Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2015, Volume 4, Issue 1, pp. 828-862, Article ID Tech-330
ISSN 2320 - 0243

Research Article **Open Access**

Modelling of Spatially Distributed Surface Runoff and Infiltration in the Olifants River Catchment/Water Management Area Using GIS

Abraham Thomas

Remote Sensing Competency, Council for Geoscience (CGS), Pretoria, South Africa

Correspondence should be addressed to Abraham Thomas, athomas@geoscience.org.za

Publication Date: 10 February 2015

Article Link: http://technical.cloud-journals.com/index.php/IJARSG/article/view/Tech-330

Abstract This study aimed to model the amount of rainfall leaving the Olifants River Catchment area as surface runoff and entering into the subsurface as infiltration (as part of these waters may contribute to the water ingress in the abandoned/closed mines) using the RINSPE model implemented in ArcView GIS 3.3. The runoff and infiltration depths and the total volumes were calculated by the model for 7 scenarios using National Land-Cover 2000 Dataset. Scenarios 1 & 2: used one inch uniform rainfall to predict the expected runoff and infiltration at any location in the catchment for average and dry antecedent moisture conditions (AMCII & AMCI); scenario 3 used annual rainfall and assumed 40 rainfall events in a year for AMCII; scenarios 4 to 6 used annual rainfall and assumed 35, 40 and 46 rainfall events in a year for AMCI, and scenario 7 assumed 40 rainfall events in a year for AMCI and excluded the catchments areas of Letaba and Shingwedzi Rivers. Scenarios 1 and 2 show that runoff and infiltration are respectively 11.36 & 59.83% and 6.16% & 65.03% of the rainfall. Scenario 3 predicted a total infiltration of 6,449.793 million cubic meters or MCM (14.46% of total rainfall); the total runoff predicted is 16,589.1 MCM (37.2% of total rainfall). Scenarios 4, 5, 6 and 7 showed infiltrations of respectively 22.24%, 24.57%, 19.3% and 22.71% of total rainfall whereas the surface runoff predicted are respectively 13,120.85, 14,776.52, 11,310.57 and 10,748.07. MCMs (29.43%, 33.14%, 25.37% and 31.49% of total rainfall). Spatially distributed runoff and infiltration maps will help to understand the amount of rainfall leaving mined areas as polluted runoff and the amount of water infiltrating into the subsurface horizons, which may later contribute to water ingress or appear as part of the acid mine drainage formed in the catchment.
Keywords *Olifants River Catchment; Arcview GIS; Surface Runoff; Infiltration; GIS Modelling; RINSPE Model*

1. Introduction

The Olifants River originating near Bethal in the Highveld of Mpumalanga Province is presently one of the most threatened river systems in South Africa (Van Vuuren, 2009; Ballance et al., 2001). It has been reported that the water quality in the Olifants River has been deteriorating as a result of industrial, mining and agricultural activities (De Villiers and Mkwelo, 2009). The deteriorating water quality in the Olifants River is attributable mainly to gold- and coal-mining activities in the upper catchment. The water availability in some parts of this catchment is impacted by coal mining. The mining process can impact on the natural hydrological system by disturbing the integrity of the overlying rock and soil strata resulting in increased infiltration and recharge of the groundwater system at some places (eWISA, Year Unknown). Mining activities can also result in increased runoff and decreased infiltration and groundwater recharge due to the compaction of the ground surface resulting from various human activities on land (transport means, infrastructure developments etc.).

The Council for Geoscience (CGS) has embarked on a catchments area based approach to address nationwide environmental impacts from past and current mining activities through a project called "Environment Impacts of South African Mines- a Holistic Approach towards Best Management Practices on Acid Mine Drainage (AMD) Impact Prevention and Remediation". The Olifants River, the Vaal River and the Komati-Crocodile River catchments areas have been targeted during the years 2013-14. It has been identified that surface runoff and water infiltrated into the ground (forming potential recharge) are sources of water for the mine water ingress. The predictions of runoff and infiltration will help to understand the amount of water leaving the area and the amount of water entering into the subsurface as recharge. Accurate assessment of the volume of runoff and infiltration taking place in a given catchment area is critical to understand the volume of polluted surface water as well as how much of the infiltrated water forms part of the groundwater regime in the catchment area. Therefore efforts were made in CGS to estimate the amount of the runoff and infiltration taking place in these catchment areas through spatially distributed hydrological modelling. An important goal of spatially distributed hydrologic modeling done in this study is to provide estimates of infiltration and surface runoff from a single rainfall event and annual rainfall data, at any point in a catchment and accumulated runoff appearing as a component of stream flow along the river system. The results obtained from such a modeling will be used to estimate how much of the surface and infiltrated water might be polluted due to mining water drainage.

Getting estimates of runoff from storms/rainfalls is important for water resource engineers (for flood control management) and similarly, spatially distributed estimates of runoff, infiltration and ground water recharge are important for hydrologists for water resource assessment studies. Earlier hydrologic modeling studies, which aimed to simulate the rainfall-runoff response of catchments in semi-arid regions of southern Africa, used semi-distributed or lumped models such as ACRU, Monash and Pitman (Schulze, 1994; Hughes, 1995; Anderson, 1997). These models require many input parameters representing specific catchment characteristics and do not give or produce fully spatially distributed (pixel based) predictions of runoff and infiltration values. Due to the relative short period of time available for data collection for a large catchment area, this study wanted to use fairly easy to use completely spatially distributed hydrologic model requiring less input parameters.

In many runoff–infiltration assessment studies, the methods commonly used are the rational method, Curve Number (CN) method, Horton's model for infiltration capacity and the Green Ampt infiltration model (Thomas, 2001). The Rational method is one of the simplest and widely used methods commonly applied in urban hydrology in order to calculate peak runoff in small urban catchments. The Horton infiltration method appears simple but its application require field measurements of infiltration rate and parameters of this method cannot be estimated from soil and land cover. The Green Ampt model is an accurate physically based model for determining infiltration, but it has parameters to be measured in field and the input data needed for the implementation of model is hard to determine. Many models developed or used to estimate runoff are based on Curve Number, which is an empirical parameter used in hydrology for predicting direct surface runoff or infiltration from rainfall excess (USDA-SCS, 1993). The curve number method was developed in the 1950s by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), which was formerly called the Soil Conservation Service or SCS and is described in NRCS's National Engineering

Handbook, Section 4 (USDA-SCS, 1993). Although the CN method is designed for a single storm event, it can be scaled to find average annual runoff values (Ma, 2004). This method is also described in most engineering hydrology textbooks, and it was thoroughly reviewed by Ponce and Hawkins (1996). Many of the hydrologic models meant to estimate non-point source pollution and assess water quality in catchments, such as ANSWERS (Beasley and Huggins, 1980), CREAMS (Knisel, 1980), GLEAMS (Leonard et al., 1987), AGNPS (Young et al., 1989), EPIC (Sharpley and Williams, 1990), SWAT (Arnold et al., 1998), L-THIA (Ma, 2004), UGIf (Thomas and Tellam, 2006), N-SPECT (NOAA, 2004), RINSPE (Thomas et al., 2009) etc., have implemented the SCS Curve Number method to estimate surface runoff.

GIS has been used as a tool in distributed hydrologic modeling as it can handle various spatial data, do the required calculations for modeling and store the results for further calculations and analysis. From the above mentioned models, one can see that only ANSWERS, SWAT, L-THIA, UGIf, N-SPECT and RINSPE are implemented fully in a GIS environment whereas other models can take input data processed in a GIS and modeling is done in stand-alone programs of these models without using a GIS and later the modeling results from these models could be analyzed and visualized in a GIS; In all of these above listed models except UGIf and RINSPE, the initial abstraction is assumed as a fraction (20%) of the potential maximum retention capacity of the soil (parameter S in CN method and normally calculated from the CN values). UGif model was developed for modelling urban ground water recharge and pollutant fluxes in recharge water in Birmingham aquifer using UK land use/land cover conditions and it can predict runoff and infiltration also, however, it has not incorporated any algorithm to predict the accumulated runoff volumes. UGIf and RINSPE allows the user to input land cover/land use specific values of initial abstraction values so that the runoff predicted by these models is more accurate as compared to the predictions from the other models listed above.

Though the SCS CN method has been extensively all over the world for runoff estimation, very limited studies were found in Southern Africa that used GIS based or spatially distributed modeling approach implementing the CN method. Thomas et al. (2009) had used NSPECT and RINSPE for assessing surface runoff and NPS pollutant loads in Kuils-Eerste River catchment. De Hamera et al. (2007) had used the SCS method to establish rainfall runoff relationship in two ungagged catchments viz. the upper Mnyabezi River (22 km^2) and upper Bengu River (8 km^2), which are tributaries of the Thuli River in southern Zimbabwe and calibrated results obtained from the CN method by varying the initial abstraction values between 5.0 and 15.0% of actual retention S. and using the measured daily water levels of the downstream reservoir. The catchments were each divided into subareas by Thiessen-polygons. For each polygon the amount of discharge was calculated based on the precipitation, land use, land treatment, antecedent moisture conditions and hydrological soil group. Tsheko (2007) had used the SCS method for estimating rainfall-runoff using a composite CN calculated for the whole catchment and compared with the runoff calculated using the Pitman and Monash models and the gauged runoff of the Thagale River catchment (south-eastern Botswana). In this study, the input data were prepared in a GIS module; the runoff was estimated using composite CN value for the 3 sub-catchments (instead of calculating runoff from each land cover unit underlain by particular hydrologic soil group through distributed modeling) and the predicted runoff was found to be either over- or under-estimating the mean annual runoff volumes found using the other two models.

It has been found from the results of the runoff modeling done model by Thomas et al. (2009) for the Kuils-Eerste River catchment of Western Cape Province using the N-SPECT model that certain areas of the catchment had no runoff at all because the initial abstraction predicted by the model as 20% of S value was much higher than expected in the field conditions; hence the predicted runoff is not accurate in certain areas of the catchment. This situation actually had motivated the author to develop another model called 'Runoff, Infiltration and Non-point Source Pollution Estimation' (RINSPE) model in ArcView GIS 3.3 for the WRC project on Kuils-Eerste River catchment with additional algorithms written in Avenue programming language that allows reading of initial abstraction values from an input table for the land use/land cover types and predict runoff, infiltration, accumulated runoff and pollutant loads in runoff for either a single rainfall event or annual rainfall data (Thomas et al., 2009).

This paper is aimed to present the results obtained from attempts made to estimate the surface runoff, cumulative infiltration and accumulated runoff in the Olifants River catchment area in different scenarios (single rainfall event and multiple rainfall events in a year using annual rainfall data) using simple to use GIS based hydrologic model that implements the CN method and easily available data.

2. Characteristics of the Area of Modelling

The area chosen for this modelling work is the Olifants River catchment / Water Management Area (WMA) covering an area 76,635.69 km^2 and is located within three provinces (Mpumalanga, Limpopo and Gauteng) of north-eastern South Africa (Figure 1). The catchment of Olifants River is a principal sub-catchment of the Limpopo River. It rises in the north of South Africa (in the Mpumalanga province) and flows north-east (through Limpopo Province) into Mozambique (Figure 1). The Olifants River originates at Trichardt, to the east of Johannesburg, in the province of Gauteng, and flows north-east, through the provinces of Mpumalanga and Limpopo, into Mozambique. The main tributaries of the Olifants River are the Letaba, Wilge, Elands and Ga-Selati Rivers on the left bank and the Steelpoort, Blyde, Klaserie and Timbavati Rivers on the right bank (IWMI, 2008). The Olifants River runs through the world renowned Kruger National Park.

The topography in the Olifants River catchment is characterized by rolling gently sloped hills in the southern part of the catchment, before the river cuts through the Drakensberg to enter the relatively featureless Lowveld region. The geology in the Olifants River catchment is complex and consists mainly of hard rock formations (igneous and metamorphosed rocks) associated with the occurrence of the Bushveld Igneous Complex as the most prominent feature. The eastern limb of this formation cuts through the northern part of the catchment area. Rich coal deposits occur in the Upper Olifants sub-catchment area in the vicinity of Witbank and Middelburg. A large dolomitic intrusion extends along the Blyde River, curving westwards along the northern extremity of the water management area (DWAF, 2004a).

This catchment has extensive coal reserves located in the upstream southern region of the catchment in the vicinity of Witbank and Middelburg. The downstream eastern portions of the catchment have mineral deposits such as copper in the Phalaborwa area, with chromium and vanadium in the Steelpoort valley. The platinum reefs along the Lebowakgomo to Burgersfort axis (Dilokong Corridor) are also starting to be extensively exploited (DWAF, 2004a).

***Figure 1**: Location Map of the Olifants River Catchment / Water Management Area*

3. Method Used for Modelling of Surface Runoff and Infiltration

The tern 'Runoff' refers to the portion of rainfall that makes its way to stream channels, lakes, or oceans as surface runoff (also called direct surface runoff) and/or subsurface runoff which comes in the form of interflow, throughflow, return flow and base flow from groundwater storage. In this study only the surface runoff flow is dealt with. Surface runoff will only occur when the rate of precipitation exceeds the rate of water infiltration into the soil. The amount of rainwater that runs off during/immediately after a rainfall event depends heavily on the amount of rainfall, initial abstraction (i.e., initial loss due to interception, evaporation, depression and detention storage), and the type and hydrologic condition of the ground it lands on i.e., infiltration characteristics of the soil, soil moisture, antecedent rainfall, impervious surface etc. (Thomas, 2001). Following a rainfall event, the rainfall reaching the surface after the initial abstraction translates into infiltration, surface runoff, interflow and baseflow.

It is important to note that surface runoff and infiltration in any location can be estimated through the following equation:

$$\text{Surface Runoff} = \text{Rainfall} - \text{Initial abstraction} - \text{Infiltration} \quad (1)$$

From a literature survey it was found that the NRCS Curve Number method is widely used all over the world and is fairly easy to use for runoff and infiltration estimation. As it requires only a few easily available spatial input data sets such as land use/land cover, soil types and rainfall it was decided to use the CN method for a quick estimation of runoff and infiltration taking place in the identified study area. The NRCS curve number method is an empirical description of infiltration and rainfall excess. It combines infiltration with initial abstraction or initial losses (interception and detention storage) to estimate the rainfall excess, which would appear as runoff (Figure 2). This model is relatively simple requiring few input parameters, and has been widely applied in the fields of soil physics and hydrology (US EPA, 1998a). The method is an empirically based one, and is applicable to the situation in which amounts of rainfall, runoff, and infiltration are of interest (US EPA, 1998b).

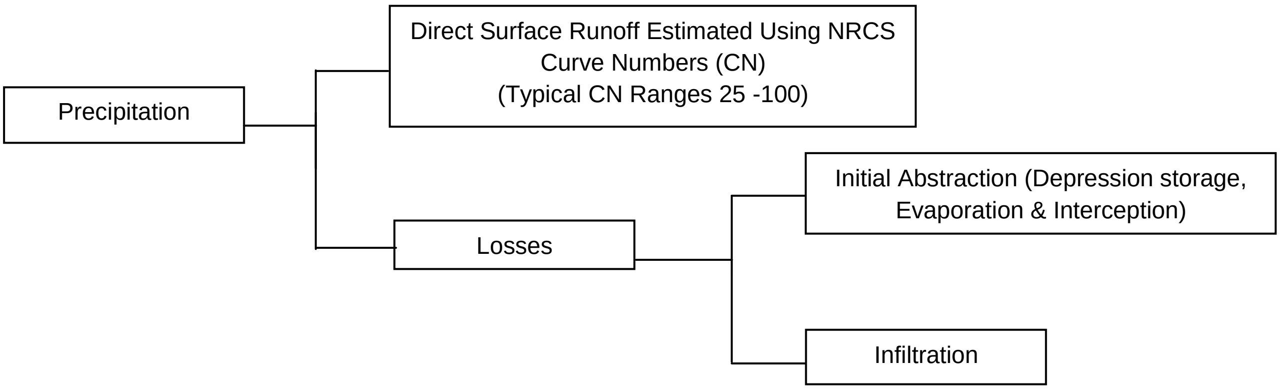

***Figure 2**: Conceptual Components of Rainfall in SCS Curve Method*

The USDA NRCS curve method predicts direct surface runoff using the following equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (2)$$

In which: Q = Total rainfall excess (runoff) for storm event (inches), P = Total rainfall for storm event (inches), I_a = Total initial loss or "initial abstraction" (inches),

S = Potential maximum retention capacity of soil at beginning of storm or maximum amount of water that will be absorbed after runoff begins (inches).

S, also called the retention parameter, is a statistically derived parameter related to the initial soil moisture content or soil moisture deficit (US EPA, 1998a). The value of S is determined based on the type of soil and the amount and kind of plants covering the ground (cover types). This is derived through its relationship to the value of the NRCS runoff curve number (CN). A curve number is a numerical description of the impermeability of the land in a watershed. This number varies from 0 (100 % rainfall infiltration) to 100 (0 % infiltration –e.g., road/concrete). The following relation relates the value of S to the 'curve number':

$$S = \frac{1000}{CN} - 10 \qquad (3)$$

CN = runoff curve number (0-100, based on the soil and land use information).

CN is determined through several factors. The most important are the hydrologic soil group (HSG), the ground cover type, treatment, hydrologic condition, the antecedent runoff condition (ARC), and whether impervious areas are connected directly to drainage systems, or whether they first discharge to a pervious area before entering the drainage system. Soils are extremely important in determining the runoff curve number. Soils are generally classified into four HSG's (hydrological soil groups: A, B, C, and D) as shown in Table 1 based on soil texture and according to how well the soil absorbs water after a period of prolonged wetting.

Table 1: *Hydrologic Soil Groups Identified From Soil Textures.*

Soil Group	Nature / Description	USDA Soil Texture
A	Well drained (high infiltration)	Sand, loamy sand, or sandy loam
B	Moderate to well drained (moderate infiltration)	Silt loam or loam
C	Poor to moderately well drained (low infiltration)	Sandy clay loam
D	Poorly drained (very low infiltration)	Clay loam, silty clay loam, sandy clay, silty clay, or clay

The terms 'initial abstraction or initial surface loss' incorporates rainfall loss due to interception, evaporation from surface during rainfall events, depression and detention storages. The value of I_a depends a greatly on the cover types (the kind of plants covering the soil or land use), the kind of soil (hydrologic soil groups, its treatment, and hydrologic condition) and antecedent soil moisture of the area being studied.

4. Selection of Appropriate GIS Based Hydrologic Model Implementing Curve Number Method

After examining available GIS based hydrologic models mentioned in the Introduction of this paper that implement the CN method, the Runoff, Infiltration and Non-point Source Pollution Estimation (RINSPE) model implemented in ArcView GIS 3.3 platform through Avenue programming was finally selected for the estimation of surface runoff and infiltration. RINSPE model was developed as one of the deliverables of a Water Research Commission funded research project on assessment of non-point source pollution in the Kuils-Eerste River catchments of Western Cape (Thomas et al., 2009). RINPSE is an event-based/annual based model that can estimate runoff & infiltration (using the NRCS CN method) and the pollutant loading from different land cover within a catchment. The term 'runoff' predicted by this model using the CN method refers to surface runoff or direct surface runoff from rainfall only and it does not incorporate other components of runoff to streams such as return flow, interflow and base flow from ground water. RINSPE model requires inputs of land use/land cover, soil, annual or event based rainfall data, Event Mean Concentration (EMC) of the pollutants to be investigated, DEM, and is capable of generating estimates of cumulative infiltration, quantity and quality of distributed and accumulated runoff and pollutant loading from the catchment for a given storm event or annual rainfall. The Interface of RINSPE Model for Runoff and Infiltration Estimation using the NRCS curve number method with various steps involved in the model run (including input data preparation) is shown in Figure 3. The user has to go through each step until the sub-menu of 'Runoff and Infiltration Depths (Using Aerial Rainfall)' if grid data sets is used as inputs.

As compared to other GIS based runoff estimation models employing NRCS curve number like N-SPECT (NOAA, 2004), in which the Initial Abstraction (I_a) is assumed as a fraction (20%) of the potential maximum retention values, (hence having a limitation of not having runoff at all in certain areas of catchments receiving lesser annual rainfalls), the RINSPE model has the advantage of its ability to assign realistic individual initial abstraction/initial loss values using a table, thus providing better estimates of runoff and infiltration.

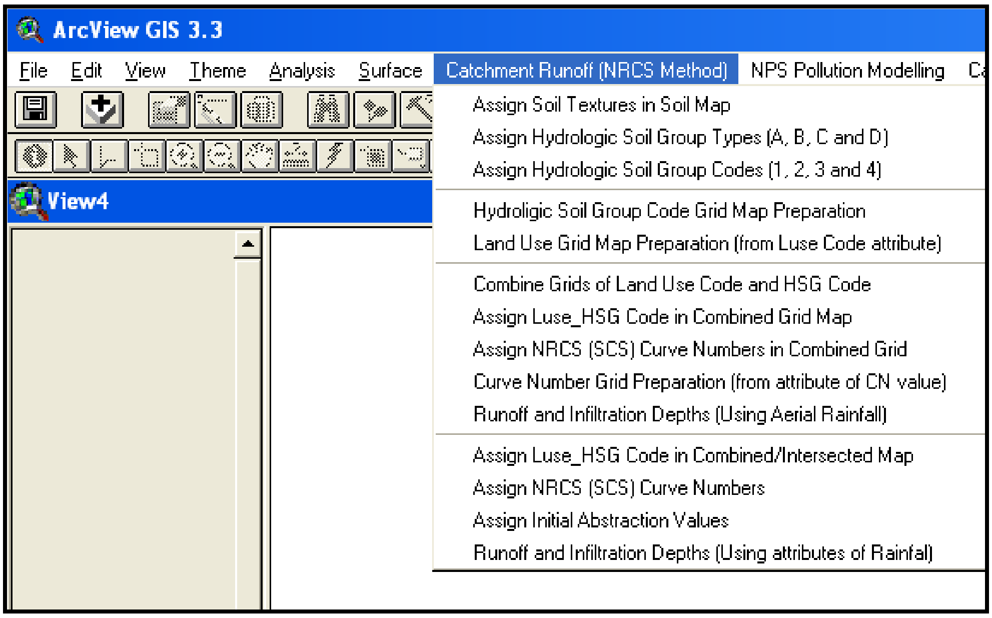

Figure 3: *Interface of RINSPE Model for Runoff and Infiltration Estimation*

5. Data Needed/Used for Runoff and Infiltration Estimation Using CN Method

GIS based runoff and infiltration estimation using the NRCS Curve Number method normally requires the following spatial inputs: land use/land cover map, soil type/hydrologic soil group map, rainfall distribution map and values of initial abstraction or initial losses for each type of land use/land cover. A depression-free digital elevation model (DEM) is also needed to simulate runoff volume accumulation at any point in the catchment using the commands of flow direction and flow accumulation. As there was not any latest land cover data covering the Olifants River catchment area, it was decided to use the freely available National Land Cover (NLC) data of year 2000 and other available data sets such as SRTM elevation (having 90 meter resolution), Land Type data (in vector format) for soil texture extraction, SRTM elevation and annual rainfall data (1km resolution). These data sets were procured from the ARC Institute for Soil, Climate and Water based in Pretoria.

6. Preparation of Input Data

6.1. Identification of the Extent of the Study Area

The study area identified for this modeling work is based on the boundaries of the revised Water Management Areas (WMAs) identified by the Department of Water Affairs in 2012 and published in the Government Gazette dated 20 July 2012. In some of the available old literatures that shows hydrological modeling studies of the Olifants River catchment (Rasiuba, 2007; De Langa et al., 2003; Prasad et al., 2007; IWMI, 2008) the catchment area identified for the Olifants River is smaller in extent with varying areas figures reported (about 54,000, 54,308, 54,475 or 54,563 km^2) as it excludes the upper portion of the WMA covering the catchment area of Letaba River and Shingwedzi River (Figure 1). A recent study carried out by the Environomics and MetroGIS for the Environmental Management Framework for the Olifants River catchment and the Letaba River catchment areas have already used a bigger study area (covering approximately 74 000 km^2) that comprises the catchment areas of these rivers (DEA, 2009). The study area boundaries shown in some of the old literature are not matching with the boundary of the water management area identified in this study.

6.2. Preparation of Land Use/Land Cover

The procured data of NLC 2000 was in 'imagine' image format and having decimal degree coordinate system. It was clipped/sub-setted in ArcView GIS using the Primary catchment boundary of the Olifants River catchment and later projected to the UTM (Zone 35 South projection) by specifying grid cell size a 30m using the 'Project Raster' command in ArcGIS for accurate volume calculations. The procured data of NLC 2000 had 49 land cover classes (Table 2) and on examining these classes it was found that some of the classes are of same nature or have more or less similar hydrologic characteristics for using in a hydrologic model meant for runoff estimation using the CN method (as CN values are the same for some classes). Therefore, the NLC data was processed further in ArcView GIS in order to merge some of the meaningless classes to make a suitable land use /land cover map for the hydrologic modelling purpose. Column 3 in Table 1 shows the classes identified for merging and such identified classes were merged by reclassifying the grid using the "Reclassify" menu of the Spatial Analyst extension. After this reclassification of the identified classes, the final land use/land cover map generated (Figure 4) has 28 classes and their areas statistics are given in Table 3.

Table 2: *Land Use/Land Cover Classes of Witwatersrand Area Based on Reclassified NLC 2000 and Assigned Curve Numbers and Initial Loss (I_a) Values*

NLC ID	ORIGINAL NLC DESCRIPTION	Reclassified NLC ID	Modified Land Use / Land Cover Types	NRCS Curve Numbers for AMC II				Ia (mm)
				CN_HSG_A	CN_HSG_B	CN_HSG_C	CN_HSG_D	
1	Forest (indigenous)							
2	Woodland (previously termed Forest and Woodland)	1 & 2 as 1	Indigenous Forest / Woodland	30	55	70	77	10.0
3	Thicket, Bushland, Bush Clumps, High Fynbos	3	Thicket, Bushland, Bush Clumps, High Fynbos	36	60	73	79	8.0
4	Shrubland and Low Fynbos							
5	Herbland	4 & 5 as 4	Shrubland, Herbland and Low Fynbos	39	61	74	80	8.0
6	Unimproved (natural) Grassland	6	Natural Grassland	49	69	79	84	7.5
7	Improved Grassland	7	Improved Grassland	39	61	74	80	7.5
8	Forest Plantations (Eucalyptus spp)							
9	Forest Plantations (Pine spp)							
10	Forest Plantations (Acacia spp)							
11	Forest Plantations (Other / mixed spp)	8 - 11 as 8	Forest Plantations (Eucalyptus,Pine, Acacia &Other)	30	55	70	77	10.0
12	Forest Plantations (clearfelled)	12	Forest Plantations (clearfelled)	43	65	76	82	5.5
13	Waterbodies							
14	Wetlands	13 & 14 as 13	Waterbodies / Wetlands	100	100	100	100	0.0
15	Bare Rock and Soil (natural)							
16	Bare Rock and Soil (erosion : dongas / gullies)							
17	Bare Rock and Soil (erosion : sheet)	15 -17 as 15	Bare Rock and Soil	77	86	91	94	2.5
18	Degraded Forest & Woodland	18	Degraded Forest & Woodland	43	65	76	82	5.5
19	Degraded Thicket, Bushland, etc	19	Degraded Thicket, Bushland, etc	45	66	77	83	5.5
20	Degraded Shrubland and Low Fynbos							
21	Degraded Herbland	20 & 21 as 20	Degraded Shrubland, Herbland and Low Fynbos	49	69	79	84	5
22	Degraded Unimproved (natural) Grassland	22	Degraded Unimproved (natural) Grassland	51	68	79	84	5.5
23	Cultivated, permanent, commercial, irrigated	23, 26 & 29 as 23	Cultivated (irrigated)	74	83	88	90	4.0
24	Cultivated, permanent, commercial, dryland	24, 27 & 28 as 24	Cultivated (dryland)	67	78	85	89	5
25	Cultivated, permanent, commercial, sugarcane	25	Cultivated (sugar cane)	62	73	81	84	5.5
26	Cultivated, temporary, commercial, irrigated							
27	Cultivated, temporary, commercial, dryland							
28	Cultivated, temporary, subsistence, dryland							
29	Cultivated, temporary, subsistence, irrigated							
30	Urban / Built-up (residential)							
31	Urban / Built-up (rural cluster)	30 & 31 as 30	Residential ; High Density	81	88	91	93	4.0
32	Urban / Built-up (residential, formal suburbs)	32	Residential : Formal Suburb	54	70	80	85	5.0
33	Urban / Built-up (residential, flatland)							
34	Urban / Built-up (residential, mixed)							
35	Urban / Built-up (residential, hostels)	33 -35 as 33	Residential : Medium Density	61	75	83	87	4.5
36	Urban / Built-up (residential, formal township)	36	Residential Formal Township	77	85	90	92	5.0
37	Urban / Built-up (residential, informal township)	37	Residential Informal Township	81	88	91	93	4.5
38	Urban / Built-up (residential, informal squatter camp)	38	Residentila Informal Squatter Camp	89	92	94	95	4.0
39	Urban / Built-up (smallholdings, woodland)							
40	Urban / Built-up (smallholdings, thicket, bushland)							
41	Urban / Built-up (smallholdings, shrubland)							
42	Urban / Built-up (smallholdings, grassland)	39 - 42 as 39	Residential : Low Densty	51	68	79	84	5.5
43	Urban / Built-up, (commercial, mercantile)	43	Commercial: mercantile	95	98	98	98	3
44	Urban / Built-up, (commercial, education, health, IT)	44	Commercial: institutional	81	88	91	93	3.0
45	Urban / Built-up, (industrial / transport : heavy)	45	Industrial / transport : heavy	89	92	94	95	3.0
46	Urban / Built-up, (industrial / transport : light)	46	Industrial / transport : light	77	85	90	92	3.5
47	Mines & Quarries (underground / subsurface mining)	47	Mines & Quarries : Underground Mining	57	72	81	86	4
48	Mines & Quarries (surface-based mining)	48	Mines & Quarries : Surface Based Mining	76	85	89	91	4.5
49	Mines & Quarries (mine tailings, waste dumps)	49	Mines & Quarries : Tailings / Waste Dumps	51	68	79	84	4.5

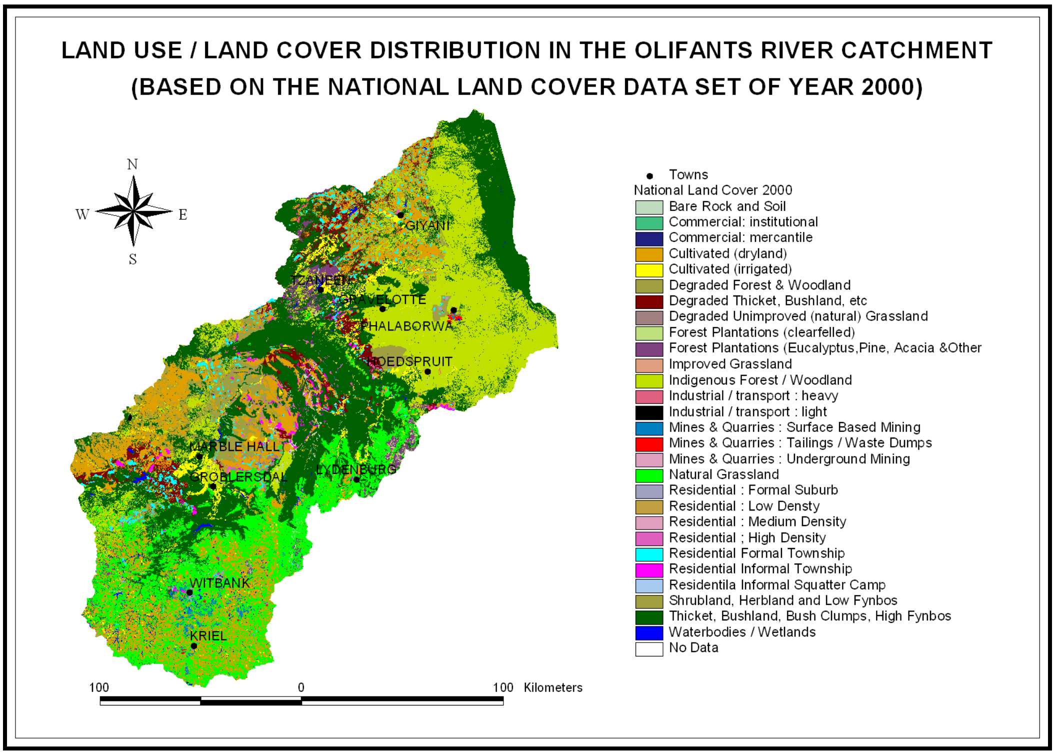

Figure 4: *Land Use / Land Cover Map of the Olifants River Catchment Area Based on NLC 2000*

6.2.1. Examination/Assessment of Land Use/Land Cover Distribution

Land use/Land Cover distribution (Table 3) reveals that the total area of the catchment is 73,635.6933 km^2 and the major land use/land cover categories are 1) Thicket, Bushland, Bush Clumps, High Fynbos (29.22%), 2) Indigenous Forest/Woodland (20.82%), 3) Cultivated (dryland):15.91%, 4) Natural Grassland (15.18%), 5) Degraded Forest & Woodland (5.88%), 6) Degraded Thicket, Bushland, etc. (3.23%), 7) Cultivated (irrigated): 2.62%, 8) Residential Formal Township (1.78%) and 9) Forest Plantations (Eucalyptus, Pine, Acacia & Other (1.41%). The other categories of land use/ land cover units including water bodies (0.93%) have areas less than 1% of the total area of the catchment. Figure 4 reveals that the land cover category Thicket, Bushland, Bush Clumps, High Fynbos are seen in the central, northern, north-eastern (Kruger National Park) and south-western parts of the catchment whereas the Indigenous Forest/Woodland category is seen mainly in the north-eastern (Kruger National Park) and south-western parts. Cultivated (dryland) and Natural Grassland are observed in the western, central and north-eastern parts and southern and south-western parts of the catchment respectively. Degraded Forest & Woodland are seen in the central part whereas the Degraded Thicket, Bushland, etc. are seen in the central, northern and western parts.

6.3. Preparation of Hydrologic Soil Group (HSG) Map from the Land Type Data

The Land Type data extracted for the study area was having decimal degree coordinate system and hence it was first projected to UTM Zone 35 South. The hydrologic soil groups (HSG) were derived from the Land Type data by reclassifying the soil textures (Figure 5) present in it. The attribute of Land Type data has multiple records of soil texture descriptions for different soil horizons (A, B, and E) and percentage values of the different texture units present in each horizon. For surface runoff modelling it is better to use the soil texture descriptions given in the top soil horizon (A horizon). For some Land Type units texture details of only B horizons is present and for some units there are more than one texture descriptions for a particular horizon. The normal querying of soil texture in RINSPE model using the sub-menu ‘Assign Soil Texture in a Soil Map’ under the Menu ‘Catchment Runoff (NRCS

Method)' cannot be applied to the Land Type data if there are more than one soil texture description for a particular soil unit. Running this sub menu to select the soil texture from a particular field (e.g. the A horizon) gives the first texture description of multiple values in the attribute table for a particular unit instead of choosing the soil texture of having the highest percentage if there are more than one texture in the attribute table. Querying the attribute table of the Land Type data and identifying and selecting correct textures (by making a link between the land type units and a corresponding field in the attribute table) from such an attribute table were difficult and time consuming and hence such querying could not done on this data.

In order to speed up the process of selecting the correct soil texture description having the maximum percentage value of a given soil horizon of the Land Type data, an Avenue script was written that allowed querying of the different percentage values of the selected horizon field (either A or B horizon if A is absent) and identifying the highest percentage and corresponding soil texture description. This script assigns highest value from a set of available values through selection using a chosen value field (e.g. particular soil profile type) to a new field called 'Max_Value' and assigns its corresponding soil texture description code to another texture field called 'NewTexture'. These texture description codes of highest percentage from the attribute table were joined to the attribute table of the shapefile of soil boundaries and later the shapefile was exported for assigning the full texture description.

After writing the correct soil texture descriptions from the Land Type data attribute table, the sub menu 'Assign Hydrologic Soil Group Types (A, B, C, and D)' was run to assign the HSG types to different textures and later sub menu called Assign Hydrologic Soil Group Codes (A, B, C, and D)' was run to assign the HSG code values of 1 to 4 to HSG types A, B, C and D. After assigning the HSG code values, the vector data was converted to a grid of HSG types by running the sub menu called 'Hydrologic Soil Group Code Grid Map Preparation'. The obtained HSG grid map is shown in Figure 5. Land Type data had contained water bodies also; such units were given a HSG code value of 5.

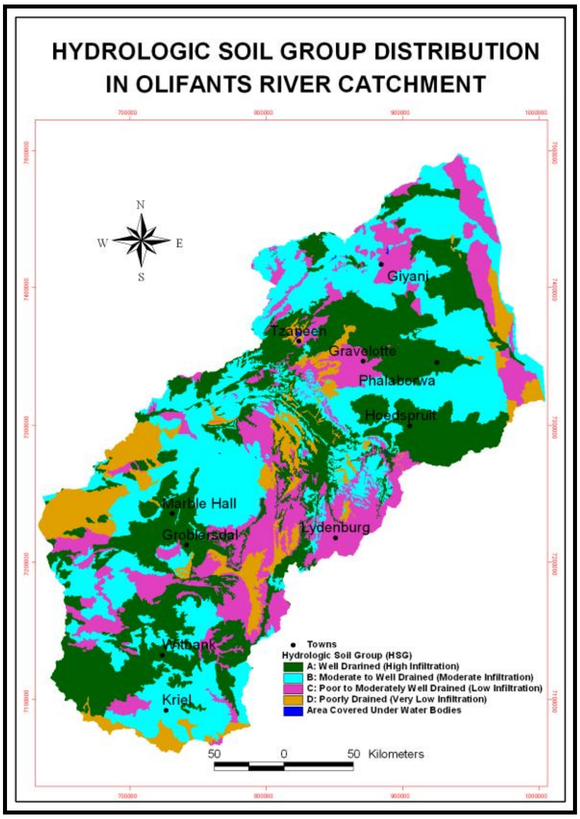

Figure 5: *Hydrologic Soil Group Map of the Olifants River Catchment Area*

6.4. Preparation of Annual Rainfall and SRTM Elevation Grids

The long term annual rainfall grid map (Figure 6) and the SRTM elevation grid map were also having decimal degree coordinate system and hence they were projected to UTM projection Zone 35 South (converted/reclassified to grid maps having 30 m cell size).

On examining Figure 6 one can see that the long term annual rainfall ranges from 381 mm to 1647 mm; the eastern region (south and south-western part of Hoedspruit) and north–eastern regions (west and north-western part of Tzaneen) receives the maximum rainfall (1304 to 1467 mm). The north-eastern (Kruger National Park) and central to western parts of the catchment (north of Marble Hall area) receive lesser amounts (381 to 521mm) of rainfall. The mean annual rainfall obtained from this averaged data is 605.55mm. The total annual rainfall volume received in the catchment having an area of 76,635.69 km^2 is 44,590,293.05 Megalitres [ML] or 4,459.02 million cubic meters (MCM).

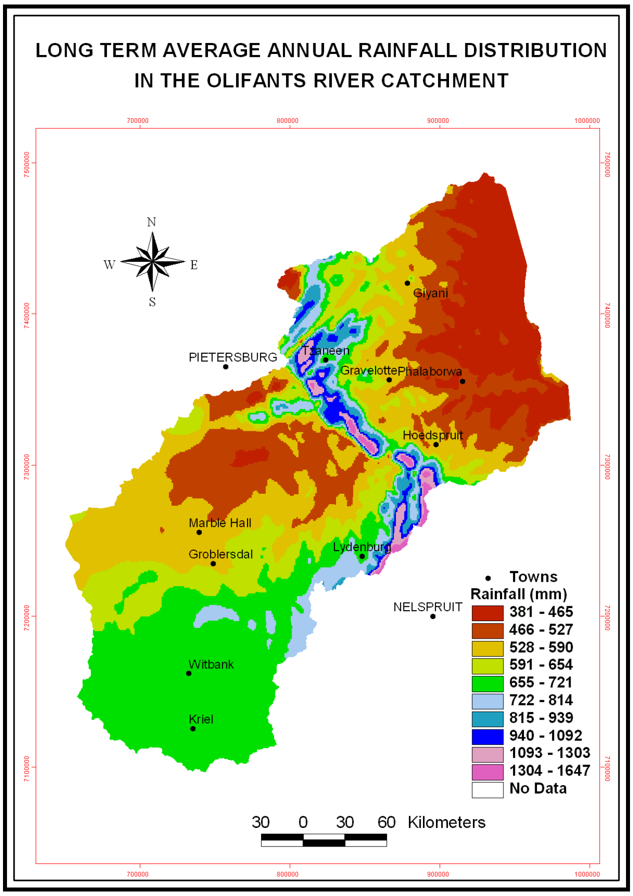

Figure 6: *Annual Rainfall Distribution of the Olifants River Catchment Area*

Using the Fill Sinks command in the Hydrologic Modelling Sample Extension 1.1 of ArcView 3.3, a depression free elevation grid (Figure 7) was prepared from the SRTM elevation grid (which was a bit time consuming as it took around 4 hours to produce such a depression free DEM). On examining the SRTM elevation data it was found that there were some negative elevation values at a location south of Phalaborwa. Applying 'Fill Sinks' commands made to elevate the negative elevation values to values closer to the surrounding areas, thus avoided local filling of runoff when a flow accumulation command is applied to it.

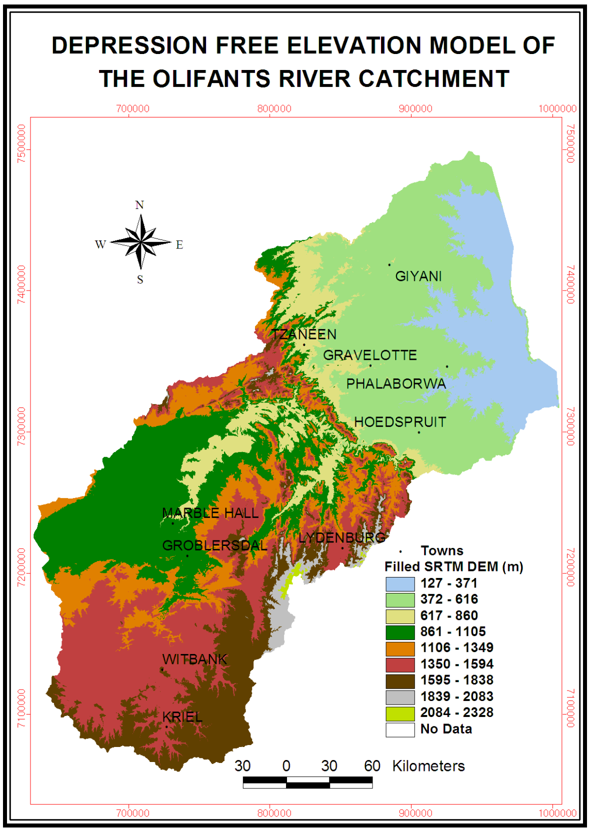

__Figure 7__: Depression Free DEM of the Olifants River Catchment Area

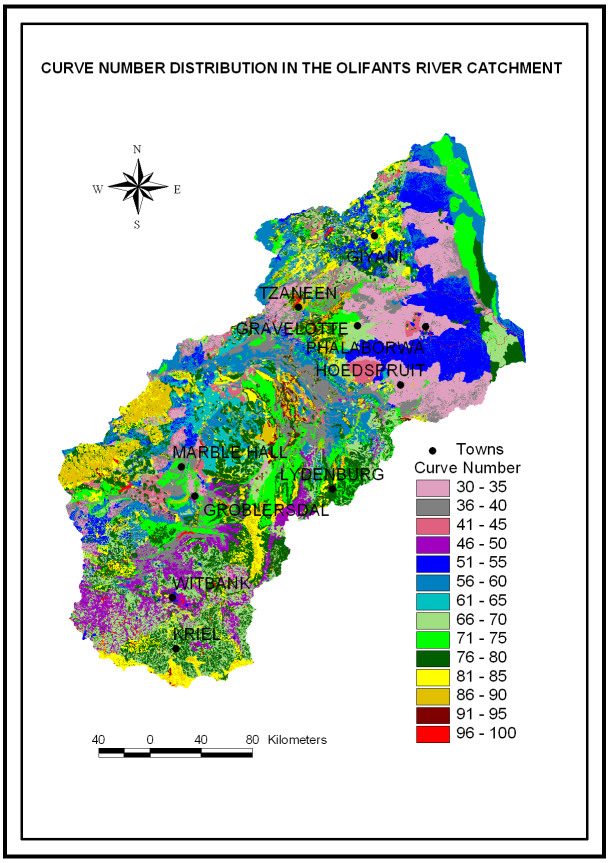

__Figure 8:__ Curve Number MAP of the Olifants River Catchment Area

7. Modelling of Runoff and Infiltration

The input values of CN for Antecedent Moisture Condition (AMC) and I and II and I_a were identified for the different land use/land cover types and HSG combinations through a literature search done on the Internet and from other means/sources (USDA-SCS, 1993; Browne, 1990; NCSPA, 1999; Thomas et al., 2009). AMC I represent a condition of the catchment where the soils are dry but not to the wilting point and when satisfactory plowing or cultivation takes place whereas the AMC II represents the average case for annual floods, which is an average of the conditions which have preceded the occurrence of the maximum annual flood or rainfall events (ASCE, 1996). In this study attempts were made to estimate runoff and infiltration for the average and dry conditions (using CN values of AMC2 and AMC1) for a one inch (25.4mm) uniform rainfall throughout the study area and also using spatially varying annual mean rainfall data. .

The input maps of land use/land cover and HSG were processed / converted into grid maps and were combined as one grid map of land use and HSG in the RINSPE model. A table of Curve Number Values for Antecedent Moisture Condition (AMC) II and initial abstraction values were prepared first (using the values shown in Table 1) and the identified CN values were assigned to the combined map (Figure 8). Later the grids of land use, CN values and rainfall were combined together (as input grid for the modeling) and initial abstraction or initial loss values were assigned through a map query done in RINSPE model. Curve numbers for AMC I was computed from those for AMC II using the following equation (Hawkins et al., 1985).

$$CN_I = CN_{II} / (2.3 - 0.013\, CN_{II}) \qquad (4)$$

Where CN_I is Curve Number for AMC I and CN_{II} is Curve Number for AMC II.

A new numeric field for CN values for AMC1 was added to the attribute table of the input grid for the runoff and infiltration modeling and the above formula was applied to calculate the CN values for AMC1 using the Calculate Tool. In order to estimate the runoff and infiltration for a uniform rainfall of 25.4 mm, another numeric field was added and a rainfall amount of 25.4mm was assigned to it using the “Calculate’ tool.

The runoff estimation program of RINSPE model will allow the user to input the number of rainfall events for the rainfall grid used and depending on the number of rainfall events in a year, it will divide the rainfall amount by the number of events specified and will calculate I_a, runoff and infiltration for each rainfall event and will add all calculated values., The default value of number of rainfall events set in the RINSPE model is 40 and if this default value is selected the model will scale or divide the total annual rainfall amount of each grid cell into 40 and will calculate runoff and infiltration for 40 rainfall events and finally add the predicted values for each event.

In order to identify the appropriate number of rainfall events or rainy days for the annual rainfall data of the study area, an effort was made to identify major cities or towns that are falling within the area of study or lying close to it for which information on the number of rainfall events in a given year (preferably year 2000 as the NLC data is of the same year) are available online. It was found that only two major cities/towns viz. Nelspruit and Polokwane (Pietersburg) are lying close to the catchment, for which long term historic daily rainfall are available online until 2002 (SAWS, 2010). The study area falls in between these towns. From the daily rainfall data of these two towns, the number of days having more than 2.5 mm rainfall (lowest initial abstraction value) were identified for the year 2000 and for a 12 year period: 1991 to 2002.

It was found that for the year 2000, Pietersburg had received a total rainfall of 645mm from 107 rainy days, of which only 48 days had rainfall above 2.5mm. For the same year 2000, Nelspruit had received a total rainfall of 1273mm from 117 rainy days of which 59 days had rainfall above 2.5mm. The historic daily rainfall data for this period shows that the number of rainy days having more than 2.5mm varied from 20 to 48 days for Pietersburg and 30 to 62 for Nelspruit. It was noted that for a 12 years period (1991 to 2002) the average number of rainy days having more than 2.5 mm for the rainfall data of Pietersburg is 34.8 and for 45.7 days for Nelspruit; whereas the average of these two figures 40.2. From these 3 average figures of rainy days having more than 2.5mm rain identified for these 2 cities, rainfall events of 35, 40 and 46 were considered as appropriate rainy days for the modeling for different scenarios (dry condition and average condition) using long-term annual rainfall data. Therefore, attempts were made to do the runoff modeling for different scenarios assuming a single event of uniform rainfall of 25,4 mm (one inch) throughout the study area and later assuming 35, 40 and 46 rainfall events for the long term rainfall data prepared based on the identified average values of number of rainy days exceeding 2.5mm rainfall obtained for the above mentioned major cities, using CN values for AMC II (average runoff potential) and AMC I (for dry periods as soils are dry and having lowest runoff potential).

One should be very cautious when selecting the number of rainfall events (rainy days) while using an annual rainfall data. When annual rainfall amounts are used for runoff modeling in RINSPE, one should look at the lowest and highest rainfall amount and the initial loss values in identifying the number of rainfall events. The lowest I_a value chosen is 2.5mm for land cover Bare Rock and Soil and therefore runoff can occur in a rainfall event in such areas only when the rainfall amount in an event is greater than 2.5mm. Choosing a higher number of rainy days in a year can result in a situation of having no runoff in certain areas. The minimum rainfall amount observed in the study area is 381mm and uniformly dividing the rainfall amounts by a higher number of rainy days like 46 days can lead to a situation of having an available minimum rainfall of 8.28mm per event in the lowest rainfall areas of 381mm. The initial abstraction assigned for indigenous forest/woodland is 10mm per rainfall event and it covers 7,969 km^2 or 20.82% of the total area. In a scenario of 46 events for a year, no runoff will be obtained in the model in indigenous forest/woodland areas having less than 460mm (46 events x 10mm =460mm) rainfall, which is not the real situation as there would be a few rainfall events in such areas exceeding 10mm and hence some runoff is expected in such areas.

The modelling of surface runoff (direct surface runoff) and infiltration was done for the following seven different scenarios:

Scenario 1: using CN values for AMC II (average runoff potential) and assuming a uniform rainfall of one inch (25.4mm) throughout the catchment that will help to know the expected runoff and infiltration depths and/or volumes at any location in the catchment.

Scenario 2: using CN values for AMC I (lowest runoff potential) and assuming a uniform rainfall of one inch (25.4mm) throughout the catchment.

Scenario 3: using the long term annual rainfall amounts & CN values for AMC II (average runoff potential) and assuming 40 rainfall events for the whole year.

Scenario 4: using the long term annual rainfall amounts & CN values for AMC I (lowest runoff potential) and assuming 40 rainfall events for the whole year.

Scenario 5: using the long term annual rainfall amounts & CN values for AMC I (lowest runoff potential) and assuming 35 rainfall events for the whole year.

Scenario 6: using the long term annual rainfall amounts & CN values for AMC I (lowest runoff potential) and assuming 46 rainfall events for the whole year.

Scenario 7: excluding the area of Secondary catchment of Letaba and Shingwedzi Rivers in the northern part of the study area and using the long term annual rainfall amounts & CN values for AMC I (lowest runoff potential) and assuming 40 rainfall events for the whole year.

The purpose of identifying above scenarios 3 to 7 was to compare the results of this modeling and also to compare with the results of other estimations for this catchment area so that some model calibration by changing the input values of number of rainfall events, CN and initial abstraction or validations of the surface runoff predictions could be made at a later stage which will help to improve the predictions by the RINSPE model using NLC 2000.

7.1. Runoff Flow Accumulation

The accumulated surface runoff is estimated using a depression free DEM and applying the flow direction and flow accumulation commands and using the runoff volume distribution grid as the weight grid. The sub menu of “Accumulated Surface Runoff Volume” under the menu of NPS Pollution Modelling has been used to generate the accumulated surface runoff volume. When this program of runoff accumulation is run, firstly a flow direction grid is generated from the DEM by calculating the downstream flow path of water leaving each cell. Flow direction is determined by evaluating the relative elevation of the eight cells surrounding the cell in question. The neighbouring cell with the least elevation is identified as the direction of outflow from the current cell. The value of the current cell in the output flow direction grid is assigned based on the value of the cell it flows into. Then a flow accumulation grid is created based on the flow direction grid and is used to derive a stream network. The values of the cells in a user-specified weight grid of runoff are summed according to the hydrologic linkages represented by the flow direction grid. Each cell contains the total value of all upstream cells that flow through it along the flow paths dictated by the flow direction grid (Jenson and Domingue, 1988).

8. Results and Discussion

The results obtained from this hydrologic modelling exercise for 7 different scenarios are shown in Figures 9 to 18 and Tables 3 to 10. Table 6 shows the summary results obtained from each scenario where Table 10 shows the results of runoff accumulation for four different scenarios.

8.1. Scenarios 1 & 2 (One Inch Uniform Rainfall and AMC II & I)

Figures 9 to 12 show infiltration and runoff depth distribution for a one inch rainfall event for average (AMC II) and dry conditions (AMC I). Figures 9 and 10 reveal that the infiltration depths from a one inch rainfall range from zero to 19.3mm for AMC II and zero to 20.4mm for AMC I whereas the runoff depths (Figures 11 & 12) range from 0.4 to 25.4mm and 0.2 to 25.4mm respectively for AMC II and AMC I. The spatial distribution of the infiltration values looks very similar to the distribution of the CN values identified based on the land cover and HSGs. Figures 9 and 10 reveals that high infiltration (18.1 to 19.3mm for AMC II and 19.1 to 20.4mm for AMCII) is observed in certain patches south and south-west of Phalaborwa, north-west of Hoedspruit and east of Marble Hall due to the presence of Degraded Forest and Woodland on HSG A. Figures 11 shows that a significant portion of the catchment area especially areas around Phalaborwa, Hoedspruit and west of Tzaneen have minimum runoff (0.4 to 1.5mm) due to the presence of Indigenous Forest/Woodland and Forest Plantations. Figure 12 shows that for dry condition, the runoff produced is very low (ranging from 0.2 to 2mm) for majority of the catchment area except certain portions of the western, central and southern parts.

Tables 3 shows the summarized volumes of rainfall, initial loss, infiltration and runoff based on NLC 2000 for a scenario of one inch (25.4mm) uniform rainfall for AMC II. During a one inch rainfall event, the total volume of rainfall received in the catchment is 1,870,346.61 ML (mega litres) or 1870.346 MCM (million cubic meters). For a one inch rainfall event, the volume of rainfall lost as initial abstraction or initial loss from the catchment is 538.804 MCM (28.81% of the rainfall volume); the total volume of cumulative infiltration is 1,119.048 MCM (59.83% of the total rainfall volume whereas the total volume of runoff is 212.494 MCM (11.36% of the rainfall volume). The average initial loss predicted by the model for a uniform rainfall of 25.4mm is 7.32mm; average infiltration is 15.2mm and the mean surface runoff is 2.89mm. This shows that the infiltration is quite high as compared to runoff during a one inch rainfall event.

Table 4 shows the summarized model predictions of initial loss, infiltration and runoff in depths (mm) based on NLC 2000 for a one inch rainfall (AMC II) and their respective percentage values. Indigenous Forest / Woodland and Forest Plantation categories have got the lower runoff of 0.92mm and 1.21mm respectively % whereas the areas of Water Bodies, Commercial: mercantile categories have got higher runoff values (25.4mm and 16.29mm). Mines & Quarries have got highest infiltration amounts of 70 to 73% of rainfall whereas the Commercial and Residential Informal Squatter Camp areas have got lowest infiltration amounts (24& and 45% of rainfall respectively). Table 6 shows that for a one inch uniform rainfall event during the dry condition (AMC I), the predicted infiltration is 5% higher (65.03% of the rainfall) than average condition (AMC II) and the surface runoff is less (6.16% of the total rainfall).

8.2. Scenarios 3 & 4 (40 Rainfall Events and AMC II & I)

Figures 13 and 14 show that the infiltration depths for AMC II and 40 rainfall events using the annual rainfall data ranges from zero to 383.24mm whereas the runoff depths ranges from 0 to 1501mm. The Kruger National Park area has got the lowest runoff (0 - 71mm) because of lower rainfall (381 to 465mm) and the presence of the land cover Thicket, Bushland, Bush Clumps, High Fynbos in that region whereas the areas south of Tzaneen, west of Hoedspruit and east of Lydenburg have got maximum runoff (859 to 1501mm) because of very high rainfall (1093 to 1640mm) received in the escarpment zones and higher curve number given for the cultivated (irrigated) land cover in these areas. The distribution of infiltration is following the spatial distribution patterns seen in the Curve Number map and the rainfall distribution map. Certain patches of areas in the north west of Marble Hall and certain areas of Kruger National Park have got lower runoff values. The areas of higher infiltration are found in the north and north-west of Tzaneen (244.4mm to 383.2mm) and around Witbank, Marble Hall and Hoedspruit (180.7 to 244.4) mainly because of higher rainfall amounts received and the presence of well drained and moderate to well drained HSGs in those areas. For a mean annual rainfall of 605.55, the mean initial loss predicted by the model is 292.68mm; mean infiltration is 87.59mm and the mean surface runoff is 225.29mm. For scenario 3 (Table 6) the volume of annual rainfall lost as initial loss from the catchment is 21,551.39 million cubic meters (MCM) (48.33% of the rainfall). The higher initial losses are contributed by the following 4 land covers viz. 1) Thicket, Bushland, Bush Clumps, High Fynbos (53% of the rainfall); 2) Indigenous Forest / Woodland (77% of rainfall); 3) Natural Grassland (42% of rainfall) and 4) Cultivated –dry land (32.6% of rainfall). Table 3 shows that the total volume of cumulative infiltration predicted for a year is 6,449.79 MCM (14.46% of the rainfall volume whereas the total annual volume of surface runoff (direct surface runoff) is 16,589.1 Million cubic meters (37.2% of the rainfall volume). Studies on the hydrological properties of fynbos catchments in Southern Africa by Cowling et al., (2004) has reported that runoff in most catchments amounts to between 35 to 55 % of rainfall depending on the density of the biomass which actually contribute to high interception loss.

8.3. Scenario 4 (AMC I & 40 rainfall events)

The results of this scenario shown in Figures 13 & 14 and Table 6 show that the average surface runoff for the WMA is 29.43% of total rainfall amount whereas the average infiltration is 22.24% of the rainfall. The spatial distributions of infiltration and runoff are more or less similar to the scenario of AMC II, but their amounts vary. Dry conditions (AMC I with lower CN values) has resulted in lower runoff and higher infiltration. The Kruger National Park area has got the lowest runoff of 0 to 20mm whereas the highest runoff values ranges from 750 to 999mm and observed in the escarpments zone area due to high rainfall in this region. The total runoff volume predicted is 13,120.85 MCM whereas the total infiltration volume is 9,918.05 MCM.

8.4. Scenario 5 (AMC I & 35 rainfall events)

This scenario as shown in Table 6 has resulted in higher runoff (33.14% of rainfall or 14,776.52 MCM) and infiltration (24.57 % of rainfall or 10,955.62 MCM) and lower initial loss (42.29% of rainfall) volumes. These values appeared to be less realistic as compared to scenarios 3 and 4.

8.5. Scenario 6 (AMC I & 46 rainfall events)

This scenario as shown in Table 6 has resulted in having a higher initial loss volume of 24,674 MCM (55.33% of total rainfall) and producing a total runoff volume of 11,310.57 MCM (25.37% of rainfall or 153.6mm average runoff) and a total infiltration volume of 8,605.72 (19.3 % of rainfall or 116.9mm average infiltration). Choosing 46 rainfall events or rainy days in a year has resulted in a situation of having no runoff in certain areas of low rainfall especially in the Kruger National Park area (4623.35 km^2). The minimum rainfall amount observed in the study area is 381mm and uniformly dividing the rainfall amounts by 46 events has led to a situation of having an available minimum rainfall of 8.28mm per event. The initial abstraction assigned for indigenous forest/woodland is 10mm per rainfall event and it covers 7,969 km2 or 20.82% of the total area. In this scenario, no runoff is produced in such areas having less than 460mm annual rainfall, which is not the real situation as there would be a few rainfall events exceeding 10mm and hence some runoff is expected in such areas. For the same scenario, Thicket, bushland, bush clumps and high fynbos area has produced runoff in areas having rainfall above 368mm as the initial abstraction assigned to it is 8mm. It was found that when a higher number of rainy days or rainfall events in year (for example 54 events) was chosen to divide the annual rainfall, then the available minimum rainfall per event in certain areas was lower than 8mm and hence such areas having woodland or forest plantations did not have any runoff as the assigned initial abstraction for such land covers is 8mm.

8.6. Scenario 7 (AMC I & 40 Rainfall Events and Excluding Letaba and Shingwedzi Catchments)

Table 6 shows that the total study area covered in this scenario is 54,621.4 square km. With a total annual rainfall volume of 34,126.49 MCM, the total annual runoff generated is 10,748.07 (196.mm or 31.49% of total rainfall) whereas the total annual infiltration is 7,750.14 MCM (141.89mm or 22.71% of total rainfall).

8.7. Accumulated Runoff Simulation

The accumulated annual surface runoff volume simulated at the outlet of the catchment for Scenario 1 (AMC II & one inch uniform rainfall event) is 200.98MCM (10.75% of the one inch rainfall). For Scenario 3 (AMC II & assuming 40 days rainfall events in a year) one can see that the total annual runoff volume predicted by the model that will exit through the outlet of the catchment is 16,183.19 MCM (36.3% of rainfall volume). The accumulated runoff volume predicted at the outlet of the catchment for Scenario 4 (AMC I and assuming 40 rainfall events in a year) is 12,831.8013 MCM. This accumulated runoff volume leaving the outlet of the Olifants River in the WMA is not exactly matching with the summarized total volume figure (13,120.85 MCM) shown in Table 5, which means that the WMA identified by the DWAF is not matching to the catchment area identified for the Olifants River. On zooming to the accumulated grid near the outlet of Olifants river, it can be seen that the accumulated runoff from the Shingwedzi river is not seen to meet with the Olifants River in the South African territory (the WMA identified by DWA) The difference observed in the total accumulated runoff volume figure shown in the map is due to the fact that the accumulated runoff from Shingwedzi River is not actually added to the accumulated runoff seen at the outlet of Olifants River seen in the WMA.

For Scenario 6 (AMC I & 40 rainfall events in a year) the accumulated runoff volume predicted at the outlet of the catchment is, 11,109.705 MCM (Figure 17). On examining the accumulated surface runoff of this scenario, it was noted that the accumulated annual surface runoff volume just before the tributary Letaba River meets Olifants River (Figure 18) is 9271.54 MCM; the contribution of runoff volume from the Letaba River is 1837.15 MCM. The MAR reported by the DWAF for the Letaba River is 574 MCM and its annual runoff volume figures ranges from 100 to 1700 MCM (DAWF, 2001). The predicted accumulated runoff from Shingwedzi River is found to be 161.3072 MCM. These accumulated runoff volume figures are the expected accumulated surface runoff values in an ideal condition where there is no abstraction of river water for irrigation or interruption of flow due to man-made ponding or dams.

The accumulated runoff volume predicted for scenarios 1, 3, 4 & 6 were found to be more or less similar to the total runoff volume obtained by summarizing based on the land use/land cover units of the study area (Table 6), The modeling of runoff accumulation is a very time consuming process (it takes 5 to 6 hours for one accumulation simulation) for this catchment because of its large size; therefore, in view of much time needed for such simulations, no further efforts were made to get the accumulated runoff volume figures for the other scenarios.

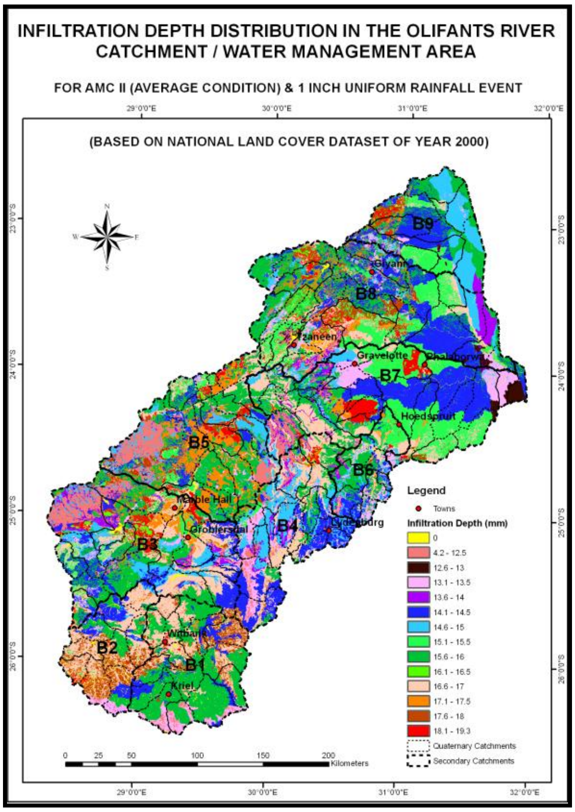

Figure 9: *Infiltration Depth Distribution in Olifants River Catchment / WMA for a One Inch Rainfall Event (Average Condition)*

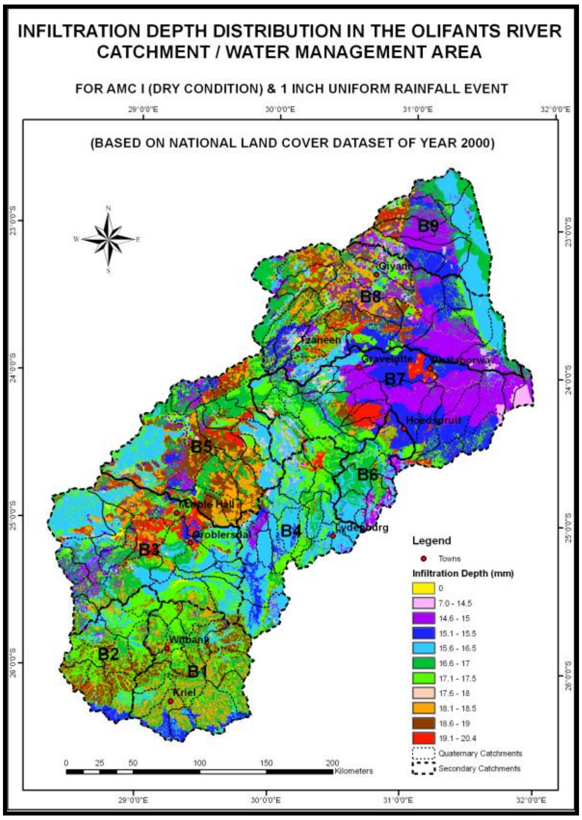

Figure 10: *Infiltration Depth Distribution in Olifants River Catchment / WMA for a One Inch Rainfall Event (Dry Condition)*

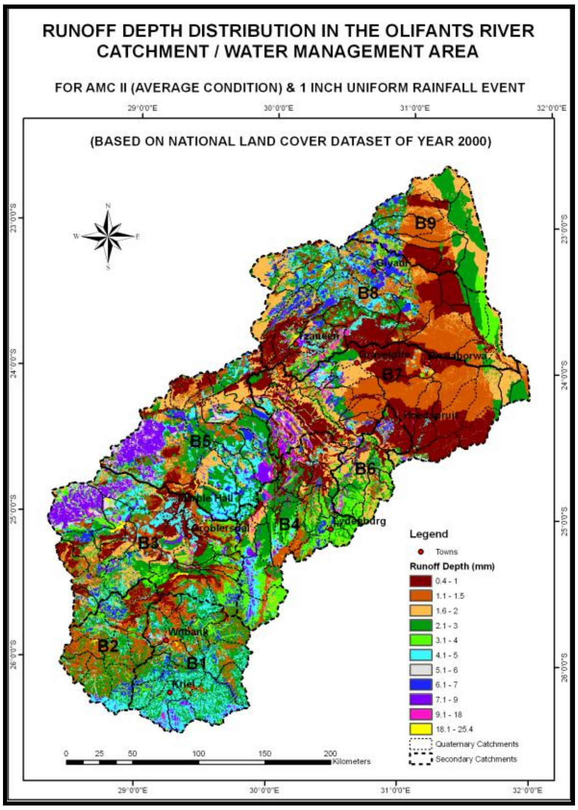

Figure 11: *Runoff Depth Distribution in Olifants River Catchment / WMA for a One Inch Rainfall Event (Average Condition)*

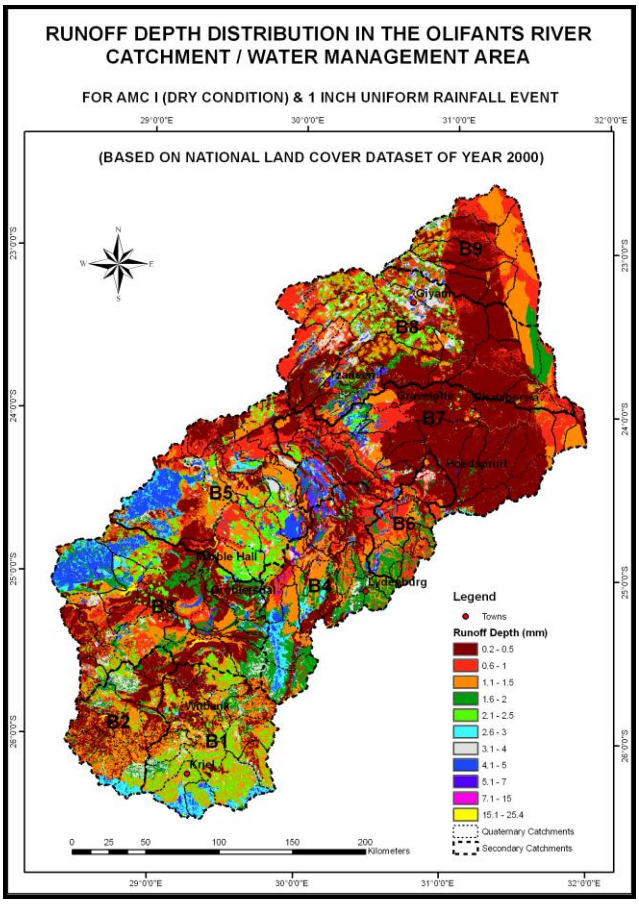

Figure 12: *Infiltration Depth Distribution in Olifants River Catchment / WMA for a One Inch Rainfall Event (Dry Condition)*

Table 3: *RINSPE Model Results for a Scenario of One Inch Uniform Rainfall (AMC II): Summarized Volumes of Rainfall, Initial Loss, Infiltration and Runoff Based on NLC 2000*

Land Use / Land Cover (Based on NLC 2000)	Code	Area (m^2)	% Area	Rainfall Vol (m^3)	Initial Loss Vol (m^3)	Infiltration Vol (m^3)	Runoff Vol (m^3)
Bare Rock and Soil	15	417,149,100	0.57	10,595,587.14	1,042,839.00	5,756,663.44	3,796,084.70
Commercial: institutional	44	6,797,700	0.01	172,661.58	20,393.10	82,237.21	70,031.27
Commercial: mercantile	43	8,616,600	0.01	218,861.64	25,849.80	52,668.99	140,342.85
Cultivated (dryland)	24	11,718,346,500	15.91	297,646,001.10	58,591,021.50	179,101,669.84	59,953,309.76
Cultivated (irrigated)	23	1,925,962,200	2.62	48,919,439.88	7,700,346.00	29,242,907.79	11,976,186.09
Degraded Forest & Woodland	18	4,332,286,800	5.88	110,040,084.72	23,825,963.70	75,018,992.17	11,195,128.85
Degraded Thicket, Bushland, etc	19	2,380,845,600	3.23	60,473,478.24	13,094,596.35	40,857,394.09	6,521,487.80
Degraded Unimproved (natural) Grassland	22	156,001,500	0.21	3,962,438.10	858,008.25	2,578,734.41	525,695.44
Forest Plantations (Eucalyptus,Pine, Acacia &Other	8	1,039,568,400	1.41	26,405,037.36	10,375,497.00	14,769,905.88	1,259,634.48
Forest Plantations (clearfelled)	12	164,421,000	0.22	4,176,293.40	904,266.00	2,751,989.11	520,038.29
Improved Grassland	7	17,276,400	0.02	438,820.56	129,573.00	283,340.43	25,907.13
Indigenous Forest / Woodland	1	15,331,237,200	20.82	389,413,424.88	153,308,286.00	221,929,370.96	14,175,767.92
Industrial / transport : heavy	45	22,104,900	0.03	561,464.46	66,314.70	268,210.97	226,938.79
Industrial / transport : light	46	31,837,500	0.04	808,672.50	111,431.25	476,357.93	220,883.32
Mines & Quarries : Surface Based Mining	48	354,859,200	0.48	9,013,423.68	1,596,866.40	5,340,498.62	2,076,058.66
Mines & Quarries : Tailings / Waste Dumps	49	56,625,300	0.08	1,438,282.62	254,813.85	1,048,374.60	135,094.17
Mines & Quarries : Underground Mining	47	195,300	0.00	4,960.62	781.20	3,486.06	693.36
Natural Grassland	6	11,177,076,600	15.18	283,897,745.64	83,828,074.50	171,261,438.20	28,808,232.94
Residential : Formal Suburb	32	100,431,900	0.14	2,550,970.26	502,159.50	1,777,343.08	271,467.68
Residential : Low Densty	39	82,043,100	0.11	2,083,894.74	451,217.25	1,431,112.93	201,564.56
Residential : Medium Density	33	6,490,800	0.01	164,866.32	29,208.60	93,400.69	42,257.03
Residential ; High Density	30	283,370,400	0.38	7,197,608.16	1,133,452.80	3,669,237.89	2,394,917.47
Residential Formal Township	36	1,313,579,700	1.78	33,364,924.38	6,567,552.00	18,557,067.74	8,240,304.64
Residential Informal Township	37	498,915,000	0.68	12,672,441.00	2,245,117.50	6,356,633.24	4,070,690.26
Residentila Informal Squatter Camp	38	7,802,100	0.01	198,173.34	31,208.40	88,525.57	78,439.37
Shrubland, Herbland and Low Fynbos	4	1,566,000	0.00	39,776.40	12,528.00	22,802.53	4,445.87
Thicket, Bushland, Bush Clumps, High Fynbos	3	21,514,312,800	29.22	546,463,545.12	172,096,790.40	336,227,698.59	38,139,056.13
Waterbodies / Wetlands	13	685,973,700	0.93	17,423,731.98	0.00	0.00	17,423,731.98
	Total	**73,635,693,300**	**100**	**1,870,346,610**	**538,804,156**	**1,119,048,063**	**212,494,391**
				% of Rainfall	***28.81%***	***59.83%***	***11.36%***
	Average in mm for the whole area			*25.40*	*7.32*	*15.20*	*2.89*

Table 4: *RINSPE Model Results for a Scenario of One Inch Uniform Rainfall (AMC II): Summarized Depths of Rainfall, Initial Loss, Infiltration and Runoff Based on NLC 2000*

Land Use / Land Cover (Based on NLC 2000)	Code	Area (m^2)	% Area	Rainfall (mm)	Ini. Loss (mm)	Infiltration (mm)	Runoff (mm)	% Ini. Loss	% Infiltration	% Runoff
Bare Rock and Soil	15	417,149,100	0.57	25.40	2.50	13.80	9.10	9.84	54.33	35.83
Commercial: institutional	44	6,797,700	0.01	25.40	3.00	12.10	10.30	11.81	47.63	40.56
Commercial: mercantile	43	8,616,600	0.01	25.40	3.00	6.11	16.29	11.81	24.06	64.12
Cultivated (dryland)	24	11,718,346,500	15.91	25.40	5.00	15.28	5.12	19.68	60.17	20.14
Cultivated (irrigated)	23	1,925,962,200	2.62	25.40	4.00	15.18	6.22	15.74	59.78	24.48
Degraded Forest & Woodland	18	4,332,286,800	5.88	25.40	5.50	17.32	2.58	21.65	68.17	10.17
Degraded Thicket, Bushland, etc	19	2,380,845,600	3.23	25.40	5.50	17.16	2.74	21.65	67.56	10.78
Degraded Unimproved (natural) Grassland	22	156,001,500	0.21	25.40	5.50	16.53	3.37	21.65	65.08	13.27
Forest Plantations (Eucalyptus,Pine, Acacia &Other	8	1,039,568,400	1.41	25.40	9.98	14.21	1.21	39.29	55.94	4.77
Forest Plantations (clearfelled)	12	164,421,000	0.22	25.40	5.50	16.74	3.16	21.65	65.90	12.45
Improved Grassland	7	17,276,400	0.02	25.40	7.50	16.40	1.50	29.53	64.57	5.90
Indigenous Forest / Woodland	1	15,331,237,200	20.82	25.40	10.00	14.48	0.92	39.37	56.99	3.64
Industrial / transport : heavy	45	22,104,900	0.03	25.40	3.00	12.13	10.27	11.81	47.77	40.42
Industrial / transport : light	46	31,837,500	0.04	25.40	3.50	14.96	6.94	13.78	58.91	27.31
Mines & Quarries : Surface Based Mining	48	354,859,200	0.48	25.40	4.50	15.05	5.85	17.72	59.25	23.03
Mines & Quarries : Tailings / Waste Dumps	49	56,625,300	0.08	25.40	4.50	18.51	2.39	17.72	72.89	9.39
Mines & Quarries : Underground Mining	47	195,300	0.00	25.40	4.00	17.85	3.55	15.75	70.27	13.98
Natural Grassland	6	11,177,076,600	15.18	25.40	7.50	15.32	2.58	29.53	60.33	10.15
Residential : Formal Suburb	32	100,431,900	0.14	25.40	5.00	17.70	2.70	19.69	69.67	10.64
Residential : Low Densty	39	82,043,100	0.11	25.40	5.50	17.44	2.46	21.65	68.67	9.67
Residential : Medium Density	33	6,490,800	0.01	25.40	4.50	14.39	6.51	17.72	56.65	25.63
Residential ; High Density	30	283,370,400	0.38	25.40	4.00	12.95	8.45	15.75	50.98	33.27
Residential Formal Township	36	1,313,579,700	1.78	25.40	5.00	14.13	6.27	19.68	55.62	24.70
Residential Informal Township	37	498,915,000	0.68	25.40	4.50	12.74	8.16	17.72	50.16	32.12
Residentila Informal Squatter Camp	38	7,802,100	0.01	25.40	4.00	11.35	10.05	15.75	44.67	39.58
Shrubland, Herbland and Low Fynbos	4	1,566,000	0.00	25.40	8.00	14.56	2.84	31.50	57.33	11.18
Thicket, Bushland, Bush Clumps, High Fynbos	3	21,514,312,800	29.22	25.40	8.00	15.63	1.77	31.49	61.53	6.98
Waterbodies / Wetlands	13	685,973,700	0.93	25.40	0.00	0.00	25.40	0.00	0.00	100.00

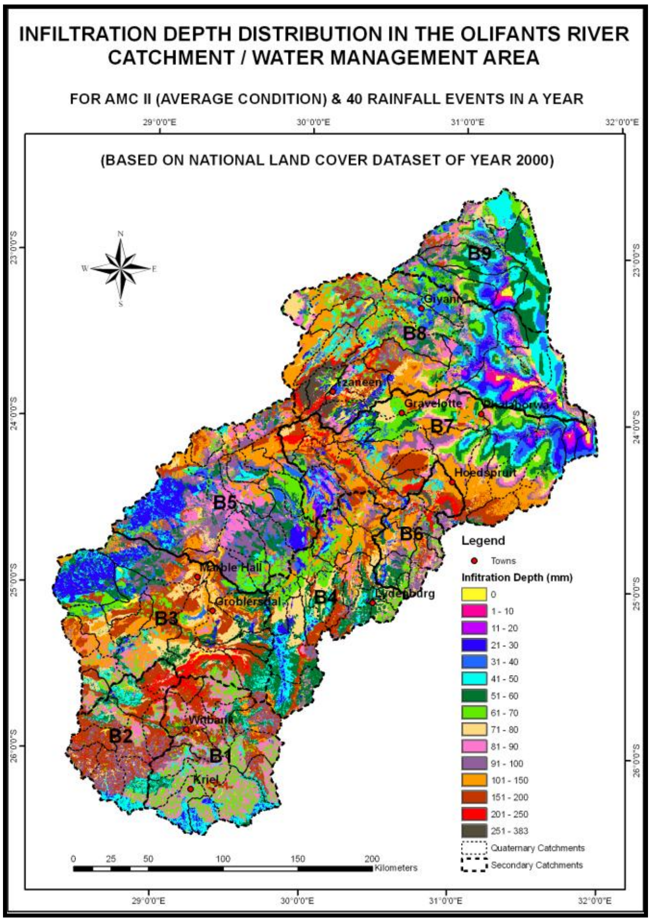

Figure 13: *Annual Infiltration Depth Map of the Olifants River Catchment/WMA for AMC II*

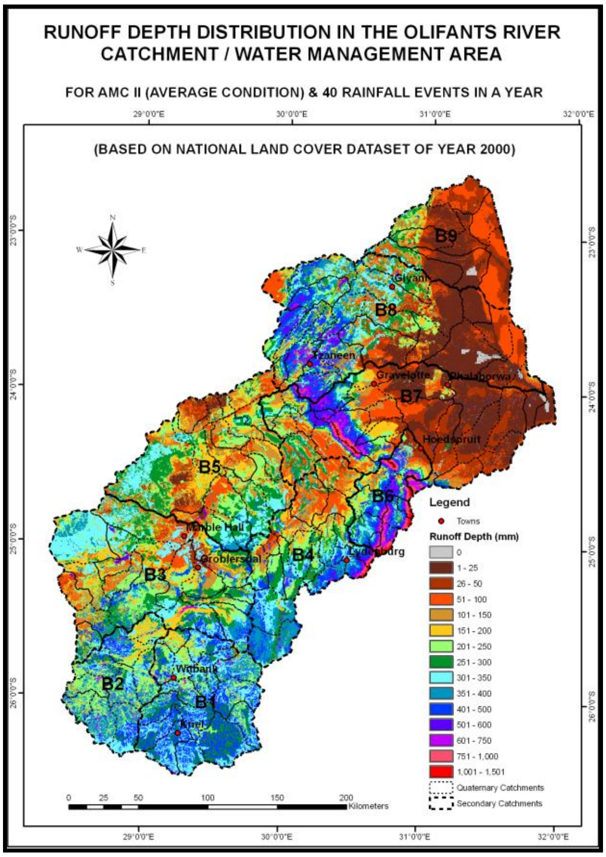

Figure 14: *Annual Runoff Depth Map of the Olifants River Catchment /WMA for AMC II*

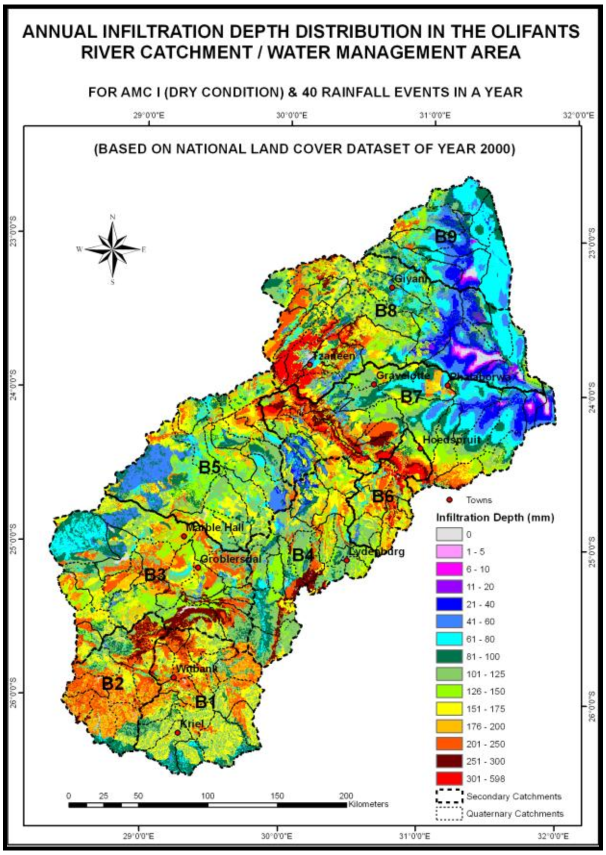

Figure 15: *Annual Infiltration Depth Map of the Olifants River Catchment Area for AMC I*

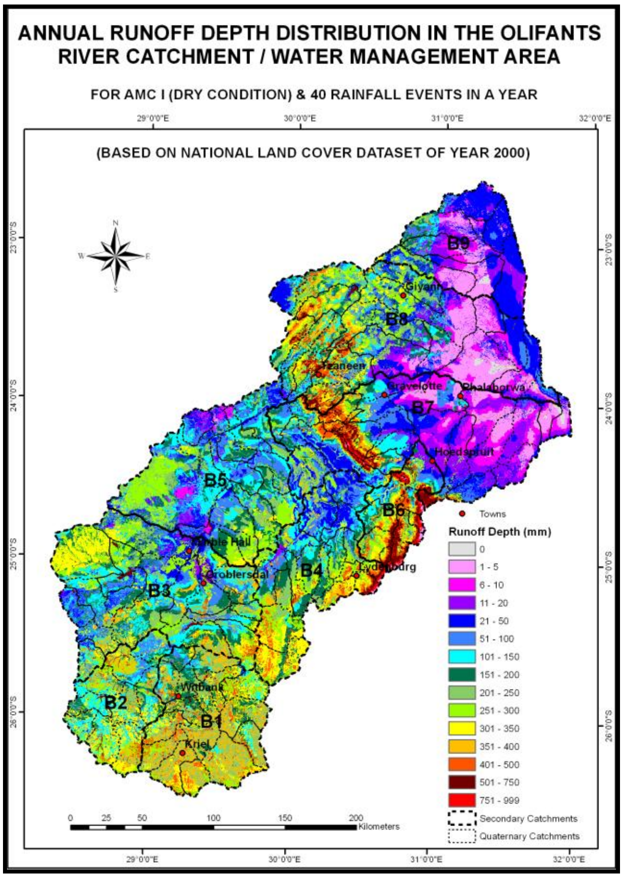

Figure 16: *Annual Runoff Depth Map of the Olifants River Catchment Area for AMC I*

Table 5: *RINSPE Model Results for Olifants River Catchment: Summarized Volumes of Annual Rainfall, Initial Loss, Infiltration and Surface Runoff Based on NLC 2000 for AMC I and 40 Rainfall Events in a Year*

Land Use / Land Cover (Based on NLC 2000)	Code	Area (m^2)	% Area	Ann Rainfall Vol (m^3)	Initial Loss Vol (m^3)	Infiltration Vol (m^3)	Runoff Vol (m^3)
Bare Rock and Soil	15	417149100	0.57	233516881.80	41713560.00	32539624.00	159263697.80
Commercial: institutional	44	6797700	0.01	3755679.30	815724.00	399594.55	2540360.75
Commercial: mercantile	43	8616600	0.01	5894735.40	1033992.00	165589.22	4695154.18
Cultivated (dryland)	24	11718346500	15.91	7190226669.60	2343640860.00	1328989422.56	3517596387.04
Cultivated (irrigated)	23	1925962200	2.62	1199842206.30	308013840.00	197216585.22	694611781.08
Degraded Forest & Woodland	18	4332286800	5.88	2275471284.30	953038548.00	690389565.10	632043171.20
Degraded Thicket, Bushland, etc	19	2380845600	3.23	1453186910.70	523783854.00	422773819.46	506629237.24
Degraded Unimproved (natural) Grassland	22	156001500	0.21	97146756.00	34320330.00	23176074.32	39650351.68
Forest Plantations (Eucalyptus,Pine, Acacia &Other	8	1039568400	1.41	943378954.20	415019880.00	260517170.82	267841903.38
Forest Plantations (clearfelled)	12	164421000	0.22	166572756.90	36170640.00	33826501.58	96575615.32
Improved Grassland	7	17276400	0.02	11564096.40	5182920.00	3627522.56	2753653.84
Indigenous Forest / Woodland	1	15331237200	20.82	7969071564.00	6131559900.60	1388876811.50	448634851.90
Industrial / transport : heavy	45	22104900	0.03	14298405.30	2652588.00	1226834.59	10418982.71
Industrial / transport : light	46	31837500	0.04	19823967.90	4457250.00	3000691.97	12366025.93
Mines & Quarries : Surface Based Mining	48	354859200	0.48	239185980.00	63874656.00	36966800.13	138344523.87
Mines & Quarries : Tailings / Waste Dumps	49	56625300	0.08	31411638.90	10192554.00	10681709.12	10537375.78
Mines & Quarries : Underground Mining	47	195300	0.00	119912.40	31248.00	31976.05	56688.36
Natural Grassland	6	11177076600	15.18	7933258656.00	3353122980.00	1864156771.16	2715978904.84
Residential : Formal Suburb	32	100431900	0.14	64482430.50	20086380.00	18789091.77	25606958.73
Residential : Low Densty	39	82043100	0.11	60637258.80	18048690.00	18055329.75	24533239.05
Residential : Medium Density	33	6490800	0.01	4444418.70	1168344.00	604140.87	2671933.83
Residential ; High Density	30	283370400	0.38	167550444.00	45338112.00	19121739.68	103090592.32
Residential Formal Township	36	1313579700	1.78	783380448.00	262702080.00	115129082.14	405549285.86
Residential Informal Township	37	498915000	0.68	291914272.80	89804700.00	33923126.73	168186446.07
Residentila Informal Squatter Camp	38	7802100	0.01	4777918.20	1248336.00	401028.88	3128553.32
Shrubland, Herbland and Low Fynbos	4	1566000	0.00	1643147.10	501120.00	248802.71	893224.39
Thicket, Bushland, Bush Clumps, High Fynbos	3	21514312800	29.22	12990713760.00	6883871616.00	3413214701.67	2693627442.33
Waterbodies / Wetlands	13	685973700	0.93	433021898.70	0.00	0.00	433021898.70
	Total	**73,635,693,300**	**100**	**44,590,293,052**	**21,551,394,703**	**9,918,050,108**	**13,120,848,242**
				% of Rainfall	***48.33%***	***22.24%***	***29.43%***
	Average in mm for the whole area			605.55	292.68	134.69	178.19

Table 6: *Summarised Results of Hydrological Modelling using RINSPE Model for Different Scenarios in Olifants River Catchment / WMA*

Scenario 1: One Inch (25.4mm) Uniform Rainfall; AMC II	Scenario 2: One Inch (25.4mm) Uniform Rainfall; AMC I	Scenario 3: Using Annual Rainfall (40 rainfall events in a year; AMC II)	Scenario 4: Using Annual Rainfall (40 rainfall events in a year; AMC I)	Scenario 5: Using Annual Rainfall (46 rainfall events in a year; AMC I)	Scenario 6: Annual Rainfall (40 events & excl. Letaba-Shingwedzi River catchment; AMC I)
73,635.69	73,635.69	73,635.69	73,635.69	73,635.69	54,621.40
1,870.35	1,870.35	44,590.29	44,590.29	44,590.29	34,126.49
538.80	538.80	21,551.39	21,551.39	24,674.00	15,628.28
1,119.05	1,216.28	6,449.79	9,918.05	8,605.72	7,750.14
212.49	115.26	16,589.10	**13,120.85**	11,310.57	**10,748.07**
25.40	25.40	605.55	605.55	605.55	624.78
7.32	7.32	292.68	292.68	335.08	286.12
15.20	16.52	87.59	134.69	116.87	141.89
2.89	1.57	225.29	178.19	153.60	196.77
28.81%	28.81%	48.33%	48.33%	55.33%	45.80%
59.83%	65.03%	14.46%	22.24%	19.30%	22.71%
11.36%	6.16%	37.20%	29.43%	25.37%	31.49%

Table 7: *Summarized Total Volumes of Initial Loss, Infiltration and Runoff from 40 Rainfall Events in Olifants WMA in a Year for AMC I Based on the Extent of Tertiary Catchments*

Tertiary Catchment Label	Area (km^2)	Rainfall Vol in Million Cubic Meters (MCM)	Mean Rainfall Depth (mm)	Direct Runoff Vol in Million Cubic Meters (MCM)	Average Runoff as Percentage of Rainfall (%)	Infiltration Vol in Million Cubic Meters (MCM)	Average Infiltration Percentage (%)	Initial Loss Vol in Million Cubic Meters (MCM)	Average Initial Loss Percentage (%)	Water Management Region
B11	4,715.74	3,245.72	688.16	1,360.76	41.9%	699.91	21.6%	1,184.80	36.5%	Upper Olifants
B12	2,392.53	1,657.96	693.01	675.20	40.7%	387.85	23.4%	594.97	35.9%	Upper Olifants
B20	4,355.25	2,972.49	682.38	1,074.29	36.1%	776.33	26.1%	1,121.66	37.7%	Upper Olifants
B31	6,145.80	3,617.06	588.48	1,139.01	31.5%	820.83	22.7%	1,657.16	45.8%	Upper Middle Olifants
B32	5,096.79	3,309.99	649.43	1,051.75	31.8%	814.93	24.6%	1,443.28	43.6%	Upper Middle Olifants
B41	5,050.25	3,171.03	627.90	1,064.13	33.6%	648.43	20.4%	1,458.60	46.0%	Mountain/Steelpoort
B42	2,094.04	1,398.70	713.58	555.38	39.7%	319.36	22.8%	619.61	44.3%	Mountain/Steelpoort
B51	6,172.82	3,305.97	535.56	1,015.11	30.7%	739.96	22.4%	1,550.88	46.9%	Lower Middle Olifants
B52	3,562.16	1,868.08	524.42	473.74	25.4%	470.51	25.2%	923.89	49.5%	Lower Middle Olifants
B60	2,847.15	1,815.12	841.87	991.54	54.6%	516.29	28.4%	889.15	49.0%	Lower Olifants
B71	3,043.58	1,827.78	656.31	566.80	31.0%	542.72	29.7%	888.16	48.6%	Lower Olifants
B72	4,473.17	2,558.35	601.31	587.20	23.0%	583.33	22.8%	1,519.24	59.4%	Lower Olifants
B73	4,661.69	2,298.58	513.51	190.69	8.3%	428.57	18.6%	1,774.64	77.2%	Lower Olifants
B81	4,961.31	3,050.14	657.37	1,007.60	33.0%	831.87	27.3%	1,421.83	46.6%	Letaba
B82	5,459.77	3,333.05	611.98	1,053.56	31.6%	744.69	22.3%	1,543.11	46.3%	Letaba
B83	3,273.06	1,435.31	438.58	63.54	4.4%	179.45	12.5%	1,192.29	83.1%	Letaba
B90	5,318.82	2,424.45	455.92	247.78	10.2%	411.55	17.0%	1,765.21	72.8%	Shingwedzi
Total/Average	73,623.95	43,289.75		13,118.08	29.86%	9,916.59	22.8%	21,548.49	51.1%	

8.8. Limitations and their Implications on the Estimates

Major limitation of this study are the lack of recent land use/land cover map for the whole study area, assigning of initial loss and CN values based on literature instead of using values derived through field measurements and monitoring, use of averaged annual rainfall data and dividing it based on selected number of rainfall events and assuming the same rainfall distribution thus obtained for all the rainfall events, lack of calibration and inability to do some validation of the results obtained. In order to do a calibration of the model results, one needs to derive or partition direct surface runoff through a hydrograph separation method or collect or measure rainfall, initial abstraction, direct surface runoff and infiltration at some selected typical areas of the catchments and compare the model predictions with the observed values. The measurement of quick rise in stream flow or measurements of quick rise in water level in a reservoir immediately after a rainfall can also help to calibrate the direct surface runoff predictions in certain section of the catchment. Runoff measurements from the fields resulting from the rainfall events in a year were difficult to carry out. The easiest method for the direct surface runoff calibration would have been to take measurements of the some of the parameters used in this study as rain occurred, but this was not feasible because one would have had to be in the field during the rainfall event. As it was not feasible for such field measurements in this study covering a vast area, the model results obtained were not calibrated. The option available in this study was to get a quick estimate of direct surface runoff and infiltration distribution at any point in the catchment using CN values for average condition and dry or lowest runoff condition.

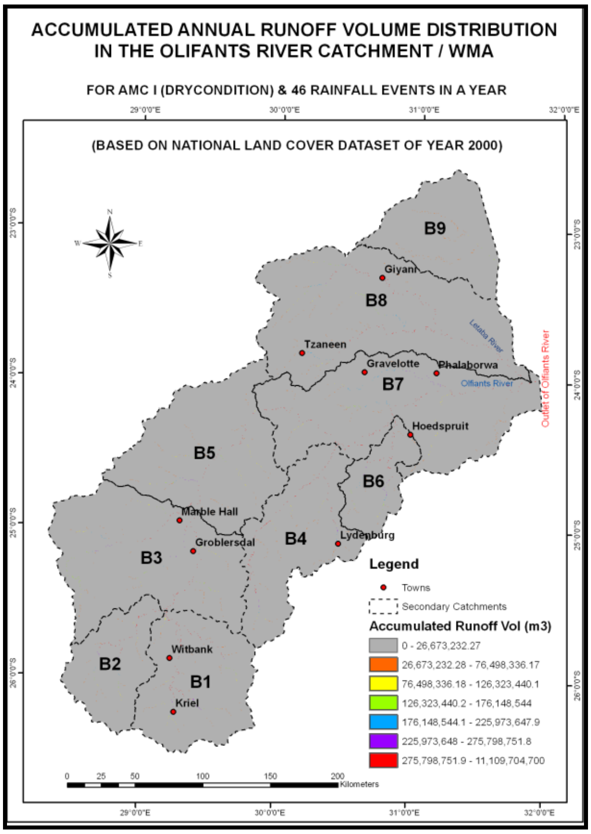

Figure 17: *Accumulated Annual Runoff Volume Distribution for Olifants River*

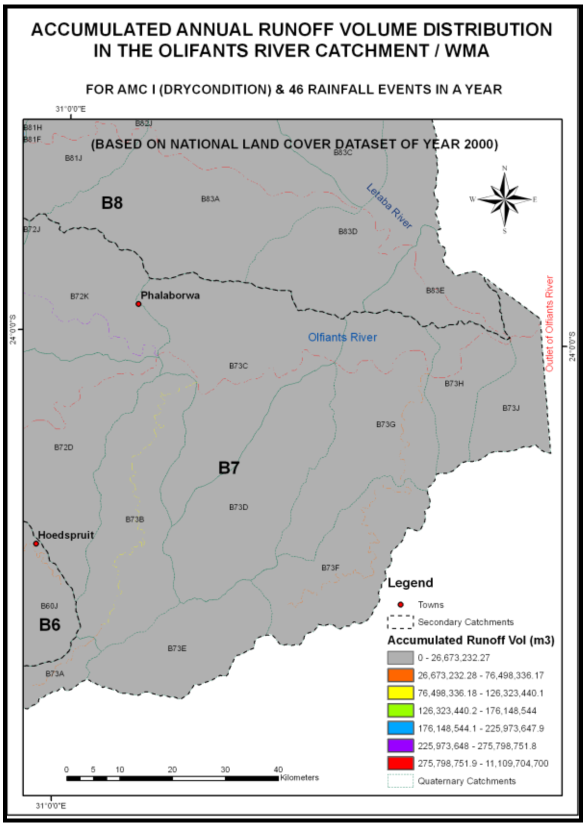

Figure 18: *Zoomed View of the Outlet Portion of the Olifants River Showing Accumulated Runoff Volume Distribution*

9. Comparison of Model Results with Other Runoff Predictions/Studies

Other studies showing runoff results for the Olifants River catchment excluded Letaba (Quaternary Catchment B8 or Tertiary Catchments B81, B82 and B83) and Shingwedzi (Tertiary Catchment B90) river catchment areas and some studies have reported only the mean or average values for a particular catchment (either Tertiary or Quaternary catchment). In order to compare such results with the results of this study, the predictions (Scenarios of AMC1 and 40 & 46 rainfall events) obtained from the RINSPE model were summarized based on the Tertiary and Quaternary catchment boundaries. There are 17 Tertiary Catchments and 145 Quaternary catchments covered in the WMA of Olifants River. Table 7 shows the summarized total volumes of initial loss, infiltration and runoff from 40 rainfall events in a year for AMC I based on the extent of 17 Tertiary catchments. Table 8 shows the runoff modeling results obtained from RINSPE model for scenario 6: AMC I & 46 rainfall events (Zonal Stats summary obtained using the extents of the 17 Tertiary catchments falling in the study area) and the MAR & MAP (Mean Annual Precipitation) obtained from the WR90 study (Midgley et al., 1990) for a comparison. In this comparison there is no similarity in the values of runoff predictions except for B83 and B90. The highest percentage of rainfall as MAR in WR90 study is 17.3% (402.6 MC) whereas the surface runoff from this study shows that 37.2% of rainfall (892 MCM) appears as surface runoff. The results from other hydrologic modeling studies like WR90 (Midgley et al., 1990) or WR2005 (Middleton and Bailey, 2008) give uniform mean annual runoff (naturalized stream flow) figures for the whole quaternary catchments whereas the results from the RINSPE model give cell based distribution of direct surface runoff and infiltration volumes and it varies spatially for each catchment or sub-catchment.

From the WR90 study the 'mean annual runoff' (MAR) estimated for the Olifants River catchment (excluding Letaba and Shingwedzi catchments) as reported by De Langa et al., (2003) is 1992 MCM and the average value of observed runoff at the mouth of the Olifants River is 1,235 MCM. MAR is defined as the average annual stream flow passing a specified point or the average annual flow observed in a river basin and it is calculated based on the observed stream flows at DWAF gauging stations.

Table 8: *Comparison of Runoff (AMC1) from RINSPE for 46 Event Rainfalls in a Year with the Mean Annual Runoff (MAR) Flow from WR90*

Tertiary Catchment	WR90 MAP (mm)	WR90 MAR (mm)	% of MAP as MAR in WR90	Rainfall Vol in RINSPE (MCM)	RINSPE Mean Annual Rainfall (mm)	RINSPE Surface Runoff (mm)	% of Annual Rain as Runoff in RINSPE	Total Runoff Vol in RINSPE (10^6 m^3)	WR90 Net MAR Vol (10^6 m^3)
B11	687	37	5.4%	3245.7	688	258	37.4%	1215.2	175.8
B12	696	34	4.9%	1658.0	693	252	36.4%	603.9	81.6
B20	670	38	5.7%	2972.5	682	219	32.1%	952.8	166.9
B31	589	12	2.0%	3617.1	588	158	26.9%	973.2	75.4
B32	651	32	4.9%	3310.0	649	177	27.2%	900.4	165.3
B41	659	46	7.0%	3171.0	628	179	28.5%	904.1	232.8
B42	727	79	10.9%	1494.5	714	232	32.4%	484.9	164.9
B51	551	7.5	1.4%	3306.0	536	140	26.2%	865.9	46.6
B52	548	17	3.1%	1868.1	524	109	20.8%	388.9	59.6
B60	823	142	17.3%	2396.9	842	313	37.2%	892.0	402.6
B71	685	67	9.8%	1998.1	656	160	24.4%	486.6	202.3
B72	567	31	5.5%	2689.4	601	110	18.4%	494.2	137.5
B73	539	17	3.2%	2393.8	513	30	5.9%	141.4	78.7
B81	684	77	11.3%	3261.3	657	180	27.4%	893.5	381
B82	609	28	4.6%	3341.4	612	168	27.4%	915.2	151.9
B83	544	13	2.4%	1435.3	439	9	2.1%	30.8	41.3
B90	502	16	3.2%	2424.5	456	31	6.8%	165.3	86.4
			Total	44583.4				11308.3	2650.6

MAP: Mean Annual Precipitation

The stream flow observed in a river is the net effect of: 1) various processes in a hydrologic cycle such as rainfall, interception, evaporation, runoff and infiltration process, evapotranspiration, subsurface flow (interflow, throughflow and baseflow from the groundwater), 2) the interactions between the aquifer and the streams and 3) human activities (holding of water by dams, abstraction of river and groundwater for various uses). The RINSPE model has taken into account of losses from the total amount of rainfall through the effects of initial abstraction (interception, evaporation, depression storage etc.), infiltration and direct surface runoff. In this modeling study for direct surface runoff estimation, the effects of evapotranspiration as well as the interaction between the aquifer and the streams are ignored. Evapotranspiration is ignored because its magnitude during the time period in which the direct surface runoff results from single events is negligible when compared to other fluxes such as infiltration. Likewise, the response time of subsurface soil system is much longer than the response time of surface runoff or direct surface runoff process and hence the effect of stream-aquifer interaction can also be ignored in estimating direct surface runoff. The loss of infiltrated water and ground water through evapotranspiration is quite high and therefore the net amount of water observed in a stream as stream flow component of the hydrologic cycle will be sometimes less than the total predicted or observed direct surface runoff in a catchment (depending on the nature and characteristics of the catchment and nature of human activities). Olifants River catchment has 8 major dams and they hold some of the overland flow component of runoff, Farmers or industry abstract water from the dams and also from streams / rivers for irrigation, other purposes like power generation, mining etc., Large quantities of groundwater are abstracted for irrigation in the northwest part of the WMA as well as for rural water supplies throughout most of the catchment area; hence in such situations, the runoff measured at the outlet of the catchment will be lower than the situation having no abstraction from rivers or dams. It is important to note the fact that not all runoff generated in a catchment ends up in rivers and become stream flow; some of it evaporates on its journey downslope, can be diverted and used by human being and animals. Most of the runoff originate from the higher rainfall receiving southern and mountainous regions and is controlled by several dams. In view of above mentioned facts, a comparison of direct surface runoff predictions for a given year with MAR or naturalized mean stream flow will not always reveal similarity in results obtained from such studies.

The result of total MAR (Table 9) from the WSAM study (Schultz and Watson, 2002) for the five water management regions of the Olifants catchment shows a range of MAR values (677 MCM to 8020 MCM) for the total area of 54,308 km^2. Table 9 reveals the accumulated runoff leaving the secondary catchments of the Olifants River for four scenarios and its comparisons to WSAM study and WR90 study. The wide range in MAR follows the higher inter-annual variability of the rainfall pattern. MAR reported in other literatures for the Olifants River catchment area differs significantly, for example (Le Maitre et al., 2000) has reported a MAR value of 2904.10 MCM for this catchment whereas results from WR90 and WR2005 study shows MAR values of 2609.4 MCM and 2613.8 MCM respectively from the average flow calculated for the whole study area (DEA, 2009).

According to Ballance et al. (2001) and eWISA (Year Unknown), the mean annual runoff (MAR) for the Olifants catchment is 2400 MCM. Most surface runoff of this catchment originates from the higher southern and mountainous area and is controlled by several dams (NWRS, 2004). The Mountain region (Steelpoort sub-basin) as well as the catchment of the Blyde River provides the largest contribution of runoff that is 42% of the runoff (De Langa et al., 2003).

The results of MAR obtained from other studies using the mean flow predicted for a long period (e.g., year 1920 to 1989 in WR90 study) cannot be really compared to the results of this study as RINSPE model calculated the runoff at each pixel of the grid used and gave finally the total estimated direct surface runoff volume for a given period (a year) only based on the land covers of NLC2000 and the number of rainfall events chosen. The runoff predictions of this study is actually not a mean runoff value for the catchment based on estimations of runoff for different years using different annual rainfall amounts and different land use/land cover data for a chosen period. The direct surface runoff predicted by the RINSPE model includes the rainfall falling on to the water bodies (dams, lakes etc.) and also the rivers. The other studies showing MAR values may not have considered the total volume of rainfall falling onto water bodies as runoff (433.021 MCM in a year) when predictions of MAR were made.

As Tertiary catchment B60 showed the highest runoff percentage (17.3% of the rainfall) in WR90 study, an attempt was made to compare the WR90 MAR values for the Quaternary catchments with the predictions from this study. Table 10 shows the comparison of runoff modeling results obtained from RINSPE model for the Quaternary catchment of Tertiary catchment B60 for the scenario 6: AMC I & 46 rainfall events with the MAR obtained in WR90 study. The total average value of 402.5 MCM obtained from the WR90 study for this catchment is the mean or average value of the results obtained on a monthly basis for the period 1920 to 1989 and its annual total ranges from 174.84 MCM (in 1982) to 1645.41 MCM (in 1938). There is minor similarity in the runoff predicted for the for the Quaternary catchments B60B and B60C, but when Quaternary catchments B60F, B60G, B60H and B60J are compared one can see that the runoff from RINSPE is much higher (24.4 to 39.6% of rainfall) for these catchments as compared to the results of WR 90 study (4 to 8% of rainfall).

Table 9: *Summary of Simulated Accumulated Runoff Volumes in the Olifants WMA and its Comparison to MAR of WR90 and WSAM Study*

Sub-Catchment (to Sub-Catchment)	Water Management Region of South Africa	Scenario: 1 (1 inch Rain & AMC II); MCM	Scenario: 3 (AMC II & 40 Events); MCM	Scenario: 4 (AMC I & 40 Events); MCM	Scenario: 6 (AMC I & 46 Events); MCM	MAR of WR90 Study; MCM	WSAM Mean Annual Flow (MAF); MCM	Range in MAF; MCM
B1 (to B3)	Upper Olifants	26.30	2,489.65	2,030.53	1,814.21	257.43	424	80-1365
B2 (to B3)	Upper Olifants	14.28	1,359.38	1,066.17	945.37	166.93		
B3 (to B5)	Upper Middle Olifants	77.53	6,582.55	5,252.39	4,603.64	240.77	249	42-897
B4 (to B7)	Mountain/Steelpoort	23.89	1,987.62	1,615.33	1,385.33	397.74	396	138-1509
B5 (to B7)	Lower Middle Olifants	111.64	8,529.95	6,764.38	5,877.94	106.12	121	13-636
B6 (to B7)	Lower Olifants	7.30	1,192.57	987.43	888.17	402.58		
B7 *(at the catchment outlet; includes runoff from Letaba (B8); excludes runoff from Shingwedzi (B9))*	Lower Olifants	200.99	16,183.19	12,831.80	11,109.70	418.46	849	259-4595
B8 (to B7; Letaba)	Letaba	35.95	2,710.95	2,121.83	1,837.15	574.09	645.33*	100 - 2700**
B9 *(from Shingwedzi to Olifants River; RSA part only)*	Shingwedzi	10.09	340.39	238.29	161.31	86.43	no data	no data
Total Accumulated Runoff for the Olifants Catchment		165	13,472	10,710	9272	1990.03	2040	677-8020
Total Accumulated Runoff Volume for Olifants WMA		247.02	19,234.54	15,191.93	13,108.16	2650.55	no data	no data
* Data from WR2005 Study; ** Data from DWAF, 2001 [44].								

Table 10: *Comparison of runoff (AMC1) from RINSPE for 46 Event Rainfalls in a year for the Quaternary catchments of Tertiary catchment B60 with the MAR flow from WR90*

Quaternary Catchment	WR90 MAP (mm)	WR90 MAR	% of MAP as MAR in WR90	Rain Vol (MCM)	RINSPE MAP (mm)	RINSPE Runoff (mm)	% of MAP as Runoff in RINSPE	RINSPE Total Runoff Vol (10^6 m^3)	WR90 Net MAR Vol (10^6 m^3)
B60A	1193	441	37%	248.2	1183.98	629	53.1%	131.9	92.6
B60B	1026	349	34%	298.8	987.677	416	42.1%	125.9	105.5
B60C	1352	539	40%	103.2	1092.89	575	52.6%	54.3	50.7
B60D	1004	218	22%	237.4	972.195	420	43.3%	102.7	53.2
B60E	1027	201	20%	78.8	942.119	457	48.5%	38.2	16.6
B60F	766	46	6%	298.9	746.814	296	39.6%	118.5	18.3
B60G	681	30	4%	329.4	733.626	231	31.4%	103.5	13.3
B60H	778	48	6%	292.3	758.216	241	31.8%	92.9	18.6
B60J	607	50	8%	510.1	752.236	183	24.4%	124.2	33.7
			Total	2397				892.1	402.5

9.1. Comparison with Field Measurements in a Quaternary Catchment (B72A)

The data collected (Table 11) in field for a Quaternary catchment (Sekororo, B72A quaternary catchment) during 2005/2006 cropping season from a M.Sc. research (Rasiuba, 2007) indicates that on average, 39% of the received rainfall has been lost to runoff while 61% has been used for evapotranspiration demand which is close to the annual runoff prediction (41.5% of rainfall) obtained from the RINSPE model for the dry condition (AMC I & 46 rainfall events) of the catchment. This quaternary catchment (located between longitude S 30^0 15' 00" and E 30^0 45' 00") covers an area of 535km^2 and it represents only 1% of the whole Olifants River catchment. The WR90 study has predicted a MAR value of 79mm from a mean annual precipitation (MAP) of 713mm.

Table 11: *Measured and the Calculated Water Balance Values for 2005/2006 Cropping Season for the Four Sites of B72A; Source: Rasiuba (2007)*

Place	Rainfall (mm)	Irrigation (mm)	ΔS (mm)	Runoff (mm)	D (mm)	Evapotranspiration (mm)	Run-off percentage (%)
Worcester	1072	0	-44	436	0	592	41
Enable	1112	0	-22	411	0	677	37
Ha-Fanie	1234	0	-42	406	0	786	33
Sofaya	1422	120	-40	630	0	872	44
Average							39

Where D is deep drainage beyond the root zone of the crop during the cropping season (mm)
ΔS is the seasonal change in soil water content (mm) of the root zone

10. Conclusions

Runoff and infiltration in general represents the response of a catchment to precipitation and it also reflects the integrated effects of a wide range of catchment, climate and precipitation characteristics.

The RINSPE model could be used successfully to estimate the surface runoff, cumulative infiltration and accumulated runoff in the Olifants River Catchment area for different scenarios (dry and average conditions using a one inch uniform rainfall distribution and spatially varying long term average rainfall distribution) using the NLC data of year 2000, Land Type data and SRTM elevation. Results reveal that the distribution of surface runoff and infiltration is fully dependent on the rainfall distribution and the nature of the land use/land cover types underlain by different types of hydrologic soil groups. The runoff predicted by the RINSPE model represents the quickflow component of runoff and it includes the sum of channel precipitation and surface runoff (overland flow) direct surface runoff and it does not include the contribution of interflow from the catchment that forms part of surface runoff as return flow or discharge (baseflow) from the groundwater which forms part of the total flow in a river.

The runoff results presented in this study is the immediate direct surface runoff predicted by the RINSPE model in ideal conditions using the land covers of year 2000 for different scenarios of dry and average condition using a uniform one inch rainfall event and spatially varying average annual rainfall (by dividing the total annual rainfall amounts by 35, 40 and 46 rainfall events), in which there is no abstraction of runoff water for irrigation or interruption of surface runoff flow due to man-made ponding or dam. The predicted surface runoff includes the runoff from stream/river channel precipitation as well the runoff from other water bodies (lakes, dams etc.) due to direct falling of precipitation into such land covers. Model simulations of dry conditions show high infiltration volumes and low runoff volumes as compared to the average conditions. The maps showing the results for the simulation of one inch uniform rainfall are useful to know the expected runoff and infiltration at any point in catchment during such a rainfall. The summarized volume tables and the maps showing the spatial distribution of annual runoff and infiltration for the different scenarios are very useful in understanding the expected total annual volumes and depths of water observed as runoff and infiltration at any location in the study area. The spatially distributed predictions (maps) of runoff and infiltration will help to understand the amount of water leaving the mining areas/abandoned mines as polluted runoff and the amount of water entering the subsurface horizons as infiltration, which may later contribute to water ingress or appear as part of the acid mine drainage formed in the catchment.

Comparison of the total volume of the surface runoff of this study for a year with the results of other studies (WR90 study and WSAM study) that predicted the total mean annual runoff (MAR) shows that the direct surface runoff predicted by the RINSPE model is not matching with the MAR values of other studies. Mean runoff predictions of only two Quaternary catchments (B60B and B60C) of WR90 study showed some similarity with the results obtained from this study. Results of other studies available are of older periods (for example the WR90 study used the data for the period 1920 to 1989) and these studies did not use any spatially varying data like the rainfall grid or the NLC2000 data for their predictions. It is important to note that other modeling studies were aimed in simulating the annual or monthly stream flows after accounting for the major loss through evapotranspiration and they were not spatially distributed (using a GIS based approach described in this study) and have not included the rainfall data of the year 2000. During the year 2000 there were devastating flooding events that occurred in Feb 2000 due to high rainfalls (120mm to 270mm) and it affected the Olifants River catchment area (especially Hoedspruit, Phalaborwa and, Kruger National Park area) and southern parts of Mozambique.

Out of the five simulations from the RINSPE model for this catchment using the average annual rainfall, the scenario of AMC I (dry condition) with 46 rainfall events predicted a total annual runoff volume of 10,748 MCM for the Olifants River catchment (excluding Letaba and Shingwedzi River catchment area) and this runoff volume figure matches with the range of Mean Annual Flow (MAF) of 677 to 8020 MCM reported from the WSAM study (Schultz and Watson, 2002). The results of the same scenario show that only two Tertiary catchments (B83 and B90) show some similarity with the MAR values of WR90 study. However, the comparison of surface runoff measurements in field for a Quaternary catchment (B72A) showed much similarity with the summarized runoff prediction obtained from the RINSPE model.

It is important to note the fact that the MAR predicted by other models or studies represents the total volume of water that can be expected from a stream or river in a given period of time (known as yield of a catchment) after accounting for the major losses through evapotranspiration, whereas the surface runoff from the RINSPE model shows the expected immediate surface runoff without accounting for any such loss. Therefore, the runoff results obtained from the RINSPE model are in fact not comparable with the MAR values of other previous studies that used a different approach for the runoff or MAR calculation (because the previous studies of this catchment showing MAR values used different uniform or average rainfall amounts for the whole area of the sub-catchments (Quaternary catchments) instead of using spatially varying rainfall amounts). GIS based runoff modeling with spatially varying rainfall will give more accurate results as compared to the approaches using an average rainfall amount throughout a particular sub-catchment.

Acknowledgments

The author would like to thank Mr. Harold Weepener of the Institute for Climate and Water of Agricultural Research Council (ARC) at Pretoria for providing various spatial datasets (annual rainfall, National Land Cover (NLC) 2000, SRTM elevation etc.) and Mr. Daniel Sebaka of the Council for Geoscience (CGS) for providing the layers of boundaries of various Primary catchments and major towns.

References

Anderson, N.J., 1997: *Modelling the Sustainable Yield of Groundwater Resource in Riverbed Aquifers in Arid and Semi-arid Areas*. MPhil to PhD Transfer Report. Department of Civil Engineering, University of London. London, England.

Arnold, G., Srinavasan, R., Muttiah, R.S., and Williams, J.R. *Large Area Hydrologic Modeling and Assessment. Part I. Model Development.* Journal of the American Water Resources Association. 1998. 34 (1) 73-89.

ASCE, 1996: *Hydrology Handbook*. Second Edition. American Society of Civil Engineers (ASCE). ASCE Manuals and Reports on Engineering Practice No 28. ASCE Publications. 784.

Balance, A., Hill, L., Roux, D., Silberbauer, M., and Strydom, W., 2001: *State of the Rivers Report: Crocodile, Sabie-Sand and Olifants River Systems.* Resource Quality Services, DWAF, Pretoria, South Africa.

Beasley, D.B., and Huggins, L.F., 1980: *ANSWERS (Areal Nonpoint Source Watershed Environment Simulation) - User's Manual.* Department of Agricultural Engineering, Purdue University, West Lafayette, Indiana.

Browne, F.X., 1990: *Stormwater Management.* In: Standard Handbook of Environmental Engineering; Robert A. Corbit (Ed.). New York: McGraw-Hill Publishing Company.

Cowling, R.M., Richardson, D.M., and Pierce, S.M., 2004: *Vegetation in Southern Africa*. Cambridge University Press, 01 Apr 2004. The Edinburgh Building, Cambridge CB2 2RU, UK.

De Hamera, W., Love, D., Booija, M.J., and Hoekstra, A.Y., 2007: *A Rainfall-Runoff Model for Two Small Ungauged Catchment Using the Water Balance of a Reservoir for Calibration.* In: 8th WATERNET/WARFSA/GWP-SA Symposium, (31 October-2 November) 2007, Lusaka, Zambia.

De Langa, M., Merrey, D.J., Levite, H., and Svendsen, M., 2003: *Water Resources Planning and Management in the Olifants Basin of South Africa: Past, Present and Future.* Chapter 10 of the IWMI Book on River Basin Management.

De Villiers, S., and Mkwelo, S.T. *Has Monitoring Failed the Olifants River, Mpumalanga?* Water SA. 2009. 35 (5) 671-676.

DEA, 2009: *Environmental Management Framework for the Olifants and Letaba Rivers Catchment Areas (OLEMF).* Vol.1. Environmental Management Framework Report. Department of Environmental Affairs. Republic of South Africa.

DWAF, 2001: *Letaba and Luvuhu River System*. State of the Rivers Report. South African River Health Programme. Department of Water Affairs and Forestry.

DWAF, 2004a: *Internal Strategic Perspective: Limpopo Water Management Area*. Prepared by Goba Moahloli Keeve Steyn (Pty) Ltd, in association with Tlou & Matji (Pty) Ltd and Golder Associates (Pty) Ltd. on behalf of the Directorate: National Water Resource Planning. Report No. P WMA 01/000/00/0304. Department of Water Affairs and Forestry, South Africa.

DWAF, 2004b: *Olifants Water Management Area: Internal Strategic Perspective*. Prepared by GMKS, Tlou and Matji and WMB on behalf of the Directorate: National Water Resource Planning. DWAF Report No P WMA 04/000/00/0304. Department of Water Affairs and Forestry, South Africa.

EWISA, Year Unknown: *The Olifants River Limpopo/Mpumalanga Province*. E-Book of the Water Institute of Southern Africa (WISA), Gauteng, South Africa.

Hawkins, R.H., Hjelmfelt, A.T., and Zevenbergen, A.W. *Runoff Probability, Storm Depth, and Curve Numbers*. Journal of Irrigation and Drainage Engineering, ASCE. 1985. 111 (4) 330-340.

Hughes, D.A. *Monthly Rainfall–Runoff Models Applied to Arid and Semi-Arid Catchments for Water Resource Estimation Purposes.* Hydrological Science Journal. 1995. 40 (6) 751-769.

IWMI, 2008: *Baseline Report: Olifants River Basin in South Africa.* International Water Management Institute (IWMI), September.

Jenson, S.K., and Domingue, J.O. *Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis.* Photogrammetric Engineering and Remote Sensing. 1988. 54 (11) 1593-1600.

Knisel, W.G. 1980: ‘CREAMS: A Fieldscale Model for Chemical, Runoff, and Erosion from Agricultural Management Systems,’ USDA, Science and Education Administration, Conservation Report No. 26. United States Department of Agriculture, Soil Conservation Service. Washington, D.C.

Le Maitre, D.C., Versfeld, D.B., and Chapman, R.A. *The Impact of Invading Alien Plants on Surface Water Resources in South Africa: A Preliminary Assessment.* Technical Note. Water SA. 2000. 26 (3) 397-408.

Leonard, R.A., Knisel, W.G., and Still, D.A. *GLEAMS: Groundwater Loading Effects of Agricultural Management Systems.* Transactions of ASAE. 1987. 30 (5) 1403-1418.

Ma, Y. *L-THIA: A Useful Hydrologic Impact Assessment Model.* Nature and Science. 2004. 2 (1) 68-73.

Middleton, B.J., and Bailey, A.K., 2008: Book of Maps, Version 1: December 2008. Water Resources of South Africa, 2005 Study (WR2005). TT 382/08. Water Research Commission, South Africa.

Midgley, D.C., Pitman, W.V., and Middleton, B.J., 1990: *Surface Water Resources of South Africa* 1990. Vol.1 Appendices, 1st Edition. Report 298/1.1/94. Water Research Commission, South Africa.

NCSPA, 1999: *Modern Sewer Design.* Fourth Edition. American Iron and Steel Institute, Washington, DC.

NOAA, 2004: *Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) Technical Guide.* Version 1.0 Release 1, November 2004. NOAA Coastal Services Center. Charleston, SC, USA.

NWRS, 2004: *D4 Water Management Area 4: Olifants. National Water Resource Strategy.* First Edition, September 2004. Department of Water Affairs and Forestry.

Ponce, V.M., and Hawkins, R.H. *Runoff Curve Number: Has It Reached Maturity?* Journal of Hydrologic Engineering. 1996. 1 (1) 11-19.

Prasad, K.C., Strzepek, K.M., and Van Koppen, B. *An Approach to Assessing Socioeconomic Implications of Water Management Alternatives.* Water Policy. 2007. 9 (2) 131-147.

Rasiuba, T.C., 2007: *Water Budget, Water Use Efficiency in Agriculture in Olifants Catchment. Research Report of the MSc in Engineering.* University of Witwatersand, Johannesburg.

SAWS, 2010: *Archive of Rainfall Data of 16 Major MetroCast forecast cities obtained from the South African Weather Service.* http://www.1stweather.com/regional/data/data_daily_rain.shtml (Accessed on 29 April 2014).

Schultz, C.B., and Watson, M.D., 2002: *WSAM: Water Situation Assessment Model – Version 3: A Decision Support System for Reconnaissance Level Planning.* Volume 1: Theoretical Guide. ARCUSGIBB and DWAF, Republic of South Africa.

Schulze, R.E., 1994: *Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System.* Water Research Commission, Report TT69/95, Pretoria.

Sharpley, A.N., and Williams, J.R., 1990: 'EPIC-Erosion/Productivity Impact Calculator,' USDA, Agricultural Research Service, Technical Bulletin No. 1768. Washington, D.C. 235.

Thomas, A., 2001: A Geographic Information System Methodology for Modelling Urban Groundwater Recharge and Pollution. PhD Thesis. The School of Earth Sciences. The University of Birmingham, Birmingham, United Kingdom. September 2001.

Thomas, A., and Tellam, J.H. *Modelling of Recharge and Pollutant Fluxes to Urban Groundwaters.* The Science of the Total Environment. 2006. 360 (1-3) 158 -179.

Thomas, A., Chingombe, W., Ayuk, J., and Scheepers, T. *A Comprehensive Investigation of the Kuils-Eerste River Catchments Water Pollution and Development of a Catchment Sustainability Plan.* Report to the Water Research Commission. December 2009. WRC Report No. 1692/1/10.

Tsheko, R. *Comparison Between the United States Soil Conservation Service (SCS) and the Two Models Commonly Used for Estimating Rainfall-Runoff in South-Eastern Botswana.* Water SA. 2006. 32 (1) 29-36.

US EPA, 1998a: *Estimation of Infiltration Rate in the Vadose Zone: Compilation of Simple Mathematical Models*. Vol.I. EPA/600/R-87/128a, February 1998. United States Environmental Protection Agency.

US EPA, 1998b: *Estimation of Infiltration Rate in the Vadose Zone: Application of Selected Mathematical Models*. Vol.II. EPA/600/R-87/128b, February 1998. United States Environmental Protection Agency.

USDA-SCS, 1993: National Engineering Handbook. Section 4, Hydrology. United States Department of Agriculture, Soil Conservation Service. Washington, DC. http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?cid=stelprdb1043063 (Accessed on 18 June 2014).

Van Vuuren L. *Experts Unite to Save Abused River from Extinction*. The Water Wheel. Jan/Feb 2009. 14 (17).

Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P. *AGNPS: A Non-Point-Source Pollution Model for Evaluating Agricultural Watersheds.* Journal of Soil and Water Conservation. 1989. 44 (2) 168-173.