land and water management

The current approach and tool are aimed at strategic land use planning. In the future operational land and water management can be incorporated, for example to respond to occurring droughts and floods. The focus on land planning and management may also be widened to incorporate options to improve water management and water saving. Assessments for short periods during the year would require a dynamic hydrological model which incorporates

hydrological processes, particularly the slow components (soil moisture, groundwater recharge and –flow) and storage.

Prioritization in interventions

By investigating the stochastic characteristics of indicators options for interventions in management practices and water saving can be evaluated. For example, a high standard deviation in the water productivity for one of the land uses in a certain subarea indicates that there is scope for improvement. Possible interventions are the training of farmers and/or the introduction of more modern agricultural and on-farm water management practices. The feasibility of interventions require the knowledge of local stakeholders as emerging farmers may experience other constraints than sugarcane enterprises.

The tool may also reveal water productivity differences between various areas. Apart from biophysical factors (e.g. the climate, soils) this may be due to farming practices. By evaluating these spatial differences target areas for interventions can be identified.

With the stochastic data from the pixel-to-pixel information location-specific crop production functions (showing the yield as a function of the consumptive water use) can be derived. This can help to optimize water allocation strategies and to develop strategies for fractional irrigation in times of scarcity. As operational water management, on-farm water management, water saving and water allocation are key issues in the Inkomati basin it is recommended to extend the tool with these functionalities.

Acknowledgement

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