# WatPLAN

# Spatial earth observation monitoring for planning and water allocation in the international Incomati Basin

[FP/2007-2012] - 262949

# Final Publishable Summary Report

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# 1 Executive summary

Equitable and efficient water management and allocation, especially across country borders, needs accurate information on the use and availability of water resources in space and time.

The Incomati River Basin is shared between South Africa, Mozambique and Swaziland and transparency is needed in water allocation to ensure that international obligations are met. An operational monitoring system that covers the entire basin can fulfil that need for transparency by providing quantified information on water use.

The "Spatial Earth Observation Monitoring for Planning and Water Allocation in the International Incomati Basin project" - or WatPLAN - setup and operates such a monitoring system. This joint European Union-Africa GMES earth observation project combines earth observation and in situ data to provide near-real time quantified information at field scale on (agricultural) water need and consumption.

The novelty of the WatPLAN project extends beyond the unique technical use of remote sensing data; the joint efforts of a consortium of international SME`s and universities have resulted in an unique operational monitoring system that is capable of providing weekly quantified information at field scale. To obtain this information the Surface Energy Balance Algorithm for Land (SEBAL) model is used. This model has been applied and evaluated in more than 30 countries including many African countries. The energy balance describes how solar energy is distributed; part is reflected of or absorbed by the surface, and part is used for plant growth. These components of the energy balance can be derived from satellite data using the model to quantify an important component of the water cycle - Evapotranspiration (ET). Subsequently biomass production, the actual-, and potential water consumption and water deficit is derived on a pixel-by-pixel basis. Another important parameter within the WatPLAN project is rainfall. This is derived by combining microwave data from the FEWS-NET sensor with in situ rainfall data measured using low cost meteorology stations installed as part of the project. Combined these data products provide valuable insight in various aspects of the water balance important for water management. For example, combining rainfall and crop water use provides insight into the distribution of renewable water resources across the Incomati Basin. Crop yield can be derived from the biomass production estimates. Dividing crop yield (kg) by crop water use ($m^3$) gives us water productivity which defines how much water is used per kg harvestable crop (crop per drop).

These data products have the potential to assist different users including the Tripartite Permanent Technical Committee (TPTC), the Inkomati Catchment Management Agency (ICMA), irrigation boards and farmers in objective and sound water resources management. The data products provided can also be used as the basic inputs for water accounting, which is a relatively new framework designed to provide explicit spatial information on water depletion and net withdrawal processes in complex river basins. Water accounting contributes to better water allocation, verification of water use and sustainable utilization of scarce water resources. The data products are disseminated using an internet based portal where data can be viewed per sub basin and for the various land use classes (forest plantations, natural vegetation, sugarcane and other irrigated crops). The WatPLAN portal currently has over 70 unique registered stakeholders who frequently visit the data portal. Weekly data has been provided for the entire basin of 46,469 km2 with information for every 30m x 30m pixel. Data is freely available on www.watplan.com and training material can be viewed online at www.watplan.eu.

## 1.1 Project context and objectives

### 1.1.1 Background

The transboundary Incomati River Basin [Figure 1] covers 46,800km2 and is shared by South Africa (61%), Swaziland (5%) and Mozambique (32%). The river basin extends over several parallel river catchments which all drain in an easterly direction, and flow together at the border with Mozambique or within Mozambique, to form the Incomati River which discharges into the Indian Ocean immediately North of Maputo. The main river is the Komati River, the most Southern tributary of the Incomati River, which rises in South Africa and flows into Swaziland, then re-enters South Africa where it is joined by the Crocodile River at the border with Mozambique, before flowing into Mozambique as the Incomati River. The Sabie River is the other main river in the water management area. It flows into Corumana Dam in Mozambique just downstream of the border with South Africa and upstream of its confluence with the Incomati River.

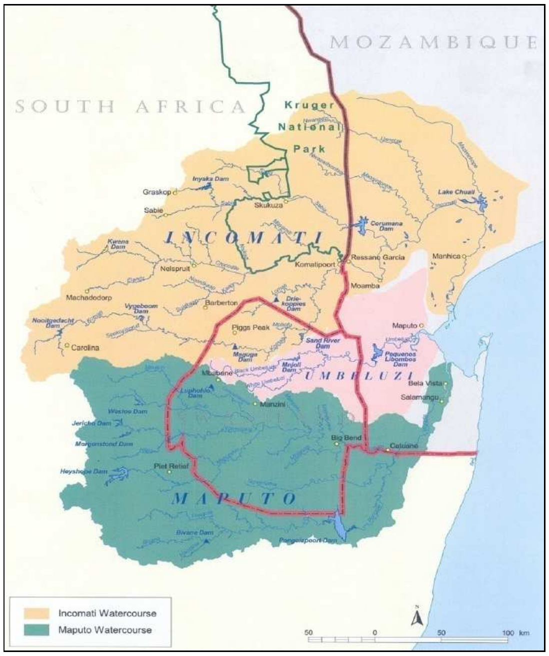


Figure 1 The Incomati River Basin

The need for cooperation between South Africa, Swaziland and Mozambique to ensure the best joint utilization of the water goes back a number of decades to an agreement between South Africa and Portugal in 1964, to which Swaziland acceded in 1967. The Governments of Mozambique, South Africa and Swaziland have been collaborating in the exchange of information, agreements on sharing of water, and joint studies since the early 1980s. The Tripartite Permanent Technical Committee (TPTC), responsible for providing advice to the three watercourse States on matters relating to the utilization, development and management of water resources of common interest, was established in 1983. During the Johannesburg World Summit on Sustainable Development in August 2002, the Tripartite Interim Agreement for Co-operation on the Protection and Sustainable Utilization of the Incomati and Maputo Watercourses (IIMA) was signed by Mozambique, South Africa and Swaziland. The general objective of the IIMA is to promote cooperation among the Parties to ensure the protection and sustainable utilization of the water resources of the Incomati and Maputo Watercourses. The IIMA is an interim agreement to formalize the water use, water resource development and management, and the exchange of information to enable the parties to proceed with much needed development in a spirit of cooperation until more comprehensive agreements have been concluded for the two watercourses.

One of the most important objectives for the development of South Africa and its neighboring countries is the alleviation of hunger and poverty. This is a key Millennium Development Goal (MDG) as defined by the United Nations in 2000. Another important MDG is to ensure environmental sustainability. One of the main constraints for achieving these objectives is proper water allocation and a clear insight in water use. Poor governance and a lack of data often lead to a lack of water sharing in an equitable and environmental sustainable way. South Africa introduced a new water act in 1998 with the purpose to share water resources more equally and efficiently among all users. There are economic incentives built in for eradicating poverty. The water act is currently implemented at the catchment scale by means of Catchment Management Agencies (CMA). The Incomati CMA is the first operating CMA in South Africa. This CMA needs to develop a strategy for operating the Incomati River and allocate all water diversions from the river in a political manner that meets the requirements of the act. The Incomati is currently over-allocated, and less water should be diverted from the river in order to meet the goals of the IIMA.

The CMA has insufficient data infrastructure for implementing the water act. Their current work is based on scarce ground observation networks and few hydrological models (SapWat and MikeBasin) with minimum input data availability. The same situation applies to the partners of the TPTC agreement. Benchmark values need to be prepared for allocating water resources to historic disadvantaged people through a mechanism of compulsory licensing and ensuring water availability. It is possible to reduce upstream water use and enhance streamflow. This is feasible only if the current water resources are better understood, and a monitoring and compliance system can be set up for irrigated agriculture, the ecological reserve and plantation forests.

### 1.1.2 Relevance of the project

This project focuses on water resources allocation and the identification of current water use. High resolution monitoring of water use in various agro-ecosystems is foreseen. For this purpose an operational monitoring website will be developed containing weekly updates of data based on earth observation, such as water use and rainfall surplus, among others. The new earth observation data distribution system will be registered on GEOSS (Global Earth Observation System of Systems) in order to make data accessible to multiple users via the GEO-portal of GEOSS. The main products generated on a weekly basis from earth observation will be:

- Rainfall
- Water consumption (i.e. evapotranspiration)
- Biomass production

These parameters are the basic inputs for water accounting, which is a relatively new concept that contributes to better water allocation, verification of water use and sustainable utilization of scarce water resources. Other more process oriented products can also be generated such as water productivity or sustainability indicators. The eventual set of data generated as a result of this project, will be chosen in close collaboration with the end-users.

This project contributes to the goals of other projects and programs, such as:

- PRIMA (Progressive Realization of the Incomati-Maputo Agreement): This project aims to achieve the objectives of the IIMA signed in 1983 by the three countries within the SADC Region (Mozambique, South Africa and Swaziland) that initiated the TPTC. PRIMA aims at:
  - Integrated Water Resources Management
  - Protection of the Environment
  - Sustainable Utilization of the Water Resources
  - Monitoring Water Quality and Prevention of Pollution
  - Disaster Management – Floods, droughts and Accidental Pollution
- RISKOMAN (risk-based operational water management for the Incomati Basin): the output of this project will be an integrated water allocation policy tool for a heavily committed river basin. This project will be implemented by a multidisciplinary partnership of UNESCO-IHE Institute for Water Education, the University of KwaZulu-Natal, Eduardo Mondlane University and the Komati Basin Water Authority KOBWA.

WatPlan continues where other projects ended, by developing more advanced products selected by end-users (water resources decision-makers) and delivering these at near-real time intervals (weekly) with a much higher resolution (<=30 meter). To give an example, current and past projects like AMESD (www.amesd.org), GMES for Africa (www.gmes.info), VGT4AFRICA (www.vgt4africa.org), and AEGOS (www.aegos-project.org) generate data with a relatively low resolution of 1 km at 10 days intervals. The data produced in these projects are basic remote sensing parameters such as LAI (leaf area index), dry matter production, surface albedo and NDVI (normalized difference vegetation index). WatPlan will generate this data as well, but at a higher resolution and with a near-real time frequency. More importantly, WatPlan will include a set of water parameters such as water consumption, water deficit and soil moisture on a weekly basis with a spatial resolution of at least 30 meter. The data products that will be generated as a result of this project will be chosen in close collaboration with the end-users (CMA, TPTC) and will therefore be directly useful for the decision-makers involved in water resources management, water allocation and planning, which is the basis of downstream services.

### 1.1.3 Concept and objectives

Equitable and efficient water allocation requires transparent and rational decision-making, based on objective and regular monitoring. However, good quality data and monitoring systems that provide decision-makers with tools that can help in efficient resource allocation are lacking. Therefore, there is a need for rational planning of water use and water allocation based on quantitative, objective and regular measurements. These data should be organized in a transparent and accessible way, e.g. on a website, so that everyone can access such information, which is key in this project. Remote sensing technology can provide objective and high quality data on a regular basis on, for example, water use.

The two main end-users for the proposed project are the Incomati CMA and the TPTC. This project initiative aims to assist the Incomati CMA in South Africa and the TPTC members - in other words, decision-makers on the Incomati catchment in South Africa, Mozambique and Swaziland - with their water resources planning and monitoring. The three TPTC members are:

- Department of Water and Environmental Affairs, South Africa
- Ministry of Natural Resources & Energy, Swaziland
- National Directorate of Water, Mozambique

The main objective of this project is to develop and implement an operational earth observation monitoring system that - based on high resolution satellite images and in-situ ground measurements - delivers water management indicators on a weekly basis to support transparent and rational decision-making on water allocation and sustainable water utilization in the context of an international river basin.

Water allocation and verification of water use are the key-issues for sustainable utilization of water. These will lead to more equitable and efficient water allocation, which eventually leads to poverty alleviation and environmental sustainability. Improved data for water allocation will help to implement the ecological reserve, reduce poverty, increase equity, introduce compulsory licensing, and prevent a severe economic prejudice.

# 2 Main S&T results/foregrounds

## 2.1 Confirming Stakeholders needs

WatPLAN identified the important stakeholders across sectors and country boundaries and confirmed their needs and perceptions around data (Deliverable 2.2). Key stakeholder groups responsible for sustainable water allocation and use in the Incomati were identified (Government, Water Users Organizations, Research Institutes and the Private Sector). Through consultation processes, five needs were highlighted, partially confirming data needs (thematic and hydro-meteorological). These included (1) updated, recent land use-land cover information, (2) high resolution (10- 30m resolution) hydro-meteorological data (3) accuracy assessment of spatial data products, (4) stakeholder involvement and data sharing and (5) continuation of data supply beyond the project. WatPLAN considered the needs highlighted, expectations raised and challenges pointed out throughout the project.

## 2.2 Landcover mapping

At the start of WatPLAN, land cover information for the Incomati catchment was available from Globcover2009 (Arino et al, 2012) and the National Land Cover (NLC) 2000 (Van den Berg, 2008). Land cover information is required for the SEBAL evapotranspiration and biomass modelling to extract information according to different land cover types, to be displayed on the WatPLAN web portal, but at a higher resolution.

Therefore a new land cover map was generated using multiple satellite images (DMC, Landsat-7 and Spot-5) recorded over the period August 2011 to July 2012. Visible and near infra-red data from the DMC images (22m resolution) were used as the basis of the classification, but was occasionally supplemented with Landsat-7 data (30 m). The multiple DMC images used allowed capturing of agricultural crop development. For the natural vegetation classification two early autumn DMC images were used representing an optimal date for natural vegetation growth. SPOT-5 imagery was used for agricultural field boundary delineation.

Mapping the agricultural land use was done in two steps. First, fields were mapped into three broad categories consisting of annual crops, horticulture and sugarcane. Here pivot irrigation systems and field boundaries were identified. The second step involved supervised classification, where multi-season imagery consisting of a 12 month data sets (covering the complete cropping season) was used, allowing for distinction between different crops due to crop phenological changes. Natural features such as wetlands, grasslands and natural vegetation were classified through a combination of supervised and unsupervised classification. Landscape features were identified using visual, on screen interpretation and linking that to spectral classes in the images. Agricultural field boundaries were delineated using SPOT-5 data, using on-screen digitizing techniques. Visible and infra-red data were used for display purposes to show maximum contrast between features and allow optimal identification of feature boundaries. Spot-5 data consisted of a single, data coverage.

The resulting land cover map for the Incomati catchment contains 48 classes. The updated map [Figure 2] is an improvement to the previously available GlobCover 2009 and NLC 2000 maps and shows a greater distinction between land cover types [Figure 3], specifically related to agricultural crops. For example the NLC 2000 map only distinguished between two cultivated classes: permanent, commercial sugarcane and permanent, commercial horticulture, whereas the new map distinguishes between multiple sugarcane (pivot and non-pivot) and horticultural classes (e.g. mango, citrus, banana, avocado, etc.).

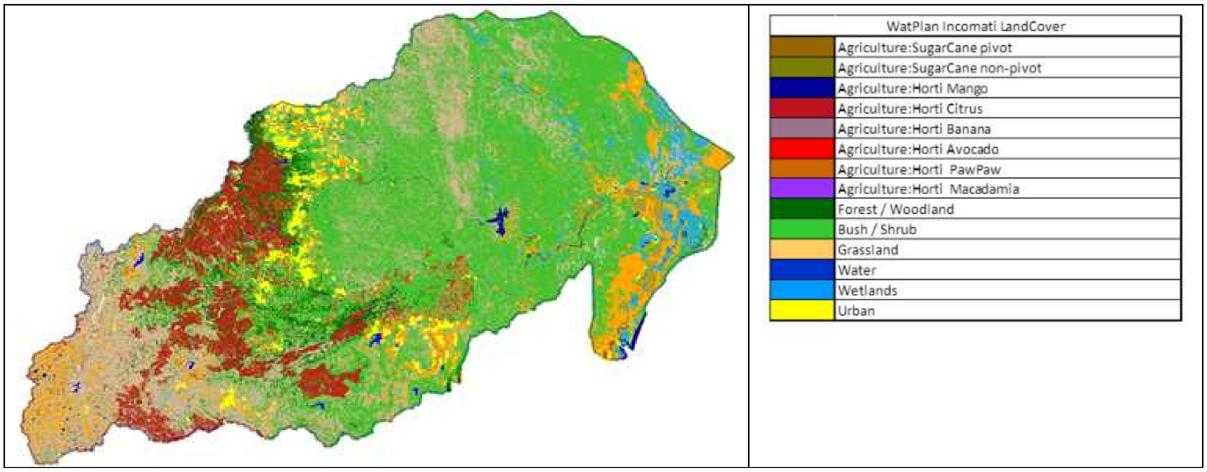


Figure 2 The updated land cover map for the Incomati catchment generated as part of WatPLAN

The land cover map accuracy was not statistically determined, but relied on expert opinion. For example, fruit orchards were visually checked by means of aerial photography to confirm the type.

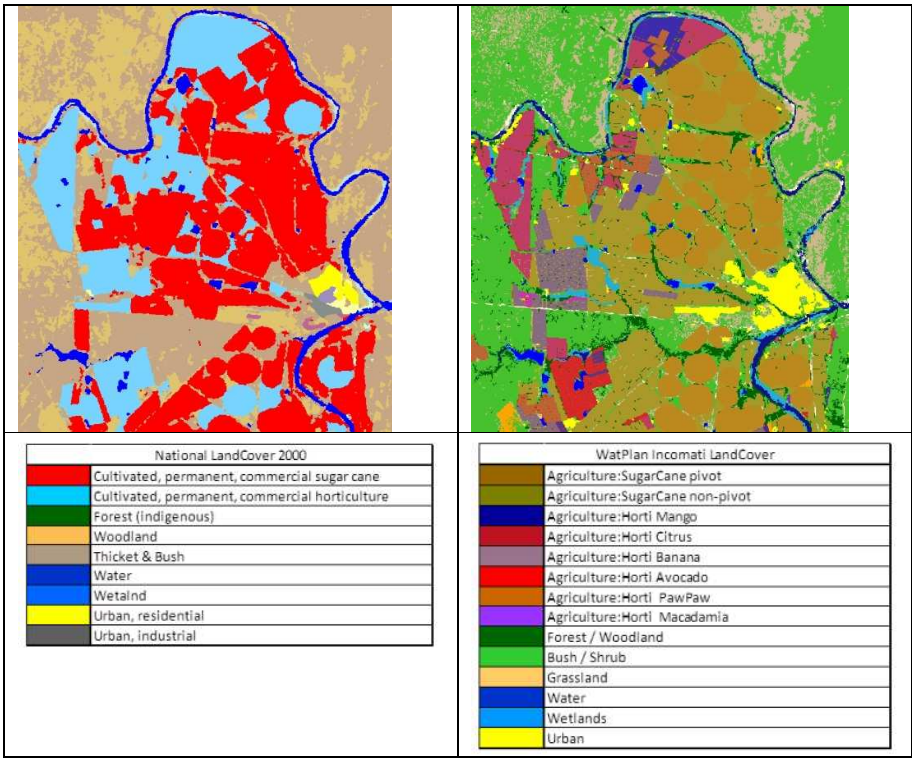


Figure 3 A sample of the old NLC 2000 map (left) is compared to the newly generated land cover map (right). More class discrimination is visible in the newly generated land cover map.

## 2.3 Weekly High resolution hydro-meteorological data updates

Estimating hydro-meteorological data from remote sensing algorithms is gaining popularity. The size of the study area (Incomati catchment), the required frequency of data provision (weekly) and overall period (1 November 2011 to 31 July 2013) of data delivery, limit the amount of satellites that can be used; therefore a combination of a number of satellites and field stations were used in combination.

### 2.3.1 Evapotranspiration, evapotranspiration deficit and biomass data

Globally, ET from land surfaces accounts for 60% of the annual rainfall on land (Oki and Kanae, 2006 quoted in Tang *et al.*, 2013). Because of this, the accurate estimation of ET can greatly improve water balance estimations at catchment level (Cleugh *et al.*).

ET is often calculated as the residual of the water balance modelling which remains complex, requiring rainfall and streamflow data (Senay *et al.*, 2011). Also, often field scale estimates of ET cannot be extrapolated directly to larger scales without introducing errors since field scale estimates of ET often fail to accurately describe larger scale conditions (Teixeira *et al.*, 2009). Hence, limitations to measuring ET at large scales using ground-based methods have motivated the development of satellite remote sensing techniques (Ruhoff *et al.*, 2011) and remote sensing derived ET data can provide a solution here at various spatial and temporal scales (Teixeira *et al.*, 2009).

The advent of earth observing satellites brought numerous remote sensing based ET algorithms and since the need for spatial ET mapping was great, it became imperative to keep developing, modifying, and improving these algorithms (Paul *et al.*, 2013). Since publishing the Surface Energy Balance Algorithm for Land (SEBAL) model formulation in 1998 by Bastiaanssen *et al.*, many studies investigated the accuracy of the SEBAL energy balance and ET estimates against measured and modeled values and over different temporal and spatial scales. SEBAL has been successfully applied to remote sensing data to estimate surface evapotranspiration (ET) at different spatial and temporal resolutions in more than 30 countries (Tang *et al.*, 2013).

Bastiaanssen *et al.* (1998, 2005) summarises the accuracy of SEBAL at various spatial scales and under a range of climatic conditions. At field scale the accuracy of ET under a range of land cover and soil water stress range between 85 (daily) to 95% (seasonal). ET accuracy at larger scales (catchment) over a year was 96%. According to Bastiaanssen *et al.* (2005), the accuracy of ET estimates from SEBAL is better at larger time and spatial scales. In general an accuracy of +/−15% at a spatial scale of 100ha and daily time step was found. The error in ET over a season was estimated to be 1 to 5%. Similar values were quoted more recently by Tang *et al.*, (2003) for temporal scales ranging from daily, seasonal to annual (85, 95 and 96 % respectively).

The SEBAL model is a surface energy balance model and based on physical and empirical parameterization. It provides spatial estimates of actual evapotranspiration, evapotranspiration deficit, biomass production and biomass water use efficiency at pixel scale. SEBAL combines the broadband surface albedo, Normalised Difference Vegetation Index (NDVI) and surface temperature with spatially gridded weather data (air temperature, relative humidity, wind speed and solar radiation), a digital elevation map (DEM) and a land cover map to determine the energy balance and ET for each pixel.

For WatPLAN, the broadband surface albedo and NDVI data were derived using the Disaster Management Constellation (DMC) sensor data and the surface temperature from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor data. Spatial gridding of the weather data (air temperature, relative humidity, wind speed) was done using MeteoLook, a physically based distribution model (Voogt, 2006). MeteoLook produced spatially gridded weather data at a 300m resolution, which is resampled to 30m resolution. Meteorological data for the Incomati catchment was obtained in this study from the National Oceanic and Atmospheric Administration (NOAA) meteorological stations database.

Incoming solar radiation was estimated using the DEM, the solar radiation model of Tasumi *et al.* (2006) in combination with atmospheric transmissivity data taken from remote sensing products of the Land Surface Analysis Satellite Applications Facility (http://landsaf.meteo.pt). The surface roughness and zero-displacement height were derived using the available land cover map and NDVI data to incorporate seasonal changes in these two parameters.

Meijninger and Jarmain (2013) outline the SEBAL modelling steps. The satellite data (a combination of data from two images) containing instantaneous information of the earth's surface is processed in four steps. (1) In this step, the instantaneous energy balance is solved at the time of the satellite overpass. The sensible heat flux is derived using two 'anchor' pixels within the surface temperature image. These carefully selected pixels consist of a 'wet' pixel (often a water pixel) and a 'dry' pixel representing areas where the ET is considered maximum and zero respectively. Subsequently, the latent energy flux (or evaporation expressed as an energy flux) is derived as the closure term of the energy balance. Then the evaporative fraction is calculated at this time step. (2) In this step, the daily energy balance is solved for the image. Assuming the evaporative fraction remains reasonable stable during the day the daily evaporative fraction is derived from the instantaneous estimate and this is used to extrapolate the instantaneous to daily estimates of ET. The evaporative fraction will be modified slightly if advection processes is present, using an empirical advection model. With the daily net radiation, soil heat flux and daily mean weather data known, the daily ET is calculated. The Penman-Monteith equation (Allen *et al.*, 1998) is applied in reverse order to derive the daily average surface resistance or crop resistance. (3) This last term, together with the Penman-Monteith equation and the corresponding weekly mean net radiation, soil heat flux and weather data is used to estimate the weekly ET. It is assumed that the daily average stomatal resistance remains fairly constant over this time, but it is adjusted for advection. (4) In the final step, SEBAL estimates biomass production for each pixel from solar radiation absorption by chlorophyll and the conversion of this energy into total dry matter produced, by means of light use efficiency. The absorption of solar radiation for photosynthesis depends on global radiation and light interception (Zwart and Bastiaanssen, 2007). The light use efficiency is calculated from a crop specific maximum light use efficiency ($e_{max}$) and the stomatal resistance. A maximum light use efficiency of 2.5 g/MJ is often used for $c_3$ plants. For sugarcane for example a value of 3.27 g/MJ was proposed by Varlet-Grancher *et al.* (1982) and Bastiaanssen and Ali (2003). In each of the steps, spatially gridded MeteoLook meteorological data is used.

Because SEBAL requires all input data to be at the same resolution, DMC data was resampled from 22m to 30m resolution. The MODIS land surface temperatures were first re-sampled to 250m using a broad band surface thermal emissivity relationship based on the 250 m NDVI (Normalized Difference Vegetation Index) (Van de Griend and Owe, 1992). Then a thermal sharpening tool was applied and the surface temperature further downscaled to a 30m resolution. The thermal sharpening establishes a relationship between land surface temperature and the MODIS reflectances in the visible and near infra-red bands. This relationship is then applied to the higher resolution data, but taking into account the corresponding (local) lower resolution land surface temperatures.

A total of 65 DMC and 69 MODIS images were used in the modelling over the period 1 November 2011 to 31 June 2013, representing roughly one set of image per week (Deliverable 3.1 and 3.2).

### 2.3.2 Precipitation

Precipitation maps were taken from the Famine Early Warning Systems Network (FEWS NET or in short FEWS) for the period 3 November 2011 to to June 2013. The daily FEWS precipitation maps (http://igskmncngs600.cr.usgs.gov/ftp2/bulkdailydata/africa/rfe2/days/) with a spatial resolution of 0.1° were aggregated to produce weekly maps and annual precipitation datasets (http://earlywarning.usgs.gov/fews/africa/web/readme.php?symbol=dailyrfe).

Transmissivity maps were derived from Meteosat Second Generation (MSG) data. The MSG satellite is a geostationary satellite centred over Africa and collects visible, infra-red and near-infrared data at a 1 to 3km resolution. The MSG incoming shortwave radiation at the surface is compared to extraterrestrial shortwave radiation and transmissivity computed at an hourly time step and aggregated to daily values. Daily transmissivity data at 3km resolution was resampled to 300 m and linked to the FEWS data.

Since FEWS rainfall data is available at coarse (0.1°) spatial resolution and the field data at a single point, different downscaling and interpolation methods were investigated. The accuracy of spatial FEWS rainfall data was evaluated against raingauge data available in the Incomati catchment.
The FEWS data at a weekly time step was disaggregated to a 300m spatial resolution using bilinear sampling ($0.1^o$ to 300m), applying an NDVI-rainfall relationship and applying a transmissivity-rainfall relationship. These downscaled data sets were compared to rainfall point data. Spatial interpolation of field data using Inverse Distributed Weighting (IDW) and different Kriging approaches was also investigated.

### 2.3.3 Operationalisation of Monitoring System

To communicate the spatial hydro-meteorological data with the stakeholders the WatPLAN Operational Monitoring System, a data display and dissemination portal (Deliverable 4.1), was designed. A number of criteria were set for this system and tested with stakeholders during workshops: it had to be web-based, accessible to all stakeholders in the Incomati, easy to navigate, data displayed in spatial and a summary (graph) format, relevant parameter maps displayed for main land cover classes and sub-catchments. Also, importantly, the website updates had to be frequent (weekly) and the data available, relevant. Stakeholder feedback (cosmetic, functional and design) was considered throughout the project to tweak the system to become fully operational (deliverable 4.2).

A Content Management System (CMS) written in PHP code was used to design a user interface, that was built using HTML and CSS following web standards. The user interface was made available in the English and Portuguese languages.

The interface was made available online since February 2012 (to date) at the website www.watplan.com. This web interface, or portal, contains historical data for five hydrological and growth parameters from the entire Incomati Catchment: Biomass Production (BM) in kg/ha, Evapotranspiration (ET) in mm/week, Precipitation (PRECIP) in mm/week, Evapotranspiration deficit (ETDEF) in mm/week and Precipitation minus Evapotranspiration (RAINET) in mm/week. Data was updated weekly over the period 1 November 2011 to June 2013.

The webportal allowed hydro-meteorological maps to be displayed for each sub-catchment and for different land cover class groups: the entire selected sub-catchment, irrigated crops, (irrigated) sugarcane, forest plantation and natural vegetation. The weekly parameter data sets are displayed as spatial maps, representing quantitative values and can be interpreted using the map specific legends provided [Figure 4]. The parameter maps are overlaying either a Google Earth map or a standard map of the area making navigation easy. On the same screen, the data displayed (parameter, area and date) is also summarised in table or graph format. Access to the data required stakeholders to register on the webportal to enable monitoring of website visits and data access. By July 2013, more than 70 stakeholders were registered.

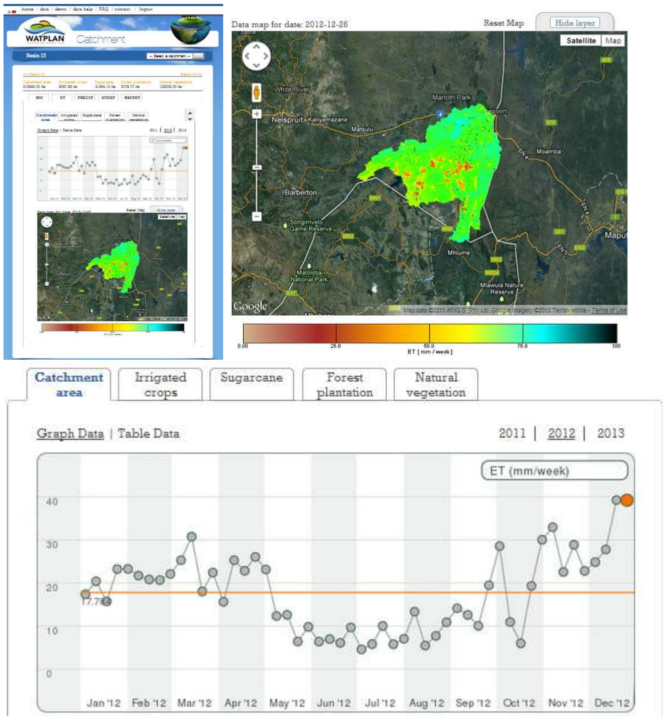


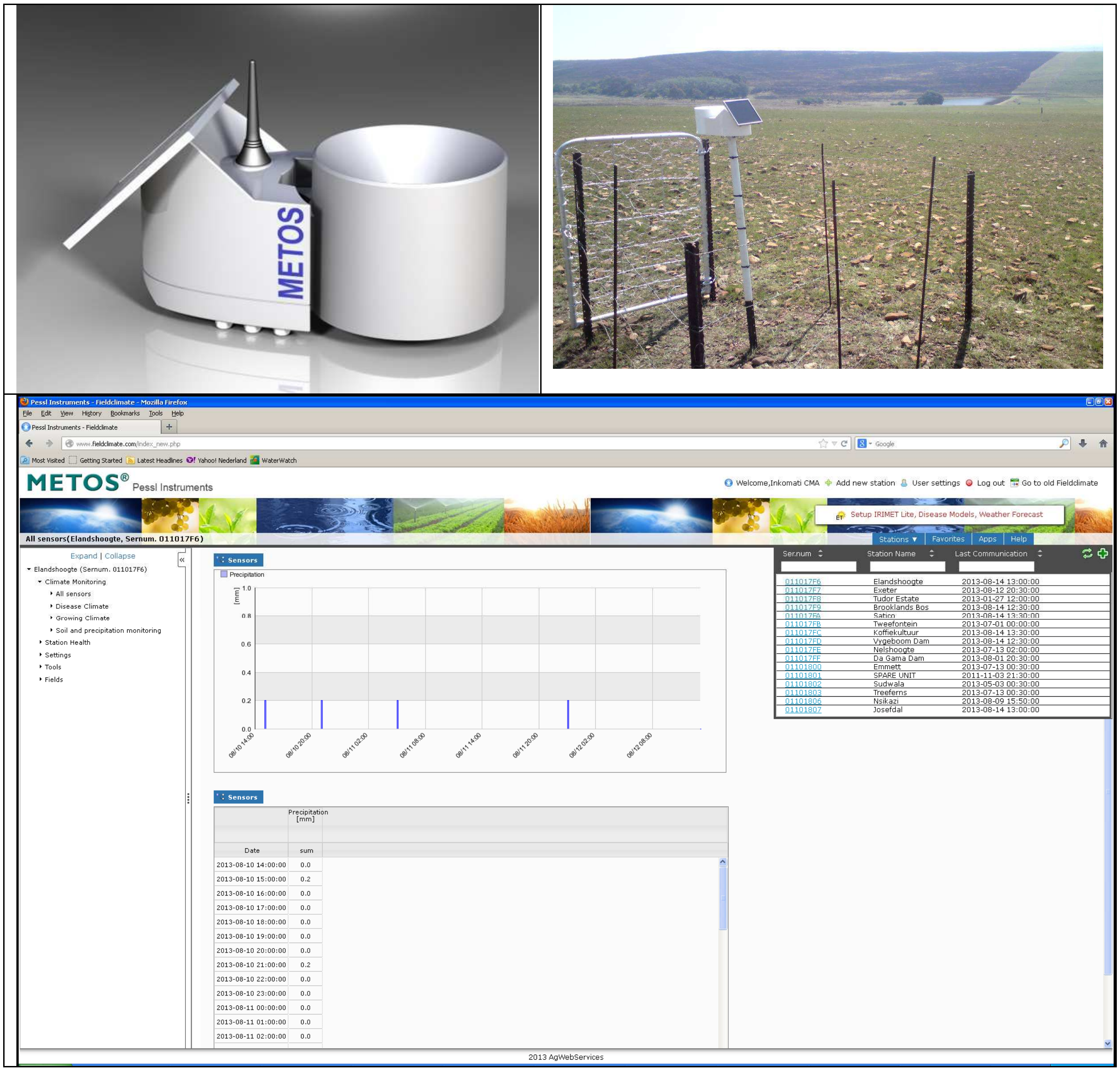
Figure 4 WatPLAN webportal display of weekly evapotranspiration for catchment 12 for the week ending 26 December 2012. Data is displayed in both spatial (map) and table format.

## 2.3.4 Validation

Validation of the High resolution hydro-meteorological data has been an important part of the project, because only by validation confidence and trust in the operational monitoring system can be guaranteed. Therefore data generated in the project was validated using in-situ measurements using a network of meteorological stations, consisting of already available stations supplemented with rain gauges installed by the project.

### *2.3.4.1 Development of an in-situ monitoring network*

Part of the Incomati catchment is covered by a network of meteorological stations, that was extended by the project in areas not well covered. Fifteen rain gauges ECO D2 automated gauges [Figure 5] from Pessl Instruments GmBH were installed at secure sites. Data was required at near real time and was therefore transmitted using a GPRS connection and uploaded onto a website from which it can be accessed and downloaded. The rain gauges are set to output data every 30 minutes. The systems are maintained by the ICMA stakeholder that will keep making use of the network after the project.



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| 011017F7 | Exeter | 2013-08-12 20:30:00 |
| 011017F8 | Tudor Estate | 2013-01-27 12:00:00 |
| 011017F9 | Brooklands Bos | 2013-08-14 12:30:00 |
| 011017FA | Satico | 2013-08-14 13:30:00 |
| 011017FB | Tweefontein | 2013-07-01 00:00:00 |
| 011017FC | Koffiekultuur | 2013-08-14 13:30:00 |
| 011017FD | Vygeboom Dam | 2013-08-14 12:30:00 |
| 011017FE | Nelshoogte | 2013-07-13 02:00:00 |
| 011017FF | Da Gama Dam | 2013-08-01 20:30:00 |
| 01101800 | Emmett | 2013-07-13 00:30:00 |
| 01101801 | SPARE UNIT | 2011-11-03 21:30:00 |
| 01101802 | Sudwala | 2013-05-03 00:30:00 |
| 01101803 | Treeferns | 2013-07-13 00:30:00 |
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| | Precipitation [mm] |
|---|---|
| Date | sum |
| 2013-08-10 14:00:00 | 0.0 |
| 2013-08-10 15:00:00 | 0.2 |
| 2013-08-10 16:00:00 | 0.0 |
| 2013-08-10 17:00:00 | 0.0 |
| 2013-08-10 18:00:00 | 0.0 |
| 2013-08-10 19:00:00 | 0.0 |
| 2013-08-10 20:00:00 | 0.0 |
| 2013-08-10 21:00:00 | 0.2 |
| 2013-08-10 22:00:00 | 0.0 |
| 2013-08-10 23:00:00 | 0.0 |
| 2013-08-11 00:00:00 | 0.0 |
| 2013-08-11 01:00:00 | 0.0 |
| 2013-08-11 02:00:00 | 0.0 |

**Figure 5 Pessl ECO D2 automated gauge (upper left) and one of the installed stations upper (right) and the online interface (down)**

Next to the project installed rain gauges, three other rainfall data sources were used to evaluate the accuracy of the satellite derived rainfall data products. These sources are the World Meteorological Organisation (WMO), the South African Sugarcane Research Institute (SASRI) and the National Oceanic and Atmospheric Administration (NOAA). Data is available online for the WMO (www.wmo.int), SASRI (http://portal.sasa.org.za/weatherweb/) and NOAA. Details on the location of each station distributed across the South African side of the Incomati catchment are provided in Figure 6.

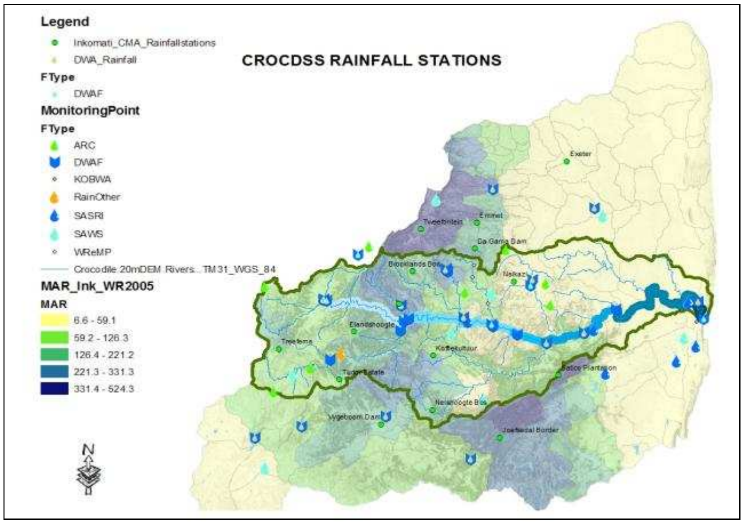


Figure 6 Location of weather stations (with raingauges) and raingauge stations within the Incomati catchment. The position of raingauges as part of the existing networks (ARC, DWAF, KOBWA, etc.) and the newly installed gauges (Inkomati CMA rainfall stations) are shown.

To complete the network, surface energy balances and evapotranspiration data is required. This data is not routinely measured at field or catchment scale and were not measured as part of WatPLAN. Therefore, data for validation was sourced from research projects in the Incomati catchment and used to evaluate the accuracy of the SEBAL data. Data was available and obtained at two sites with two distinctly different land use types: a homogenous irrigated sugarcane site and a heterogeneous savanna (natural veld) site [Figure 7].

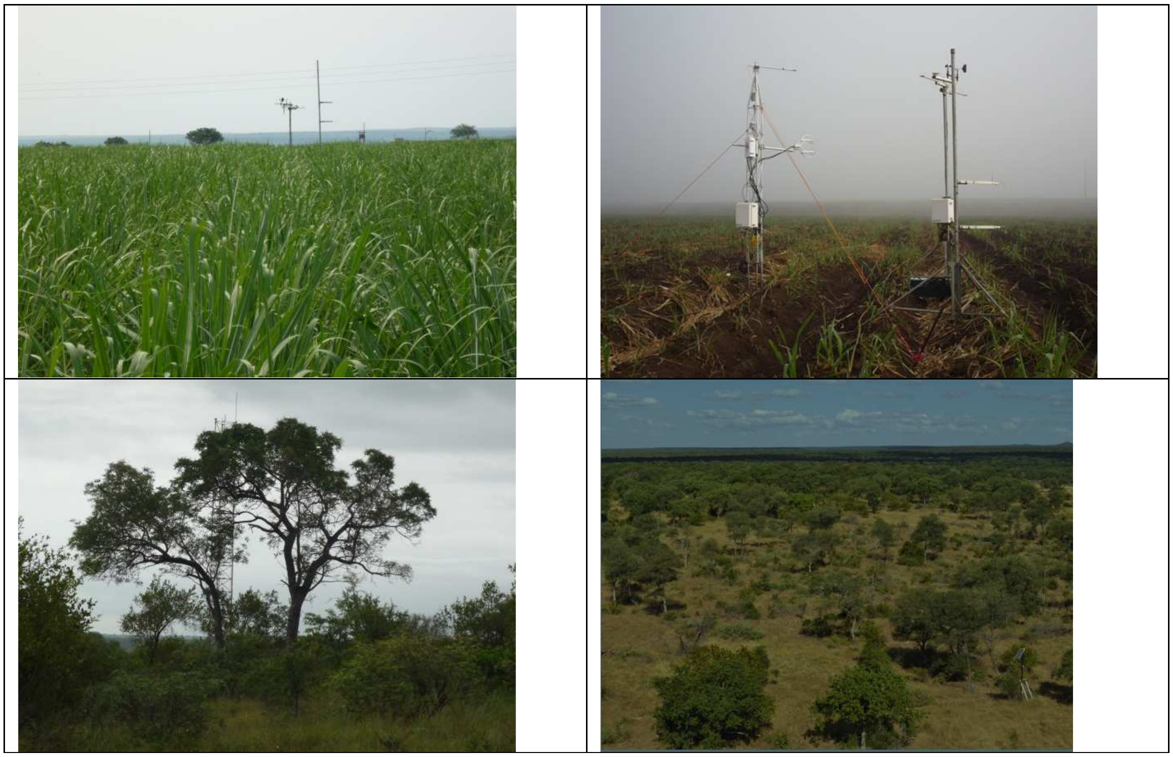


Figure 7 Photos of the uniform sugarcane field (top) and savanna veld (bottom) with instrumentation where energy balance and ET data were collected.

The sugarcane field measurements were made at a field approximate 4.3 ha in size, situated south of Komatipoort that is irrigated using an above ground drip irrigation system. The growing season is 12 months long and the crop was harvested in May 2012. A surface renewal system was used to measure the energy balance and ET of this field and calibration of this system was done from July to September 2012. For calibration, a Campbell Scientific, open path eddy covariance system was used to estimate ET directly from the covariance of the instantaneous deviation in vertical windspeed (measured with a CSAT3 sonic anemometer) and instantaneous deviation in water concentration (measured with a Li-7500 infra-red gas analyser). ET was also indirectly estimated as the residual of the energy balance (Jarmain *et al.*, 2013).

The second site, comprises of *Acacia* savanna (natural veld) and is situated within the Kruger National Park in close proximity to the Skukuza camp. Kutsch *et al.* (2008) provides a detailed description of the site. The flux tower with eddy covariance system is located at the boundary of two plant communities: a fine-leaf Acacia savanna to the south east and broad-leaf Combretum savanna to the north. Sensible and latent heat fluxes and ET were measured using a closed-path eddy covariance system mounted at 16 m on the flux tower. The closed path system consisted of a 3-dimensional Gill sonic anemometer and a LiCor Li-6262 gas analyzer.

#### *2.3.4.2 Validation of precipitation data*

Different downscaling and interpolation methods were applied to the FEWS derived spatial rainfall data and compared to point based raingauge data to determine the accuracy of the data estimates and to determine if local calibration is required.

Rainfall is closely related to other data like vegetation and the local terrain which can be used in the rainfall downscaling procedures. Downscaling procedures involve assumptions relevant to specific areas and time scales and typically involve establishing a relationship between one variable at coarse scale and another at a higher spatial resolution (Duan and Bastiaanssen, 2013). Hence, the (coarse) spatial resolution of rainfall can be enhanced by establishing a statistical relationship between rainfall and these factors available at higher resolutions (Immerzeel et al., 2009).

First the weekly rainfall estimates from the FEWS satellite were resampled to a subset of 300m and then to 30m using bilinear sampling. The subsets were compared to weekly raingauge data from 20 weather stations in the Incomati catchment. FEWS subset data (average) from a 3 x 3 pixel grid surrounding the raingauge position was used. Comparing the weekly FEWS and raingauge data for each individual station over a 22 week period, show agreement in dates when rainfall events were recorded. However, the comparisons show a consistent underestimation of rainfall by FEWS when compared to the raingauge data from all stations investigated, with the exception of the Coopersdal and Komati-Croc bridge raingauges. The extreme rainfall events during January 2012 greatly affected the linear regressions [Figure 8].

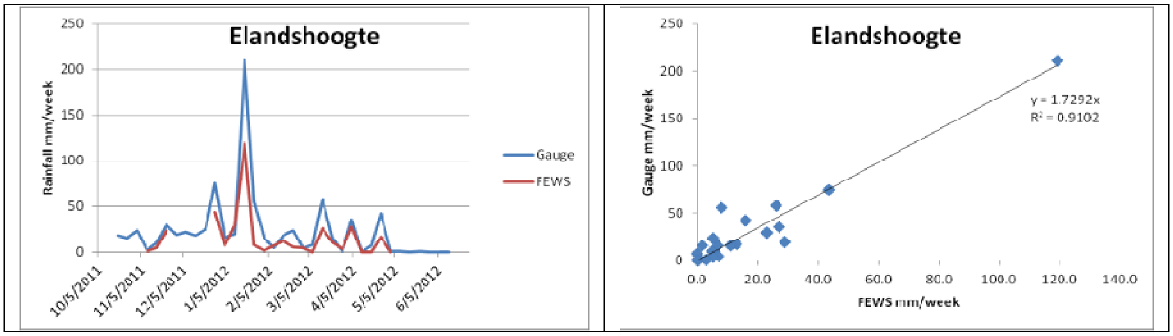


**Figure 8 An example of the rainfall time series and scatter graphs for the stations Elandshoogte. A consistent underestimation of the FEWS rainfall when compared to the gauge data is clear, showing the impact of the single high rainfall event on the regression.**

Next disaggregation was used. Disaggregating rainfall with NDVI is based on the theory that at longer timescales (months, season and year) a relationship should exist between rainfall and the presence of actively growing vegetation. This is particularly relevant for naturally vegetated terrain, where rainfall is the dominant source of available water to plants. The Incomati catchment contains large areas under natural field vegetation, irrigated agriculture and forestry. FEWS Rainfall and FEWS NDVI data sets were averaged over a year, for six consecutive years (2003 to 2009). No significant relationship was visible between these datasets, even whilst taking into account the longterm datasets. This poor relationship between rainfall and NDVI data is likely explained by large scale production of irrigated agricultural crops (e.g. sugarcane, citrus and nuts) and forestry within the Incomati catchment. Hence the high average annual NDVI values corresponding to low average annual rainfall, is possibly related to the availability of additional (irrigation) water.

Spatial rainfall estimates for the Incomati catchment were also disaggregated spatially using transmissivity data. Daily transmissivity derived from the Meteosat Second Generation (MSG) satellite were used. Transmissivity data at a 3km resolution was resampled to 300m and linked to the 0.1° FEWS data. The low resolution weekly FEWS data was enhanced with the higher resolution patterns in the daily transmissivity. Weekly raingauge data from two WMO (Maputo, Graskop) and six SASRI stations were subsequently compared to the original FEWS data (0.1°) as well as the FEWS data disaggregated using transmissivity data to a 300m resolution. Similarly, the weekly rainfall data summed over a 52 week period were compared. No significant relationship was found and disaggregating the FEWS rainfall with transmissivity information did not seem to improve the rainfall estimates. FEWS images do seem to capture rainfall events correctly though and can hence be used to determine whether rainfall occurred or not, but it cannot be used as reliable estimate of rainfall amount in the Incomati.

Another frequently used deterministic (mathematical) method for spatial interpolation (or data disaggregation) is Inverse Distance Weighting (IDW). The assumption here is that a greater similarity exists between points closer to each other compared to those further apart, meaning that with increased distance between points, differences in parameter values at the points also increase.

Three sets of raingauge data, consisting of a group of 12 raingauges and two separate groups of 10 raingauges each were used to evaluate the accuracy of the IDW interpolated FEWS rainfall data. To test the assumption that there should be a similarity in rainfall from stations in close proximity, the cumulative rainfall estimates for three pairs of stations situated in close proximity to each other, were compared [Figure 9]. Data from the Vygeboom and Nelshoogte stations show an expected normal and linear relationship, despite the absence of part of the data from the Vygeboom station. Rainfall data from the Koffiekultuur and Nelshoogte stations show agreements for the first part of the data record, but then rainfall is recorded at Nelshoogte but not at Koffiekultuur. A similar trend is seen (agreement and differences) for rainfall estimates from Sudwala and Brooklands Bros. This means that within the Incomati catchment localised rainfall events occur.

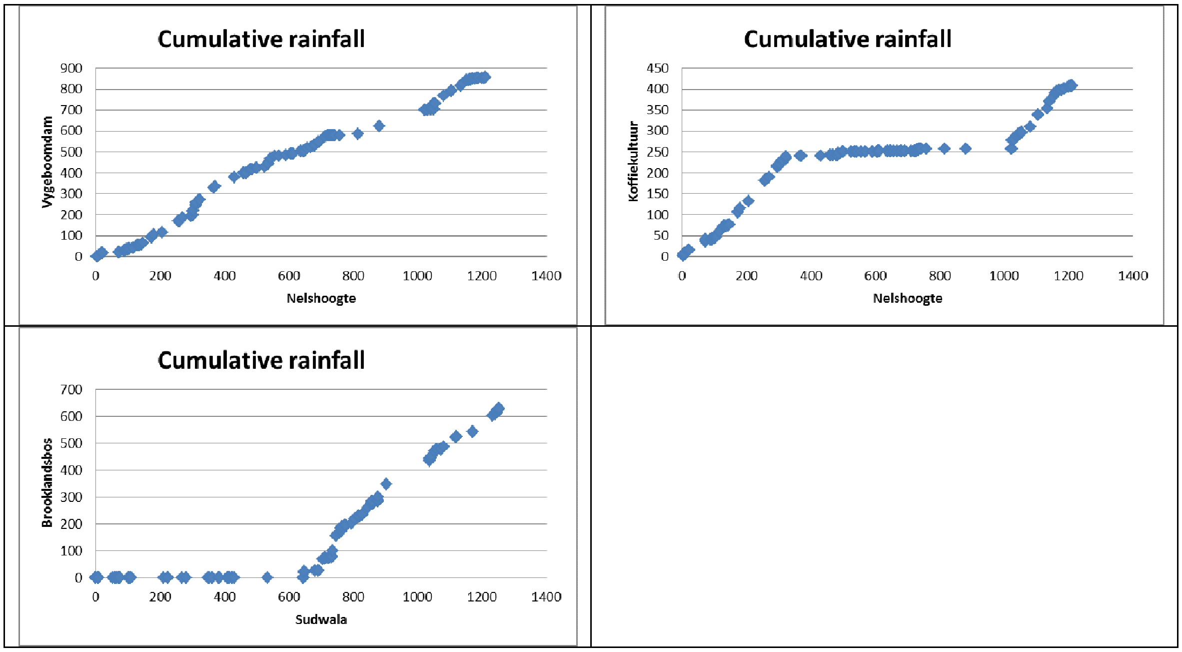


Figure 9 Cumulative rainfall (mm) comparisons between three sets of rainfall stations situated in close proximity

FEWS annual rainfall estimates, disaggregated to 300m using IDW, were also compared to annual rainfall estimates from 12 raingauges [Figure 10]. No clear trend is visible in the data compared and the general linear regression shows an overestimation in rainfall using the IDW method. The interpolated FEWS rainfall compared to more measured rainfall data sets showed a similar trend. Annual rainfall interpolated with IDW again both overestimated and underestimated rainfall.

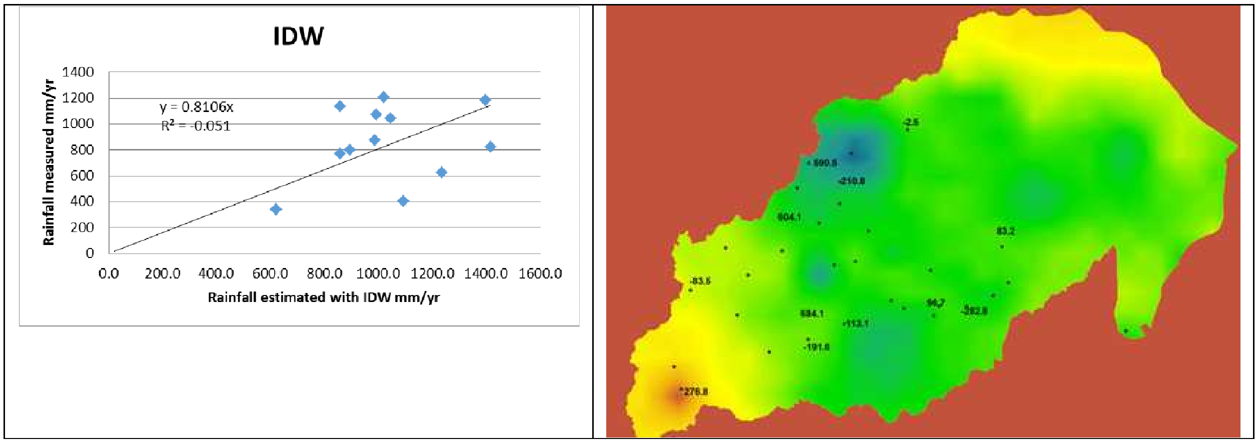


Figure 10 (Left) Annual rainfall measured at 12 raingauges and estimated using an Inverse Distance Weighting function applied to FEWS data and (right) IDW FEWS rainfall interpolated, with values indicating over and underestimation in rainfall compared to field data

Finally measured rainfall was combined with spatial rainfall to obtain a more complete picture of spatial rainfall distribution, using a kriging interpolation method as described by Cheema and Bastiaanssen (2012). The difference between the locally measured rainfall and the spatial rainfall was calculated and this difference was then interpolated to produce a difference rainfall map. Interpolation was done using different Kriging approaches. Results from the Kriging approaches were unsatisfactory [Figure 11].

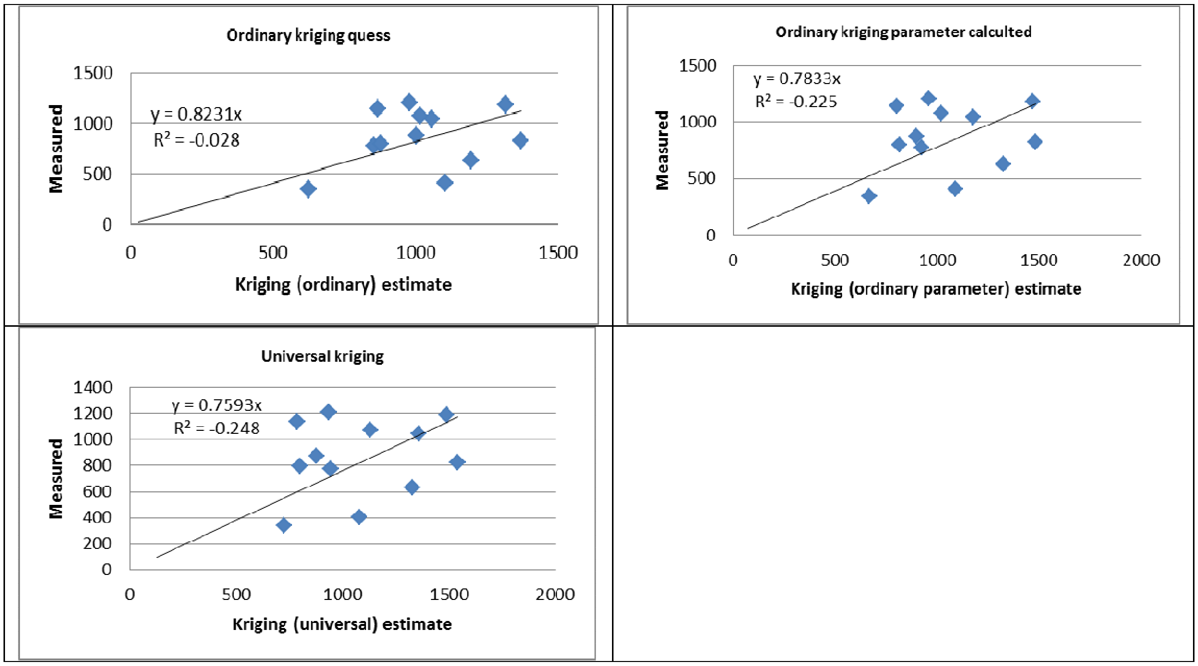


Figure 11 Scatter graphs comparing annual rainfall measured at twelve stations with rainfall estimated with different Kriging methods

### *2.3.4.3 Validation of ET data*

Although SEBAL validation studies have been conducted under a wide range of conditions in the past (climatic, vegetation, spatial and temporal scales) and by various authors, none has focussed on validating weekly ET data made available operationally. In WatPLAN, the accuracy of energy balance and ET from SEBAL for two hydrological extreme sites were compared against flux tower data available in the network.

SEBAL solves the surface energy balance at the time of satellite overpass and integrates the fluxes to provide estimates of daily and weekly ET.

The energy balance [Figure 12] describes how solar energy is distributed; part is reflected of or absorbed by the surface, and part is used for evapotranspiration and plant growth. By deriving these energy fluxes, biomass production, the actual-, and potential water consumption and water deficit can be derived on a pixel-by-pixel basis.

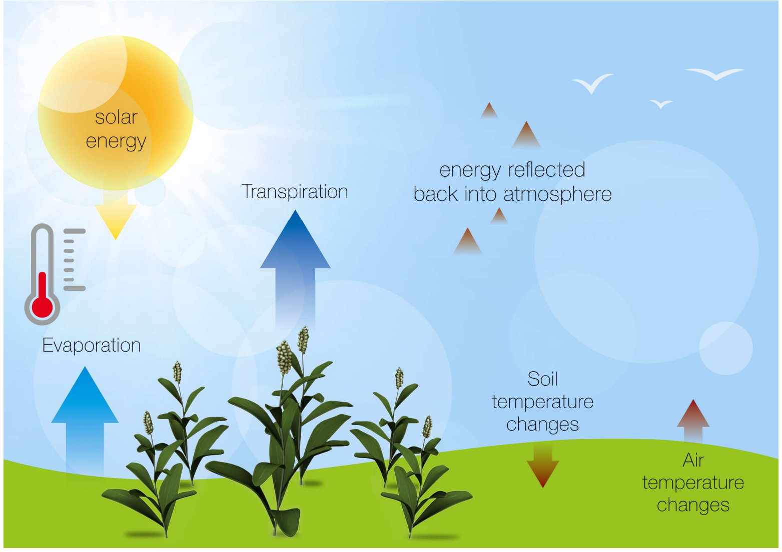


Figure 12 Energy balance

Data were compared with measurements at a homogeneous irrigated sugarcane site and a heterogeneous savanna site, for a period spanning summer to autumn / early winter. Jarmain *et al.* (2013) discussed the SEBAL sugarcane data accuracy and below it is integrated with data from the savanna (natural veld) site. Measured net radiation (*Rn*) data curves at the homogenous, irrigated sugarcane site and the dryland, heterogeneous savanna site show that most days of image capture were cloud-free and there was a decrease in net radiation from summer to autumn [Figure 13, Figure 14]. The SEBAL estimates of net radiation significantly explains > 94 % of the variation in the measured $R_n$ at the time and day of the satellite overpass.

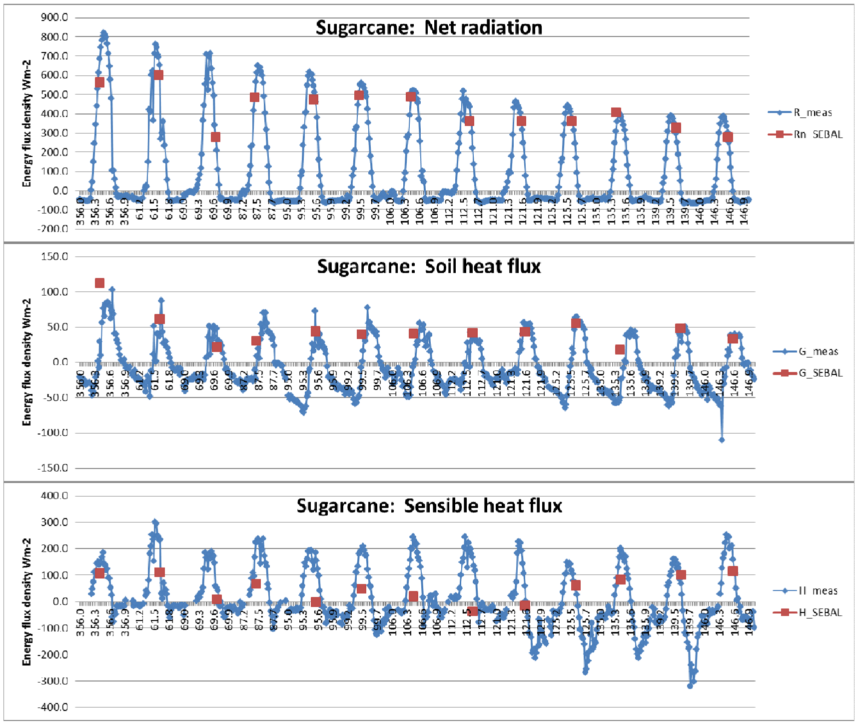


Figure 13 Energy balance data (Net radiation, Rn), Soil heat flux density, G and Sensible heat flux density, H) measured at and estimated for the irrigated sugarcane site using SEBAL for a selection of dates. The SEBAL data represents the

instantaneous energy balance estimate at the closest half an hour of the satellite overpass and measured data is at 30 minute intervals.

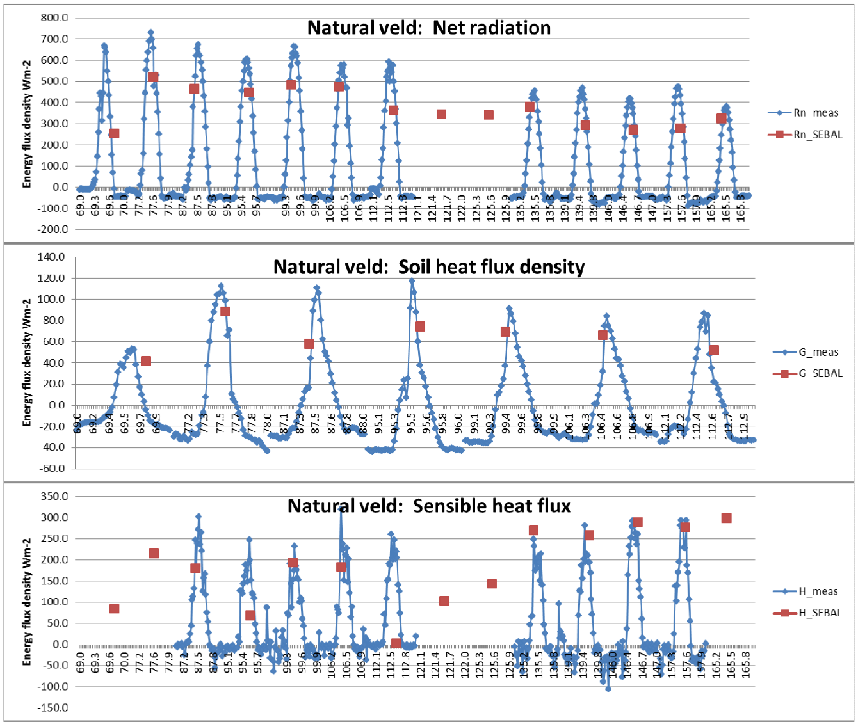


Figure 14 Energy balance data (Net radiation, Rn), Soil heat flux density, G and Sensible heat flux density, H) measured at and estimated for the savanna (natural veld) site using SEBAL for a selection of dates. The SEBAL data represents the instantaneous energy balance estimate at the closest half an hour of the satellite overpass and measured data is at 30 minute intervals.

Soil heat fluxes (*G*) at both the sugarcane and savanna sites were small fractions of the net radiation (<12 %) for the entire sample period and reflect the complete canopy covers. Comparisons of *G* showed significant agreement at the sugarcane site, but not at the savanna site. Estimates of *G* are complex especially at a sub-daily interval and also in heterogeneous canopies and often do not contribute greatly to the energy balance where near complete canopy covers exist. SEBAL uses as inputs into the *G* calculations estimates of albedo, NDVI and surface temperature and errors in any of these parameters will affect the accuracy of *G*.

Maximum 30 minute sensible heat fluxes (*H*) measured at the sugarcane and savanna sites during the sample period shown were higher at the savanna than the sugarcane site. At both sites, SEBAL mostly underestimated *H*. Since the important input parameters for the estimation of *H* in SEBAL, includes spatially gridded weather data (air temperature, windspeed), land surface temperature, a land cover map and derived data (frictional velocity, surface roughness) any inaccuracies in these data sets will affect the accuracy of *H*. The representation of weather conditions, specifically air temperature and windspeed across a catchment adequately is difficult, and might require more weather data.

SEBAL estimates the evaporative fraction (*EF*) [Figure 15] at the time of the satellite overpass as the fraction of latent energy flux (*LE*) to the available energy (*Rn*-*G*). Evaporative fraction estimated from the measurements show randomness (scatter) in the data at both sites – more so at the savanna than the sugarcane site. Still, SEBAL estimates of *EF* significantly explain 94-99 % of the variation in the measured *EF* at both sites at the time of the satellite overpass.

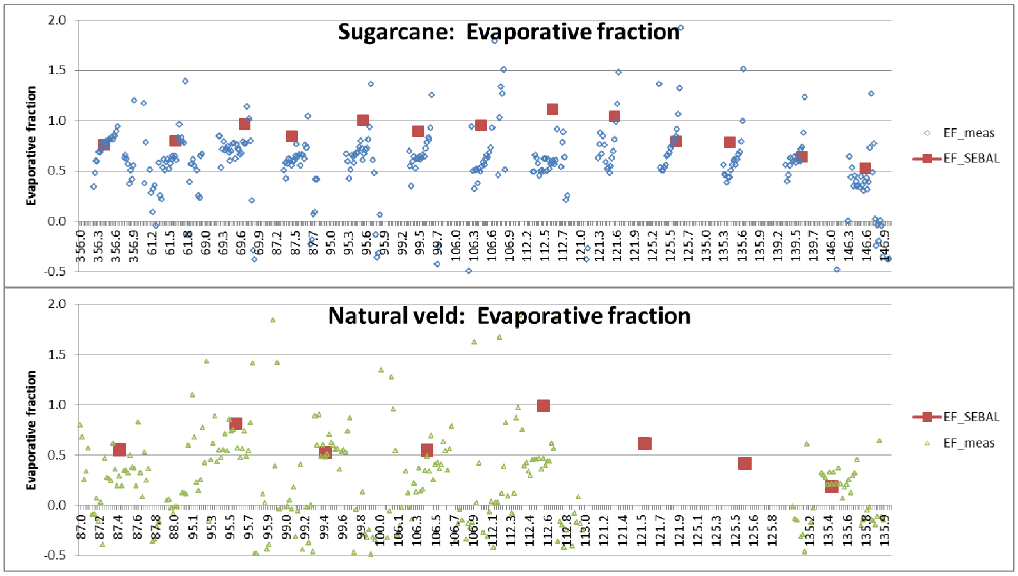


**Figure 15 Evaporative fraction (*EF*) measured at and estimated for the sugarcane (top) and savanna (bottom) sites using SEBAL for a selection of dates. The SEBAL data represents the instantaneous energy balance estimate at the closest half an hour of the satellite overpass and measured data is at 30 minute intervals**

Daily ET at both sites showed a decrease in *ET* from summer to autumn/early winter. Daily *ET* estimated for sugarcane using SEBAL, consistently exceeded that estimated using the surface renewal method during summer and parts of autumn, whereas the SEBAL daily *ET* estimates for the savanna site showed more scatter. SEBAL estimates of daily *ET* explained 96 (sugarcane) and 93 % (savanna) of the variation in the measured *ET*. The agreement in the *ET* data (SEBAL and measured) was statistically significant for both sites although the SEBAL estimates in general (linear regression) exceeded the measured *ET* by 34 and 18 % at the sugarcane and savanna sites respectively. At the savanna site, differences in daily *ET* also existed between the two eddy covariance method estimates. Daily *ET* differences at the sugarcane site is affected by the weighting factors applied to derive *H* with the surface renewal method and suggest an overestimation in the weighting factors applied for a fully developed sugarcane canopy, leading to an overestimation in *H*.

The weekly estimates of *ET* as provided through the WatPLAN webportal were compared at the sugarcane and savanna sites to the measured estimates, although few corresponding data points existed [Figure 16]. As for the daily timestep, the weekly estimates of *ET* using SEBAL at the sugarcane site mainly exceeded the estimates based on measurements, whereas the ET estimates for the savanna site showed greater randomness. SEBAL estimates of weekly *ET* significantly explained 94 (sugarcane) and 84 % (savanna) of the variation in the measured weekly *ET* estimates. At this time step, the weekly SEBAL estimates were 31 % higher than that measured at the sugarcane site and 19 % lower at the savanna site.

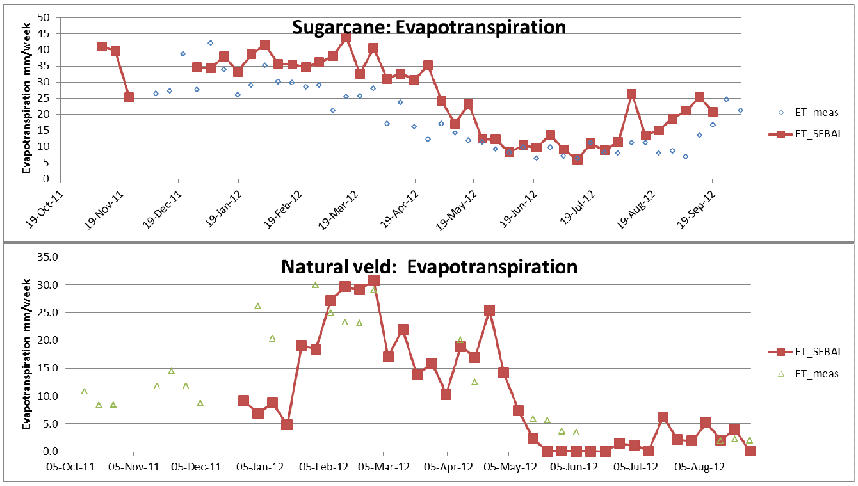


Figure 16 A comparison of the weekly ET data estimated with SEBAL and measured with the eddy covariance system at the savanna site for the period 1 October 2011 to 30 September 2012

# 3 Potential impact and main dissemination activities

## 3.1 The potential impact

When trying to understand the complexity of the hydrology in a catchment as diverse as the Incomati, consistent and suitable data which can explain trends in the hydrology of the catchment is needed. The WatPLAN operational system sets the basis for decision making and planning and is fundamental to water resources and land management.

The WatPLAN project has implemented an operational monitoring system that provides thematic and hydro-meteorological data for the Incomati catchment to stakeholders in the fields of water management and agricultural production. By interacting with stakeholders during workshops, the WatPLAN researchers learned about possible uses and needs for the spatial data that can impact both current and future decision making related to water. The spatial data provided by WatPLAN will impact a wide range of applications from strategic to operational purposes used by researchers, industry and across.

By having access to the data sets, researchers can investigate factors influencing water resources at catchment level, using the time series information to quantify and qualify the land uses and their respective water consumption. For example, since ET is not routinely measured in the landscape the WatPLAN ET data sets provide data previously not available. This can result in a better understanding of landscape processes (seasonal and geographical differences in ET) as well as the testing of hypothesis. The spatial ET data can also improve hydrological modelling at catchment scale. At landscape scale, both ET and biomass data can be used to investigate the long-term impact of fire frequency and seasonality on the dominant savanna landscapes. The spatial data sets provided through WatPLAN do not only assist us in gaining a better understanding of landscape processes and feedback, but can be directly used in decision support and management by different stakeholders.

One direct impact already is that the Incomati Management Authority (ICMA) is in an advanced stage of implementing a system whereby WatPLAN type data is merged with other relevant data to provide consistent and up-to-date information for the management of the catchment in terms of their mandate [Figure 17].

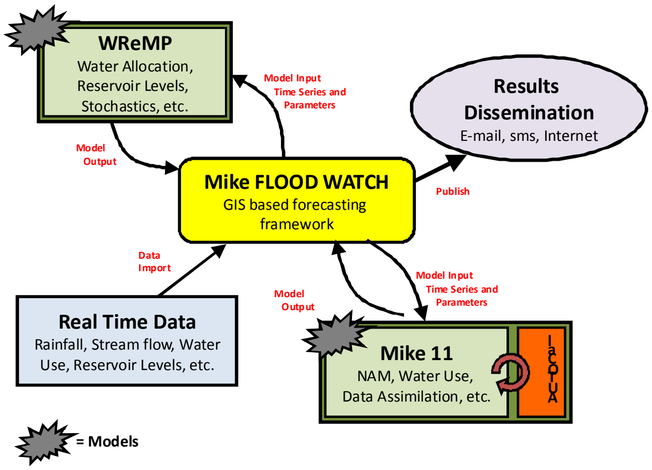


Figure 17 Crocodile River system Water resources management Decision Support System

The development of such user defined applications is focused on the deployment of tools such as the WatPLAN web portal which can provide the necessary data foundation for analysis, modeling and decision making. In countries in Southern Africa where water use is licensed, use needs to be monitored and any unlawful water use must be identified and acted upon. In the past, the necessary authorities did not have timeous data to detect unlawful use: however having access to data from the WatPLAN web portal allows one to detect and react to any unlawful use [Figure 18]. This ability to proactively monitor an area gives one the ability to react to changes in the weather and mitigate against these through management interventions whilst being cognizant of the impacts of these decisions and the catchment as a whole.

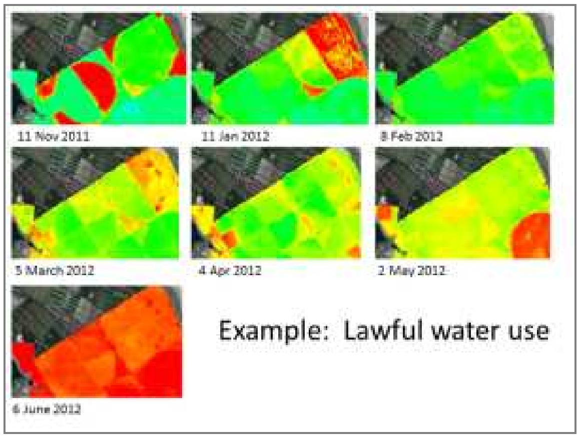
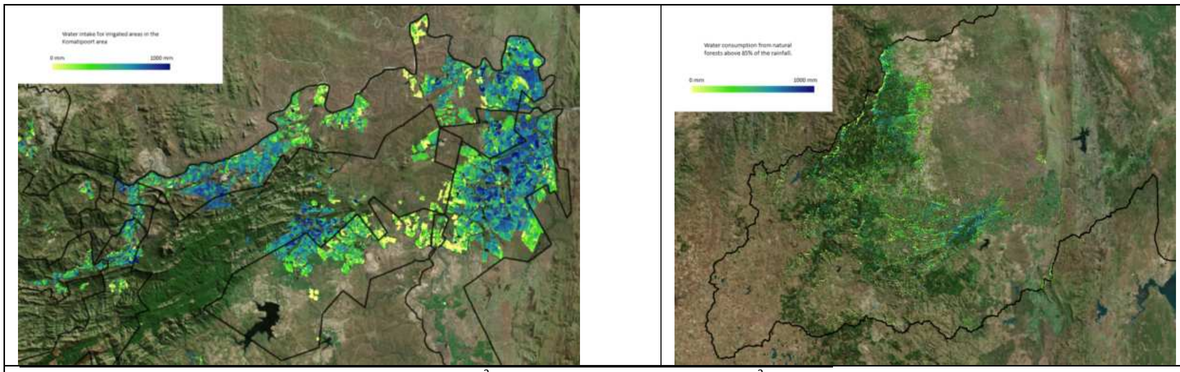


Figure 18 Monitoring lawful water consumption using ET estimates

When trying to understand the catchment and independently verify water use, it is valuable to analysis rainfall (rain gauges) in context of spatial ET to quantify areas where there is groundwater, soil moisture or upstream water being used. This directly influences the amount of water available for ET and depending on the type of land use in the area, this can be managed to improve stream flow or the irrigated area. For this, studies have been conducted to model and analyse the spatial ET/P and prepare a map of land uses where ET is higher that the norm as a way of identifying these land uses.  Overall, this allows one to compare actual water consumption of a given land use with allocated water resources, providing a tool to influence policy and decision making and monitor international agreements.

For example, the trilateral agreement between Swaziland, Mozambique and South-Africa was analysed in line with the actual land use and water consumption in the catchment and showed interesting (interim) results [Figure 19]. For example, the actual water consumed by irrigation was found to be lower that the water allocated in the agreement.  Also the total area under forestry was lower than agreed, however the actual water use associated with this area is significantly higher than the runoff reduction agreed upon. This is also reflected in more water used than precipitated, and therefore indicates that groundwater or soil moisture plays a large role in their survival. In summary, 23% more water is used in the catchment than allocated as part of the trilateral agreement and may need to be addressed. This example clearly shows that using this data in combination with the satellite imagery derived land cover gives one an ideal tool to understand and manage a catchment such as the Incomati.



| | Trilateral agreement [$Mm^3$] | Calculated [$Mm^3$] |
|---|---|---|
| **Irrigation** | 786 | 426 |
| **Forest plantations** | 475 | 1132 |
| **Total** | 1261 | 1558 |

Figure 19 Water consumption by irrigation (left) and natural forest (right)

Where development and food security needs to be aligned with environmental and socio-economic factors, having access to up-to-date and consistent data allows one understand the prevailing circumstances and adapt management practices and policy in line with requirements or legislative requirements. This may include the identification of areas suitable for commercial agriculture, subsistence agriculture, sustainable farming, forestry or other land uses. This may be a result of the determination of water use efficiencies in an area based on the existing land uses and would indicate where this can be improved or adapted in line with current thinking. This could also be indicative of carbon sequestration requirements and policy in this regard.

When thinking about decision making within the agricultural industry, one needs data across a production area to understand yields, water consumption and the impact of water stress on this production to derive for example water productivity. Being able to analyse yields between various producers and linking them to irrigation practices and rainfall allows one to inform all farmers of practices which will be beneficial to their production. This also allows one to improve efficiencies and production across the area. The TSB Sugar RSA project has used the ET data to link water stress to final production yields at a farm or producer level. This project highlighted the value of the spatial data as it allows one to link the factors to given farms or fields and provides the necessary tools to quantify and qualify patterns and trends.

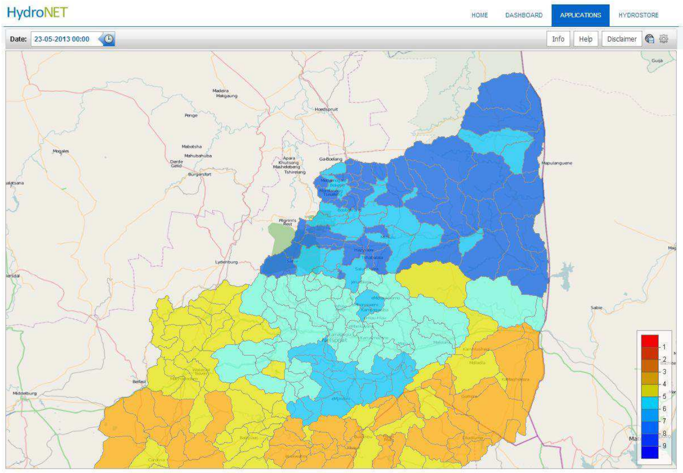


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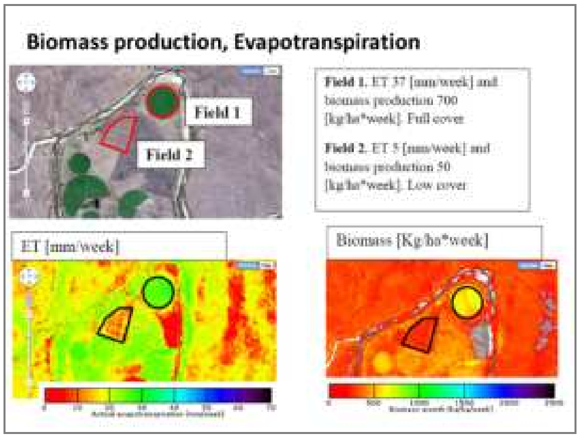
Figure 20 Water productivity in the Incomati catchment

At an operational level, individual farm owners or managers need up-to-date and consistent data to effectively manage their farms down to a field level. This requires the identification of the individual fields and supplying data at that level to the responsible person on a regular basis, hereby improving the overview efficiency and productivity of the area [Figure 20]. Thus being able to provide producers with crop development and water stress related information throughout the growing season [Figure 21] assists them to adapt to changing conditions and to optimise management practices and therefore reduce costs. This also allows farmers to understand differences between farms or fields and how they can adapt to these differences by varying management practices. This may result in varying irrigation regimes or fertilizer applications, such as nitrogen, to account for the identified variance. Being able to provide this level of detail is therefore paramount to ensuring profitability and maximising production. Nitrogen deficiencies or water stress are just two of the variables that can be monitored, quantified and deployed through tools such as the WatPLAN derived datasets.



Biomass production, Evapotranspiration

**Field 1.** ET 37 [mm/week] and biomass production 700 [kg/ha*week]. Full cover

**Field 2.** ET 5 [mm/week] and biomass production 50 [kg/ha*week]. Low cover

Figure 21 Biomass production and evapotranspiration for crops

Even on an engineering or operational level, satellite imagery derived data can assist to detect problems or deficiencies in irrigation systems and the spatial resolution of data allows one to identify individual valves, pumps or pipes which need to be investigated. It is this level of information which can assist the managers to optimise production on a day-to-day basis. Where irrigation systems needs to be managed and enhanced, spatial data can be used to understand the impact of existing irrigation regimes and allows one to adapt these in line with prevailing conditions or changes to crops or new hybrids, etc.

Most of the current examples discussed above are based on data viewed through the WatPLAN webportal (and hence qualitative in nature), the future use of this type of data will likely take on a very different form (more quantitative). Based on experience and feedback through WatPLAN and other projects executed in South Africa, the applications or tools developed will likely be stakeholder specific (Table 1) and won't be based on webportals, but will rather summarise the spatial datasets and make it available in yet other formats (e.g. cellphones, Apps, PDF reports, etc.) but also integrate these data sets into existing data basis or programmes already used by various stakeholders.

Table 1 Stakeholder specific tools

| Farm level | Water resources consultants | Water boards | National | Transboundary |
|---|---|---|---|---|
| Improved water management and saving | Determining water availability | Monitoring hydrometeorological parameters | Support hydrometeorological monitoring networks | Monitoring compliance of water sharing agreement |
| Improving crop production | Water balance calculation | Water licensing and costing | Water balance calculations | Complete catchment integrated water resources management |
| | Water resource and land use planning | Conflict resolution between different water users | Water resources planning and allocation | Water resources planning and allocation |
| | Drought monitoring and management | Drought monitoring and management | Drought monitoring and management | Drought monitoring and management |
| | Improved dam design | | | |
| | Improved irrigation scheme design | | | |

## 3.2 The main dissemination activities

An important part of the WATPLAN project was Training, Data sharing, Evaluation and End-User Support. The general objective was building capacity and providing guidance in order to make the end-users (or ´third-parties´) aware of the possibilities of the WATPLAN system for water allocation and planning while simultaneously providing end-users (TPTC, CMA, TSB, and other water managers) with the knowledge to continue using the operational monitoring system.

### 3.2.1 Folder

A logo and flyer was designed for the WatPLAN project to be used for promotional and dissemination activities.

### 3.2.2 Website

General information on the project, deliverables and training materials are made available to the general public, stakeholders and WatPLAN users via the WatPLAN.eu website. Here also announcements are made regarding training etc. The website was specifically designed for this purpose and will remain online after the project has ended.

### 3.2.3 Webportal

The WATPLAN Operational Monitoring System has been online since February 2012 at the website www.watplan.com. The system contains weekly updated data of five hydrological and growth parameters from the Incomati Basin. The five parameters are: Biomass Production (BM), Evapotranspiration (ET), Precipitation (PRECIP), Evapotranspiration deficit (ETDEF) and Precipitation minus Evapotranspiration (RAINET). The data of each parameter is displayed separately by clicking on the parameter tabs. After the user logs into the system, a sub catchment of the Incomati Basin has to be selected. Within the sub catchment, the user can also select different land use types: natural vegetation, forest plantation, irrigated crops, sugarcane or the entire sub catchment area (all land use types combined). The latter option is set as default. Note that the sub division of land use types is only available if it exists within a sub catchment.

The data is shown in various ways:

1) A graph shows the weekly average of the parameter for the selected sub catchment and selected land use type (graph data), except for rainfall where the total is shown. The graph depicts historical data, starting from November 2011. An additional red line indicates the overall average of the parameter for the sub catchment and land use type.
2) Alternatively, the same data sets (average and totals) can be displayed and viewed in table format (table data).
3) Most importantly however, is that all the parameter data sets can be displayed in map format. The parameter data is showed as color maps overlaying either a Google Earth map or a standard map of the area. A color coded legend is displayed to indicate the value of the parameter displayed.

The data map is always shown simultaneously with either the data graph or the data table. The webportal is available in two languages, English and Portuguese and has over 70 unique registered stakeholders who frequently visit the data portal.

### 3.2.4 Presentations

Two presentations were held by the consortium, one at the International conference on fresh water governance for sustainable development – 5th – 7th November 2012, South Africa and one at the 2nd GMES & Africa Workshop, Water Resources Management, in Abuja, Nigeria in May 2013. Also a presentation was given by one of the stakeholders, the Dept of Water Affairs Swaziland at the United Nations/Pakistan International Workshop on Integrated Use of Space Technologies for Food and Water Security in Islamabad, Pakistan in March 2013.

### 3.2.5 Stakeholder involvement and awareness of the system

Stakeholders have been involved in the project in multiple ways throughout the duration of the project. During the development of the proposal three major stakeholders were approached and agreed to participate and contribute with the implementation of the project. The identified stakeholders were ICMA, TSB and the TPTC.

During a stakeholder inventory, important stakeholders within the water and land use sector in the International Incomati Basin were identified and subdivided in four main categories. The main- and sub-categories identified include:

- Government (water management related);
    - Policy makers and strategic planners;
    - Operational water authorities;
- Water Users Organizations;
- Private Sector, with:
    - Sugarcane;
    - Other Irrigated Agriculture;
    - Forestry;
    - Parks and Natural Vegetation; and

- Research Institutions.

Identification was done with the help of three important stakeholders, namely ICMA in South Africa, Ministry of Natural Resources and Energy in Swaziland and PRIMA[1] in Mozambique. The stakeholder inventory resulted in a long list of stakeholders for each country. Based on the stakeholder long list, a selection was made for a stakeholder short list. The shortlisted stakeholders were invited to a Multi-Stakeholder Platform (in total 67 stakeholders), during which the stakeholders were informed about WATPLAN and participated in the early development of WATPLAN by giving opinions, expectations, recommendations and concerns.

Separate Multi-Stakeholder Platform (MSP) meetings were held in the three countries in September 2011. The main objective was to inform the stakeholders about the project and get their feedback regarding the data provided and the web application. Finally, based on the shortlist of stakeholders and the participation and interest shown by each of the individual stakeholders during the MSP several end-user representatives were selected and asked to evaluate and test the web application on a regular basis. See also paragraph 4.4. The selected end-user representatives are:

| | | |
|---|---|---|
| 1. | ICMA | South Africa |
| 2. | Irrigation boards (Lomati, Komati and Crocodile) | South Africa |
| 3. | TSB | South Africa |
| 4. | DWA/KRBA | Swaziland |
| 5. | Mhlume water | Swaziland |
| 6. | KOBWA | South Africa/Swaziland |
| 7. | ARA Sul | Mozambique |
| 8. | Maragra açúcar | Mozambique |

Three distinct training sessions were organized for the stakeholders:

- Training on image processing (task 6.1)
- Training for end-users (task 6.2)
- Training for decision-makers (task 6.5)

The objective and focus of the training was different for each session, the following paragraphs will briefly summarize the three sessions.

A five day training course on image processing was organised in June 2012 in Pietermaritzburg in South Africa. Invitations were sent to staff of UKZN and GTI, and to some stakeholders of WATPLAN to whom this course could be relevant and interesting (e.g. ICMA and the universities of Swaziland and Mozambique). The main objective of this course was to expose researchers to spatial technologies that can be used to quantify the water balance, to use these technologies and to interpret and integrate the data products of these technologies for water resources management assessment and improvement. In total 22 participants attended the training, mainly PhD and post-doctorate students and researchers of UKZN. From the invited stakeholders only ICMA attended the course, seeing they are a very important stakeholder for WATPLAN, their participation in the course is regarded very valuable and therefore highly appreciated.

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[1] The Programme for the Progressive Realization of the IncoMaputo Agreement (PRIMA) aims to achieve the objectives and purposes of the Interim IncoMaputo Agreement (IIMA) by supporting the TPTC.

Technical training sessions were held in March 2012 in all three countries. The main objective was to demonstrate the use of the operational monitoring system and get stakeholders feedback regarding the data uses and web application. During the training three case studies were presented and included exercises and demonstrations. The case studies included:

Case 1: Land cover use changes
Case 2: Water resource management
Case 3: Field level monitoring

Most of the stakeholders from the long lists received an invitation, in total approximately 150 invitations were sent to 115 different stakeholders.

- In South Africa 23 participants attended the training session in Nelspruit, representing 16 different stakeholders. Key persons or stakeholders present during the training were DWA, KOBWA, Brain Jackson from ICMA, Willie du Toit representing the main irrigation boards, TSB, representatives from the citrus and forestry industry, and Eddie Riddell representing the RISKOMAN-project.
- In Swaziland 8 participants attended the training session in Matsapha, representing 6 different stakeholders. The low turn-out was attributed to another water related conference that was organized on the same day and in the same venue. This caused confusion and a lower turn-out. Key persons or stakeholders present during the training were KOBWA and Bernard Shongwe from KRBA (and close colleague of Sindy Mthimkhulu, a key person in the Swazi water sector).
- In Mozambique 19 participants attended the training session in Maputo, representing 12 different stakeholders. Key persons or stakeholders present during the training were PRIMA, ARA Sul and representatives from the sugarcane industry.

A training session for decision-makers was organised in November 2012 at the International Conference on Fresh Water Governance for Sustainable Development, in Central Drakensberg in South Africa. Prior to the conference an Incomati Special Session was organized to provide a platform for integrating knowledge on water governance, operational management and applied water science in the transboundary Incomati catchment. The main objective of this training for decision makers was to expose a wider range of professionals (outside of the consortium partners) to the new technologies and the benefits of an operational monitoring system. In total 10 participants attended the training.

### 3.2.6 Conferences

*International conference on fresh water governance for sustainable development – 5th – 7th November 2012, South Africa.*

This international conference brings together policy makers, water managers, scientists and civil society, in a forum where new ideas beyond academic exchange for the future can be shared, nurtured and hopefully developed from the water sector and beyond. A special Incomati session was planned at the weekend of the 3rd/4th November. The aim of this session was to provide a platform for integrating knowledge on water governance, operational management and applied water science in the transboundary Incomati catchment, with the following two themes:

1. Incomati catchment transboundary water management, governance, agreements and institutions
2. Applied Water Research Initiatives in the Incomati, at the science-management interface

The WatPLAN project was presented at the Incomati special session, and a training session for decision-makers was organised as described earlier.

*2nd GMES & Africa Workshop, Water Resources Management, in Abuja, Nigeria in May 2013.*

The objective of the workshop was to gather experts who are responsible for Water Resources Management activities in their countries so that they can provide a consolidated and validated contribution to the GMES and Africa Action Plan in respect to Water Resources Management.

A presentation of the WatPLAN FP7 project was well received and was selected by the European Union for presentation as one of the most promising projects executed by EU FP7 program. The emphasis of the presentation was put on operational services for verifying water withdrawals. Six potential leads for applications to water resources management decision making which emerged from the presentation. Contacts with several (international) river basins in Africa have been established during the workshop.

### 3.2.7 (Peer-reviewed) publications

Two peer-reviewed articles have been accepted or published. With the large interest generated, more publications are expected. A newsletter was published by the BRAGMA project, including a WatPLAN description.

### 3.2.8 GMES

In 2012 WatPLAN registered to GMES. Through this registration the WatPLAN operational monitoring system is accessible through the GMES Space Component Data Portal [Figure 22]. By using the link all users of GMES can link to the WatPLAN system and register to get access to the data. The project can be accessed using the menu GMES Services -> Downstream Services at the GMESdata portal, or using the link:
[http://gmesdata.esa.int/web/gsc/core_services/downstream_services](http://gmesdata.esa.int/web/gsc/core_services/downstream_services)

**All Downstream Services**

**Introduction**

The following sections provide a brief description of the 'Downstream Services' (DS) that make up the 2009, 2010 and 2011 FP7 Calls

**Downstream Services Descriptions**

scarce environments. It addresses water governance and management in accordance with the vision of bridging and integrating sustainable development and economic competitiveness. The project is developing new services for water managers and food producers, including maps detailing irrigation water requirements in different areas, crop water consumption estimates, and a range of additional information products in support of sustainable irrigation water use and management under conditions of water scarcity and drought. Applying an integrated approach based on public participatory geographic information systems (ppgis) and social multi criteria evaluation, SIRIUS is developing a GMES service that takes into account the interrelated economic, environmental, technical, social and political dimensions of the food-water challenge.

**SubCoast**

SubCoast is a collaborative project aimed at developing a GMES-service for monitoring and forecasting subsidence hazards in costal areas around Europe. The objective of SubCoast will be to develop a GMES service for monitoring the extent and impact of subsidence in coastal lowlands, and demonstrate its capability in a variety of settings around Europe. The service will be designed to appropriately determine the effects of subsidence on current and future flood risk in coastal lowlands. SubCoast will monitor the integrity of coastal barrier systems and infrastructure, and assess the impact of subsidence due to natural or man-made causes such as ground water pumping and oil/gas production on land use and hydrology.

**WATPLAN (Spatial earth observation monitoring for planning and water allocation in the international Incomati Basin)**

This project proposal focuses on water resources allocation and the identification of historical and current water use and high resolution monitoring of several water resource indicators on a weekly basis. For this purpose an operational earth observation system will be developed which includes a website with weekly updates of water resource data on water use. This system can be linked to GEOSS (Global Earth Observation System of Systems) in order to make data accessible for multiple users. The main data generated on a weekly basis as a result of this project are:

- Water use and evaporation
- Rainfall
- Soil moisture
- Biomass production

Figure 22 GMES Website

In support of the SBA Water of GEOSS to make data available for water resources management, the Incomati Catchment Management Agency (ICMA), an important stakeholder to WatPLAN in South Africa has had access to all the data generated for the WatPLAN project. ICMA has used this data to develop a database for the Incomati Catchment, which in its turn displays some key parameters for its users.

# 4 Address of project public website and relevant contact details

The WatPLAN public website: www.watplan.eu
The operational monitoring system: www.watplan.com

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