UNIVERSITY OF ZAMBIA, IWRM CENTRE
SCHOOL OF MINES

# APPLICATION OF REMOTE SENSING USING A GIS BASED SOIL WATER ASSESSMENT TOOL (SWAT) TO ESTIMATE RIVER DISCHARGE IN THE KABOMPO RIVER BASIN, ZAMBIA

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# AUTHOR'S DECLARATION

I, Mwiza Muzumara, hereby declare that the work contained in this thesis is my own original work and that. I have not previously in its entirety or in part submitted it to any other university for a degree award.

Signature: ……………………………………….

Date: ……………………………………….

# APPROVAL

This Dissertation of Mwiza Muzumara is approved as fulfilling the requirement of the Degree of Masters of Science in Integrated Water Resources Management by the University of Zambia.

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Sign:……………………… External Examiner:……………………………….

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| Alpha-BF | Base flow recession factor |
| ArcSWAT | Soil and Water Assessment Tool in ArcGIS interface |
| Ch_K2 | Effective hydraulic conductivity for the main channel |
| Ch_n2 | Manning's "n" for main channel |
| Ch_slope | Channel Slope |
| CN2 | SCS Curve Number for antecedent moisture condition II |
| DEM | Digital Elevation Models |
| DWA | Department of Water Affairs |
| ESA | European Space Agency |
| Epco | Plant uptake compensation factor |
| ECMWF | European Centre for Medium-Range Weather Forecasts |
| Esco | Soil evaporation compensation factor |
| EM | Electoral Magnetic |
| GLCC | Global Land Cover Characterization |
| HYDATA | Hydrological database for Department of Water Affairs |
| IR | Infrared |
| JICA | Japan International Cooperation Agency |
| GIS | Geographic Information System |
| Gw_delay | Groundwater delay |
| Gw_revap | Revap Coefficient |
| Gwqmn | Threshold water level in shallow aquifer for base flow |
| MARS | Metrological Archive and Retrieval System |
| HRU | Hydrologic Response Unit |
| NIR | Near infrared |
| Rchrg_dp | Deep Aquifer Percolation coefficient |
| Revapmn | Revap threshold |
| RS | Remote Sensing |
| SCS | Soil Conservation Service |
| Sol_awc | Soil available water capacity |
| Sol_k | Soil Saturated hydraulic conductivity |

| | |
|---|---|
| Sol_z | depth of individual soil layer |
| SRTM | Shuttle radar topographic Mission |
| SSE | Sum of Square of Errors |
| SSURGO | The Soil Survey and Geographic |
| STATSGO | The State Soil and Geographic |
| SUFI-2 | Sequential Uncertainty Fitting Algorithm |
| Surlag | Surface runoff lag |
| SWAT | Soil and Water Assessment Tool |
| TRMM | Tropical rainfall measuring mission |
| USGS | United Sates Geological Survey |

## ABSTRACT

The Kabompo river basin with an area of 72,000 $km^2$, in North-Western Zambia is one of the major tributaries of the upper Zambezi River. Key water resources management problems in the Kabompo include water allocation to agriculture and ecosystems, effects of land-cover change on the flow regime and potential impacts from mine tailing dams. The objectives for the study were to apply Remote Sensing and a GIS based Soil Water Assessment Tool (SWAT) to estimate river discharge for the basin in order to address the water resource management challenges. Because of paucity of observed data in the Kabompo basin, the model primarily depended on remote sensing datasets for calibration and validation. The Kabompo basin was discretized into 177 sub-basins with a total of 1004 hydrological response units. Methodology included the use of a semi-distributed; ArcGIS based Soil Water Assessment Tool (SWAT) software for hydrological modeling. Remote sensing data sets that included weather data, drainage network and slopes, landuse/ land cover and soils were used to create a database for the sub-basins using ArcGIS. The simulated flow from the SWAT model was calibrated with ESA ERS-2 and ENVISAT radar altimetry river stage values converted to discharge. Observed river flow data for six stations over different time periods between 1990 and 2007 were used in validation and uncertainty analysis of the radar altimetry flow data and remotely sensed weather data, respectively.

The model's results showed good correlation with observed data giving a Nash Sutcliffe coefficient of 0.87 and an $R^2$ value of 0.93, after calibration. The simulation results obtained from the model can be used in a number of water resources management activities like water rights, water allocation, and flood warning. The model is able to generate estimated river flow and stage values even for un-gauged streams. It's also able to simulate long-term data of a wider area including inaccessible locations than conventional hydrological techniques.

It is concluded that remote sensing is a useful tool for estimation of hydrological data where it is lacking or in unguaged and in accessible areas. Its wide use in a country like Zambia should greatly improve water resources management in a number of areas.

# CHAPTER 1: INTRODUCTION

## 1.1 Theoretical Background

The Kabompo River, a tributary to the Zambezi River, has its source in the North-Western Province of Zambia along the watershed between the Zambezi and Congo River basins. The Kabompo river watershed is approximately 72,200 $km^2$ and occupies most parts of the North-Western province and part of Western provinces covering seven (7) districts, namely, Chavuma, Kasempa, Lukulu, Mufumbwe, Mwinilunga, Solwezi and Zambezi. This part of Zambia is sparsely populated by different ethnic groups (IWRM, 2006). However, with the advent of large scale mining and a number of small scale mineral processing industries, there has been rapid economic and population growth mostly due to migration of people in search of jobs from other parts of the country (Sichela, 2009). Studies have shown that industrial and population growth lead to an increase in demand of water resources for industrial, agriculture and commercial uses with negative impacts on flora and fauna (Hinrichsen and Robey, 2000). The need to improve water resources information, flood and drought management, land management, watershed protection and management has been SADC's strategy for the shared waters courses that include the Zambezi river basin (SADC-HYCOS, 2002). The main emphasis by SADC-HYCOS has been to establish a reliable water resources information system at national and regional levels. Zambia's Ministry of Energy and Water Development also aims at developing water resources guidelines considering both quality and quantity nation-wide through the Water Rights Management Unit (MWED, 2010). This study intends to develop a hydrological model that would help address water resource management challenges in the Kabompo river basin.

## 1.2 Research problem

The use of traditional hydrological methods in acquiring land, hydrological and meteorological data have proved to be expensive and time consuming in water resources and land management in Zambia. There are a number of gaps in hydrological data records on stream flow (discharge) and water levels due to poor and inconsistent reporting of data from monitoring stations in various parts of the country including the

Kabompo basin (DWA, 2007). Remote Sensing (RS) and Geographic Information System (GIS) based data acquisition methods have been shown to provide faster, cheaper and much wider coverage of data acquisition and have been a major contribution to a number of hydrological models worldwide. Nayak and Jaiswal (2003) showed that remote sensing data can be used to derive thematic information on land use, soil, vegetation and drainage in combination with climate parameters (precipitation, temperature), and topographic parameters (height, contour, slope) to provide necessary input to a hydrological model.

Hydrological models try to simulate the watershed behavior by solving the equations that govern the physical processes occurring within the watershed.They are usually used to simulate the watershed response for a given input.Hydrological models take time series data and produce another time series as output. For example, time series of rainfall data is used in rainfall-runoff models to predict discharge at the outlet of a watershed.

This study used Remote Sensing techniques to develop a hydrological model for the Kabompo River basin.

## 1.3 Aim and Objectives

The aim of the research was to create a hydrological database and develop a hydrological model for the Kabompo River basin using the Arc GIS based soil Water Assessment Tool.

### 1.3.1 Overall objective

The overall objective of this study was to apply remote sensing data into the Soil Water Assessment Tool (SWAT) to predict water discharge in the Kabompo River basin.

### 1.3.2 Specific Objectives

To archive the overall objective the following specific objectives were formulated.

i. To review current hydrological models relevant to Zambia.

ii. To compile RS data base for the Kabompo catchment.
iii. To derive forcing variables from RS datasets necessary for hydrological estimations.
iv. To develop and calibrate with real time data a simulation model, using the ArcSWAT modelling software.

## 1.4 Research questions

To achieve the research objectives, a number of research questions were formulated.

i. How can paucity of hydrological data such as stream flow be argumented using Remote Sensing?
ii. What type of model can be used to generate synthetic hydrological data for the Kabompo River Basin?
iii. How can the accuracy of the generated data be tested?
iv. Would the hydrological Model be useful for water quality assessment?
v. In what areas would the model apply?

## 1.5 Justification of Study

It is expected that the hydrological model will be useful in the planning and evaluation of impacts of the Kabompo River watershed and estimating flows in un-gauged streams, and apply to water resources management of the Kabompo basin. The model is should simulate and estimate stream flow data at a daily time step even for very small catchment areas. Due to insufficient in-situ data, the selection of an ArGIS based modeling tool (SWAT) which is open source software will enable the application of remote sensing data to estimate river flows in the Kabompo basin possible.

## 1.6 Organization of the Thesis

Chapter 1 introduces the background of the Kabompo river basin and outlines the aim and objectives of the study. In Chapter 2, the theoretical background for remote sensing and hydrological modeling are described in relation to the study objectives. It further presents the concepts and terminologies for the modeling tool ArcSWAT, used in developing the hydrological model for the basin. Chapter 3 describes the location and access of the Kabompo river basin, including its physical, social and economic characteristics. Chapter 4 outlines the source and type of data used in compiling an input database for the hydrological model, techniques used in collecting field data and data analysis carried out using various concepts, techniques and software. In Chapter 5, results for calibration exercise, Radar altimetry, field survey and SWAT simulations are presented. The findings and future application for the model are discussed in Chapter 6 illustrated with practical examples within the Kabompo basin. Finally, Chapter 7 concludes the research findings and presents some recommendations for future research and how the model can be improved.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

This chapter describes the use of remote sensing methods in hydrology and review some of the river basin models developed by other scholars. It identifies some of the possible applications of the hydrological models to water resource management in Zambia and ends with a description of some of the SWAT governing equations and numerical data analysis.

## 2.2 Background of remote sensing method in hydrology

Imagery acquired by airborne or satellite sensors provides an important source of information for mapping and monitoring the natural and manmade features on the land surface (Randall, 2006). Remote sensing (RS) is defined as the acquisition of information about an object without being in physical contact with it. The science of remote sensing in its broadest sense includes earth observation or weather satellite platforms, ocean and atmospheric observing weather buoy platforms, magnetic resonance imaging (MRI), positron emission tomography (PET), X-radiation (X-RAY) and space probes (Campbell, 2002). In remote sensing, information is acquired by detecting and measuring changes that the object imposes on the surrounding field, be it an electromagnetic, acoustic, or potential field (Elachi and Zyl, 2006). Remote sensors measure electromagnetic (EM) radiation that has interacted with the Earth's surface. Interactions with matter can change the direction, intensity, wavelength content, and polarization of EM radiation (Randall, 2006). Figure 1 shows regions of the electromagnetic spectrum with different wavelength and energy levels.

Two types of sensors can be distinguished depending on the energy source. **Passive sensor:** Sensor detects the reflected or emitted electro-magnetic radiation from natural sources. **Active sensor:** Sensor detects reflected responses from objects that are irradiated from artificially-generated energy sources. Remote sensing images are acquired by detecting radiation in a small number of narrow wavelength bands.

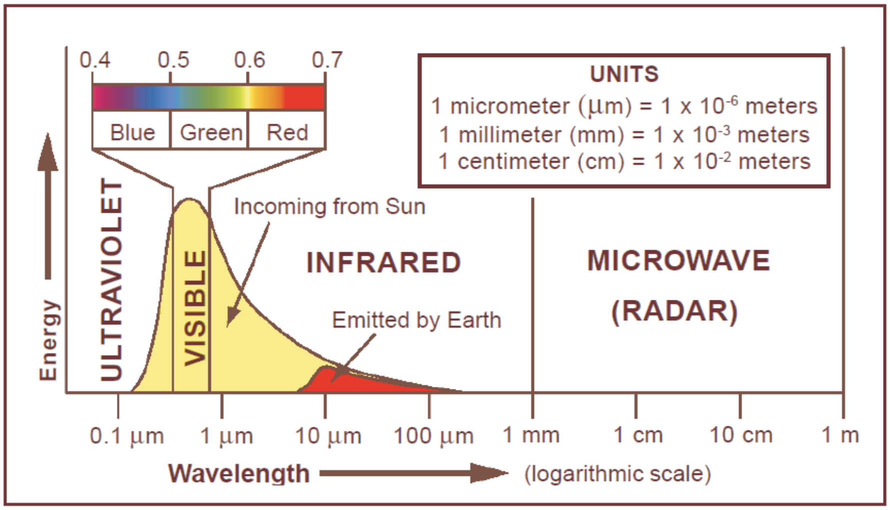



**Figure 1:** The electromagnetic Spectrum (source: Randall, 2006).

Most satellite systems use from three to six spectral bands in the visible to middle infrared wavelength region. Some systems also employ one or more thermal infrared bands. Examples of the band ranges for some of the satellite sensors used in remote sensing are shown Table1.

Table 1: Some satellites and sensors used in remote sensing.

| Platform /Sensor / Launch Yr. | Image Cell Size | Image Size (Cross x Along-Track | Spec. Bands | Visible Bands (µm) | Near IR Bands (µm) |
|---|---|---|---|---|---|
| **SPOT 5 HRG** 2002 | 10 m (Vis, NIR) 20 m (MIR) | 60 x 60 km | 4 | G 0.50-0.59 R 0.61-0.68 | 0.79-0.89 |
| **QuickBird** 2001 | 2.4 or 2.8 m | 16.5 x 16.5 km | 4 | B 0.45-0.52 G 0.52-0.60 R 0.63-0.69 | 0.76-0.90 |
| **Ikonos-2 VNIR** 1999 | 4m | 11 x 11 km | 4 | B 0.45-0.52 G 0.52-0.60 R 0.63-0.69 | 0.76-0.90 |
| **Terra (EOS-AM-1) ASTER** 1999 | 15 m (Vis, NIR) 30 m (MIR) 90 m (TIR) | 60 x 60 km | 4 | G 0.52-0.60 R 0.63-0.69 | 0.76-0.86 |
| **SPOT 4 HRVIR (XS)** | 20 m | 60 x 60 km | 4 | G 0.50-0.59 R 0.61-0.68 | 0.79-0.89 |
| **SPOT 1, 2, 3 HRV (XS)** | 20 m | 60 x 60 km | 3 | G 0.50-0.59 R 0.61-0.68 | 0.79-0.89 |

| Platform /Sensor / Launch Yr. | Image Cell Size | Image Size (Cross x Along-Track | Spec. Bands | Visible Bands (µm) | Near IR Bands (µm) |
|---|---|---|---|---|---|
| **IRS-1C, 1D** **LISS III** 1995 | 23.6 m 70.8 m (MIR) | 142 x 142 km 70 x 70 km Pan | 3 | G 0.52-0.59 R 0.62-0.68 | 0.77-0.86 |
| **Landsat 7** **ETM+** 1999 | 30 m | 185 x 170 km | 7 | B 0.45-0.515 G 0.525-0.605 R 0.63-0.69 | 0.75-0.90 |
| **Landsat 4, 5** **TM** 1982 | 30m | 185 x 170 km | | B 0.45-0.52 G 0.52-0.60 R 0.63-0.69 | 0.76-0.90 |
| **IRS-1A, 1B** **LISS I, II** 1988 | 36.25 m (LISSII) 72.5 m (LISS 1) | 148 x 148 km | 7 | B 0.45-0.52 G 0.52-0.60 R 0.63-0.69 | 0.77-0.86 |

Source: Randall (2006).

### 2.2.1 Types of remote sensing

Remote sensing can be split in three section of the electromagnetic spectrum; Visible and Reflective, Infrared and, microwave Remote sensing (Elachi and Zyl, 2006). Figure 2 shows the three types of remote sensing.

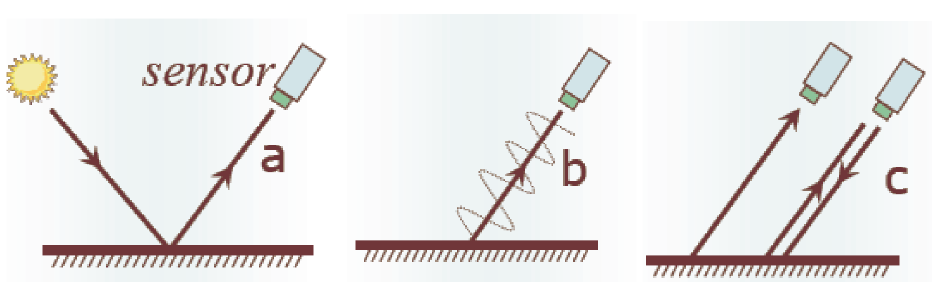



**Figure 2**: Shows types of remote sensing **(a)** Visible and reflective Infrared with the sun as the source of radiation **(b)** Thermal remote sensing , the object is the source of radiation **(c )** microwave remote sensing , radar is source of radiation

The visible wavelengths cover a range from approximately 0.4µm to 0.7 µm. The longest visible wavelength is red and the shortest is violet. **Blue** (0.45—0.52µm) provides the best data for mapping depth-detail of water-covered areas. It is also used for soil-vegetation discrimination, forest mapping, and distinguishing cultural features. **Green**

(0.52—0.60 µm) is useful for mapping detail such as depth or sediment in water bodies. Cultural features such as roads and buildings also show up well in this band. Finally, **Red** (0.60—0.70 µm) in healthy vegetation is highly absorbed by Chlorophyll hence; this band is useful for distinguishing plant species, as well as soil and geologic boundaries (Lillesand et al, 2004)

Thermal Radiation is between 3 µm and 35 µm is useful for crop stress detection, heat intensity, insecticide applications, thermal pollution, and geothermal mapping. This channel is commonly used for water surface temperature measurements.

The microwave region is the longest wavelength used in remote sensing. The shortest wavelengths in this range have properties similar to thermal infrared region. The main advantage of this spectrum is its ability to penetrate through clouds, fog, and rain and images can be acquired in the active or passive mode (Shefali, 2000; Lillesand et al, 2004).

Every object reflects and emits electromagnetic radiation over a range of wavelengths in its own characteristic way according to is chemical composition and physical state. This is termed spectral reflectance. An object may portray its unique spectral signature. i.e., the object/feature or condition exhibits a diagnostic spectral response pattern that differs from other objects (see Figure 3). It is this difference in signature that allows for individual identification of these features or conditions in remote sensing (Laverghetta, 2005).

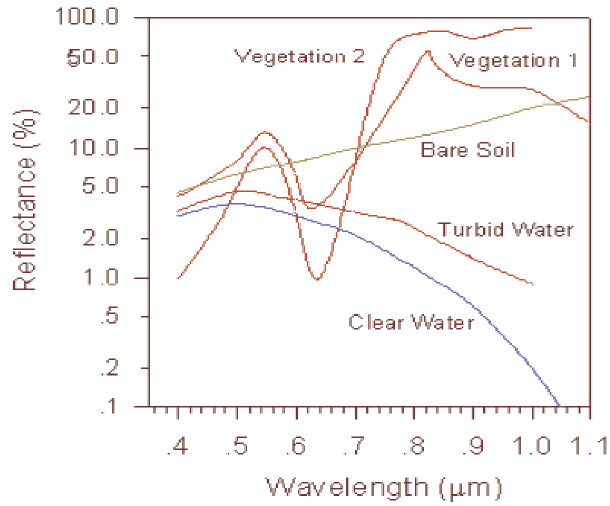
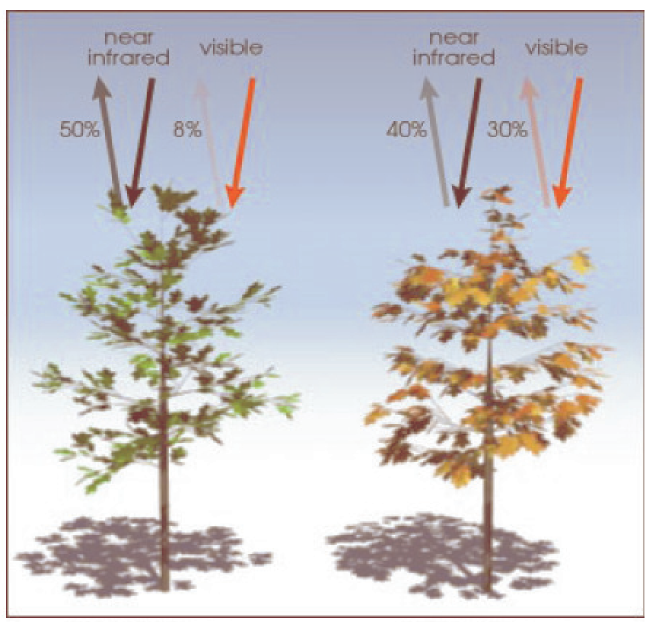



**Figure 3**: Spectral reflectance of different objects and materials. Source: Laverghetta (2005)

A standard remote sensing application for detecting temporal change in land cover, especially vegetation, is the Normalized Difference Vegetation Index (NDVI) shown in Figure 4. The NDVI can be defined as a ratio formula between the visible red and NIR EM bands.




$$NDVI = \frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad NDVI = \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

**Figure 4**: Vegetation indexes source (Lillesand et al, 2004)

This application helps to distinguish healthy and stronger vegetation reflection from other materials with similar reflective properties in the same EM band wavelength groups (Lillesand et al, 2004). Healthy vegetation absorbs most of the visible light especially red that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation Figure 4 (right ) reflects more visible light and less near-infrared light.

### 2.2.2 Types of remote sensing data and applications

The type of remote sensing data being acquired depends on the type of information being sought, as well as on the size and dynamics of the object or phenomena being studied (Elachi and Zyl, 2006). The different types of remote sensing data and their characteristics are summarized in Table 2. Table 3 shows how remote sensing can be used to measure some of the widely used parameters in hydrology.

**Table 2**: Type of remote sensing data and sensors.

| Types of Remote Sensing Data | | |
|---|---|---|
| **Important type of information needed** | **Type of sensor** | **Examples of sensors** |
| wide coverage | Imaging sensors, Cameras | Large-format camera (1984), Seasat imaging radar (1978), Magellan radar mapper (1989), Mars Global Surveyor Camera (1996), Mars Rover Camera (2004) |
| High spectral resolution over, limited areas or along track lines | Spectrometers spectroradiometers | Shuttle multispectral imaging radiometer (1981), Hyperion (2000) |
| Limited spectral resolution with high spatial resolution | Multispectral mappers | Landsat multispectral mapper and thematic mapper (1972–1999), SPOT (1986–2002), Galileo NIMS (1989) |
| High spectral and spatial resolution | Imaging spectrometer | Spaceborne imaging spectrometer (1991), ASTER (1999), Hyperion (2000) |
| High-accuracy intensity measurement along line tracks or wide swath | Radiometers, scatterometers | Seasat (1978), ERS-1/2 (1991, 1997), NSCAT (1996), QuikSCAT (1999), SeaWinds (2002) scatterometers SeaWinds (2002) scatterometers |

| Important type of information needed | Type of sensor | Examples of sensors |
|---|---|---|
| High-accuracy measurement of location and profile | Altimeters, sounders | Seasat (1978), GEOSAT (1985), TOPEX/Poseidon (1992), and Jason (2001) altimeter, Pioneer Venus orbiter radar (1979), Mars orbiter altimeter (1990) |
| Three-dimensional topographic mapping | Scanning altimeters and interferometers | Shuttle Radar Topography Mission (2000) |

Source (Elachi and Zyl, 2006).

**Table 3**: How remote sensing can help solve the stated parameter source.

| **Feature/ Condition/object** | **How remote sensing can help?** |
|---|---|
| Evapotranspiration | measure albedo, surface temperature as key inputs to surface energy balance |
| Precipitation | measure cloud temperature and/or radar beam reflection |
| Soil moisture | measure electrical permittivity of top soil in the microwave range which is strongly correlated with water content |
| Water storage | measure changes in gravity field (GRACE) |
| River and lake stages | Measure radar/laser beam reflection (Radar altimetry) |
| Topography | from radar or laser reflection, stereo-photos |
| Water quality of groundwater | Measure electrical properties of deeper subsurface using active electromagnetic techniques |

Source: Bauer (2010)

Interpretation and analysis of remotely sensed imagery requires an understanding of the processes that determine the relationships between the property the sensor actually measures and the surface properties of interest. Knowledge of these relationships is a prerequisite for appropriate processing and interpretation. There are many difficulties and uncertainties involved in interpreting the multispectral satellite imagery data and this is an ongoing area of research. It is also important to note that the use of RS technology involves large amount of spatial data management and requires efficient system to handle such data and some computer tools such as the Geographical Information System (GIS) technology has been proved to provide suiTable alternatives for efficient management of large and complex databases (Seth, 2009).

In hydrology, remote sensing has great likelihood to provide spatial data rather than point data, measurements of hydrological variables not available through traditional techniques such as soil moisture and snow water content and has the ability, through satellite sensors, to provide long term, global data, even for remote and generally inaccessible regions of the Earth (Edwin and Nandish, 1996). There are various archives of global datasets available online that could be used for hydrological modeling, they range from topographic data (SRTM) to soil data (FAO soils maps) and Land use (Global land use maps) and Climate Data (Haguma, 2007). Other technology available today are the Gravity Recovery and Climate Experiment (GRACE), a joint mission of NASA and the German Space Agency, this technology, uses gravity to show how mass is distributed around the planet and how it varies over time. GRACE data are important tools for studying Earth's hydrology, geology, and climate (Chen et al, 2010; Davis, 2002).

### 2.2.3 ESA Radar Altimetry data

Satellite radar altimeters are nadir pointing active microwave sensors functioning at the main nominal frequency of 13.575 GHz Ku band. Figure 5 shows a radar altimetry antenna.

**Figure 5**: Radar altimeter antenna. Source (earth.esa.int, 2010).

Radar altimetry was initially developed to operate over ocean surfaces and make precise measurements of the sea surface topography (Augusto et. al, 2009). The instrument automatically detects, acquires and tracks the earliest part of the radar echoes from any surface without interruption. A secondary channel at a nominal frequency of 3.2 GHz (S band) is also operated to estimate the ionospheric range delay (Figure 6).

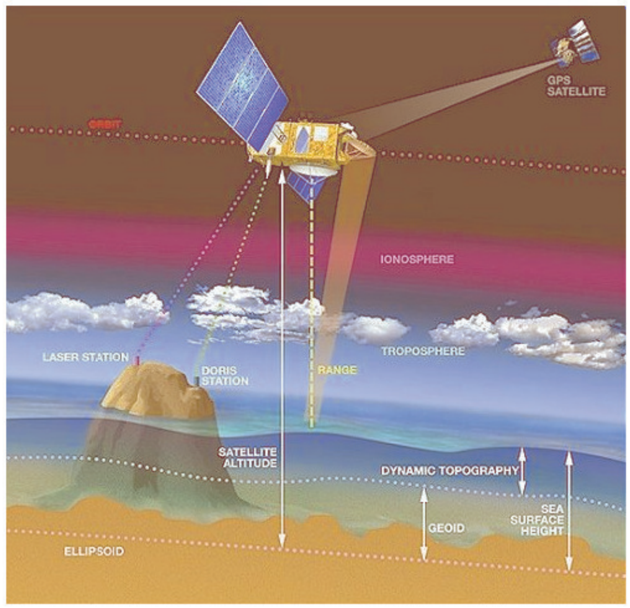



**Figure 6**: ENVISAT satellite. Source (earth.esa.int, 2010)

Radar altimeter provides the range by measuring the time in which a radar pulse goes to the Earth's surface and comes back to the instrument. From its 800 km-high polar orbit, the Radar Altimeter 2 (RA-2) instrument on ENVISAT satelite sends 1800 separate radar pulses down to Earth per second then records how long their echoes take to return – timing their journey down to under a nanosecond to calculate the exact distance to the planet below. Its beam footprint width is about 3.4 km. ENVISAT orbits on a 35-day repeat cycle orbit, providing observations of the Earth surface from 82.4° latitude North to 82.4° latitude South with an equatorial ground-track spacing of about 85 km. The altitude of the satellite above the reference ellipsoid is computed with a precise orbit determination system. The surface height above the ellipsoid is calculated by subtracting the corrected range from the satellite altitude (Berry et al., 2006, Frédéric et al., 2009).

Radar altimetry has many limitations over land due to the complexity of returned waveforms. An altimeter waveform (or radar echo) represents the histogram of the energy backscattered by the ground surface to the satellite with respect to time. Many radar echoes are multipeaked or present a noisy shape revealing the presence in the altimeter footprint of several reflectors such as water, vegetation canopy, rough topography or vegetation (Frédéric et al., 2009). To overcome this, an innovative tracking algorithm, known as Model Free Tracker (MFT), has been designed on RA-2 which makes the instrument concentrates its effort maintaining the earliest part of radar echoes within the tracking window, independently of its shape. The MFT decides whether the range window is using the adequate resolution, whether the resolution could be increased, or decreased, based on the Signal to Noise ratio (SNR) of the on-board waveform position compared to reference values stored in the on-board memory. When the radar echo is about to move out of the tracking window, due for example to a sudden change in the surface elevation, the window is broadened to recapture the echo. This allows uninterrupted radar operation over all type of surfaces and its boundaries, and will avoid a dedicated mode change, commanded from ground. Ocean, ice sheets and land surface topography are measured to the highest possible accuracy, and new terrains are tracked (earth.esa.int, 2010). A study was conducted on the Amazon Basin using ENVISAT RA-2 data products.

In their Preliminary Results of ENVISAT RA-2 Derived Water Levels validation over the Amazon Basin, Frédéric et al. (2009) showed that ENVISAT RA-2 exhibits a strong capability for the monitoring of inland waters. For different test zones, the large number of validated data showed the lowest RMS differences (< 0.3 m on the rivers and < 0.5 m on the wetlands). They also showed The results, for one year of RA-2 data, are 2 or 3 times better than those obtained with 10-year of Topex/Poseidon( T/P) data by Birkett et al. (1998).

## 2.3 Review of river basin modeling

A number of hydrological models have been developed by a wide range of researchers and engineers for management of surface and groundwater quantity, quality and other studies. Watersheds may be modeled by a lumped model using basin average input data and producing total basin stream flow. Such a model may produce reasonable result but because of the distributed nature of hydrological properties like soil type, slope and land-use, the model cannot be expected to accurately represent the watershed conditions (Madhav, 2003). With the development of GIS, the hydrological catchment models have been more physically based and distributed considering spatial heterogeneity.

Using remote sensing and GIS, Madhav (2003) developed a spatially distributed hydrological model for the Kathmandu Valley basin, Nepal. The SCS curve number method was used to assess the runoff changes due to land-use changes. The model was developed using different datasets from different sources. Landuse maps were derived from topographic maps and Landsat TM images through digital image processing and Visual image interpretation using an interpretation key generated through field survey and verifications. Other datasets used include soil maps, precipitation and stream gauging data. The results of the study showed that the spatially distributed hydrological model was the best model to assess the hydrological change due to land-use changes. GIS appeared to have been an efficient tool for presentation of input data as required by the model. The runoff values computed by the model matched much better during the wet season than dry season. A sensitivity analysis carried out showed that the runoff estimation with distributed approach were very close with observed values. The analysis also shows the distributed approach gives better performance when compared to lamped methods.

Ramona et al. (1998) developed a hydrological model for the Cape Fear River Basin in North Carolina using the ArcGIS based Mike Basin software. The project tasks involved an extensive collection, review, and interpolation of hydrologic data, model schematization, and estimations of agricultural water use as well as municipal and industrial withdrawals and discharges. Other data sets used to develop the model included; a Digital Elevation Model (DEM), precipitation and Stream Flow Gauge data. The results showed very close matches between observed and simulated hydrographs. However, uncertainties in routing parameters, reservoir operations, and inconsistencies in gauging data contributed to a less than 100% perfect match in some cases.

By using SWAT, Vassilios et al (2009), developed a hydrological model for the Kosynthos River watershed located in North-eastern Greece. The watershed was delineated into 32 sub-basins resulting into 135 Hydrological response units (Areas with the same soil types, slope and landuse). The model was calibrated and verified using continuous meteorological data from three stations, and runoff and nutrient concentrations measured at four monitoring sites located within the main tributaries of the watershed, for the time period from November 2003 to November 2006. Calibration and verification results showed good agreement between simulated and measured data.

Schuol et al. (2008) used a semi-distributed hydrological model SWAT to estimate the fresh water component of blue water flow (i.e., water yield plus deep aquifer recharge), green water flow (i.e., actual evapotranspiration) and green water storage (i.e., soil water) with monthly resolution for the whole Africa. Using the program SUFI-2 (Sequential Uncertainty Fitting Algorithm), the model was calibrated and validated at 207 discharge stations, and prediction uncertainties were quantified. The model results are generally good albeit with large prediction uncertainties in some cases.

Coskun et al. (2005) used GIS and remote sensing integration to provide determination of runoff from the Yuvacık basin in north-west Turkey. Satellite images were used to determine curve number distribution of the basin area with 30 m spatial resolution. Using the Natural Resources Conservation Service Curve Number (NRCS-CN) method, the curve number was estimated according to the factors of hydrological soil group, land use, land treatment, drainage basin characteristics, meteorological and hydrological parameters. Remotely sensed images from Landsat satellite was used to develop land use map of the study area. GIS analysis, based on land use and hydrological soil map data, was processed so as to determine spatially distributed runoff curve numbers on a 30-

meter grid. Simulated results proved to be very useful for flood forecasts and management of hydraulic structures. Parameters obtained were useful to understand hydrological characteristics of basin area.

## 2.4 Possible application of the ArcSWAT model

In the past, most ArcSWAT model application mainly focused on sediment routing, Nutrient routing and, Pesticide routing (Kurz, 2007; Van and Flynn 2008). Effects of various land use changes have also been studied using SWAT, for example, pikounis et. al.(2010) used the soil water assessment tool (swat) to estimate the effect of specific land use changes on the river Pinios in Thessaly (Ali Efenti catchment), by comparing the simulated and observed discharge time series at the outlet of the watershed.

Due to insufficient hydrological data for the Kabompo river basin, SWAT was chosen to be applied on the Kabompo river basin because all the necessary variables needed to operate it could be obtained from remote sensing derived data. Unlike other modeling tools which are either too expensive or have numerous data input requirements, SWAT is a freeware, and has been used by a number of researchers all over the world in a number of applications.

Simulated discharge from the Kabompo river basin model will be useful in water resource management activities such as water rights, water allocation, sediment loading and spatial and temporal mapping of freshwater (surface water) availability.

## 2.5 Water Rights and Water Allocation in Zambia

Internationally, access to and use of water is now formally recognized as being a human right, and the right of access to clean and affordable water. The ownership of all water resources in Zambia is vested in the President though legal pluralism exists within state law (Republic of Zambia, 1949). The use, diversion and apportionment of all water is assumed to fall under the Water Act (1948) which provides for the ownership, control and use of mainly surface water (Chileshe et al., 2005, Republic of Zambia, 1949). The

Water Act is the main legislation that deals with water allocation in Zambia. Water rights are obtained through the Water Development Board under the Ministry of Energy and Water Development (MEWD). The Water Board has been established as the authorizing entity for water use. The Water Board may, at its discretion, grant, refuse or modify an application in whole or in part; or attach conditions to the granting. However, this does not apply to traditional land which is governed by riparian system. The local chief has a right to withdraw land rights for a valid reason like non-cultivation or if the owner is not abiding by the rules and regulations of the chiefdom (Pakhus, 2006). Water use according to the act is classified into three categories; primary, secondary and tertiary uses of water.

Primary use of water applies to water for domestic purposes and the support of animal life. Secondary use of water refers to the use of water for the irrigation of land and pisciculture. Tertiary use applies to water for mechanical and industrial purposes such as generation of power. Primary uses of water have priority where conflict over water uses and allocations arise (Chileshe et al., 2005).

Even though the current Act is likely to have an addition to address the provision on abstraction of groundwater (registration of borehole construction), the major challenge on the water resource has existed at the secondary water use level. Irrigation schemes have been highly encouraged by the Zambian government to increase the national food security and employment. However, these irrigation activities have led to an increase in water abstraction from most rivers resulting in an imbalance between the needs of the environment and the water users. Worse of all rivers have been reported to “dry up”. Even from a Southern African Development Community (SADC) perspective, human consumption and irrigation are the two major factors affecting the future of water use and demand in the region (Herbertson et al., (2001). The Kafue flats in Zambia for example, are an area of increasing water demand for irrigated agriculture, industry and hydropower. The Mkushi Farming block mainly in the Lunsemfwa river catchment, is another area where tension between water users has existed more especially in drought periods. Presently, water rights have been revised to match actual monthly crop water requirements. The original fixed lump sum tariff has been replaced by an actual use tariff with rising blocks. Small scale farmers are protected by a flat fee for up to 500m3/day. In order to resolve the problems associated with new water allocation strategies, the Zambian Water Board promoted an education campaign for farming communities - as a result of which a number of Catchment Management Associations were set up. Their primary objective is to regulate water abstractions while striking a balance between the needs of the environment and farmers. They are registered with the Water Board and operate as a co-operative society (Herbertson et al., (2001).

The model in this study will be able to estimate river discharge of any sub-basin in the Kabompo basin which lacks historical river flow data. Discharge values are a key decision making tool for water board before allocating a water right to an applicant (Pakhus, 2006). The flow regime of a river of interest should be determined before allocating water rights to applicants. Discharge values in combination with SWAT topographic report can help estimate sediment loading to hydraulic structures such as dams and weirs, a major threat in erosion prone areas. Various landuse and water abstraction activities can be deliberately adjusted to determine the effect of landuse and water demand changes on the water resource by observing change in simulated discharge. This would help in water management planning. Finally, the simulated discharge once combined with river and soil sampling data at strategic locations, would be very useful in water quality analysis of various nutrients, chemicals and heavy metals in the basin. Based on the complex nature of this subject matter, the later is to be handled by different researcher under the same IWRM program.

## 2.6 SWAT governing equations and numerical data analysis

The Soil Water Assessment Tool (SWAT) was selected since, it requires easily accessible data such as weather, soil properties, topography and vegetation. Besides, values can be quantified if not available (Neitsch et al., 2005). SWAT has been used by a number of researchers and scientist for over 30years and can be downloaded for free from the internet.

SWAT partitions a watershed into a number of sub watersheds or sub-basins. The use of sub-basins is considered beneficial when different areas of a watershed have different landuses or soil types hence, the application of unique data sets spatially to a sub basin is very possible and the model can also reflect differences in evapotranspiration for various crops and soils. For more efficient data computation, SWAT further sub divides the sub-basins into smaller units called Hydrological Response Units (HRU). These are lumped land areas within the sub-basin that are comprised of unique landcover, soil and management (Neitsch et al., 2005). HRU allows for more accurate runoff to be predicted separately for each unit and routed obtaining a total runoff.

Figure 7 shows an overall water movement from precipitation to the deep aquifer in SWAT. Following a rainfall event, Water may either infiltrate into the soil or flow as overland flow (surface runoff). Infiltrated water may either evapotranspirate or slowly contributes to surface water via underground paths. Some water may be lost from the basin once it infiltrates into the deep aquifer whose exist is assumed to be outside the basin. But can be recovered once pumped out in activities such as irrigation. Snow does not exist in the Kabompo basin region; hence, it has been canceled out from the original schematic representation as shown in Figure 7.

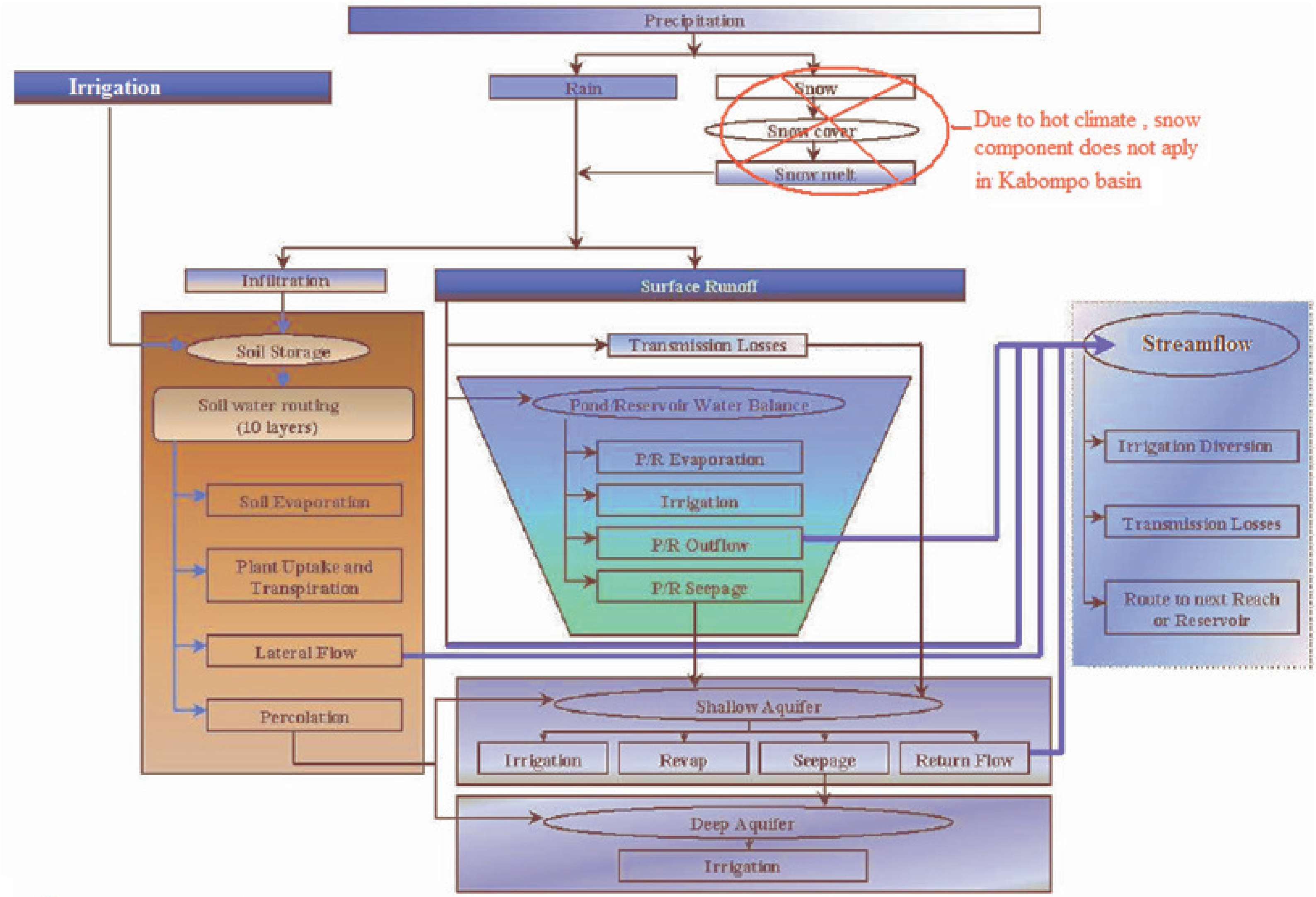



**Figure** 7:Schematic representation of water pathway in SWAT source: (Neitsch et al.,)

### 2.6.1 Land phase of the hydrological cycle

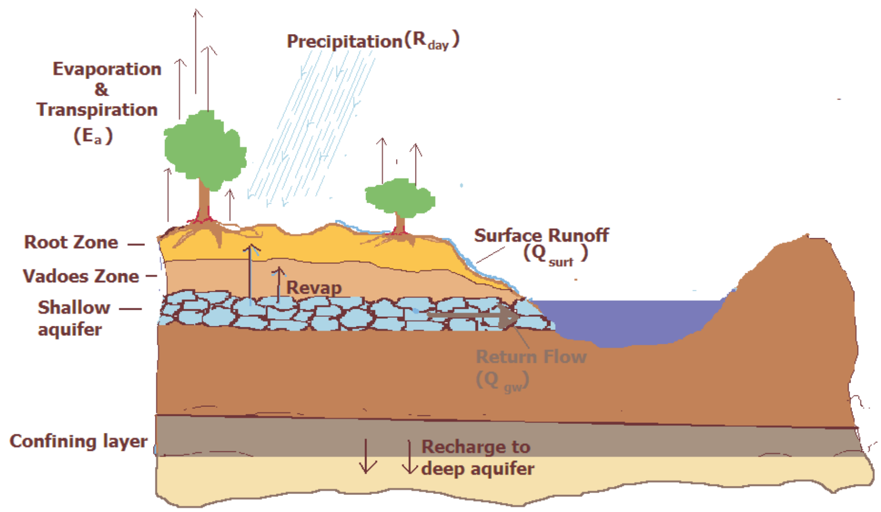



**Figure 8**: Schematic representation of the land phase cycle (source: Neitsch et al., 2005)

Neitsch et al. (2005) describes the land phase of the hydrological cycle for the SWAT to be based on the equation

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \qquad (2.6.1)$$

Where $SW_t$ is the final soil Water Content (mm $H_2O$), $SW_0$ is the Initial soil Water Content, t is the time (days), $R_{day}$ is the amount of Precipitation in day i (mm $H_2O$), $Q_{surf}$ is the Surface runoff in day i (mm $H_2O$), $E_a$ is the evapotranspiration in i (mm $H_2O$), $w_{seep}$ is the water entering vadose zone soil profile in day i (mm $H_2O$) and $Q_{gw}$ is the return flow on day i (mm $H_2O$). See Figure 8.

### 2.6.2 Surface runoff

Is computed using a modified SCC curve number method. The curve number drops none linearly as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation. The SCS curve number is given by the equation (Soil Conservation Service, 1972).

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad (2.6.2)$$

Where: $I_a$ is the initial abstraction which includes surface storage (mm $H_2O$) and $S$ is the retention parameter (mm $H_2O$). The Retention parameter varies due to change in soils, landuse management, slopes and temporal change in soil water content. The retention parameter is given by the equation:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \qquad (2.6.3)$$

Where: $CN$ is the curve number for the day. The initial abstraction is approximated by 0.2S (SCS, 1972), hence equation 2.6.2 becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} - 0.8S)} \qquad (2.6.4)$$

Runoff only occurs when $R_{day} > I_a$. The Sub-basin time of concentration is estimated using Manning's formula considering both overland and channel flow.

## 2.6.3 Evapotranspiration

The potential evaporation method used in this study is the Hargreaves Method (Hargreaves and Samani, 1985) which only requires air temperature. It is given by the equation:

$$\lambda E_o = 0.0023 \cdot H_o \cdot (T_{mx} - T_{mn})^{0.5} \cdot (\overline{T}_{av} + 17.8) \qquad (2.6.5)$$

Where: $\lambda$ is the latent heat of vaporization (MJ $Kg^{-1}$), $E_o$ is the reference evapotranspiration ($mmd^{-1}$), $H_o$ is the extraterrestrial radiation (MJ $m^{-2}d^{-1}$), $T_{mx}$ is the maximum air temperature for a given day ($^{\circ}C$), $T_{mn}$ is the minimum air temperature for a given day ($^{\circ}C$), and $\overline{T}_{av}$ is the mean air temperature for a given day ($^{\circ}C$).

### 2.6.4 Recharge

Recharge is the water that moves past the lowest depth of the soil profile by percolating throw the vadose zone and contributing to both the shallow and deep aquifer. Recharge to both aquifers is given by the equation:

$$w_{rchrg,i} = (1 - \exp\left[-1/\delta_{gw}\right]) \cdot w_{seep} + \exp\left[-1/\delta_{gw}\right] \cdot w_{rchrg,i-1} \quad (2.6.6)$$

Where: $w_{rchrg,i-1}$ is the amount of recharge entering the aquifers on day i (mm $H_2O$), $\delta_{gw}$ is the delay time or drainage time of the overlaying geological formations (days), $w_{seep}$ is the total amount of water entering the aquifers on day i(mm $H_2O$), and $w_{rchrg,i-1}$ is amount of recharge entering the aquifers on day i-1(mm $H_2O$) Sangrey et al. (1984). Furthermore, the total amount of water exiting the bottom of the soil profile on day I is given by;

$$w_{seep} = w_{perc,ly=n} + w_{crk,btm} \quad (2.6.7)$$

Where: $w_{perc,ly=n}$ is the amount of water percolating out of the lowest layer, n, in the soil profile on day i (mm $H_2O$), and $w_{crk,btm}$ is the amount of water flow past lowest boundary of the soil profile (mm $H_2O$). Neitsch et al. (2005) shows that the SWAT calculates the amount of water diverted from shallow aquifer to deep aquifer as:

$$w_{deep} = \beta_{deep} \cdot w_{rchrg} \quad (2.6.8)$$

Where: $w_{deep}$ is the amount of water moving into the deep aquifer on day i (mm $H_2O$), $\beta_{deep}$ is the aquifer percolation coefficient, and $w_{rchrg}$ is the amount of recharge entering both aquifers on day i (mm $H_2O$). Hence the recharge to the shallow aquifer is given by

$$w_{rchrg,sh} = \cdot w_{rchrg} - w_{deep} \quad (2.6.9)$$

Where: $w_{rchrg,sh}$ is the amount of water entering the shallow aquifer on day i (mm $H_2O$).

### 2.6.5 Return flow or base flow

Return flow or base flow is the volume of stream flow originating from ground water. Base flow is allowed to enter the reach only if the amount of water stored in the shallow aquifer exceeds a threshold value specified by the user, $aq_{shth,q}$ Neitsch et al.(2005).

Based on the steady state response of ground water to recharge used by Hooghoudt (1940) and the water Table fluctuation due to non steady state response to ground water by Smedema and Rycroft (1983), the ground water for a given day is given by:

$$Q_{gw,i} = Q_{gw,i-1} \cdot \exp\left[-\alpha_{gw} \cdot \Delta t\right] + w_{rchrg,sh} \cdot (1 - \exp\left[-\alpha_{gw} \cdot \Delta t\right]) \quad (2.7.0)$$

Where: $Q_{gw,i}$ is the groundwater flow into the main channel on day I(mm $H_2O$), $Q_{gw,i-1}$ is the groundwater flow into the main channel on day i-1(mm $H_2O$), and $\alpha_{gw}$ is the base flow recession constant, $\Delta t$ is the time step (1day). Neitsch et al. (2005) further shows that given the threshold value for $aq_{shth,q}$ .I then:

$$Q_{gw,i} = 0 \quad \text{if} \quad \begin{matrix} aq_{sh} > aq_{shth,q} \\ aq_{sh} \leq aq_{shth,q} \end{matrix} \quad (2.7.1)$$

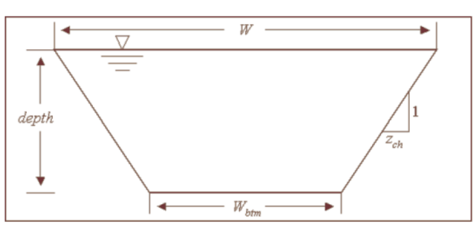
Where: $aq_{sh}$ is the amount of water stored in the shallow aquifer at the beginning of the day i(mm $H_2O$).The base flow recession constant is given by:

$$\alpha_{gw} = \frac{1}{N} in\left[\frac{Q_{gw,N}}{Q_{gw,0}}\right] = \frac{1}{BFD} \cdot in[10] = \frac{2.3}{BFD} \quad (2.7.2)$$

Where: $Q_{gw,N}$ is the ground water flow on day N (mm $H_2O$), $Q_{gw,0}$ is the ground water flow at the start of the recession ,and $BFD$ is the number of base flow days for a watershed.

### 2.6.6 Routing phase of the hydrological cycle

SWAT assumes the main channels or reach have a trapezoidal shape (Neitsch et al., 2005).




Trapezoidal shape approximated by SWAT source: Neitsch et al., (2005).

When using SWAT the user is required to define the depth and width of the channel when filled to the top of the bank, as long as the channel length and slope along the channel length and Manning's n value. SWAT assumes side slopes of 2:1 or $z_{ch} = 2$. Neitsch et al., (2005) indicates that once the volume exceeds the maximum amount that can be held by the channel, excess water spreads across the flood plain shown below (sketch not to scale). The flood plain side slopes are approximated to be 4:1.


The manning's equation for uniform channel flow is used to calculate the rate and velocity in a reach segment

$$v_c = \frac{R_{ch}^{2/3} \cdot slp^{1/2}}{n} \tag{2.7.3}$$

Where: $v_c$ is the flow velocity (m s$^{-1}$), $R_{ch}$ is the hydraulic radius for a given depth (m), $slp$ is the slope along the channel length (m m$^{-1}$), and $n$ is the Manning's coefficient for the channel (Neitsch et al., 2005).

## 2.6.7 Routing method

To route water to the main channel, the variable storage coefficient method based on the variations of the Kinematic wave model (Chow et al, 1988) and initially developed by Williams (1969) has been chosen in this study. The variable storage coefficient is:

$$V_{out2} = SC \cdot (V_{in} + V_{stored}) \tag{2.7.4}$$

Where: $SC$ is the storage coefficient , $V_{out2}$ is the volume of out flow at end of time step (m³ $H_2O$), $V_{in}$ is the volume of in flow during the time step (m³ $H_2O$), and $V_{stored}$ is the stored volume during time step (m³ $H_2O$)

### 2.6.8 Channel water balance

Water storage in the reach at the end of the time step is calculated as:

$$V_{stored,2} = V_{stored,1} + V_{in} - V_{out} - t_{loss} - E_{ch} + div + V_{bank} \qquad (2.7.5)$$

Where $V_{stored,2}$ is the volume of water in the reach at the end of the time step (m$^3$ $H_2O$), $V_{stored,1}$ is the volume of water in the reach at the beginning of the time step (m$^3$ $H_2O$) , $V_{in}$ is the volume of the reach during the time step (m$^3$ $H_2O$), $V_{out}$ is the volume of water flowing out of the reach during the time step, $t_{loss}$ is the volume of water lost trough transmission via the river bed (m$^3$ $H_2O$), $E_{ch}$ is the evaporation from the reach for the day (m$^3$ $H_2O$), $div$ is the volume of water added or removed for the day trough diversion, and $V_{bank}$ is the volume of water added to the reach via return flow from the bank storage (m$^3$ $H_2O$) (Neitsch et al., 2005).

# CHAPTER 3: DESCRIPTION OF STUDY AREA

## 3.1 Introduction

This chapter describes the location, physical characteristics and social economic characteristics of the Kabompo river basin.

## 3.2 Location and access

The Kabompo river basin lies between Latitudes 11$^{0}$S and 15$^{0}$S, Longitudes 23$^{0}$E and 26$^{0}$E in Northwestern and Western Provinces of Zambia as shown in Figure 9. It occupies eight districts shown in Figure 10. The basin can be best accessed through M8 road that crosses the basin from Solwezi through Kabompo to Zambezi town. The basin can also be accessed from the Lusaka Mongu road through the D792 road.

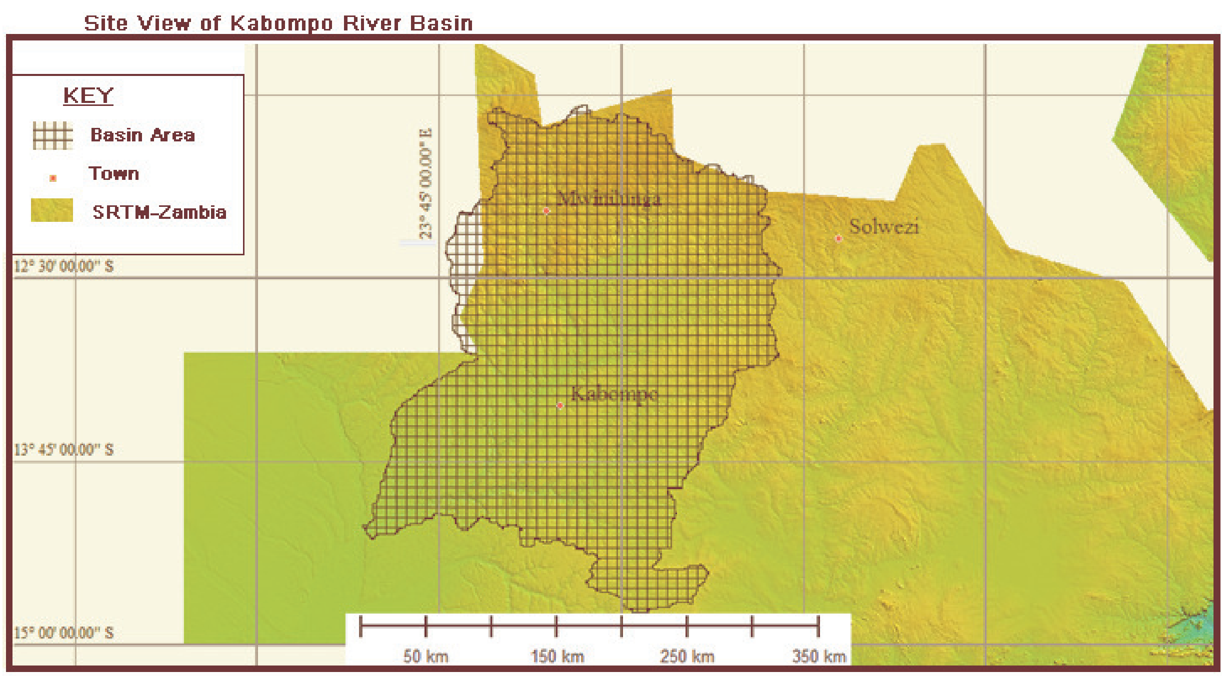



**Figure 9**: Location of Kabompo Basin


**Figure 10**: Districts located in Kabompo basin, Zambia.

## 3.3 Physical Characteristics

### 3.3.1 Climate

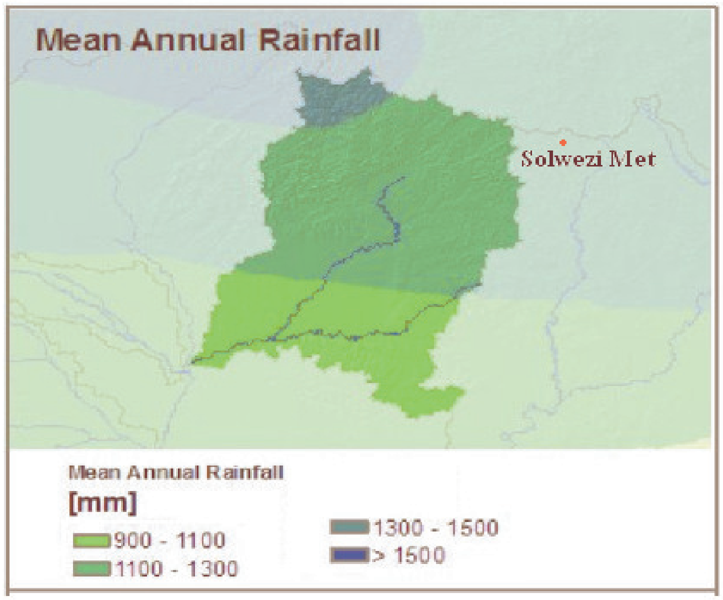
Kabompo basin experiences two distinctive seasons, a dry half from May to October and a wet half from November to April. According to JICA (1995), from the synoptic point of view it is more convenient to divide the year into four (4) unequal seasons as follows;

1. Winter Season : June to August
2. Hot Pre-rain season : September to October
3. Rainy season : November to March
4. Post rainy season : April and May

The mean annual rainfall for the Kabompo basin varies between 900mm in the south most to 1400mm in the north (IWRM, 2006) (Figure 11a). The mean monthly rainfall distribution for Solwezi station shows that precipitation is highest from the month of

December to March (Figure 11b). JICA (1995) indicates that distribution of temperature in most parts of Zambia that includes the basin depends on altitude rather than latitude. The average temperature for the Month of July varies from 14°C to 16°C while November temperatures vary between 20 °C to 22 °C.

**(a)**




**(b)**

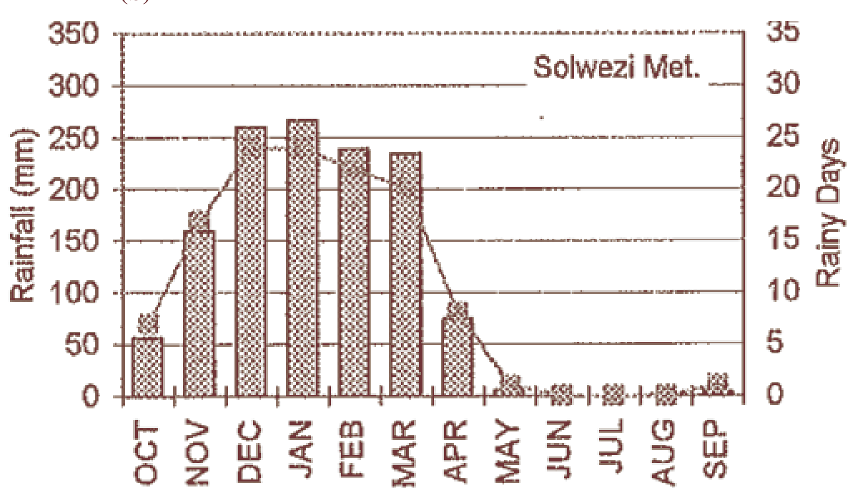



**Figure 11:** Showing rainfall amounts in the basin: (**a)** Mean Annual Rainfall distribution in the basin **(b)** Mean Monthly Rainfall distribution in Solwezi town. Source (IWRM, 2006)

Annual mean relative humidity for most part of the North Western Province is higher than 65% and reaches as high as 80% during the period December to March, and is low as 50% from August to October. Annual mean wind speed ranges approximately from 1.4

m $s^{-1}$ to 2.0 m $s^{-1}$. Monthly wind speed is weak in the rainy season at 1.0 – 1.5 m $s^{-1}$ and is strong in the dry season at 2.0 – 2.5 m $s^{-1}$ (JICA, 1995).

### 3.3.2 Hydrology

Kabompo River is one of the main tributaries of the Zambezi River. Some of the tributaries of the Kabompo River are the Lumwana East, Mutanda, West Lunga, Maheba, Mumbeji and the Dongwe (Figure 12). Based on Department of Water affairs discharge data measured at Watopa Pontoon, the Kabompo has an average annual discharge of 210 m $s^{-1}$ with lowest and highest discharge records of 37 and 1039 m $s^{-1}$ respectively, recorded between the periods of the year 1958 and 2007. The river length from the source to the outlet is approximately 410km falling from an elevation of 1443m above sea level by 389m.

### 3.3.3 Geomorphology

According to JICA (1995), most parts of Zambia are classified as Central African Plateau. The elevation of the plateau ranges from 600 to 1,850m above mean seal level. The highest parts of the plateau are located in the northern direction and Northwest of Zambia. Elevation gradually reduces in the southwest/south to the Zambezi River. The plateau is gently undulating in all places. The Central African plateau is subdivided into two major sub units that are Dgraded plateau and Aggraded plateau. The surface of Degraded plateau shows the effect of erosion and is traversed by a network of rivers. The terrain of the plateau is dominated by high drainage density, swamps, lakes, flood plains and isolated hills. The surface of Aggraded plateau is formed by sediments and characterized by largely gently undulating plains with widely spaced rivers and by sand dunes and pans. The distribution of Aggraded plateau is extensive in Western and Northwestern Provinces (JICA, 1995). Figure 14 shows distribution of Aggraded and Degraded plateau in the Kabompo basin.

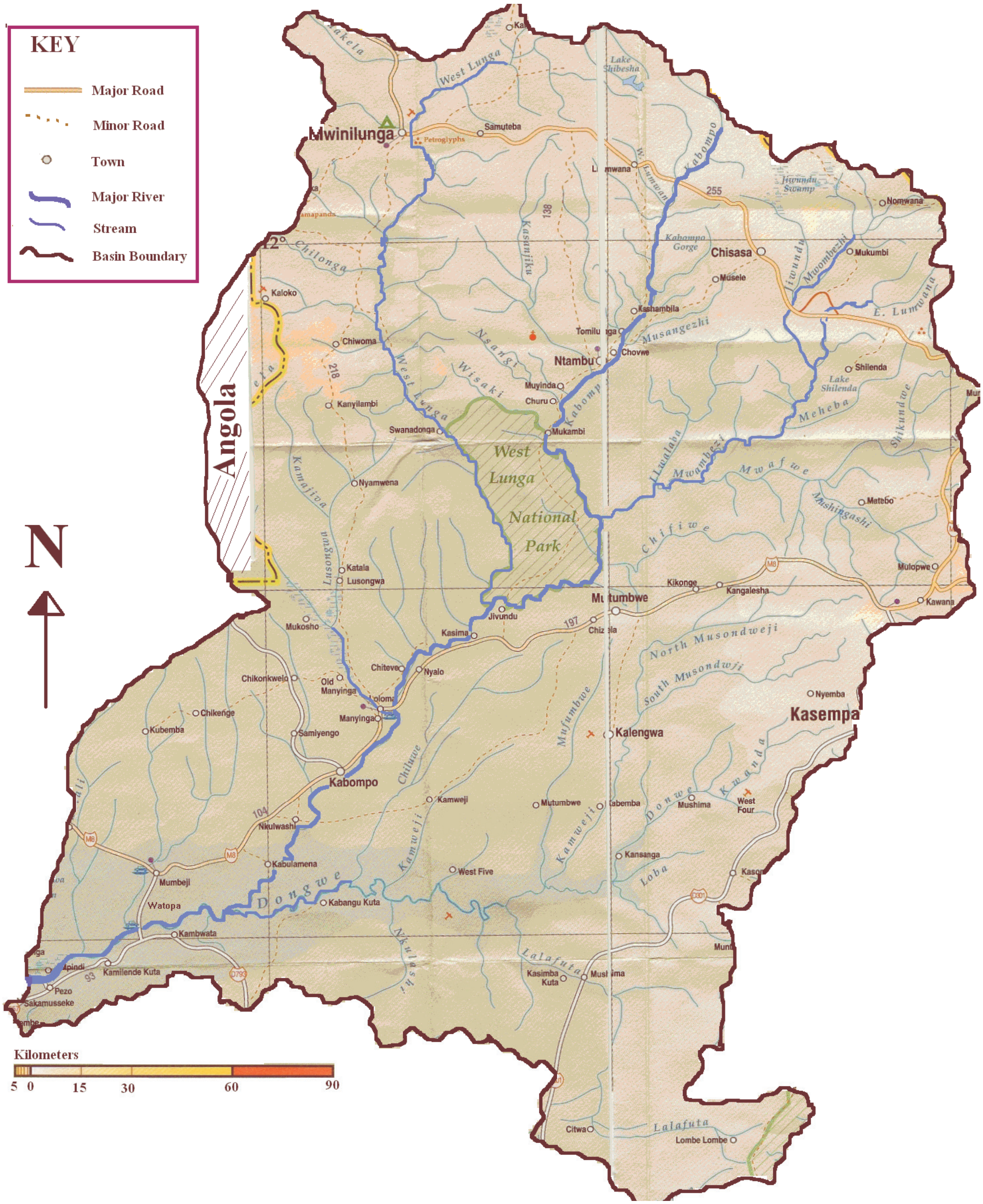



**Figure 12:** Showing Kabompo Basin map with rivers, streams, road network and towns. Clipped from scanned map of Zambia originally developed by (hunt-africa.com, 2010)

### 3.3.4 Geology

Craig et al. (2010) report that the geology of Zambia is dominated by the northeast trending Kibaran Mobile Belt (KMB) which separates the Archaean Congo Craton to the northwest with the Kalahari and Zimbabwe Cratons to the southeast. It is pointed out that the KMB was probably initiated in the Palaeoproterozoic (ca 1800 Ma), but is dominated by Neoproterozoic rocks and structures. The Kabompo basin region is dominated by Kabompo granitic domes flanked by a sequence considered equivalent to the basal Lower Roan rocks (850 Ma to 800Ma) a composition of the Katanga Supergroup. Figure 13 below shows a geology map for the Kabompo River basin

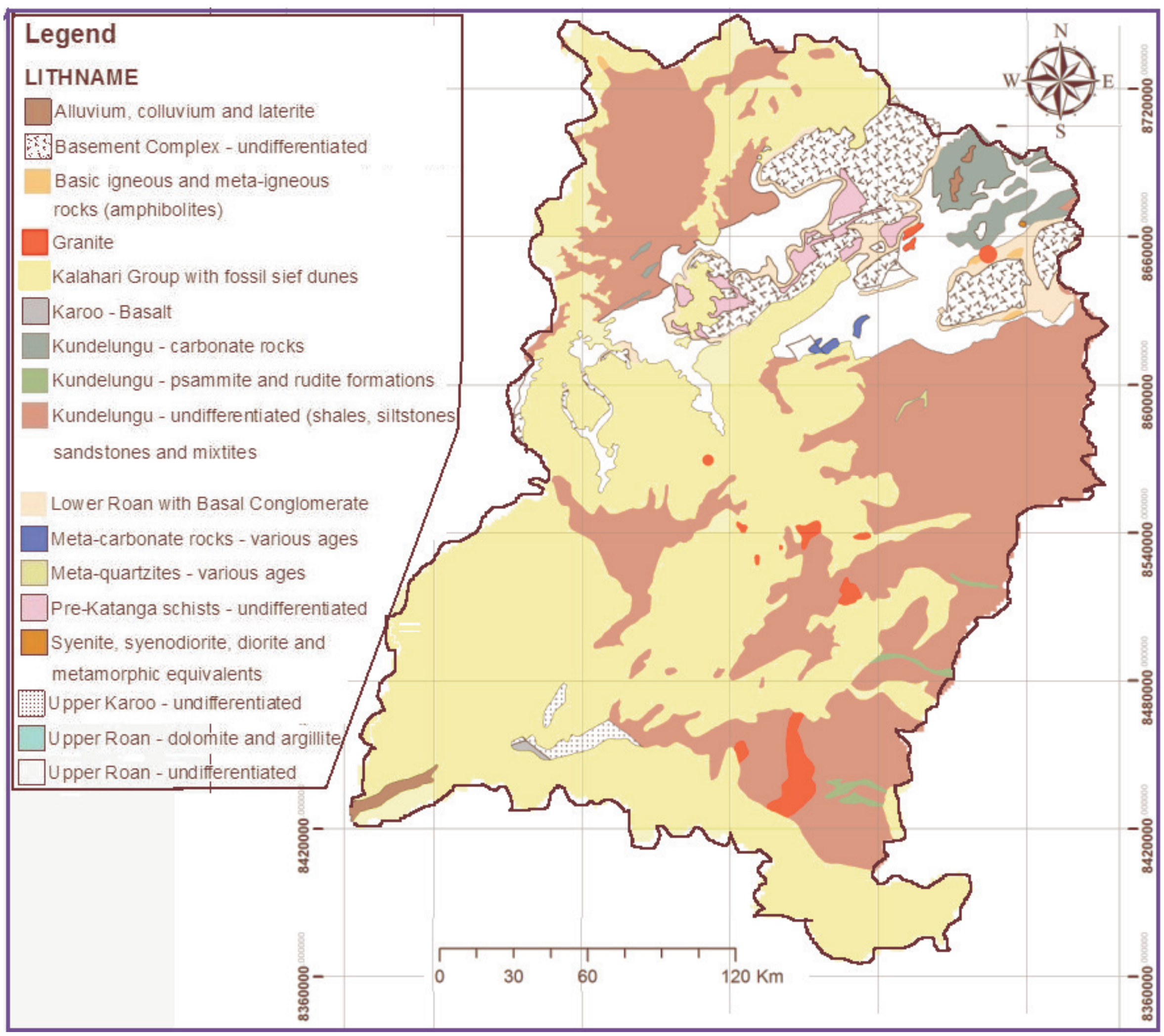



**Figure 13:** Map showing geology for the Kabompo river basin. Source: (Porada, 1989)

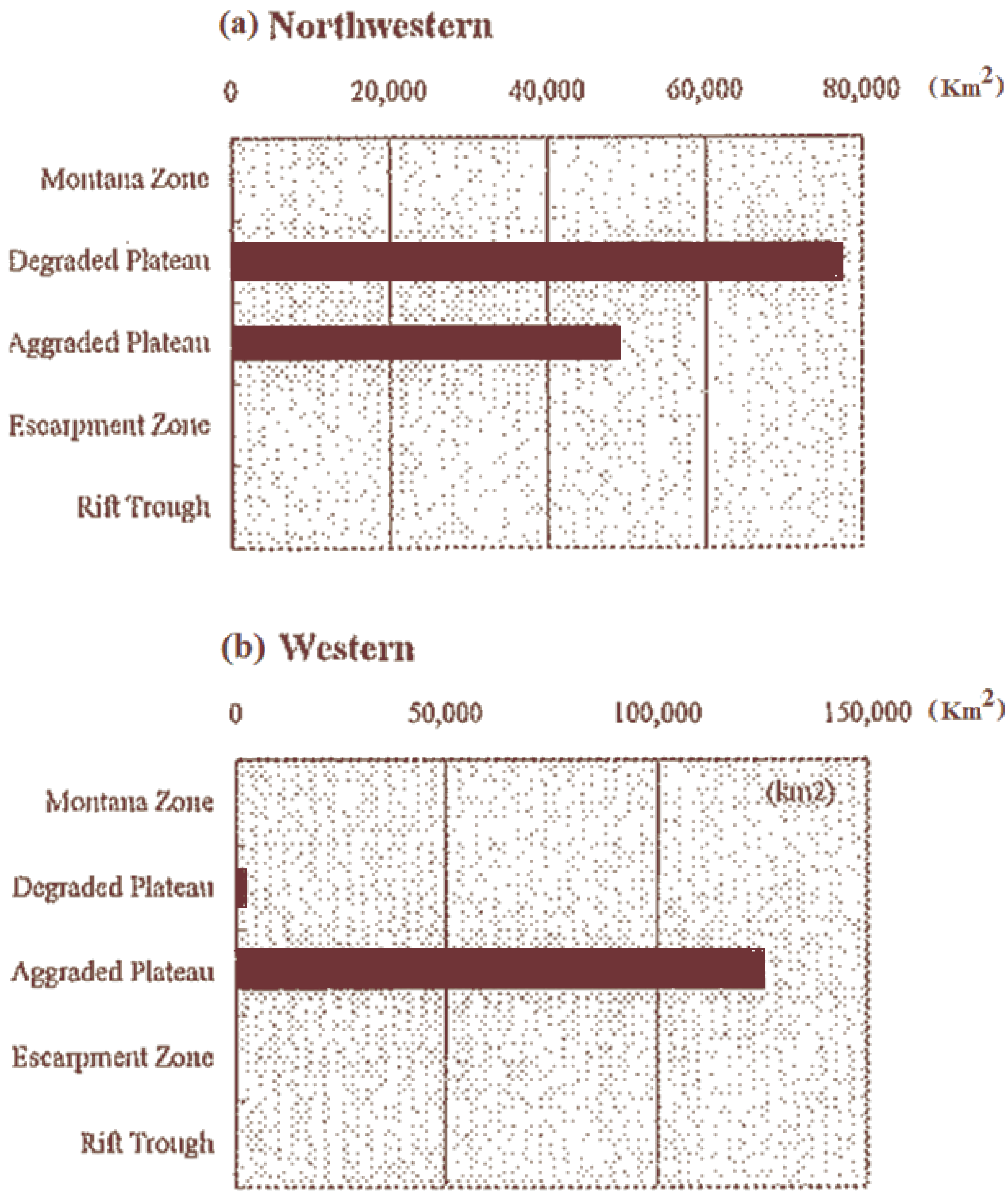



**Figure 14:** Plateau distribution in Kabompo basin region (a) Distribution of aggraded plateau in Northwestern Province (b) in Western provinces. Source (JICA, 1995).

The shaded DEM shown in Figure 15 is generated from a Shuttle Radar topographic mission (SRTM) image showing the topography of the Kabompo basin. From the image it can be seen that the topography for the Kabompo river basin varies between 1020m to 1625m above sea level. Most of the area in the north lies in hilly terrain between 1200 to 1625 above sea level while the south part of the basin is flat with elevation ranging between 1020 to 1200 above mean sea level.

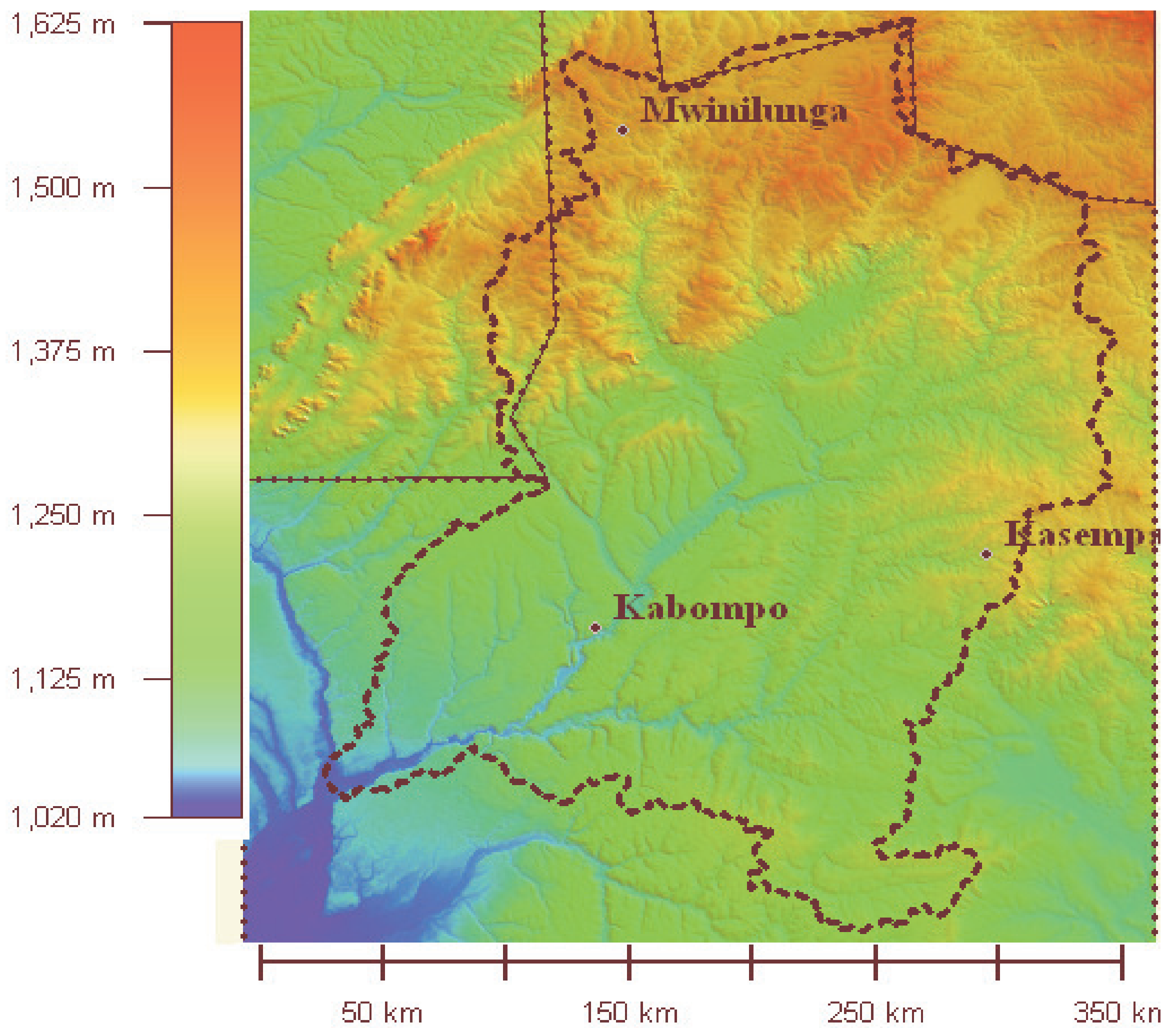



**Figure 15:** Shaded DEM of the Kabompo basin terrain, depicted from an SRTM Image

### 3.3.5 Soils

FAO soil classifications associate Zambian Soil distribution to be related to topographic classification. Typical example of this is that Fluvisol-Vertisol is distributed only in the rift trough zone and Arenosol is distributed in the Aggraded plateau zone. Soil series reflect the condition of not only topography but also climate and geology (JICA, 1995). FAO Classification of soils in the North-Western and Western provinces as follows:

### 3.3.6 Soils in North Western province

Ferrasol is distributed in level to undulating plateau zones which covers middle and eastern part of North-western province. Arenosol is distributed in slightly dissected pleatue zones which cover the Western part of North-Western province. Other than these soils, Cleysol is distributed in the zone between Kasempa and main course of Kafue River.

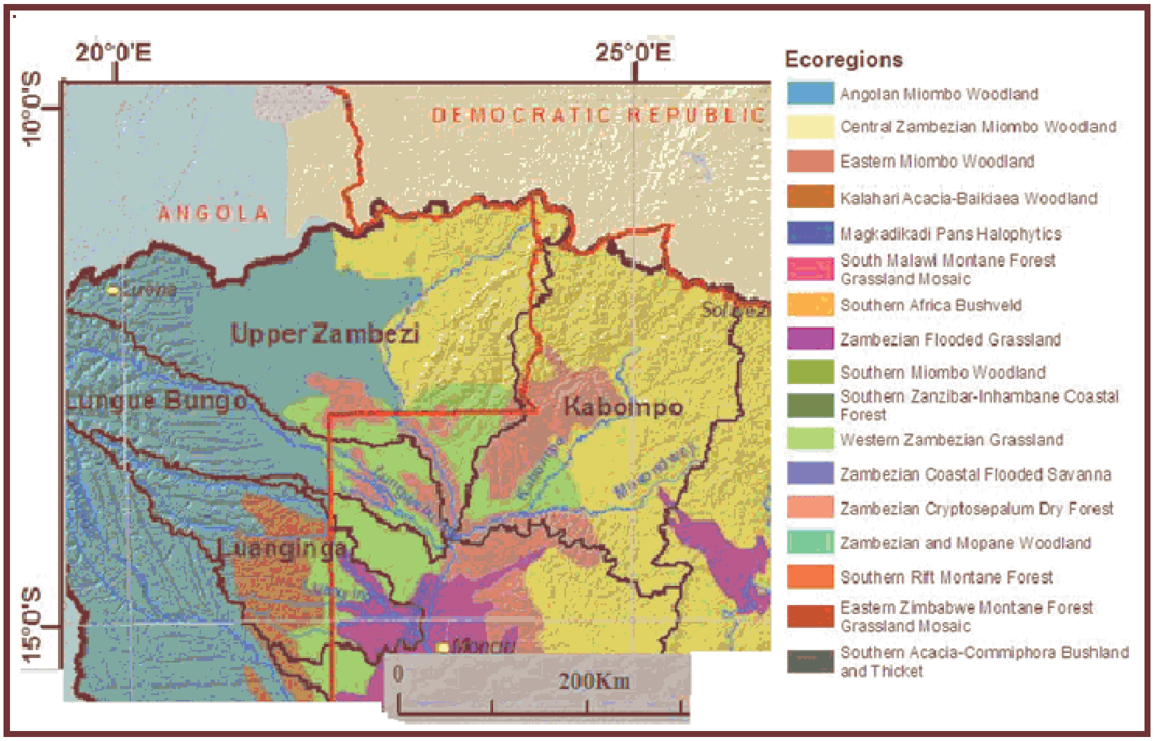
### 3.3.7 Soils in western province

Acrisol is distributed in pan complex zone which covers a large part of Western Province. While cleysol is diributed in flood plains along main courses and tributaries of Zambezi river. Other than these soils, pedzil is distributed in middle of Western province namely eastern part of mongu.

### 3.3.8 Vegetation

Vegetation in most parts of Zambia is classified as tropical grasslands or savanna. However, there are various vegetation types which include grasslands, woodlands and forests. Forests and woodlands are found in the high rainfall areas and rivers. Grasslands are of two types that is, plateau grasslands and flood plain grasslands. Deciduous woodlands cover much of the country on the plateau and escarpments. The most dominant feature is always trees with tall grass in between, in many areas. The IWRM strategy for the Zambezi River Basin has classified the ecoregions and land cover for the Kabompo river basin as mainly covered by Central Zambezian Miombo woodlands as shown in Figure 16.

(a)




(b)

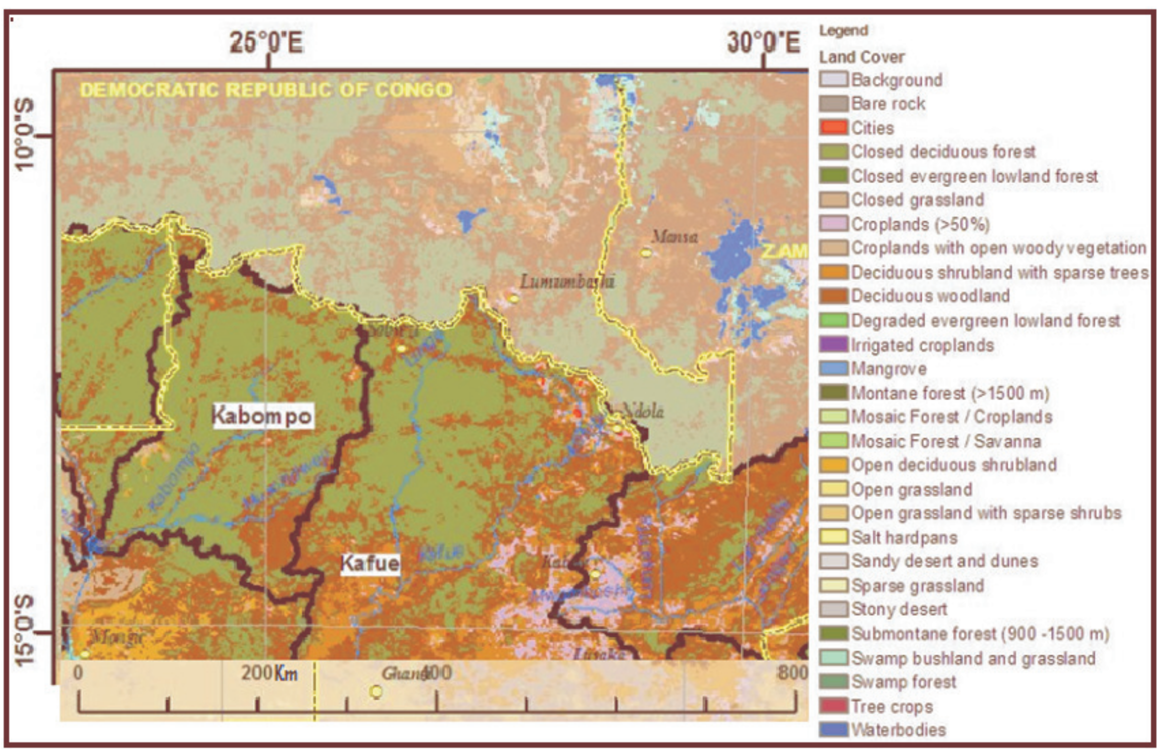



**Figure 16:** Areial view of various landuses in the Kabompo basin region (a) Ecoregions **(b)** vegetation and land cover. Source (IWRM, 2006)

Land use classification by JICA in ( 1995) for the Western and North Western Provinces is shown in Figure 17, indicates that grasslands occupies most parts of the Kabompo region followed by Savana.

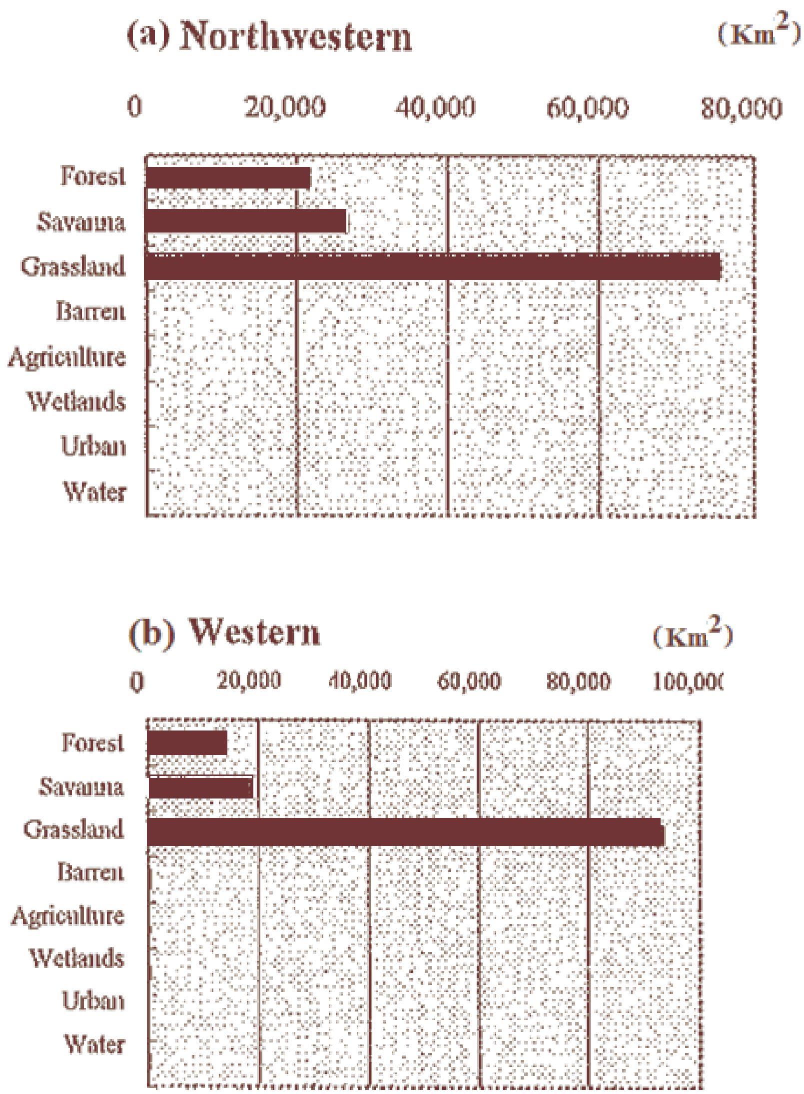



**Figure 17:** Graphs showing (a) landuses in Kabompo region for North western Province (b) and , Landuse for Western Province. Source: (JICA, 1995).

## 3.4 Social Economic characteristics

### 3.4.1 Population

Generally, the whole Kabompo basin is sparsely populated compared to most parts of Zambia. However, the population density varies from 0-2 people per square kilometer in least poulated areas and 50-100 people per square kilometer in higly populated ares such as Lukulu  and some stretches along main roads (Figure 18).

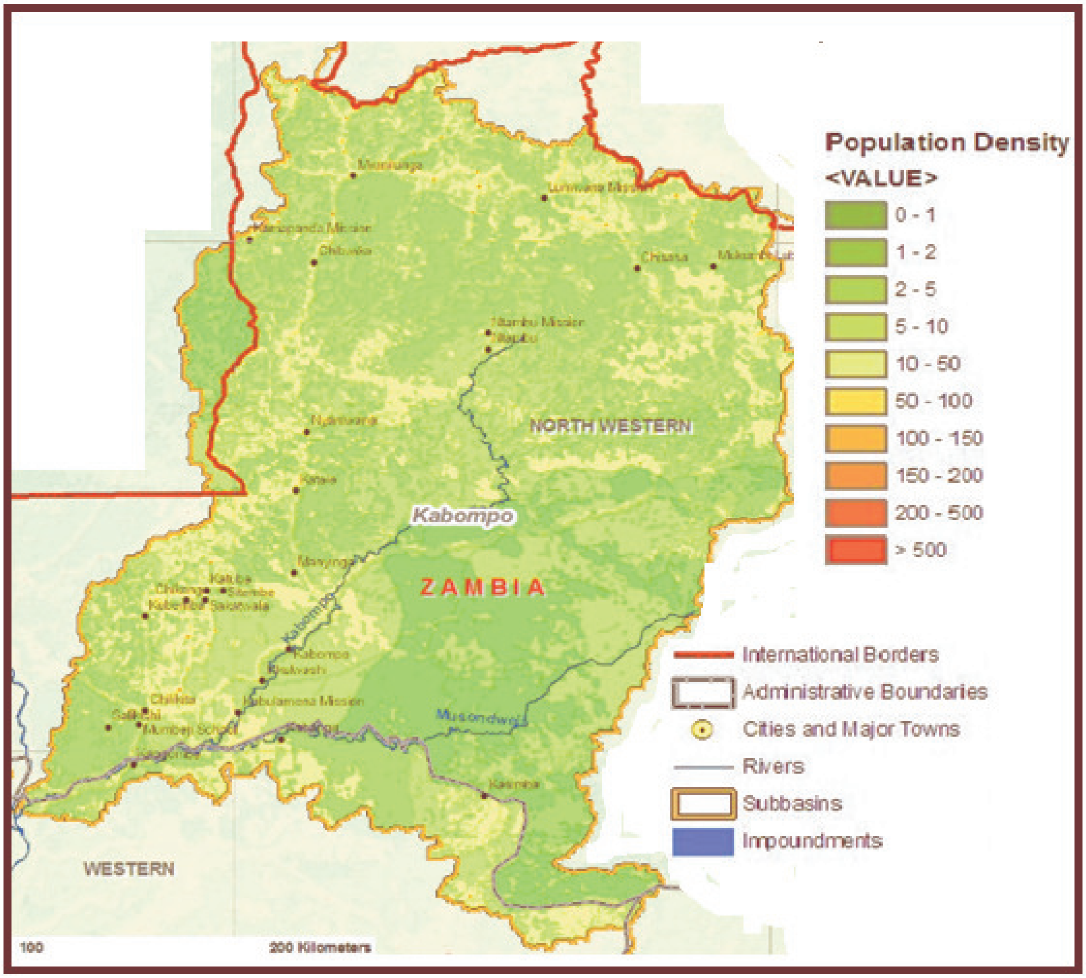



**Figure 18:** Population density for Kabompo Basin. Source: (IWRM, 2006)

### 3.4.2 Economic activites

People's livelihoods are dependent on forest products such as game, timber and honey. The north part of the basin around Mwinilunga was at one time the leading producer of pineapples in Zambia which declined in the early 90's. In the last decade, there has been accelerated  population growth  mostly in the northern parts of the basin  which is rich in minerals such as copper, uranium, gold and silver with the potential  for oil and gas existance (Sichela, 2009). A number of  large and small scale mines have either started to mine or are prospecting.

# CHAPTER 4: METHODOLOGY

## 4.1 Introduction

This chapter presents the different types and sources of data used in developing the data base and hydrological model for the Kabompo basin. It describes the analysis carried out on ECMWF, TRMM, Radar altimetry data and SWAT model parameters before being incorporated into SWAT. It also highlights the error analysis performed on the simulated data and Study limitations.

## 4.2 Source and type of data

Two types of data sets were needed for the study, namely, secondary and primary data. Primary data collected, included locations of all gauging stations, dams, major reservoirs, commercial abstraction points and discharge points. It also included locating and surveying river cross sections of radar altimetry targets and acquisition of remote sensed data sets such as precipitation (daily TRMM_3B42 data) and temperatures (sub-daily ECMWF data) from local sources and the Global Climate databases. Secondary data such as metrological and hydrological reports were also collected from a number of websites, private and government departments.

## 4.3 Secondary data

### 4.3.1 Meteorological data

Meteorological data for six different towns shown in Figure 19, from 2000 to 2006 was collected from the Meteorological Department headquarters in Lusaka, Kabwe, and Mutanda research station in Solwezi.

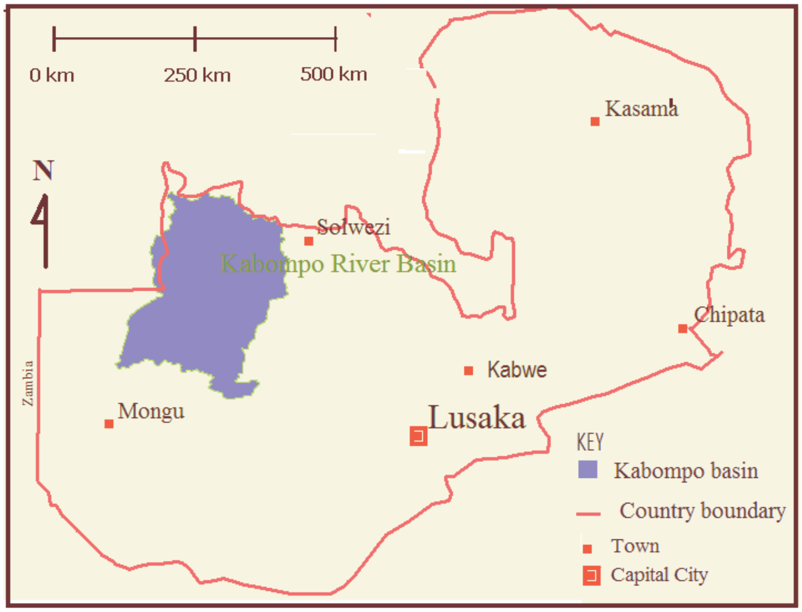



**Figure 19:** Location of stations used in the comparison

The aim of this task was to quantify the average error and levels of uncertainly for the whole remote sensed weather data collected for Zambia, by using the minimum sum of square error technique. This analysis was needed to verify whether the Remote sensed weather data was reliable and in agreement with observed data. Results are presented in chapter five

## 4.4 Primary data

### 4.4.1 Maximum and Minimum Temperature data

Daily maximum and minimum temperature data were collected are the European Centre for Medium-Range Weather Forecasts (ECMWF). The data is sub-daily and has a spatial resolution of 0, 25 degrees (27.75km X 27.75km) from 2000 to 2008. The data is part of ERA-Interim, the latest ECMWF global atmospheric reanalysis of the period 1989 to present (Berrisford et. al, 2009). The ERA-Interim project was initiated in 2006 to provide a bridge between ECMWF's previous reanalysis. The ERA-Interim Archive is part of ECMWF's Meteorological Archive and Retrieval System (MARS), which is accessible to registered users in ECMWF Member States and Co-operating States. MARS supports the supply of ERA-Interim data on a range of grids. For details see http://www.ecmwf.int/services/archive

### 4.4.2 Precipitation data

TRMM is a satellite based program used to measure tropical rainfall and to quantify the associated distribution and transport of latent heat, which drives the global atmospheric system (Wolf et al, 2004). The TRMM (3B 42) datasets for the period 1998 to 2006 were assembled. It has a spatial resolution of 0.25º (27.75km X 27.75km) and temporal resolution of 1 day. TRMM data can be downloaded by following instructions from: http://daac.gsfc.nasa.gov/precipitation/TRMM_README/TRMM_3B42_readme.shtm

### 4.4.3 Soil data

Soil data used was from a FAO soil map of Zambia with a scale of 1: 2,500,000. The map is based on the soil survey done in 1983 by Mt. Makulu Research Station in Zambia and compiled by the National Council for Scientific Research. This map can be obtained from:
http://eusoils.jrc.ec.europa.eu/esdb_archive/EuDASM/africa/lists/s1_czm.htm

### 4.4.4 Landuse data

The land cover map accessed for this research is from the Global Land Cover Characterization database (GLCC) from the U.S. Geological Survey and has a 1km resolution (USGS, 2008). The data set is derived from 1-km Advanced Very High Resolution Radiometer (AVHRR) data spanning (USGS, 2008). It is based on a flexible data base structure and seasonal land cover regions concepts. The land cover map was used to derive Curve Numbers (CN) needed in SWAT for various locations in the Kabompo basin. For details see http://edc2.usgs.gov/glcc/globdoc2_0.php.

### 4.4.5 Radar altimetry data

The data sets used in this study are a product of both ERS-2 and ENVISAT from 1995 to 2003 with a temprol resolution of 35 days. The data sets used covered five targets located in different sites of the basin. Details for the Targets are explained in setion 4.5.3.

### 4.4.6 Shuttle Radar Topographic Mission (SRTM)

The Digital Elevation Model used in the SWAT interface was derived from the SRTM image downloaded from the CGIAR-CSI GeoPortal website (http://srtm.csi.cgiar.org/). The SRTM 90m Digital Elevation Model 's have a resolution of 90m at the equator, and are provided in mosaice 5 deg x 5 deg tiles for easy download and use.

### 4.4.7 Landsat7 and MODIS images

Landsat images were clipped to the basin shape for monitoring vegetation distribution and flood extents in the lower parts of the Kabompo river basin (Figure 20). The images were used to approximate river widths which are required in the SWAT interface.

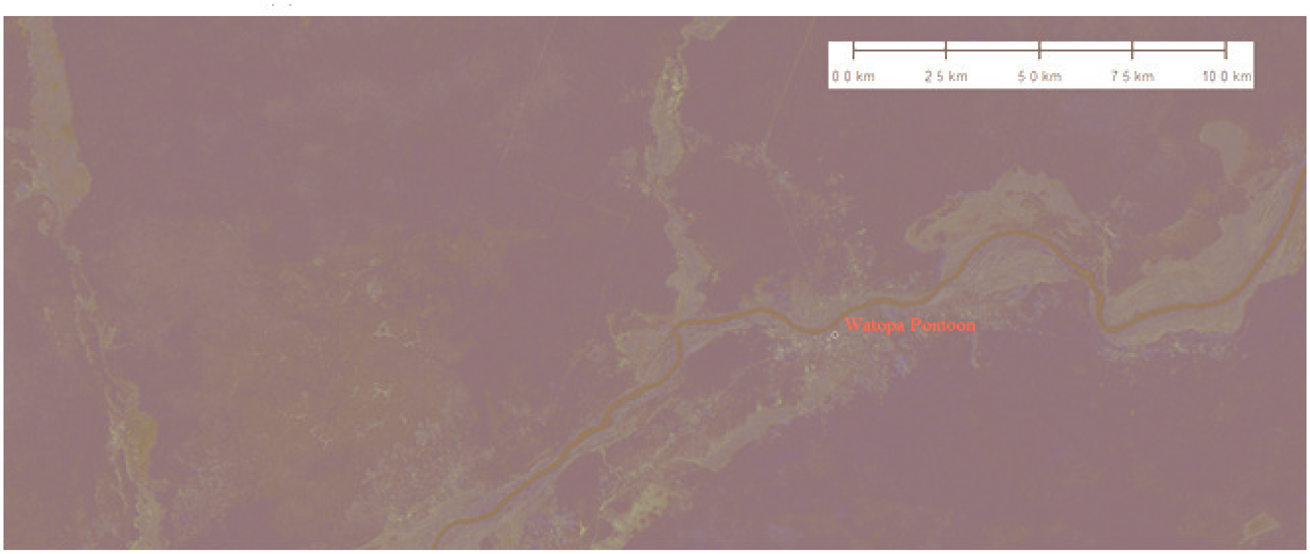



**Figure 20**: Views showing Kabompo River (a) A 3D view of a 90 SRTM image with highlighted streams for the Kabompo river basin, and (b) Landsat image showing Kabompo river and Watopa pontoon.

## 4.4.8 Field Data Collection

River cross sections and mean velocities were collected for five radar altimetry targets. The main equipment used during the field work were the Type AA current meter (Figure 22), sounding weights, winch, boat, wading boots, stopwatch and tag line. The section method was used to carry out the discharge measurements. Eroded marks on the river bank were also used to relate the current water level to the highest possible flood level that has been reached at a particular site.

## 4.4.9 Calculation of river cross section variables

The flow mean velocities at radar altimetry targets were calculated by getting the average value between velocities at 0.2 and 0.8 of the measured depth, respectively. Figure 21 illustrates the two methods used. For depth less than 1m, one point method was used while that greater than 1 m used the two point method which had to be averaged for discharge calculations (Oklahoma Water Resource Board, 2005). The units are in m $s^{-1}$.

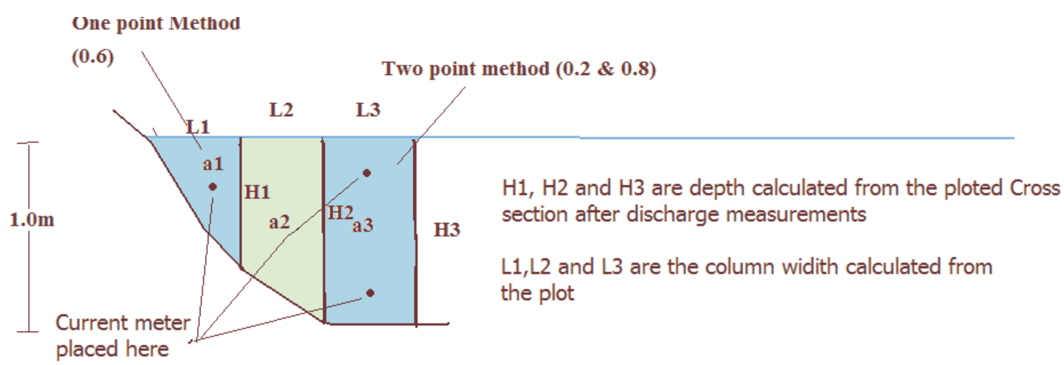



**Figure 21**: River Cross section and current meter positions set during field measurements.

The Type A-A current meter (Figure 22) factory derived formula for its velocity was given by the formula;

Velocity (m/s) = 0.6818*(Number of Revs / Number of Sec) +0.0072    4.1

Where: (Number of Revs): is the number of revolutions observed and (Number of Sec) is the time elapsed in seconds.

Apendix A shows the recorded data for different sites.

The Area for each of the sections in $m^2$ can be calculated as

a1 = ½ (H1*L1) (Triangle Formula used) 4.2

a2 = ½ (H1+H2)*L2 (Trapezoidal Formula used) 4.3

a3 = L3*H3 (Rectangle formula used) 4.4

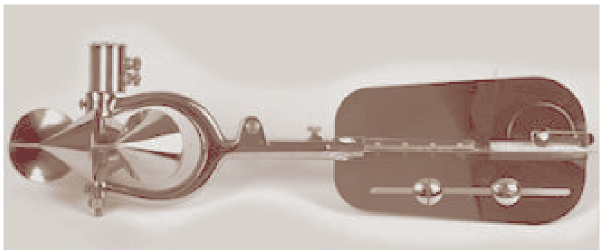


**Figure 22:** Type A-A current meter

## 4.5 Data analysis

Weather data, radar altimetry data and field survey data being some of the key data needed in the hydrological model before it was complete, were assembled and analyzed. Three main software ArcGIS, ArcSWAT and MATLAB were used for the analysis in this research. ArcGIS being the main software was used to compile all the data sets as highlighted in the following sections.

### 4.5.1 ArcSWAT and ArcGIS (Input data processing)

The Semi-distributed ArcGIS based Soil Water Assessment Tool (SWAT) software was used in the study to delineate classify and simulate the watershed parameters for the Kabompo river basin. The interface between the model SWAT and ArcGIS is called ArcSWAT. ArcGIS calculates basic hydrologic information for the model (i.e. surface slope, water flow paths, flow directions, stream network, and sub-basins), it also calculates the position and the size of the hydrologic response units and provides the necessary files which are used by the SWAT model (Winchell et al., 2007). In this study, all input datasets were manually set to a spatial reference of WGS_UTM_1984_ZONE_35S, using ArcCatalog and ArcMap within the ArcGIS interface. The dual were also used to manually convert input datasets into Raster and Vector datasets for input data in .dbf, txt, dem and .rst file formats. Useful maps were automatically generated by ArcSWAT based on the input data and they included; Stream Network, Sub-basin distribution, Soil classification, land cover and Topography.

The simulated flow from the model was calibrated with radar altimetry values converted to discharge using Manning's channel flow method explained in section 4.5.4 see Appendix F for converted data. Observed river flow data for six stations of different time series from 1965 to 2006 and details for the validation and uncertainty analysis have been explained in the proceeding sections. The remote sensed weather data in Appendix D was converted to ArcGIS Dbase Table format for easy input in the ArcSWAT model (Winchell et al., 2009). To determine the levels of uncertainty in remote sensed datasets, a comparison was made between remote sensed weather data against metrological data for five selected towns. Not all datasets for these towns was used as SWAT input. It was only used to assess the levels of uncertainty for the data over the whole Zambia.

### 4.5.2 MATLAB

MATLAB which stands for Matrix Laboratory is a high level language and interactive environment that enables one to perform computationally intensive tasks faster than with traditional languages such as C, C++, and FORTRAN. MATLAB was used in calculating river cross section areas presented in section 5.1.3. It was also used to read and plot results of ArcSWAT simulations by reading the text output file generated by ArcSWAT. A full script for this is shown in Appendix C.

### 4.5.3 Radar Altimetry target analysis

The ESA water levels in this study were initially derived from ERS-2 and ENVISAT. The data sets used are from 1995 to 2003. Five radar altimetry targets were surveyed with the aim of converting the change of the mean water elevations above sea level to discharge. Targets for Kabompo river basin are shown in Figure 23. Radar altimetry data had to be transformed from elevation values to water levels by first determining the mean as shown in Figure 24(a).


**Figure 23:** Radar altimetry target locations in the Kabompo basin

An experiment was done by plotting observed data at a station very close to the Radar altimetry target ERS2-31called Watopa Pontoon (1959) and the mean also calculated. The two mean values were superimposed on the same graph so that the radar altimetry data could be plotted against water levels in the same periods. This was done in order to eliminate elevation values since the actual elevations at the Radar target and Hydrological stations are not known as shown in Figure 24(b). Extreme values that appeared not to be practical such as those above 10m or below 1m in Figure 24(b) were filtered out. Water Affairs data from 1958 to 2006 was also used to derive a rating curve Figure 24(c) which was then applied to its close radar Altimetry ERS2_31 to generate river flow (Figure 24d).

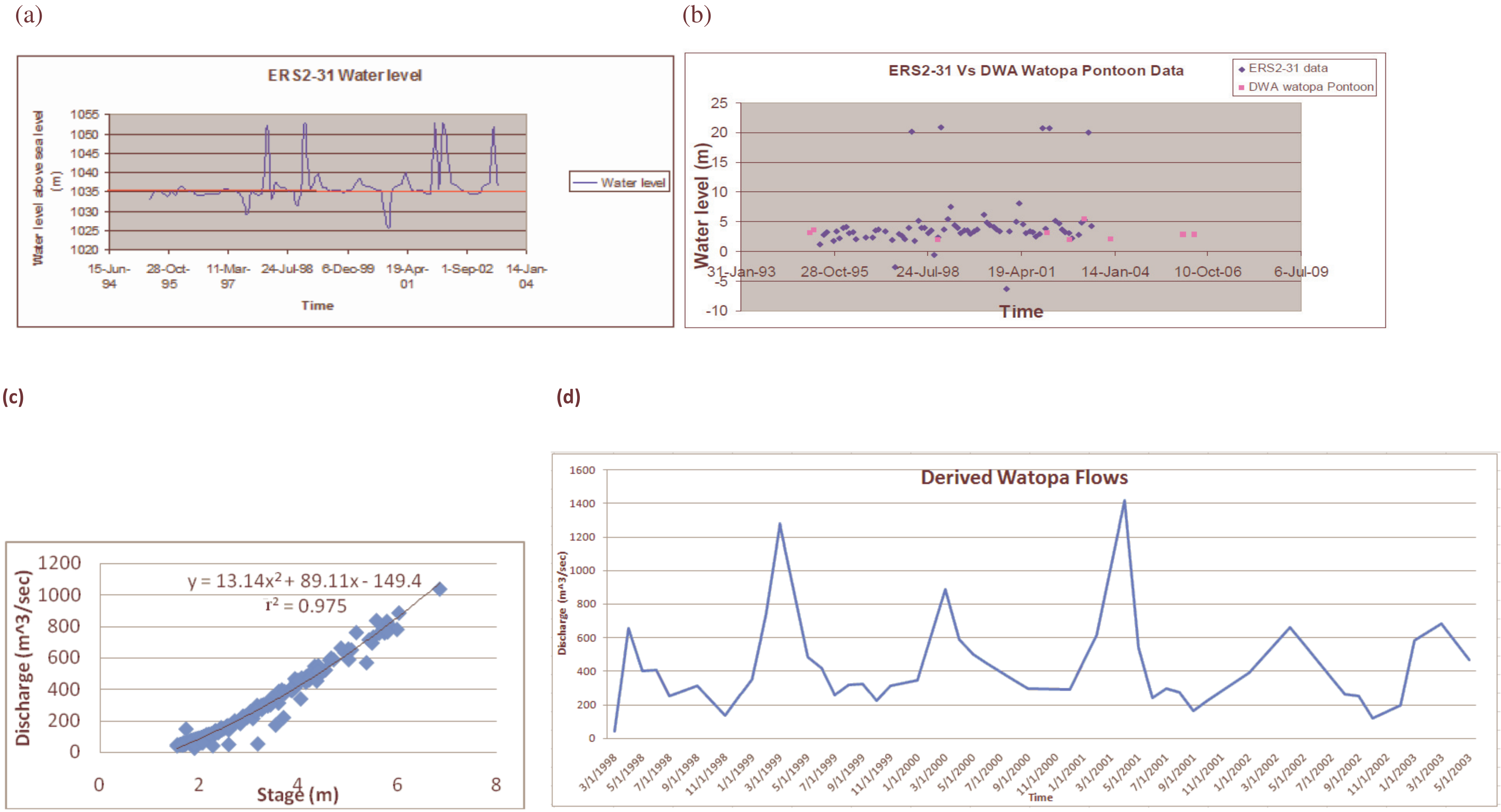



**Figure 24:** Conversion of Target ERS2-31 elevations to discharge **(a)** Chosen mean for ERS2-31 data (b) A plot of ERS2_31 and Water Affairs data**(c)** Rating curve derived from DWA data from the year 1958 to 2006( d) Derived flow values of ERS2_31 based on DWA rating curve

### 4.5.4 Manning's River Flow Principle

The Manning's channel flow principle was used to convert the ESA radar altimeter values to discharge. By assuming a channel has a continuous homogeneous flow over a considerable distance, the flow through a section at this uniform stretch can be approximated by the Manning's equation;

$$Q = A * \left\{ \frac{1}{n} \right\} * R^{\frac{2}{3}} * S^{\frac{1}{2}} \qquad (5.1)$$

Where Q is the discharge (m³/sec), A is the Cross Section Area (m²), n is the Manning's coefficient, R is the Hydraulic radius (m), and S is the Channel slope (change in elevation/distance)

R = Area/ Wetted Perimeter (5.2)

Wetted Area = ∑ Single section areas. (5.3)

Calculated using Trapezoidal Formula (See Section 4.4.9 and MNX Function in Matlab script Shown in Appendix $C_1$).

Because the channel flow has been considered homogenous we will let "n" and "S" be constant. This therefore implies that we can determine the discharge of a channel at some stage given the profile of a section and a set of initial measurement comprising stage and discharge of the same section. Hence with the early assumptions made, it can be shown that;

$$Q_c = Q_i \left[ \frac{A_c * R_c^{\frac{2}{3}}}{A_i * R_i^{\frac{2}{3}}} \right] \qquad (5.4)$$

Where $Q_c$ is the Calculated discharge (m³/sec), $Q_i$ is the initial discharge (m³/sec), $A_c$ is the calculated final cross section based on the river profile (m²), $A_i$ is the initial measured or calculated cross section (m²), $R_c$ is the final calculated hydraulic radius (m), and $R_i$ is the initial hydraulic radius (m).

The hydraulic radius R can be calculated as

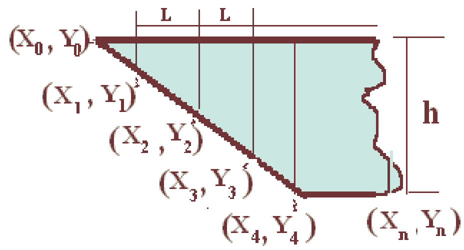



**Figure 25**: Wetted Perimeter calculation.

Where, X and Y are points obtained from Field Measurements

$$WettedPerimeter(R) = (X_n - X_0) + \sum_{i=n}^{i=0} \sqrt{(X_{i+1} - X_i) + (}Y_{i+1`} - Y_i) \tag{5.5}$$

The value of L in Figure 25 depends on the River bed irregularity, the more irregular the bed the smaller the value of L. This Value can be as small as 0.01m and in order archive this; a formulated Matlab Script shown in Appendix 5 was used. The script is capable of Calculating R on any Stage (h) at any time. This is where values for radar altimetry fluctuation elevation values are used including in the Section Area Calculations outlined in Section 4.4.9. By putting all the necessary parameters including measured discharge and Section area in equation 5.2, the Matlab script Discharge_MNX yields varying discharge values at varying h.

### 4.5.5 Matlab Script

A MATLAB a script shown in Appendix V, was formulated to calculate the final discharge values, cross section area and hydraulic radius of any river channel using equation 4.5.1 given;

1. The river profile in form of (x, y) coordinate Table that indicates the distance from a chosen river bank and depth across the river. For example, in my script for the ERS2_31 target it has been named 'ERS2_31_PF'
2. The initial known water level and discharge values of the section at a particular time. ( $Q_i$ (m³/sec), $Wl_1$ (m))
3. A set of water levels and dates, when discharge needs to be predicted

### 4.5.6 MATLAB script Verification

An analysis was done on the developed Matlab script to verify whether the formulated Discharge_MNX scripts could accurately calculate the discharge (flow), cross section area and the hydraulic radius at any water level, some ideal river channel sections (TEST sections) with known section areas, hydraulic radius and rating curves were created (Figure 26). These channels have been formulated in such a way that using simple arithmetic procedures the area and hydraulic radius can easily be calculated. The two profiles of different shapes are shown below.

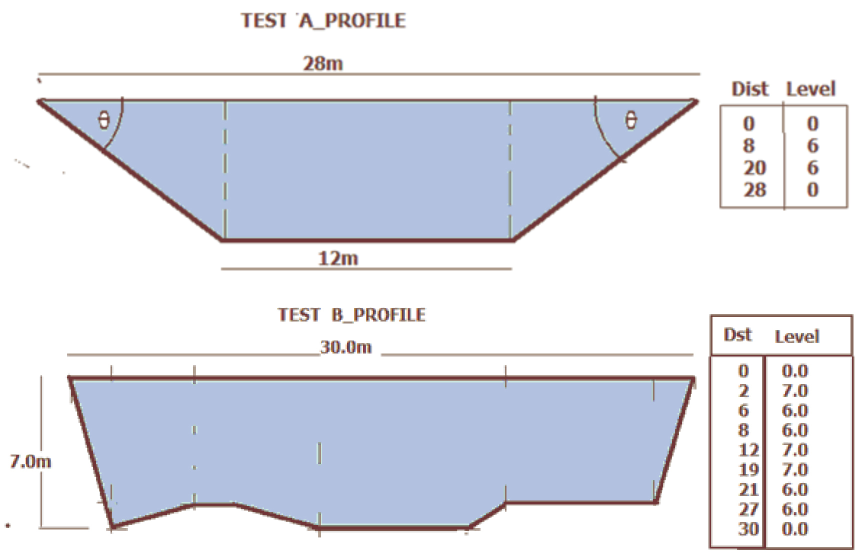



**Figure 26**: Discharge_MNX test Profiles with Distance (Dist) from Left bank and Depth or Water level (a) Test A Profile , and (b) Test B_Profile

To generate known values the Manning's formula was used with the following assumptions n = 0.3, S= (20cm/100m) =0.002 for both channels. This makes equation 5.1 become:

$$Q = A * \left\{ \frac{1}{0.3} \right\} * R^{\frac{2}{3}} * 0.002^{\frac{1}{2}} \qquad (5.6)$$

The Cross-section are and the wetted perimeter were then manually calculated at varying water level or stage (h) that was within the Profiles Limits. The results for this experiment yielded graph shown in Figure 27.

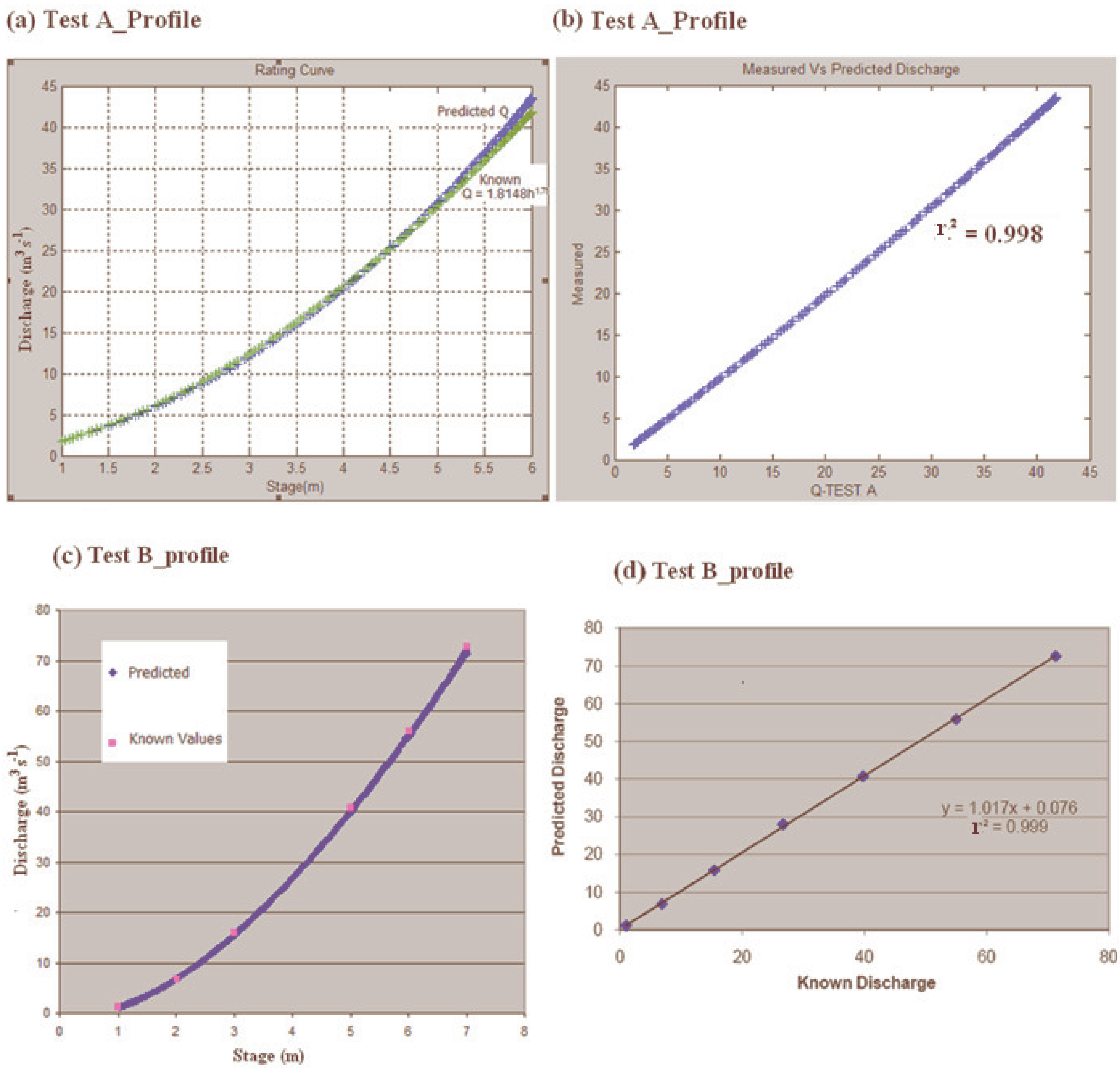



**Figure 27**: Discharge prediction results for test section profiles (a) Predicated and Known rating curve for Test A profile (b) Measured Vs. Predicated Discharge for Test A profile (c) Predicated and Known rating curve for Test B profile (d) ) Measured Vs. Predicated Discharge for Test B profile

Having run the two ideal river sections with rating curves that fully obey Manning's theorem, it can be concluded that the Matlab script Discharge_MNX calculates the Discharge (Flow), section area and hydraulic radius quit well.

### 4.5.7 NASH–SUTCLIFFE (NS) AND ROOT MEAN SQUARE ERROR (RMSE)

Due to the limited water affairs data the NS and RMSE coefficients were only used on Radar altimetry data against simulated flow. The Nash-Sutcliffe (NS) model coefficient equation was used to assess the predictive power of hydrological model. The formula used was given as:

$$NS = 1 - \frac{\sum_{t=1}^{T}(Q_{sim}^{t} - Q_{esa}^{t})^2}{\sum_{t=1}^{T}(Q_{sim}^{t} - \overline{Q}_{sim})^2}$$

Where $Q_{sim}$ is the simulated discharge in at t, $Q_{esa}$ is the radar altimetry discharge at time t. $\overline{Q}_{sim}$ is the average simulated discharge and T is the number of time steps. NS=1 represents a perfect model while NS=0 indicate that the model's prediction are as accurate as the mean while. NS<0 shows that the mean is a better predictor than the model (Wikimedia, 2009). Simulated and Radar altimetry data are shown in Appendix F and G.

### ROOT MEAN SQUARE ERROR (RMSE)

**RMSE** is a quadratic scoring rule which measures the average magnitude of error. This tool was used to assess the closeness of fit between simulated and observed flow data shown in Appendix F and G. The RMSE was automatically calculated using Microsoft Excel. Mathematically RMSE is given as;

$$RMSE = \sqrt{\left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{N}\right]}$$

Where $P_i$ are the model predicted values, $O_i$ are the observed values for the N observations.

## 4.6 Study Limitations

SWAT model requires expert interpretation of types of crops and soils used in its database. This observation was also made by Lewarne (2009). Entering database parameters requires a full understanding of various physical properties for plants and soils. Most of the SWAT defaults database that is downloaded with the software contains US Geological Survey data mostly for the USA. See Appendix $B_{1.}$ Hence Basic Knowledge of using ArcGIS is needed to develop database for unavailable datasets (Vassilios et al, 2009). SWAT will only accept input data in .txt or .dbf other formats such a Microsoft excel spread sheet are rejected.

Calibration is another process that requires knowledge of the SWAT interface. During the calibration exercise for example, it was observed that the sensitivity analysis results could not really agree with the trial and error method used when calibrating the model. In this study, sensitivity analysis had ranked the base flow recession constant (ALPHA_BF) in the ninth position, it was observed during calibration however, that it had a great effect on base flow which was always over estimated by the model. Adjusting the threshold water level in the shallow aquifer (Gwqmn) ranked numer 1 by the sensitivity analysis, could not cause much variation to stream flow as compared to baseflow recession constant adjustments.

Most SWAT simulation results for various parameters are contained in the TextInOut folder of the Project file. Reading these files is not just a touch of a button. It requires opening and plotting these using packages such as WordPad and Microsoft excel. This task increases required time when conducting manual calibration which mostly relies on the observed simulation graph plots. To overcome this problem in study, a MATLB script was developed and used to quickly read and plot results from the TextInOut folder.

# CHAPTER 5: RESULTS

## 5.1 Introduction

This chapter presents results for the analysis for the input data that includes ESA radar altimetry (Appendix F), weather data shown in Appendix D and Field survey data. It also presents comparisons between simulated flows, radar altimetry derived flows and in situ flows from the Department of Water Affairs.

### 5.1.1 Weather data validation results

Weather data validation results for four towns are shown from Figure 28 to 31 for Chipata, Kabwe, Mongu, and Solwezi. The root mean square error from the scatter plots and, cumulative plots were used to measure levels of uncertainties of the data.

It was observed that the two methods used to analyze the data yielded varying results from town to town. It can be observed from Figure 28 to 31 that a plot of daily precipitation data for all towns has good timing but different intensity levels. At an instance TRMM reading may be higher than metrological yet some other time it is lower. The interesting part is that when one is zero the probability of the other to be equally zero is almost 100%. Cumulative plots agreed much better than scatter plots. Apart from Kabwe town which showed annual variation between Meteorological and TRMM data of less than 100mm, Chipata, Solwezi and Kasama showed Variations between 180 to 220mm per annum. It was noticed that scatter plot showed much lower mean square values because of the different intensity levels despite the correct timing. The possible cause of this behavior could be linked to spatial distribution variation and has been explained in detail in chapter six. Figure 28 shows daily results for Chipata town in which the root mean square error value is 0.202, somewhat too low. However a cumulative plot even for one month period shows much more close readings to each other. The average variations between metrological and ECMWF data shown in Figure 28d were less than $3^{o}$C.

## CHIPATA DATA

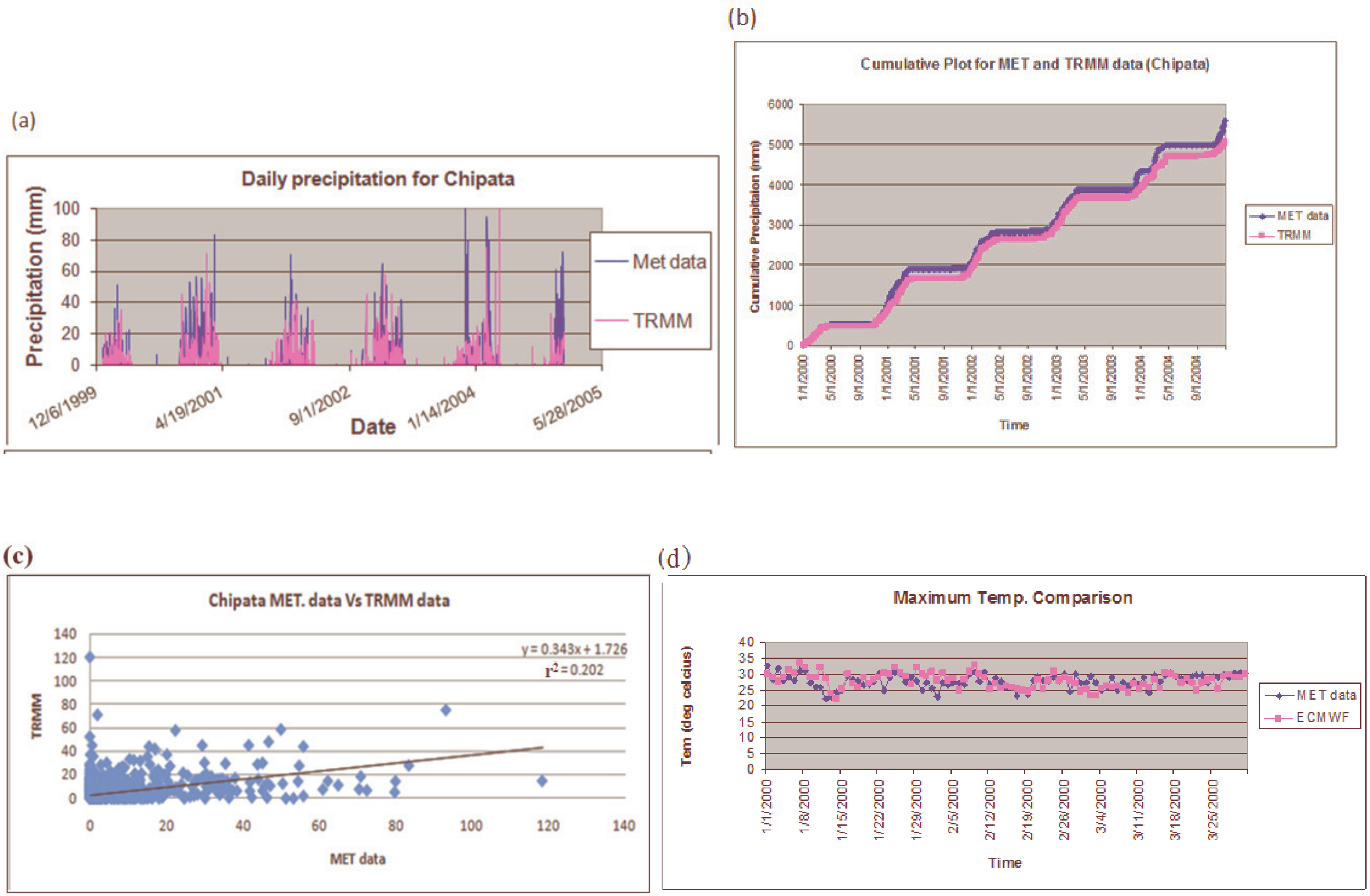



**Figure 28:** Graphs showing weather data comparison for Chipata (a) TRMM vs. Met data (b) Cumulative plot of TRMM against Met-data; (c) Closeness of fit between TRMM and Met-data, and (d) ECMWF maximum temperature data against Met-data

A plot of Kabwe data showed much better correlation as compared to Chipata data as shown in Figure 29. Precipitation comparisons between TRMM and Metrological data showed better timing giving an $R^2$ of 0.34. It can be observed from the plotted data in Figure 29a that the correlation between the two data sets is good for precipitation of less than 30mm for Kabwe town. A cumulative plot between the two data sets has good correlation for the first season but suddenly increases at the end of the year 2002 possibly due to accumulated difference in rainfall intensities. Plotting ECMWF maximum temperature data against metrological data also showed good correlation with an average difference of less than $3^oC$.

Figure 30 shows a plot of Mongu data. Results for this town displayed much more discrepancies of $R^2$ of 0.046 as compared to Chipata and Kabwe town. It can be observed that the correlation of precipitation data gets much poorer when precipitation of more than 20mm is recorded by the metrological department. Plotting ECMWF temperature data also showed higher discrepancies as compared to the other two towns, Chipata and Kabwe. There are many possible sources of error for the poor $R^2$ values obtained for Mongu. Some of these could be spatial difference of the Metrological collecting rain gauge with the TRMM virtue station or may be due to mechanical or human error from the Metrological data.

Results for Solwezi town shown in Figure 31, also shows that for precipitation of less than 30mm the correlations between the two data sets is better. A cumulative plot of the two precipitation data in Figure 31b related much better as compared to daily plots of precipitation data.

Based on the weather comparison results, plots differed from town to town but the general observation was that on most occasions TRMM under estimates precipitation amounts where metrological readings are more than 30mm despite the timing of rainfall occurrence being accurate. The RMSE value in all plots was less than 0.5 with the lowest value for Mongu town being 0.046

## KABWE DATA

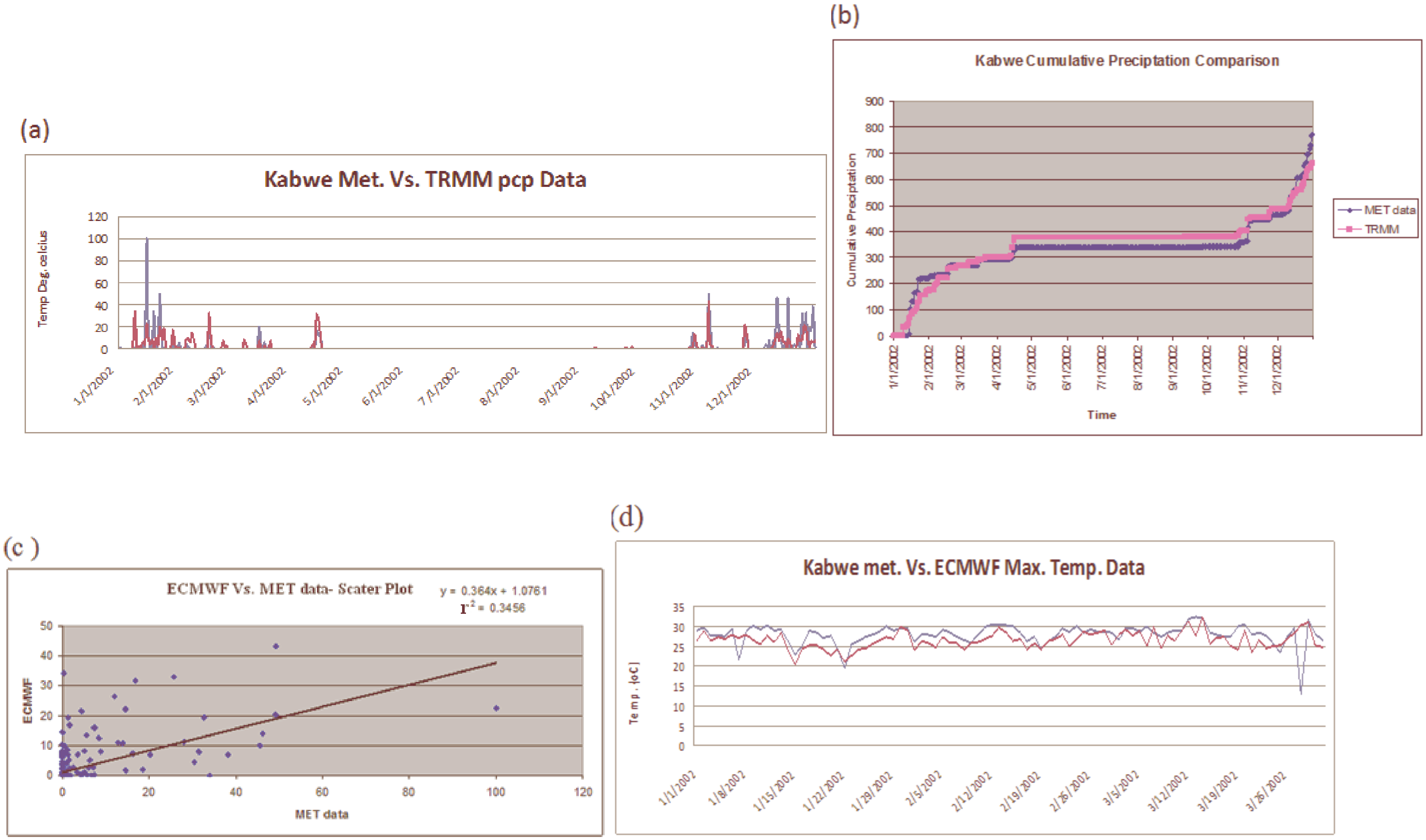
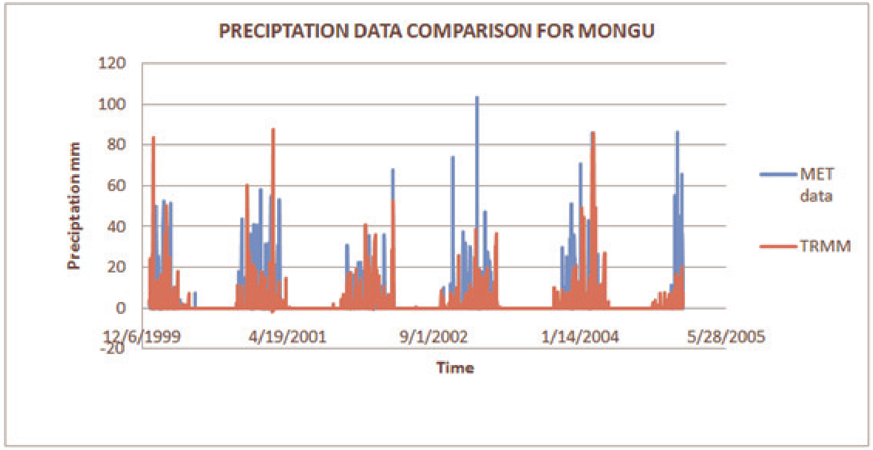
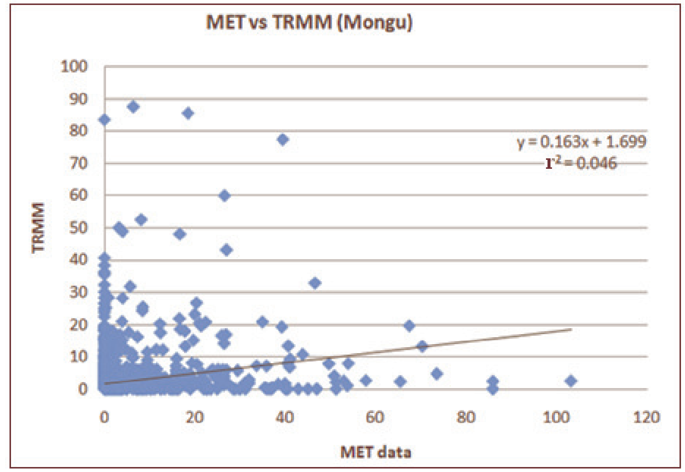



**Figure 29**: Weather data comparison Kabwe (a) TRMM vs. Met data (b) Cumulative plot of TRMM against Met-data(c) Closeness of fit between TRMM and Met-data, and (d) Maximum temperature comparison of ECMWF against Met-data for Kabwe.

## MONGU DATA

(a)




(c)

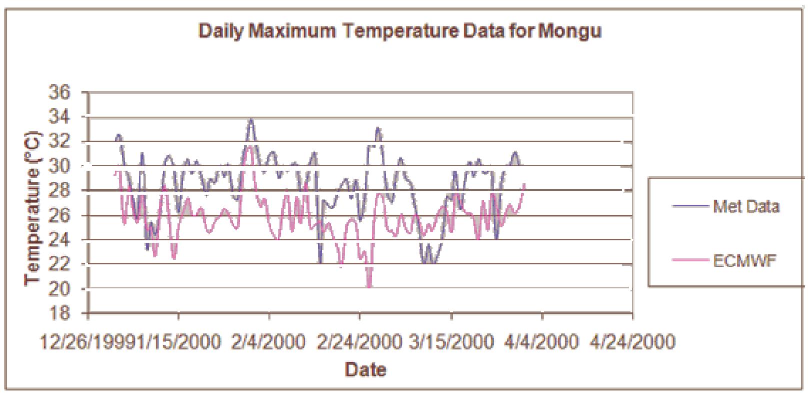



**Figure 30**: Weather data comparison (a) TRMM vs. Met data; (b) Closeness of fit between TRMM and Met-data; (c) Maximum temperature comparison of ECMWF against Met-data for Mongu.

## Solwezi Data

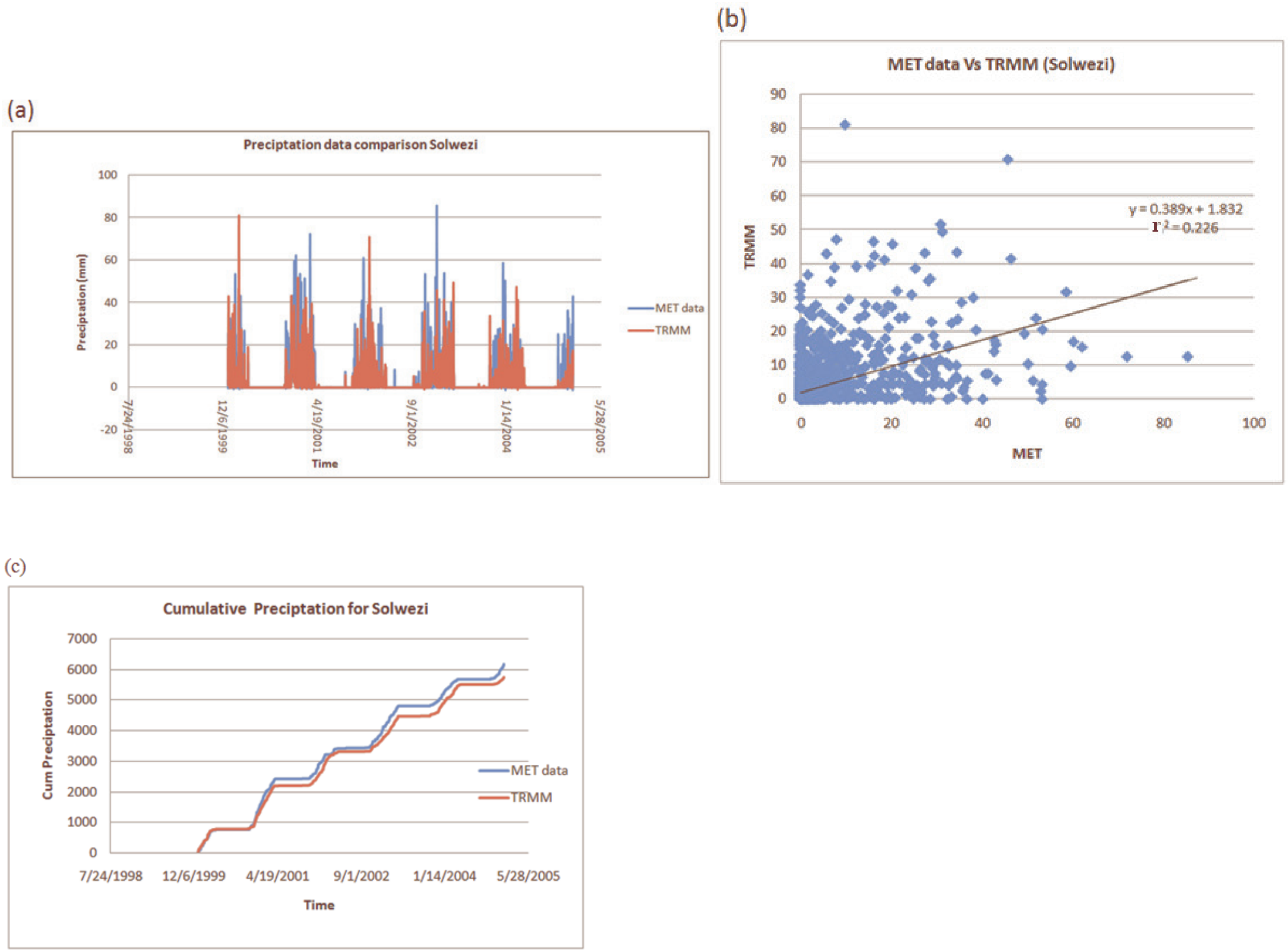



**Figure 31**: Weather data comparison for Solwezi (a) TRMM vs. Met data; (b) Scatter plot of TRMM against Met-data, and (d) Maximum temperature comparison of ECMWF against Met-data.

## 5.1.2 Radar Altimetry results

A comparison of river flow data from the Department of Water Affairs was made between stations on the Kabompo River from Manyinga town to Watopa Pontoon. Datasets from three hydrological stations with distance as shown in the Table of Figure 32, and of different periods were used for the comparison

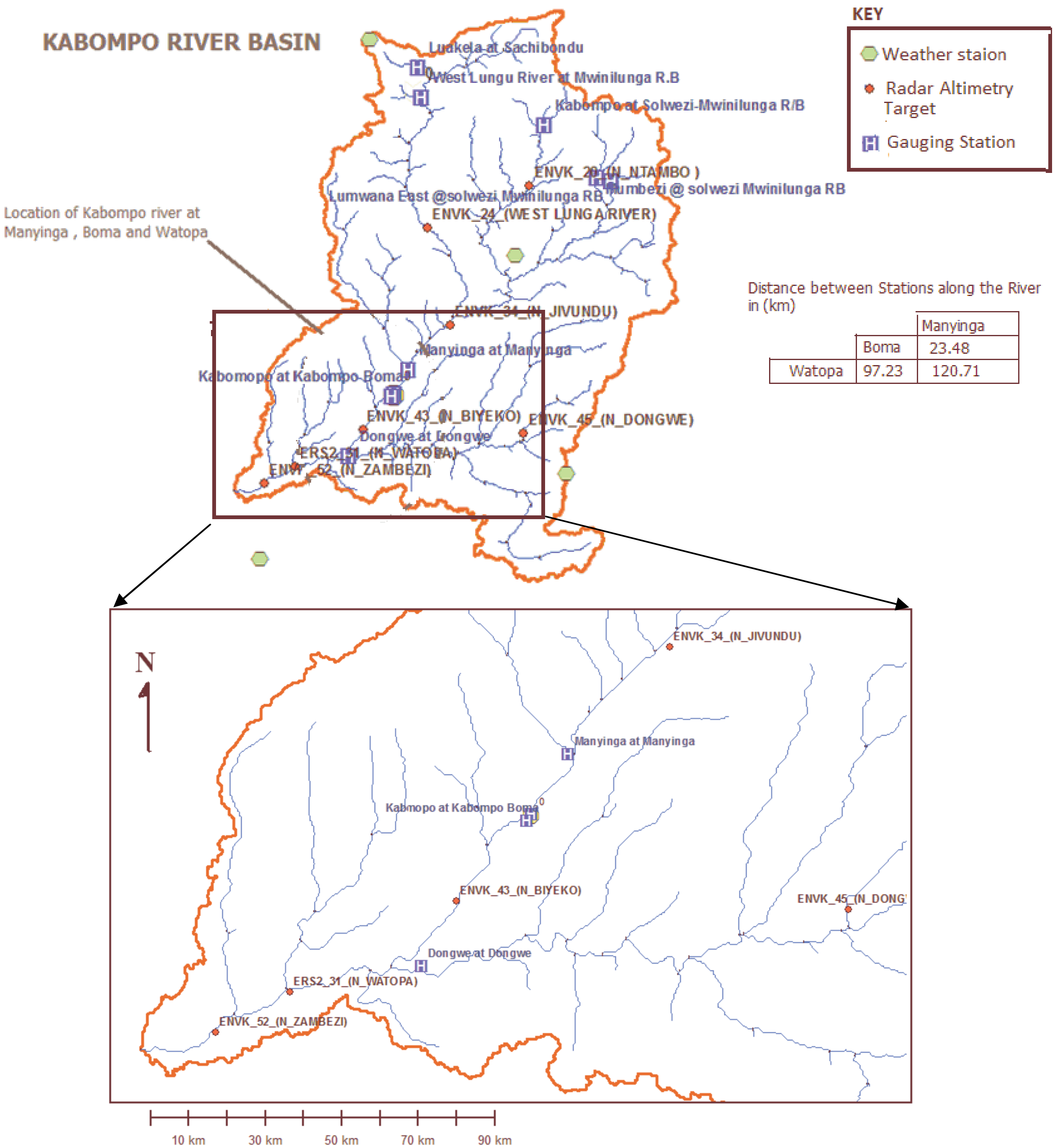



**Figure 32:** Showing Location of Watopa, Boma and Manyinga with close radar Altimetry targets

A plot of the three stations Manyinga Vs Watopa and Watopa Vs Kabompo Boma yielded results shown in Figures 33c and 33d.

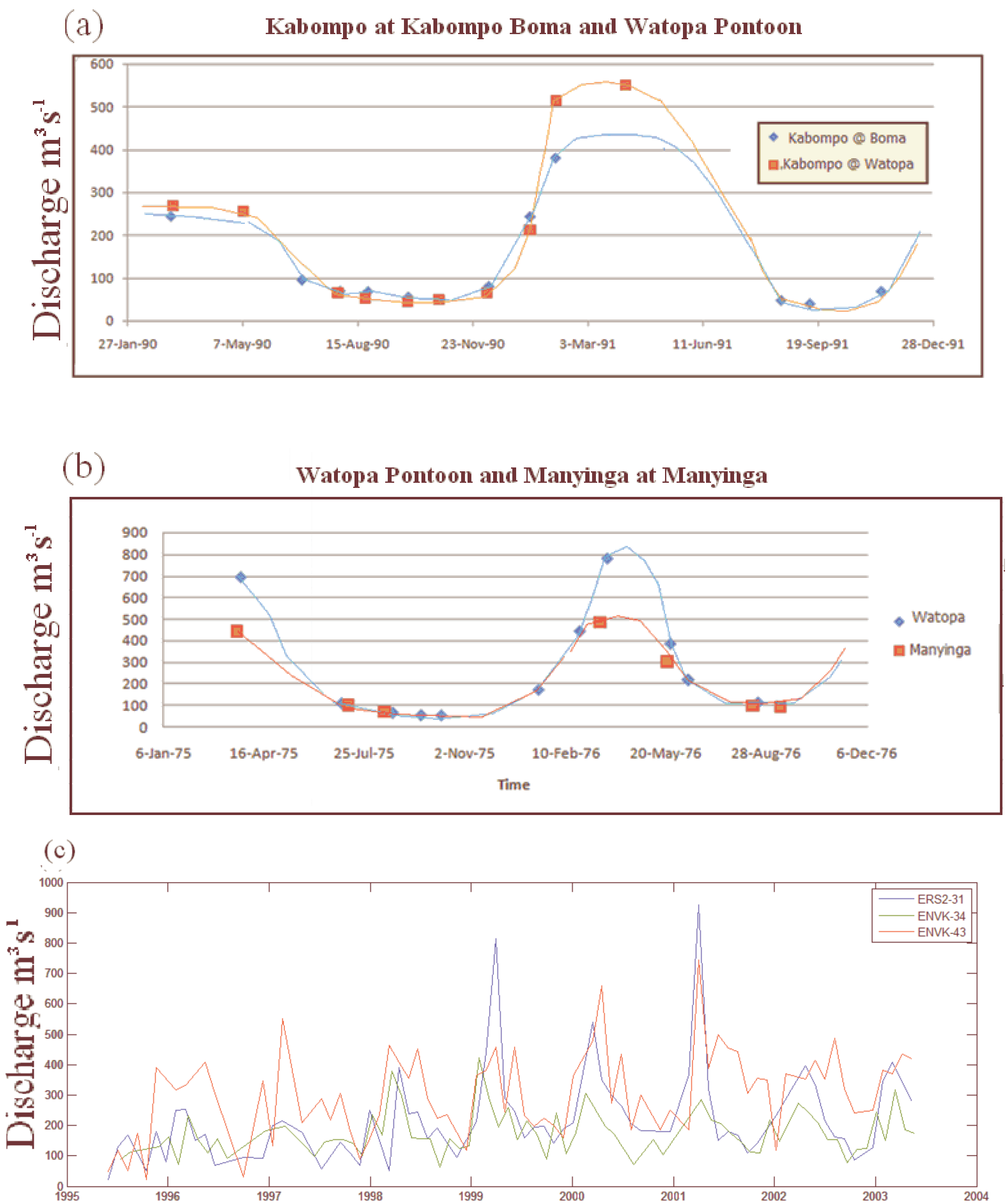



**Figure 33**: Shows flow relationship between stations on the Kabompo river (a) plot of Boma vs. Watopa (b) Watopa Vs. Manyinga (c) Radar altimetry data plot of Watopa vs. ERS2-31, ENVK-34 and ENVK-43 flow values for stations

From the plot, it was observed that even though the stations were a number of kilometers apart, their hydrographs exhibit the same frequency but different amplitudes (Figure 33a and 33b). This behavior was also expected from the radar altimetry derived flow data shown in Figure 33c.

### 5.1.3 Field Survey Results

Using the cross section method discussed in section 4.4.9, flow velocities, section depths and width measured for radar altimetry targets ENVK43, ERS2-31, ENVK34 and ENVK20 are presented and are a summary of field data collected shown in Appendix I to IV. It should be noted that the discharge and cross section area in the summarized Tables below are calculated from the field data using the two point method explained in Section 4.4.9 and not from the mean depth and velocity in the summarized Tables. To account for cross section of the whole flood plain, side slopes were extrapolated from the river bed until the expected level (Markings from site) was reached. This was included in the MATLAB script.

Target ENVK-43 is loctated at a Village called Biyeko 5 km upstream from Kabulamema mission. Area location GPS: 13°49'38.8''S, 024 °02'50.5'' . The river cross section survey was conducted on 6th October, 2009. Table 4 shows a summary of calculated river section area and discharge Appendix A containes the actual feild measurtements.

**Table 4** : Discharge and Cross section measurements for Envk 43

| **Mean depth (m)** | **Mean Velocity ($ms^{-1}$)** | **Cross Section Area ($m^2$)** | **Discharge ($m^3s^{-1}$)** |
|---|---|---|---|
| 1.095 | 0.6505 | 84.81 | 69.4596 |

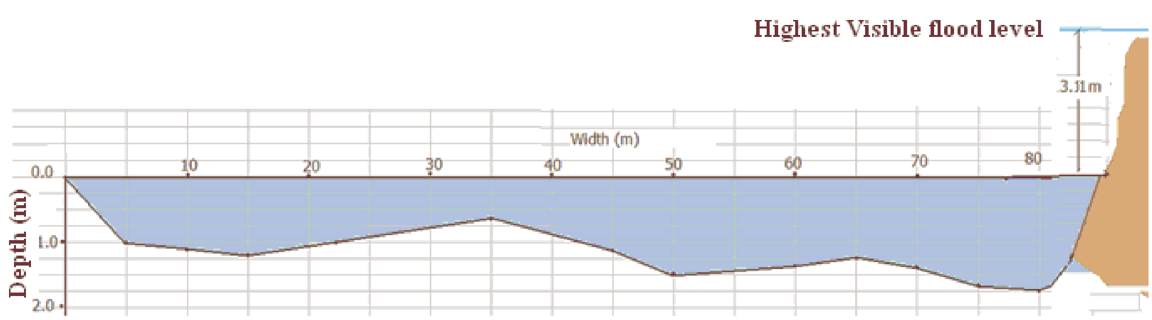



**Figure 34**: Section profile view of Kabompo River at target ENVK 43 (Biyeko Village)

The river bed is highly irregular as it can be seen from Figure 34 and mostly comprised of laterite rocks. The River has a number of rapids in this part of the basin making river navigation by boat a big challenge. The measured flow velocity varied from 0.43ms$^{-1}$ in deep areas to 0.97ms$^{-1}$ in very shallow parts of the selected section. Some of the highest floods experienced by the local people were easily identified from the markings on river banks and trees. The highest visible flood level from the past was measured at 3.11m from the current water level during the discharge measurements exercise

Target ERS2-31 is located 1.8km downstream of Watopa Pontoon. Its GPS location is 14$^{o}$ 02'16.8''S, 023 $^{o}$37'43.7''. Table 5 shows a summary of field measurements done on the target on the 6th October , 2009. A profile section survey was conducted giving Figure 35. More detailes of the measurements are given in Appendix 2. The highest visible flood level experinced in the past was measured to be 3.82m from the water level at the time of the river survey.

**Table 5** : Discharge and Cross section measurements for Ers2-31

| **Mean depth (m)** | **Mean Velocity (ms$^{-1}$)** | **Cross Section Area (m$^{2}$)** | **Discharge (m$^{3}$s$^{-1}$)** |
|---|---|---|---|
| 2.675 | 0.2011 | 295.25 | 62.651 |

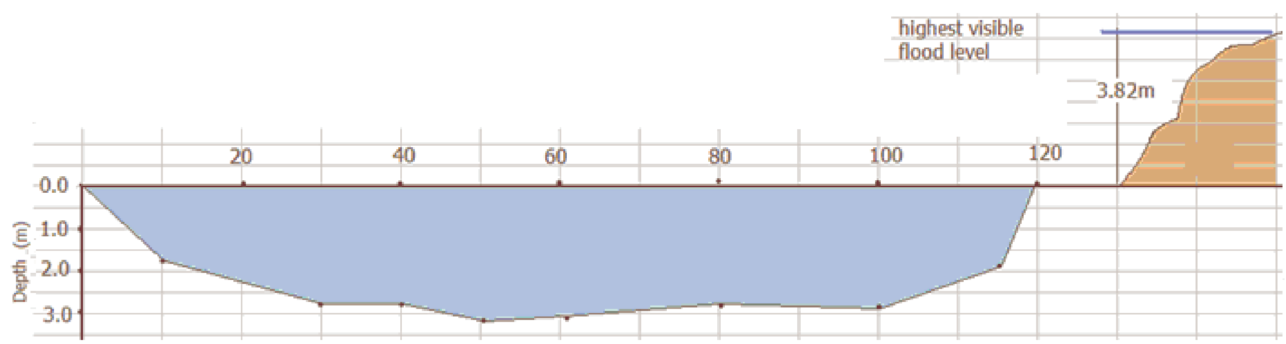



**Figure 35**: Section Profile view of The Kabompo River at ERS2-31 near Watopa Pontoon

ENVK – 34 is located 15Km downstream from Jivundu in the West Lunga National Park. Table 6 shows a summary of the measurements carried out on the target more details are presented in Appendix III. A section profile survey was also conducted and the section profile is shown in Figure 36. The highest flood level based on visible marks on Banks and Trees was measured to be 2.72m above the water surface.

**Table 6**: Discharge and Cross section measurements for ENVK-34

GPS: 14°02'16.8''S, 023°37'43.7'' , Date: 9th October , 2009

| **Mean depth (m)** | **Mean Velocity ($ms^{-1}$)** | **Cross Section Area ($m^2$)** | **Discharge ($m^3s^{-1}$)** |
|---|---|---|---|
| 2.311 | 0.3884 | 201.704 | 82.991 |

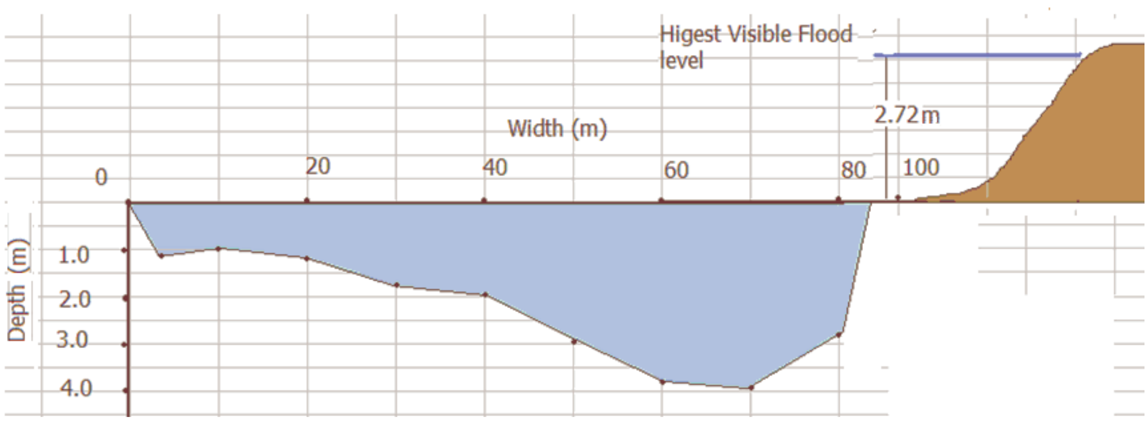



**Figure 36**: Profile section view of the Kabompo river downstream jivundu (AT ENVK 34)

Target ENVK-20 is located 12 km upstream from Ntambo Mission. The GPS location for the target is 14°02'16.8''S, 023 °37'43.7''. River measurements were carried out on 12th October, 2009. Table 7 shows a summary of the field measurements. More details are presented in Appendix IV. The highest visible flood level experienced was measured to be 2.50m above water level (Figure 37).

**Table 7**: Discharge and Cross section measurements for ENVK-20

| **Mean depth (m)** | **Mean Velocity ($ms^{-1}$)** | **Cross Section Area ($m^2$)** | **Discharge ($m^3s^{-1}$)** |
|---|---|---|---|
| 0.6553 | 0.35995 | 14.939 | 6.0033 |

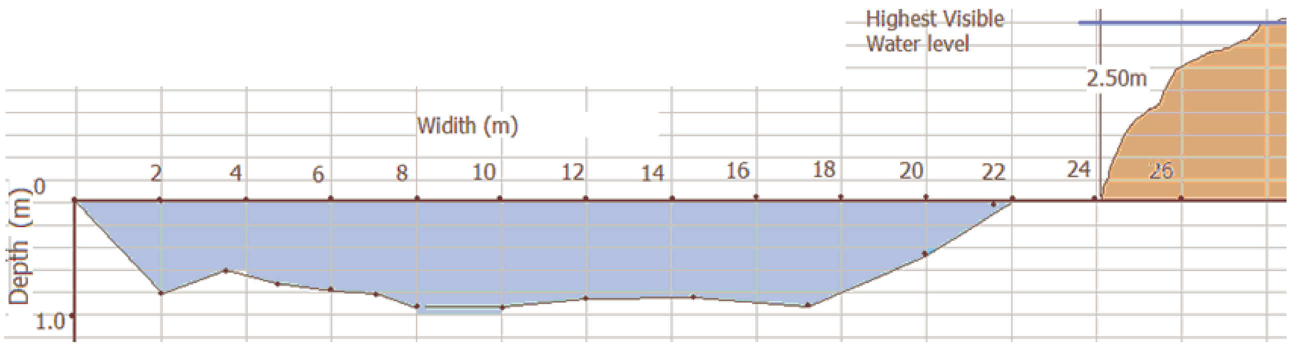



**Figure 37**: section view of the Kabompo River at Target ENVK 20 near Ntambo mission

### 5.1.4 Sensitivity Analysis and Calibration results of Model

Sensitivity analysis is done to estimate the rate of change in the output of a model with respect to changes in models input. Sensitivity analysis was conducted within the SWAT interface using the Latin-hypercube sampling method in which parameters were ranked as shown in Table 8. This method uses a sophisticated way to perform random sampling such as Monte-Carlo sampling for a robust analysis requiring not too many runs (Srinivasan, 2005).

**Table 8:** Sensitivity analysis ranking of parameters used in the model.

| Rank | Parameter | Minimum | Maximum | Default Value | Final Value |
|---|---|---|---|---|---|
| 1 | GWqmn | 0.00 | 1000.00 | 0.00 | 60-100 |
| 2 | ESCO | 0.00 | 1.00 | 0.95 | 0.6-0.8 |
| 3 | Cn2 | -25.000 | 25.000 | 56-80 | 25-69 |
| 4 | Sol_AWC | -25.000 | 25.000 | 0.17 | 0.14-0.17 |
| 5 | Sol_Z | -25.000 | 25.000 | 76.2-203 | 76.2-203 |
| 6 | GW_Revap | -0.03600 | 0.0360 | 0.02 | 0.18-0.20 |
| 7 | EPCO | 0.000 | 1.000 | 0.0 | 0.0-0.2 |
| 8 | Surlag | 0.0000 | 10.0000 | 4.0000 | 3-5 |
| 9 | Alpha_BF | 0.0000 | 1.0000 | 0.048 | 0.006-0.008 |
| 10 | GW_Delay | -10.000 | 10.000 | 31 | 5-8 |
| 11 | Sol_K | -25.000 | 25.000 | 2.5-450 | 2.5-450 |
| 12 | Revapmn | -100.0000 | 1000.000 | | 60-350 |
| 14 | Rchrge_DP | 0.00 | 100.00 | 0.05 | 0.20-0.49 |

The model was manually calibrated by trial and error using the ESA Radar altimetry values converted to discharge at three Targets ENVK-34 (near Jivundu), ENVK-43 (near Biyeko Village) and ERS2-31 (near Watopa Pontoon). Initial surface runoff levels were too high but were reduced by adjusting the antecedent moisture condition II (Cn2), threshold water level in the shallow aquifer (GW_qmn), Base flow recession factor (Alpha_BF) and deep aquifer percolation coefficient (Rchrge_Dp) thereby increasing groundwater contribution through increased surface infiltration and deep aquifer percolation. Parameters were adjusted by trial and error graphically until the best fit was observed between the simulated and Radar Altimetry data. This approach was convenient for the little calibration data available instead of Auto calibration.

### 5.1.5 SWAT RESULTS

The basin was divided into 177 sub basins (see Figure 38 and 39) which were further subdivided forming a total of 1004 hydrological response units (HRU) not shown in the map. Hydrological response units are fully discussed in Section 2.6. The sub-basin delineation, stream network, main outlet and boundary of the Kabompo basin are illustrated in Figures 38.

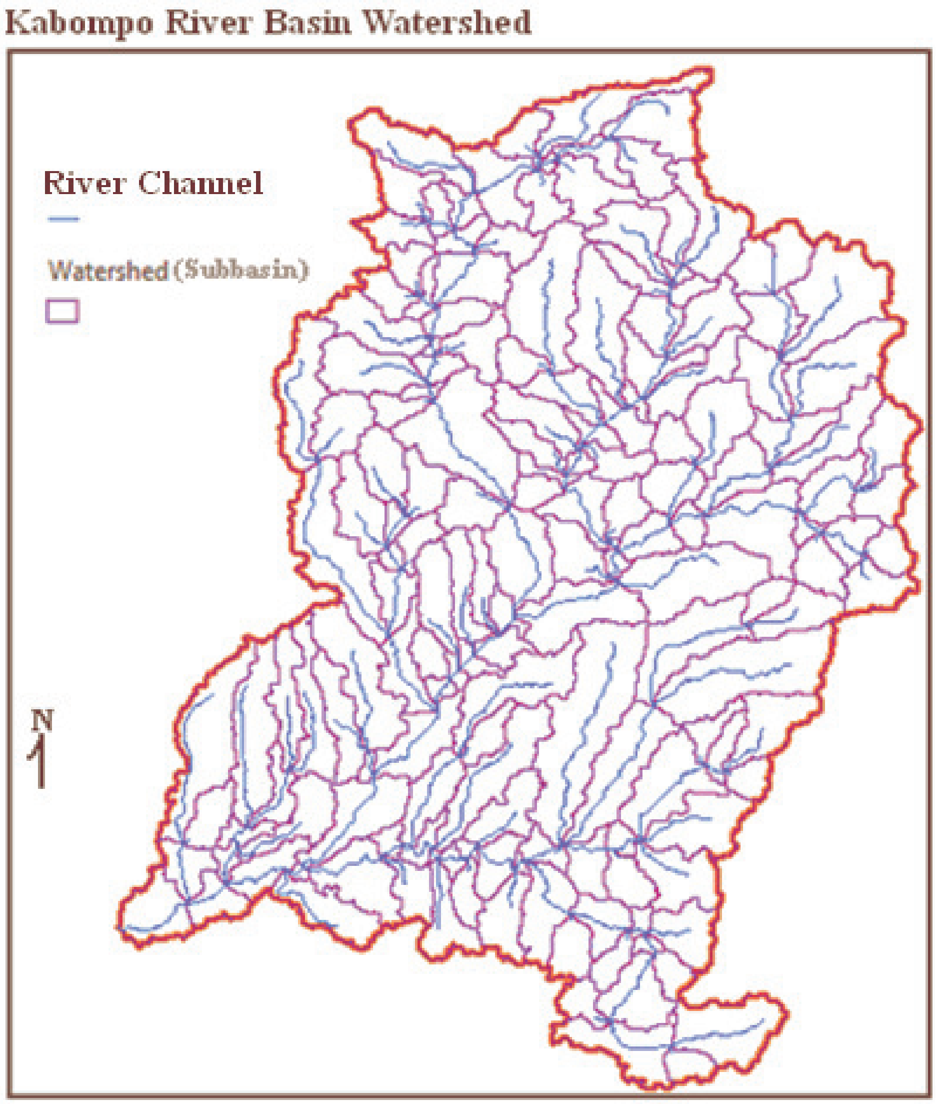



**Figure 38**: Generated Steam network Map for Kabompo basin with threshold stream generation area=20,000ha

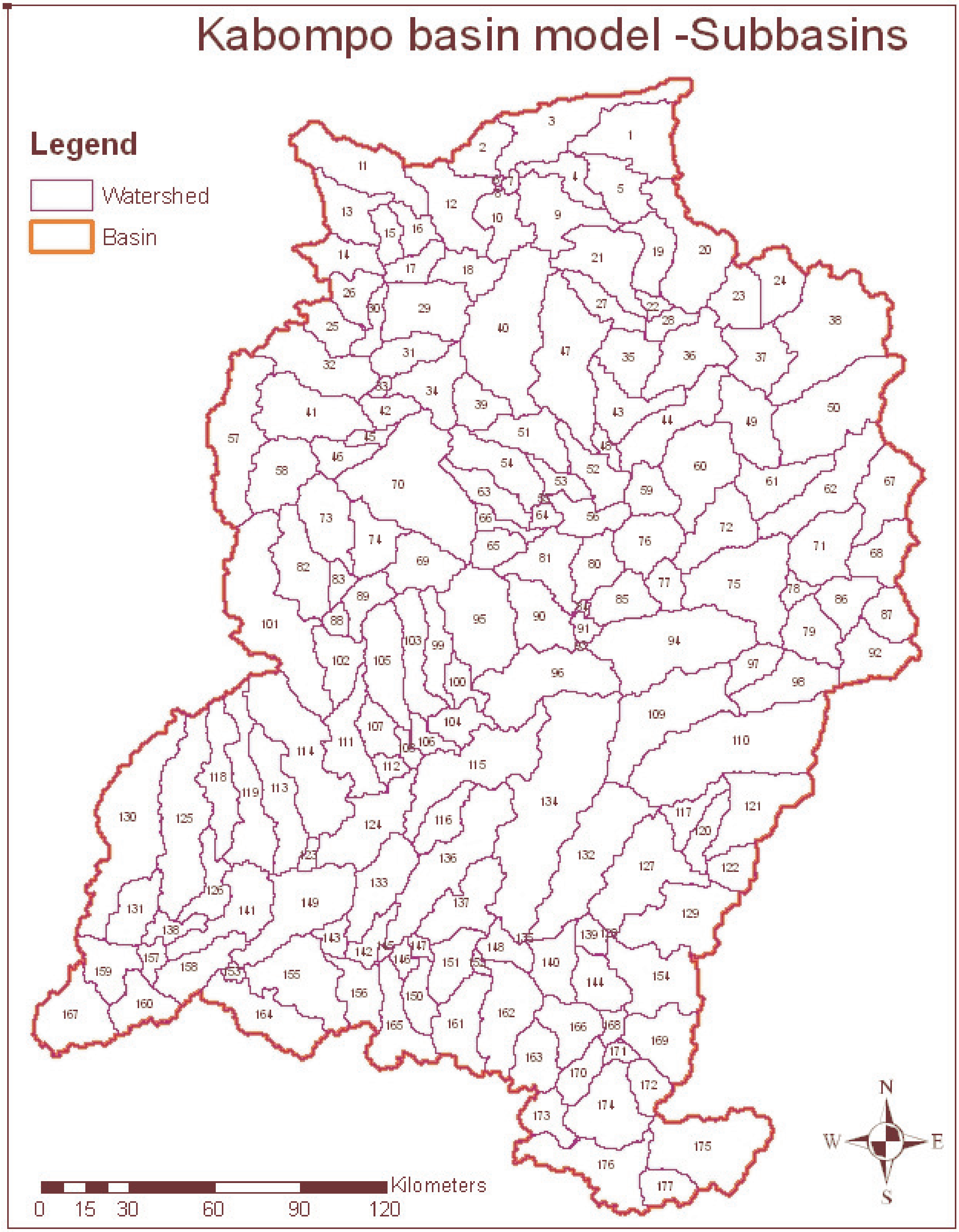



**Figure 39**: Sub-basins for the Kabompo River basin generated by ArcSWAT.

Based on FAO classification, the Kabompo basin soil map shown in Figure 40 identifies six (6) dominant soil types namely: Gleysols, Ferrasols, Lithosols, Acrisols, Orthic Ferasols and Arenosols. FAO description of the named soils is shown in Table 9.

**Table 9:** Description of Kabompo basin soils.

| **Soil Type** | **Major Soil Units** | **Associated soil units** | **Description** |
|---|---|---|---|
| Gleysols | Dystric Gleysols | Humic Gleysols | Hydromorphi sand plain soils or very poorly drained soils in large dambos (Grasslands) |
| Ferrasols | Orthic / Xanthic Ferrasols | Rhodic Ferralsols<br>Ferric Acrisols | Strongly leached reddish to brownish clayey to loamy soils , derived from acidic rocks (Miombo) |
| Lithosols | Lithosols | _ | Shallow soils derived from acidic rocks occurring on hill ranges (Miombo) |
| Acrisols | Ferric Acrisols<br>Ferric Luvisols | Orthic/ Xanthic Ferralsols | Moderately leached reddish to brownish clayey to loamy soils, derived from acid rocks ( Miombo) |
| Orthic Ferrasols | Orthic/ Xanthic Ferrasols<br>Rhodic/ Orthic Ferrasols | _ | Association strongly leached reddish to brownish clayey to loamy soils, derived from acid brocks and moderately to strongly leached red clayey soils, derived from basic rocks. |
| Arenolsols | Albic Arenosols<br>Ferralic Arenosols | | Non or weakly podzolic sandy soils on Kalahari sands ( Kalahari and cyptosepalum) |

Source (FAO, 1995)

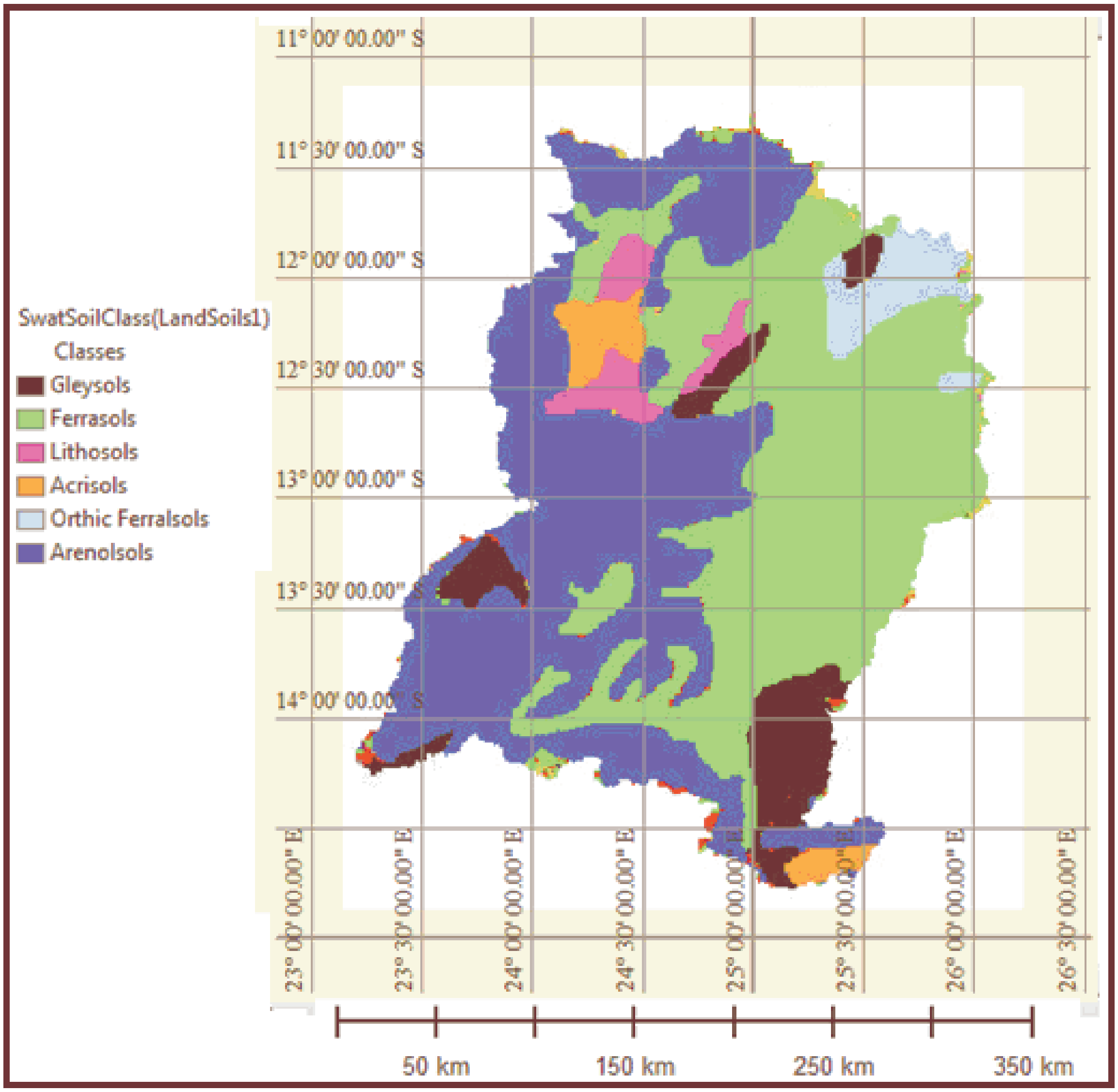



**Figure 40**: Shows a Clipped, delineated and classified 2,500,000 FAO Soil map of Kabompo river basin

The Kabompo river basin model listed (8) dominant landuses shown in Figure 41. Based on the Global Land Cover Characterization from the U.S Geological Survey the eight landuse are listed as; Agricultural land pasture (AGRP), Agricultural Land-Close-grown (AGRC), Forest and shrubs (FORS), Range grasses (RNGE), Forest Deciduous (FRSD), Forest Evergreen (FRSE), Forest Mixed (FRST) and Barren or Sparsely Vegetated equivalent to Southwestern US (Arid) Range (SWRN)

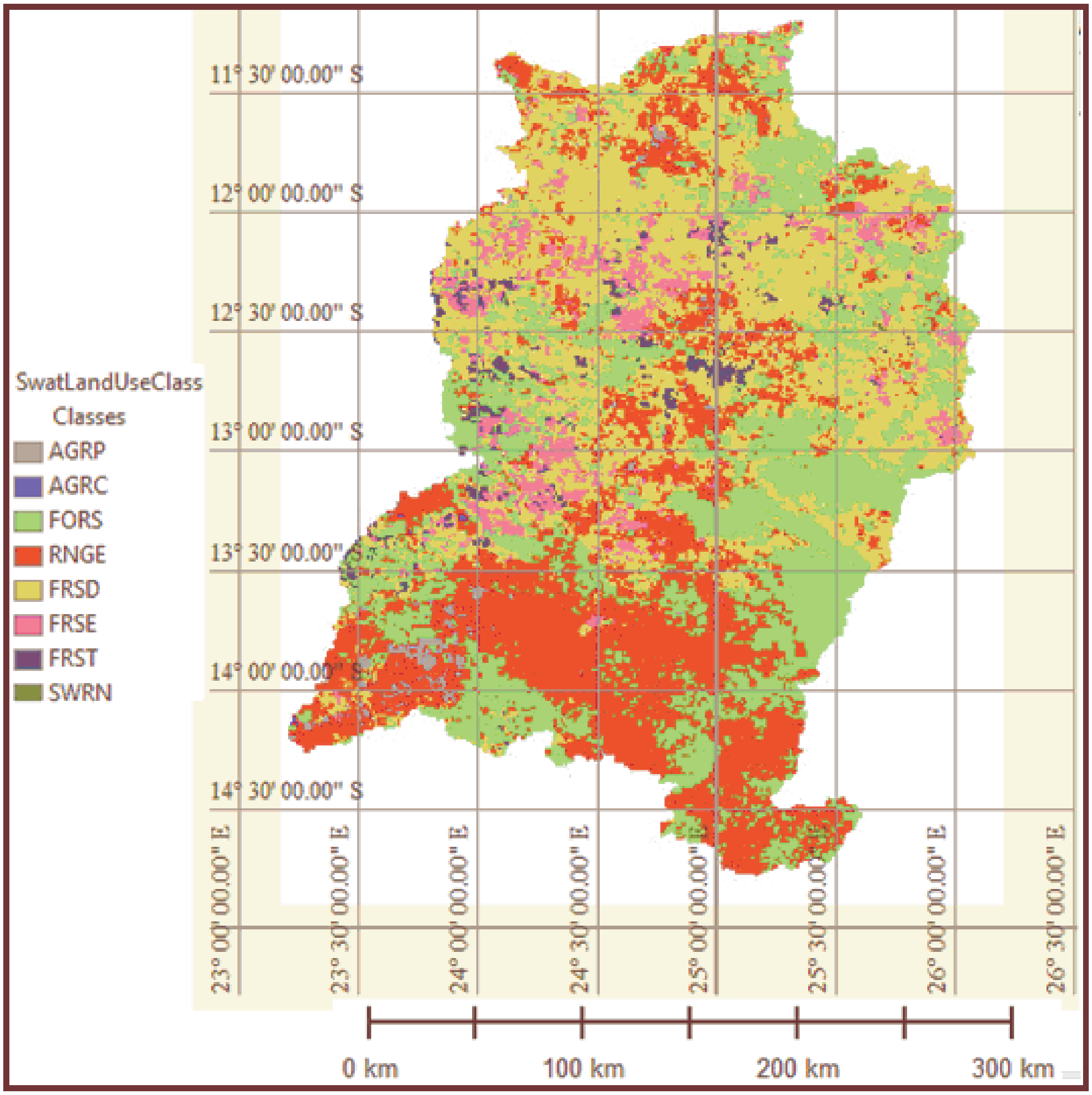



**Figure 41**: Shows a Land Cover Characterization (GLCC) 1km resolution based on USGS classification.

Three slope classes corresponding to slopes between 0 and 2%, 2 and 4% and higher than 4% are shown in the slope distribution map in Figure 42. The final HRU Report shown in Table 12, show that more than 79% of the Kabompo basin is in the slope between 0 and 2%. Detailed description of various sub-basins characteristic that includes landuse, soil type and topography, have been outlined in a Final Hydrological response unit report generated by SWAT in a (.txt) file format (Table 10).

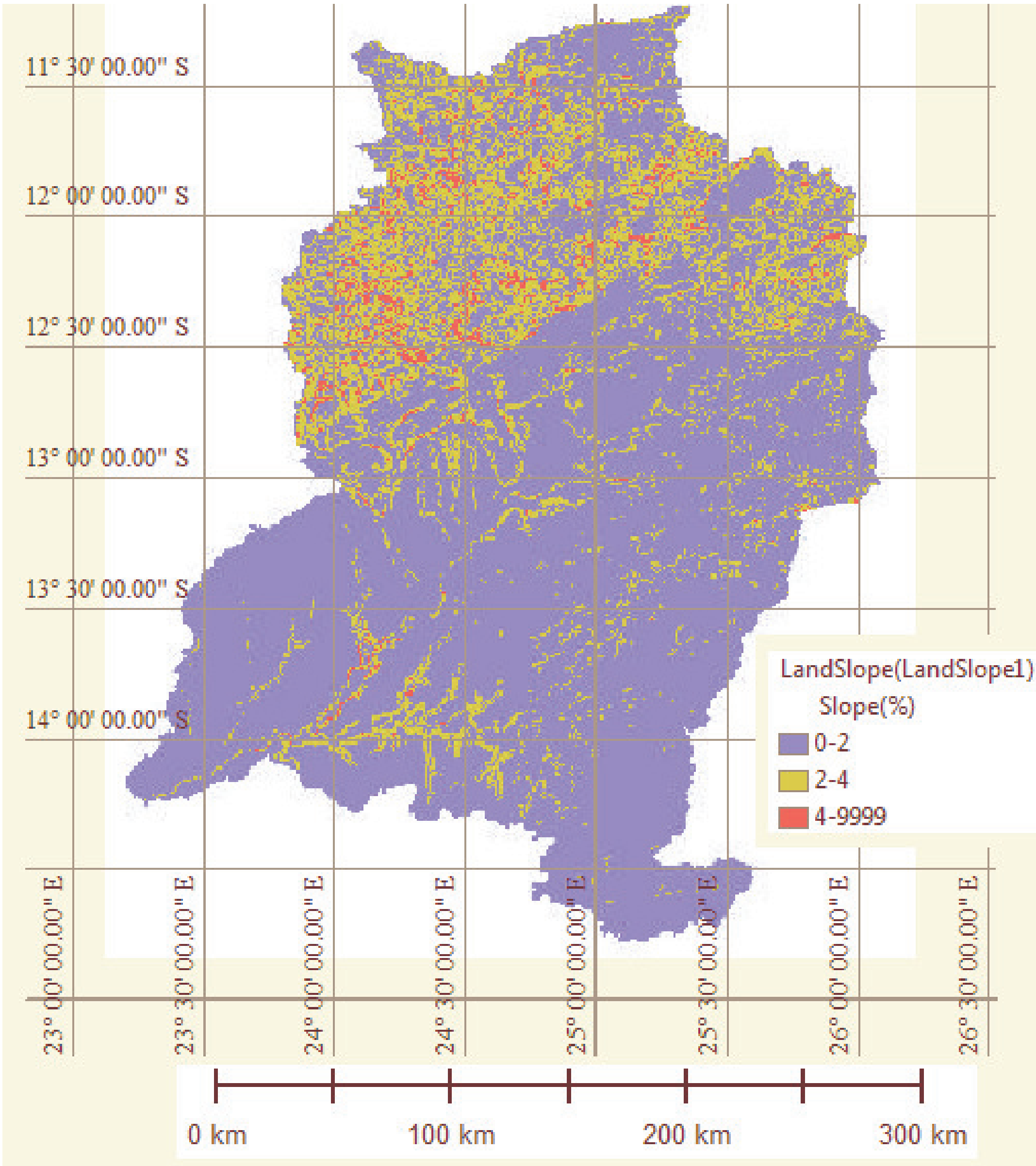



**Figure 42**: Slope distribution in Kabompo basin extracted from SRTM 90m DEM.

The number of sub basin generated after a selection of stream threshold value of 20,000 ha was 177 sub basins and 1004 HRUs. Table 10 outlines the details. From the report, it can be observed that the dominant landuse of the Kabompo basin is deciduous forest followed by range grasses. The report also shows that Arenosols and Ferrasols dominate the soils types in the basin.

**Table 10**: Part of the final HRU report generated by SWAT in txt file format

SWAT model simulation Date: 8/1/2010 12:00:00 AM Time: 00:00:00
MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 10 / 10 / 10 [%]
Number of HRUs: 1008
Number of Subbasins: 177

| | Area [ha] | Area[acres] | |
|---|---|---|---|
| Watershed | 7213961.2500 | 17826058.9468 | |

| | Area [ha] | Area[acres] | % Area |
|---|---|---|---|
| LANDUSE: | | | |
| Range-Grasses --> RNGE | 2200291.4927 | 5437030.2930 | 30.50 |
| Frorest and Shrubs --> FORS | 1852542.0513 | 4577724.0360 | 25.68 |
| Forest-Deciduous --> FRSD | 2673974.2228 | 6607524.0032 | 37.07 |
| Agricultural land pasture --> AGRP | 37342.8332 | 92276.0079 | 0.52 |
| Forest-Evergreen --> FRSE | 389067.6436 | 961405.6006 | 5.39 |
| Forest-Mixed --> FRST | 60743.0064 | 150099.0061 | 0.84 |
| SOILS: | | | |
| Arenolsols | 3037337.6832 | 7505413.2820 | 42.10 |
| Ferrasols | 2982898.7522 | 7370891.9616 | 41.35 |
| Lithosols | 220703.1251 | 545368.4573 | 3.06 |
| Gleysols | 512589.3716 | 1266633.9668 | 7.11 |
| Orthic Ferralsols | 264666.9508 | 654005.2687 | 3.67 |
| Acrisols | 195765.3671 | 483746.0105 | 2.71 |
| SLOPE: | | | |
| 0-2 | 5717104.0589 | 14127249.9847 | 79.25 |
| 2-4 | 1406696.9642 | 3476018.5335 | 19.50 |
| 4-9999 | 90160.2269 | 222790.4286 | 1.25 |

### 5.1.6 SWAT simulation results

The model was run from the year 1995 to 2008. A three year warm up period (1995-1998) was chosen for the model state variable to be initiated. This period is important for the stabilization of parameters (e.g. groundwater depth and soil water content). Since the radar altimetry data accessed during this research is only up to the year 2003, most of the validated results presented are from the year 2000 to 2003 with a few results covering periods up to 2008. The period 1998 to 2000 was used for model calibration. Daily and monthly simulation results were graphically illustrated and are discussed below.

Simulation results for ERS2-31 against Watopa Pontoon (Sub-basin 160 of Hydrological Model) are illustrated in Figure 43. It should be noted that the temporal resolution for radar altimetry target is about 35days, meaning radar altimetry data is represented by one measurement every month. This is illustrated in Figure 43a for ERS2-31 versus Watopa pontoon data on the distances between the nodes of the plotted data. Target ERS2-31 is only 1.8 km downstream of Watopa Pontoon on the Kabompo River. In cases where Department of Water Affairs (DWA) data has been used, the time in between the plotted nodes is not fixed and gap between DWA discharge measurements could vary from a few days to years (Figure 43a). The data was plotted in excel to obtain a scatter plot shown in Figure 43b with $r^2$= 0.56 and Ns = 0.46. The daily simulated discharge for this station was also compared with a few DWA observation readings measured between the period September 2000 and April 2006 which gave good results of $r^2$= 0.934 and Ns = 0.87 (Figure 43b). The "spikes" seen at the picks of daily simulated hydrograph are as a result of sudden increment in river discharge following "heavy" rainfall.

**ERS2-31 and Watopa (Sub-Basin 160)**

**(a)**

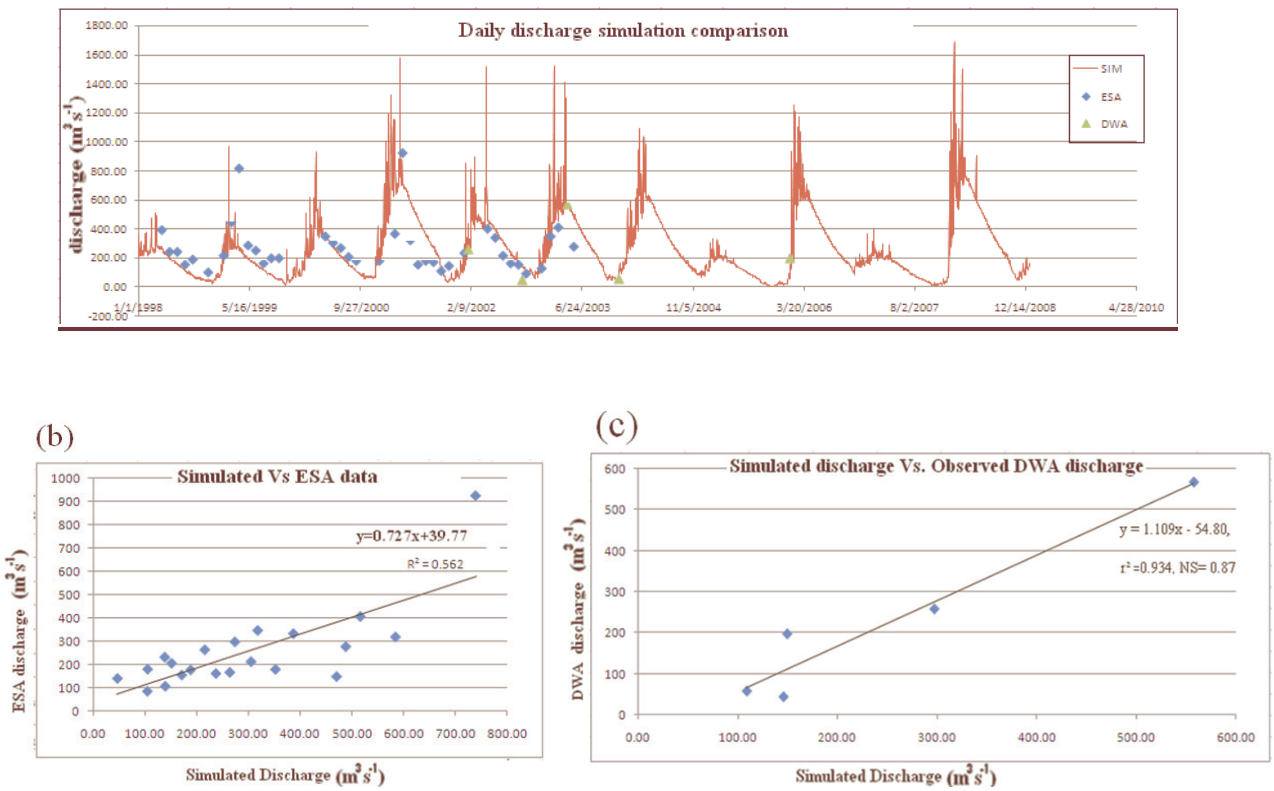
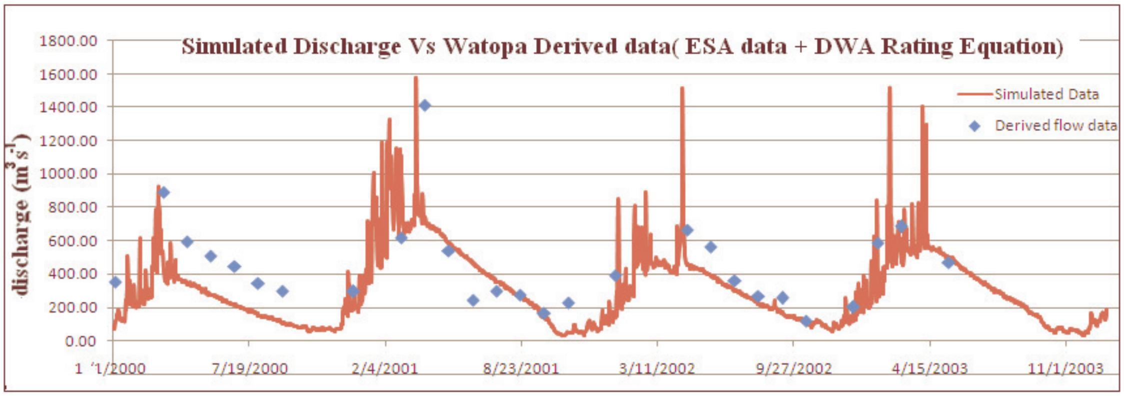



**Figure 43**: Daily simulation results graphs (a) Daily Simulated flow against ERS2-31 data and DWA data; (b) Scatter plot for Simulated vs. ERS2-31 flow data, and (c) Scatter plot for Simulated vs. DWA observed data.

Results for Discharge data calculated based on the Department of Water Affairs rating equation using Radar altimetry ERS2-31 water levels data are presented in Figure 44. To derive the data, it was assumed that the section profile for target ERS2-31 and Watopa Pontoon station were the same. This method eliminated the use of river section profile at the target.

A comparison of the two datasets shows that the precision between the two datasets improved with time from the start of the simulation. Correlation coefficients of $r^2 = 0.42$ and NS = -0.14 were obtained

**(a)**




**(b)**

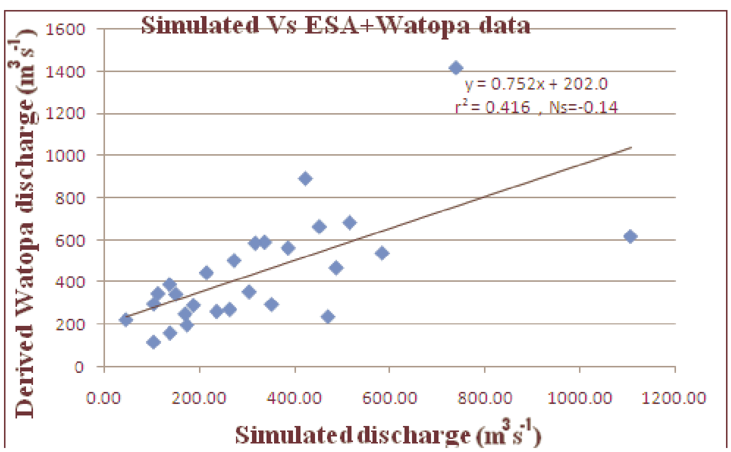
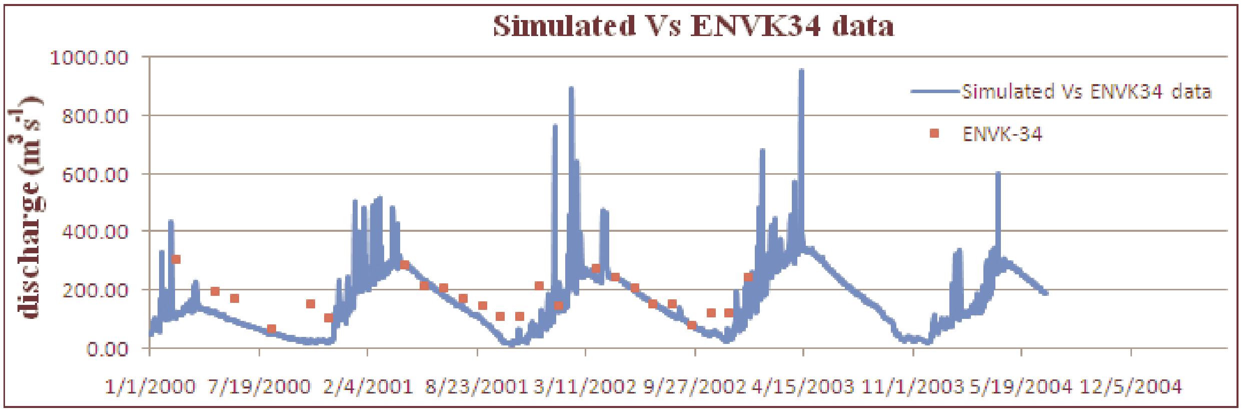



**Figure 44**: Daily simulated discharge comparison results (a) Simulated discharge Vs Derived ESA flow data based on DWA rating equation, and (b) Scatter plot between daily simulated and Derived (Calculated) data

Figure 45a and 45b shows results for Target ENVK-34 located in Sub-basin 100 of the hydrological model, 20km downstream the West Lunga National park in the Northwestern

Province. Daily simulated results for this Sub-basin showed reasonable correlation with radar altimetry derived flows with $r^2$=0.482 and Ns=0.41.

ENVK-34 (SUB-BASIN 100)



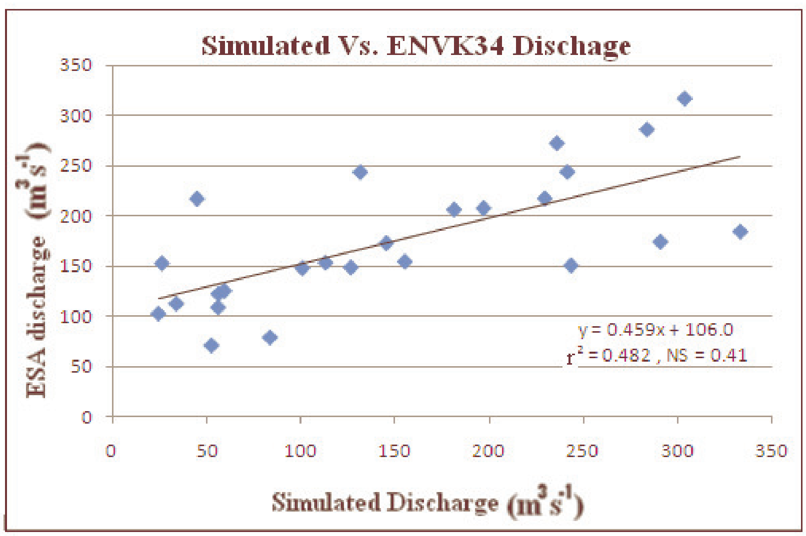
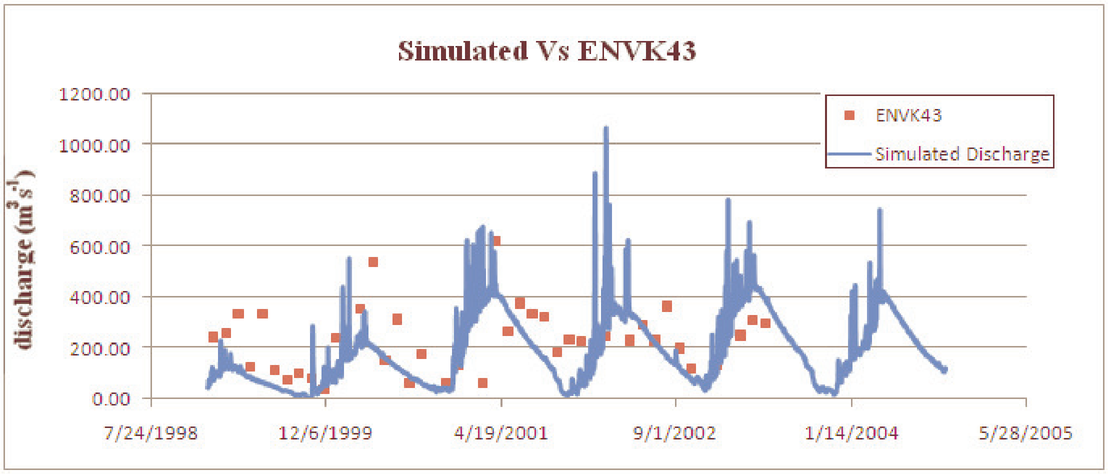




**Figure 45**: Simulation results graphs for ENVK-34 near Jivundu **(a)** Simulated flow against ENVK-34, and **(b)** Scatter plot of daily simulated flow vs. ENVK-34 data

A plot was also done on Target ENVK-43, located in Sub-basin 149 of the Kabompo river basin model, 5km upstream Kabulamema Mission located in the south of Kabompo district (Figure 46). Radar altimetry data for target ENVK43 exhibit unrealistic fluctionms which made poor correlation between Simulated and Radar altimetry derived discharge of $r^2$ = 0.09

and Ns = 0.47. In this case low correlation may be attributed to changing radar position on the target which was observed when locating targets on the ground.

**ENVK-43 (Sub-Basin 149)**



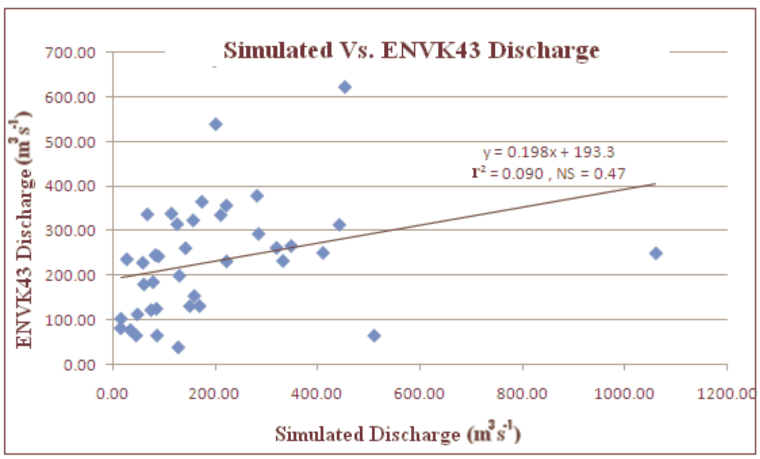




**Figure 46:** Simulation results graph for ENVK-43: (a) Simulated flow against ENVK-43 near Biyeko Village, and (**b**) Scatter plot of daily simulated flow vs. ENVK-43 data

Figure 47 to Figure 50 are examples of average monthly discharge data for DWA which have been compared with simulated monthly discharge values of the Kabompo basin model from the year 2000 to 2008. Depending on the availabity of flow records for a particular station, average monthly values for periods between 2 to 40 years were used. The average values create a basis for comparison because there is insufficent or no observed data for most stations in the Kabompo basin. Hence, average values from DWA records help to determine practical discharge range of a river or stream. For example, arcording to DWA records Lumwana East river located in Sub-basin 50 (Figure 47) of the model, had average flow values for the month of April of about 10 $m^3 s^{-1}$ from 1976 to 1978. Simulated data for the same sation in the month of April, show a value of 8.5 $m^3 s^{-1}$. Figure 47 also shows that the river exeperinces very low flows less than 1 $m^3 s^{-1}$. Likewise, Manyinga river at Manyinga Boma (Figure 48) in Kabompo District had average flow values for the month March between 1972 and 2006 of 25 $m^3 s^{-1}$ while simulated discharge indicates a values of 29.6 $m^3 s^{-1}$. Simillar comparisons were done for West Lunga river Sub-basin 16 and Luakela river Sub-basin

**Lumwana East River (Sub-Basin 50)**

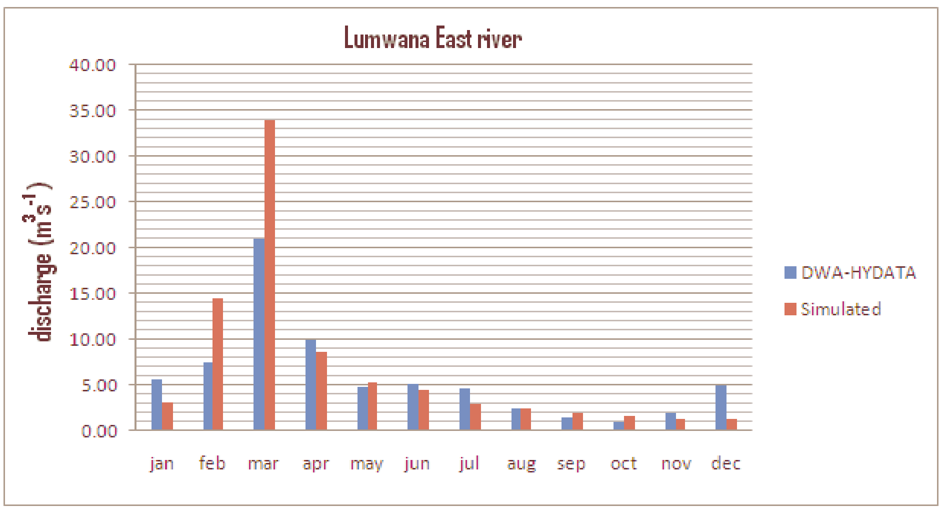



**Figure 47**: Grapgh showing simulation results comparison between avearge DWA monthly discharge values for Lumwana east river at Solwezi Miniluga Road bridge (1976-1978) aginst average monthly simulated discharge (2000-2007)

A comparison made between simulated flow (Figure 48) aginst DWA monthly discharge for Manyinga River at Manyinga sation showed that the Maximum discharge simulated during the period between 1995 and 2008 was 29.7 $m^3 s^{-1}$, which was within a resonable range to the average DWA value of 25 $m^3 s^{-1}$ . Figure 49 shows results for West Lunga River at Solwezi Mwinilunga Road Bridge in which the average simulated discharge for the month of March was 84 $m^3 s^{-1}$ while average DWA data for a period of 40 years showed a value of 110 $m^3 s^{-1}$ .

## Manyinga River (Sub-Basin 111)

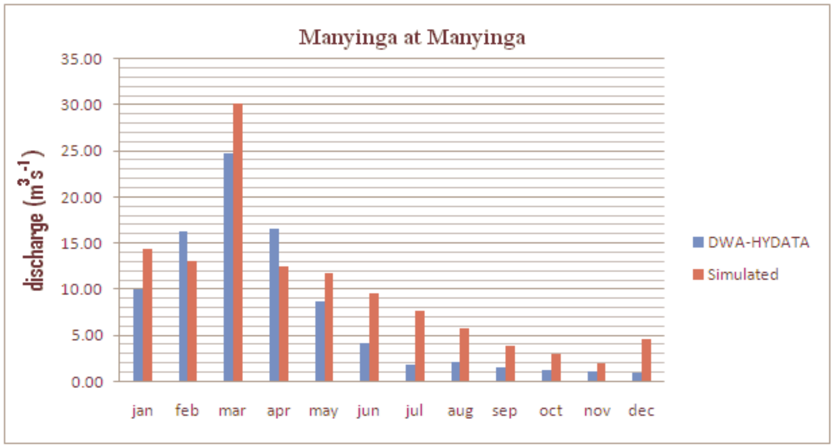



**Figure 48**: Simulation results comparison graphs between DWA avearge monthly discharge values for Manyinga Riverand (1962-2006) aginst average monthly simulated discharge (2000-2007).

Finally, a comapriosn was made between average monthly DWA data for Lukakela River at Sachibondo in Figure 50 , in which the average maximum simulated in the period between the year 2000 and 2004 was 12.6 $m^3$ $s^{-1}$ while average DWA data for the same station shows a possible practical value of 24.4 $m^3$ $s^{-1}$.

## West Lunga River (Sub-Basin 16)

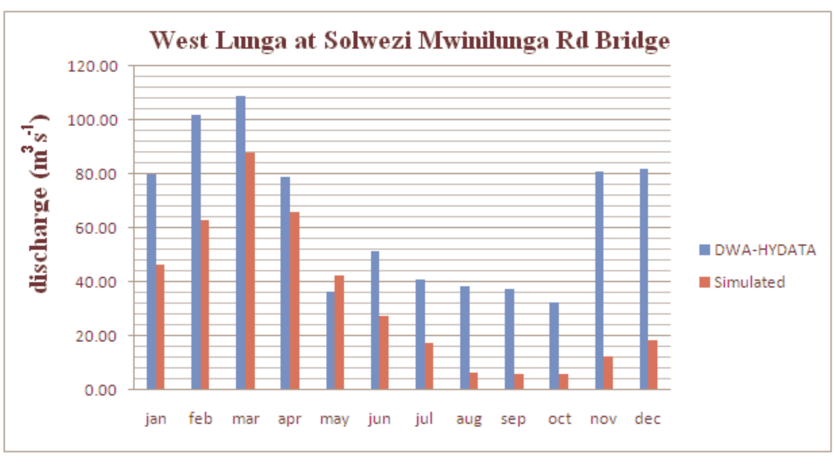



**Figure 49**: simulation results comparison between average DWA monthly discharge values for West Lunga River at Solwezi Mwiniluga Road bridge (1961-2006) aginst averge monthly simulated flow for West lunga river at the bridge

## Luakela River (Sub-Basin 11)

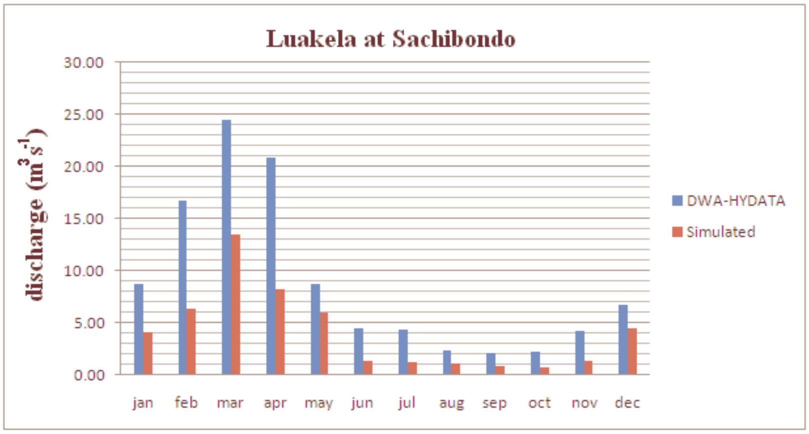



**Figure 50:** Simulation results comparison between avearge DWA monthly discharge values for Luakela River at Sachibondo in Mwiniluga District (1971-2006) aginst average monthly simulated discharge (2000-2007)

# CHAPTER 6: DISCUSSION

## 6.1 Introduction

This chapter discusses the findings of the research in line with the study. It presents the challenges and possible application of the developed model. The chapter also discusses possible sources of uncertainties which may have effect on the model's accuracy

## 6.2 Development of Kabompo basin hydrological Model.

In this research, a database and hydrological model for the Kabompo river basin were successfully developed using remote sensing datasets and a GIS based software SWAT also referred to as ArcSWAT when plugged in GIS. Datasets were converted to ArcSWAT compatible raster (GRIDs) and vector datasets (shape files and feature classes) see section 4.5.1.The database formulated is composed of ArcSWAT input data needed to simulate river flow parameters and was compiled by using the ArcSWAT interface itself. It was noticed that the combination of GIS and SWAT could easily calculate basic hydrological information such as, surface slopes, water flow paths positions, and soil and sub-basin distributions. It could easily overlay one layer of an activity, for example, landuse onto another e.g. stream distribution. The database has data in .txt or .dbf file format shown in Section 5.3.5 Table 9 or maps in shapefiles, TIFF, PNG or JEPG formats such as those shown in Figures 38 to 41 in Section 5.3.5. Compositions of this database include weather parameters, soil, landuse/landcover and stream network distributions for all the 177 sub-basins in the model.

Based on the input data from the database, the hydrological model was able to simulate stream flow parameters successfully. The hydrological model could generate results for all sub-basins in a single run. The model operates on a daily time step using input data to account for some spatial differences in channel morphology, soils, landuse, climate and topography. The developed model is available in a soft-copy and can be run from any computer without ArcGIS by using SWAT editor.

The model developed is "flexible" and mostly relies on the accuracy of the input data which is mainly; Precipitation, Minimum/Maximum Temperature, landcover/ landuse, Topography and soil data. It should be noted however that, what makes the Hydrological model for Kabompo basin model unique is a combination of the basin's weather, soil, landuse and topography of the basin. Using the same principles and equations a similar model can be developed for another area as long as input parameters of that area are used.

The overall process involved in setting up the Kabompo river basin model is also illustrated in Figure 51. Important parameters necessary in the model are also illustrated in the Figure. It was observed while setting up the model that SWAT software was perfuming better on Computers with a ram size of at I Gb or higher. SWAT is a continuous time model operating on a daily time step and the main driving equations for the illustration in Figure 51 remains a series of equations in section 2.6 that includes; Land phase cycle (equation 2.1), Routing phase (equation 2.5) and the overall channel water balance (equation 2.6).

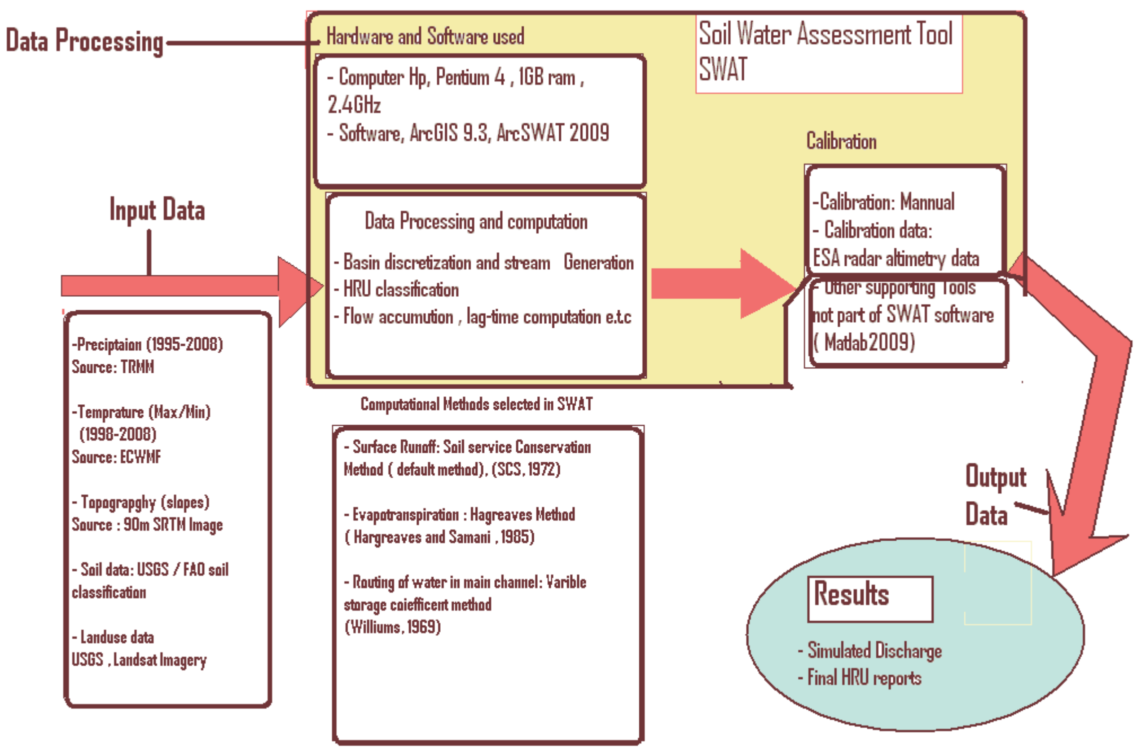



**Figure 51**: Build of the Kabompo river basin model

Computations were done for each Sub-basin and added as water movement was traced from one reach (river channel) to the other until to the basin's outlet. Appendices $B_2$ to $B_4$ show subroutine (From model's source Code) performed on each Sub-basin. Modifications can be done to these subroutines to add other necessary function for other modeling applications but the process requires the use of a complier such FORTRAN so that it can be feed back in the model and run successfully again. The source code contains hundreds of subroutines but not all of them could be validated and presented as the ones shown in Appendices $B_2$ to $B_4$. Validation was mostly done on input weather data.

Validation was conducted on remote sensed weather data (precipitation and temperature) on six Zambian towns as shown in Section 5.2. The correlation coefficient ($r^2$) for TRMM (precipitation) datasets, ranged from 0.090 to 0.934 for different stations. It was noticed that the timing of the rain was correct, but the total amount of precipitation for a particular time varied, this was probably caused by the difference in actual location of the correcting rain gauge and the TRMM co-ordinates. The validation results does not imply TRMM data is of poor quality because Wolf et al, (2004) conducted a ground validation of space-based rain estimates from the TRMM satellites for 10 sites located around four continents and got correlation coefficients ($r^2$) as good as 0.96. Their technique included a broad distribution of rain gauges spread across a site covering a radius of up to 100km. Skøien et al., 2003 also confirms that larger sampling density of rain gauges in a catchment provides better rainfall estimates. Hence, the poor rain gauge setup of meteorological data used in this study, made it difficult to determine the amount of precipitation even for areas just a few kilometers (e.g. 6Km) from the station. TRMM data used had a spatial distribution of 0.25 degrees, which translate to 27km grid spacing. This spacing makes it difficult to make an accurate approximation of rainfall that falls in the middle of the grids. Hence, if a metrological station is in the middle of these grids its results may not match perfectly with TRMM data even though the measurement was done at the same time.

While calibrating the model, most of the hydrological data from the Department of Water Affairs HYDATA database used in the study was partially consistent from the 1960s to 1980s. It suddenly develops huge gaps with some stations having one stage/flow measurement in a period of three years. It is for this reason that another source of independent data was needed to shape the hydrological models simulations to acceptable levels. Fortunately, ESA radar altimetry had enough targets in the basin to help calibrate the model. It is for this reason that field surveys were conducted for the ESA data to be utilized. For the radar altimetry data to be used it had to be converted to discharge using manning's channel flow principle

Converting elevation changes to discharge (see Section 4.5.4) was challenging because the actual elevation of the target station with respect to the Radar altimetry satellite was unknown, hence, other means had to be explored to do so. This other method which has been explained in Section 5.2.3, involved manually merging Radar altimetry and gauging station mean water level values ( for a year or more) together on the same graph. The observed fluctuation range/limits were then used to approximate a reference elevation value for the station with respect to altimetry data. Mean values were used because the temporal resolution of radar altimetry data is almost one month, hence, it was difficult to find a common measurement occurring on the same date for the two datasets at the station.

When this method could not work for some stations, an elevation was calculated by searching for a common date in both radar altimetry and hydrological station water level dataset for a level which was read by both gauging station and radar altimeter. The difference between water level and radar altimetry elevation values was considered to be a fixed value and was applied to the rest of the data to convert other corresponding radar altimetry elevation change to known heights and later converted to discharge

Using the two methods proved to work well in a number of cases, but still posed a challenge in situations where the radar altimetry along track strike a river at an angle instead of passing the path perpendicular to the river at the target. It should be noted that radar altimetry readings on a target are not fixed bound to a specific co-ordinate (Berry et al. 2006). The co-ordinate of targets varies and may vary even 3kms in a narrow band on the ground from previous readings. However, when processing the data, values clustered in a reasonable radius of less than 100m, elevation change were considered to occur in a single location. Hence, when a river was struck at an angle (not perpendicular ), the assumption of the river characteristics to be uniform were no longer applicable worse if some readings on the river were further than 300m from one end. This behavior could be the reason why target ENVK-43 shown in Figure 46 responded very differently as compared to the other stations.

## 6.3 Findings

The developed model managed to simulate discharge for various stations or sub-basins successfully. The best result being a simulation of the Kabompo River at ESA target ERS2-31 in Sub-basin 160 which gave $r^2$ of 0.93 and NS of 0.87 in a comparison between simulated and Department of Water affairs data for a few readings taken between the year 2002 and 2004. This successful result can be attributed to close location between a DWA gauging station and radar altimetry target ERS2-31. This result can further be verified by comparing simulated data with observed discharge data for the period between 2004 and 2009

The close location of Target ERS2-31 (Watopa Pontoon) in sub-basin 160 to a DWA gauging station of less 1.8km was so unique and convenient that, radar altimetry elevation values were directly compared with DWA water level data; it was observed that fluctuations in radar altimetry elevation values corresponded well with observed data as shown in Figure 24b section 5.2.3. A comparison of ERS2-31 discharge data against daily simulated discharge, gave reasonable good results whose RMSE and NS coefficients' were 0.56 and 0.46 respectively. A very good correlation ($r^2$ = 0.93 and NS= 0.87 ) was obtained when comparisons were done between Daily simulated and DWA data (Kabpompo river at Watopa Pontoon gauging station data) for the period between the year 2000 and 2004, despite the fact that very few discharge records were available for the station. A similar comparison using DWA data could not be made for the other station due to non availability of observed data in the simulation period. This is the reason why radar altimetry data alongside Manning's principle was used to calibrate the model in the period between 1995 and 2000, when DWA data was still scanty. Not all targets however, obeyed the Manning's principle as it was observed for target ENVK-43 located in sub basin 149 (Figure 46).

Generated discharge from the ENVK-43 elevation data failed to correspond with simulated discharge ($r^2$ = 0.090 and NS = 0.47), Radar altimetry converted discharge was noticed not to follow a logical order but rather Radom behavior of discharge value of one value to the next as it can be seen in Figure 46. Unrealistic discharg drops were observed to move quit fast from high picks and maintained very high flows even in dry seasons. This behavior was also observed from earlier comparisons done in Figure 32c with other generated discharge data using a method outlined in Section 4.5.3. The cause of this unrealistic behavior is still drawn back to the earlier discussion in this section of radar altimetry target tracking complexity, where the satellite may strikes the river at many locations as wide as 3km depending on angle made between the satellite path and the river (Berry et al. 2006).

Comparisons were also done for four (4) other stations in the basin namely; Lumwana East River (Sub-basin 50), Manyinga River at Manyinga station (Sub-basin 111), West Lunga River at Solwezi-Mwinilunga Road Bridge (Sub-basin 16) and Luakela River at Sachibondo (Sub-basin 11). Monthly simulation results were compared with average monthly discharge records from DWA database. The comparison was done by focusing on the minimum and maximum values to see whether the simulated discharge values were practical. Simulation results for three stations; Lumwana East River, Manyinga River and, West Lunga River were within accepTable range with the average monthly values from the Department of Water Affairs (DWA) database. Table 13 shows results for the four stations.

**Table 11**: Comparison of simulated discharge against observed monthly average DWA data

| **S/N** | **River / Station** | **Sub-basin** | **Simulated discharge ($m^3 s^{-1}$)** | | **DWA Discharge ($m^3 s^{-1}$)** | |
|---|---|---|---|---|---|---|
| | | | **Maximum** | **Minimum** | **Maximum** | **Minimum** |
| 01 | Lumwana East at Solwezi-Mwinilunga Rd. bridge | 50 | 18.3 | 0.12 | 21.3 | 0.35 |
| 02 | Manyinga River at Manyinga | 111 | 28.7 | 1.2 | 25.5 | 0.9 |
| 03 | West Lunga River at Solwezi-Mwinilunga Rd. bridge | 16 | 88.6 | 0.14 | 110.2 | 32 |
| 04 | Luakela River at Sachibondo | 11 | 12.9 | 0.3 | 24.8 | 2.1 |

## 6.4 Model uncertainties and solutions

Due to the inconsistency and unavailability of observed flow data it was difficult to validate the simulation results for most sub-basins. Hence, results verification was in most cases dependent on radar altimetry rather than other independent sources. Some sources of uncertainty in the model variables such as water storage in the unsaturated and saturated zone, deep aquifer percolation and evaporation parameters which are difficult to observe directly, were automatically determined through calibration discharge time-series at the outlet of a catchment (Neitsch et al., 2005). For geomorphologic parameters, scholars have shown that incorrect topographic parameters reduce annual runoff, soil erosion and sediment yield. The SRTM data sets used in this study had a resolution of 90m. A 30m resolution image such as those for ASTER, could probably improve the accuracy of the simulations. Finally, during model discretization, choosing the stream threshold generation area was critical because dividing the watershed in smaller units affected the computational efficiency of the ARCSWAT. The threshold area chosen was 20,000 ha or 200 $km^2$ resulting in 177 sub basins and 1004 hydrological response units. This threshold value was ideal for the basin and gave better results than for lower threshold values. To run the model it took approximately eight minutes to complete one single run from 1995 to 2008. Further subdividing the watershed lengthened the time. By dividing the watershed into bigger units, the model tends to lump variables for different landuses, topography and soils making input data with high spatial resolution insignificant. The output data was easily read by a Matlab script shown in Appendix VI.

The developed model has proved that remote sensing alongside GIS can indeed generate input variables to assemble a hydrological Model. It can also be concluded therefore that, building a very successful hydrological model does not only required basic knowledge of the model processes or quality of input data, but also requires great understanding of computational capabilities of the software and hardware being used in building the model. The developed model will be very useful a number of applications in Water resource management.

## 6.5 Possible applications for the developed hydrological model

The generated stream flow values from the model are available for almost any important river or stream in the Kabompo basin including those located in active economic and industrial zones such as the mines or commercial farms. A comparison of simulated data with both radar altimetry and DWA data has shown that the model generates discharge with $r^2$ and NS values as good as 0.64 and 0.539 respectively. According to the Nash-Sutcliffe (NS) definition, if NS > 0, the hydrological model is said to predict more accurately than the observed mean values. This therefore is an assurance that the generated stream flow values can be safely used in various water resource management applications including approximation of trace elements and sediment movements in the basin by using the flows alongside soil and sediment sampling results.

The generated stream flow more especially at high picks would help engineers approximate sediment loading and fill periods to dams at the same time make it possible to size bridges, drainage culverts and other hydraulic structures. Water resource management such as water rights and water allocation activities can also make use of stream flows in areas where gauged data is not available which is a common trend in Zambia today. Figure 52 shows a water allocation practical example.

Luakela River at Sachibondo is a gauging station located in a remote part of Northwestern province shown in Figure 52. It is likely that a farmer or industry in this area may want to abstract water from the stream near the station and would have forwarded his or her water rights application letter to the Water Development Board. Usually the biggest challenge when allocating water to an applicant is the luck of historic stream flow records to help portion the stream flow. If we assume that there is no historic flow records to quantify discharge for this part of the stream, then the developed model would help solve this problem by approximating the stream flow. In this particular example, the simulation results over a period of eight years from the year 2000 shows that the highest possible water abstraction on the Luakela River at a place called Sachibondo may not exceed $63.9m^3$/day in the driest season. This would be the basis for quantifying water needed by the famer. Hence water resources are managed easily. If pumping rate exceeded the allocated quantity, the river could possibly stop flowing downstream affecting various ecological activates which requires water. Hence, if no river flow records are available, the simulated flow for the stream would help determine the optimal pumping rate for a combination of various water users in the Sub-basin.

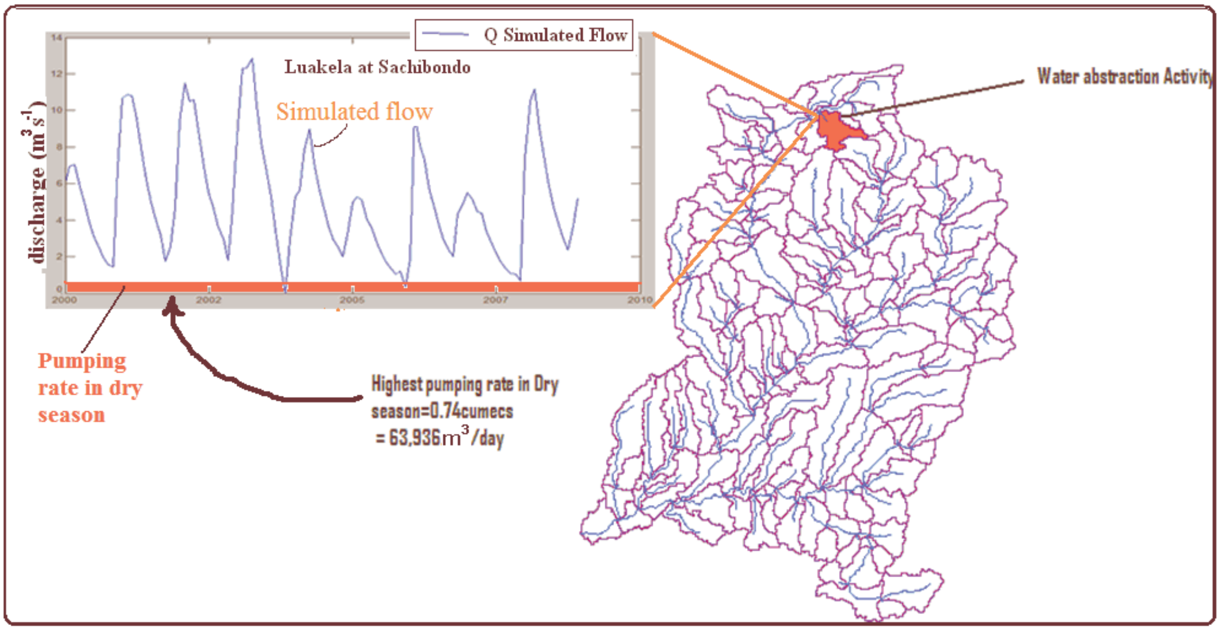



**Figure 54**: Water allocation example for Luakela Riveer at Sachibondo

Other applications of th hydrological modeling that may be useful include effects on landuse changes on surface runoff and soil erosion. As discussed earlier, Pikounis et al.(2010) have used the soil water assessment tool (SWAT) to estimate the effect of specific land use changes by comparing the simulated and observed discharge time series at the outlet of the watershed based on pre-specified landuse scenarios. Adjusting landuse parameters such as vegetation cover to fit human or natural phenomenon helps solve “what if?” kind of questions. It would basically help determine the effect of landuse changes on surface runoff, infiltration and stream flow (Stephane et al.2009).

# CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

## 7.1 Introduction

This chapter makes conclusions and provides recommendations for use and improvement of the model and future applications.

## 7.2 Summary

The main objectives for the research work have been fulfilled. Remote sensing was successfully applied using an a GIS based Soil Water Assessment Tool (SWAT) to approximate river/ stream discharge in the Kabompo river basin. The model was calibrated with radar altimetry data and validated with flow data for eight (8) hydrological stations in the Kabompo River basin. The model's results showed fairly good correlation in most cases with observed data and daily simulations with the Nash Sutcliffe coefficient (NS) and Root Mean Square as good as ($r^2=0.93$ and Ns = 0.87) for observed data at Watopa Pontoon , and very low correlations between simulated and radar altimetry derived discharge for target ENVK-43 of ($r^2=0.09$ and Ns = 0.47) . Comparisons were also made between monthly simulation results and average DWA data in areas where there was very little or no observed data in the simulation period of 1995 to 2008. The results showed that the model was able to simulate discharge value within acceptable limits.

Use of the model for various applications would help solve key water resources management problems such as water allocation to agriculture and industries. It can also be used to study changes in stream flow regimes as a result of changes either in landuse practices or excessive surface water abstraction.

## 7.3 Conclusion

Remote sensing with GIS are useful tools for hydrological modeling in approximating hydrological data more especially where it is lacking. This study has applied remote sensing and ArcSWAT successfully to come up with a hydrological model for the Kabompo basin capable of approximating river discharge and has various possible applications. Wide use of Remote Sensing and GIS in Zambia would help improve water resources management.

## 7.4 Recommendations

To help improve simulation results, a number of recommendations have been put forward.

1. There is need to collect more observed stream flow data from other independent sources other than DWA data for Radar altimetry data analysis. Pressure transducers which are known to measure water levels accurately and cheaply can be used to either validate the Radar altimetry data or Kabompo basin model simulations.
2. Use of higher resolution images for landuse, DEM and soil maps would greatly improve the accuracy of the simulations.
3. To avoid approximating the elevations at radar altimetry targets, it would be better to use more accurate elevation measurement methods available.
4. More research on hydrological modelling should be done in Zambia in order to increase quantification of its water resources.

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# APPENDICES

# APPENDIX A: FIELD SURVEY RESULTS

## Appendix $A_1$ : ENVK-43 data

DISCHARGE MEASUREMENT USING TYPE A-A PRICE CURRENT METER

Station: ENVK 43 GPS: 13°49'38.8"S , 024°02'50.5" Date: 6th October 2009

Start time: 11:10 Stage 1.36 End Time: 14:00 Water level

| No# | Distance From LWB (m) | W (m) | Depth (m) | Revolutions (/s) | Time (s) | Velocity (m/s) | Mean Velocity | Section Area | Discharge ($m^3$/s) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 5 | 10 | 1 | 45 | 40 | 0.774225 | 0.774225 | 6 | 4.64535 | LWB |
| | | | | | | | | | | |
| 1 | 15 | 10 | 1.2 | 47 | 40 | 0.808315 | 0.799793 | 12 | 9.59751 | |
| | | | | 46 | 40 | 0.79127 | | | | |
| 2 | 25 | 10 | 1 | 57 | 40 | 0.978765 | 0.978765 | 10 | 9.78765 | |
| | | | | | | | | | | |
| 3 | 35 | 10 | 0.65 | 50 | 40 | 0.85945 | 0.85945 | 7.25 | 6.2310125 | |
| | | | | | | | | | | |
| 4 | 45 | 10 | 1.2 | 55 | 40 | 0.944675 | 0.953198 | 9.5 | 9.05537625 | |
| | | | | 56 | 40 | 0.96172 | | | | |
| 5 | 65 | 20 | 1 | 45 | 40 | 0.774225 | 0.774225 | 24.06 | 18.6278535 | |
| | | | | | | | | | | |
| 6 | 75 | 10 | 1.36 | 45 | 40 | 0.774225 | 0.79127 | 12.8 | 10.128256 | |
| | | | | 47 | 40 | 0.808315 | | | | |
| 7 | 81 | 6 | 1.35 | 25 | 40 | 0.433325 | 0.433325 | 3.2 | 1.38664 | |
| | | | | | | | | | | |
| | | | 5m to Rb | | | | | | | RWB |
| | | | | | | | | | 69.45964825 | ($m^3$/s) |
| | | | | | | | | | 6,001,313.61 | per day |

**Appendix $A_2$ :** ERS2-31 data

DISCHARGE MEASUREMENT USING TYPE A-A PRICE CURRENT METER

Station: ERS2( 31) GPS: 14°02'16.8"S , 023°37'43.7" Date: 6th October 2009

Start time: 15:40 Water Level End Time: 17:50 Water level

| No# | Distance From LWB (m) | W (m) | Depth (m) | Revolutions (/s) | Time (s) | Velocity (m/s) | Mean Velocity | Section Area | Discharge ($m^3/s$) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 4 | 4 | 1.2 | 7 | 45 | 0.1132 | 0.1132 | 9 | 1.0188 | LWB |
| | | | | 7 | 45 | 0.1132 | | | | |
| 1 | 16 | 12 | 2.3 | 11 | 42 | 0.1857 | 0.15195 | 22.75 | 3.4568625 | |
| | | | | 7 | 43 | 0.1182 | | | | |
| 2 | 22 | 6 | 3.1 | 13 | 40 | 0.2288 | 0.197279 | 30 | 5.91837 | |
| | | | | 10 | 43 | 0.165758 | | | | |
| 3 | 41 | 19 | 3 | 13 | 42 | 0.2282 | 0.198865 | 45 | 8.948925 | |
| | | | | 10 | 42 | 0.16953 | | | | |
| 4 | 47 | 6 | 3.1 | 17 | 40 | 0.297 | 0.24135 | 30 | 7.2405 | |
| | | | | 11 | 42 | 0.1857 | | | | |
| 5 | 57 | 10 | 3.1 | 19 | 41 | 0.32316 | 0.2659 | 30 | 7.977 | |
| | | | | 13 | 44 | 0.20864 | | | | |
| 6 | 74 | 17 | 2.7 | 15 | 40 | 0.2629 | 0.2373 | 58 | 13.7634 | |
| | | | | 12 | 43 | 0.2117 | | | | |
| 7 | 101 | 27 | 2.9 | 10 | 40 | 0.17765 | 0.203225 | 70.5 | 14.3273625 | |
| | | | | 13 | 40 | 0.2288 | | | | |
| 8 | 117 | 16 | to RWB | | | | | | 0 | |
| | | | | | | | | | 62.65122 | ($m^3/s$) |
| 9 | | | | | | | 1.609069 | 295.25 | 5,413,065.41 | ($m^3$/day) |
| | | | | | | | 0.2011336 | | | |

## **Appendix $A_3$ :** ENVK-34 data

DISCHARGE MEASUREMENT USING TYPE A-A PRICE CURRENT METER

Station: Envk ( 24) GPS: 35L 0245620, 8548241 Date: 9th October 2009

Start time: 12:00 Water Level End Time: 17:00 Water level

| No# | Distance From LWB (m) | Distance (m) | Depth (m) | Revolutions (/s) | Time (s) | Velocity (m/s) | Mean Velocity | Section Area | Discharge ($m^3/s$) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 2.1 | | 1 | 5 | 48 | 0.078221 | 0.078221 | 2.75 | 0.21510775 | |
| | | | | | | | | | | |
| 1 | 12.1 | | 0.9 | 27 | 40 | 0.467415 | 0.467415 | 9.5 | 4.4404425 | |
| | | | | | | | | | | |
| 2 | 22.1 | | 1.1 | 28 | 40 | 0.48446 | 0.48446 | 13.437 | 6.50968902 | |
| | | | | | | | | | | |
| 3 | 32.1 | | 1.5 | 17 | 40 | 0.29969 | 0.3696255 | 19.375 | 7.161494063 | |
| | | | | 26 | 41 | 0.439561 | | | | |
| 4 | 42.1 | | 2.2 | 27 | 40 | 0.467415 | 0.535595 | 22.75 | 12.18478625 | |
| | | | | 35 | 40 | 0.603775 | | | | |
| 5 | 52.1 | | 3.2 | 28 | 41 | 0.47282 | 0.531022 | 31.5 | 16.727193 | |
| | | | | 35 | 41 | 0.589224 | | | | |
| 6 | 62.1 | | 4 | 25 | 40 | 0.433325 | 0.4281275 | 38.76 | 16.5942219 | |
| | | | | 25 | 41 | 0.42293 | | | | |
| 8 | 72.1 | | 4 | 18 | 40 | 0.314 | 0.3269 | 31 | 10.1339 | |
| | | | | 20 | 41 | 0.3398 | | | | RWB |
| 9 | 78.1 | | 2.9 | 17 | 42 | 0.28317 | 0.275035 | 32.812 | 9.02444842 | |
| | | | | 16 | 42 | 0.2669 | | | | |
| 10 | 4m to LB | | 0 | | | | | | | |
| | | | | | | | | | 82.9912829 | ($m^3/s$) |
| | | | | | | | | | 7,170,446.84 | ($m^3/day$) |

## **Appendix A$_4$ :** ENVK-20 data

**DISCHARGE MEASUREMENT USING TYPE A-A PRICE CURRENT METER**

Station: Envk ( 20) GPS: 35L 0296024, 8640080 Date: 12th October 2009

Start time: 14:20 Water Level End Time: 16:30 Water level

| No# | Distance From LWB (m) | Distance (m) | Depth (m) | Revolutions (/s) | Time (s) | Velocity (m/s) | Mean Velocity | Section Area | Discharge ($m^3/s$) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1.4 | | 0.36 | 3 | 50 | 0.04811 | 0.04811 | 0.55 | 0.0264594 | |
| | | | | | | | | | | |
| 1 | 2.7 | | 0.62 | 8 | 46 | 0.12577 | 0.12577 | 0.66 | 0.0830108 | |
| | | | | | | | | | | |
| 2 | 3.6 | | 0.28 | 26 | 48 | 0.37651 | 0.37651 | 0.4 | 0.1506032 | |
| | | | | | | | | | | |
| 3 | 4.1 | | 0.46 | 27 | 46 | 0.39257 | 0.39257 | 0.6 | 0.235539 | |
| | | | | | | | | | | |
| 4 | 6.1 | | 0.69 | 29 | 47 | 0.42789 | 0.42789 | 1.4 | 0.599039 | |
| | | | | | | | | | | |
| 5 | 8.1 | | 0.87 | 26 | 40 | 0.45037 | 0.45037 | 1.6 | 0.720592 | |
| | | | | | | | | | | |
| 6 | 10.1 | | 0.87 | 28 | 41 | 0.47282 | 0.47282 | 1.8 | 0.851076 | |
| | | | | | | | | | | |
| 8 | 12.1 | | 0.81 | 30 | 41 | 0.50608 | 0.50608 | 1.7 | 0.8603326 | |
| | | | | | | | | | | |
| 9 | 14.1 | | 0.8 | 27 | 42 | 0.4455 | 0.4455 | 1.7 | 0.75735 | |
| | | | | | | | | | | |
| 10 | 15.6 | | 0.92 | 25 | 40 | 0.43333 | 0.43333 | 1.38 | 0.5979885 | |
| | | | | | | | | | | |
| 11 | 17.1 | | 0.82 | 24 | 42 | 0.3968 | 0.3968 | 1.237 | 0.4908416 | |
| | | | | | | | | | | |
| 12 | 18.6 | | 0.6 | 21 | 42 | 0.3481 | 0.3481 | 1.0125 | 0.3524513 | |
| | | | | | | | | | | |
| 13 | 19.9 | | 0.48 | 19 | 42 | 0.31563 | 0.31563 | 0.9 | 0.2840697 | |
| | | | | | | | | | | |
| | 1.9m to | | | | | | | | 6.0093531 | ($m^3/s$) |
| | | | | | | | | | 519,208.11 | ($m^3/day$) |

# **Appendix $B_1$** : SWAT Database land cover/ Landuse terms

| | USGS_type | Symbol | SWAT_type |
|---|---|---|---|
| 0 | | | |
| 1 | Urban and Built-Up Land | URMD | Residential Medium density |
| 2 | Dryland Cropland and Pasture | CRDY | Avg(Ag.Land gen. and Pasture) |
| 3 | Irrigated Cropland and Pasture | CRIR | Avg(Ag.Land gen. and Pasture) |
| 4 | Mixed Dryland/Irrigated Cropl | MIXC | Agricultural Land-Generic |
| 5 | Cropland/Grassland Mosaic | CRGR | Avg(Ag.Land gen. and Range-Grasses) |
| 6 | Cropland/Woodland Mosaic | CRWO | Avg(Ag.Land.gen and Forest Mixed) |
| 7 | Grassland | GRAS | Range-Grasses |
| 8 | Shrubland | SHRB | Range-Brush |
| 9 | Mixed Shrubland/Grassland | MIGS | Avg(Range-Grass and Range-Brush) |
| 10 | Savanna | SAVA | Avg(Range-Grass and SW US Arid Range) |
| 11 | Deciduous Broadleaf Forest | FODB | Forest-Deciduous |
| 12 | Deciduous Needleleaf Forest | FODN | Forest-Deciduous |
| 13 | Evergreen Broadleaf Forest | FOEB | Forest-Evergreen |
| 14 | Evergreen Needleleaf Forest | FOEN | Forest-Evergreen |
| 15 | Mixed Forest | FOMI | Forest-Mixed |
| 16 | Water Bodies | WATB | Water |
| 17 | Herbaceous Wetland | WEHB | Wetlands-Mixed |
| 18 | Wooded Wetland | WEWO | Wetlands-Forested |
| 19 | Barren or Sparsely Vegetated | BSVG | Southwestern US (Arid) Range |
| 20 | Herbaceous Tundra | TUHB | Altai Wildrye |
| 21 | Wooded Tundra | TUWO | Avg(altai wildrye and range brush, temp reduced ) |
| 22 | Mixed Tundra | TUMI | Avg(SW US arid Range and altai wildrye, temp reduced) |
| 23 | Bare Ground Tundra | TUBG | Avg(SW US arid Range and altai wildrye, temp reduced) |
| 24 | Snow or Ice | ICES | Water |

# APPENDIX $B_2$ : Subroutine land phase cycle

```
    subroutine surface

!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine models surface hydrology

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    ihru        |none          |HRU number
!!    ovrlnd(:)   |mm H2O        |overland flow onto HRU from upstream
!!                               |routing unit
!!    peakr       |mm/hr         |peak runoff rate
!!    precipday   |mm H2O        |effective precipitation for the day in HRU
!!    qday        |mm H2O        |surface runoff loading to main channel
!!                               |for day
!!    surfq(:)    |mm H2O        |surface runoff generated in HRU during
!!                               |the day
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    precipday   |mm H2O        |effective precipitation for the day in HRU
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    j           |none          |HRU number
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: Max
!!    SWAT: canopyint, snom, crackvol, dailycn, volq, crackflow, surfst_h2o,
!!    SWAT: alph, pkq, tran, eiusle, ysed

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~


      use parm

      integer :: j
      j = 0
      j = ihru

      !! compute canopy interception
      if (idplt(nro(j),icr(j),j) > 0) then
        call canopyint
      end if

      !! compute snow melt
      call snom

      !! compute crack volume
      if (icrk == 1) call crackvol

      !! add overland flow from upstream routing unit
      precipday = precipday + ovrlnd(j)
      if (nstep > 0) then
        do ii = 1, 24
          hhprecip(ii) = hhprecip(ii) + ovrlnd(j) / 24
        end do
        do ii = 1, nstep
          precipdt(ii+1) = precipdt(ii+1) + ovrlnd(j) / nstep
        end do
      end if

      !!calculate daily curve number value
```

```
call dailycn

if (precipday > 0.) then
  !! compute runoff - surfq in mm H2O
  call volq

  !! adjust runoff for loss into crack volume
  if (surfq(j) > 0. .and. icrk == 1) call crackflow
end if

!! calculate amount of surface runoff reaching main channel during day
!! (qday) and store the remainder
call surfst_h2o

!! calculate half-hour rainfall
if (precipday > 0.01) call alph(0)

if (qday > 0.0001) then
  !! compute peak rate - peakr in m3/s
  call pkq(0)
end if

if (qday > 0.0001 .and. peakr > 0.) then
  !! compute transmission losses for non-HUMUS datasets
  call tran
  call eiusle
end if

if (surfq(j) > 1.e-6 .and. peakr > 1.e-6) call ysed(0)

if (qday < 0.) qday = 0.

return
end
```

# APPENDIX $B_3$ : Subroutine land phase cycle

```
subroutine route

!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine simulates channel routing

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    alpha_bnke(:)|none         |Exp(-alpha_bnk(:))
!!    bankst(:)   |m^3 H2O       |bank storage
!!    ch_l2(:)    |km            |length of main channel
!!    ch_revap(:) |none          |revap coeff: this variable controls the amount
!!                               |of water moving from bank storage to the root
!!                               |zone as a result of soil moisture depletion
!!    ch_w(2,:)   |m             |average width of main channel
!!    da_ha       |ha            |area of watershed in hectares
!!    hru_sub(:)  |none          |Sub-basin number for HRU
!!    ievent      |none          |rainfall/runoff code
!!                               |0 daily rainfall/curve number technique
!!                               |1 daily rainfall/Green&Ampt technique/daily
!!                               |  routing
!!                               |2 sub-daily rainfall/Green&Ampt technique/
!!                               |  daily routing
!!                               |3 sub-daily rainfall/Green&Ampt/hourly routing
!!    inum1       |none          |reach number
!!    inum2       |none          |inflow hydrograph storage location number
!!    irte        |none          |water routing method:
!!                               |0 variable storage method
!!                               |1 Muskingum method
!!    iwq         |none          |stream water quality code
!!                               |0 do not model stream water quality
!!                               |1 model stream water quality (QUAL2E)
!!    nhru        |none          |number of HRUs in watershed
!!    pet_day     |mm H2O        |potential evapotranspiration on day
!!    rchdep      |m             |depth of flow on day
!!    rnum1       |none          |fraction of overland flow
!!    rttlc       |m^3 H2O       |transmission losses from reach on day
!!    rtwtr       |m^3 H2O       |water leaving reach on day
!!    shallst(:)  |mm H2O        |depth of water in shallow aquifer
!!    sub_fr(:)   |none          |fraction of watershed area in Sub-basin
!!    varoute(3,:)|metric tons   |sediment
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    revapday    |m^3 H2O       |amount of water moving from bank storage
!!                               |into the soil profile or being taken
!!                               |up by plant roots in the bank storage zone
!!    rtwtr       |m^3 H2O       |water leaving reach on day
!!    sedrch      |metric tons   |sediment transported out of reach on day
!!    shallst(:)  |mm H2O        |depth of water in shallow aquifer
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    ii          |none          |counter
!!    jrch        |none          |reach number
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: Min
!!    SWAT: rchinit, rtover, rtday, rtmusk, rthourly, rtsed, rthsed, watqual
!!    SWAT: noqual, hhwatqual, hhnoqual, rtpest, rthpest, rtbact, irr_rch
!!    SWAT: rchuse, reachout

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~
```

```
      use parm

      integer :: jrch, ii
      real :: subwtr

      jrch = 0
      jrch = inum1

!! initialize variables for route command loop
      call rchinit

!! route overland flow
      call rtover

      vel_chan(jrch) = 0.
      dep_chan(jrch) = 0.

!! route water through reach
      if (ievent < 3) then
        if (irte == 0) call rtday
        if (irte == 1) call rtmusk
      else
        if (irte == 0) call rthourly
        if (irte == 1) call rthmusk
      endif

!! average daily water depth for sandi doty 09/26/07
      dep_chan(jrch) = rchdep

!! if reach is an irrigation canal, restrict outflow
      if (icanal(jrch) == 1) then
        rchstor(jrch) = rchstor(jrch) + rtwtr
        rtwtr = 0.
      end if

!! add transmission losses to bank storage/deep aquifer in Sub-basin
      if (rttlc > 0.) then
        bankst(jrch) = bankst(jrch) + rttlc * (1. - trnsrch)
        subwtr = 0.
        subwtr = rttlc * trnsrch / (da_ha * sub_fr(jrch) * 10.)
        do j = hru1(jrch), hru1(jrch) + hrutot(jrch) - 1
          deepst(j) = deepst(j) + subwtr
        end do
      end if

!! compute revap from bank storage
      revapday = ch_revap(jrch) * pet_day * ch_l2(jrch) * ch_w(2,jrch)
      revapday = Min(revapday,bankst(jrch))
      bankst(jrch) = bankst(jrch) - revapday

!! compute contribution of water in bank storage to streamflow
      qdbank = bankst(jrch) * (1. - alpha_bnke(jrch))
      bankst(jrch) = bankst(jrch) - qdbank
      rtwtr = rtwtr + qdbank
      if (ievent > 2) then
        do ii = 1, 24
          hrtwtr(ii) = hrtwtr(ii) + qdbank / 24.
        end do
      end if

!! perform in-stream sediment calculations
        if (inum1 /= inum2) then
          !! do not perform sediment routing for headwater Sub-basins
            if (ievent < 3) then
              call rtsed
            else
              call rthsed
            end if
        else
          if (ievent < 3) then
```

```
          if (rtwtr > 0. .and. rchdep > 0.) then
            sedrch = varoute(3,inum2) * (1. - rnum1)
          end if
        else
          do ii = 1, 24
            if (hrtwtr(ii) > 0. .and. hdepth(ii) > 0.) then
              hsedyld(ii) = hhvaroute(3,inum2,ii) * (1. - rnum1)
              sedrch = sedrch + hsedyld(ii)
            end if
          end do
        end if
      end if

!! perform in-stream nutrient calculations
      if (ievent < 3) then
        if (iwq == 2) call watqual2
        if (iwq == 1) call watqual
        if (iwq == 0) call noqual
      else
        if (iwq == 1) call hhwatqual
        if (iwq == 0) call hhnoqual
      end if

!! perform in-stream pesticide calculations
      if (ievent < 3) then
        call rtpest
      else
        call rthpest
      end if

!! perform in-stream bacteria calculations
      call rtbact

!! remove water from reach for irrigation
      call irr_rch

!! remove water from reach for consumptive water use
      call rchuse

!! summarize output/determine loadings to next routing unit
      call rtout

      return
      end
```

# APPENDIX $B_4$ : Subroutine daily water balance

```
subroutine watbal

!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine computes the daily water balance for each HRU
!!    changes in storage should equal water losses from the system
!!    write statements can be uncommented for model debugging

!!    this subroutine will give errors for HRUs receiving irrigation water
!!    from reaches or reservoirs

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    aird(:)     |mm H2O        |amount of water applied to HRU on current
!!                               |day
!!    bsprev      |mm H2O        |surface runoff lagged from prior day
!!    bss(1,:)    |mm H2O        |amount of lateral flow lagged
!!    bssprev     |mm H2O        |lateral flow lagged from prior day of
!!                               |simulation
!!    curyr       |none          |current year of simulation
!!    deepst(:)   |mm H2O        |depth of water in deep aquifer
!!    deepstp     |mm H2O        |depth of water in deep aquifer in HRU
!!    ep_day      |mm H2O        |actual amount of transpiration that occurs on
!!                               |day in HRU
!!    es_day      |mm H2O        |actual amount of evaporation (from soil) that
!!                               |occurs on day in HRU
!!    etday       |mm H2O        |actual amount of evapotranspiration that
!!                               |occurs on day in HRU
!!    gw_q(:)     |mm H2O        |groundwater contribution to streamflow from
!!                               |HRU on current day
!!    gwseep      |mm H2O        |amount of water recharging deep aquifer on
!!                               |current day
!!    iida        |julian date   |current day of simulation
!!    inflpcp     |mm H2O        |amount of precipitation that infiltrates into
!!                               |soil (enters soil)
!!    ihru        |none          |HRU number
!!    latq(:)     |mm H2O        |amount of water in lateral flow in HRU for the
!!                               |day
!!    precipday   |mm H2O        |precipitation for the day in HRU
!!    qday        |mm H2O        |surface runoff loading to main channel for
!!                               |day in HRU (includes effects of transmission
!!                               |losses)
!!    qtile       |mm H2O        |drainage tile flow for day in HRU
!!    rchrg(:)    |mm H2O        |amount of water recharging both aquifers on
!!                               |current day in HRU
!!    revapday    |mm H2O        |amount of water moving from the shallow
!!                               |aquifer into the soil profile or being taken
!!                               |up by plant roots in the shallow aquifer
!!    sepbtm(:)   |mm H2O        |seepage leaving the bottom of the soil profile
!!                               |on day in HRU
!!    shallst(:)  |mm H2O        |depth of water in shallow aquifer
!!    shallstp    |mm H2O        |depth of water in shallow aquifer in HRU on
!!                               |previous day
!!    sno_hru(:)  |mm H2O        |amount of water stored as snow
!!    snoev       |mm H2O        |amount of water in snow lost through
!!                               |sublimation on current day in HRU
!!    snofall     |mm H2O        |amount of precipitation falling as freezing
!!                               |rain/snow on day in HRU
!!    snomlt      |mm H2O        |amount of water in snow melt for the day in
!!                               |HRU
!!    snoprev     |mm H2O        |amount of water stored as snow on previous day
!!    sol_sw(:)   |mm H2O        |amount of water stored in soil profile on any
!!                               |given day
!!    subp(:)     |mm H2O        |precipitation for the day in HRU
!!    surf_bs(1,:)|mm H2O        |amount of surface runoff lagged over one
```

```
!!                              |day
!!    swprev      |mm H2O       |amount of water stored in soil profile in the
!!                              |HRU on the previous day
!!    tloss       |mm H2O       |amount of water removed from surface runoff
!!    twlpnd      |mm H2O       |water lost through seepage from ponds on day
!!                              |in HRU
!!    twlwet      |mm H2O       |water lost through seepage from wetlands on
!!                              |day in HRU
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units        |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    dstor       |mm H2O       |change in storage (snow, soil, shallow
!!                              |and deep aquifers)
!!    h2oloss     |mm H2O       |net movement of water out of system
!!    j           |none         |HRU number
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: Abs

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      integer :: j
      real :: dstor, h2oloss

      j = 0
      j = ihru

      dstor = 0.
      h2oloss = 0.

      dstor = sno_hru(j) - snoprev + sol_sw(j) - swprev +               &
     &        shallst(j) - shallstp + deepst(j) - deepstp +             &
     &        surf_bs(1,j) - bsprev + bss(1,j) - bssprev

!!   subtraction of snoev term in h2oloss variable removed
!!   this term is already included in the variable:
!!        etday = ep_day + es_day + canev
!!   es_day includes the value of the variable snoev (see etact.f routine)
      h2oloss = subp(j) - qday - latq(j) - etday - gw_q(j) -            &
     &          revapday + twlpnd + twlwet + aird(j) + rchrg(j) - qtile &
     &          - sepbtm(j)

!      write (17,100) iida, sno_hru(j), sol_sw(j), shallst(j), deepst(j),&
!     &                precipday, snofall, snomlt, snoev, inflpcp, qday, &
!     &                sepbtm(j), latq(j), es_day, ep_day, rchrg(j),     &
!     &                gw_q(j), revapday, gwseep, tloss

!      write (17,100) iida, dstor, h2oloss
!      if (Abs(dstor - h2oloss) > 0.001) then
!        write (17,101) j, iida, curyr, dstor - h2oloss
!      endif

 100  format (i4, 20f8.3)
 101  format (' Water Balance Problem - Subbassin', i6,' Day/Year',2i4,
     *  f10.5,' mm')
      return
      end
```

# APPENDIX C : MATLAB SCRIPTS

## Appendix $C_1$ : **Matlab Script Dischrge _MNX**

```
function [Q_2] = Discharge_MNX(Total_Area,HYDRAULIC_RADIUS_R)
%This fucntion calculates the disharge based on the intial discharge ,
%values and river profile calculatrd by function MNX
%   Detailed explanation goes here
% THIS PROGRAM WAS DEVELOPED BY MWIZA MUZUMARA AT DTU ON 9th March 2010
% MODIFIED ON-------------


load ENVK_43
load ENVK_43_WL
load ENVK_43_DATE


count=0;

ESA_DATA=ENVK_43_WL

for wl=ESA_DATA'
    count=count+1;
    [Total_Area,HYDRAULIC_RADIUS_R,A2_X_R2] = MNX(MatrixM,wl);
    TA(count)=A2_X_R2;
    HR(count)=HYDRAULIC_RADIUS_R;
    HL(count)=wl;


end
N=12;
n=[1:1:N];
A_1=294.9500;
R_1=2.5092;
Q_1=65.5;
TQAR1=Q_1/(A_1*R_1^(2/3));
TAR2=TA;
HL
Figure
Q_2=(TAR2*TQAR1)'
plot(Q_2,HL),ylabel('Stage(m)'),xlabel('Discharge (m^3/second)'),grid
title('Rating Curve')
Figure
plot(ENVK_43_DATE,Q_2),xlabel('time'),ylabel('flow (m^3/second)'),grid

end
```

MNX Function

```
function [TOTAL_SECTION_AREA,HYDRAULIC_RADIUS_R,A2_X_R2] = MNX(MatrixM,WL_INV)
MTXM=MatrixM;
MTXM_X=MTXM(:,1);
MTXM_Y=MTXM(:,2);
NC=max(MTXM_X);
XL_1=[0:0.5:NC]';
MTX1=interp1(MTXM_X,MTXM,XL_1);

MTX=MTX1;
MTC2=MTX(:,2)*-1;
MTC1=MTX(:,1);
```

```
THE_MAXIMUM_RIVER_DEPTH_IS=abs(max(MTX(:,2)));
%WL_INV=3;
WL=abs(max(MTX(:,2)))-WL_INV;
MTC2_SOT=MTC2(abs(MTC2)>=WL);
MTC1_SOT=MTC1(abs(MTC2)>=WL);
MTX_SOT=[MTC1_SOT,MTC2_SOT];
MTXC1_MIN=min(MTC1_SOT);
MTXC1_MAX=max(MTC1_SOT);
L_SECTION=0.1;


L=length(MTX_SOT(:,1));
XL = [MTXC1_MIN:L_SECTION:MTXC1_MAX];
T1=MTX_SOT(:,1);
MM=MTX_SOT(:,2)';
M2=interp1(T1,MM,XL);
Original_MatrixM=MatrixM;
MatrixM_INTERPOLATED_MTX=[XL;M2]';
t2=MatrixM_INTERPOLATED_MTX(:,1);
length(t2);
MT2=MatrixM_INTERPOLATED_MTX(:,2);
length(MT2);
%% area calculation
%%

MAXIMUM_RIVER_DEPTH=abs(max(MTC2));
N=length(MatrixM_INTERPOLATED_MTX(:,1));
River_width=max(MatrixM_INTERPOLATED_MTX(:,1));
SINGLE_SECTION_WIDTH=L_SECTION;
n=1;

    n=[0:1:N-2];

   Pn=sqrt((MatrixM_INTERPOLATED_MTX(n+1,1)-
MatrixM_INTERPOLATED_MTX(n+2,1)).^2+(MatrixM_INTERPOLATED_MTX(n+1,2)-
MatrixM_INTERPOLATED_MTX(n+2,2)).^2);
    %Pn2=sqrt((-MatrixM_interpolated(2,1)).^2+(-MatrixM_interpolated(2,2)).^2)

    PERIMETER_TEST_X_Y=[(MatrixM_INTERPOLATED_MTX(n+1,1)-
MatrixM_INTERPOLATED_MTX(n+2,1)).^2,(MatrixM_INTERPOLATED_MTX(n+1,2)-
MatrixM_INTERPOLATED_MTX(n+2,2)).^2];
    length(Pn);
       TOTAL_WETTED_PERIMETER=sum(Pn);

      MN=MatrixM_INTERPOLATED_MTX(n+1,2);
      MN_1=MatrixM_INTERPOLATED_MTX(n+2,2);
    U=(MN+MN_1);
    SINGLE_SECTION_AREA=0.5.*(2*(-WL)-U).*SINGLE_SECTION_WIDTH;


   TOTAL_SECTION_AREA=sum(SINGLE_SECTION_AREA);
   River_Profile=[t2,MT2];
   HYDRAULIC_RADIUS_R=(TOTAL_SECTION_AREA/TOTAL_WETTED_PERIMETER);

   A2_X_R2=TOTAL_SECTION_AREA*HYDRAULIC_RADIUS_R^(2/3);

   %Figure
% plot(t2,MT2),xlabel('section width(m)'),ylabel('Depth(m)')

%Figure
 %plot(MN,SINGLE_SECTION_AREA,'k.'),xlabel('section width(m)'),ylabel('Depth(m)')
```

```
%title('Length Vs Section Area')

End
```

# Appendix $C_2$: Swat Out read Script

SWAT OUT MATLAB SCRIPT DEVELOPED BY CHRITINE MILOZ AND MODIFED BY MWIZA MUZUMARA
CLEAR

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

NBReaches=177  % total number of reaches in model
Reach=167   % reach of which to plot simulated discharge
IPRINT=0  % 0:monthly, 1:daily, 2: annual   outputs
Startoutputdate=datenum(2000,01,01) % first day of output
Enddate=datenum(2004,12,31) % last day of output (required only for IPRINT=1)
timestep=365.25/12  % time in days between two outputs (required only for IPRINT=0, use 365.25/12 for one month)
RCHfile='C:\Users\Muzumara\Documents\Kabompo basin V-9\Scenarios\Default\TxtInOut\output.rch';

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%




% fromat of the output.rch file:
formatstr= '%s %u %u %u';
for i=1:43
   formatstr=[formatstr ' %n'];
end

% read the file:
fid=fopen(RCHfile,'r');
for i=1:9, fgetl(fid); end
clear a
a=textscan(fid,formatstr);  % much faster than textread!
fclose(fid);
FLOWin=a{6}(Reach:NBReaches:end);
FLOW=a{7}(Reach:NBReaches:end);
TLOSS=a{9}(Reach:NBReaches:end);
EVAP=a{8}(Reach:NBReaches:end);
MON=a{4}(Reach:NBReaches:end);


clear formatstr i
clear a


if IPRINT==0 % monthly output
   pos=[];
   cc=0;
   for i=1:length(MON)-1-1 % -1 to remove the overall sum at the end , -1 because of some empty line at the end!!!
      cc=cc+1;
      if MON(i)<13
```

```
            pos=[pos cc];
        end
    end
    Qsim=FLOW(pos);
    Qsimin=FLOWin(pos);
    TLOSS=TLOSS(pos);
    EVAP=EVAP(pos);
    TQsim=Startoutputdate+ ([1:1:length(Qsim)]-1)*timestep;
elseif IPRINT==1 % daily output
    Qsim=FLOW;
    Qsimin=FLOWin;
    %(TLOSS=TLOSS;)
    %(EVAP=EVAP;)
    TQsim=Startoutputdate:1:Enddate;
elseif IPRINT==2
    disp('Not implemented yet!')
end

load EN43_DATE
load EN43_FLOW

% PLOT
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Figure
%plot(TQsim,Qsim,'k.-','linewidth',3);


Z_DATE=TQsim'-693960.00;
Q_Flow=Qsim;


plot(Z_DATE,Q_Flow,EN43_DATE,EN43_FLOW,'k.-','linewidth',2);

legend('Q simulated','ESA Radar Alt')
datetick('x')
set(gca,'ButtonDownFcn','datetick(''x'',''keeplimits'')')
```

# **APPENDIX D:** REMOTE SENSED WEATHER DATA

## **Appendix $D_1$**: TRMM data for Station pcpKb01

**Latitude** -11.34

**Longitude** 24.15

| Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 1/1/2000 | 0 | 2/16/2000 | 0 | 4/2/2000 | 0 | | |
| 1/2/2000 | 0 | 2/17/2000 | 1.8212 | 4/3/2000 | 1.9417 | 18-May-2000 | 0 |
| 1/3/2000 | 13.762 | 2/18/2000 | 0 | 4/4/2000 | 3.645 | 19-May-2000 | 0 |
| 1/4/2000 | 1.9958 | 2/19/2000 | 0 | 4/5/2000 | 2.3675 | 20-May-2000 | 0 |
| 1/5/2000 | 13.345 | 2/20/2000 | 0.8314 | 4/6/2000 | 1.4137 | 21-May-2000 | 0 |
| 1/6/2000 | 10.009 | 2/21/2000 | 0.198 | 4/7/2000 | 1.1923 | 22-May-2000 | 0 |
| 1/7/2000 | 5.8086 | 2/22/2000 | 4.3551 | 4/8/2000 | 0.8346 | 23-May-2000 | 0 |
| 1/8/2000 | 5.3617 | 2/23/2000 | 6.0575 | 4/9/2000 | 1.8225 | 24-May-2000 | 0 |
| 1/9/2000 | 4.7362 | 2/24/2000 | 0.7126 | 4/10/2000 | 0 | 25-May-2000 | 0 |
| 1/10/2000 | 0 | 2/25/2000 | 0.6731 | 4/11/2000 | 0 | 26-May-2000 | 0 |
| 1/11/2000 | 0 | 2/26/2000 | 0.2375 | 4/12/2000 | 0 | 27-May-2000 | 0 |
| 1/12/2000 | 0 | 2/27/2000 | 1.5837 | 4/13/2000 | 0 | 28-May-2000 | 0 |
| 1/13/2000 | 1.4 | 2/28/2000 | 46.837 | 4/14/2000 | 0 | 29-May-2000 | 0 |
| 1/14/2000 | 7.7745 | 2/29/2000 | 4.6322 | 4/15/2000 | 7.1708 | 30-May-2000 | 0 |
| 1/15/2000 | 0.9234 | 3/1/2000 | 13.865 | 4/16/2000 | 2.5549 | 31-May-2000 | 0 |
| 1/16/2000 | 0 | 3/2/2000 | 8.3325 | 4/17/2000 | 0 | 6/1/2000 | 0 |
| 1/17/2000 | 3.3958 | 3/3/2000 | 1.0586 | 4/18/2000 | 0.2896 | 6/2/2000 | 0 |
| 1/18/2000 | 0.7447 | 3/4/2000 | 0.7854 | 4/19/2000 | 0 | 6/3/2000 | 0 |
| 1/19/2000 | 17.307 | 3/5/2000 | 1.6904 | 4/20/2000 | 0 | 6/4/2000 | 0 |
| 1/20/2000 | 0 | 3/6/2000 | 0.7684 | 4/21/2000 | 0 | 6/5/2000 | 0 |
| 1/21/2000 | 16.979 | 3/7/2000 | 0 | 4/22/2000 | 0 | 6/6/2000 | 0 |
| 1/22/2000 | 44.89 | 3/8/2000 | 4.1321 | 4/23/2000 | 0 | 6/7/2000 | 0.96 |
| 1/23/2000 | 12.183 | 3/9/2000 | 1.5367 | 4/24/2000 | 0 | 6/8/2000 | 0 |
| 1/24/2000 | 0.4468 | 3/10/2000 | 0.1537 | 4/25/2000 | 0 | 6/9/2000 | 0 |
| 1/25/2000 | 20.136 | 3/11/2000 | 3.2613 | 4/26/2000 | 0 | 6/10/2000 | 0 |
| 1/26/2000 | 0 | 3/12/2000 | 5.6688 | 4/27/2000 | 0 | 6/11/2000 | 0 |
| 1/27/2000 | 4.9149 | 3/13/2000 | 18.663 | 4/28/2000 | 0 | 6/12/2000 | 0 |
| 1/28/2000 | 0 | 3/14/2000 | 0.7001 | 4/29/2000 | 1.9588 | 6/13/2000 | 0 |
| 1/29/2000 | 2.5021 | 3/15/2000 | 0 | 4/30/2000 | 0 | 6/14/2000 | 0 |
| 1/30/2000 | 0 | 3/16/2000 | 0 | 01-May-2000 | 0 | 6/15/2000 | 0 |
| 1/31/2000 | 35.745 | 3/17/2000 | 17.672 | 02-May-2000 | 0 | 6/16/2000 | 0 |
| 2/1/2000 | 1.3857 | 3/18/2000 | 0 | 03-May-2000 | 0 | 6/17/2000 | 0 |
| 2/2/2000 | 0 | 3/19/2000 | 2.6466 | 04-May-2000 | 0 | 6/18/2000 | 0 |
| 2/3/2000 | 0 | 3/20/2000 | 0 | 05-May-2000 | 0 | 6/19/2000 | 0 |
| 2/4/2000 | 11.957 | 3/21/2000 | 41.919 | 06-May-2000 | 12.092 | 6/20/2000 | 0 |
| 2/5/2000 | 1.4253 | 3/22/2000 | 1.1269 | 07-May-2000 | 0 | 6/21/2000 | 0 |
| 2/6/2000 | 1.3065 | 3/23/2000 | 10.279 | 08-May-2000 | 0 | 6/22/2000 | 0 |
| 2/7/2000 | 0 | 3/24/2000 | 5.1566 | 09-May-2000 | 0 | 6/23/2000 | 0 |
| 2/8/2000 | 0 | 3/25/2000 | 12.089 | 10-May-2000 | 0 | 6/24/2000 | 0 |
| 2/9/2000 | 6.4534 | 3/26/2000 | 0.1195 | 11-May-2000 | 0 | 6/25/2000 | 0 |
| 2/10/2000 | 0 | 3/27/2000 | 4.7809 | 12-May-2000 | 0 | 6/26/2000 | 0 |

| Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 2/12/2000 | 1.0294 | 3/29/2000 | 0 | 14-May-2000 | 0 | 6/28/2000 | 0 |
| 2/13/2000 | 0 | 3/30/2000 | 3.2954 | 15-May-2000 | 2.8698 | 6/29/2000 | 0 |
| 2/14/2000 | 2.3359 | 3/31/2000 | 0 | 16-May-2000 | 6.1265 | 6/30/2000 | 0 |
| 2/15/2000 | 0.6731 | 4/1/2000 | 0 | 17-May-2000 | 0 | 7/1/2000 | 0 |
| 7/2/2000 | 0 | 8/19/2000 | 0.006 | 06-Oct-2000 | 0 | 11/23/2000 | 2.143512 |
| 7/3/2000 | 0 | 8/20/2000 | 0 | 07-Oct-2000 | 0 | 11/24/2000 | 0.96529 |
| 7/4/2000 | 0 | 8/21/2000 | 0 | 08-Oct-2000 | 0 | 11/25/2000 | 10.84532 |
| 7/5/2000 | 0 | 8/22/2000 | 0 | 09-Oct-2000 | 3.408 | 11/26/2000 | 4.216047 |
| 7/6/2000 | 0 | 8/23/2000 | 0.054 | 10-Oct-2000 | 0.18 | 11/27/2000 | 0 |
| 7/7/2000 | 0 | 8/24/2000 | 0 | 11-Oct-2000 | 0 | 11/28/2000 | 1.12144 |
| 7/8/2000 | 0 | 8/25/2000 | 0 | 12-Oct-2000 | 0 | 11/29/2000 | 1.334372 |
| 7/9/2000 | 0 | 8/26/2000 | 0 | 13-Oct-2000 | 0 | 11/30/2000 | 1.43374 |
| 7/10/2000 | 0 | 8/27/2000 | 0 | 14-Oct-2000 | 0.09 | 12/1/2000 | 14.21215 |
| 7/11/2000 | 0 | 8/28/2000 | 0 | 15-Oct-2000 | 0 | 12/2/2000 | 12.84275 |
| 7/12/2000 | 0 | 8/29/2000 | 0 | 16-Oct-2000 | 0 | 12/3/2000 | 22.46556 |
| 7/13/2000 | 0 | 8/30/2000 | 0 | 17-Oct-2000 | 0 | 12/4/2000 | 12.43563 |
| 7/14/2000 | 0 | 8/31/2000 | 0 | 18-Oct-2000 | 0 | 12/5/2000 | 4.663362 |
| 7/15/2000 | 0 | 9/1/2000 | 0 | 19-Oct-2000 | 0 | 12/6/2000 | 5.773685 |
| 7/16/2000 | 0 | 9/2/2000 | 0 | 20-Oct-2000 | 0 | 12/7/2000 | 37.04781 |
| 7/17/2000 | 0 | 9/3/2000 | 0.024 | 21-Oct-2000 | 0 | 12/8/2000 | 17.58013 |
| 7/18/2000 | 0 | 9/4/2000 | 0 | 22-Oct-2000 | 0.006 | 12/9/2000 | 2.997875 |
| 7/19/2000 | 0 | 9/5/2000 | 0.054 | 23-Oct-2000 | 0 | 12/10/2000 | 14.32318 |
| 7/20/2000 | 0 | 9/6/2000 | 0 | 24-Oct-2000 | 1.836 | 12/11/2000 | 52.77741 |
| 7/21/2000 | 0 | 9/7/2000 | 0 | 25-Oct-2000 | 5.856 | 12/12/2000 | 19.5417 |
| 7/22/2000 | 0 | 9/8/2000 | 0 | 26-Oct-2000 | 0.048 | 12/13/2000 | 27.90615 |
| 7/23/2000 | 0 | 9/9/2000 | 0.06 | 27-Oct-2000 | 0 | 12/14/2000 | 10.51107 |
| 7/24/2000 | 0 | 9/10/2000 | 0 | 28-Oct-2000 | 2.484 | 12/15/2000 | 3.071897 |
| 7/25/2000 | 0 | 9/11/2000 | 0 | 29-Oct-2000 | 0 | 12/16/2000 | 2.923853 |
| 7/26/2000 | 0 | 9/12/2000 | 0 | 30-Oct-2000 | 0.618 | 12/17/2000 | 17.06198 |
| 7/27/2000 | 0 | 9/13/2000 | 0 | 31-Oct-2000 | 0 | 12/18/2000 | 17.09899 |
| 7/28/2000 | 0 | 9/14/2000 | 0 | 11/1/2000 | 4.3012 | 12/19/2000 | 9.992917 |
| 7/29/2000 | 0 | 9/15/2000 | 3.018 | 11/2/2000 | 0.1703 | 12/20/2000 | 20.42996 |
| 7/30/2000 | 0 | 9/16/2000 | 0 | 11/3/2000 | 0 | 12/21/2000 | 15.98867 |
| 7/31/2000 | 0 | 9/17/2000 | 0.054 | 11/4/2000 | 9.9084 | 12/22/2000 | 9.141668 |
| 8/1/2000 | 0 | 9/18/2000 | 0.12 | 11/5/2000 | 3.6056 | 12/23/2000 | 0 |
| 8/2/2000 | 0 | 9/19/2000 | 0 | 11/6/2000 | 0.0568 | 12/24/2000 | 0 |
| 8/3/2000 | 0 | 9/20/2000 | 0 | 11/7/2000 | 0.3549 | 12/25/2000 | 0 |
| 8/4/2000 | 0 | 9/21/2000 | 0 | 11/8/2000 | 0.4684 | 12/26/2000 | 21.2442 |
| 8/5/2000 | 0 | 9/22/2000 | 0 | 11/9/2000 | 0.3407 | 12/27/2000 | 20.76306 |
| 8/6/2000 | 0 | 9/23/2000 | 0 | 11/10/2000 | 4.5851 | 12/28/2000 | 0.333097 |
| 8/7/2000 | 0 | 9/24/2000 | 0 | 11/11/2000 | 10.278 | 12/29/2000 | 5.144502 |
| 8/8/2000 | 0 | 9/25/2000 | 0 | 11/12/2000 | 0.4684 | 12/30/2000 | 2.220648 |
| 8/9/2000 | 0 | 9/26/2000 | 0 | 11/13/2000 | 2.6545 | 12/31/2000 | 49.22437 |
| 8/10/2000 | 0 | 9/27/2000 | 0 | 11/14/2000 | 0.4259 | 1/1/2001 | 0 |
| 8/11/2000 | 0 | 9/28/2000 | 0 | 11/15/2000 | 0.5252 | 1/2/2001 | 14.51323 |
| 8/12/2000 | 0 | 9/29/2000 | 0 | 11/16/2000 | 4.8123 | 1/3/2001 | 0.412849 |
| 8/13/2000 | 0 | 9/30/2000 | 0 | 11/17/2000 | 0.0284 | 1/4/2001 | 30.0427 |
| 8/14/2000 | 0 | 01-Oct-2000 | 0 | 11/18/2000 | 0 | 1/5/2001 | 0.349334 |
| 8/15/2000 | 0 | 02-/10/2000 | 0 | 11/19/2000 | 0 | 1/6/2001 | 8.479283 |

| Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day |
|---|---|---|---|---|---|---|---|
| 1/12/2001 | 9.2097 | 3/2/2001 | 6.72 | 4/20/2001 | 0 | 6/8/2001 | 0 |
| 1/13/2001 | 3.4298 | 3/3/2001 | 0 | 4/21/2001 | 0.6583 | 6/9/2001 | 0 |
| 1/14/2001 | 0.6669 | 3/4/2001 | 0 | 4/22/2001 | 0.1795 | 6/10/2001 | 0 |
| 1/15/2001 | 11.179 | 3/5/2001 | 0 | 4/23/2001 | 0 | 6/11/2001 | 0 |
| 1/16/2001 | 14.45 | 3/6/2001 | 6.0155 | 4/24/2001 | 2.5971 | 6/12/2001 | 0 |
| 1/17/2001 | 12.29 | 3/7/2001 | 2.8722 | 4/25/2001 | 1.125 | 6/13/2001 | 0 |
| 1/18/2001 | 0 | 3/8/2001 | 10.866 | 4/26/2001 | 0 | 6/14/2001 | 0 |
| 1/19/2001 | 0 | 3/9/2001 | 8.6167 | 4/27/2001 | 2.8604 | 6/15/2001 | 0 |
| 1/20/2001 | 4.1285 | 3/10/2001 | 0 | 4/28/2001 | 0 | 6/16/2001 | 0 |
| 1/21/2001 | 15.371 | 3/11/2001 | 2.818 | 4/29/2001 | 0 | 6/17/2001 | 0 |
| 1/22/2001 | 0 | 3/12/2001 | 1.1381 | 4/30/2001 | 0 | 6/18/2001 | 0 |
| 1/23/2001 | 0 | 3/13/2001 | 0 | 01-May-2001 | 0 | 6/19/2001 | 0 |
| 1/24/2001 | 16.355 | 3/14/2001 | 25.986 | 02-May-2001 | 0 | 6/20/2001 | 0 |
| 1/25/2001 | 6.6056 | 3/15/2001 | 9.2129 | 03-May-2001 | 0 | 6/21/2001 | 0 |
| 1/26/2001 | 14.323 | 3/16/2001 | 11.381 | 04-May-2001 | 0 | 6/22/2001 | 0 |
| 1/27/2001 | 5.6846 | 3/17/2001 | 4.769 | 05-May-2001 | 0 | 6/23/2001 | 0 |
| 1/28/2001 | 15.561 | 3/18/2001 | 0 | 06-May-2001 | 0 | 6/24/2001 | 0 |
| 1/29/2001 | 0 | 3/19/2001 | 23.791 | 07-May-2001 | 0 | 6/25/2001 | 0 |
| 1/30/2001 | 3.2075 | 3/20/2001 | 8.6167 | 08-May-2001 | 0 | 6/26/2001 | 0 |
| 1/31/2001 | 5.6211 | 3/21/2001 | 9.6464 | 09-May-2001 | 0 | 6/27/2001 | 0 |
| 2/1/2001 | 0 | 3/22/2001 | 4.1729 | 10-May-2001 | 0 | 6/28/2001 | 0 |
| 2/2/2001 | 4.9365 | 3/23/2001 | 32.868 | 11-May-2001 | 0 | 6/29/2001 | 0 |
| 2/3/2001 | 0 | 3/24/2001 | 1.7884 | 12-May-2001 | 0 | 6/30/2001 | 0 |
| 2/4/2001 | 16.575 | 3/25/2001 | 2.3574 | 13-May-2001 | 0 | 7/1/2001 | 0 |
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| 2/6/2001 | 0 | 3/27/2001 | 11.57 | 15-May-2001 | 0 | 7/3/2001 | 0 |
| 2/7/2001 | 6.2337 | 3/28/2001 | 6.0967 | 16-May-2001 | 0 | 7/4/2001 | 0 |
| 2/8/2001 | 0 | 3/29/2001 | 1.6529 | 17-May-2001 | 0 | 7/5/2001 | 0 |
| 2/9/2001 | 11.026 | 3/30/2001 | 27.205 | 18-May-2001 | 0 | 7/6/2001 | 0 |
| 2/10/2001 | 3.9276 | 3/31/2001 | 4.9858 | 19-May-2001 | 0 | 7/7/2001 | 0 |
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| 2/13/2001 | 1.045 | 4/3/2001 | 6.8937 | 22-May-2001 | 0 | 7/10/2001 | 0 |
| 2/14/2001 | 13.008 | 4/4/2001 | 0.5745 | 23-May-2001 | 0 | 7/11/2001 | 0 |
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| 2/18/2001 | 0 | 4/8/2001 | 2.8484 | 27-May-2001 | 0 | 7/15/2001 | 0 |
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| 2/25/2002 | 10.095 | 4/15/2002 | 0 | 6/3/2002 | 0 | 7/22/2002 | 0 |
| 2/26/2002 | 3.8291 | 4/16/2002 | 14.61 | 6/4/2002 | 0 | 7/23/2002 | 0 |
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| 9/5/2002 | 0 | 24-Oct-2002 | 3.4745 | 12/12/2002 | 41.83 | 1/30/2003 | 10.3468 |
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| 9/22/2002 | 0.162 | 11/10/2002 | 9.3085 | 12/29/2002 | 0.596 | 2/16/2003 | 0 |
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| 08-Oct-2002 | 0.6273 | 11/26/2002 | 0.4433 | 1/14/2003 | 13.202 | 3/4/2003 | 2.862274 |
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| 3/17/2003 | 0 | 05-May-2003 | 0 | 6/23/2003 | 0 | 8/11/2003 | 0 |
| 3/18/2003 | 5.193 | 06-May-2003 | 0 | 6/24/2003 | 0 | 8/12/2003 | 0 |
| 3/19/2003 | 11.183 | 07-May-2003 | 0 | 6/25/2003 | 0 | 8/13/2003 | 0 |
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| 4/3/2003 | 3.9419 | 22-May-2003 | 0 | 7/10/2003 | 0 | 8/28/2003 | 0 |
| 4/4/2003 | 32.387 | 23-May-2003 | 0 | 7/11/2003 | 0 | 8/29/2003 | 0 |
| 4/5/2003 | 0 | 24-May-2003 | 0 | 7/12/2003 | 0 | 8/30/2003 | 0 |
| 4/6/2003 | 0 | 25-May-2003 | 0 | 7/13/2003 | 0 | 8/31/2003 | 0 |
| 4/7/2003 | 3.6012 | 26-May-2003 | 0 | 7/14/2003 | 0 | 9/1/2003 | 0 |
| 4/8/2003 | 19.028 | 27-May-2003 | 0 | 7/15/2003 | 0 | 9/2/2003 | 0 |
| 4/9/2003 | 23.286 | 28-May-2003 | 1.32 | 7/16/2003 | 0 | 9/3/2003 | 0 |
| 4/10/2003 | 14.356 | 29-May-2003 | 0 | 7/17/2003 | 0 | 9/4/2003 | 0 |
| 4/11/2003 | 1.0706 | 30-May-2003 | 0 | 7/18/2003 | 0 | 9/5/2003 | 2.059773 |
| 4/12/2003 | 0 | 31-May-2003 | 0 | 7/19/2003 | 0 | 9/6/2003 | 0 |
| 4/13/2003 | 1.8249 | 6/1/2003 | 0 | 7/20/2003 | 0 | 9/7/2003 | 0 |
| 4/14/2003 | 0.4623 | 6/2/2003 | 0 | 7/21/2003 | 0 | 9/8/2003 | 0 |
| 4/15/2003 | 0 | 6/3/2003 | 0 | 7/22/2003 | 0 | 9/9/2003 | 0 |
| 4/16/2003 | 0 | 6/4/2003 | 0 | 7/23/2003 | 0 | 9/10/2003 | 3.365971 |
| 4/17/2003 | 0 | 6/5/2003 | 0 | 7/24/2003 | 0 | 9/11/2003 | 7.284564 |
| 4/18/2003 | 0 | 6/6/2003 | 0 | 7/25/2003 | 0 | 9/12/2003 | 0 |
| 4/19/2003 | 0 | 6/7/2003 | 0 | 7/26/2003 | 0 | 9/13/2003 | 0 |
| 4/20/2003 | 0 | 6/8/2003 | 0 | 7/27/2003 | 0 | 9/14/2003 | 0 |
| 4/21/2003 | 0 | 6/9/2003 | 0 | 7/28/2003 | 0.036 | 9/15/2003 | 0 |
| 4/22/2003 | 0 | 6/10/2003 | 0 | 7/29/2003 | 0 | 9/16/2003 | 0 |
| 9/17/2003 | 0 | 11/4/2003 | 4.3285 | 12/22/2003 | 2.1749 | 2/8/2004 | 4.265277 |
| 9/18/2003 | 0 | 11/5/2003 | 1.7043 | 12/23/2003 | 2.5768 | 2/9/2004 | 2.655344 |
| 9/19/2003 | 0.3265 | 11/6/2003 | 4.2908 | 12/24/2003 | 7.9906 | 2/10/2004 | 9.115985 |

| Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day |
|---|---|---|---|---|---|---|---|
| 9/21/2003 | 0 | 11/8/2003 | 2.9033 | 12/26/2003 | 1.253 | 2/12/2004 | 2.049006 |
| 9/22/2003 | 0 | 11/9/2003 | 1.6666 | 12/27/2003 | 0 | 2/13/2004 | 2.404446 |
| 9/23/2003 | 0 | 11/10/2003 | 4.0344 | 12/28/2003 | 1.844 | 2/14/2004 | 1.191769 |
| 9/24/2003 | 0 | 11/11/2003 | 0 | 12/29/2003 | 1.5839 | 2/15/2004 | 2.049006 |
| 9/25/2003 | 0 | 11/12/2003 | 3.5065 | 12/30/2003 | 4.7991 | 2/16/2004 | 0.125449 |
| 9/26/2003 | 0 | 11/13/2003 | 0.6334 | 12/31/2003 | 13.83 | 2/17/2004 | 10.78864 |
| 9/27/2003 | 0 | 11/14/2003 | 2.7298 | 1/1/2004 | 0 | 2/18/2004 | 0.627247 |
| 9/28/2003 | 0 | 11/15/2003 | 0.362 | 1/2/2004 | 4.3413 | 2/19/2004 | 0 |
| 9/29/2003 | 0 | 11/16/2003 | 0.558 | 1/3/2004 | 0 | 2/20/2004 | 2.738977 |
| 9/30/2003 | 0 | 11/17/2003 | 0.098 | 1/4/2004 | 2.9704 | 2/21/2004 | 1.986281 |
| 01-Oct-2003 | 0 | 11/18/2003 | 0 | 1/5/2004 | 3.9986 | 2/22/2004 | 3.303499 |
| 02-Oct-2003 | 0 | 11/19/2003 | 0.6259 | 1/6/2004 | 1.1996 | 2/23/2004 | 12.23131 |
| 03-Oct-2003 | 0 | 11/20/2003 | 1.4026 | 1/7/2004 | 14.623 | 2/24/2004 | 11.52043 |
| 04-Oct-2003 | 0 | 11/21/2003 | 2.3377 | 1/8/2004 | 0.5712 | 2/25/2004 | 7.464236 |
| 05-Oct-2003 | 0 | 11/22/2003 | 13.664 | 1/9/2004 | 0 | 2/26/2004 | 4.11892 |
| 06-Oct-2003 | 0 | 11/23/2003 | 2.5111 | 1/10/2004 | 1.5137 | 2/27/2004 | 0.564522 |
| 07-Oct-2003 | 0 | 11/24/2003 | 0.1433 | 1/11/2004 | 30.846 | 2/28/2004 | 0.167266 |
| 08-Oct-2003 | 0.3902 | 11/25/2003 | 0.4977 | 1/12/2004 | 26.276 | 2/29/2004 | 0 |
| 09-Oct-2003 | 0 | 11/26/2003 | 4.0495 | 1/13/2004 | 5.0268 | 3/1/2004 | 0 |
| 10-Oct-2003 | 0 | 11/27/2003 | 2.4508 | 1/14/2004 | 11.853 | 3/2/2004 | 0 |
| 11-Oct-2003 | 0 | 11/28/2003 | 0.739 | 1/15/2004 | 5.4266 | 3/3/2004 | 0 |
| 12-Oct-2003 | 0 | 11/29/2003 | 2.1039 | 1/16/2004 | 3.9986 | 3/4/2004 | 3.87039 |
| 13-Oct-2003 | 0 | 11/30/2003 | 0.8823 | 1/17/2004 | 8.7112 | 3/5/2004 | 0 |
| 14-Oct-2003 | 0 | 12/1/2003 | 7.4941 | 1/18/2004 | 5.3695 | 3/6/2004 | 10.88547 |
| 15-Oct-2003 | 0 | 12/2/2003 | 17.092 | 1/19/2004 | 5.1981 | 3/7/2004 | 16.25564 |
| 16-Oct-2003 | 4.0235 | 12/3/2003 | 26.028 | 1/20/2004 | 0.3142 | 3/8/2004 | 1.499776 |
| 17-Oct-2003 | 1.0092 | 12/4/2003 | 41.111 | 1/21/2004 | 0.5141 | 3/9/2004 | 1.306257 |
| 18-Oct-2003 | 4.4541 | 12/5/2003 | 1.9385 | 1/22/2004 | 5.2553 | 3/10/2004 | 5.515306 |
| 19-Oct-2003 | 0.8612 | 12/6/2003 | 6.5721 | 1/23/2004 | 0 | 3/11/2004 | 9.434076 |
| 20-Oct-2003 | 1.8166 | 12/7/2003 | 42.506 | 1/24/2004 | 0 | 3/12/2004 | 3.580111 |
| 21-Oct-2003 | 3.1488 | 12/8/2003 | 19.74 | 1/25/2004 | 54.009 | 3/13/2004 | 0 |
| 22-Oct-2003 | 0 | 12/9/2003 | 0.1655 | 1/26/2004 | 8.5683 | 3/14/2004 | 10.69195 |
| 23-Oct-2003 | 1.4802 | 12/10/2003 | 4.1608 | 1/27/2004 | 2.2278 | 3/15/2004 | 1.596536 |
| 24-Oct-2003 | 10.213 | 12/11/2003 | 6.3357 | 1/28/2004 | 2.1992 | 3/16/2004 | 1.886815 |
| 25-Oct-2003 | 1.0092 | 12/12/2003 | 2.0804 | 1/29/2004 | 0.5141 | 3/17/2004 | 2.128715 |
| 26-Oct-2003 | 1.7897 | 12/13/2003 | 6.1702 | 1/30/2004 | 0.714 | 3/18/2004 | 18.72301 |
| 27-Oct-2003 | 0 | 12/14/2003 | 1.844 | 1/31/2004 | 0 | 3/19/2004 | 1.306257 |
| 28-Oct-2003 | 0 | 12/15/2003 | 5.6028 | 2/1/2004 | 1.1709 | 3/20/2004 | 6.192625 |
| 29-Oct-2003 | 0.7266 | 12/16/2003 | 0.331 | 2/2/2004 | 1.6517 | 3/21/2004 | 0.628938 |
| 30-Oct-2003 | 2.5298 | 12/17/2003 | 4.7281 | 2/3/2004 | 0 | 3/22/2004 | 16.73944 |
| 31-Oct-2003 | 2.947 | 12/18/2003 | 18.747 | 2/4/2004 | 0.8363 | 3/23/2004 | 5.757205 |
| 11/1/2003 | 0 | 12/19/2003 | 7.6359 | 2/5/2004 | 0.4809 | 3/24/2004 | 4.06391 |
| 11/2/2003 | 0.558 | 12/20/2003 | 10.449 | 2/6/2004 | 0.3136 | 3/25/2004 | 8.805137 |
| 11/3/2003 | 0.181 | 12/21/2003 | 0.4492 | 2/7/2004 | 1.6936 | 3/26/2004 | 8.611618 |

# Appendix $D_2$: TRMM data for Station pcpKb04

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **itude** | | | | | | | -13.82 |
| **ngitude** | | | | | | | 25.85 |
| **Date** | **pcp(mm/day)** | **Date** | **pcp(mm/day)** | **Date** | **pcp(mm/day)** | **Date** | **pcp(mm/day)** |
| 1/1/1998 | 3.3283 | 2/21/1998 | 0 | 4/13/1998 | 0 | 6/3/1998 | 0 |
| 1/2/1998 | 2.4038 | 2/22/1998 | 3.2778 | 4/14/1998 | 0 | 6/4/1998 | 0 |
| 1/3/1998 | 16.919 | 2/23/1998 | 12.621 | 4/15/1998 | 0 | 6/5/1998 | 0 |
| 1/4/1998 | 5.6396 | 2/24/1998 | 0 | 4/16/1998 | 4.9844 | 6/6/1998 | 0 |
| 1/5/1998 | 2.5147 | 2/25/1998 | 0.3484 | 4/17/1998 | 0 | 6/7/1998 | 0 |
| 1/6/1998 | 0 | 2/26/1998 | 0.1807 | 4/18/1998 | 0 | 6/8/1998 | 0 |
| 1/7/1998 | 0 | 2/27/1998 | 1.484 | 4/19/1998 | 0 | 6/9/1998 | 0 |
| 1/8/1998 | 10.207 | 2/28/1998 | 2.6713 | 4/20/1998 | 0 | 6/10/1998 | 0 |
| 1/9/1998 | 3.6057 | 3/1/1998 | 4.3876 | 4/21/1998 | 0 | 6/11/1998 | 0 |
| 1/10/1998 | 0.0925 | 3/2/1998 | 12.719 | 4/22/1998 | 0 | 6/12/1998 | 0 |
| 1/11/1998 | 0.2034 | 3/3/1998 | 12.978 | 4/23/1998 | 0 | 6/13/1998 | 0 |
| 1/12/1998 | 2.5147 | 3/4/1998 | 0 | 4/24/1998 | 0 | 6/14/1998 | 0 |
| 1/13/1998 | 0 | 3/5/1998 | 0 | 4/25/1998 | 0 | 6/15/1998 | 0 |
| 1/14/1998 | 2.866 | 3/6/1998 | 0 | 4/26/1998 | 0 | 6/16/1998 | 0 |
| 1/15/1998 | 2.2374 | 3/7/1998 | 0 | 4/27/1998 | 0 | 6/17/1998 | 0 |
| 1/16/1998 | 0.2219 | 3/8/1998 | 0 | 4/28/1998 | 0 | 6/18/1998 | 0 |
| 1/17/1998 | 9.2453 | 3/9/1998 | 0 | 4/29/1998 | 0 | 6/19/1998 | 0.174 |
| 1/18/1998 | 0 | 3/10/1998 | 0 | 4/30/1998 | 0 | 6/20/1998 | 0 |
| 1/19/1998 | 0 | 3/11/1998 | 13.385 | 01-May-1998 | 0 | 6/21/1998 | 0 |
| 1/20/1998 | 15.051 | 3/12/1998 | 0 | 02-May-1998 | 0 | 6/22/1998 | 0 |
| 1/21/1998 | 6.1019 | 3/13/1998 | 36.767 | 03-May-1998 | 0 | 6/23/1998 | 0 |
| 1/22/1998 | 6.0094 | 3/14/1998 | 0 | 04-May-1998 | 0 | 6/24/1998 | 0 |
| 1/23/1998 | 0 | 3/15/1998 | 1.0923 | 05-May-1998 | 0 | 6/25/1998 | 0 |
| 1/24/1998 | 14.478 | 3/16/1998 | 4.4432 | 06-May-1998 | 0 | 6/26/1998 | 0 |
| 1/25/1998 | 7.1558 | 3/17/1998 | 7.2202 | 07-May-1998 | 0 | 6/27/1998 | 0 |
| 1/26/1998 | 3.4023 | 3/18/1998 | 13.144 | 08-May-1998 | 0 | 6/28/1998 | 0 |
| 1/27/1998 | 15.477 | 3/19/1998 | 17.18 | 09-May-1998 | 0 | 6/29/1998 | 0 |
| 1/28/1998 | 3.6796 | 3/20/1998 | 0 | 10-May-1998 | 0 | 6/30/1998 | 0 |
| 1/29/1998 | 0.8506 | 3/21/1998 | 0.4073 | 11-May-1998 | 0 | 7/1/1998 | 0 |
| 1/30/1998 | 17.141 | 3/22/1998 | 0 | 12-May-1998 | 0 | 7/2/1998 | 0 |
| 1/31/1998 | 4.5487 | 3/23/1998 | 0 | 13-May-1998 | 0 | 7/3/1998 | 0 |
| 2/1/1998 | 0 | 3/24/1998 | 0 | 14-May-1998 | 0 | 7/4/1998 | 0 |
| 2/2/1998 | 15.55 | 3/25/1998 | 0 | 15-May-1998 | 0 | 7/5/1998 | 0 |
| 2/3/1998 | 0 | 3/26/1998 | 0 | 16-May-1998 | 0 | 7/6/1998 | 0 |
| 2/4/1998 | 0 | 3/27/1998 | 0 | 17-May-1998 | 0 | 7/7/1998 | 0 |
| 2/5/1998 | 0 | 3/28/1998 | 0.1481 | 18-May-1998 | 0 | 7/8/1998 | 0 |
| 2/6/1998 | 0 | 3/29/1998 | 0 | 19-May-1998 | 0 | 7/9/1998 | 0 |
| 2/7/1998 | 0 | 3/30/1998 | 0 | 20-May-1998 | 0 | 7/10/1998 | 0 |
| 2/8/1998 | 0 | 3/31/1998 | 0 | 21-May-1998 | 0 | 7/11/1998 | 0 |
| 2/9/1998 | 0 | 4/1/1998 | 0 | 22-May-1998 | 0 | 7/12/1998 | 0 |
| 2/10/1998 | 0 | 4/2/1998 | 0 | 23-May-1998 | 0 | 7/13/1998 | 0 |
| 2/11/1998 | 0 | 4/3/1998 | 0 | 24-May-1998 | 0 | 7/14/1998 | 0 |
| 2/12/1998 | 0 | 4/4/1998 | 0 | 25-May-1998 | 0 | 7/15/1998 | 0 |
| 2/13/1998 | 0 | 4/5/1998 | 0 | 26-May-1998 | 0 | 7/16/1998 | 0 |
| 2/14/1998 | 0 | 4/6/1998 | 0 | 27-May-1998 | 0 | 7/17/1998 | 0 |
| 2/15/1998 | 0 | 4/7/1998 | 0 | 28-May-1998 | 0 | 7/18/1998 | 0 |
| 2/16/1998 | 0 | 4/8/1998 | 0 | 29-May-1998 | 0 | 7/19/1998 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 2/18/1998 | 4.8005 | 4/10/1998 | 0 | 31-May-1998 | 0 | 7/21/1998 | 0 |
| 2/19/1998 | 1.355 | 4/11/1998 | 0 | 6/1/1998 | 0 | 7/22/1998 | 0 |
| 2/20/1998 | 0.8775 | 4/12/1998 | 0 | 6/2/1998 | 0 | 7/23/1998 | 0 |
| 7/24/1998 | 0 | 9/13/1998 | 0.324 | 11/3/1998 | 0 | 12/24/1998 | 5.228 |
| 7/25/1998 | 0 | 9/14/1998 | 0 | 11/4/1998 | 0 | 12/25/1998 | 3.674 |
| 7/26/1998 | 0 | 9/15/1998 | 0 | 11/5/1998 | 0 | 12/26/1998 | 4.041 |
| 7/27/1998 | 0 | 9/16/1998 | 0 | 11/6/1998 | 1.0115 | 12/27/1998 | 1.978 |
| 7/28/1998 | 0 | 9/17/1998 | 0 | 11/7/1998 | 1.3603 | 12/28/1998 | 4.268 |
| 7/29/1998 | 0 | 9/18/1998 | 0 | 11/8/1998 | 8.3012 | 12/29/1998 | 0 |
| 7/30/1998 | 0 | 9/19/1998 | 0 | 11/9/1998 | 0.4883 | 12/30/1998 | 2.657 |
| 7/31/1998 | 0 | 9/20/1998 | 0 | 11/10/1998 | 0 | 12/31/1998 | 0 |
| 8/1/1998 | 0 | 9/21/1998 | 0 | 11/11/1998 | 0 | 1/1/1999 | 8.455 |
| 8/2/1998 | 0 | 9/22/1998 | 0 | 11/12/1998 | 15.033 | 1/2/1999 | 6.021 |
| 8/3/1998 | 0 | 9/23/1998 | 0.03 | 11/13/1998 | 1.8137 | 1/3/1999 | 16.69 |
| 8/4/1998 | 0 | 9/24/1998 | 0 | 11/14/1998 | 5.4411 | 1/4/1999 | 17.29 |
| 8/5/1998 | 0 | 9/25/1998 | 0 | 11/15/1998 | 6.4177 | 1/5/1999 | 10.47 |
| 8/6/1998 | 0 | 9/26/1998 | 0.54 | 11/16/1998 | 0 | 1/6/1999 | 1.409 |
| 8/7/1998 | 0 | 9/27/1998 | 0.252 | 11/17/1998 | 0.4883 | 1/7/1999 | 1.313 |
| 8/8/1998 | 0 | 9/28/1998 | 0 | 11/18/1998 | 2.7903 | 1/8/1999 | 5.444 |
| 8/9/1998 | 0 | 9/29/1998 | 0.204 | 11/19/1998 | 5.9643 | 1/9/1999 | 0.929 |
| 8/10/1998 | 0 | 9/30/1998 | 0 | 11/20/1998 | 0 | 1/10/1999 | 2.53 |
| 8/11/1998 | 0 | 01-Oct-1998 | 0 | 11/21/1998 | 1.3254 | 1/11/1999 | 10.44 |
| 8/12/1998 | 0 | 02-Oct-1998 | 0 | 11/22/1998 | 1.6742 | 1/12/1999 | 14.8 |
| 8/13/1998 | 0 | 03-Oct-1998 | 1.2311 | 11/23/1998 | 0.9069 | 1/13/1999 | 13.03 |
| 8/14/1998 | 0 | 04-Oct-1998 | 0 | 11/24/1998 | 0 | 1/14/1999 | 11.5 |
| 8/15/1998 | 0 | 05-Oct-1998 | 0 | 11/25/1998 | 0 | 1/15/1999 | 2.082 |
| 8/16/1998 | 0 | 06-Oct-1998 | 0 | 11/26/1998 | 11.371 | 1/16/1999 | 5.348 |
| 8/17/1998 | 0 | 07-Oct-1998 | 0 | 11/27/1998 | 0 | 1/17/1999 | 0.128 |
| 8/18/1998 | 0 | 08-Oct-1998 | 0 | 11/28/1998 | 21.904 | 1/18/1999 | 0 |
| 8/19/1998 | 0 | 09-Oct-1998 | 0 | 11/29/1998 | 0 | 1/19/1999 | 20.88 |
| 8/20/1998 | 0 | 10-Oct-1998 | 0 | 11/30/1998 | 7.9524 | 1/20/1999 | 1.793 |
| 8/21/1998 | 0 | 11-Oct-1998 | 0 | 12/1/1998 | 29.901 | 1/21/1999 | 0.929 |
| 8/22/1998 | 0 | 12-Oct-1998 | 0 | 12/2/1998 | 0 | 1/22/1999 | 14.09 |
| 8/23/1998 | 0 | 13-Oct-1998 | 0.8898 | 12/3/1998 | 6.359 | 1/23/1999 | 6.725 |
| 8/24/1998 | 0 | 14-Oct-1998 | 0 | 12/4/1998 | 9.383 | 1/24/1999 | 6.853 |
| 8/25/1998 | 0 | 15-Oct-1998 | 0 | 12/5/1998 | 3.7023 | 1/25/1999 | 12.75 |
| 8/26/1998 | 0 | 16-Oct-1998 | 0.0975 | 12/6/1998 | 0 | 1/26/1999 | 0 |
| 8/27/1998 | 0 | 17-Oct-1998 | 0 | 12/7/1998 | 2.1197 | 1/27/1999 | 0 |
| 8/28/1998 | 0 | 18-Oct-1998 | 0 | 12/8/1998 | 12.577 | 1/28/1999 | 0 |
| 8/29/1998 | 0 | 19-Oct-1998 | 0 | 12/9/1998 | 0 | 1/29/1999 | 0.512 |
| 8/30/1998 | 0 | 20-Oct-1998 | 0 | 12/10/1998 | 12.011 | 1/30/1999 | 7.462 |
| 8/31/1998 | 0 | 21-Oct-1998 | 1.2311 | 12/11/1998 | 11.87 | 1/31/1999 | 19.92 |
| 9/1/1998 | 0 | 22-Oct-1998 | 0 | 12/12/1998 | 11.559 | 2/1/1999 | 8.369 |
| 9/2/1998 | 0.054 | 23-Oct-1998 | 0 | 12/13/1998 | 9.7504 | 2/2/1999 | 0 |
| 9/3/1998 | 0 | 24-Oct-1998 | 0 | 12/14/1998 | 13.707 | 2/3/1999 | 0 |
| 9/4/1998 | 0 | 25-Oct-1998 | 0.0853 | 12/15/1998 | 2.7132 | 2/4/1999 | 0 |
| 9/5/1998 | 0 | 26-Oct-1998 | 0 | 12/16/1998 | 0.5652 | 2/5/1999 | 3.242 |
| 9/6/1998 | 0 | 27-Oct-1998 | 0 | 12/17/1998 | 0 | 2/6/1999 | 23.73 |
| 9/7/1998 | 0 | 28-Oct-1998 | 8.4838 | 12/18/1998 | 0 | 2/7/1999 | 41.09 |
| 9/8/1998 | 0 | 29-Oct-1998 | 1.0605 | 12/19/1998 | 21.79 | 2/8/1999 | 14.4 |
| 9/9/1998 | 0 | 30-Oct-1998 | 0 | 12/20/1998 | 2.6849 | 2/9/1999 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 9/11/1998 | 0 | 11/1/1998 | 0 | 12/22/1998 | 19.105 | 2/11/1999 | 0 |
| 9/12/1998 | 0 | 11/2/1998 | 0 | 12/23/1998 | 0 | 2/12/1999 | 0 |
| 2/13/1999 | 0.9299 | 4/5/1999 | 0 | 26-May-1999 | 0 | 7/16/1999 | 0 |
| 2/14/1999 | 0 | 4/6/1999 | 0 | 27-May-1999 | 0 | 7/17/1999 | 0 |
| 2/15/1999 | 3.5688 | 4/7/1999 | 0 | 28-May-1999 | 0 | 7/18/1999 | 0 |
| 2/16/1999 | 0 | 4/8/1999 | 0 | 29-May-1999 | 0 | 7/19/1999 | 0 |
| 2/17/1999 | 0 | 4/9/1999 | 0 | 30-May-1999 | 0 | 7/20/1999 | 0 |
| 2/18/1999 | 0 | 4/10/1999 | 0 | 31-May-1999 | 0 | 7/21/1999 | 0 |
| 2/19/1999 | 0 | 4/11/1999 | 0 | 6/1/1999 | 0 | 7/22/1999 | 0 |
| 2/20/1999 | 0.6786 | 4/12/1999 | 0.9 | 6/2/1999 | 0 | 7/23/1999 | 0 |
| 2/21/1999 | 5.881 | 4/13/1999 | 0 | 6/3/1999 | 0 | 7/24/1999 | 0 |
| 2/22/1999 | 9.5252 | 4/14/1999 | 0 | 6/4/1999 | 0 | 7/25/1999 | 0 |
| 2/23/1999 | 13.999 | 4/15/1999 | 0 | 6/5/1999 | 0 | 7/26/1999 | 0 |
| 2/24/1999 | 8.0424 | 4/16/1999 | 0 | 6/6/1999 | 0 | 7/27/1999 | 0 |
| 2/25/1999 | 4.3479 | 4/17/1999 | 0 | 6/7/1999 | 0 | 7/28/1999 | 0 |
| 2/26/1999 | 0 | 4/18/1999 | 0 | 6/8/1999 | 0 | 7/29/1999 | 0 |
| 2/27/1999 | 0 | 4/19/1999 | 0 | 6/9/1999 | 0 | 7/30/1999 | 0 |
| 2/28/1999 | 1.4074 | 4/20/1999 | 0 | 6/10/1999 | 0 | 7/31/1999 | 0 |
| 3/1/1999 | 0 | 4/21/1999 | 0 | 6/11/1999 | 0 | 8/1/1999 | 0 |
| 3/2/1999 | 2.3125 | 4/22/1999 | 0 | 6/12/1999 | 0 | 8/2/1999 | 0 |
| 3/3/1999 | 3.9108 | 4/23/1999 | 0 | 6/13/1999 | 0 | 8/3/1999 | 0 |
| 3/4/1999 | 2.3295 | 4/24/1999 | 0 | 6/14/1999 | 0 | 8/4/1999 | 0 |
| 3/5/1999 | 0 | 4/25/1999 | 0 | 6/15/1999 | 0 | 8/5/1999 | 0 |
| 3/6/1999 | 0 | 4/26/1999 | 0 | 6/16/1999 | 0 | 8/6/1999 | 0 |
| 3/7/1999 | 3.5877 | 4/27/1999 | 0 | 6/17/1999 | 0 | 8/7/1999 | 0 |
| 3/8/1999 | 2.4315 | 4/28/1999 | 0 | 6/18/1999 | 0 | 8/8/1999 | 0 |
| 3/9/1999 | 1.3263 | 4/29/1999 | 0 | 6/19/1999 | 0 | 8/9/1999 | 0 |
| 3/10/1999 | 0 | 4/30/1999 | 0 | 6/20/1999 | 0 | 8/10/1999 | 0 |
| 3/11/1999 | 0 | 01-May-1999 | 0 | 6/21/1999 | 0 | 8/11/1999 | 0 |
| 3/12/1999 | 0 | 02-May-1999 | 0 | 6/22/1999 | 0 | 8/12/1999 | 0 |
| 3/13/1999 | 0 | 03-May-1999 | 0 | 6/23/1999 | 0 | 8/13/1999 | 0 |
| 3/14/1999 | 5.3391 | 04-May-1999 | 0 | 6/24/1999 | 0 | 8/14/1999 | 0 |
| 3/15/1999 | 6.0532 | 05-May-1999 | 0 | 6/25/1999 | 0 | 8/15/1999 | 0 |
| 3/16/1999 | 9.0458 | 06-May-1999 | 0 | 6/26/1999 | 0 | 8/16/1999 | 0 |
| 3/17/1999 | 0 | 07-May-1999 | 0 | 6/27/1999 | 0 | 8/17/1999 | 0 |
| 3/18/1999 | 4.2338 | 08-May-1999 | 0 | 6/28/1999 | 0 | 8/18/1999 | 0 |
| 3/19/1999 | 7.0054 | 09-May-1999 | 0 | 6/29/1999 | 0 | 8/19/1999 | 0 |
| 3/20/1999 | 21.254 | 10-May-1999 | 0 | 6/30/1999 | 0 | 8/20/1999 | 0 |
| 3/21/1999 | 1.7854 | 11-May-1999 | 0 | 7/1/1999 | 0 | 8/21/1999 | 0 |
| 3/22/1999 | 1.9044 | 12-May-1999 | 0 | 7/2/1999 | 0 | 8/22/1999 | 0 |
| 3/23/1999 | 0 | 13-May-1999 | 0 | 7/3/1999 | 0 | 8/23/1999 | 0 |
| 3/24/1999 | 0 | 14-May-1999 | 0 | 7/4/1999 | 0 | 8/24/1999 | 0 |
| 3/25/1999 | 2.5675 | 15-May-1999 | 0 | 7/5/1999 | 0 | 8/25/1999 | 0 |
| 3/26/1999 | 0 | 16-May-1999 | 0 | 7/6/1999 | 0 | 8/26/1999 | 0 |
| 3/27/1999 | 0 | 17-May-1999 | 0 | 7/7/1999 | 0 | 8/27/1999 | 0 |
| 3/28/1999 | 0 | 18-May-1999 | 0 | 7/8/1999 | 0 | 8/28/1999 | 0 |
| 3/29/1999 | 0 | 19-May-1999 | 0 | 7/9/1999 | 0 | 8/29/1999 | 0 |
| 3/30/1999 | 0 | 20-May-1999 | 0 | 7/10/1999 | 0 | 8/30/1999 | 0.327 |
| 3/31/1999 | 0 | 21-May-1999 | 0 | 7/11/1999 | 1.0835 | 8/31/1999 | 0 |
| 4/1/1999 | 0 | 22-May-1999 | 0 | 7/12/1999 | 0 | 9/1/1999 | 0 |
| 4/2/1999 | 0 | 23-May-1999 | 0 | 7/13/1999 | 0 | 9/2/1999 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 4/4/1999 | 0 | 25-May-1999 | 0 | 7/15/1999 | 0.3187 | 9/4/1999 | 0 |
| 9/5/1999 | 0 | 26-Oct-1999 | 0.305 | 12/16/1999 | 6.2401 | 2/5/2000 | 10.95 |
| 9/6/1999 | 0 | 27-Oct-1999 | 5.7279 | 12/17/1999 | 0 | 2/6/2000 | 4.071 |
| 9/7/1999 | 0 | 28-Oct-1999 | 0.8864 | 12/18/1999 | 0 | 2/7/2000 | 0.977 |
| 9/8/1999 | 0 | 29-Oct-1999 | 0.0667 | 12/19/1999 | 0 | 2/8/2000 | 0 |
| 9/9/1999 | 0 | 30-Oct-1999 | 0.4003 | 12/20/1999 | 0 | 2/9/2000 | 0 |
| 9/10/1999 | 0 | 31-Oct-1999 | 0 | 12/21/1999 | 3.3963 | 2/10/2000 | 0 |
| 9/11/1999 | 0 | 11/1/1999 | 0 | 12/22/1999 | 0 | 2/11/2000 | 19.58 |
| 9/12/1999 | 0 | 11/2/1999 | 0.0179 | 12/23/1999 | 1.0639 | 2/12/2000 | 1.099 |
| 9/13/1999 | 0 | 11/3/1999 | 0 | 12/24/1999 | 2.9871 | 2/13/2000 | 0 |
| 9/14/1999 | 0 | 11/4/1999 | 0 | 12/25/1999 | 0.1228 | 2/14/2000 | 3.094 |
| 9/15/1999 | 0 | 11/5/1999 | 0 | 12/26/1999 | 0.9207 | 2/15/2000 | 17.06 |
| 9/16/1999 | 0 | 11/6/1999 | 0 | 12/27/1999 | 0.7365 | 2/16/2000 | 0 |
| 9/17/1999 | 0 | 11/7/1999 | 0 | 12/28/1999 | 0 | 2/17/2000 | 18.89 |
| 9/18/1999 | 0 | 11/8/1999 | 0.2322 | 12/29/1999 | 2.3119 | 2/18/2000 | 20.36 |
| 9/19/1999 | 0 | 11/9/1999 | 0.9286 | 12/30/1999 | 1.514 | 2/19/2000 | 0 |
| 9/20/1999 | 0 | 11/10/1999 | 5.9469 | 12/31/1999 | 0.5524 | 2/20/2000 | 8.876 |
| 9/21/1999 | 0 | 11/11/1999 | 3.786 | 1/1/2000 | 1.8286 | 2/21/2000 | 0.489 |
| 9/22/1999 | 0.0091 | 11/12/1999 | 1.1787 | 1/2/2000 | 20.653 | 2/22/2000 | 6.799 |
| 9/23/1999 | 0 | 11/13/1999 | 0 | 1/3/2000 | 14.665 | 2/23/2000 | 9.364 |
| 9/24/1999 | 0 | 11/14/1999 | 0 | 1/4/2000 | 3.8366 | 2/24/2000 | 7.654 |
| 9/25/1999 | 0 | 11/15/1999 | 0 | 1/5/2000 | 13.41 | 2/25/2000 | 0.489 |
| 9/26/1999 | 0 | 11/16/1999 | 0 | 1/6/2000 | 7.5656 | 2/26/2000 | 5.985 |
| 9/27/1999 | 0 | 11/17/1999 | 0 | 1/7/2000 | 3.7649 | 2/27/2000 | 18.93 |
| 9/28/1999 | 0 | 11/18/1999 | 6.3576 | 1/8/2000 | 16.386 | 2/28/2000 | 15.06 |
| 9/29/1999 | 0.0272 | 11/19/1999 | 0 | 1/9/2000 | 4.6613 | 2/29/2000 | 17.63 |
| 9/30/1999 | 0.2808 | 11/20/1999 | 0.1786 | 1/10/2000 | 3.5497 | 3/1/2000 | 4.283 |
| 01-Oct-1999 | 0 | 11/21/1999 | 0 | 1/11/2000 | 0 | 3/2/2000 | 5.118 |
| 02-Oct-1999 | 0 | 11/22/1999 | 0 | 1/12/2000 | 0 | 3/3/2000 | 22.98 |
| 03-Oct-1999 | 0 | 11/23/1999 | 0 | 1/13/2000 | 1.9362 | 3/4/2000 | 1.958 |
| 04-Oct-1999 | 0.0381 | 11/24/1999 | 5.1968 | 1/14/2000 | 8.9639 | 3/5/2000 | 4.805 |
| 05-Oct-1999 | 0 | 11/25/1999 | 5.6611 | 1/15/2000 | 11.079 | 3/6/2000 | 14.99 |
| 06-Oct-1999 | 0 | 11/26/1999 | 0.8929 | 1/16/2000 | 2.9043 | 3/7/2000 | 27.45 |
| 07-Oct-1999 | 0 | 11/27/1999 | 1.643 | 1/17/2000 | 0 | 3/8/2000 | 15.09 |
| 08-Oct-1999 | 0 | 11/28/1999 | 0 | 1/18/2000 | 0.502 | 3/9/2000 | 12.61 |
| 09-Oct-1999 | 0 | 11/29/1999 | 0.2679 | 1/19/2000 | 0 | 3/10/2000 | 0.026 |
| 10-Oct-1999 | 0 | 11/30/1999 | 0 | 1/20/2000 | 4.6613 | 3/11/2000 | 16.5 |
| 11-Oct-1999 | 0 | 12/1/1999 | 0 | 1/21/2000 | 33.453 | 3/12/2000 | 2.742 |
| 12-Oct-1999 | 0 | 12/2/1999 | 3.028 | 1/22/2000 | 38.904 | 3/13/2000 | 5.745 |
| 13-Oct-1999 | 0.1906 | 12/3/1999 | 0 | 1/23/2000 | 6.5616 | 3/14/2000 | 0 |
| 14-Oct-1999 | 0 | 12/4/1999 | 0.3478 | 1/24/2000 | 0.7888 | 3/15/2000 | 5.797 |
| 15-Oct-1999 | 0 | 12/5/1999 | 2.005 | 1/25/2000 | 30.226 | 3/16/2000 | 0 |
| 16-Oct-1999 | 0.305 | 12/6/1999 | 0.0614 | 1/26/2000 | 0 | 3/17/2000 | 3.63 |
| 17-Oct-1999 | 0.6195 | 12/7/1999 | 9.0431 | 1/27/2000 | 15.059 | 3/18/2000 | 0 |
| 18-Oct-1999 | 0.0667 | 12/8/1999 | 6.3629 | 1/28/2000 | 8.4261 | 3/19/2000 | 4.962 |
| 19-Oct-1999 | 0 | 12/9/1999 | 13.36 | 1/29/2000 | 3.478 | 3/20/2000 | 0.131 |
| 20-Oct-1999 | 0 | 12/10/1999 | 0.1228 | 1/30/2000 | 1.3267 | 3/21/2000 | 1.018 |
| 21-Oct-1999 | 0 | 12/11/1999 | 6.056 | 1/31/2000 | 0 | 3/22/2000 | 1.097 |
| 22-Oct-1999 | 0 | 12/12/1999 | 1.3094 | 2/1/2000 | 0 | 3/23/2000 | 0 |
| 23-Oct-1999 | 0 | 12/13/1999 | 13.749 | 2/2/2000 | 2.4429 | 3/24/2000 | 0 |
| 24-Oct-1999 | 0.0667 | 12/14/1999 | 4.2556 | 2/3/2000 | 3.0129 | 3/25/2000 | 19.04 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 3/27/2000 | 0 | 17-May-2000 | 0 | 7/7/2000 | 0 | 8/27/2000 | 0.096 |
| 3/28/2000 | 0 | 18-May-2000 | 0 | 7/8/2000 | 0 | 8/28/2000 | 0 |
| 3/29/2000 | 0 | 19-May-2000 | 0 | 7/9/2000 | 0 | 8/29/2000 | 0.162 |
| 3/30/2000 | 0 | 20-May-2000 | 0 | 7/10/2000 | 0 | 8/30/2000 | 0 |
| 3/31/2000 | 0 | 21-May-2000 | 0 | 7/11/2000 | 0 | 8/31/2000 | 0.264 |
| 4/1/2000 | 25.156 | 22-May-2000 | 0 | 7/12/2000 | 0 | 9/1/2000 | 0 |
| 4/2/2000 | 3.28 | 23-May-2000 | 0 | 7/13/2000 | 0 | 9/2/2000 | 0 |
| 4/3/2000 | 0 | 24-May-2000 | 0 | 7/14/2000 | 0 | 9/3/2000 | 0 |
| 4/4/2000 | 0 | 25-May-2000 | 0 | 7/15/2000 | 0 | 9/4/2000 | 0 |
| 4/5/2000 | 12.007 | 26-May-2000 | 0 | 7/16/2000 | 0 | 9/5/2000 | 0 |
| 4/6/2000 | 1.5229 | 27-May-2000 | 0 | 7/17/2000 | 0 | 9/6/2000 | 0 |
| 4/7/2000 | 0 | 28-May-2000 | 0 | 7/18/2000 | 0 | 9/7/2000 | 0 |
| 4/8/2000 | 0 | 29-May-2000 | 0 | 7/19/2000 | 0 | 9/8/2000 | 0 |
| 4/9/2000 | 0 | 30-May-2000 | 0 | 7/20/2000 | 0 | 9/9/2000 | 0 |
| 4/10/2000 | 0 | 31-May-2000 | 0 | 7/21/2000 | 0 | 9/10/2000 | 0 |
| 4/11/2000 | 0 | 6/1/2000 | 0 | 7/22/2000 | 0 | 9/11/2000 | 0 |
| 4/12/2000 | 0 | 6/2/2000 | 0 | 7/23/2000 | 0 | 9/12/2000 | 0.042 |
| 4/13/2000 | 0 | 6/3/2000 | 0 | 7/24/2000 | 0 | 9/13/2000 | 0 |
| 4/14/2000 | 0 | 6/4/2000 | 0 | 7/25/2000 | 0 | 9/14/2000 | 0.036 |
| 4/15/2000 | 0 | 6/5/2000 | 0 | 7/26/2000 | 0 | 9/15/2000 | 0 |
| 4/16/2000 | 0 | 6/6/2000 | 0 | 7/27/2000 | 0 | 9/16/2000 | 0 |
| 4/17/2000 | 0 | 6/7/2000 | 2.7 | 7/28/2000 | 0 | 9/17/2000 | 0 |
| 4/18/2000 | 0 | 6/8/2000 | 0 | 7/29/2000 | 0 | 9/18/2000 | 0 |
| 4/19/2000 | 0 | 6/9/2000 | 0 | 7/30/2000 | 0 | 9/19/2000 | 0 |
| 4/20/2000 | 0 | 6/10/2000 | 0 | 7/31/2000 | 0 | 9/20/2000 | 0 |
| 4/21/2000 | 0 | 6/11/2000 | 0 | 8/1/2000 | 0 | 9/21/2000 | 0 |
| 4/22/2000 | 0 | 6/12/2000 | 0 | 8/2/2000 | 0 | 9/22/2000 | 0 |
| 4/23/2000 | 0 | 6/13/2000 | 0 | 8/3/2000 | 0 | 9/23/2000 | 0 |
| 4/24/2000 | 0 | 6/14/2000 | 0 | 8/4/2000 | 0 | 9/24/2000 | 0 |
| 4/25/2000 | 0 | 6/15/2000 | 0 | 8/5/2000 | 0 | 9/25/2000 | 0 |
| 4/26/2000 | 0 | 6/16/2000 | 0 | 8/6/2000 | 0 | 9/26/2000 | 0 |
| 4/27/2000 | 0 | 6/17/2000 | 0 | 8/7/2000 | 0 | 9/27/2000 | 0 |
| 4/28/2000 | 1.9036 | 6/18/2000 | 0 | 8/8/2000 | 0 | 9/28/2000 | 0 |
| 4/29/2000 | 0 | 6/19/2000 | 0 | 8/9/2000 | 0 | 9/29/2000 | 0 |
| 4/30/2000 | 0 | 6/20/2000 | 0 | 8/10/2000 | 0 | 9/30/2000 | 0.048 |
| 01-May-2000 | 0 | 6/21/2000 | 0 | 8/11/2000 | 0 | 01-Oct-2000 | 0 |
| 02-May-2000 | 0 | 6/22/2000 | 0 | 8/12/2000 | 0 | 02-Oct-2000 | 0 |
| 03-May-2000 | 0 | 6/23/2000 | 0 | 8/13/2000 | 0 | 03-Oct-2000 | 0 |
| 04-May-2000 | 0 | 6/24/2000 | 0 | 8/14/2000 | 0 | 04-Oct-2000 | 0.698 |
| 05-May-2000 | 13.213 | 6/25/2000 | 0 | 8/15/2000 | 0 | 05-Oct-2000 | 0.21 |
| 06-May-2000 | 0 | 6/26/2000 | 0 | 8/16/2000 | 0 | 06-Oct-2000 | 0 |
| 07-May-2000 | 0 | 6/27/2000 | 0 | 8/17/2000 | 0.012 | 07-Oct-2000 | 0.315 |
| 08-May-2000 | 0 | 6/28/2000 | 0 | 8/18/2000 | 0 | 08-Oct-2000 | 0 |
| 09-May-2000 | 2.7161 | 6/29/2000 | 0 | 8/19/2000 | 0.498 | 09-Oct-2000 | 0 |
| 10-May-2000 | 0 | 6/30/2000 | 0 | 8/20/2000 | 0 | 10-Oct-2000 | 0 |
| 11-May-2000 | 0 | 7/1/2000 | 0 | 8/21/2000 | 0.192 | 11-Oct-2000 | 0 |
| 12-May-2000 | 0 | 7/2/2000 | 0 | 8/22/2000 | 0 | 12-Oct-2000 | 0 |
| 13-May-2000 | 0 | 7/3/2000 | 0 | 8/23/2000 | 0.048 | 13-Oct-2000 | 0 |
| 14-May-2000 | 0 | 7/4/2000 | 0 | 8/24/2000 | 0 | 14-Oct-2000 | 0 |
| 15-May-2000 | 1.7767 | 7/5/2000 | 0.078 | 8/25/2000 | 0 | 15-Oct-2000 | 0 |
| 16-May-2000 | 0 | 7/6/2000 | 0 | 8/26/2000 | 0 | 16-Oct-2000 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 18-Oct-2000 | 0.9939 | 12/10/2000 | 7.3163 | 2/1/2001 | 14.275 | 3/26/2001 | 0.064 |
| 19-Oct-2000 | 1.4335 | 12/11/2000 | 47.195 | 2/2/2001 | 1.8694 | 3/27/2001 | 10.96 |
| 20-Oct-2000 | 1.9018 | 12/12/2000 | 5.8736 | 2/3/2001 | 16.315 | 3/28/2001 | 2.46 |
| 21-Oct-2000 | 0 | 12/13/2000 | 0.4809 | 2/4/2001 | 0 | 3/29/2001 | 0 |
| 22-Oct-2000 | 0 | 12/14/2000 | 0.6526 | 2/5/2001 | 6.4239 | 3/30/2001 | 0 |
| 23-Oct-2000 | 0 | 12/15/2000 | 0.4122 | 2/6/2001 | 6.6958 | 3/31/2001 | 2.524 |
| 24-Oct-2000 | 0 | 12/16/2000 | 4.1218 | 2/7/2001 | 31.236 | 4/1/2001 | 0 |
| 25-Oct-2000 | 0 | 12/17/2000 | 11.404 | 2/8/2001 | 13.052 | 4/2/2001 | 0 |
| 26-Oct-2000 | 2.2745 | 12/18/2000 | 19.304 | 2/9/2001 | 26.953 | 4/3/2001 | 0 |
| 27-Oct-2000 | 0 | 12/19/2000 | 0 | 2/10/2001 | 9.0071 | 4/4/2001 | 4.848 |
| 28-Oct-2000 | 4.6254 | 12/20/2000 | 5.4958 | 2/11/2001 | 28.755 | 4/5/2001 | 0 |
| 29-Oct-2000 | 0 | 12/21/2000 | 16.041 | 2/12/2001 | 6.4919 | 4/6/2001 | 0 |
| 30-Oct-2000 | 0 | 12/22/2000 | 0 | 2/13/2001 | 0.9177 | 4/7/2001 | 0 |
| 31-Oct-2000 | 0 | 12/23/2000 | 4.1905 | 2/14/2001 | 10.91 | 4/8/2001 | 0 |
| 11/1/2000 | 9.8065 | 12/24/2000 | 7.0758 | 2/15/2001 | 4.5885 | 4/9/2001 | 0 |
| 11/2/2000 | 0 | 12/25/2000 | 1.6831 | 2/16/2001 | 10.91 | 4/10/2001 | 0 |
| 11/3/2000 | 0.5779 | 12/26/2000 | 1.9922 | 2/17/2001 | 54.518 | 4/11/2001 | 0 |
| 11/4/2000 | 0 | 12/27/2000 | 13.499 | 2/18/2001 | 4.2146 | 4/12/2001 | 0 |
| 11/5/2000 | 0 | 12/28/2000 | 2.3701 | 2/19/2001 | 0 | 4/13/2001 | 0 |
| 11/6/2000 | 0 | 12/29/2000 | 7.4537 | 2/20/2001 | 4.8944 | 4/14/2001 | 0 |
| 11/7/2000 | 1.6615 | 12/30/2000 | 13.843 | 2/21/2001 | 11.828 | 4/15/2001 | 0 |
| 11/8/2000 | 0 | 12/31/2000 | 0.2061 | 2/22/2001 | 0.6118 | 4/16/2001 | 0 |
| 11/9/2000 | 0.0722 | 1/1/2001 | 7.7292 | 2/23/2001 | 0 | 4/17/2001 | 0 |
| 11/10/2000 | 0 | 1/2/2001 | 20.179 | 2/24/2001 | 1.3935 | 4/18/2001 | 0 |
| 11/11/2000 | 0 | 1/3/2001 | 12.508 | 2/25/2001 | 20.427 | 4/19/2001 | 0 |
| 11/12/2000 | 2.6367 | 1/4/2001 | 7.6407 | 2/26/2001 | 13.29 | 4/20/2001 | 0 |
| 11/13/2000 | 1.7879 | 1/5/2001 | 6.4017 | 2/27/2001 | 18.864 | 4/21/2001 | 0 |
| 11/14/2000 | 0 | 1/6/2001 | 13.482 | 2/28/2001 | 13.596 | 4/22/2001 | 0.298 |
| 11/15/2000 | 0 | 1/7/2001 | 7.0802 | 3/1/2001 | 6.1025 | 4/23/2001 | 0 |
| 11/16/2000 | 0 | 1/8/2001 | 8.7913 | 3/2/2001 | 3.1631 | 4/24/2001 | 0 |
| 11/17/2000 | 0 | 1/9/2001 | 4.3661 | 3/3/2001 | 0 | 4/25/2001 | 0 |
| 11/18/2000 | 0 | 1/10/2001 | 0.649 | 3/4/2001 | 0 | 4/26/2001 | 0 |
| 11/19/2000 | 0 | 1/11/2001 | 0 | 3/5/2001 | 11.566 | 4/27/2001 | 0 |
| 11/20/2000 | 0 | 1/12/2001 | 0 | 3/6/2001 | 5.2399 | 4/28/2001 | 0 |
| 11/21/2000 | 0 | 1/13/2001 | 0 | 3/7/2001 | 1.6295 | 4/29/2001 | 0 |
| 11/22/2000 | 1.0655 | 1/14/2001 | 0.472 | 3/8/2001 | 7.5723 | 4/30/2001 | 0 |
| 11/23/2000 | 1.7699 | 1/15/2001 | 0 | 3/9/2001 | 2.8755 | 01-May-2001 | 0 |
| 11/24/2000 | 3.2688 | 1/16/2001 | 29.471 | 3/10/2001 | 0 | 02-May-2001 | 0 |
| 11/25/2000 | 3.5036 | 1/17/2001 | 34.162 | 3/11/2001 | 4.0258 | 03-May-2001 | 0 |
| 11/26/2000 | 13.021 | 1/18/2001 | 3.1566 | 3/12/2001 | 0 | 04-May-2001 | 0 |
| 11/27/2000 | 6.8808 | 1/19/2001 | 18.733 | 3/13/2001 | 1.1183 | 05-May-2001 | 0 |
| 11/28/2000 | 3.1063 | 1/20/2001 | 1.4455 | 3/14/2001 | 1.1183 | 06-May-2001 | 0 |
| 11/29/2000 | 13.31 | 1/21/2001 | 20.09 | 3/15/2001 | 0.9266 | 07-May-2001 | 0 |
| 11/30/2000 | 22.864 | 1/22/2001 | 7.5817 | 3/16/2001 | 9.3615 | 08-May-2001 | 0 |
| 12/1/2000 | 18.583 | 1/23/2001 | 1.5045 | 3/17/2001 | 8.1474 | 09-May-2001 | 0 |
| 12/2/2000 | 2.6105 | 1/24/2001 | 6.5492 | 3/18/2001 | 0 | 10-May-2001 | 0 |
| 12/3/2000 | 0 | 1/25/2001 | 4.9266 | 3/19/2001 | 22.877 | 11-May-2001 | 0 |
| 12/4/2000 | 0.6183 | 1/26/2001 | 0 | 3/20/2001 | 5.3357 | 12-May-2001 | 0 |
| 12/5/2000 | 12.675 | 1/27/2001 | 0 | 3/21/2001 | 36.328 | 13-May-2001 | 0 |
| 12/6/2000 | 4.9806 | 1/28/2001 | 0 | 3/22/2001 | 0 | 14-May-2001 | 0 |
| 12/7/2000 | 16.659 | 1/29/2001 | 2.4781 | 3/23/2001 | 10.064 | 15-May-2001 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 17-May-2001 | 0 | 7/9/2001 | 0 | 8/31/2001 | 0 | 23-Oct-2001 | 0 |
| 18-May-2001 | 0 | 7/10/2001 | 0 | 9/1/2001 | 0 | 24-Oct-2001 | 6.89 |
| 19-May-2001 | 0 | 7/11/2001 | 0 | 9/2/2001 | 0 | 25-Oct-2001 | 0 |
| 20-May-2001 | 0 | 7/12/2001 | 0 | 9/3/2001 | 0 | 26-Oct-2001 | 0.091 |
| 21-May-2001 | 0 | 7/13/2001 | 0 | 9/4/2001 | 0 | 27-Oct-2001 | 8.703 |
| 22-May-2001 | 0 | 7/14/2001 | 0 | 9/5/2001 | 0 | 28-Oct-2001 | 0.535 |
| 23-May-2001 | 0 | 7/15/2001 | 0 | 9/6/2001 | 0 | 29-Oct-2001 | 4.524 |
| 24-May-2001 | 0 | 7/16/2001 | 0 | 9/7/2001 | 0 | 30-Oct-2001 | 0 |
| 25-May-2001 | 0 | 7/17/2001 | 0 | 9/8/2001 | 0 | 31-Oct-2001 | 1.813 |
| 26-May-2001 | 0 | 7/18/2001 | 0 | 9/9/2001 | 0 | 11/1/2001 | 0.733 |
| 27-May-2001 | 0 | 7/19/2001 | 0 | 9/10/2001 | 0 | 11/2/2001 | 0.282 |
| 28-May-2001 | 0 | 7/20/2001 | 0.0874 | 9/11/2001 | 0 | 11/3/2001 | 0 |
| 29-May-2001 | 0 | 7/21/2001 | 0.0874 | 9/12/2001 | 0 | 11/4/2001 | 0.696 |
| 30-May-2001 | 0 | 7/22/2001 | 0 | 9/13/2001 | 0 | 11/5/2001 | 9.459 |
| 31-May-2001 | 0 | 7/23/2001 | 0.0874 | 9/14/2001 | 0.204 | 11/6/2001 | 4.156 |
| 6/1/2001 | 0 | 7/24/2001 | 0 | 9/15/2001 | 0 | 11/7/2001 | 3.517 |
| 6/2/2001 | 0 | 7/25/2001 | 0 | 9/16/2001 | 0 | 11/8/2001 | 1.617 |
| 6/3/2001 | 0 | 7/26/2001 | 0 | 9/17/2001 | 0 | 11/9/2001 | 3.629 |
| 6/4/2001 | 0 | 7/27/2001 | 0.1499 | 9/18/2001 | 0 | 11/10/2001 | 0 |
| 6/5/2001 | 0 | 7/28/2001 | 0 | 9/19/2001 | 0 | 11/11/2001 | 0 |
| 6/6/2001 | 0 | 7/29/2001 | 0 | 9/20/2001 | 0 | 11/12/2001 | 6.281 |
| 6/7/2001 | 0 | 7/30/2001 | 0 | 9/21/2001 | 0 | 11/13/2001 | 1.824 |
| 6/8/2001 | 0 | 7/31/2001 | 0 | 9/22/2001 | 0 | 11/14/2001 | 5.905 |
| 6/9/2001 | 0 | 8/1/2001 | 0.186 | 9/23/2001 | 0 | 11/15/2001 | 0.602 |
| 6/10/2001 | 0 | 8/2/2001 | 0 | 9/24/2001 | 0 | 11/16/2001 | 2.652 |
| 6/11/2001 | 0 | 8/3/2001 | 0 | 9/25/2001 | 0 | 11/17/2001 | 4.457 |
| 6/12/2001 | 0 | 8/4/2001 | 0 | 9/26/2001 | 0 | 11/18/2001 | 5.284 |
| 6/13/2001 | 0 | 8/5/2001 | 0 | 9/27/2001 | 0 | 11/19/2001 | 7.691 |
| 6/14/2001 | 0 | 8/6/2001 | 0 | 9/28/2001 | 0 | 11/20/2001 | 10.42 |
| 6/15/2001 | 0 | 8/7/2001 | 0 | 9/29/2001 | 0 | 11/21/2001 | 6.149 |
| 6/16/2001 | 0 | 8/8/2001 | 0 | 9/30/2001 | 0 | 11/22/2001 | 1.993 |
| 6/17/2001 | 0 | 8/9/2001 | 0 | 01-Oct-2001 | 0.2538 | 11/23/2001 | 9.591 |
| 6/18/2001 | 0 | 8/10/2001 | 0.3916 | 02-Oct-2001 | 0 | 11/24/2001 | 3.291 |
| 6/19/2001 | 0 | 8/11/2001 | 0 | 03-Oct-2001 | 0 | 11/25/2001 | 0 |
| 6/20/2001 | 0 | 8/12/2001 | 0 | 04-Oct-2001 | 0 | 11/26/2001 | 8.801 |
| 6/21/2001 | 0 | 8/13/2001 | 0 | 05-Oct-2001 | 0 | 11/27/2001 | 4.288 |
| 6/22/2001 | 0.036 | 8/14/2001 | 0 | 06-Oct-2001 | 0 | 11/28/2001 | 0 |
| 6/23/2001 | 0 | 8/15/2001 | 0 | 07-Oct-2001 | 0 | 11/29/2001 | 0 |
| 6/24/2001 | 0 | 8/16/2001 | 0 | 08-Oct-2001 | 0.2085 | 11/30/2001 | 0 |
| 6/25/2001 | 0 | 8/17/2001 | 0.1077 | 09-Oct-2001 | 0 | 12/1/2001 | 11.67 |
| 6/26/2001 | 0 | 8/18/2001 | 0 | 10-Oct-2001 | 0 | 12/2/2001 | 0.956 |
| 6/27/2001 | 0 | 8/19/2001 | 0 | 11-Oct-2001 | 0 | 12/3/2001 | 0 |
| 6/28/2001 | 0 | 8/20/2001 | 0 | 12-Oct-2001 | 0 | 12/4/2001 | 17.33 |
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| 7/1/2001 | 0 | 8/23/2001 | 0 | 15-Oct-2001 | 0 | 12/7/2001 | 2.892 |
| 7/2/2001 | 0 | 8/24/2001 | 0.186 | 16-Oct-2001 | 0 | 12/8/2001 | 10.71 |
| 7/3/2001 | 0 | 8/25/2001 | 0 | 17-Oct-2001 | 0 | 12/9/2001 | 0.662 |
| 7/4/2001 | 0 | 8/26/2001 | 0.1077 | 18-Oct-2001 | 0 | 12/10/2001 | 1.422 |
| 7/5/2001 | 0 | 8/27/2001 | 0.0098 | 19-Oct-2001 | 4.2427 | 12/11/2001 | 0 |
| 7/6/2001 | 0 | 8/28/2001 | 0 | 20-Oct-2001 | 1.4596 | 12/12/2001 | 8.187 |

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| 12/16/2001 | 10.172 | 2/7/2002 | 1.2822 | 4/1/2002 | 0 | 24-May-2002 | 0 |
| 12/17/2001 | 11.667 | 2/8/2002 | 3.1849 | 4/2/2002 | 0 | 25-May-2002 | 0 |
| 12/18/2001 | 1.8628 | 2/9/2002 | 0 | 4/3/2002 | 0 | 26-May-2002 | 0 |
| 12/19/2001 | 0 | 2/10/2002 | 5.8735 | 4/4/2002 | 0 | 27-May-2002 | 0 |
| 12/20/2001 | 0 | 2/11/2002 | 67.503 | 4/5/2002 | 0 | 28-May-2002 | 0 |
| 12/21/2001 | 0 | 2/12/2002 | 0 | 4/6/2002 | 0 | 29-May-2002 | 0 |
| 12/22/2001 | 7.5739 | 2/13/2002 | 0.9927 | 4/7/2002 | 0 | 30-May-2002 | 0 |
| 12/23/2001 | 0 | 2/14/2002 | 2.8126 | 4/8/2002 | 0 | 31-May-2002 | 0 |
| 12/24/2001 | 8.873 | 2/15/2002 | 1.8199 | 4/9/2002 | 0 | 6/1/2002 | 0.156 |
| 12/25/2001 | 10.883 | 2/16/2002 | 3.3917 | 4/10/2002 | 1.4716 | 6/2/2002 | 0 |
| 12/26/2001 | 4.2894 | 2/17/2002 | 4.4258 | 4/11/2002 | 8.6989 | 6/3/2002 | 0 |
| 12/27/2001 | 0 | 2/18/2002 | 3.0195 | 4/12/2002 | 25.9 | 6/4/2002 | 0 |
| 12/28/2001 | 28.114 | 2/19/2002 | 9.0584 | 4/13/2002 | 19.491 | 6/5/2002 | 0 |
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| 1/3/2002 | 0 | 2/25/2002 | 0 | 4/19/2002 | 0 | 6/11/2002 | 0 |
| 1/4/2002 | 0 | 2/26/2002 | 0 | 4/20/2002 | 0 | 6/12/2002 | 0 |
| 1/5/2002 | 0 | 2/27/2002 | 7.3211 | 4/21/2002 | 0 | 6/13/2002 | 0 |
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| 1/7/2002 | 0 | 3/1/2002 | 2.4076 | 4/23/2002 | 0 | 6/15/2002 | 0 |
| 1/8/2002 | 2.8551 | 3/2/2002 | 0 | 4/24/2002 | 0 | 6/16/2002 | 0 |
| 1/9/2002 | 1.5635 | 3/3/2002 | 2.8203 | 4/25/2002 | 0 | 6/17/2002 | 0 |
| 1/10/2002 | 12.814 | 3/4/2002 | 0 | 4/26/2002 | 0 | 6/18/2002 | 0 |
| 1/11/2002 | 3.297 | 3/5/2002 | 0 | 4/27/2002 | 0 | 6/19/2002 | 0 |
| 1/12/2002 | 19.782 | 3/6/2002 | 0 | 4/28/2002 | 0 | 6/20/2002 | 0 |
| 1/13/2002 | 23.453 | 3/7/2002 | 0 | 4/29/2002 | 0 | 6/21/2002 | 0 |
| 1/14/2002 | 12.95 | 3/8/2002 | 2.1553 | 4/30/2002 | 0 | 6/22/2002 | 0 |
| 1/15/2002 | 3.8068 | 3/9/2002 | 0.5732 | 01-May-2002 | 0 | 6/23/2002 | 0 |
| 1/16/2002 | 1.3596 | 3/10/2002 | 0 | 02-May-2002 | 0 | 6/24/2002 | 0 |
| 1/17/2002 | 1.0537 | 3/11/2002 | 0 | 03-May-2002 | 0 | 6/25/2002 | 0 |
| 1/18/2002 | 16.043 | 3/12/2002 | 6.0303 | 04-May-2002 | 0 | 6/26/2002 | 0 |
| 1/19/2002 | 7.5457 | 3/13/2002 | 0 | 05-May-2002 | 0 | 6/27/2002 | 0 |
| 1/20/2002 | 5.6083 | 3/14/2002 | 5.652 | 06-May-2002 | 0 | 6/28/2002 | 0 |
| 1/21/2002 | 8.4634 | 3/15/2002 | 4.5514 | 07-May-2002 | 0 | 6/29/2002 | 0 |
| 1/22/2002 | 10.197 | 3/16/2002 | 0 | 08-May-2002 | 0 | 6/30/2002 | 0 |
| 1/23/2002 | 19.408 | 3/17/2002 | 0.6076 | 09-May-2002 | 0 | 7/1/2002 | 0.03 |
| 1/24/2002 | 1.9034 | 3/18/2002 | 0 | 10-May-2002 | 0 | 7/2/2002 | 0 |
| 1/25/2002 | 6.492 | 3/19/2002 | 0 | 11-May-2002 | 0 | 7/3/2002 | 0 |
| 1/26/2002 | 0.3059 | 3/20/2002 | 4.2763 | 12-May-2002 | 0 | 7/4/2002 | 0 |
| 1/27/2002 | 4.4866 | 3/21/2002 | 10.628 | 13-May-2002 | 0 | 7/5/2002 | 0 |
| 1/28/2002 | 0 | 3/22/2002 | 0 | 14-May-2002 | 0 | 7/6/2002 | 0 |
| 1/29/2002 | 0 | 3/23/2002 | 0 | 15-May-2002 | 0 | 7/7/2002 | 0 |
| 1/30/2002 | 0 | 3/24/2002 | 0.5044 | 16-May-2002 | 0 | 7/8/2002 | 0 |
| 1/31/2002 | 1.3936 | 3/25/2002 | 0.8484 | 17-May-2002 | 0 | 7/9/2002 | 0 |
| 2/1/2002 | 0 | 3/26/2002 | 0 | 18-May-2002 | 0 | 7/10/2002 | 0 |
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| 2/5/2002 | 18.613 | 3/30/2002 | 0 | 22-May-2002 | 0 | 7/14/2002 | 0 |
| 7/15/2002 | 0 | 9/6/2002 | 0 | 29-Oct-2002 | 12.437 | 12/21/2002 | 0 |
| 7/16/2002 | 0 | 9/7/2002 | 0.186 | 30-Oct-2002 | 0.7344 | 12/22/2002 | 5.138 |
| 7/17/2002 | 0 | 9/8/2002 | 0 | 31-Oct-2002 | 3.3458 | 12/23/2002 | 6.715 |
| 7/18/2002 | 0.096 | 9/9/2002 | 0.162 | 11/1/2002 | 0 | 12/24/2002 | 0 |
| 7/19/2002 | 0 | 9/10/2002 | 0 | 11/2/2002 | 11.204 | 12/25/2002 | 7.279 |
| 7/20/2002 | 0 | 9/11/2002 | 0 | 11/3/2002 | 0.574 | 12/26/2002 | 3.679 |
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| 7/22/2002 | 0 | 9/13/2002 | 0 | 11/5/2002 | 14.487 | 12/28/2002 | 20.01 |
| 7/23/2002 | 0 | 9/14/2002 | 0 | 11/6/2002 | 8.2193 | 12/29/2002 | 1.596 |
| 7/24/2002 | 0 | 9/15/2002 | 0 | 11/7/2002 | 0.5051 | 12/30/2002 | 0 |
| 7/25/2002 | 0 | 9/16/2002 | 0.006 | 11/8/2002 | 0 | 12/31/2002 | 16.41 |
| 7/26/2002 | 0 | 9/17/2002 | 0 | 11/9/2002 | 0.7117 | 1/1/2003 | 0 |
| 7/27/2002 | 0 | 9/18/2002 | 0 | 11/10/2002 | 13.293 | 1/2/2003 | 0 |
| 7/28/2002 | 0 | 9/19/2002 | 0 | 11/11/2002 | 0 | 1/3/2003 | 13.13 |
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| 7/30/2002 | 0 | 9/21/2002 | 0 | 11/13/2002 | 0 | 1/5/2003 | 0 |
| 7/31/2002 | 0 | 9/22/2002 | 0.756 | 11/14/2002 | 0 | 1/6/2003 | 0 |
| 8/1/2002 | 0 | 9/23/2002 | 0 | 11/15/2002 | 0 | 1/7/2003 | 9.144 |
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| 8/3/2002 | 0 | 9/25/2002 | 3.33 | 11/17/2002 | 0 | 1/9/2003 | 3.675 |
| 8/4/2002 | 0.0061 | 9/26/2002 | 2.52 | 11/18/2002 | 0.9643 | 1/10/2003 | 11.59 |
| 8/5/2002 | 0 | 9/27/2002 | 0.246 | 11/19/2002 | 0 | 1/11/2003 | 12.19 |
| 8/6/2002 | 0 | 9/28/2002 | 0 | 11/20/2002 | 0 | 1/12/2003 | 3.333 |
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| 8/8/2002 | 0 | 9/30/2002 | 0 | 11/22/2002 | 0 | 1/14/2003 | 0 |
| 8/9/2002 | 0 | 01-Oct-2002 | 0 | 11/23/2002 | 0.574 | 1/15/2003 | 0 |
| 8/10/2002 | 0 | 02-Oct-2002 | 10.69 | 11/24/2002 | 1.0331 | 1/16/2003 | 0 |
| 8/11/2002 | 0 | 03-Oct-2002 | 1.8116 | 11/25/2002 | 3.6505 | 1/17/2003 | 0 |
| 8/12/2002 | 0 | 04-Oct-2002 | 1.0282 | 11/26/2002 | 0.5969 | 1/18/2003 | 0 |
| 8/13/2002 | 0 | 05-Oct-2002 | 0.3101 | 11/27/2002 | 0.4133 | 1/19/2003 | 0 |
| 8/14/2002 | 0 | 06-Oct-2002 | 0 | 11/28/2002 | 8.1045 | 1/20/2003 | 0 |
| 8/15/2002 | 0 | 07-Oct-2002 | 0.0653 | 11/29/2002 | 3.6505 | 1/21/2003 | 0.541 |
| 8/16/2002 | 0 | 08-Oct-2002 | 2.1707 | 11/30/2002 | 0 | 1/22/2003 | 8.375 |
| 8/17/2002 | 0 | 09-Oct-2002 | 5.3696 | 12/1/2002 | 0 | 1/23/2003 | 17.75 |
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| 8/20/2002 | 0 | 12-Oct-2002 | 0 | 12/4/2002 | 0.7007 | 1/26/2003 | 2.307 |
| 8/21/2002 | 0 | 13-Oct-2002 | 0 | 12/5/2002 | 0 | 1/27/2003 | 16.95 |
| 8/22/2002 | 0 | 14-Oct-2002 | 0 | 12/6/2002 | 5.041 | 1/28/2003 | 6.153 |
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| 8/25/2002 | 0 | 17-Oct-2002 | 0 | 12/9/2002 | 0.4671 | 1/31/2003 | 4.102 |
| 8/26/2002 | 0 | 18-Oct-2002 | 0 | 12/10/2002 | 4.9632 | 2/1/2003 | 15.53 |
| 8/27/2002 | 0 | 19-Oct-2002 | 0 | 12/11/2002 | 1.1289 | 2/2/2003 | 0 |
| 8/28/2002 | 0.0244 | 20-Oct-2002 | 0 | 12/12/2002 | 0.6618 | 2/3/2003 | 1.746 |
| 8/29/2002 | 0 | 21-Oct-2002 | 0 | 12/13/2002 | 1.4792 | 2/4/2003 | 7.056 |
| 8/30/2002 | 0 | 22-Oct-2002 | 0 | 12/14/2002 | 0 | 2/5/2003 | 0.546 |
| 8/31/2002 | 0 | 23-Oct-2002 | 0 | 12/15/2002 | 7.7464 | 2/6/2003 | 0 |
| 9/1/2002 | 0 | 24-Oct-2002 | 0 | 12/16/2002 | 0.2725 | 2/7/2003 | 9.601 |

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| 9/3/2002 | 0 | 26-Oct-2002 | 1.0609 | 12/18/2002 | 2.6859 | 2/9/2003 | 0 |
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| 2/12/2003 | 31.605 | 4/5/2003 | 0 | 27-May-2003 | 0 | 7/18/2003 | 0 |
| 2/13/2003 | 16.657 | 4/6/2003 | 0 | 28-May-2003 | 0 | 7/19/2003 | 0 |
| 2/14/2003 | 7.1283 | 4/7/2003 | 0 | 29-May-2003 | 0 | 7/20/2003 | 0 |
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| 2/16/2003 | 14.147 | 4/9/2003 | 0 | 31-May-2003 | 0 | 7/22/2003 | 0 |
| 2/17/2003 | 16.584 | 4/10/2003 | 0 | 6/1/2003 | 0 | 7/23/2003 | 0 |
| 2/18/2003 | 0 | 4/11/2003 | 0 | 6/2/2003 | 0 | 7/24/2003 | 0 |
| 2/19/2003 | 0.0364 | 4/12/2003 | 0 | 6/3/2003 | 0 | 7/25/2003 | 0 |
| 2/20/2003 | 1.2002 | 4/13/2003 | 0 | 6/4/2003 | 0 | 7/26/2003 | 0 |
| 2/21/2003 | 17.675 | 4/14/2003 | 0 | 6/5/2003 | 0 | 7/27/2003 | 0.336 |
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| 2/23/2003 | 0 | 4/16/2003 | 0 | 6/7/2003 | 0 | 7/29/2003 | 0 |
| 2/24/2003 | 1.0911 | 4/17/2003 | 0 | 6/8/2003 | 0 | 7/30/2003 | 0 |
| 2/25/2003 | 11.056 | 4/18/2003 | 0 | 6/9/2003 | 0 | 7/31/2003 | 0 |
| 2/26/2003 | 11.747 | 4/19/2003 | 0 | 6/10/2003 | 0 | 8/1/2003 | 0 |
| 2/27/2003 | 10.729 | 4/20/2003 | 0 | 6/11/2003 | 0 | 8/2/2003 | 0 |
| 2/28/2003 | 17.493 | 4/21/2003 | 0 | 6/12/2003 | 0 | 8/3/2003 | 0 |
| 3/1/2003 | 2.101 | 4/22/2003 | 0 | 6/13/2003 | 0 | 8/4/2003 | 0 |
| 3/2/2003 | 0 | 4/23/2003 | 0 | 6/14/2003 | 0 | 8/5/2003 | 0 |
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| 3/4/2003 | 1.33 | 4/25/2003 | 0 | 6/16/2003 | 0 | 8/7/2003 | 0 |
| 3/5/2003 | 0 | 4/26/2003 | 0 | 6/17/2003 | 0 | 8/8/2003 | 0 |
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| 3/7/2003 | 0 | 4/28/2003 | 0 | 6/19/2003 | 0 | 8/10/2003 | 0 |
| 3/8/2003 | 10.89 | 4/29/2003 | 0 | 6/20/2003 | 0 | 8/11/2003 | 0 |
| 3/9/2003 | 26.619 | 4/30/2003 | 0 | 6/21/2003 | 0 | 8/12/2003 | 0 |
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| 3/11/2003 | 12.259 | 02-May-2003 | 0 | 6/23/2003 | 0 | 8/14/2003 | 0 |
| 3/12/2003 | 6.7078 | 03-May-2003 | 0 | 6/24/2003 | 0 | 8/15/2003 | 0 |
| 3/13/2003 | 4.1827 | 04-May-2003 | 0 | 6/25/2003 | 0 | 8/16/2003 | 0 |
| 3/14/2003 | 5.6091 | 05-May-2003 | 0 | 6/26/2003 | 0 | 8/17/2003 | 0 |
| 3/15/2003 | 0 | 06-May-2003 | 0 | 6/27/2003 | 0 | 8/18/2003 | 0 |
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| 3/17/2003 | 0 | 08-May-2003 | 0 | 6/29/2003 | 0 | 8/20/2003 | 0 |
| 3/18/2003 | 0 | 09-May-2003 | 0 | 6/30/2003 | 0 | 8/21/2003 | 0.008 |
| 3/19/2003 | 6.6692 | 10-May-2003 | 0 | 7/1/2003 | 0 | 8/22/2003 | 0 |
| 3/20/2003 | 17.675 | 11-May-2003 | 0 | 7/2/2003 | 0 | 8/23/2003 | 0 |
| 3/21/2003 | 4.5875 | 12-May-2003 | 0 | 7/3/2003 | 0 | 8/24/2003 | 0 |
| 3/22/2003 | 1.5806 | 13-May-2003 | 0 | 7/4/2003 | 0 | 8/25/2003 | 0 |
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| 3/24/2003 | 0 | 15-May-2003 | 0 | 7/6/2003 | 0 | 8/27/2003 | 0 |
| 3/25/2003 | 6.0717 | 16-May-2003 | 0 | 7/7/2003 | 0 | 8/28/2003 | 0.104 |
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| 3/27/2003 | 0 | 18-May-2003 | 0 | 7/9/2003 | 0 | 8/30/2003 | 0 |
| 3/28/2003 | 1.0023 | 19-May-2003 | 0 | 7/10/2003 | 0 | 8/31/2003 | 0.024 |
| 3/29/2003 | 5.2814 | 20-May-2003 | 0 | 7/11/2003 | 0 | 9/1/2003 | 0.077 |
| 3/30/2003 | 1.4456 | 21-May-2003 | 0 | 7/12/2003 | 0 | 9/2/2003 | 0 |
| 3/31/2003 | 5.4163 | 22-May-2003 | 0 | 7/13/2003 | 0 | 9/3/2003 | 0.292 |

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| 4/2/2003 | 9.483 | 24-May-2003 | 0 | 7/15/2003 | 0 | 9/5/2003 | 0 |
| 4/3/2003 | 9.0546 | 25-May-2003 | 0 | 7/16/2003 | 0 | 9/6/2003 | 0 |
| 4/4/2003 | 4.9459 | 26-May-2003 | 0 | 7/17/2003 | 0 | 9/7/2003 | 0.086 |
| 9/8/2003 | 0.1203 | 30-Oct-2003 | 0 | 12/21/2003 | 0 | 2/11/2004 | 7.999 |
| 9/9/2003 | 0.2148 | 31-Oct-2003 | 0 | 12/22/2003 | 47.487 | 2/12/2004 | 1.796 |
| 9/10/2003 | 0 | 11/1/2003 | 0 | 12/23/2003 | 0 | 2/13/2004 | 20.43 |
| 9/11/2003 | 0.0086 | 11/2/2003 | 0 | 12/24/2003 | 0.4802 | 2/14/2004 | 8.706 |
| 9/12/2003 | 0 | 11/3/2003 | 0 | 12/25/2003 | 0.9856 | 2/15/2004 | 7.59 |
| 9/13/2003 | 0 | 11/4/2003 | 0 | 12/26/2003 | 6.8488 | 2/16/2004 | 5.958 |
| 9/14/2003 | 0 | 11/5/2003 | 0.8878 | 12/27/2003 | 9.376 | 2/17/2004 | 0.925 |
| 9/15/2003 | 0 | 11/6/2003 | 5.1051 | 12/28/2003 | 1.8954 | 2/18/2004 | 6.176 |
| 9/16/2003 | 0 | 11/7/2003 | 5.4797 | 12/29/2003 | 8.6684 | 2/19/2004 | 12.57 |
| 9/17/2003 | 0.1719 | 11/8/2003 | 0 | 12/30/2003 | 29.72 | 2/20/2004 | 10.69 |
| 9/18/2003 | 0.0172 | 11/9/2003 | 0 | 12/31/2003 | 17.994 | 2/21/2004 | 7.59 |
| 9/19/2003 | 0.0859 | 11/10/2003 | 0 | 1/1/2004 | 4.484 | 2/22/2004 | 11.02 |
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| 9/22/2003 | 0 | 11/13/2003 | 5.6323 | 1/4/2004 | 0 | 2/25/2004 | 11.13 |
| 9/23/2003 | 0 | 11/14/2003 | 0.6798 | 1/5/2004 | 0 | 2/26/2004 | 0.463 |
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| 9/26/2003 | 0 | 11/17/2003 | 0 | 1/8/2004 | 0.3402 | 2/29/2004 | 3.21 |
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| 9/29/2003 | 0.1461 | 11/20/2003 | 17.299 | 1/11/2004 | 15.802 | 3/3/2004 | 28.34 |
| 9/30/2003 | 0.0859 | 11/21/2003 | 8.1848 | 1/12/2004 | 28.048 | 3/4/2004 | 13.4 |
| 01-Oct-2003 | 0.3522 | 11/22/2003 | 0 | 1/13/2004 | 1.6699 | 3/5/2004 | 0 |
| 02-Oct-2003 | 0 | 11/23/2003 | 0.5133 | 1/14/2004 | 1.0205 | 3/6/2004 | 21.36 |
| 03-Oct-2003 | 0 | 11/24/2003 | 1.4427 | 1/15/2004 | 0.6185 | 3/7/2004 | 29.45 |
| 04-Oct-2003 | 0.9309 | 11/25/2003 | 0 | 1/16/2004 | 0 | 3/8/2004 | 2.681 |
| 05-Oct-2003 | 1.0064 | 11/26/2003 | 0.3468 | 1/17/2004 | 25.574 | 3/9/2004 | 4.638 |
| 06-Oct-2003 | 1.107 | 11/27/2003 | 3.3433 | 1/18/2004 | 0.4948 | 3/10/2004 | 0 |
| 07-Oct-2003 | 1.0315 | 11/28/2003 | 0 | 1/19/2004 | 2.7832 | 3/11/2004 | 0.511 |
| 08-Oct-2003 | 1.0064 | 11/29/2003 | 7.4357 | 1/20/2004 | 1.4844 | 3/12/2004 | 1.745 |
| 09-Oct-2003 | 0 | 11/30/2003 | 2.0948 | 1/21/2004 | 0 | 3/13/2004 | 2.851 |
| 10-Oct-2003 | 0 | 12/1/2003 | 2.5525 | 1/22/2004 | 11.535 | 3/14/2004 | 0 |
| 11-Oct-2003 | 0.3271 | 12/2/2003 | 0 | 1/23/2004 | 6.7106 | 3/15/2004 | 13.36 |
| 12-Oct-2003 | 0 | 12/3/2003 | 1.5669 | 1/24/2004 | 1.0514 | 3/16/2004 | 8.298 |
| 13-Oct-2003 | 0 | 12/4/2003 | 0 | 1/25/2004 | 12.37 | 3/17/2004 | 1.915 |
| 14-Oct-2003 | 0 | 12/5/2003 | 0 | 1/26/2004 | 1.7008 | 3/18/2004 | 0 |
| 15-Oct-2003 | 0 | 12/6/2003 | 0 | 1/27/2004 | 0.7113 | 3/19/2004 | 0 |
| 16-Oct-2003 | 0 | 12/7/2003 | 0 | 1/28/2004 | 20.781 | 3/20/2004 | 0 |
| 17-Oct-2003 | 11.02 | 12/8/2003 | 1.1878 | 1/29/2004 | 16.977 | 3/21/2004 | 2.255 |
| 18-Oct-2003 | 1.736 | 12/9/2003 | 3.0074 | 1/30/2004 | 0 | 3/22/2004 | 11.28 |
| 19-Oct-2003 | 0 | 12/10/2003 | 2.6283 | 1/31/2004 | 0 | 3/23/2004 | 9.489 |
| 20-Oct-2003 | 14.29 | 12/11/2003 | 3.8667 | 2/1/2004 | 2.9382 | 3/24/2004 | 3.319 |
| 21-Oct-2003 | 0.9309 | 12/12/2003 | 5.8884 | 2/2/2004 | 0 | 3/25/2004 | 2.425 |
| 22-Oct-2003 | 1.8869 | 12/13/2003 | 1.6932 | 2/3/2004 | 0 | 3/26/2004 | 29.74 |
| 23-Oct-2003 | 0 | 12/14/2003 | 2.5272 | 2/4/2004 | 14.718 | 3/27/2004 | 6.936 |
| 24-Oct-2003 | 5.6608 | 12/15/2003 | 7.1268 | 2/5/2004 | 0 | 3/28/2004 | 0 |
| 25-Oct-2003 | 5.9124 | 12/16/2003 | 0.3285 | 2/6/2004 | 0 | 3/29/2004 | 7.702 |

# Appendix $D_3$: TRMM data for Station pcpKb05

| Latitude | | | | | | -11.34 | |
|---|---|---|---|---|---|---|---|
| Longitude | | | | | | 24.15 | |
| **Date** | **Pcp(mm/day)** | **Date** | **Pcp(mm/day)** | **Date** | **Pcp(mm/day)** | **Date** | **Pcp(mm/day)** |
| 1-Jan-98 | 43.45897 | 19-Feb-98 | 0 | 9-Apr-98 | 0 | 28-May-1998 | 0 |
| 2-Jan-98 | 0.223283 | 20-Feb-98 | 1.652302 | 10-Apr-98 | 0 | 29-May-1998 | 0 |
| 3-Jan-98 | 14.98025 | 21-Feb-98 | 0.539861 | 11-Apr-98 | 0 | 30-May-1998 | 0 |
| 4-Jan-98 | 2.273426 | 22-Feb-98 | 0 | 12-Apr-98 | 0 | 31-May-1998 | 0 |
| 5-Jan-98 | 3.268049 | 23-Feb-98 | 0 | 13-Apr-98 | 0 | 1-Jun-98 | 0 |
| 6-Jan-98 | 1.502085 | 24-Feb-98 | 3.451839 | 14-Apr-98 | 0 | 2-Jun-98 | 0 |
| 7-Jan-98 | 1.664473 | 25-Feb-98 | 3.353682 | 15-Apr-98 | 0 | 3-Jun-98 | 0 |
| 8-Jan-98 | 5.541475 | 26-Feb-98 | 9.766578 | 16-Apr-98 | 0 | 4-Jun-98 | 0 |
| 9-Jan-98 | 5.785057 | 27-Feb-98 | 2.257601 | 17-Apr-98 | 0 | 5-Jun-98 | 0 |
| 10-Jan-98 | 0 | 28-Feb-98 | 0.179954 | 18-Apr-98 | 0 | 6-Jun-98 | 0 |
| 11-Jan-98 | 3.146259 | 1-Mar-98 | 11.28242 | 19-Apr-98 | 0 | 7-Jun-98 | 0 |
| 12-Jan-98 | 11.14385 | 2-Mar-98 | 5.209872 | 20-Apr-98 | 0 | 8-Jun-98 | 0 |
| 13-Jan-98 | 2.760588 | 3-Mar-98 | 1.877584 | 21-Apr-98 | 0 | 9-Jun-98 | 0 |
| 14-Jan-98 | 7.794603 | 4-Mar-98 | 2.58802 | 22-Apr-98 | 0 | 10-Jun-98 | 0 |
| 15-Jan-98 | 8.302064 | 5-Mar-98 | 0 | 23-Apr-98 | 0 | 11-Jun-98 | 0 |
| 16-Jan-98 | 0.608953 | 6-Mar-98 | 0.270643 | 24-Apr-98 | 0 | 12-Jun-98 | 0 |
| 17-Jan-98 | 3.531929 | 7-Mar-98 | 2.165141 | 25-Apr-98 | 0 | 13-Jun-98 | 0 |
| 18-Jan-98 | 3.065065 | 8-Mar-98 | 0 | 26-Apr-98 | 0 | 14-Jun-98 | 0 |
| 19-Jan-98 | 0 | 9-Mar-98 | 0 | 27-Apr-98 | 0 | 15-Jun-98 | 0 |
| 20-Jan-98 | 5.561774 | 10-Mar-98 | 0 | 28-Apr-98 | 0 | 16-Jun-98 | 0 |
| 21-Jan-98 | 0 | 11-Mar-98 | 2.165141 | 29-Apr-98 | 0 | 17-Jun-98 | 0 |
| 22-Jan-98 | 7.672812 | 12-Mar-98 | 0 | 30-Apr-98 | 0 | 18-Jun-98 | 0 |
| 23-Jan-98 | 16.34025 | 13-Mar-98 | 11.84062 | 01-May-1998 | 0 | 19-Jun-98 | 0 |
| 24-Jan-98 | 2.719991 | 14-Mar-98 | 0.710437 | 02-May-1998 | 0 | 20-Jun-98 | 0 |
| 25-Jan-98 | 0.608953 | 15-Mar-98 | 1.420874 | 03-May-1998 | 0 | 21-Jun-98 | 0 |
| 26-Jan-98 | 2.780887 | 16-Mar-98 | 62.83984 | 04-May-1998 | 0 | 22-Jun-98 | 0 |
| 27-Jan-98 | 4.648344 | 17-Mar-98 | 0 | 05-May-1998 | 0 | 23-Jun-98 | 0 |
| 28-Jan-98 | 5.2167 | 18-Mar-98 | 1.251722 | 06-May-1998 | 0 | 24-Jun-98 | 0 |
| 29-Jan-98 | 0.405969 | 19-Mar-98 | 9.641645 | 07-May-1998 | 0 | 25-Jun-98 | 0 |
| 30-Jan-98 | 4.729537 | 20-Mar-98 | 1.234807 | 08-May-1998 | 0 | 26-Jun-98 | 0 |
| 31-Jan-98 | 9.78385 | 21-Mar-98 | 12.00977 | 09-May-1998 | 0 | 27-Jun-98 | 0 |
| 1-Feb-98 | 2.519352 | 22-Mar-98 | 0.016915 | 10-May-1998 | 0 | 28-Jun-98 | 0 |
| 2-Feb-98 | 0 | 23-Mar-98 | 0 | 11-May-1998 | 0 | 29-Jun-98 | 0 |
| 3-Feb-98 | 0 | 24-Mar-98 | 0 | 12-May-1998 | 0 | 30-Jun-98 | 0 |
| 4-Feb-98 | 0 | 25-Mar-98 | 2.604936 | 13-May-1998 | 0 | 1-Jul-98 | 0 |
| 5-Feb-98 | 0 | 26-Mar-98 | 0.930334 | 14-May-1998 | 0 | 2-Jul-98 | 0 |
| 6-Feb-98 | 0 | 27-Mar-98 | 0 | 15-May-1998 | 0 | 3-Jul-98 | 0 |
| 7-Feb-98 | 0 | 28-Mar-98 | 0 | 16-May-1998 | 0 | 4-Jul-98 | 0 |
| 8-Feb-98 | 0 | 29-Mar-98 | 0 | 17-May-1998 | 0 | 5-Jul-98 | 0 |
| 9-Feb-98 | 0 | 30-Mar-98 | 0 | 18-May-1998 | 0 | 6-Jul-98 | 0 |
| 10-Feb-98 | 0.883409 | 31-Mar-98 | 0 | 19-May-1998 | 0 | 7-Jul-98 | 0 |
| 11-Feb-98 | 3.599074 | 1-Apr-98 | 0 | 20-May-1998 | 0 | 8-Jul-98 | 0 |
| 12-Feb-98 | 3.582715 | 2-Apr-98 | 0 | 21-May-1998 | 0 | 9-Jul-98 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 14-Feb-98 | 0.932487 | 4-Apr-98 | 0 | 23-May-1998 | 0 | 11-Jul-98 | 0 |
| 15-Feb-98 | 3.615433 | 5-Apr-98 | 0 | 24-May-1998 | 0 | 12-Jul-98 | 0 |
| 16-Feb-98 | 0 | 6-Apr-98 | 0 | 25-May-1998 | 0 | 13-Jul-98 | 0 |
| 17-Feb-98 | 2.699305 | 7-Apr-98 | 0 | 26-May-1998 | 0 | 14-Jul-98 | 0 |
| 18-Feb-98 | 8.065198 | 8-Apr-98 | 0 | 27-May-1998 | 0 | 15-Jul-98 | 0 |
| 16-Jul-98 | 0 | 4-Sep-98 | 0 | 24-Oct-1998 | 0 | 13-Dec-98 | 1.912938 |
| 17-Jul-98 | 0 | 5-Sep-98 | 0 | 25-Oct-1998 | 0 | 14-Dec-98 | 14.87309 |
| 18-Jul-98 | 0 | 6-Sep-98 | 0 | 26-Oct-1998 | 0 | 15-Dec-98 | 3.443289 |
| 19-Jul-98 | 0 | 7-Sep-98 | 0 | 27-Oct-1998 | 0 | 16-Dec-98 | 0.884734 |
| 20-Jul-98 | 0 | 8-Sep-98 | 0 | 28-Oct-1998 | 1.789837 | 17-Dec-98 | 0 |
| 21-Jul-98 | 0.144 | 9-Sep-98 | 0 | 29-Oct-1998 | 0 | 18-Dec-98 | 34.2655 |
| 22-Jul-98 | 0 | 10-Sep-98 | 0 | 30-Oct-1998 | 0.687859 | 19-Dec-98 | 9.803807 |
| 23-Jul-98 | 0 | 11-Sep-98 | 0 | 31-Oct-1998 | 0 | 20-Dec-98 | 0 |
| 24-Jul-98 | 0 | 12-Sep-98 | 0 | 1-Nov-98 | 0 | 21-Dec-98 | 6.145313 |
| 25-Jul-98 | 0 | 13-Sep-98 | 0.018 | 2-Nov-98 | 0 | 22-Dec-98 | 4.232375 |
| 26-Jul-98 | 0 | 14-Sep-98 | 0 | 3-Nov-98 | 0 | 23-Dec-98 | 1.315145 |
| 27-Jul-98 | 0 | 15-Sep-98 | 0 | 4-Nov-98 | 0 | 24-Dec-98 | 7.030047 |
| 28-Jul-98 | 0 | 16-Sep-98 | 0 | 5-Nov-98 | 0 | 25-Dec-98 | 1.052116 |
| 29-Jul-98 | 0 | 17-Sep-98 | 0 | 6-Nov-98 | 1.102816 | 26-Dec-98 | 5.523609 |
| 30-Jul-98 | 0 | 18-Sep-98 | 0 | 7-Nov-98 | 0 | 27-Dec-98 | 7.3409 |
| 31-Jul-98 | 0 | 19-Sep-98 | 0 | 8-Nov-98 | 2.7429 | 28-Dec-98 | 7.819134 |
| 1-Aug-98 | 0 | 20-Sep-98 | 0 | 9-Nov-98 | 0 | 29-Dec-98 | 0 |
| 2-Aug-98 | 0 | 21-Sep-98 | 0 | 10-Nov-98 | 5.796852 | 30-Dec-98 | 0 |
| 3-Aug-98 | 0 | 22-Sep-98 | 0 | 11-Nov-98 | 22.11287 | 31-Dec-98 | 1.004292 |
| 4-Aug-98 | 0 | 23-Sep-98 | 0 | 12-Nov-98 | 2.573237 | 1-Jan-99 | 6.04814 |
| 5-Aug-98 | 0 | 24-Sep-98 | 0 | 13-Nov-98 | 0.73521 | 2-Jan-99 | 9.530404 |
| 6-Aug-98 | 0 | 25-Sep-98 | 0 | 14-Nov-98 | 3.562943 | 3-Jan-99 | 16.82483 |
| 7-Aug-98 | 0 | 26-Sep-98 | 0.39 | 15-Nov-98 | 12.58341 | 4-Jan-99 | 54.68985 |
| 8-Aug-98 | 0 | 27-Sep-98 | 0 | 16-Nov-98 | 8.256979 | 5-Jan-99 | 8.504052 |
| 9-Aug-98 | 0 | 28-Sep-98 | 0.126 | 17-Nov-98 | 20.61417 | 6-Jan-99 | 0 |
| 10-Aug-98 | 0 | 29-Sep-98 | 0.078 | 18-Nov-98 | 0 | 7-Jan-99 | 20.63699 |
| 11-Aug-98 | 0 | 30-Sep-98 | 0 | 19-Nov-98 | 0 | 8-Jan-99 | 10.11689 |
| 12-Aug-98 | 0 | 01-Oct-1998 | 0 | 20-Nov-98 | 6.44723 | 9-Jan-99 | 7.074492 |
| 13-Aug-98 | 0 | 02-Oct-1998 | 0.512385 | 21-Nov-98 | 0.084832 | 10-Jan-99 | 0.623142 |
| 14-Aug-98 | 0 | 03-Oct-1998 | 0.308835 | 22-Nov-98 | 4.43954 | 11-Jan-99 | 41.05404 |
| 15-Aug-98 | 0 | 04-Oct-1998 | 0 | 23-Nov-98 | 1.046261 | 12-Jan-99 | 29.03107 |
| 16-Aug-98 | 0 | 05-Oct-1998 | 0 | 24-Nov-98 | 0 | 13-Jan-99 | 18.58429 |
| 17-Aug-98 | 0 | 06-Oct-1998 | 0 | 25-Nov-98 | 2.544959 | 14-Jan-99 | 32.44002 |
| 18-Aug-98 | 0 | 07-Oct-1998 | 0 | 26-Nov-98 | 0 | 15-Jan-99 | 8.137498 |
| 19-Aug-98 | 0 | 08-Oct-1998 | 0 | 27-Nov-98 | 10.29295 | 16-Jan-99 | 22.35979 |
| 20-Aug-98 | 0 | 09-Oct-1998 | 0 | 28-Nov-98 | 9.981896 | 17-Jan-99 | 1.136317 |
| 21-Aug-98 | 0 | 10-Oct-1998 | 0 | 29-Nov-98 | 0.367605 | 18-Jan-99 | 0 |
| 22-Aug-98 | 0 | 11-Oct-1998 | 0 | 30-Nov-98 | 0.706933 | 19-Jan-99 | 3.262331 |
| 23-Aug-98 | 0 | 12-Oct-1998 | 0 | 1-Dec-98 | 8.72778 | 20-Jan-99 | 41.89712 |
| 24-Aug-98 | 0 | 13-Oct-1998 | 0.4071 | 2-Dec-98 | 0 | 21-Jan-99 | 0 |
| 25-Aug-98 | 0 | 14-Oct-1998 | 0 | 3-Dec-98 | 0 | 22-Jan-99 | 5.938174 |
| 26-Aug-98 | 0 | 15-Oct-1998 | 0 | 4-Dec-98 | 28.23974 | 23-Jan-99 | 6.634626 |
| 27-Aug-98 | 0 | 16-Oct-1998 | 0.238645 | 5-Dec-98 | 0.789087 | 24-Jan-99 | 0.989696 |
| 28-Aug-98 | 0 | 17-Oct-1998 | 0 | 6-Dec-98 | 5.045374 | 25-Jan-99 | 2.126013 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 30-Aug-98 | 0 | 19-Oct-1998 | 0 | 8-Dec-98 | 3.204171 | 27-Jan-99 | 6.268072 |
| 31-Aug-98 | 0.036 | 20-Oct-1998 | 0.063171 | 9-Dec-98 | 0 | 28-Jan-99 | 18.95084 |
| 1-Sep-98 | 0 | 21-Oct-1998 | 0 | 10-Dec-98 | 14.75353 | 29-Jan-99 | 0 |
| 2-Sep-98 | 0 | 22-Oct-1998 | 0 | 11-Dec-98 | 7.508281 | 30-Jan-99 | 0.989696 |
| 3-Sep-98 | 0 | 23-Oct-1998 | 0 | 12-Dec-98 | 4.351934 | 31-Jan-99 | 21.91993 |
| 1-Feb-99 | 15.49452 | 23-Mar-99 | 2.821082 | 12-May-1999 | 0 | 1-Jul-99 | 0 |
| 2-Feb-99 | 0 | 24-Mar-99 | 1.696462 | 13-May-1999 | 0 | 2-Jul-99 | 0 |
| 3-Feb-99 | 10.34521 | 25-Mar-99 | 5.413428 | 14-May-1999 | 0 | 3-Jul-99 | 0 |
| 4-Feb-99 | 2.143602 | 26-Mar-99 | 0.8387 | 15-May-1999 | 0 | 4-Jul-99 | 0 |
| 5-Feb-99 | 0.0233 | 27-Mar-99 | 0 | 16-May-1999 | 0 | 5-Jul-99 | 0 |
| 6-Feb-99 | 6.384208 | 28-Mar-99 | 0 | 17-May-1999 | 0 | 6-Jul-99 | 0 |
| 7-Feb-99 | 7.292908 | 29-Mar-99 | 0 | 18-May-1999 | 0 | 7-Jul-99 | 0 |
| 8-Feb-99 | 1.794102 | 30-Mar-99 | 0 | 19-May-1999 | 0 | 8-Jul-99 | 0 |
| 9-Feb-99 | 3.681404 | 31-Mar-99 | 0 | 20-May-1999 | 0 | 9-Jul-99 | 0 |
| 10-Feb-99 | 3.238704 | 1-Apr-99 | 0 | 21-May-1999 | 0 | 10-Jul-99 | 0 |
| 11-Feb-99 | 1.631002 | 2-Apr-99 | 0 | 22-May-1999 | 0 | 11-Jul-99 | 0 |
| 12-Feb-99 | 19.05942 | 3-Apr-99 | 0 | 23-May-1999 | 0 | 12-Jul-99 | 0 |
| 13-Feb-99 | 0 | 4-Apr-99 | 1.398 | 24-May-1999 | 0 | 13-Jul-99 | 0 |
| 14-Feb-99 | 5.032806 | 5-Apr-99 | 0 | 25-May-1999 | 0 | 14-Jul-99 | 0 |
| 15-Feb-99 | 3.681404 | 6-Apr-99 | 0 | 26-May-1999 | 0 | 15-Jul-99 | 0 |
| 16-Feb-99 | 0 | 7-Apr-99 | 0 | 27-May-1999 | 0 | 16-Jul-99 | 0 |
| 17-Feb-99 | 1.234901 | 8-Apr-99 | 0 | 28-May-1999 | 0 | 17-Jul-99 | 0 |
| 18-Feb-99 | 0 | 9-Apr-99 | 0 | 29-May-1999 | 0 | 18-Jul-99 | 0 |
| 19-Feb-99 | 0 | 10-Apr-99 | 0 | 30-May-1999 | 0 | 19-Jul-99 | 0 |
| 20-Feb-99 | 4.100805 | 11-Apr-99 | 0 | 31-May-1999 | 0 | 20-Jul-99 | 0 |
| 21-Feb-99 | 1.374702 | 12-Apr-99 | 0 | 1-Jun-99 | 0 | 21-Jul-99 | 0 |
| 22-Feb-99 | 3.797904 | 13-Apr-99 | 0 | 2-Jun-99 | 0 | 22-Jul-99 | 0 |
| 23-Feb-99 | 2.563003 | 14-Apr-99 | 0 | 3-Jun-99 | 0 | 23-Jul-99 | 0 |
| 24-Feb-99 | 0.815501 | 15-Apr-99 | 0 | 4-Jun-99 | 0 | 24-Jul-99 | 0 |
| 25-Feb-99 | 2.796003 | 16-Apr-99 | 0 | 5-Jun-99 | 0 | 25-Jul-99 | 0 |
| 26-Feb-99 | 0.0233 | 17-Apr-99 | 0 | 6-Jun-99 | 0 | 26-Jul-99 | 0 |
| 27-Feb-99 | 4.450305 | 18-Apr-99 | 0 | 7-Jun-99 | 0 | 27-Jul-99 | 0 |
| 28-Feb-99 | 0.3262 | 19-Apr-99 | 0.006 | 8-Jun-99 | 0 | 28-Jul-99 | 0 |
| 1-Mar-99 | 0 | 20-Apr-99 | 0 | 9-Jun-99 | 0 | 29-Jul-99 | 0 |
| 2-Mar-99 | 13.49545 | 21-Apr-99 | 0 | 10-Jun-99 | 0 | 30-Jul-99 | 0 |
| 3-Mar-99 | 1.582093 | 22-Apr-99 | 0 | 11-Jun-99 | 0 | 31-Jul-99 | 0 |
| 4-Mar-99 | 14.20072 | 23-Apr-99 | 0 | 12-Jun-99 | 0 | 1-Aug-99 | 0 |
| 5-Mar-99 | 2.763898 | 24-Apr-99 | 0 | 13-Jun-99 | 0 | 2-Aug-99 | 0 |
| 6-Mar-99 | 0 | 25-Apr-99 | 0 | 14-Jun-99 | 0 | 3-Aug-99 | 0 |
| 7-Mar-99 | 55.18266 | 26-Apr-99 | 0 | 15-Jun-99 | 0 | 4-Aug-99 | 0 |
| 8-Mar-99 | 28.43956 | 27-Apr-99 | 0 | 16-Jun-99 | 0 | 5-Aug-99 | 0 |
| 9-Mar-99 | 2.458916 | 28-Apr-99 | 0 | 17-Jun-99 | 0 | 6-Aug-99 | 0 |
| 10-Mar-99 | 0 | 29-Apr-99 | 0 | 18-Jun-99 | 0 | 7-Aug-99 | 0 |
| 11-Mar-99 | 0 | 30-Apr-99 | 0 | 19-Jun-99 | 0 | 8-Aug-99 | 0 |
| 12-Mar-99 | 0 | 01-May-1999 | 0 | 20-Jun-99 | 0 | 9-Aug-99 | 0 |
| 13-Mar-99 | 0 | 02-May-1999 | 0 | 21-Jun-99 | 0 | 10-Aug-99 | 0 |
| 14-Mar-99 | 3.926642 | 03-May-1999 | 0 | 22-Jun-99 | 0 | 11-Aug-99 | 0 |
| 15-Mar-99 | 8.749167 | 04-May-1999 | 0 | 23-Jun-99 | 0 | 12-Aug-99 | 0 |
| 16-Mar-99 | 0.609964 | 05-May-1999 | 0 | 24-Jun-99 | 0 | 13-Aug-99 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 18-Mar-99 | 0.266859 | 07-May-1999 | 0 | 26-Jun-99 | 0 | 15-Aug-99 | 0 |
| 19-Mar-99 | 7.52924 | 08-May-1999 | 0 | 27-Jun-99 | 0 | 16-Aug-99 | 0 |
| 20-Mar-99 | 5.108446 | 09-May-1999 | 0 | 28-Jun-99 | 0 | 17-Aug-99 | 0 |
| 21-Mar-99 | 2.382671 | 10-May-1999 | 0 | 29-Jun-99 | 0 | 18-Aug-99 | 0 |
| 22-Mar-99 | 0.28592 | 11-May-1999 | 0 | 30-Jun-99 | 0 | 19-Aug-99 | 0 |
| 20-Aug-99 | 0 | 09-Oct-1999 | 0 | 28-Nov-99 | 17.49104 | 17-Jan-00 | 1.858091 |
| 21-Aug-99 | 0 | 10-Oct-1999 | 0 | 29-Nov-99 | 39.12015 | 18-Jan-00 | 0.068818 |
| 22-Aug-99 | 0 | 11-Oct-1999 | 0.011082 | 30-Nov-99 | 0.996204 | 19-Jan-00 | 1.204319 |
| 23-Aug-99 | 0 | 12-Oct-1999 | 0.14407 | 1-Dec-99 | 0 | 20-Jan-00 | 12.97223 |
| 24-Aug-99 | 0 | 13-Oct-1999 | 0.055412 | 2-Dec-99 | 1.916318 | 21-Jan-00 | 0.929046 |
| 25-Aug-99 | 0.049498 | 14-Oct-1999 | 0.80901 | 3-Dec-99 | 0 | 22-Jan-00 | 30.6241 |
| 26-Aug-99 | 0 | 15-Oct-1999 | 0 | 4-Dec-99 | 5.396527 | 23-Jan-00 | 1.204319 |
| 27-Aug-99 | 0 | 16-Oct-1999 | 0 | 5-Dec-99 | 0.947145 | 24-Jan-00 | 0.929046 |
| 28-Aug-99 | 0 | 17-Oct-1999 | 1.363126 | 6-Dec-99 | 0.550666 | 25-Jan-00 | 5.952774 |
| 29-Aug-99 | 0 | 18-Oct-1999 | 0 | 7-Dec-99 | 12.13668 | 26-Jan-00 | 0 |
| 30-Aug-99 | 0 | 19-Oct-1999 | 0.410046 | 8-Dec-99 | 8.590389 | 27-Jan-00 | 5.436638 |
| 31-Aug-99 | 0 | 20-Oct-1999 | 0.28814 | 9-Dec-99 | 0 | 28-Jan-00 | 6.021593 |
| 1-Sep-99 | 0 | 21-Oct-1999 | 0 | 10-Dec-99 | 1.674025 | 29-Jan-00 | 2.167773 |
| 2-Sep-99 | 0 | 22-Oct-1999 | 0 | 11-Dec-99 | 1.057279 | 30-Jan-00 | 0 |
| 3-Sep-99 | 0 | 23-Oct-1999 | 0.055412 | 12-Dec-99 | 3.744529 | 31-Jan-00 | 1.066682 |
| 4-Sep-99 | 0 | 24-Oct-1999 | 0 | 13-Dec-99 | 9.030922 | 1-Feb-00 | 0 |
| 5-Sep-99 | 0 | 25-Oct-1999 | 0 | 14-Dec-99 | 13.01774 | 2-Feb-00 | 4.727103 |
| 6-Sep-99 | 0 | 26-Oct-1999 | 0.642775 | 15-Dec-99 | 7.885537 | 3-Feb-00 | 5.022547 |
| 7-Sep-99 | 0 | 27-Oct-1999 | 3.557426 | 16-Dec-99 | 7.356898 | 4-Feb-00 | 0 |
| 8-Sep-99 | 0 | 28-Oct-1999 | 0.410046 | 17-Dec-99 | 0 | 5-Feb-00 | 3.212953 |
| 9-Sep-99 | 0 | 29-Oct-1999 | 0.531951 | 18-Dec-99 | 1.035252 | 6-Feb-00 | 0 |
| 10-Sep-99 | 0 | 30-Oct-1999 | 1.606937 | 19-Dec-99 | 0 | 7-Feb-00 | 4.727103 |
| 11-Sep-99 | 0 | 31-Oct-1999 | 0 | 20-Dec-99 | 1.982398 | 8-Feb-00 | 2.363552 |
| 12-Sep-99 | 0 | 1-Nov-99 | 0 | 21-Dec-99 | 0 | 9-Feb-00 | 5.502644 |
| 13-Sep-99 | 0 | 2-Nov-99 | 0 | 22-Dec-99 | 0 | 10-Feb-00 | 0 |
| 14-Sep-99 | 0 | 3-Nov-99 | 0 | 23-Dec-99 | 0 | 11-Feb-00 | 22.93383 |
| 15-Sep-99 | 0 | 4-Nov-99 | 0 | 24-Dec-99 | 0 | 12-Feb-00 | 0 |
| 16-Sep-99 | 0 | 5-Nov-99 | 0 | 25-Dec-99 | 5.11018 | 13-Feb-00 | 0 |
| 17-Sep-99 | 0 | 6-Nov-99 | 0 | 26-Dec-99 | 3.480209 | 14-Feb-00 | 0 |
| 18-Sep-99 | 0 | 7-Nov-99 | 2.030723 | 27-Dec-99 | 0 | 15-Feb-00 | 11.52231 |
| 19-Sep-99 | 0 | 8-Nov-99 | 1.513463 | 28-Dec-99 | 0 | 16-Feb-00 | 11.89162 |
| 20-Sep-99 | 0 | 9-Nov-99 | 5.517435 | 29-Dec-99 | 7.334871 | 17-Feb-00 | 3.434536 |
| 21-Sep-99 | 0 | 10-Nov-99 | 14.86642 | 30-Dec-99 | 12.4891 | 18-Feb-00 | 30.283 |
| 22-Sep-99 | 0 | 11-Nov-99 | 9.176568 | 31-Dec-99 | 0 | 19-Feb-00 | 5.465713 |
| 23-Sep-99 | 0 | 12-Nov-99 | 0.862099 | 1-Jan-00 | 0 | 20-Feb-00 | 0.517027 |
| 24-Sep-99 | 0 | 13-Nov-99 | 0 | 2-Jan-00 | 0.653773 | 21-Feb-00 | 6.75828 |
| 25-Sep-99 | 0 | 14-Nov-99 | 0 | 3-Jan-00 | 67.20097 | 22-Feb-00 | 4.948686 |
| 26-Sep-99 | 4.29 | 15-Nov-99 | 0 | 4-Jan-00 | 18.78737 | 23-Feb-00 | 0 |
| 27-Sep-99 | 0.15 | 16-Nov-99 | 0 | 5-Jan-00 | 11.83673 | 24-Feb-00 | 8.346291 |
| 28-Sep-99 | 0 | 17-Nov-99 | 0 | 6-Jan-00 | 5.574275 | 25-Feb-00 | 5.207199 |
| 29-Sep-99 | 0.024 | 18-Nov-99 | 0.287366 | 7-Jan-00 | 0 | 26-Feb-00 | 2.622065 |
| 30-Sep-99 | 0.534 | 19-Nov-99 | 2.701244 | 8-Jan-00 | 26.01328 | 27-Feb-00 | 16.87723 |
| 01-Oct-1999 | 0 | 20-Nov-99 | 0.957888 | 9-Jan-00 | 0 | 28-Feb-00 | 15.28922 |
| 02-Oct-1999 | 0 | 21-Nov-99 | 0 | 10-Jan-00 | 0 | 29-Feb-00 | 32.86813 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 04-Oct-1999 | 0.930915 | 23-Nov-99 | 0.440629 | 12-Jan-00 | 0 | 2-Mar-00 | 16.17313 |
| 05-Oct-1999 | 0.210564 | 24-Nov-99 | 0 | 13-Jan-00 | 2.752728 | 3-Mar-00 | 29.27602 |
| 06-Oct-1999 | 0 | 25-Nov-99 | 0.287366 | 14-Jan-00 | 21.43687 | 4-Mar-00 | 0.241751 |
| 07-Oct-1999 | 0 | 26-Nov-99 | 5.230069 | 15-Jan-00 | 0 | 5-Mar-00 | 3.747137 |
| 08-Oct-1999 | 0 | 27-Nov-99 | 0.153262 | 16-Jan-00 | 4.817274 | 6-Mar-00 | 0 |
| 7-Mar-00 | 14.4567 | 26-Apr-00 | 0 | 15-Jun-00 | 0 | 4-Aug-00 | 0 |
| 8-Mar-00 | 10.37111 | 27-Apr-00 | 0 | 16-Jun-00 | 0 | 5-Aug-00 | 0 |
| 9-Mar-00 | 13.24794 | 28-Apr-00 | 0 | 17-Jun-00 | 0 | 6-Aug-00 | 0 |
| 10-Mar-00 | 10.46781 | 29-Apr-00 | 0 | 18-Jun-00 | 0 | 7-Aug-00 | 0 |
| 11-Mar-00 | 4.76249 | 30-Apr-00 | 0.990456 | 19-Jun-00 | 0 | 8-Aug-00 | 0 |
| 12-Mar-00 | 7.929426 | 01-May-2000 | 0 | 20-Jun-00 | 0 | 9-Aug-00 | 0 |
| 13-Mar-00 | 13.12707 | 02-May-2000 | 0 | 21-Jun-00 | 0 | 10-Aug-00 | 0 |
| 14-Mar-00 | 0 | 03-May-2000 | 0 | 22-Jun-00 | 0 | 11-Aug-00 | 0 |
| 15-Mar-00 | 0.217576 | 04-May-2000 | 0 | 23-Jun-00 | 0 | 12-Aug-00 | 0 |
| 16-Mar-00 | 0 | 05-May-2000 | 2.117337 | 24-Jun-00 | 0 | 13-Aug-00 | 0 |
| 17-Mar-00 | 0.846128 | 06-May-2000 | 2.838525 | 25-Jun-00 | 0 | 14-Aug-00 | 0 |
| 18-Mar-00 | 5.632792 | 07-May-2000 | 0 | 26-Jun-00 | 0 | 15-Aug-00 | 0 |
| 19-Mar-00 | 0 | 08-May-2000 | 0.249642 | 27-Jun-00 | 0 | 16-Aug-00 | 0 |
| 20-Mar-00 | 0 | 09-May-2000 | 0 | 28-Jun-00 | 0 | 17-Aug-00 | 0 |
| 21-Mar-00 | 5.850368 | 10-May-2000 | 0 | 29-Jun-00 | 0 | 18-Aug-00 | 0 |
| 22-Mar-00 | 17.43023 | 11-May-2000 | 0 | 30-Jun-00 | 0 | 19-Aug-00 | 0 |
| 23-Mar-00 | 2.780134 | 12-May-2000 | 0 | 1-Jul-00 | 0 | 20-Aug-00 | 0.012 |
| 24-Mar-00 | 0 | 13-May-2000 | 0 | 2-Jul-00 | 0 | 21-Aug-00 | 0 |
| 25-Mar-00 | 0 | 14-May-2000 | 3.772372 | 3-Jul-00 | 0 | 22-Aug-00 | 0 |
| 26-Mar-00 | 0 | 15-May-2000 | 0 | 4-Jul-00 | 0 | 23-Aug-00 | 0 |
| 27-Mar-00 | 1.160404 | 16-May-2000 | 0 | 5-Jul-00 | 0 | 24-Aug-00 | 0 |
| 28-Mar-00 | 0 | 17-May-2000 | 0 | 6-Jul-00 | 0 | 25-Aug-00 | 0 |
| 29-Mar-00 | 0 | 18-May-2000 | 0 | 7-Jul-00 | 0 | 26-Aug-00 | 0 |
| 30-Mar-00 | 0 | 19-May-2000 | 0 | 8-Jul-00 | 0 | 27-Aug-00 | 0 |
| 31-Mar-00 | 0 | 20-May-2000 | 0 | 9-Jul-00 | 0 | 28-Aug-00 | 0 |
| 1-Apr-00 | 0 | 21-May-2000 | 0 | 10-Jul-00 | 0 | 29-Aug-00 | 0 |
| 2-Apr-00 | 0 | 22-May-2000 | 0 | 11-Jul-00 | 0 | 30-Aug-00 | 0 |
| 3-Apr-00 | 0 | 23-May-2000 | 0 | 12-Jul-00 | 0 | 31-Aug-00 | 0 |
| 4-Apr-00 | 0 | 24-May-2000 | 0 | 13-Jul-00 | 0 | 1-Sep-00 | 0 |
| 5-Apr-00 | 0 | 25-May-2000 | 0 | 14-Jul-00 | 0 | 2-Sep-00 | 0 |
| 6-Apr-00 | 2.795287 | 26-May-2000 | 0 | 15-Jul-00 | 0 | 3-Sep-00 | 0 |
| 7-Apr-00 | 0 | 27-May-2000 | 0 | 16-Jul-00 | 0 | 4-Sep-00 | 0 |
| 8-Apr-00 | 10.82898 | 28-May-2000 | 0 | 17-Jul-00 | 0 | 5-Sep-00 | 0 |
| 9-Apr-00 | 0 | 29-May-2000 | 0 | 18-Jul-00 | 0 | 6-Sep-00 | 0 |
| 10-Apr-00 | 0.02201 | 30-May-2000 | 0 | 19-Jul-00 | 0 | 7-Sep-00 | 0 |
| 11-Apr-00 | 0 | 31-May-2000 | 0 | 20-Jul-00 | 0 | 8-Sep-00 | 0 |
| 12-Apr-00 | 0 | 1-Jun-00 | 0 | 21-Jul-00 | 0 | 9-Sep-00 | 0.054 |
| 13-Apr-00 | 0 | 2-Jun-00 | 0 | 22-Jul-00 | 0 | 10-Sep-00 | 0 |
| 14-Apr-00 | 0 | 3-Jun-00 | 0 | 23-Jul-00 | 0 | 11-Sep-00 | 0 |
| 15-Apr-00 | 0 | 4-Jun-00 | 0 | 24-Jul-00 | 0 | 12-Sep-00 | 0 |
| 16-Apr-00 | 0 | 5-Jun-00 | 0 | 25-Jul-00 | 0 | 13-Sep-00 | 0 |
| 17-Apr-00 | 1.078496 | 6-Jun-00 | 0 | 26-Jul-00 | 0 | 14-Sep-00 | 0 |
| 18-Apr-00 | 0 | 7-Jun-00 | 0 | 27-Jul-00 | 0 | 15-Sep-00 | 0 |
| 19-Apr-00 | 0 | 8-Jun-00 | 0 | 28-Jul-00 | 0 | 16-Sep-00 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 21-Apr-00 | 1.67277 | 10-Jun-00 | 0 | 30-Jul-00 | 0 | 18-Sep-00 | 0.3 |
| 22-Apr-00 | 0 | 11-Jun-00 | 0 | 31-Jul-00 | 0 | 19-Sep-00 | 0 |
| 23-Apr-00 | 0 | 12-Jun-00 | 0 | 1-Aug-00 | 0 | 20-Sep-00 | 0 |
| 24-Apr-00 | 0 | 13-Jun-00 | 0 | 2-Aug-00 | 0 | 21-Sep-00 | 0 |
| 25-Apr-00 | 0 | 14-Jun-00 | 0 | 3-Aug-00 | 0 | 22-Sep-00 | 0 |
| 23-Sep-00 | 0 | 12-Nov-00 | 0.168644 | 1-Jan-01 | 0 | 20-Feb-01 | 0 |
| 24-Sep-00 | 0.006 | 13-Nov-00 | 1.548457 | 2-Jan-01 | 30.20843 | 21-Feb-01 | 42.83425 |
| 25-Sep-00 | 0 | 14-Nov-00 | 0.444606 | 3-Jan-01 | 1.170045 | 22-Feb-01 | 2.423173 |
| 26-Sep-00 | 0 | 15-Nov-00 | 0 | 4-Jan-01 | 13.45551 | 23-Feb-01 | 0 |
| 27-Sep-00 | 0 | 16-Nov-00 | 0 | 5-Jan-01 | 3.377174 | 24-Feb-01 | 0 |
| 28-Sep-00 | 0 | 17-Nov-00 | 0 | 6-Jan-01 | 25.95372 | 25-Feb-01 | 0 |
| 29-Sep-00 | 0 | 18-Nov-00 | 0 | 7-Jan-01 | 28.69269 | 26-Feb-01 | 1.192947 |
| 30-Sep-00 | 0 | 19-Nov-00 | 0 | 8-Jan-01 | 18.96004 | 27-Feb-01 | 20.83929 |
| 01-Oct-2000 | 0 | 20-Nov-00 | 0 | 9-Jan-01 | 0 | 28-Feb-01 | 0 |
| 02-Oct-2000 | 0 | 21-Nov-00 | 0 | 10-Jan-01 | 0 | 1-Mar-01 | 7.581105 |
| 03-Oct-2000 | 0 | 22-Nov-00 | 0 | 11-Jan-01 | 0 | 2-Mar-01 | 4.876734 |
| 04-Oct-2000 | 0 | 23-Nov-00 | 0.107319 | 12-Jan-01 | 0.345695 | 3-Mar-01 | 0 |
| 05-Oct-2000 | 0 | 24-Nov-00 | 0.7359 | 13-Jan-01 | 2.978296 | 4-Mar-01 | 0.620675 |
| 06-Oct-2000 | 0 | 25-Nov-00 | 1.487131 | 14-Jan-01 | 0 | 5-Mar-01 | 3.546716 |
| 07-Oct-2000 | 0 | 26-Nov-00 | 0.643913 | 15-Jan-01 | 1.24982 | 6-Mar-01 | 8.64512 |
| 08-Oct-2000 | 0 | 27-Nov-00 | 7.251682 | 16-Jan-01 | 2.366681 | 7-Mar-01 | 3.635384 |
| 09-Oct-2000 | 0 | 28-Nov-00 | 3.403538 | 17-Jan-01 | 1.435964 | 8-Mar-01 | 4.477729 |
| 10-Oct-2000 | 0 | 29-Nov-00 | 0 | 18-Jan-01 | 51.96062 | 9-Mar-01 | 0.687176 |
| 11-Oct-2000 | 0 | 30-Nov-00 | 1.701769 | 19-Jan-01 | 0.664798 | 10-Mar-01 | 0 |
| 12-Oct-2000 | 0 | 1-Dec-00 | 5.245914 | 20-Jan-01 | 5.903407 | 11-Mar-01 | 9.132794 |
| 13-Oct-2000 | 0 | 2-Dec-00 | 1.369952 | 21-Jan-01 | 0 | 12-Mar-01 | 19.48477 |
| 14-Oct-2000 | 0 | 3-Dec-00 | 0 | 22-Jan-01 | 0.239327 | 13-Mar-01 | 1.108349 |
| 15-Oct-2000 | 0 | 4-Dec-00 | 9.656492 | 23-Jan-01 | 0.850942 | 14-Mar-01 | 11.17215 |
| 16-Oct-2000 | 0 | 5-Dec-00 | 4.577645 | 24-Jan-01 | 0 | 15-Mar-01 | 0 |
| 17-Oct-2000 | 0 | 6-Dec-00 | 14.46803 | 25-Jan-01 | 24.86345 | 16-Mar-01 | 1.330018 |
| 18-Oct-2000 | 0 | 7-Dec-00 | 10.72572 | 26-Jan-01 | 0.930717 | 17-Mar-01 | 2.305365 |
| 19-Oct-2000 | 0 | 8-Dec-00 | 1.169471 | 27-Jan-01 | 0 | 18-Mar-01 | 0 |
| 20-Oct-2000 | 0.459775 | 9-Dec-00 | 7.41779 | 28-Jan-01 | 9.333765 | 19-Mar-01 | 4.61073 |
| 21-Oct-2000 | 0.036782 | 10-Dec-00 | 0 | 29-Jan-01 | 13.74802 | 20-Mar-01 | 2.726538 |
| 22-Oct-2000 | 0 | 11-Dec-00 | 1.169471 | 30-Jan-01 | 11.1952 | 21-Mar-01 | 8.489951 |
| 23-Oct-2000 | 0.064368 | 12-Dec-00 | 0 | 31-Jan-01 | 4.174932 | 22-Mar-01 | 1.529521 |
| 24-Oct-2000 | 0 | 13-Dec-00 | 5.379569 | 1-Feb-01 | 1.118388 | 23-Mar-01 | 0 |
| 25-Oct-2000 | 3.521876 | 14-Dec-00 | 0 | 2-Feb-01 | 6.598488 | 24-Mar-01 | 2.305365 |
| 26-Oct-2000 | 1.397716 | 15-Dec-00 | 0.568029 | 3-Feb-01 | 11.03476 | 25-Mar-01 | 10.44065 |
| 27-Oct-2000 | 2.657499 | 16-Dec-00 | 20.48246 | 4-Feb-01 | 10.84836 | 26-Mar-01 | 5.608245 |
| 28-Oct-2000 | 2.565544 | 17-Dec-00 | 6.816347 | 5-Feb-01 | 0 | 27-Mar-01 | 0 |
| 29-Oct-2000 | 1.379325 | 18-Dec-00 | 11.8952 | 6-Feb-01 | 8.797983 | 28-Mar-01 | 4.721565 |
| 30-Oct-2000 | 14.79556 | 19-Dec-00 | 5.546636 | 7-Feb-01 | 43.54256 | 29-Mar-01 | 2.748705 |
| 31-Oct-2000 | 0 | 20-Dec-00 | 14.76875 | 8-Feb-01 | 35.26649 | 30-Mar-01 | 0 |
| 1-Nov-00 | 0 | 21-Dec-00 | 1.603846 | 9-Feb-01 | 1.86398 | 31-Mar-01 | 3.214211 |
| 2-Nov-00 | 0.306625 | 22-Dec-00 | 3.976203 | 10-Feb-01 | 2.460453 | 1-Apr-01 | 0 |
| 3-Nov-00 | 1.180506 | 23-Dec-00 | 17.17452 | 11-Feb-01 | 14.16624 | 2-Apr-01 | 0 |
| 4-Nov-00 | 0 | 24-Dec-00 | 18.00986 | 12-Feb-01 | 11.29572 | 3-Apr-01 | 8.190437 |
| 5-Nov-00 | 0 | 25-Dec-00 | 0.801923 | 13-Feb-01 | 2.274055 | 4-Apr-01 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 7-Nov-00 | 7.328339 | 27-Dec-00 | 2.739904 | 15-Feb-01 | 0 | 6-Apr-01 | 0 |
| 8-Nov-00 | 0 | 28-Dec-00 | 0.601442 | 16-Feb-01 | 2.982367 | 7-Apr-01 | 0 |
| 9-Nov-00 | 0 | 29-Dec-00 | 0 | 17-Feb-01 | 3.019647 | 8-Apr-01 | 0 |
| 10-Nov-00 | 0 | 30-Dec-00 | 2.338943 | 18-Feb-01 | 0 | 9-Apr-01 | 0.878276 |
| 11-Nov-00 | 0.199306 | 31-Dec-00 | 1.937981 | 19-Feb-01 | 0 | 10-Apr-01 | 0 |
| 11-Apr-01 | 8.231287 | 31-May-2001 | 0 | 20-Jul-01 | 0 | 8-Sep-01 | 0 |
| 12-Apr-01 | 1.674852 | 1-Jun-01 | 0 | 21-Jul-01 | 0 | 9-Sep-01 | 0 |
| 13-Apr-01 | 0 | 2-Jun-01 | 0 | 22-Jul-01 | 0 | 10-Sep-01 | 0 |
| 14-Apr-01 | 0 | 3-Jun-01 | 0 | 23-Jul-01 | 0 | 11-Sep-01 | 0 |
| 15-Apr-01 | 0 | 4-Jun-01 | 0 | 24-Jul-01 | 0 | 12-Sep-01 | 0 |
| 16-Apr-01 | 0 | 5-Jun-01 | 0 | 25-Jul-01 | 0 | 13-Sep-01 | 0 |
| 17-Apr-01 | 0 | 6-Jun-01 | 0 | 26-Jul-01 | 0 | 14-Sep-01 | 0.102 |
| 18-Apr-01 | 0 | 7-Jun-01 | 0 | 27-Jul-01 | 0.114 | 15-Sep-01 | 0 |
| 19-Apr-01 | 0 | 8-Jun-01 | 0 | 28-Jul-01 | 0 | 16-Sep-01 | 0 |
| 20-Apr-01 | 0 | 9-Jun-01 | 0 | 29-Jul-01 | 0 | 17-Sep-01 | 0 |
| 21-Apr-01 | 0 | 10-Jun-01 | 0 | 30-Jul-01 | 0 | 18-Sep-01 | 0 |
| 22-Apr-01 | 0 | 11-Jun-01 | 0 | 31-Jul-01 | 0 | 19-Sep-01 | 0 |
| 23-Apr-01 | 0 | 12-Jun-01 | 0 | 1-Aug-01 | 0 | 20-Sep-01 | 0 |
| 24-Apr-01 | 0 | 13-Jun-01 | 0 | 2-Aug-01 | 0 | 21-Sep-01 | 0 |
| 25-Apr-01 | 0 | 14-Jun-01 | 0 | 3-Aug-01 | 0 | 22-Sep-01 | 0.102 |
| 26-Apr-01 | 0 | 15-Jun-01 | 0 | 4-Aug-01 | 0 | 23-Sep-01 | 0.048 |
| 27-Apr-01 | 0 | 16-Jun-01 | 0 | 5-Aug-01 | 0 | 24-Sep-01 | 0 |
| 28-Apr-01 | 0 | 17-Jun-01 | 0 | 6-Aug-01 | 0 | 25-Sep-01 | 0 |
| 29-Apr-01 | 0 | 18-Jun-01 | 0 | 7-Aug-01 | 0 | 26-Sep-01 | 0 |
| 30-Apr-01 | 0 | 19-Jun-01 | 0 | 8-Aug-01 | 0 | 27-Sep-01 | 0 |
| 01-May-2001 | 0 | 20-Jun-01 | 0 | 9-Aug-01 | 0 | 28-Sep-01 | 0 |
| 02-May-2001 | 0 | 21-Jun-01 | 0 | 10-Aug-01 | 0 | 29-Sep-01 | 0 |
| 03-May-2001 | 0 | 22-Jun-01 | 0 | 11-Aug-01 | 0 | 30-Sep-01 | 0 |
| 04-May-2001 | 0 | 23-Jun-01 | 0 | 12-Aug-01 | 0 | 01-Oct-2001 | 0 |
| 05-May-2001 | 0 | 24-Jun-01 | 0 | 13-Aug-01 | 0 | 02-Oct-2001 | 0 |
| 06-May-2001 | 0 | 25-Jun-01 | 0 | 14-Aug-01 | 0 | 03-Oct-2001 | 0 |
| 07-May-2001 | 0 | 26-Jun-01 | 0 | 15-Aug-01 | 0 | 04-Oct-2001 | 0 |
| 08-May-2001 | 0 | 27-Jun-01 | 0 | 16-Aug-01 | 0 | 05-Oct-2001 | 0 |
| 09-May-2001 | 0 | 28-Jun-01 | 0 | 17-Aug-01 | 0 | 06-Oct-2001 | 0 |
| 10-May-2001 | 0 | 29-Jun-01 | 0 | 18-Aug-01 | 0 | 07-Oct-2001 | 0 |
| 11-May-2001 | 0 | 30-Jun-01 | 0 | 19-Aug-01 | 0 | 08-Oct-2001 | 0 |
| 12-May-2001 | 0 | 1-Jul-01 | 0 | 20-Aug-01 | 0 | 09-Oct-2001 | 0 |
| 13-May-2001 | 0 | 2-Jul-01 | 0 | 21-Aug-01 | 0 | 10-Oct-2001 | 0 |
| 14-May-2001 | 0 | 3-Jul-01 | 0 | 22-Aug-01 | 0 | 11-Oct-2001 | 0 |
| 15-May-2001 | 0 | 4-Jul-01 | 0 | 23-Aug-01 | 0 | 12-Oct-2001 | 0 |
| 16-May-2001 | 0 | 5-Jul-01 | 0 | 24-Aug-01 | 0 | 13-Oct-2001 | 0 |
| 17-May-2001 | 0 | 6-Jul-01 | 0 | 25-Aug-01 | 0 | 14-Oct-2001 | 0 |
| 18-May-2001 | 0 | 7-Jul-01 | 0 | 26-Aug-01 | 0 | 15-Oct-2001 | 0 |
| 19-May-2001 | 0 | 8-Jul-01 | 0 | 27-Aug-01 | 0 | 16-Oct-2001 | 0 |
| 20-May-2001 | 0 | 9-Jul-01 | 0 | 28-Aug-01 | 0 | 17-Oct-2001 | 0 |
| 21-May-2001 | 0 | 10-Jul-01 | 0 | 29-Aug-01 | 0 | 18-Oct-2001 | 0.125056 |
| 22-May-2001 | 0 | 11-Jul-01 | 0 | 30-Aug-01 | 0 | 19-Oct-2001 | 8.078587 |
| 23-May-2001 | 0 | 12-Jul-01 | 0 | 31-Aug-01 | 0.126 | 20-Oct-2001 | 1.375611 |
| 24-May-2001 | 0 | 13-Jul-01 | 0 | 1-Sep-01 | 0 | 21-Oct-2001 | 0.025011 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 26-May-2001 | 0 | 15-Jul-01 | 0 | 3-Sep-01 | 0 | 23-Oct-2001 | 0 |
| 27-May-2001 | 0 | 16-Jul-01 | 0 | 4-Sep-01 | 0 | 24-Oct-2001 | 1.167185 |
| 28-May-2001 | 0 | 17-Jul-01 | 0 | 5-Sep-01 | 0 | 25-Oct-2001 | 0.508559 |
| 29-May-2001 | 0 | 18-Jul-01 | 0 | 6-Sep-01 | 0 | 26-Oct-2001 | 0.025011 |
| 30-May-2001 | 0 | 19-Jul-01 | 0 | 7-Sep-01 | 0 | 27-Oct-2001 | 0.200089 |
| 28-Oct-2001 | 13.3726 | 17-Dec-01 | 17.50214 | 5-Feb-02 | 50.82746 | 27-Mar-02 | 3.411486 |
| 29-Oct-2001 | 1.300577 | 18-Dec-01 | 1.737249 | 6-Feb-02 | 7.976126 | 28-Mar-02 | 0.307034 |
| 30-Oct-2001 | 1.625722 | 19-Dec-01 | 0.726015 | 7-Feb-02 | 0 | 29-Mar-02 | 7.073148 |
| 31-Oct-2001 | 0.333481 | 20-Dec-01 | 0.207433 | 8-Feb-02 | 20.99837 | 30-Mar-02 | 0 |
| 1-Nov-01 | 0.479383 | 21-Dec-01 | 0 | 9-Feb-02 | 8.220294 | 31-Mar-02 | 0 |
| 2-Nov-01 | 0.753315 | 22-Dec-01 | 4.30423 | 10-Feb-02 | 5.208899 | 1-Apr-02 | 0 |
| 3-Nov-01 | 2.431154 | 23-Dec-01 | 0 | 11-Feb-02 | 12.85947 | 2-Apr-02 | 0 |
| 4-Nov-01 | 12.73788 | 24-Dec-01 | 1.763179 | 12-Feb-02 | 19.3299 | 3-Apr-02 | 0 |
| 5-Nov-01 | 17.3605 | 25-Dec-01 | 1.866895 | 13-Feb-02 | 2.685839 | 4-Apr-02 | 0 |
| 6-Nov-01 | 0 | 26-Dec-01 | 3.73379 | 14-Feb-02 | 0 | 5-Apr-02 | 0 |
| 7-Nov-01 | 0 | 27-Dec-01 | 0 | 15-Feb-02 | 31.37548 | 6-Apr-02 | 0 |
| 8-Nov-01 | 1.215577 | 28-Dec-01 | 3.111492 | 16-Feb-02 | 0 | 7-Apr-02 | 0 |
| 9-Nov-01 | 0 | 29-Dec-01 | 1.14088 | 17-Feb-02 | 22.2599 | 8-Apr-02 | 0 |
| 10-Nov-01 | 0 | 30-Dec-01 | 12.91269 | 18-Feb-02 | 0 | 9-Apr-02 | 0 |
| 11-Nov-01 | 0.821799 | 31-Dec-01 | 0.622298 | 19-Feb-02 | 21.44601 | 10-Apr-02 | 0 |
| 12-Nov-01 | 3.424161 | 1-Jan-02 | 0 | 20-Feb-02 | 0 | 11-Apr-02 | 28.84243 |
| 13-Nov-01 | 11.81336 | 2-Jan-02 | 0 | 21-Feb-02 | 0 | 12-Apr-02 | 10.28994 |
| 14-Nov-01 | 6.146369 | 3-Jan-02 | 0 | 22-Feb-02 | 0 | 13-Apr-02 | 29.45447 |
| 15-Nov-01 | 0 | 4-Jan-02 | 0 | 23-Feb-02 | 9.522518 | 14-Apr-02 | 15.68355 |
| 16-Nov-01 | 0 | 5-Jan-02 | 0 | 24-Feb-02 | 0 | 15-Apr-02 | 0 |
| 17-Nov-01 | 0 | 6-Jan-02 | 0 | 25-Feb-02 | 0 | 16-Apr-02 | 19.92958 |
| 18-Nov-01 | 2.105859 | 7-Jan-02 | 0 | 26-Feb-02 | 3.174173 | 17-Apr-02 | 0 |
| 19-Nov-01 | 22.97612 | 8-Jan-02 | 0 | 27-Feb-02 | 9.807381 | 18-Apr-02 | 0 |
| 20-Nov-01 | 5.53002 | 9-Jan-02 | 9.192844 | 28-Feb-02 | 4.110147 | 19-Apr-02 | 0 |
| 21-Nov-01 | 1.403906 | 10-Jan-02 | 19.02212 | 1-Mar-02 | 0 | 20-Apr-02 | 0 |
| 22-Nov-01 | 6.231973 | 11-Jan-02 | 14.28427 | 2-Mar-02 | 0.443493 | 21-Apr-02 | 0 |
| 23-Nov-01 | 10.59778 | 12-Jan-02 | 2.156783 | 3-Mar-02 | 0.90973 | 22-Apr-02 | 0 |
| 24-Nov-01 | 1.540872 | 13-Jan-02 | 0 | 4-Mar-02 | 0 | 23-Apr-02 | 0 |
| 25-Nov-01 | 0 | 14-Jan-02 | 4.207494 | 5-Mar-02 | 0 | 24-Apr-02 | 0 |
| 26-Nov-01 | 16.24764 | 15-Jan-02 | 1.626426 | 6-Mar-02 | 0 | 25-Apr-02 | 0 |
| 27-Nov-01 | 0 | 16-Jan-02 | 1.591069 | 7-Mar-02 | 0 | 26-Apr-02 | 0 |
| 28-Nov-01 | 14.8095 | 17-Jan-02 | 0.459642 | 8-Mar-02 | 6.254391 | 27-Apr-02 | 0 |
| 29-Nov-01 | 6.608631 | 18-Jan-02 | 23.05283 | 9-Mar-02 | 1.717115 | 28-Apr-02 | 0 |
| 30-Nov-01 | 0 | 19-Jan-02 | 6.823919 | 10-Mar-02 | 0 | 29-Apr-02 | 0 |
| 1-Dec-01 | 0 | 20-Jan-02 | 11.17284 | 11-Mar-02 | 0 | 30-Apr-02 | 0 |
| 2-Dec-01 | 6.197054 | 21-Jan-02 | 9.829272 | 12-Mar-02 | 8.790263 | 01-May-2002 | 0 |
| 3-Dec-01 | 3.137421 | 22-Jan-02 | 7.248204 | 13-Mar-02 | 0 | 02-May-2002 | 0 |
| 4-Dec-01 | 8.271382 | 23-Jan-02 | 1.909283 | 14-Mar-02 | 2.649587 | 03-May-2002 | 0 |
| 5-Dec-01 | 0.726015 | 24-Jan-02 | 9.12213 | 15-Mar-02 | 2.444898 | 04-May-2002 | 0 |
| 6-Dec-01 | 2.02247 | 25-Jan-02 | 15.41569 | 16-Mar-02 | 0.523095 | 05-May-2002 | 0 |
| 7-Dec-01 | 7.882446 | 26-Jan-02 | 7.531061 | 17-Mar-02 | 0 | 06-May-2002 | 0 |
| 8-Dec-01 | 11.2273 | 27-Jan-02 | 6.434991 | 18-Mar-02 | 0 | 07-May-2002 | 0 |
| 9-Dec-01 | 1.452029 | 28-Jan-02 | 19.02212 | 19-Mar-02 | 0 | 08-May-2002 | 0 |
| 10-Dec-01 | 0 | 29-Jan-02 | 0.494999 | 20-Mar-02 | 23.52788 | 09-May-2002 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 12-Dec-01 | 9.127043 | 31-Jan-02 | 30.26567 | 22-Mar-02 | 1.853574 | 11-May-2002 | 0 |
| 13-Dec-01 | 6.741565 | 1-Feb-02 | 17.25448 | 23-Mar-02 | 0 | 12-May-2002 | 0 |
| 14-Dec-01 | 13.82021 | 2-Feb-02 | 10.09224 | 24-Mar-02 | 2.933878 | 13-May-2002 | 0 |
| 15-Dec-01 | 0.492653 | 3-Feb-02 | 0 | 25-Mar-02 | 0 | 14-May-2002 | 0 |
| 16-Dec-01 | 0 | 4-Feb-02 | 32.18937 | 26-Mar-02 | 4.332587 | 15-May-2002 | 0 |
| 16-May-2002 | 0 | 5-Jul-02 | 0 | 24-Aug-02 | 0 | 13-Oct-2002 | 0 |
| 17-May-2002 | 0 | 6-Jul-02 | 0 | 25-Aug-02 | 0 | 14-Oct-2002 | 0 |
| 18-May-2002 | 0 | 7-Jul-02 | 0 | 26-Aug-02 | 0 | 15-Oct-2002 | 0 |
| 19-May-2002 | 0 | 8-Jul-02 | 0 | 27-Aug-02 | 0 | 16-Oct-2002 | 0 |
| 20-May-2002 | 0 | 9-Jul-02 | 0 | 28-Aug-02 | 0 | 17-Oct-2002 | 0 |
| 21-May-2002 | 0 | 10-Jul-02 | 0 | 29-Aug-02 | 0.179793 | 18-Oct-2002 | 0 |
| 22-May-2002 | 0 | 11-Jul-02 | 0 | 30-Aug-02 | 0 | 19-Oct-2002 | 0 |
| 23-May-2002 | 0.252 | 12-Jul-02 | 0 | 31-Aug-02 | 0.068197 | 20-Oct-2002 | 0 |
| 24-May-2002 | 0 | 13-Jul-02 | 0 | 1-Sep-02 | 0 | 21-Oct-2002 | 0 |
| 25-May-2002 | 0 | 14-Jul-02 | 0 | 2-Sep-02 | 0 | 22-Oct-2002 | 0 |
| 26-May-2002 | 0 | 15-Jul-02 | 0 | 3-Sep-02 | 0 | 23-Oct-2002 | 0 |
| 27-May-2002 | 0 | 16-Jul-02 | 0 | 4-Sep-02 | 0 | 24-Oct-2002 | 0 |
| 28-May-2002 | 0 | 17-Jul-02 | 0 | 5-Sep-02 | 0 | 25-Oct-2002 | 3.503247 |
| 29-May-2002 | 0 | 18-Jul-02 | 0 | 6-Sep-02 | 0 | 26-Oct-2002 | 5.125556 |
| 30-May-2002 | 0 | 19-Jul-02 | 0 | 7-Sep-02 | 0.252 | 27-Oct-2002 | 0.082291 |
| 31-May-2002 | 0 | 20-Jul-02 | 0 | 8-Sep-02 | 0 | 28-Oct-2002 | 0.517258 |
| 1-Jun-02 | 0 | 21-Jul-02 | 0 | 9-Sep-02 | 0.03 | 29-Oct-2002 | 25.85114 |
| 2-Jun-02 | 0 | 22-Jul-02 | 0 | 10-Sep-02 | 0.024 | 30-Oct-2002 | 0.305652 |
| 3-Jun-02 | 0 | 23-Jul-02 | 0 | 11-Sep-02 | 0.072 | 31-Oct-2002 | 0.552526 |
| 4-Jun-02 | 0 | 24-Jul-02 | 0 | 12-Sep-02 | 0 | 1-Nov-02 | 0 |
| 5-Jun-02 | 0 | 25-Jul-02 | 0 | 13-Sep-02 | 0 | 2-Nov-02 | 3.471348 |
| 6-Jun-02 | 0 | 26-Jul-02 | 0 | 14-Sep-02 | 0 | 3-Nov-02 | 0 |
| 7-Jun-02 | 0 | 27-Jul-02 | 0 | 15-Sep-02 | 0 | 4-Nov-02 | 1.952634 |
| 8-Jun-02 | 0 | 28-Jul-02 | 0 | 16-Sep-02 | 0 | 5-Nov-02 | 9.933636 |
| 9-Jun-02 | 0 | 29-Jul-02 | 0 | 17-Sep-02 | 0 | 6-Nov-02 | 0.681872 |
| 10-Jun-02 | 0 | 30-Jul-02 | 0 | 18-Sep-02 | 0 | 7-Nov-02 | 3.626319 |
| 11-Jun-02 | 0 | 31-Jul-02 | 0 | 19-Sep-02 | 0 | 8-Nov-02 | 0 |
| 12-Jun-02 | 0 | 1-Aug-02 | 0 | 20-Sep-02 | 0 | 9-Nov-02 | 7.051177 |
| 13-Jun-02 | 0 | 2-Aug-02 | 0 | 21-Sep-02 | 0 | 10-Nov-02 | 0 |
| 14-Jun-02 | 0 | 3-Aug-02 | 0 | 22-Sep-02 | 0.18 | 11-Nov-02 | 0.511404 |
| 15-Jun-02 | 0 | 4-Aug-02 | 0 | 23-Sep-02 | 0.702 | 12-Nov-02 | 0.216959 |
| 16-Jun-02 | 0 | 5-Aug-02 | 0 | 24-Sep-02 | 0 | 13-Nov-02 | 0 |
| 17-Jun-02 | 0 | 6-Aug-02 | 0 | 25-Sep-02 | 0.042 | 14-Nov-02 | 0 |
| 18-Jun-02 | 0 | 7-Aug-02 | 0 | 26-Sep-02 | 0.99 | 15-Nov-02 | 0 |
| 19-Jun-02 | 0 | 8-Aug-02 | 0 | 27-Sep-02 | 0.198 | 16-Nov-02 | 1.270762 |
| 20-Jun-02 | 0 | 9-Aug-02 | 0 | 28-Sep-02 | 0 | 17-Nov-02 | 0.340936 |
| 21-Jun-02 | 0 | 10-Aug-02 | 0 | 29-Sep-02 | 0 | 18-Nov-02 | 0 |
| 22-Jun-02 | 0 | 11-Aug-02 | 0 | 30-Sep-02 | 0 | 19-Nov-02 | 0 |
| 23-Jun-02 | 0 | 12-Aug-02 | 0 | 01-Oct-2002 | 0 | 20-Nov-02 | 0 |
| 24-Jun-02 | 0 | 13-Aug-02 | 0 | 02-Oct-2002 | 2.374684 | 21-Nov-02 | 0 |
| 25-Jun-02 | 0 | 14-Aug-02 | 0 | 03-Oct-2002 | 3.35042 | 22-Nov-02 | 0 |
| 26-Jun-02 | 0 | 15-Aug-02 | 0 | 04-Oct-2002 | 0 | 23-Nov-02 | 0 |
| 27-Jun-02 | 0 | 16-Aug-02 | 0 | 05-Oct-2002 | 0.599549 | 24-Nov-02 | 1.658189 |
| 28-Jun-02 | 0 | 17-Aug-02 | 0 | 06-Oct-2002 | 0.329164 | 25-Nov-02 | 6.741235 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 30-Jun-02 | 0.03 | 19-Aug-02 | 0 | 08-Oct-2002 | 0 | 27-Nov-02 | 1.503218 |
| 1-Jul-02 | 0 | 20-Aug-02 | 0 | 09-Oct-2002 | 0.576037 | 28-Nov-02 | 18.70499 |
| 2-Jul-02 | 0 | 21-Aug-02 | 0 | 10-Oct-2002 | 0 | 29-Nov-02 | 1.890645 |
| 3-Jul-02 | 0 | 22-Aug-02 | 0 | 11-Oct-2002 | 0 | 30-Nov-02 | 3.951759 |
| 4-Jul-02 | 0 | 23-Aug-02 | 0 | 12-Oct-2002 | 0 | 1-Dec-02 | 0.233971 |
| 2-Dec-02 | 0 | 21-Jan-03 | 1.350783 | 12-Mar-03 | 11.11357 | 01-May-2003 | 0 |
| 3-Dec-02 | 0 | 22-Jan-03 | 4.356274 | 13-Mar-03 | 8.179866 | 02-May-2003 | 0 |
| 4-Dec-02 | 12.51055 | 23-Jan-03 | 9.590557 | 14-Mar-03 | 1.639425 | 03-May-2003 | 0 |
| 5-Dec-02 | 9.950638 | 24-Jan-03 | 0.911778 | 15-Mar-03 | 1.898281 | 04-May-2003 | 0 |
| 6-Dec-02 | 5.973135 | 25-Jan-03 | 0 | 16-Mar-03 | 0 | 05-May-2003 | 0 |
| 7-Dec-02 | 8.725732 | 26-Jan-03 | 4.72774 | 17-Mar-03 | 0 | 06-May-2003 | 0 |
| 8-Dec-02 | 4.197711 | 27-Jan-03 | 9.725637 | 18-Mar-03 | 0 | 07-May-2003 | 0 |
| 9-Dec-02 | 2.174552 | 28-Jan-03 | 11.38035 | 19-Mar-03 | 0.155314 | 08-May-2003 | 0 |
| 10-Dec-02 | 0 | 29-Jan-03 | 1.418322 | 20-Mar-03 | 1.811996 | 09-May-2003 | 0 |
| 11-Dec-02 | 6.344736 | 30-Jan-03 | 3.680883 | 21-Mar-03 | 6.885584 | 10-May-2003 | 0 |
| 12-Dec-02 | 0 | 31-Jan-03 | 8.206005 | 22-Mar-03 | 7.213469 | 11-May-2003 | 0 |
| 13-Dec-02 | 9.069806 | 1-Feb-03 | 0 | 23-Mar-03 | 0 | 12-May-2003 | 0 |
| 14-Dec-02 | 0 | 2-Feb-03 | 5.018322 | 24-Mar-03 | 0 | 13-May-2003 | 0 |
| 15-Dec-02 | 0.330312 | 3-Feb-03 | 11.15183 | 25-Mar-03 | 11.6658 | 14-May-2003 | 0 |
| 16-Dec-02 | 7.308144 | 4-Feb-03 | 5.575914 | 26-Mar-03 | 2.070852 | 15-May-2003 | 0 |
| 17-Dec-02 | 1.995633 | 5-Feb-03 | 0 | 27-Mar-03 | 0 | 16-May-2003 | 0 |
| 18-Dec-02 | 0.798253 | 6-Feb-03 | 1.219731 | 28-Mar-03 | 0 | 17-May-2003 | 0 |
| 19-Dec-02 | 14.49242 | 7-Feb-03 | 3.484946 | 29-Mar-03 | 3.03725 | 18-May-2003 | 0 |
| 20-Dec-02 | 2.380996 | 8-Feb-03 | 0 | 30-Mar-03 | 7.765696 | 19-May-2003 | 0 |
| 21-Dec-02 | 1.307484 | 9-Feb-03 | 0.034849 | 31-Mar-03 | 6.574956 | 20-May-2003 | 0 |
| 22-Dec-02 | 18.23596 | 10-Feb-03 | 0 | 1-Apr-03 | 8.318636 | 21-May-2003 | 0 |
| 23-Dec-02 | 1.761662 | 11-Feb-03 | 0 | 2-Apr-03 | 18.79866 | 22-May-2003 | 0 |
| 24-Dec-02 | 3.509561 | 12-Feb-03 | 8.816913 | 3-Apr-03 | 1.489363 | 23-May-2003 | 0 |
| 25-Dec-02 | 8.216501 | 13-Feb-03 | 8.991161 | 4-Apr-03 | 10.77064 | 24-May-2003 | 0 |
| 26-Dec-02 | 2.835175 | 14-Feb-03 | 25.8583 | 5-Apr-03 | 11.84225 | 25-May-2003 | 0 |
| 27-Dec-02 | 0.041289 | 15-Feb-03 | 4.53043 | 6-Apr-03 | 0 | 26-May-2003 | 0 |
| 28-Dec-02 | 0 | 16-Feb-03 | 8.43357 | 7-Apr-03 | 0 | 27-May-2003 | 0 |
| 29-Dec-02 | 0 | 17-Feb-03 | 0.069699 | 8-Apr-03 | 0.072652 | 28-May-2003 | 0 |
| 30-Dec-02 | 0 | 18-Feb-03 | 0 | 9-Apr-03 | 0 | 29-May-2003 | 0 |
| 31-Dec-02 | 4.445444 | 19-Feb-03 | 1.045484 | 10-Apr-03 | 0 | 30-May-2003 | 0 |
| 1-Jan-03 | 11.92066 | 20-Feb-03 | 7.77143 | 11-Apr-03 | 0.871822 | 31-May-2003 | 0 |
| 2-Jan-03 | 1.080626 | 21-Feb-03 | 12.05791 | 12-Apr-03 | 0.690193 | 1-Jun-03 | 0 |
| 3-Jan-03 | 2.769105 | 22-Feb-03 | 35.12826 | 13-Apr-03 | 0 | 2-Jun-03 | 0 |
| 4-Jan-03 | 2.735335 | 23-Feb-03 | 0 | 14-Apr-03 | 0 | 3-Jun-03 | 0 |
| 5-Jan-03 | 7.699462 | 24-Feb-03 | 0 | 15-Apr-03 | 0 | 4-Jun-03 | 0 |
| 6-Jan-03 | 0 | 25-Feb-03 | 10.73363 | 16-Apr-03 | 0 | 5-Jun-03 | 0 |
| 7-Jan-03 | 2.566487 | 26-Feb-03 | 8.782064 | 17-Apr-03 | 0 | 6-Jun-03 | 0 |
| 8-Jan-03 | 18.9785 | 27-Feb-03 | 29.0296 | 18-Apr-03 | 0 | 7-Jun-03 | 0 |
| 9-Jan-03 | 0.844239 | 28-Feb-03 | 14.35798 | 19-Apr-03 | 0 | 8-Jun-03 | 0 |
| 10-Jan-03 | 4.829048 | 1-Mar-03 | 1.553139 | 20-Apr-03 | 0.236118 | 9-Jun-03 | 0 |
| 11-Jan-03 | 2.937953 | 2-Mar-03 | 13.27071 | 21-Apr-03 | 0 | 10-Jun-03 | 0 |
| 12-Jan-03 | 2.600257 | 3-Mar-03 | 5.798386 | 22-Apr-03 | 0 | 11-Jun-03 | 0 |
| 13-Jan-03 | 0 | 4-Mar-03 | 4.10719 | 23-Apr-03 | 0 | 12-Jun-03 | 0 |
| 14-Jan-03 | 4.457583 | 5-Mar-03 | 3.865591 | 24-Apr-03 | 0 | 13-Jun-03 | 0 |

| Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) | Date | Pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 16-Jan-03 | 0 | 7-Mar-03 | 0 | 26-Apr-03 | 0 | 15-Jun-03 | 0 |
| 17-Jan-03 | 0 | 8-Mar-03 | 2.519537 | 27-Apr-03 | 0 | 16-Jun-03 | 0 |
| 18-Jan-03 | 5.403131 | 9-Mar-03 | 17.46419 | 28-Apr-03 | 0 | 17-Jun-03 | 0 |
| 19-Jan-03 | 0 | 10-Mar-03 | 0 | 29-Apr-03 | 0 | 18-Jun-03 | 0 |
| 20-Jan-03 | 0 | 11-Mar-03 | 0 | 30-Apr-03 | 0 | 19-Jun-03 | 0 |
| 20-Jun-03 | 0 | 9-Aug-03 | 0 | 28-Sep-03 | 0 | 17-Nov-03 | 0 |
| 21-Jun-03 | 0 | 10-Aug-03 | 0 | 29-Sep-03 | 0 | 18-Nov-03 | 0 |
| 22-Jun-03 | 0 | 11-Aug-03 | 0 | 30-Sep-03 | 0 | 19-Nov-03 | 0.511678 |
| 23-Jun-03 | 0 | 12-Aug-03 | 0.159457 | 01-Oct-2003 | 0 | 20-Nov-03 | 1.009143 |
| 24-Jun-03 | 0 | 13-Aug-03 | 0 | 02-Oct-2003 | 0 | 21-Nov-03 | 0 |
| 25-Jun-03 | 0 | 14-Aug-03 | 0 | 03-Oct-2003 | 0 | 22-Nov-03 | 0 |
| 26-Jun-03 | 0 | 15-Aug-03 | 0 | 04-Oct-2003 | 0 | 23-Nov-03 | 0.668024 |
| 27-Jun-03 | 0 | 16-Aug-03 | 0 | 05-Oct-2003 | 0 | 24-Nov-03 | 6.054859 |
| 28-Jun-03 | 0 | 17-Aug-03 | 0 | 06-Oct-2003 | 0 | 25-Nov-03 | 1.03757 |
| 29-Jun-03 | 0 | 18-Aug-03 | 0 | 07-Oct-2003 | 0 | 26-Nov-03 | 2.274125 |
| 30-Jun-03 | 0 | 19-Aug-03 | 0 | 08-Oct-2003 | 0 | 27-Nov-03 | 8.058932 |
| 1-Jul-03 | 0 | 20-Aug-03 | 0 | 09-Oct-2003 | 0 | 28-Nov-03 | 12.67825 |
| 2-Jul-03 | 0.192 | 21-Aug-03 | 0 | 10-Oct-2003 | 0 | 29-Nov-03 | 1.535035 |
| 3-Jul-03 | 0 | 22-Aug-03 | 0 | 11-Oct-2003 | 0 | 30-Nov-03 | 15.36456 |
| 4-Jul-03 | 0 | 23-Aug-03 | 0 | 12-Oct-2003 | 0 | 1-Dec-03 | 0.379912 |
| 5-Jul-03 | 0 | 24-Aug-03 | 0 | 13-Oct-2003 | 0 | 2-Dec-03 | 0 |
| 6-Jul-03 | 0 | 25-Aug-03 | 0 | 14-Oct-2003 | 0 | 3-Dec-03 | 4.157921 |
| 7-Jul-03 | 0 | 26-Aug-03 | 0 | 15-Oct-2003 | 0 | 4-Dec-03 | 0.675398 |
| 8-Jul-03 | 0 | 27-Aug-03 | 0 | 16-Oct-2003 | 0 | 5-Dec-03 | 0 |
| 9-Jul-03 | 0 | 28-Aug-03 | 0 | 17-Oct-2003 | 0 | 6-Dec-03 | 0 |
| 10-Jul-03 | 0 | 29-Aug-03 | 0 | 18-Oct-2003 | 2.268186 | 7-Dec-03 | 4.959957 |
| 11-Jul-03 | 0 | 30-Aug-03 | 0 | 19-Oct-2003 | 1.118558 | 8-Dec-03 | 3.503629 |
| 12-Jul-03 | 0 | 31-Aug-03 | 0 | 20-Oct-2003 | 1.817656 | 9-Dec-03 | 8.991241 |
| 13-Jul-03 | 0 | 1-Sep-03 | 0 | 21-Oct-2003 | 2.81193 | 10-Dec-03 | 5.213232 |
| 14-Jul-03 | 0 | 2-Sep-03 | 0 | 22-Oct-2003 | 0 | 11-Dec-03 | 2.574956 |
| 15-Jul-03 | 0 | 3-Sep-03 | 0 | 23-Oct-2003 | 0 | 12-Dec-03 | 30.09744 |
| 16-Jul-03 | 0 | 4-Sep-03 | 0 | 24-Oct-2003 | 0.403924 | 13-Dec-03 | 1.94177 |
| 17-Jul-03 | 0 | 5-Sep-03 | 0 | 25-Oct-2003 | 1.538017 | 14-Dec-03 | 2.216151 |
| 18-Jul-03 | 0 | 6-Sep-03 | 0 | 26-Oct-2003 | 0.295175 | 15-Dec-03 | 5.360975 |
| 19-Jul-03 | 0 | 7-Sep-03 | 0 | 27-Oct-2003 | 2.936214 | 16-Dec-03 | 0 |
| 20-Jul-03 | 0 | 8-Sep-03 | 0 | 28-Oct-2003 | 0 | 17-Dec-03 | 0 |
| 21-Jul-03 | 0 | 9-Sep-03 | 0 | 29-Oct-2003 | 0.916596 | 18-Dec-03 | 0.274381 |
| 22-Jul-03 | 0 | 10-Sep-03 | 0 | 30-Oct-2003 | 2.547826 | 19-Dec-03 | 4.200134 |
| 23-Jul-03 | 0 | 11-Sep-03 | 4.033565 | 31-Oct-2003 | 0 | 20-Dec-03 | 8.61133 |
| 24-Jul-03 | 0 | 12-Sep-03 | 0 | 1-Nov-03 | 0.469038 | 21-Dec-03 | 0 |
| 25-Jul-03 | 0 | 13-Sep-03 | 0 | 2-Nov-03 | 0 | 22-Dec-03 | 0.823142 |
| 26-Jul-03 | 0 | 14-Sep-03 | 0 | 3-Nov-03 | 0 | 23-Dec-03 | 4.347878 |
| 27-Jul-03 | 0 | 15-Sep-03 | 0 | 4-Nov-03 | 1.918793 | 24-Dec-03 | 3.524736 |
| 28-Jul-03 | 0 | 16-Sep-03 | 0 | 5-Nov-03 | 1.122849 | 25-Dec-03 | 10.76416 |
| 29-Jul-03 | 0 | 17-Sep-03 | 0 | 6-Nov-03 | 0 | 26-Dec-03 | 0.337699 |
| 30-Jul-03 | 0 | 18-Sep-03 | 0 | 7-Nov-03 | 5.742167 | 27-Dec-03 | 30.16076 |
| 31-Jul-03 | 0 | 19-Sep-03 | 0 | 8-Nov-03 | 4.192919 | 28-Dec-03 | 8.189206 |
| 1-Aug-03 | 0 | 20-Sep-03 | 0 | 9-Nov-03 | 0 | 29-Dec-03 | 0.464336 |
| 2-Aug-03 | 0 | 21-Sep-03 | 0 | 10-Nov-03 | 0 | 30-Dec-03 | 8.505798 |

## **Appendix D4**: Chipata TRMM data

| Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day) | Date | pcp(mm/day) |
|---|---|---|---|---|---|---|---|
| 1-Jan-00 | 4.339967728 | 25-Feb-00 | 10.59620404 | 20-Apr-00 | 0 | 14-Jun-00 | 0 |
| 2-Jan-00 | 4.722906202 | 26-Feb-00 | 0.263962388 | 21-Apr-00 | 0 | 15-Jun-00 | 0 |
| 3-Jan-00 | 0 | 27-Feb-00 | 5.090703249 | 22-Apr-00 | 0 | 16-Jun-00 | 0 |
| 4-Jan-00 | 0 | 28-Feb-00 | 0 | 23-Apr-00 | 1.7386303 | 17-Jun-00 | 0 |
| 5-Jan-00 | 5.552605629 | 29-Feb-00 | 5.241538584 | 24-Apr-00 | 0 | 18-Jun-00 | 0 |
| 6-Jan-00 | 2.967772007 | 1-Mar-00 | 28.45960784 | 25-Apr-00 | 0.989682 | 19-Jun-00 | 0 |
| 7-Jan-00 | 0 | 2-Mar-00 | 0 | 26-Apr-00 | 0 | 20-Jun-00 | 0 |
| 8-Jan-00 | 0 | 3-Mar-00 | 1.007132292 | 27-Apr-00 | 0 | 21-Jun-00 | 0 |
| 9-Jan-00 | 11.16903493 | 4-Mar-00 | 10.07132268 | 28-Apr-00 | 0 | 22-Jun-00 | 0 |
| 10-Jan-00 | 10.05213106 | 5-Mar-00 | 0 | 29-Apr-00 | 0 | 23-Jun-00 | 0 |
| 11-Jan-00 | 8.456555009 | 6-Mar-00 | 0 | 30-Apr-00 | 0 | 24-Jun-00 | 0 |
| 12-Jan-00 | 20.99778557 | 7-Mar-00 | 2.111728907 | 01-May-2000 | 0 | 25-Jun-00 | 0 |
| 13-Jan-00 | 0.829699695 | 8-Mar-00 | 3.346278191 | 02-May-2000 | 0 | 26-Jun-00 | 0 |
| 14-Jan-00 | 2.744391203 | 9-Mar-00 | 10.00634646 | 03-May-2000 | 0 | 27-Jun-00 | 0 |
| 15-Jan-00 | 0 | 10-Mar-00 | 9.681464851 | 04-May-2000 | 0 | 28-Jun-00 | 0 |
| 16-Jan-00 | 1.372195601 | 11-Mar-00 | 6.660068333 | 05-May-2000 | 0 | 29-Jun-00 | 0 |
| 17-Jan-00 | 0 | 12-Mar-00 | 35.83441448 | 06-May-2000 | 0 | 30-Jun-00 | 0 |
| 18-Jan-00 | 0 | 13-Mar-00 | 2.501586616 | 07-May-2000 | 0 | 1-Jul-00 | 0 |
| 19-Jan-00 | 7.084359802 | 14-Mar-00 | 5.717911839 | 08-May-2000 | 0 | 2-Jul-00 | 0 |
| 20-Jan-00 | 4.499525547 | 15-Mar-00 | 9.908882618 | 09-May-2000 | 0 | 3-Jul-00 | 0 |
| 21-Jan-00 | 0.574407458 | 16-Mar-00 | 3.768623829 | 10-May-2000 | 0 | 4-Jul-00 | 0 |
| 22-Jan-00 | 0 | 17-Mar-00 | 0 | 11-May-2000 | 0 | 5-Jul-00 | 0 |
| 23-Jan-00 | 0 | 18-Mar-00 | 0 | 12-May-2000 | 0 | 6-Jul-00 | 0 |
| 24-Jan-00 | 0 | 19-Mar-00 | 4.840732574 | 13-May-2000 | 0 | 7-Jul-00 | 0 |
| 25-Jan-00 | 0.287203729 | 20-Mar-00 | 8.316963196 | 14-May-2000 | 0 | 8-Jul-00 | 0 |
| 26-Jan-00 | 2.329541445 | 21-Mar-00 | 0.357369542 | 15-May-2000 | 0 | 9-Jul-00 | 0 |
| 27-Jan-00 | 0 | 22-Mar-00 | 8.251987457 | 16-May-2000 | 0 | 10-Jul-00 | 0 |
| 28-Jan-00 | 0 | 23-Mar-00 | 0 | 17-May-2000 | 0 | 11-Jul-00 | 0 |
| 29-Jan-00 | 0.319115251 | 24-Mar-00 | 3.833600402 | 18-May-2000 | 0 | 12-Jul-00 | 0 |
| 30-Jan-00 | 11.64770818 | 25-Mar-00 | 0 | 19-May-2000 | 0 | 13-Jul-00 | 0 |
| 31-Jan-00 | 0 | 26-Mar-00 | 6.205234051 | 20-May-2000 | 0 | 14-Jul-00 | 0 |
| 1-Feb-00 | 18.55278373 | 27-Mar-00 | 0 | 21-May-2000 | 0 | 15-Jul-00 | 0 |
| 2-Feb-00 | 21.1924085 | 28-Mar-00 | 0 | 22-May-2000 | 0 | 16-Jul-00 | 0 |
| 3-Feb-00 | 5.316956282 | 29-Mar-00 | 0 | 23-May-2000 | 0 | 17-Jul-00 | 0 |
| 4-Feb-00 | 5.166121006 | 30-Mar-00 | 4.223457813 | 24-May-2000 | 0 | 18-Jul-00 | 0 |
| 5-Feb-00 | 0 | 31-Mar-00 | 0 | 25-May-2000 | 0 | 19-Jul-00 | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 6-Feb-00 | 1.018140554 | 1-Apr-00 | 0 | 26-May-2000 | 0 | 20-Jul-00 | 0 |
| 7-Feb-00 | 6.749895334 | 2-Apr-00 | 2.300341606 | 27-May-2000 | 0 | 21-Jul-00 | 0 |
| 8-Feb-00 | 0 | 3-Apr-00 | 6.660291672 | 28-May-2000 | 0 | 22-Jul-00 | 0 |
| 9-Feb-00 | 0 | 4-Apr-00 | 0 | 29-May-2000 | 0 | 23-Jul-00 | 0 |
| 10-Feb-00 | 0 | 5-Apr-00 | 0 | 30-May-2000 | 0 | 24-Jul-00 | 0 |
| 11-Feb-00 | 16.93130159 | 6-Apr-00 | 0 | 31-May-2000 | 0 | 25-Jul-00 | 0 |
| 12-Feb-00 | 11.99143314 | 7-Apr-00 | 0 | 1-Jun-00 | 0 | 26-Jul-00 | 0 |
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| 14-Feb-00 | 18.6282022 | 9-Apr-00 | 0 | 3-Jun-00 | 0 | 28-Jul-00 | 0 |
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| 17-Feb-00 | 0.527924776 | 12-Apr-00 | 4.62743187 | 6-Jun-00 | 0 | 31-Jul-00 | 0 |
| 18-Feb-00 | 11.53892708 | 13-Apr-00 | 0 | 7-Jun-00 | 0 | 1-Aug-00 | 0 |
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| 21-Feb-00 | 15.64919853 | 16-Apr-00 | 7.596477509 | 10-Jun-00 | 0 | 4-Aug-00 | 0 |
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| 24-Feb-00 | 1.395229816 | 19-Apr-00 | 0 | 13-Jun-00 | 0 | 7-Aug-00 | 0 |
| 8-Aug-00 | 0 | 04-Oct-2000 | 0 | 30-Nov-00 | 20.155398 | 26-Jan-01 | 0 |
| 9-Aug-00 | 0 | 05-Oct-2000 | 0 | 1-Dec-00 | 16.309859 | 27-Jan-01 | 5.9502716 |
| 10-Aug-00 | 0 | 06-Oct-2000 | 0 | 2-Dec-00 | 0.7298732 | 28-Jan-01 | 1.951689 |
| 11-Aug-00 | 0 | 07-Oct-2000 | 0 | 3-Dec-00 | 1.6001065 | 29-Jan-01 | 11.591128 |
| 12-Aug-00 | 0 | 08-Oct-2000 | 0 | 4-Dec-00 | 5.4179047 | 30-Jan-01 | 1.7612804 |
| 13-Aug-00 | 0 | 09-Oct-2000 | 0 | 5-Dec-00 | 4.7441758 | 31-Jan-01 | 16.137136 |
| 14-Aug-00 | 0 | 10-Oct-2000 | 0 | 6-Dec-00 | 5.502121 | 1-Feb-01 | 1.5377507 |
| 15-Aug-00 | 0 | 11-Oct-2000 | 0 | 7-Dec-00 | 0 | 2-Feb-01 | 18.616103 |
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| 17-Aug-00 | 0 | 13-Oct-2000 | 0 | 9-Dec-00 | 3.5090055 | 4-Feb-01 | 0 |
| 18-Aug-00 | 0 | 14-Oct-2000 | 0 | 10-Dec-00 | 0.028072 | 5-Feb-01 | 3.3084939 |
| 19-Aug-00 | 0 | 15-Oct-2000 | 0 | 11-Dec-00 | 0 | 6-Feb-01 | 7.618856 |
| 20-Aug-00 | 0 | 16-Oct-2000 | 0.054024473 | 12-Dec-00 | 0 | 7-Feb-01 | 13.257275 |
| 21-Aug-00 | 0 | 17-Oct-2000 | 0.11480201 | 13-Dec-00 | 16.113354 | 8-Feb-01 | 4.2171645 |
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| 27-Aug-00 | 0 | 23-Oct-2000 | 0 | 19-Dec-00 | 1.7123948 | 14-Feb-01 | 0 |
| 28-Aug-00 | 0 | 24-Oct-2000 | 0 | 20-Dec-00 | 13.221934 | 15-Feb-01 | 71.272418 |

| Date | Met data | TRMM | Date | Met data | TRMM | Date | Met data |
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| 1-Sep-00 | 0 | 28-Oct-2000 | 0 | 24-Dec-00 | 5.8951296 | 19-Feb-01 | 0.8154739 |
| 2-Sep-00 | 0 | 29-Oct-2000 | 0.85088551 | 25-Dec-00 | 13.278078 | 20-Feb-01 | 0 |
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| 4-Sep-00 | 0 | 31-Oct-2000 | 0.11480201 | 27-Dec-00 | 16.253715 | 22-Feb-01 | 0.6756783 |
| 5-Sep-00 | 0 | 1-Nov-00 | 1.514359117 | 28-Dec-00 | 2.1334755 | 23-Feb-01 | 4.7996459 |
| 6-Sep-00 | 0.017999999 | 2-Nov-00 | 0 | 29-Dec-00 | 5.3898325 | 24-Feb-01 | 6.6868854 |
| 7-Sep-00 | 0 | 3-Nov-00 | 4.236599952 | 30-Dec-00 | 16.506363 | 25-Feb-01 | 37.348702 |
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| 14-Sep-00 | 0 | 10-Nov-00 | 12.49346256 | 6-Jan-01 | 6.8309112 | 4-Mar-01 | 30.214439 |
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| 16-Sep-00 | 0 | 12-Nov-00 | 3.497448385 | 8-Jan-01 | 7.3307344 | 6-Mar-01 | 0.2479134 |
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| 18-Sep-00 | 0 | 14-Nov-00 | 4.651245713 | 10-Jan-01 | 9.2586221 | 8-Mar-01 | 0.6817617 |
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| 20-Sep-00 | 0 | 16-Nov-00 | 3.605617046 | 12-Jan-01 | 0.8806402 | 10-Mar-01 | 4.8652992 |
| 21-Sep-00 | 0 | 17-Nov-00 | 0 | 13-Jan-01 | 3.903378 | 11-Mar-01 | 2.3551769 |
| 22-Sep-00 | 0 | 18-Nov-00 | 0.594926775 | 14-Jan-01 | 6.2834867 | 12-Mar-01 | 21.692419 |
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| 24-Sep-00 | 0 | 20-Nov-00 | 5.101947844 | 16-Jan-01 | 4.3555987 | 14-Mar-01 | 5.1751913 |
| 25-Sep-00 | 0 | 21-Nov-00 | 0 | 17-Jan-01 | 1.1662532 | 15-Mar-01 | 8.3670759 |
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| 28-Sep-00 | 0 | 24-Nov-00 | 0.630982943 | 20-Jan-01 | 1.8326836 | 18-Mar-01 | 5.3921154 |
| 29-Sep-00 | 0 | 25-Nov-00 | 19.90300512 | 21-Jan-01 | 0.4522206 | 19-Mar-01 | 12.395667 |
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| 02-Oct-2000 | 0 | 28-Nov-00 | 0 | 24-Jan-01 | 1.6184739 | 22-Mar-01 | 9.2967501 |
| 03-Oct-2000 | 0.067530587 | 29-Nov-00 | 8.2388345 | 25-Jan-01 | 0 | 23-Mar-01 | 16.238325 |

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| 24-Mar-01 | 3.532765388 | 20-May-2001 | 0 | 16-Jul-01 | 0 | 11-Sep-01 | 0 |
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| 2-Apr-01 | 16.02853405 | 29-May-2001 | 0 | 25-Jul-01 | 0 | 20-Sep-01 | 0 |

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| 8-Apr-01 | 0 | 4-Jun-01 | 0 | 31-Jul-01 | 1.08 | 26-Sep-01 | 0 |
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| 12-Apr-01 | 0 | 8-Jun-01 | 0 | 4-Aug-01 | 0 | 30-Sep-01 | 0 |
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| 19-Apr-01 | 0 | 15-Jun-01 | 0 | 11-Aug-01 | 0 | 07-Oct-2001 | 0 |
| 20-Apr-01 | 0 | 16-Jun-01 | 0 | 12-Aug-01 | 0 | 08-Oct-2001 | 0 |
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| 05-May-2001 | 0 | 1-Jul-01 | 0 | 27-Aug-01 | 0 | 23-Oct-2001 | 0 |
| 06-May-2001 | 0 | 2-Jul-01 | 0 | 28-Aug-01 | 0 | 24-Oct-2001 | 0 |
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| 10-May-2001 | 0 | 6-Jul-01 | 0 | 1-Sep-01 | 0 | 28-Oct-2001 | 0 |

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| 11-May-2001 | 0 | 7-Jul-01 | 0 | 2-Sep-01 | 0 | 29-Oct-2001 | 0 |
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| 7-Nov-01 | 0 | 3-Jan-02 | 2.253470898 | 1-Mar-02 | 4.9253263 | 27-Apr-02 | 0 |
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| 12-Nov-01 | 0 | 8-Jan-02 | 17.64641178 | 6-Mar-02 | 13.031007 | 02-May-2002 | 0 |
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| 14-Nov-01 | 2.184085846 | 10-Jan-02 | 6.240380645 | 8-Mar-02 | 0 | 04-May-2002 | 0 |
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| 16-Nov-01 | 0 | 12-Jan-02 | 10.74732351 | 10-Mar-02 | 0 | 06-May-2002 | 0 |
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| 18-Nov-01 | 14.90876007 | 14-Jan-02 | 18.58246851 | 12-Mar-02 | 0 | 08-May-2002 | 0 |
| 19-Nov-01 | 0.728028536 | 15-Jan-02 | 13.45148885 | 13-Mar-02 | 0 | 09-May-2002 | 0 |
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| 22-Nov-01 | 0 | 18-Jan-02 | 3.986910343 | 16-Mar-02 | 1.4916703 | 12-May-2002 | 0 |
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| 25-Nov-01 | 9.749252319 | 21-Jan-02 | 0 | 19-Mar-02 | 2.2515776 | 15-May-2002 | 0 |
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| 28-Nov-01 | 0 | 24-Jan-02 | 7.69647038 | 22-Mar-02 | 6.0511152 | 18-May-2002 | 0 |
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| 1-Dec-01 | 0 | 27-Jan-02 | 2.912177801 | 25-Mar-02 | 0 | 21-May-2002 | 0 |
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| 3-Dec-01 | 16.51213551 | 29-Jan-02 | 0 | 27-Mar-02 | 0 | 23-May-2002 | 0 |
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| 6-Dec-01 | 0 | 1-Feb-02 | 19.98958476 | 30-Mar-02 | 0 | 26-May-2002 | 0 |
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| 30-Jun-02 | 0 | 26-Aug-02 | 0.030657988 | 22-Oct-2002 | 0 | 18-Dec-02 | 30.367039 |
| 1-Jul-02 | 0 | 27-Aug-02 | 0 | 23-Oct-2002 | 0 | 19-Dec-02 | 1.3850715 |
| 2-Jul-02 | 0 | 28-Aug-02 | 0 | 24-Oct-2002 | 0 | 20-Dec-02 | 4.364282 |
| 3-Jul-02 | 0 | 29-Aug-02 | 0 | 25-Oct-2002 | 3.9600924 | 21-Dec-02 | 0.0261334 |
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| 1/22/2003 | 0 | 8.790317696 | 3/24/2003 | 3 | 0.261817187 | 5/24/2003 | 0 | 0 |
| 1/23/2003 | 0 | 17.20439744 | 3/25/2003 | 0.3 | 0.811633348 | 5/25/2003 | 0 | 0 |

| Date | Met data | TRMM | Date | Met data | TRMM | Date | Met data | TRMM |
|---|---|---|---|---|---|---|---|---|
| 1/27/2003 | 50.5 | 12.62111878 | 3/29/2003 | 41.9 | 13.77158484 | 5/29/2003 | 0 | 0 |
| 1/28/2003 | 35.5 | 29.68869916 | 3/30/2003 | 5 | 2.146901026 | 5/30/2003 | 0 | 0 |
| 1/29/2003 | 26.2 | 1.504957199 | 3/31/2003 | 10 | 1.256722599 | 5/31/2003 | 0 | 0 |
| 1/31/2003 | 0 | 0 | 4/2/2003 | 7 | 6.539999962 | 6/2/2003 | 0 | 0 |
| 2/1/2003 | 0 | 6.016177416 | 4/3/2003 | 0.2 | 0 | 6/3/2003 | 0 | 0 |
| 2/2/2003 | 18.5 | 21.65823889 | 4/4/2003 | 0 | 4.199999809 | 6/4/2003 | 0 | 0 |
| 2/3/2003 | 0 | 3.03975296 | 4/5/2003 | 0 | 0 | 6/5/2003 | 0 | 0 |
| 2/4/2003 | 4.5 | 6.681123137 | 4/6/2003 | 0 | 0 | 6/6/2003 | 0 | 0 |
| 2/5/2003 | 9 | 14.66047478 | 4/7/2003 | 0 | 0 | 6/7/2003 | 0 | 0 |
| 2/6/2003 | 15.5 | 0.75993824 | 4/8/2003 | 0 | 0 | 6/8/2003 | 0 | 0 |
| 2/7/2003 | 1 | 0.348305017 | 4/9/2003 | 0 | 0 | 6/9/2003 | 0 | 0 |
| 2/8/2003 | 0 | 0.6649459 | 4/10/2003 | 0 | 0 | 6/10/2003 | 0 | 0 |
| 2/9/2003 | 0 | 2.786439896 | 4/11/2003 | 3.2 | 0 | 6/11/2003 | 0 | 0 |
| 2/10/2003 | 2 | 1.108243227 | 4/12/2003 | 1 | 0 | 6/12/2003 | 0 | 0 |
| 2/11/2003 | 3.1 | 2.881432354 | 4/13/2003 | 0 | 0 | 6/13/2003 | 0 | 0 |
| 2/12/2003 | 15.6 | 8.549304962 | 4/14/2003 | 0 | 0 | 6/14/2003 | 0 | 0 |
| 2/13/2003 | 0 | 3.03975296 | 4/15/2003 | 0 | 0 | 6/15/2003 | 0 | 0 |
| 2/14/2003 | 0 | 1.456548214 | 4/16/2003 | 0 | 0 | 6/16/2003 | 0 | 0 |
| 2/15/2003 | 0 | 0 | 4/17/2003 | 0 | 0 | 6/17/2003 | 0 | 0 |
| 2/16/2003 | 0 | 0 | 4/18/2003 | 0 | 0 | 6/18/2003 | 0 | 0 |
| 2/17/2003 | 41.6 | 45.21632469 | 4/19/2003 | 0 | 0 | 6/19/2003 | 0 | 0 |
| 2/18/2003 | 6 | 2.564791679 | 4/20/2003 | 0 | 0 | 6/20/2003 | 0 | 0 |
| 2/19/2003 | 15 | 1.804853201 | 4/21/2003 | 0 | 0 | 6/21/2003 | 0 | 0 |
| 2/20/2003 | 0 | 6.839443207 | 4/22/2003 | 0 | 0 | 6/22/2003 | 0 | 0 |
| 2/21/2003 | 28.5 | 15.9587028 | 4/23/2003 | 0 | 0 | 6/23/2003 | 0 | 0 |
| 2/22/2003 | 0.6 | 3.451386213 | 4/24/2003 | 0 | 0 | 6/24/2003 | 0 | 0 |
| 2/23/2003 | 2.5 | 0 | 4/25/2003 | 0 | 0 | 6/25/2003 | 0 | 0 |
| 2/24/2003 | 0 | 4.147996366 | 4/26/2003 | 0 | 0 | 6/26/2003 | 0 | 0 |
| 2/25/2003 | 0 | 6.047841072 | 4/27/2003 | 0 | 0 | 6/27/2003 | 0 | 0 |
| 2/26/2003 | 0 | 2.976424694 | 4/28/2003 | 0 | 0 | 6/28/2003 | 0 | 0 |
| 6/29/2003 | 0 | 0 | 8/29/2003 | 0 | 0 | 10/29/2003 | 0 | 3.668190479 |
| 6/30/2003 | 0 | 0 | 8/30/2003 | 0 | 0 | 10/30/2003 | 0 | 0 |
| 7/1/2003 | 0 | 0.119999997 | 8/31/2003 | 0 | 0 | 10/31/2003 | 0 | 0 |
| 7/2/2003 | 0 | 0 | 9/1/2003 | 0 | 0 | 11/1/2003 | 0 | 0 |
| 7/3/2003 | 0 | 0 | 9/2/2003 | 0 | 0 | 11/2/2003 | 0 | 0 |
| 7/4/2003 | 0 | 0 | 9/3/2003 | 0 | 0 | 11/3/2003 | 0 | 0 |
| 7/5/2003 | 0 | 0 | 9/4/2003 | 0 | 0 | 11/4/2003 | 0 | 0 |
| 7/6/2003 | 0 | 0 | 9/5/2003 | 0 | 0 | 11/5/2003 | 0 | 0 |
| 7/7/2003 | 0 | 0 | 9/6/2003 | 0 | 0 | 11/6/2003 | 0 | 10.13999987 |
| 7/8/2003 | 0 | 0 | 9/7/2003 | 0 | 0 | 11/7/2003 | 0 | 12.23999977 |
| 7/9/2003 | 0 | 0 | 9/8/2003 | 0 | 0.296015173 | 11/8/2003 | 0 | 1.079999924 |
| 7/10/2003 | 0 | 0 | 9/9/2003 | 0 | 0 | 11/9/2003 | 0 | 9.059999466 |
| 7/11/2003 | 0 | 0 | 9/10/2003 | 0 | 0 | 11/10/2003 | 0 | 0 |
| 7/12/2003 | 0 | 0 | 9/11/2003 | 0 | 0 | 11/11/2003 | 0 | 0 |
| 7/13/2003 | 0 | 0 | 9/12/2003 | 0 | 0 | 11/12/2003 | 0 | 0 |
| 7/14/2003 | 0 | 0 | 9/13/2003 | 0 | 0 | 11/13/2003 | 0 | 1.919999957 |
| 7/15/2003 | 0 | 0 | 9/14/2003 | 0 | 4.854649067 | 11/14/2003 | 0 | 0 |
| 7/16/2003 | 0 | 0 | 9/15/2003 | 0 | 0 | 11/15/2003 | 0 | 0 |
| 7/17/2003 | 0 | 0 | 9/16/2003 | 0 | 0 | 11/16/2003 | 0 | 4.499999791 |
| 7/18/2003 | 0 | 0 | 9/17/2003 | 0 | 0 | 11/17/2003 | 0 | 0 |
| 7/19/2003 | 0 | 0 | 9/18/2003 | 0 | 0 | 11/18/2003 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7/22/2003 | 0 | 0 | 9/21/2003 | 0 | 0 | 11/21/2003 | 0 | 0 |
| **Date** | **Met data** | **TRMM** | **Date** | **Met data** | **TRMM** | **Date** | **Met data** | **TRMM** |
| 7/24/2003 | 0 | 0 | 9/23/2003 | 0 | 0 | 11/23/2003 | 0 | 0 |
| 7/25/2003 | 0 | 0 | 9/24/2003 | 0 | 0 | 11/24/2003 | 0 | 0 |
| 7/26/2003 | 0 | 0 | 9/25/2003 | 0 | 0 | 11/25/2003 | 2.6 | 0 |
| 7/28/2003 | 0 | 0 | 9/27/2003 | 0 | 0 | 11/27/2003 | 4.4 | 10.73999941 |
| 7/29/2003 | 0 | 0 | 9/28/2003 | 0 | 0 | 11/28/2003 | 0 | 1.619999886 |
| 7/30/2003 | 0 | 0 | 9/29/2003 | 0 | 0 | 11/29/2003 | 0 | 3.360000134 |
| 7/31/2003 | 0 | 0 | 9/30/2003 | 0 | 0.651233435 | 11/30/2003 | 0 | 0 |
| 8/1/2003 | 0 | 0 | 10/1/2003 | 0 | 0 | 12/1/2003 | 5.8 | 5.546782732 |
| 8/2/2003 | 0 | 0 | 10/2/2003 | 0 | 0 | 12/2/2003 | 0 | 0 |
| 8/3/2003 | 0 | 0 | 10/3/2003 | 0 | 0 | 12/3/2003 | 6.5 | 0.506964028 |
| 8/4/2003 | 0 | 0 | 10/4/2003 | 0 | 0 | 12/4/2003 | 0 | 0 |
| 8/5/2003 | 0 | 0 | 10/5/2003 | 0 | 0 | 12/5/2003 | 0 | 0 |
| 8/6/2003 | 0 | 0 | 10/6/2003 | 0 | 0 | 12/6/2003 | 0 | 0 |
| 8/7/2003 | 0 | 0 | 10/7/2003 | 0 | 0 | 12/7/2003 | 0 | 0 |
| 8/8/2003 | 0 | 0 | 10/8/2003 | 0 | 0 | 12/8/2003 | 118.4 | 14.9107058 |
| 8/9/2003 | 0 | 0 | 10/9/2003 | 0 | 0 | 12/9/2003 | 9.4 | 11.77945673 |
| 8/10/2003 | 0 | 0 | 10/10/2003 | 0 | 0 | 12/10/2003 | 0.4 | 11.39177889 |
| 8/11/2003 | 0 | 0 | 10/11/2003 | 0 | 0 | 12/11/2003 | 34.8 | 16.49124002 |
| 8/12/2003 | 0 | 0 | 10/12/2003 | 0 | 0 | 12/12/2003 | 2.7 | 7.097495556 |
| 8/13/2003 | 0 | 0 | 10/13/2003 | 0 | 0 | 12/13/2003 | 70.5 | 7.783388019 |
| 8/14/2003 | 0 | 0 | 10/14/2003 | 0 | 0 | 12/14/2003 | 16.8 | 8.618387699 |
| 8/15/2003 | 0 | 0 | 10/15/2003 | 0 | 0 | 12/15/2003 | 1.4 | 2.833034039 |
| 8/16/2003 | 0 | 0 | 10/16/2003 | 0 | 0 | 12/16/2003 | 79.8 | 5.248568416 |
| 8/17/2003 | 0 | 0 | 10/17/2003 | 0 | 0 | 12/17/2003 | 12.8 | 14.04588449 |
| 8/18/2003 | 0 | 0 | 10/18/2003 | 0 | 0 | 12/18/2003 | 9.4 | 1.610356092 |
| 8/19/2003 | 0 | 0 | 10/19/2003 | 0 | 0 | 12/19/2003 | 7.6 | 5.129282594 |
| 8/20/2003 | 0 | 0 | 10/20/2003 | 0 | 2.296606064 | 12/20/2003 | 6 | 0.954285145 |
| 8/21/2003 | 0 | 0 | 10/21/2003 | 0 | 0.159486532 | 12/21/2003 | 14.1 | 0 |
| 8/22/2003 | 0 | 0 | 10/22/2003 | 0 | 0 | 12/22/2003 | 0 | 0 |
| 8/23/2003 | 0 | 0 | 10/23/2003 | 0 | 0 | 12/23/2003 | 18 | 14.07570601 |
| 8/24/2003 | 0 | 0 | 10/24/2003 | 0 | 0 | 12/24/2003 | 0 | 0 |
| 8/25/2003 | 0 | 0 | 10/25/2003 | 0 | 0 | 12/25/2003 | 0.4 | 1.461249113 |
| 8/26/2003 | 0 | 0 | 10/26/2003 | 0 | 0 | 12/26/2003 | 8.4 | 12.88284874 |
| 8/27/2003 | 0 | 0 | 10/27/2003 | 0 | 0 | 12/27/2003 | 0 | 1.043749392 |
| 8/28/2003 | 0 | 0 | 10/28/2003 | 0 | 0 | 12/28/2003 | 10 | 14.94052649 |
| 12/29/2003 | 0.2 | 4.592497468 | 2/28/2004 | 30.2 | 0 | 4/29/2004 | 0 | 0 |
| 12/30/2003 | 9.2 | 0 | 2/29/2004 | 0.1 | 1.608764291 | 4/30/2004 | 0 | 0 |
| 12/31/2003 | 12 | 0 | 3/1/2004 | 93.2 | 75.4648695 | 5/1/2004 | 0 | 0 |
| 1/1/2004 | 0 | 6.499957085 | 3/2/2004 | 54.5 | 14.49955606 | 5/2/2004 | 0 | 0 |
| 1/2/2004 | 0 | 4.222194433 | 3/3/2004 | 13.2 | 31.91022086 | 5/3/2004 | 0 | 0 |
| 1/3/2004 | 0 | 0 | 3/4/2004 | 27.4 | 14.72348738 | 5/4/2004 | 0 | 0 |
| 1/4/2004 | 0 | 0.499996722 | 3/5/2004 | 0.8 | 0 | 5/5/2004 | 0 | 0 |
| 1/5/2004 | 0 | 0 | 3/6/2004 | 9.1 | 26.36791658 | 5/6/2004 | 0 | 0 |
| 1/6/2004 | 0 | 4.249972105 | 3/7/2004 | 80 | 14.55553877 | 5/7/2004 | 0 | 0 |
| 1/7/2004 | 0 | 17.30544281 | 3/8/2004 | 0 | 0 | 5/8/2004 | 0 | 0 |
| 1/8/2004 | 0 | 20.72208667 | 3/9/2004 | 0 | 0 | 5/9/2004 | 0 | 0 |
| 1/9/2004 | 0 | 13.91657543 | 3/10/2004 | 24.7 | 0 | 5/10/2004 | 0 | 0 |
| 1/10/2004 | 0 | 9.277717113 | 3/11/2004 | 5.3 | 10.63673973 | 5/11/2004 | 0 | 0 |
| 1/11/2004 | 0 | 1.055548668 | 3/12/2004 | 0 | 0 | 5/12/2004 | 0 | 0 |
| 1/12/2004 | 0 | 8.222168505 | 3/13/2004 | 17.2 | 11.98032737 | 5/13/2004 | 0 | 0 |
| 1/15/2004 | 0 | 0 | 3/16/2004 | 0 | 0 | 5/16/2004 | 0 | 0 |
| 1/16/2004 | 0 | 0 | 3/17/2004 | 16.3 | 0 | 5/17/2004 | 0 | 0 |
| 1/17/2004 | 0 | 8.777720809 | 3/18/2004 | 0 | 0 | 5/18/2004 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1/18/2004 | 0 | 6.58329016 | 3/19/2004 | 0 | 0 | 5/19/2004 | 0 | 0 |

| Date | Met data | TRMM | Date | Met data | TRMM | Date | Met data | TRMM |
|---|---|---|---|---|---|---|---|---|
| 1/23/2004 | 0 | 10.30548781 | 3/24/2004 | 0 | 0 | 5/24/2004 | 0 | 0 |
| 1/24/2004 | 0 | 0.944438338 | 3/25/2004 | 0 | 0 | 5/25/2004 | 0 | 0 |
| 1/25/2004 | 0 | 6.083293796 | 3/26/2004 | 0 | 0 | 5/26/2004 | 0 | 0 |
| 1/26/2004 | 0 | 0.944438338 | 3/27/2004 | 0 | 0 | 5/27/2004 | 0 | 0 |
| 1/27/2004 | 0 | 21.58319342 | 3/28/2004 | 0 | 5.654266834 | 5/28/2004 | 0 | 0 |
| 1/28/2004 | 0 | 18.30543607 | 3/29/2004 | 0 | 0 | 5/29/2004 | 0 | 0 |
| 1/29/2004 | 0 | 7.777726889 | 3/30/2004 | 0 | 0 | 5/30/2004 | 0 | 0 |
| 1/30/2004 | 0 | 0 | 3/31/2004 | 3 | 0 | 5/31/2004 | 0 | 0 |
| 1/31/2004 | 0 | 12.24991968 | 4/1/2004 | 2.9 | 0 | 6/1/2004 | 0 | 0 |
| 2/1/2004 | 19 | 7.088617802 | 4/2/2004 | 0 | 0 | 6/2/2004 | 0 | 0 |
| 2/2/2004 | 8.8 | 1.83499676 | 4/3/2004 | 0 | 0 | 6/3/2004 | 0 | 0 |
| 2/3/2004 | 9.6 | 0 | 4/4/2004 | 0 | 0 | 6/4/2004 | 0 | 0 |
| 2/4/2004 | 0 | 0 | 4/5/2004 | 50 | 58.79470825 | 6/5/2004 | 0 | 0 |
| 2/5/2004 | 0 | 0 | 4/6/2004 | 8.2 | 2.134461403 | 6/6/2004 | 0 | 0 |
| 2/6/2004 | 0 | 0 | 4/7/2004 | 0 | 0 | 6/7/2004 | 0 | 0 |
| 2/7/2004 | 0 | 0 | 4/8/2004 | 7.2 | 0 | 6/8/2004 | 0 | 0 |
| 2/8/2004 | 0 | 0 | 4/9/2004 | 0 | 0 | 6/9/2004 | 0 | 0 |
| 2/9/2004 | 0 | 0 | 4/10/2004 | 0 | 0 | 6/10/2004 | 0 | 0 |
| 2/10/2004 | 0 | 0 | 4/11/2004 | 0 | 0 | 6/11/2004 | 0 | 0 |
| 2/11/2004 | 0.1 | 0 | 4/12/2004 | 0 | 0 | 6/12/2004 | 0 | 0 |
| 2/12/2004 | 0 | 0 | 4/13/2004 | 0 | 0 | 6/13/2004 | 0 | 0 |
| 2/13/2004 | 7.8 | 1.759585887 | 4/14/2004 | 0 | 0 | 6/14/2004 | 0 | 0 |
| 2/14/2004 | 27.3 | 2.4885571 | 4/15/2004 | 6.3 | 6.936999321 | 6/15/2004 | 0 | 0 |
| 2/15/2004 | 10.3 | 2.58910501 | 4/16/2004 | 0 | 12.85527849 | 6/16/2004 | 0 | 0 |
| 2/16/2004 | 0 | 3.368350089 | 4/17/2004 | 9.7 | 0 | 6/17/2004 | 0 | 0 |
| 2/17/2004 | 3.6 | 9.124709964 | 4/18/2004 | 1.8 | 10.96336937 | 6/18/2004 | 0 | 0 |
| 2/18/2004 | 0 | 8.244916737 | 4/19/2004 | 0 | 17.02717972 | 6/19/2004 | 0 | 0 |
| 2/19/2004 | 3.9 | 2.212050855 | 4/20/2004 | 0 | 0 | 6/20/2004 | 0 | 0 |
| 2/20/2004 | 0 | 29.41022265 | 4/21/2004 | 0 | 120.5970683 | 6/21/2004 | 0 | 0 |
| 2/21/2004 | 19.3 | 2.941022336 | 4/22/2004 | 0 | 0 | 6/22/2004 | 0 | 0 |
| 2/22/2004 | 10 | 14.65483689 | 4/23/2004 | 0 | 0.727657259 | 6/23/2004 | 0 | 0 |
| 2/23/2004 | 5 | 3.594582558 | 4/24/2004 | 0 | 0 | 6/24/2004 | 0 | 0 |
| 2/24/2004 | 3 | 6.812111378 | 4/25/2004 | 0 | 0 | 6/25/2004 | 0 | 0.779999971 |
| 2/25/2004 | 0 | 3.519171745 | 4/26/2004 | 0 | 0 | 6/26/2004 | 0 | 0 |
| 2/26/2004 | 0.1 | 11.03511763 | 4/27/2004 | 0 | 0 | 6/27/2004 | 0 | 0 |
| 2/27/2004 | 7.6 | 0 | 4/28/2004 | 0 | 0 | 6/28/2004 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6/29/2004 | 0 | 0 | 8/29/2004 | 0 | 12.23999977 | 10/29/2004 | 0 | 0 |
| 6/30/2004 | 0 | 0 | 8/30/2004 | 0 | 0 | 10/30/2004 | 0 | 0 |
| 7/1/2004 | 0 | 0 | 8/31/2004 | 0 | 0 | 10/31/2004 | 0 | 0.212375298 |
| 7/2/2004 | 0 | 0 | 9/1/2004 | 0 | 0 | 11/1/2004 | 0 | 0 |
| 7/3/2004 | 0 | 0 | 9/2/2004 | 0 | 0 | 11/2/2004 | 0 | 0 |
| 7/4/2004 | 0 | 0 | 9/3/2004 | 0 | 0 | 11/3/2004 | 0 | 0 |
| 7/5/2004 | 0 | 0 | 9/4/2004 | 0 | 0 | 11/4/2004 | 0 | 0 |
| 7/6/2004 | 0 | 0 | 9/5/2004 | 0 | 0 | 11/5/2004 | 0 | 0 |
| 7/7/2004 | 0 | 0 | 9/6/2004 | 0 | 0 | 11/6/2004 | 0 | 0.698078752 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7/10/2004 | 0 | 0 | 9/9/2004 | 0 | 0 | 11/9/2004 | 0 | 0 |
| 7/11/2004 | 0 | 0 | 9/10/2004 | 0 | 0 | 11/10/2004 | 17.2 | 2.952291608 |
| 7/12/2004 | 0 | 0 | 9/11/2004 | 0 | 0 | 11/11/2004 | 10.4 | 33.34780529 |
| 7/13/2004 | 0 | 0 | 9/12/2004 | 0 | 0 | 11/12/2004 | 0 | 0.261779547 |
| 7/14/2004 | 0 | 0 | 9/13/2004 | 0 | 0 | 11/13/2004 | 0 | 0 |

| Date | Met data | TRMM | Date | Met data | TRMM | Date | Met data | TRMM |
|---|---|---|---|---|---|---|---|---|
| 7/18/2004 | 0 | 0 | 9/17/2004 | 0 | 0 | 11/17/2004 | 0 | 1.178007826 |
| 7/19/2004 | 0 | 0 | 9/18/2004 | 0 | 0 | 11/18/2004 | 0 | 0.407212615 |
| 7/20/2004 | 0 | 0 | 9/19/2004 | 0 | 0 | 11/19/2004 | 0 | 0.392669261 |
| 7/21/2004 | 0 | 0 | 9/20/2004 | 0 | 0 | 11/20/2004 | 0 | 0 |
| 7/22/2004 | 0 | 0 | 9/21/2004 | 0 | 0 | 11/21/2004 | 0 | 0 |
| 7/23/2004 | 0 | 0 | 9/22/2004 | 0 | 0 | 11/22/2004 | 1.6 | 10.39846474 |
| 7/24/2004 | 0 | 0 | 9/23/2004 | 0 | 0 | 11/23/2004 | 29.9 | 15.80857575 |
| 7/25/2004 | 0 | 0 | 9/24/2004 | 0 | 0 | 11/24/2004 | 0 | 0.610818923 |
| 7/26/2004 | 0 | 0 | 9/25/2004 | 0 | 0 | 11/25/2004 | 2.4 | 0.392669261 |
| 7/27/2004 | 0 | 0 | 9/26/2004 | 0 | 0 | 11/26/2004 | 16.1 | 6.239078999 |
| 7/28/2004 | 0 | 0 | 9/27/2004 | 0 | 0 | 11/27/2004 | 0 | 0.101803154 |
| 7/29/2004 | 0 | 0 | 9/28/2004 | 0 | 0 | 11/28/2004 | 0 | 1.643393755 |
| 7/30/2004 | 0 | 0 | 9/29/2004 | 0 | 0 | 11/29/2004 | 61 | 7.591606379 |
| 7/31/2004 | 0 | 0 | 9/30/2004 | 0 | 0 | 11/30/2004 | 16.3 | 3.286787391 |
| 8/1/2004 | 0 | 0 | 10/1/2004 | 0 | 0 | 12/1/2004 | 0 | 3.397165775 |
| 8/2/2004 | 0 | 0 | 10/2/2004 | 0 | 0 | 12/2/2004 | 0 | 0.838806331 |
| 8/3/2004 | 0 | 0.420000017 | 10/3/2004 | 0 | 0 | 12/3/2004 | 0.8 | 3.900449753 |
| 8/4/2004 | 0 | 0 | 10/4/2004 | 0 | 0 | 12/4/2004 | 0 | 11.74328947 |
| 8/5/2004 | 0 | 0 | 10/5/2004 | 0 | 0.163365617 | 12/5/2004 | 0.1 | 5.578062296 |
| 8/6/2004 | 0 | 0 | 10/6/2004 | 0 | 0 | 12/6/2004 | 45.7 | 10.52701926 |
| 8/7/2004 | 0 | 0 | 10/7/2004 | 0 | 0 | 12/7/2004 | 15.6 | 6.584629655 |
| 8/8/2004 | 0 | 0 | 10/8/2004 | 0 | 0 | 12/8/2004 | 15 | 2.768060684 |
| 8/9/2004 | 0 | 0 | 10/9/2004 | 0 | 0 | 12/9/2004 | 6 | 11.65940762 |
| 8/10/2004 | 0 | 0 | 10/10/2004 | 0 | 0 | 12/10/2004 | 7 | 3.900449634 |
| 8/11/2004 | 0 | 0 | 10/11/2004 | 0 | 0 | 12/11/2004 | 41.9 | 6.249107361 |
| 8/12/2004 | 0 | 0 | 10/12/2004 | 0 | 0 | 12/12/2004 | 8.4 | 17.65687382 |
| 8/13/2004 | 0 | 0 | 10/13/2004 | 1.8 | 0 | 12/13/2004 | 0 | 0 |
| 8/14/2004 | 0 | 0 | 10/14/2004 | 0 | 4.819285989 | 12/14/2004 | 3.4 | 6.500748992 |
| 8/15/2004 | 0 | 0 | 10/15/2004 | 0 | 4.476218224 | 12/15/2004 | 3.4 | 2.768060684 |
| 8/16/2004 | 0 | 0 | 10/16/2004 | 0 | 5.260372877 | 12/16/2004 | 0.3 | 4.27791214 |
| 8/17/2004 | 0 | 0 | 10/17/2004 | 0 | 0 | 12/17/2004 | 42.4 | 0.880746722 |
| 8/18/2004 | 0 | 0 | 10/18/2004 | 0 | 0 | 12/18/2004 | 7.5 | 1.761493444 |
| 8/19/2004 | 0 | 0 | 10/19/2004 | 0 | 0 | 12/19/2004 | 13.2 | 15.72761917 |
| 8/20/2004 | 0 | 0 | 10/20/2004 | 0 | 0 | 12/20/2004 | 1.9 | 12.16269183 |
| 8/21/2004 | 0 | 0 | 10/21/2004 | 0 | 0 | 12/21/2004 | 62.3 | 14.72105074 |
| 8/22/2004 | 0 | 0 | 10/22/2004 | 0 | 0 | 12/22/2004 | 36 | 10.23343717 |
| 8/23/2004 | 0 | 0 | 10/23/2004 | 0 | 0 | 12/23/2004 | 10.4 | 11.95299006 |
| 8/24/2004 | 0 | 0 | 10/24/2004 | 0 | 0 | 12/24/2004 | 1.4 | 0 |
| 8/25/2004 | 0 | 0.179999992 | 10/25/2004 | 0 | 0 | 12/25/2004 | 14 | 3.481046438 |
| 8/26/2004 | 0 | 1.079999924 | 10/26/2004 | 0 | 0 | 12/26/2004 | 5.2 | 3.397165775 |
| 8/27/2004 | 0 | 0 | 10/27/2004 | 0 | 0 | 12/27/2004 | 12 | 17.65687382 |
| 8/28/2004 | 0 | 0 | 10/28/2004 | 0 | 0 | 12/28/2004 | 72.5 | 6.794331551 |

## **APPENDIX F:** ESA RADAR ALTIMETRY CONVERTED TO DISCHARGE

### **Appendix F$_1$:** ESA radar altimetry data conversion-Target ERS2-31

(Elevation (m), Discharge ($m^3s^{-1}$))

| | |
|---|---|
| **Latitude** | -14.049 |
| **Longitude** | 23.606 |

| | | **Converted Data** | | **Elevation Data** | | **Converted Data** | |
|---|---|---|---|---|---|---|---|
| Date | Elevation | Date | Discharge | Date | Elevation | Date | Discharge |
| 8-Aug-95 | 1035.214 | 8/8/1995 | 166.755 | 26-Oct-99 | 1034.932 | 4/18/2000 | 350.522 |
| 17-Oct-95 | 1033.734 | 10/17/1995 | 51.6941 | 30-Nov-99 | 1035.445 | 5/23/2000 | 298.647 |
| 21-Nov-95 | 1035.339 | 11/21/1995 | 178.557 | 4-Jan-00 | 1035.645 | 6/27/2000 | 264.763 |
| 26-Dec-95 | 1034.184 | 12/26/1995 | 80.4957 | 14-Mar-00 | 1038.141 | 8/1/2000 | 206.888 |
| 30-Jan-96 | 1036.028 | 1/30/1996 | 250.043 | 18-Apr-00 | 1036.853 | 9/5/2000 | 181.5355 |
| 5-Mar-96 | 1036.055 | 3/5/1996 | 253.021 | 23-May-00 | 1036.444 | 12/19/2000 | 178.5556 |
| 9-Apr-96 | 1035.024 | 4/9/1996 | 149.222 | 27-Jun-00 | 1036.158 | 2/27/2001 | 367.3743 |
| 14-May-96 | 1035.275 | 5/14/1996 | 172.344 | 1-Aug-00 | 1035.626 | 4/3/2001 | 925.508 |
| 18-Jun-96 | 1034.005 | 6/18/1996 | 68.2204 | 5-Sep-00 | 1035.371 | 5/8/2001 | 319.5102 |
| 1-Oct-96 | 1034.374 | 10/1/1996 | 94.5296 | 14-Nov-00 | 1025.656 | 6/12/2001 | 149.7104 |
| 10-Dec-96 | 1034.328 | 12/10/1996 | 91.0205 | 19-Dec-00 | 1035.34 | 7/17/2001 | 180.6799 |
| 14-Jan-97 | 1035.55 | 1/14/1997 | 199.237 | 27-Feb-01 | 1036.979 | 8/21/2001 | 167.8832 |
| 18-Feb-97 | 1035.71 | 2/18/1997 | 215.605 | 3-Apr-01 | 1040.039 | 9/25/2001 | 108.3093 |
| 29-Apr-97 | 1035.318 | 4/29/1997 | 176.436 | 8-May-01 | 1036.613 | 10/30/2001 | 141.5937 |
| 8-Jul-97 | 1033.845 | 7/8/1997 | 58.0453 | 12-Jun-01 | 1035.029 | 1/8/2002 | 232.9258 |
| 12-Aug-97 | 1029.348 | 9/16/1997 | 145.148 | 17-Jul-01 | 1035.362 | 4/23/2002 | 395.4795 |
| 16-Sep-97 | 1034.98 | 10/21/1997 | 110.201 | 21-Aug-01 | 1035.227 | 5/28/2002 | 334.0573 |
| 21-Oct-97 | 1034.574 | 11/25/1997 | 68.0824 | 25-Sep-01 | 1034.55 | 7/2/2002 | 213.5302 |
| 25-Nov-97 | 1034.003 | 12/30/1997 | 249.412 | 30-Oct-01 | 1034.94 | 8/6/2002 | 162.8692 |
| 30-Dec-97 | 1036.023 | 3/10/1998 | 51.5726 | 4-Dec-01 | 1052.674 | 9/10/2002 | 156.5191 |
| 3-Feb-98 | 1052.167 | 4/14/1998 | 389.134 | 8-Jan-02 | 1035.874 | 10/15/2002 | 86.7627 |
| 10-Mar-98 | 1033.732 | 5/19/1998 | 238.727 | 12-Feb-02 | 1052.693 | 12/24/2002 | 128.123 |
| 14-Apr-98 | 1037.14 | 6/23/1998 | 242.882 | 23-Apr-02 | 1037.185 | 1/28/2003 | 347.5955 |
| 19-May-98 | 1035.927 | 7/28/1998 | 156.219 | 28-May-02 | 1036.727 | 3/4/2003 | 407.5107 |
| 23-Jun-98 | 1035.964 | 9/1/1998 | 190.182 | 2-Jul-02 | 1035.69 | 5/13/2003 | 278.3034 |
| 28-Jul-98 | 1035.099 | 11/10/1998 | 96.1458 | 6-Aug-02 | 1035.172 | | |
| 1-Sep-98 | 1035.459 | 1/19/1999 | 212.028 | 10-Sep-02 | 1035.103 | | |
| 6-Oct-98 | 1031.455 | 2/23/1999 | 441.347 | 15-Oct-02 | 1034.27 | | |
| 10-Nov-98 | 1034.395 | 3/30/1999 | 812.962 | 24-Dec-02 | 1034.787 | | |
| 15-Dec-98 | 1052.92 | 5/4/1999 | 288.593 | 28-Jan-03 | 1036.831 | | |
| 19-Jan-99 | 1035.676 | 6/8/1999 | 247.668 | 4-Mar-03 | 1037.27 | | |
| 23-Feb-99 | 1037.504 | 7/13/1999 | 159.83 | 8-Apr-03 | 1051.939 | | |
| 30-Mar-99 | 1039.566 | 8/17/1999 | 193.8 | | | | |
| 4-May-99 | 1036.361 | 9/21/1999 | 196.782 | | | | |

# Appendix $F_2$

## ESA radar altimetry data conversion-Target ENVK-34

(Elevation (m), Discharge ($m^3s^{-1}$))

| | |
|---|---|
| **Latitude** | -14.158 |
| **Longitude** | 24.845 |

| Date | Elevation | Date | Discharge | Date | Elevation | Date | Discharge |
|---|---|---|---|---|---|---|---|
| 14-Jul-95 | 1103.85 | 7/14/1995 | 88.1646 | 1-Oct-99 | 1103.85 | 10/1/1999 | 88.0884 |
| 18-Aug-95 | 1104.18 | 8/18/1995 | 113.4305 | 5-Nov-99 | 1105.48 | 11/5/1999 | 241.1543 |
| 1-Dec-95 | 1104.37 | 12/1/1995 | 130.4837 | 18-Feb-00 | 1106.031 | 2/18/2000 | 304.4585 |
| 5-Jan-96 | 1104.71 | 1/5/1996 | 162.1277 | 28-Apr-00 | 1105.079 | 4/28/2000 | 197.637 |
| 9-Feb-96 | 1103.61 | 2/9/1996 | 71.1012 | 2-Jun-00 | 1104.823 | 6/2/2000 | 172.1383 |
| 15-Mar-96 | 1105.41 | 3/15/1996 | 232.3899 | 11-Aug-00 | 1103.6 | 8/11/2000 | 70.6843 |
| 19-Apr-96 | 1104.62 | 4/19/1996 | 153.405 | 15-Sep-00 | 1108.835 | 10/20/2000 | 152.7346 |
| 24-May-96 | 1104.11 | 5/24/1996 | 108.5942 | 20-Oct-00 | 1104.617 | 11/24/2000 | 102.3653 |
| 28-Jun-96 | 1104.65 | 6/28/1996 | 155.905 | 24-Nov-00 | 1104.036 | 4/13/2001 | 286.4638 |
| 2-Aug-96 | 1103.88 | 8/2/1996 | 90.6838 | 13-Apr-01 | 1105.875 | 5/18/2001 | 217.5135 |
| 20-Dec-96 | 1104.92 | 12/20/1996 | 181.8753 | 18-May-01 | 1105.263 | 6/22/2001 | 206.4009 |
| 28-Feb-97 | 1105.08 | 2/28/1997 | 197.4251 | 22-Jun-01 | 1105.161 | 7/27/2001 | 172.8411 |
| 9-May-97 | 1104.41 | 5/9/1997 | 134.0991 | 27-Jul-01 | 1104.83 | 8/31/2001 | 147.7919 |
| 13-Jun-97 | 1103.99 | 6/13/1997 | 98.8387 | 31-Aug-01 | 1104.565 | 10/5/2001 | 112.3277 |
| 18-Jul-97 | 1104.53 | 7/18/1997 | 144.689 | 5-Oct-01 | 1104.162 | 11/9/2001 | 108.7505 |
| 22-Aug-97 | 1104.63 | 8/22/1997 | 153.9805 | 9-Nov-01 | 1104.117 | 12/14/2001 | 217.1834 |
| 26-Sep-97 | 1104.61 | 9/26/1997 | 152.0655 | 14-Dec-01 | 1105.26 | 1/18/2002 | 148.5481 |
| 31-Oct-97 | 1104.49 | 10/31/1997 | 140.8706 | 18-Jan-02 | 1104.573 | 3/29/2002 | 272.7248 |
| 5-Dec-97 | 1104.03 | 12/5/1997 | 101.6347 | 29-Mar-02 | 1105.762 | 5/3/2002 | 244.0277 |
| 9-Jan-98 | 1105.42 | 1/9/1998 | 234.4271 | 3-May-02 | 1105.508 | 6/7/2002 | 207.8042 |
| 13-Feb-98 | 1104.78 | 2/13/1998 | 168.1447 | 7-Jun-02 | 1105.174 | 7/12/2002 | 154.4607 |
| 20-Mar-98 | 1106.62 | 3/20/1998 | 378.6547 | 12-Jul-02 | 1104.635 | 8/16/2002 | 153.3091 |
| 24-Apr-98 | 1105.97 | 4/24/1998 | 296.4537 | 16-Aug-02 | 1104.623 | 9/20/2002 | 78.6449 |
| 29-May-98 | 1104.69 | 5/29/1998 | 159.588 | 20-Sep-02 | 1103.715 | 10/25/2002 | 122.144 |
| 3-Jul-98 | 1104.67 | 7/3/1998 | 157.5484 | 25-Oct-02 | 1104.276 | 11/29/2002 | 125.2235 |
| 7-Aug-98 | 1104.66 | 8/7/1998 | 157.1611 | 29-Nov-02 | 1104.311 | 1/3/2003 | 243.7973 |
| 11-Sep-98 | 1103.48 | 9/11/1998 | 62.6696 | 3-Jan-03 | 1105.506 | 2/7/2003 | 150.5404 |
| 16-Oct-98 | 1104.66 | 10/16/1998 | 157.0643 | 7-Feb-03 | 1104.594 | 3/14/2003 | 317.2641 |
| 20-Nov-98 | 1104.29 | 11/20/1998 | 123.7239 | 14-Mar-03 | 1106.132 | 4/18/2003 | 184.446 |
| 25-Dec-98 | 1104.4 | 12/25/1998 | 132.9198 | 18-Apr-03 | 1104.944 | 5/23/2003 | 174.1492 |
| 29-Jan-99 | 1106.95 | 1/29/1999 | 423.0301 | 23-May-03 | 1104.843 | | |
| 5-Mar-99 | 1105.91 | 3/5/1999 | 291.268 | | | | |
| 9-Apr-99 | 1105.05 | 4/9/1999 | 195.189 | | | | |
| 14-May-99 | 1105.64 | 5/14/1999 | 259.6603 | | | | |
| 18-Jun-99 | 1104.61 | 6/18/1999 | 152.2566 | | | | |
| 23-Jul-99 | 1105.24 | 7/23/1999 | 214.5493 | | | | |

# Appendix $F_3$

## ESA radar altimetry data conversion-Target ENVK-43

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Latitude | -14.77 | | | | | | |
| Longitude | 23.44 | | | | | | |
| **Date** | **Elevation** | **Date** | **Discharge** | **Date** | **Elevation** | **Date** | **Discharge** |
| 30-May-95 | 1034.234 | 5/30/1995 | 47.8393 | 13-Jul-99 | 1035.675 | 8/17/1999 | 196.9989 |
| 4-Jul-95 | 1034.896 | 7/4/1995 | 118.7882 | 17-Aug-99 | 1035.452 | 9/21/1999 | 222.5311 |
| 8-Aug-95 | 1034.287 | 8/8/1995 | 52.4189 | 21-Sep-99 | 1035.616 | 10/26/1999 | 201.1 |
| 12-Sep-95 | 1035.303 | 9/12/1995 | 174.3827 | 26-Oct-99 | 1035.478 | 11/30/1999 | 158.3059 |
| 17-Oct-95 | 1033.86 | 10/17/1995 | 20.5731 | 30-Nov-99 | 1035.192 | 1/4/2000 | 362.7768 |
| 21-Nov-95 | 1036.542 | 11/21/1995 | 390.6484 | 4-Jan-00 | 1036.403 | 3/14/2000 | 477.0828 |
| 30-Jan-96 | 1036.168 | 1/30/1996 | 318.622 | 14-Mar-00 | 1036.956 | 4/18/2000 | 659.6746 |
| 5-Mar-96 | 1036.239 | 3/5/1996 | 331.8711 | 18-Apr-00 | 1037.747 | 5/23/2000 | 273.7517 |
| 9-Apr-96 | 1036.438 | 4/9/1996 | 369.8279 | 23-May-00 | 1035.917 | 6/27/2000 | 434.9833 |
| 14-May-96 | 1036.619 | 5/14/1996 | 406.7013 | 27-Jun-00 | 1036.754 | 8/1/2000 | 184.9762 |
| 18-Jun-96 | 1036.097 | 6/18/1996 | 305.211 | 1-Aug-00 | 1035.373 | 9/5/2000 | 299.7894 |
| 1-Oct-96 | 1034.027 | 10/1/1996 | 31.6017 | 5-Sep-00 | 1036.066 | 11/14/2000 | 184.9762 |
| 10-Dec-96 | 1036.31 | 12/10/1996 | 345.7387 | 14-Nov-00 | 1035.373 | 12/19/2000 | 250.9798 |
| 14-Jan-97 | 1035.015 | 1/14/1997 | 134.4326 | 19-Dec-00 | 1035.786 | 2/27/2001 | 184.5171 |
| 18-Feb-97 | 1037.297 | 2/18/1997 | 552.5421 | 27-Feb-01 | 1035.37 | 4/3/2001 | 743.2265 |
| 29-Apr-97 | 1035.531 | 4/29/1997 | 209.5643 | 3-Apr-01 | 1038.08 | 5/8/2001 | 386.1094 |
| 8-Jul-97 | 1036.01 | 7/8/1997 | 289.4543 | 8-May-01 | 1036.52 | 6/12/2001 | 498.8996 |
| 12-Aug-97 | 1035.581 | 8/12/1997 | 216.7902 | 12-Jun-01 | 1037.055 | 7/17/2001 | 455.644 |
| 16-Sep-97 | 1036.103 | 9/16/1997 | 306.3354 | 17-Jul-01 | 1036.857 | 8/21/2001 | 443.6105 |
| 21-Oct-97 | 1035.366 | 10/21/1997 | 183.9056 | 21-Aug-01 | 1036.802 | 9/25/2001 | 304.8366 |
| 25-Nov-97 | 1034.646 | 11/25/1997 | 89.0264 | 25-Sep-01 | 1036.095 | 10/30/2001 | 355.9792 |
| 30-Dec-97 | 1035.172 | 12/30/1997 | 155.4401 | 30-Oct-01 | 1036.369 | 12/4/2001 | 348.3024 |
| 3-Feb-98 | 1035.686 | 2/3/1998 | 234.1921 | 4-Dec-01 | 1036.323 | 1/8/2002 | 117.3946 |
| 10-Mar-98 | 1036.892 | 3/10/1998 | 463.3685 | 8-Jan-02 | 1034.884 | 2/12/2002 | 369.6257 |
| 14-Apr-98 | 1036.629 | 4/14/1998 | 408.3233 | 12-Feb-02 | 1036.437 | 4/23/2002 | 352.4598 |
| 19-May-98 | 1036.369 | 5/19/1998 | 355.9792 | 23-Apr-02 | 1036.344 | 5/28/2002 | 413.1781 |
| 23-Jun-98 | 1036.833 | 6/23/1998 | 450.3772 | 28-May-02 | 1036.652 | 7/2/2002 | 351.4681 |
| 28-Jul-98 | 1036.015 | 7/28/1998 | 290.3712 | 2-Jul-02 | 1036.339 | 8/6/2002 | 485.4046 |
| 1-Sep-98 | 1035.629 | 9/1/1998 | 224.6786 | 6-Aug-02 | 1036.993 | 9/10/2002 | 319.1937 |
| 6-Oct-98 | 1035.698 | 10/6/1998 | 235.9345 | 10-Sep-02 | 1036.171 | 10/15/2002 | 242.0444 |
| 10-Nov-98 | 1033.441 | 12/15/1998 | 119.8156 | 15-Oct-02 | 1035.734 | 12/24/2002 | 251.1529 |
| 15-Dec-98 | 1034.904 | 1/19/1999 | 365.3894 | 24-Dec-02 | 1035.787 | 1/28/2003 | 381.7966 |
| 19-Jan-99 | 1036.416 | 2/23/1999 | 381.182 | 28-Jan-03 | 1036.499 | 3/4/2003 | 370.6372 |
| 23-Feb-99 | 1036.496 | 3/30/1999 | 458.7275 | 4-Mar-03 | 1036.442 | 4/8/2003 | 433.6882 |
| 30-Mar-99 | 1036.871 | 5/4/1999 | 245.1227 | 8-Apr-03 | 1036.748 | 5/13/2003 | 419.9706 |
| 4-May-99 | 1035.752 | 6/8/1999 | 457.1847 | 13-May-03 | 1036.684 | | |
| 8-Jun-99 | 1036.864 | 7/13/1999 | 232.3439 | | | | |

# **APPENDIX G:** SIMULATION RESULTS OF THE KABOMPO BASIN MODEL

## Appendix $G_1$: Simulated discharge results for target ERS2-31

| Date | Discharge ( $m^3s^{-1}$ ) | Date | Discharge ( $m^3s^{-1}$ ) | Date | Discharge ( $m^3s^{-1}$ ) | Date | Discharge ( $m^3s^{-1}$ ) |
|---|---|---|---|---|---|---|---|
| 01-Jan-00 | 190.7 | 01-Aug-02 | 210.7 | 01-May-05 | 149.5 | 01-Dec-07 | 40.74 |
| 01-Feb-00 | 296.8 | 01-Sep-02 | 156.2 | 01-Jun-05 | 118.5 | 01-Jan-08 | 803.1 |
| 01-Mar-00 | 489 | 01-Oct-02 | 112.1 | 01-Jul-05 | 88.67 | 01-Feb-08 | 1148 |
| 01-Apr-00 | 358 | 01-Nov-02 | 88.62 | 01-Aug-05 | 61.28 | 01-Mar-08 | 789.7 |
| 01-May-00 | 293 | 01-Dec-02 | 139.9 | 01-Sep-05 | 26.76 | 01-Apr-08 | 666.6 |
| 01-Jun-00 | 234.5 | 01-Jan-03 | 304 | 01-Oct-05 | 6.85 | 01-May-08 | 573.7 |
| 01-Jul-00 | 184.4 | 01-Feb-03 | 532.2 | 01-Nov-05 | 16.48 | 01-Jun-08 | 462 |
| 01-Aug-00 | 136.5 | 01-Mar-03 | 572.8 | 01-Dec-05 | 21.12 | 01-Jul-08 | 365 |
| 01-Sep-00 | 96.14 | 01-Apr-03 | 615.3 | 01-Jan-06 | 196.4 | 01-Aug-08 | 282.4 |
| 01-Oct-00 | 72.08 | 01-May-03 | 486.3 | 01-Feb-06 | 836.4 | 01-Sep-08 | 214.4 |
| 01-Nov-00 | 68.69 | 01-Jun-03 | 392.4 | 01-Mar-06 | 671.8 | 01-Oct-08 | 113.1 |
| 01-Dec-00 | 217 | 01-Jul-03 | 311.7 | 01-Apr-06 | 593.4 | 01-Nov-08 | 71.3 |
| 01-Jan-01 | 546.4 | 01-Aug-03 | 239.3 | 01-May-06 | 488.8 | 01-Dec-08 | 128.2 |
| 01-Feb-01 | 1028 | 01-Sep-03 | 154.8 | 01-Jun-06 | 397.2 | 01-Jan-09 | 231.9 |
| 01-Mar-01 | 771.8 | 01-Dec-03 | 118.7 | 01-Jul-06 | 312.8 | | |
| 01-Apr-01 | 674.8 | 01-Jan-04 | 305.8 | 01-Aug-06 | 242.7 | | |
| 01-May-01 | 558.7 | 01-Feb-04 | 391.3 | 01-Sep-06 | 185.7 | | |
| 01-Jun-01 | 454.8 | 01-Mar-04 | 749.5 | 01-Oct-06 | 134.5 | | |
| 01-Jul-01 | 362.1 | 01-Apr-04 | 627.3 | 01-Nov-06 | 158.7 | | |
| 01-Aug-01 | 278.9 | 01-May-04 | 527.3 | 01-Dec-06 | 174.4 | | |
| 01-Sep-01 | 183.7 | 01-Jun-04 | 431 | 01-Jan-07 | 215.4 | | |
| 01-Oct-01 | 58.77 | 01-Jul-04 | 341.9 | 01-Feb-07 | 220.5 | | |
| 01-Nov-01 | 62.73 | 01-Aug-04 | 262.2 | 01-Mar-07 | 211.9 | | |
| 01-Dec-01 | 104.4 | 01-Sep-04 | 201.1 | 01-Apr-07 | 197.9 | | |
| 01-Jan-02 | 303.8 | 01-Oct-04 | 149.9 | 01-May-07 | 157.1 | | |
| 01-Feb-02 | 621.4 | 01-Nov-04 | 104.4 | 01-Jun-07 | 124.8 | | |
| 01-Mar-02 | 455.2 | 01-Dec-04 | 98.78 | 01-Jul-07 | 91.47 | | |
| 01-Apr-02 | 539 | 01-Jan-05 | 169.3 | 01-Aug-07 | 62.39 | | |
| 01-May-02 | 416.7 | 01-Feb-05 | 214.1 | 01-Sep-07 | 41.89 | | |
| 01-Jun-02 | 342.8 | 01-Mar-05 | 211.3 | 01-Oct-07 | 18.95 | | |
| 01-Jul-02 | 272.9 | 01-Apr-05 | 179.1 | 01-Nov-07 | 18.68 | | |