WATER RESOURCE ENGINEERING

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“Hydrological Modelling”

PCRaster Dynamic Model Representing Simplified Hydrological Runoff Model Of Hilly Catchment.

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ACKNOWLEDGMENTS

We are really grateful that we managed to complete our Water Resource Engineering project within the timeframe.

We would like to express our special thanks of gratitude to the Dr. Shaik Rehana who gave us the golden opportunity to do this wonderful project , which also helped us in doing a lot of Research and helped us to know about so many new things and softwares.

We sincerely thank her for the guidance and encouragement in finishing this project and also for teaching us in this course. Last but not least we would like to express our gratitude to the Teaching Assistant Ravi Kishore Reddy for the support, friendly advice during the project work.

ABSTRACT

PCRaster provides ideal conditions for modelling environmental processes such as surface runoff (Burrough et al., 2005). It links a dynamic environmental modelling language to a GIS. The modelling language of PCRaster is specifically developed for the modelling of environmental process. It can easily be used by environmental researchers to construct dynamic environmental models that are adapted to particular problems being studied (Burrough et al., 2005; Dijck, 2000). The integrated idea behind PCRaster allows for a more flexible and adoptable approach. It offers the researcher the freedom to focus on the processes deemed most relevant for a particular study and for which sufficient input data are available (Burrough et al., 2005; DeRoo et al., 2000; Pfeffer, 2003). Models designed in PCRaster can range in complexity from very simple empirical based models to more complex physical based approaches.

This demo gives an introduction to the Dynamic Modelling Language which is considered to be the core of the PCRaster package. The Dynamic Modelling language allows for building spatio-temporal models (*dynamic models*) inside a Geographical Information System (GIS). The text is supported by computer batch/bash files that will automatically execute the operations and models described. It is assumed you have PCRaster correctly installed.

The application is named: “A simplified hydrological runoff model of Hilly Catchment”.

INTRODUCTION AND INSTALLATION

PCRaster is Combination of two word PC and Raster. It is a dynamic modelling tool means that it represents behaviour of an object over time. This model is used for studying and analyzing rainfall-runoff with timestep. **ILWIS** software is used for generating input maps for PCRaster.

PCRaster runs on Linux and Windows operating and is a open source software and also free to use. It contains a scripting model development environment and it allows users to develop their own simulation models. Scripting languages supported include PCRcalc and Python and executes models very fast.

PCRaster is mainly applied in environmental modelling: geography, hydrology, ecology to name a few. But also other models can be constructed. Examples include rainfall-runoff models, vegetation competition models and slope stability models.

PCRaster is developed in cooperation with the PCRaster group at **Utrecht University.** Commercial support and sales is through **PCRaster Environmental Software BV.**

PCRaster is a free and open source software. It is easily available online. It can be installed from PCRaster official site :-

(http://pcraster.geo.uu.nl/downloads/latest-release/).

THEORY

The Terminologies commonly used in the simulation :-

1. **RASTER :-** A raster consists of a matrix (data-structure) of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing geographic data, such as temperature or rainfall etc.
2. **HYDRAULIC MODELLING :-** It is a mathematical model of a water/sewer/storm system and is used to analyse the system's hydraulic behaviour.
3. **DYNAMIC MODELLING :-** A dynamic model represents the behaviour of an object over time.
4. **GEOGRAPHIC INFORMATION SYSTEM (GIS) :-** It is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data.
5. **CURVE NUMBER :-** It is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess.The runoff curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition.

PROJECT DESCRIPTION AND ANALYSIS

4.1 MODEL

1. The catchment area considered contains 3 rain gauges installed.
2. The rainfall data is available for all 3 rain gauges over a period of 168 hours (1 week).
3. It is divided into 28 time-steps with each time-step of duration 6 hours.
4. The catchment area consists of three types of soil i.e. sandy, loam and clay.
5. The DEM (Digital Elevation Model) map, map of soil types, location of three rainfall measurement stations occurring in the study area is taken.
6. The model is a runoff model in hilly catchment.
7. The model that will be created will simulate the spatial pattern of superficial runoff during the week, taking into account that different amounts of water infiltrate in the different soils.

4.2 Goal

1. Estimate for each cell the rainfall based on the measurement data of the three rainstations.
2. Assign the infiltration values of the different soils to a new map with the infiltration capacity and determine the actual infiltration of rainwater.
3. Redistribute the excessive rain downstream over the study area to estimate runoff.

4.3 EQUATION USE TO CALCULATE RUNOFF

Curve number (CN) is a dimensionless number defined such that $0 \leq CN \leq 100$. For impervious and water surface CN=100. **Potential Maximum retention** depends on Curve Number. Equation for calculation runoff is:-

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

where,

Q = runoff(inch)
P = rainfall (inch)
I_a = Initial abstraction (surface storage, interception, and infilteration, inch)
S = potential maximum retention (inch)
$I_a = 0.2S$

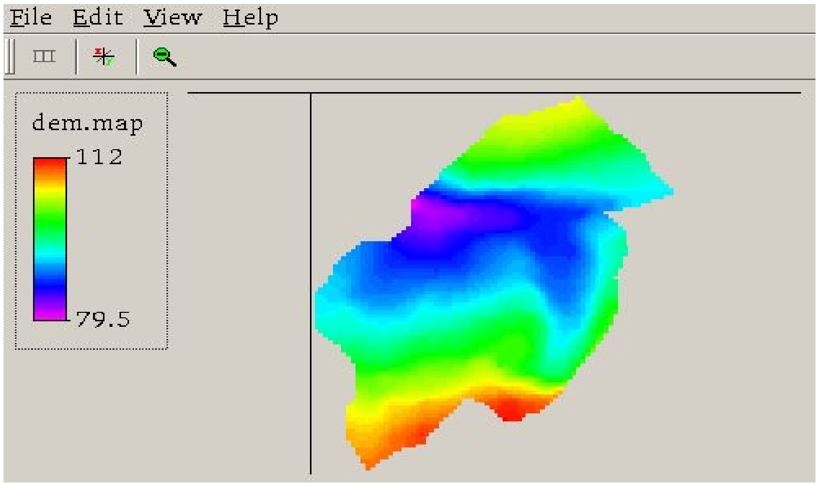
$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Curve number is used to determine S:

$$S = \frac{100}{CN} - 10$$

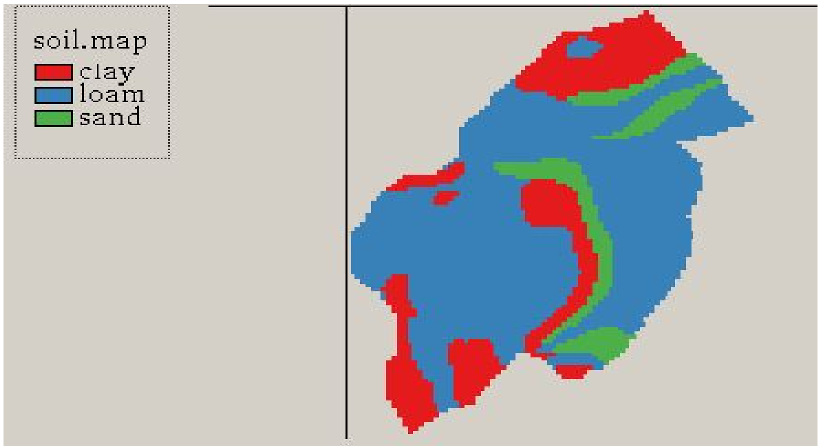
4.4 ANALYSIS

dem.map: *A Digital Elevation Map (DEM) of the study area, in metres above sea level.*



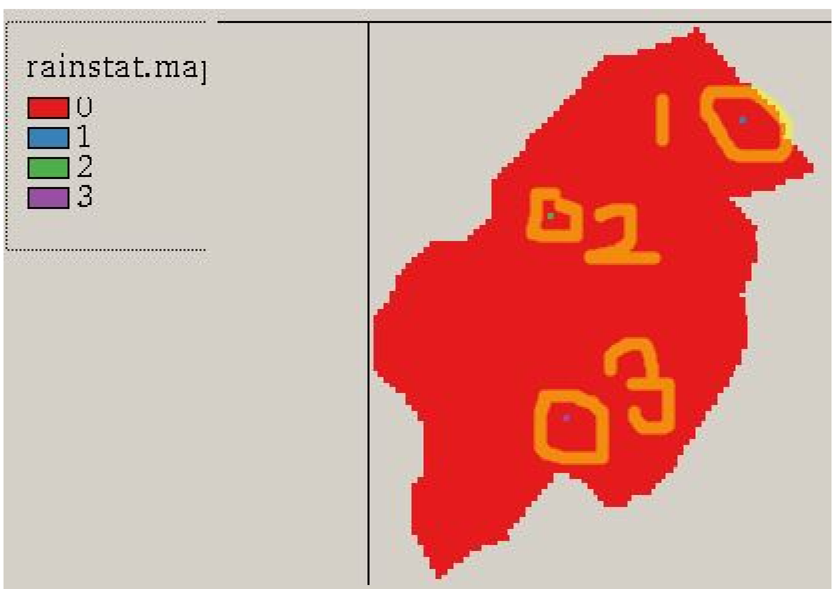
Elevation of each point on the catchment area. The region with blue and purple colour are lower elevation points while red and green marked are higher elevation points. The elevation varies from 79.5 meter to 112 meter.The rain water will flow from the higher elevation points to their local lower elevation (LLE) points.

***soil.map**: Map of soil types occurring in the study area.*



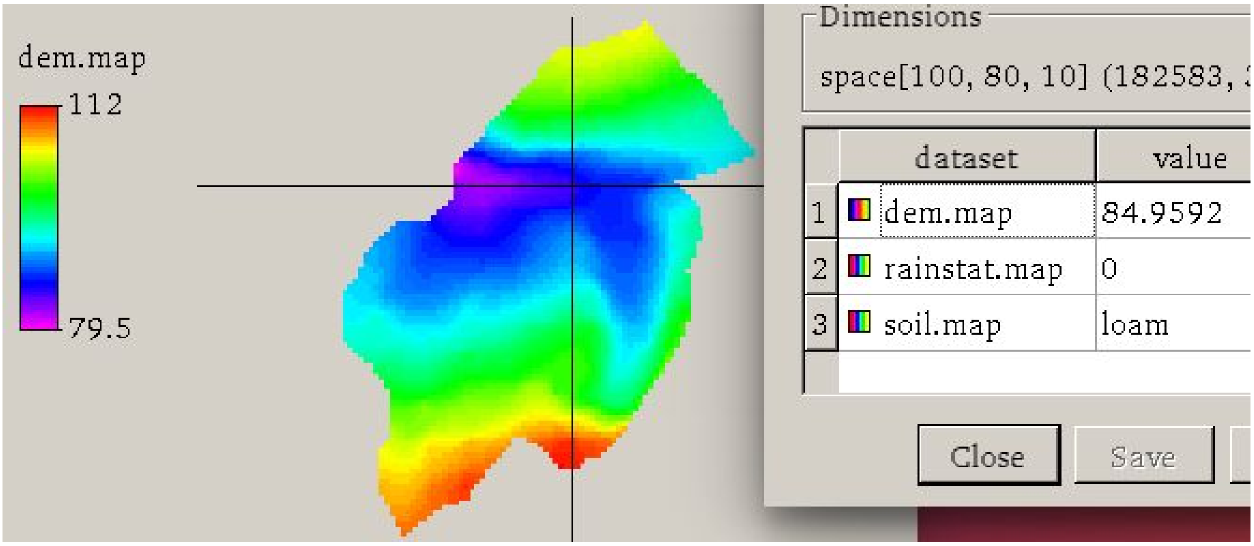
The region contains three types of soil. Namely clay, loam and sand.

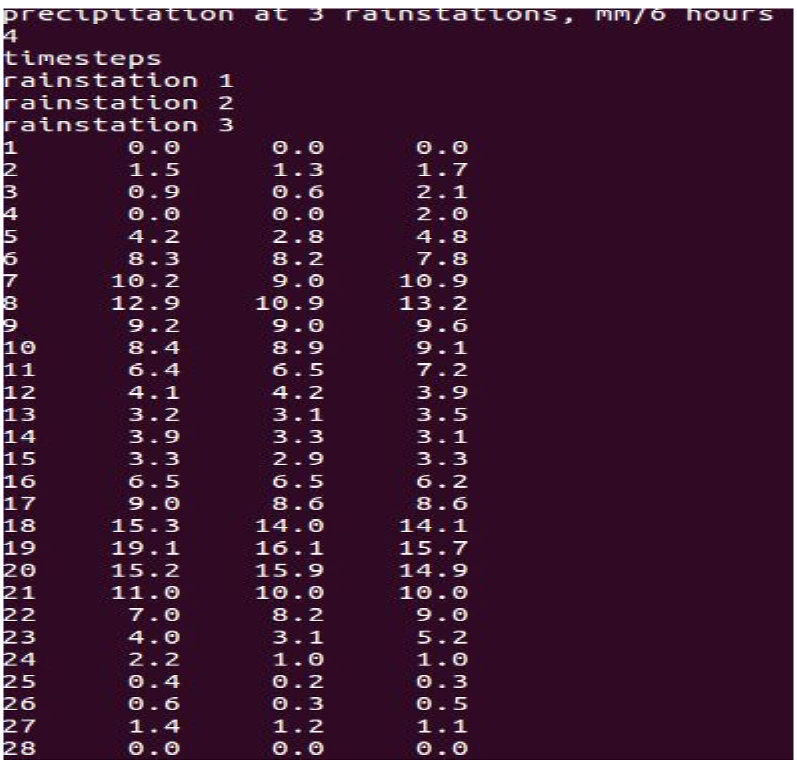
***rainstat.map**: Map with the location of three rainfall measurement stations.*



There are three rainfall measurement stations in the study area.

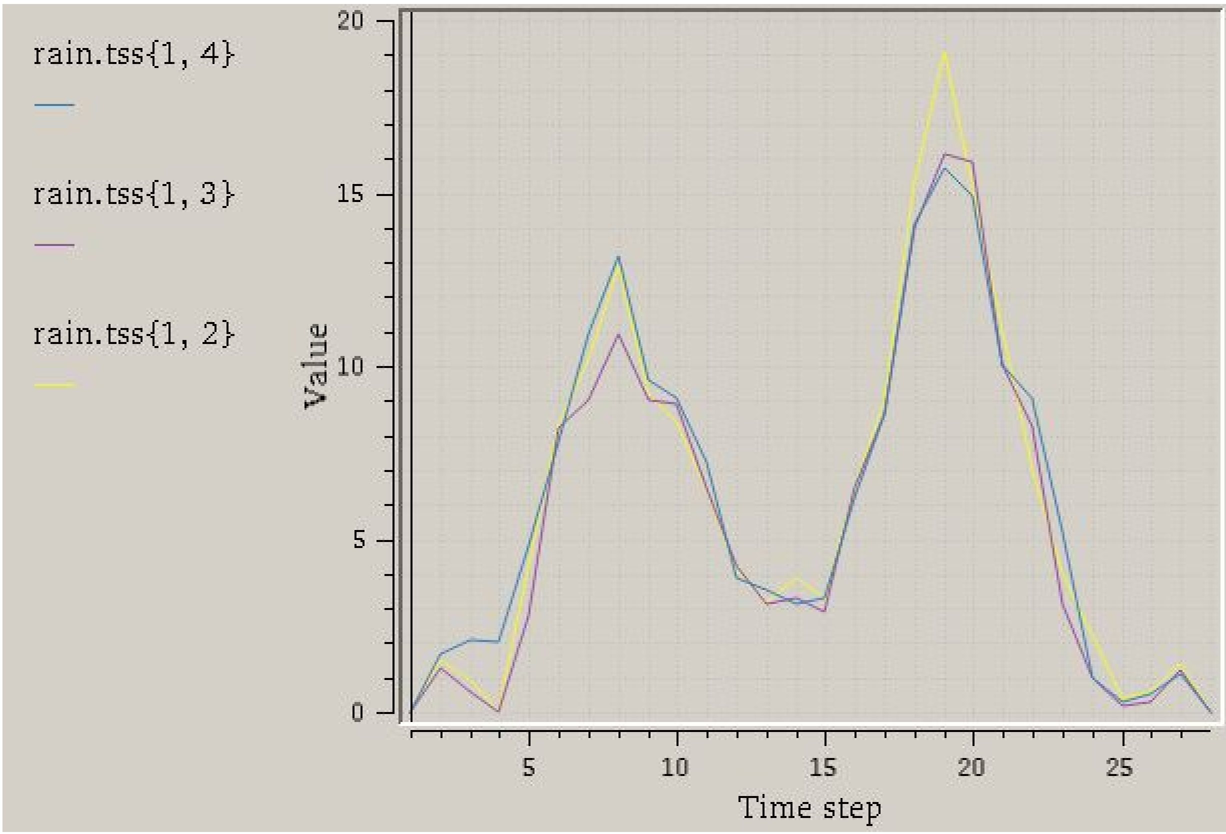
We can get the value of each individual cell as shown in below figure:-




precipitation at 3 rainstations, mm/6 hours
4
timesteps
rainstation 1
rainstation 2
rainstation 3

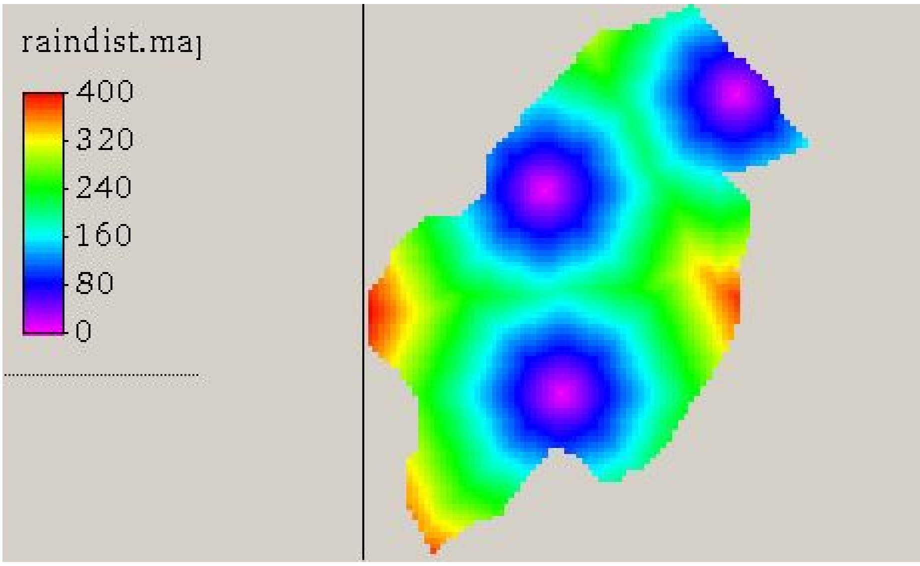
1	0.0	0.0	0.0
2	1.5	1.3	1.7
3	0.9	0.6	2.1
4	0.0	0.0	2.0
5	4.2	2.8	4.8
6	8.3	8.2	7.8
7	10.2	9.0	10.9
8	12.9	10.9	13.2
9	9.2	9.0	9.6
10	8.4	8.9	9.1
11	6.4	6.5	7.2
12	4.1	4.2	3.9
13	3.2	3.1	3.5
14	3.9	3.3	3.1
15	3.3	2.9	3.3
16	6.5	6.5	6.2
17	9.0	8.6	8.6
18	15.3	14.0	14.1
19	19.1	16.1	15.7
20	15.2	15.9	14.9
21	11.0	10.0	10.0
22	7.0	8.2	9.0
23	4.0	3.1	5.2
24	2.2	1.0	1.0
25	0.4	0.2	0.3
26	0.6	0.3	0.5
27	1.4	1.2	1.1
28	0.0	0.0	0.0

The first column denotes the timestep (each line represents 6 hours) and the succeeding columns the rainfall (mm) for rainstations 1, 2 and 3. We can analyse that rainstation, 1st rainstation has maximum rainfall for 19.1 mm in the 19th timestep and 2nd has 16.1 mm and 3rd has 15.7 mm in the same timesteps.

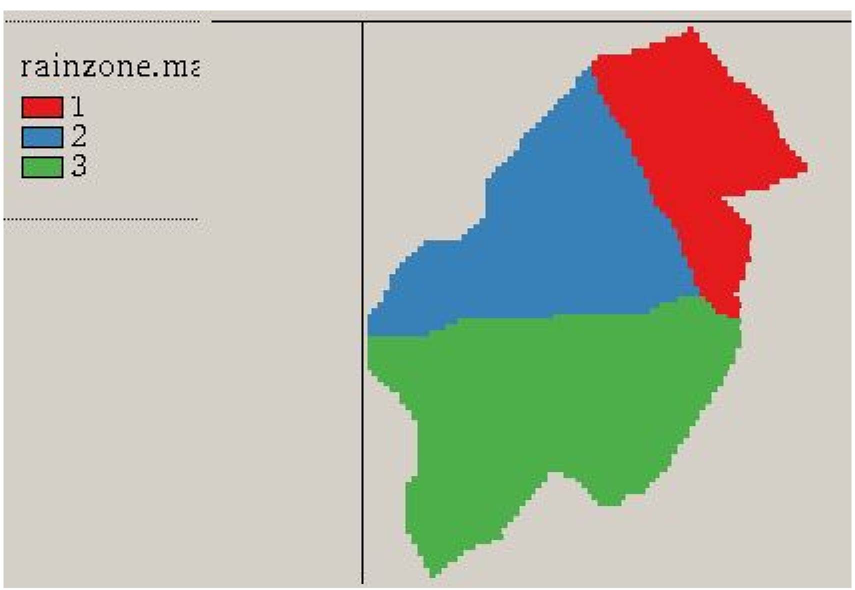


The graph shows rainfall in mm at each timestep. We can observe maximum rainfall at 19th timestep. Yellow gives the variation of rainfall at station 1, purple at station 2 and blue at station 3.The peak values of rainfall(mm) for various stations are: 19.1mm for station 1, 16.1 mm for station 2, 15.7 mm for station 3.

Till now we have only find the rainfall at the rain-stations. To find the rainfall at the zero-points(non-rainstation cells), we have to divide the zero marked cells to zones of non-zero marked areas. So we assign zone to each cell using the generic cost distance surface function named **spread** and **spreadzone**. The spread function computes the smallest cost ('distance') to reach one of the non zero points on the map. In the function one can also specify an initial cost for each cell and a friction map to vary the cost over the landscape ('relative distance' calculation).



Map in the figure is showing distance of zero points from nearest non zero points. Regions with dark blue are closest from their nearest non-zero point. This is a **relative distance plot**. Red marked regions are far from their closest non-zero points as compared to other regions.

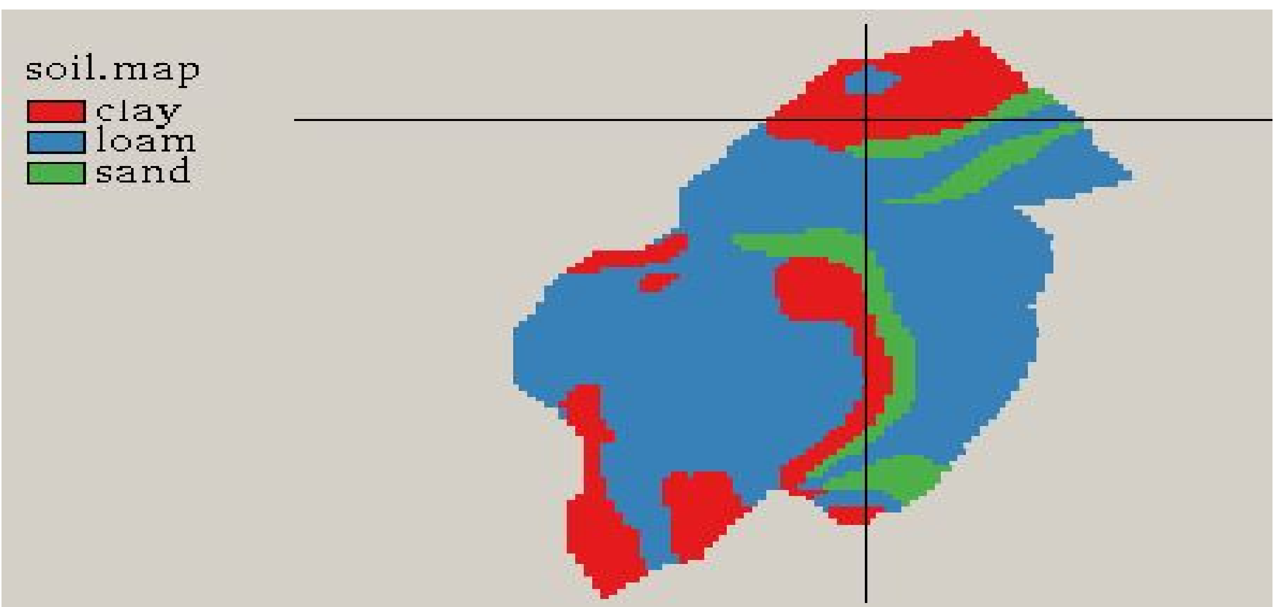


The spreadzone operator applies the same algorithm as the spread operator but for each cell it returns the unique cell value of the rainstation (1,2 and 3) on rainstat.map that is nearest. Rain-zones is allocated to each zero points. Zoning is done based on the distance of zero points and nearest non-zero points. Region marked blue is under zone 2(Rainstation-2).Region marked red is under zone 1(Rainstation-1).Region marked green is under zone 3(Rainstation-3).

https://youtu.be/eZUig7FHgyU :- This is the animation video showing amount of rainfall at each timestep of the dynamic modelling. Rainfall is varying from 0 (purple) to 19.2 mm (Red).

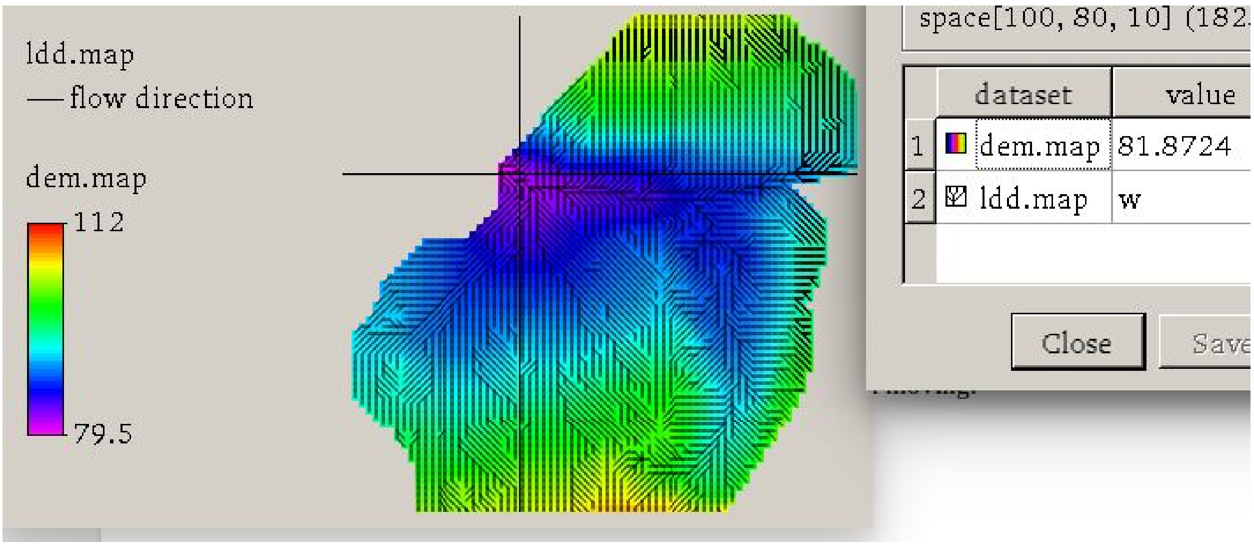
We know that some part of the rainfall and runoff will be loss due to infiltration, surface storage, interception etc. Infiltration will depend on the type of the soil. Soil map showing the different soil types in the catchment area.

The infiltration capacity (the maximum amount of water that can infiltrate during one timestep of 6 hours, mm/6 hours) is different for each soil type. Clay has a very low infiltration capacity, sand a high capacity and loam a medium capacity. The infiltration capacity of sand is 19.3 mm , for loam it is 8.3 mm and for clay it is 2.1 mm in 6 hrs time period.



The excessive rain must be redistributed downstream over the catchment. First a *local drain direction (ldd) map* is made which contains for each cell a pointer to its lowest downstream neighbour on the digital elevation map. This ldd map is generated with the lddcreate operator of PCRaster.

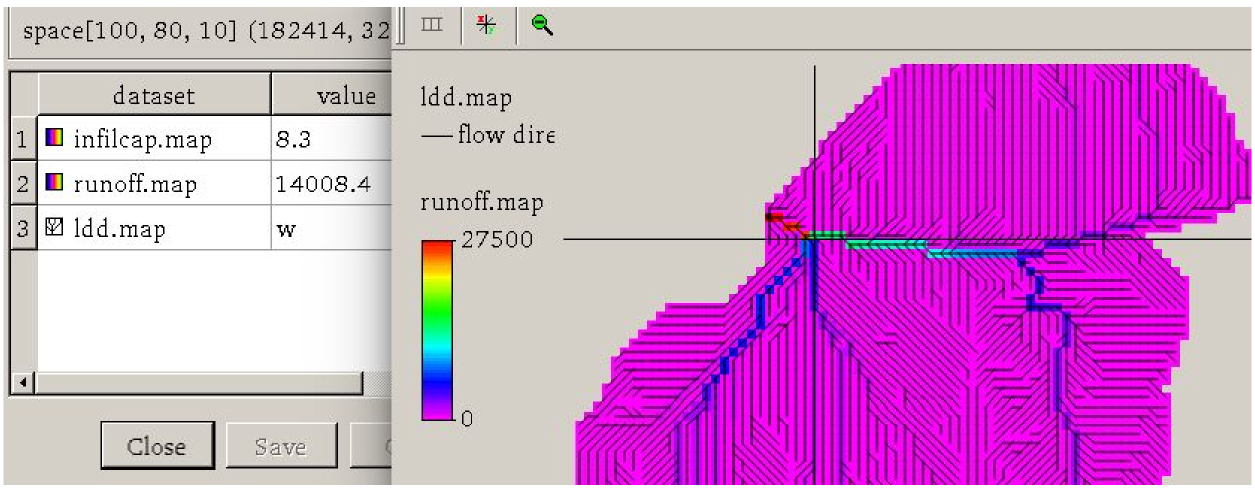
The map shows the elevation of regions. The region with lowest elevation is marked with purple. Less the elevation of the region more will be runoff. In most areas the infiltration capacity is exceeded and runoff of excessive water occurs. The soil reaches its saturation point, if infiltration capacity is exceeded.



The above figure shows the drainage directions on top of the elevation. If we click on each cell we get the direction at each point. sw -> South-west, nw -> north-west etc. Lowest elevation point is the “PIT”, where all water in moving. Pits are defined as those cells that only have neighbours at higher elevation than the cell under consideration, or a cell somewhere in the centre of a flat area which is surrounded by cells at higher elevation, as foresaid. Therefore, pits are those cells that only have neighbours pointing towards them, and no neighbours at lower or equal elevation that they can point to.

For modelling the infiltration and runoff, the (local drain direction) ldd.map and the infilcap.map are used as input map of the “accuthresholdflux” operator. This operator effects infiltration of the rain and transports the excessive water that does not infiltrate downstream over the local drain direction map.

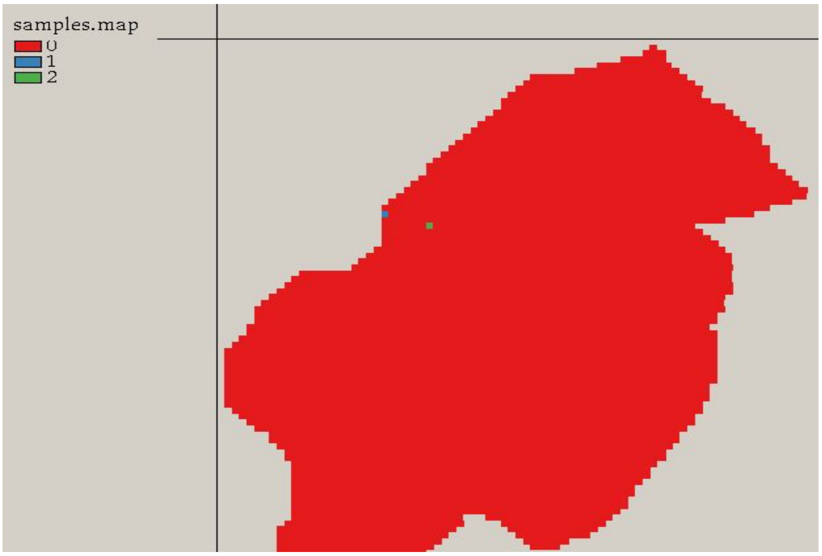
For each cell, the amount of material that is transported to its downstream cell is the amount of water that flows into the cell from upstream cells minus the infiltration capacity value on infilcap.map. As infiltration capacity is exceeded(saturation of soil) , runoff of excessive water occur. The sandy soils have an infiltration capacity of 19 mm while the amount of rain nowhere exceeds 15.3 mm. So at the sandy soils runoff will only occur when a great amount of water is supplied from upstream areas with lower infiltration capacities. Sandy soil at the top of a hill does not have upstream areas that supply water. As a result the infiltration capacity is not exceeded here and no runoff occurs. Actual infiltration of soil at particular timestamp will always be less than equal infiltration capacity.



The runoff.map shown in above figure shows runoff values of each cell in millimeters (mm).

The following video link shows the value of runoff at each timestep for each cell in m^3/sec. The runoff is converted from mm/sec to m^3/sec with the help of the operator. Link to the video is:- https://youtu.be/mfGN9CgbhHM.

The Dynamic Modelling language also allows to 'sample' the cell-value at certain locations on a map for each timestep and report these values as a timeseries. This will be done at the sampling locations on samples.map.
For calculating runoff, two sample points are selected.These points are lowest elevation points where runoff is maximum at each timestamp. Water will move from higher elevation points to these lower elevation points.




```
timeseries scalar
3
timestep
1
2
       1           0           0
       2           0           0
       3           0           0
       4           0           0
       5 0.000773611           0
       6   0.0182481  0.00777129
       7   0.0509542   0.0218796
       8   0.0906208   0.0429472
       9   0.0373574   0.0157218
      10    0.030343   0.0118546
      11      0.0091  0.00235972
      12 0.000441665           0
      13           0           0
      14           0           0
      15           0           0
      16  0.00700972  0.00219954
      17   0.0266329   0.0118639
      18    0.126316   0.0645371
      19    0.167834   0.0907851
      20    0.144018   0.0721301
      21   0.0522491   0.0254634
      22   0.0234389  0.00744537
      23   0.0012338           0
      24           0           0
      25           0           0
      26           0           0
      27           0           0
      28           0           0
```

This is the value of at two sample points in m^3/sec at each timestep. Maximum runoff is at 19th timestep which is 0.168 m^3/sec.

The relation of rainfall and runoff is shown in the video, corresponding to the two sample points. Video :- **https://youtu.be/3_jIYXIZYgw**.

CHAPTER 5

CONCLUSIONS

1. The study showed that PCRaster was a valuable tool to quantify the rate of surface runoff and assess the impacts of different land use/ cover types on runoff generation.
2. Water flows from high elevation towards local drain direction.
3. Maximum runoff will be at lowest elevation point known as “PIT”.
4. Runoff depends on many factors including amount of rainfall, infiltration capacity of soil, interception cover and losses.
5. Runoff is a dynamic process that is dependant on factors that vary both spatially and temporally.
6. The excess water or surface runoff was routed using the local drain direction map produced from the DEM.
7. Runoff is not always equal to rainfall(precipitation).
8. For each point, the amount of material that is transported to its downstream cell is the amount of water that flows into the cell from upstream cells minus the infiltration capacity and other losses.

REFERENCES

1) http://pcraster.geo.uu.nl/downloads/latest-release/
2) http://pcraster.geo.uu.nl/pcraster/4.1.0/doc/python/pcraster/quickstart.html
3) http://pcraster.geo.uu.nl/
4) http://pcraster.geo.uu.nl/quick-start-guide/
5) https://books.google.co.in/books?id=z1qignvz7YkC&pg=PA311&lpg=PA311&dq=some+good+modelling+softwares+like+pc+raster&source=bl&ots=7Xxmm-XuEC&sig=mO_DnfW28pNldUeyMikaYjc81Qs&hl=en&sa=X&ved=0ahUKEwiXyuGyv7PWAhXKMY8KHefVDXIQ6AEIQjAG#v=onepage&q=PC-Raster&f=false
6) http://pcraster.geo.uu.nl/documentation/Demo/DynamicModellingDemo.html
7) http://www.carthago.nl/__miracle/doc/thesis1.pdf
8) https://www.itc.nl/library/papers_2005/msc/ereg/harssema.pdf

Thank You