THE ENERGY AND RESOURCES INSTITUTE

Identification of flood risk on urban road network using Hydrodynamic Model

Case study of Bangalore

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Introduction

Global warming has a direct influence on precipitation and heavy rains and it is likely to increase the intensity and frequency of extreme rainfall events in future (Roy, 2009; Trenberth, 2011). The International Panel on Climate Change (IPCC) states that the warming on the earth surface is unequivocal by concluding from the observational and modelling studies that an increase in the frequency of heavy precipitation events is likely to have occurred over most land areas during the 20th century (IPCC, 2007). Several studies on Indian region has also reinforced a significant rise in the frequency and duration of monsoon breaks over India during recent decades (Ramesh Kumar et al., 2009 and Turner and Hannachi, 2010), with increase in the frequency of extreme rainfall events in certain parts of the country (Goswami et al., 2006). Thus, higher intensities of rainfall are therefore the likely hydrological future for India. Along with this climate change via changes in sea level is a threat to the coastal cities. A global average sea level rise of 9–88 cm is expected over the next hundred years (UNFCCC, 2005). Sea level rise increases the risk of coastal and delta floods, particularly in cases of storm surges (Huong and Pathirana, 2013).

Accompanying the change in climate patterns is the rapid urbanisation and growth of cities in the twentieth century. Heavily urbanized megacities in the low-lying deltas of Asia have been identified as “hotspots”, especially vulnerable to climate risks (ADB, 2008; IPCC, 2007). The level of urbanization in India has increased from 27.81% in 2001 to 31.16% in 2011 (Census 2011). To accommodate accelerating urbanisation more wet lands, open spaces, tanks and wooded areas are converted to urban and suburban areas, thus, the amount of surface area available for water infiltration into the soils decreases. Home sites, parking lots, buildings, and roadways all decrease the surface area of soil on Earth's surface. The increase in artificial surfaces due to urbanization will increase the flooding frequency due to poor infiltration and reduction of flow resistance (due to faster concentration times) (Huong and Pathirana, 2013). Because of the entire paved areas the imperviousness of the land increases with which water is redirected into sewage and storm water drainage systems. These drainage systems are presently insufficient to cope with the increase volume of water created from high intensity rainfall and generates flood (Nair, 2009; Avinash, 2016).

Over the coming decades, the pressures of urbanisation along with climate change will aggravate this situation. There is evidence in recent years where heavy precipitation events have resulted in several damaging floods in India. A number of major cities and towns in India reported a series of devastating urban floods in the recent decade. The consecutive flash floods over three major metro cities in the same year, i.e., Mumbai in July 2005, Chennai in October 2005 and again in December 2005 and Bangalore in October 2005 caused heavy damages in economy, loss of life, disruption of transport etc (Guhathakurta and Sreejith, 2011.

The transport system receive the immediate impact of floods as the storm water drains which are unable to cope the storm water are encountered with blockage and as a result the runoff inundates the urban settlements in low laying areas and submerge the roads (Avinash, 2016). Flooding of roads has the potential to cause a range of major difficulties, from harm to people, damage to vehicles, damage to the road infrastructure and the resulting economic disruption (Hankin et al., 2012). There is abundant research on how the urban transportation sector may contribute to the climate change through emissions but less attention is given to the potential impacts of flooding events on the performance of urban transportation network as integrated systems (Suarez, P., 2005).

In the present study, the aim was to understand the process of flooding from extreme rainfall. The study domain for this study is entire Bengaluru and suburban areas, where the hydrodynamic responses post event in terms of storm water depth have been studied. For this, a 2D hydrodynamic simulation model using DHI MIKE 21 HD model was developed, followed by creation of time varying flood risk map for selected precipitation events.

Model results can be used to identify areas or hotspots which would have higher risk of flooding during extreme precipitation events. This will be helpful for policy-making and planning such that identified areas can get maximum attention during any such extreme event. The results of this model can thus be used for the further urban planning and flood prediction.

Objectives

The objective of this study is to access the impacts of urban flooding on traffic congestions by using geo-spatial datasets and explore the possibility of using hydrodynamic modelling to identify the points of flood risk. The key objectives are to:

- Estimate the return period of extreme precipitation events for flood forecasting and flood risk mitigation by conducting rainfall analysis using Gumbel EV Distribution.
- Creating Hydrologically conditioned depression less DEM for the study area to generate the bathymetry data in MIKE model for 2D overland hydrodynamic simulation
- Generate flood risk maps of Bengaluru for estimation of the areas which are going to be flooded in the case of different rainfall intensities, duration and volume, with spatial information about the flood water depth.
- Identification of flood hotspots on urban road network

Literature Review

There is a wealth of information on the effect of urbanization on the hydrologic processes. Leopold (1968) stated that the percentage of impervious area (type of land use), characteristics of the channel and provision for storm sewerage are the principal factors that govern the flow regime in a catchment. After synthesizing many studies, Hollis (1975) concluded that small frequent floods are increased with shorter recurrence interval. Number of studies assessed the impact of land use change on runoff (Hollis 1975; Bultot et al 1990; Crooks and Davies 2001; Istomina et al 2005; Brath et al 2006; Rongrong and Guishan 2007; Mao and Cherkauer 2009; Sheng and Wilson 2009; Solin et al 2011). Several researchers acknowledge that urbanization in the flood plain areas would increase the peak discharge, decrease the time to peak and increase the volume of runoff (Liu et al 2004; Campana and Tucci 2001; Brilly et al 2006; Nirupama and Simonovic 2007; Saghafian et al 2008). Chen et al (2009) stressed on a better understanding and assessment of land use change impacts on watershed hydrologic processes for predicting flood potential and mitigation of hazard, and has become a crucial issue for planning, management and sustainable development of the watershed. Kibler et al (2007) measured the anthropogenic impact on the hydrology of watersheds in terms of the ratio: flood peak after development to flood peak before development over a range of return periods. The flood peak ratio depends on the impervious fraction and percent of basin sewered and these factors have been taken into account in an urban flood peak model. They concluded that the analysis of urbanization effects on flood frequency is a vexing problem because of lack of flood data in urban areas and also because of the dynamic nature of development process. The spatial and temporal changes of land use/land cover can be assessed using satellite imageries (Yu et al 2003; Geymen and Baz 2008; Kadiogullari and Baskent 2008; Solin et al 2011). Remote sensing (RS) techniques along with Geographic Information System (GIS) have been applied extensively in recent times and are recognized as powerful and effective tools for detecting land-use change, flood mapping and flood risk assessment (Sarma 1999; Islam and Sado 2000; Sanyal and Lu 2004; Dewan et al 2007).

The influence of land use changes on runoff was examined by Yu et al (2003) using a rainfall–runoff model and design hyetographs with various return periods in Ta-Chao basin, Taiwan. Their results indicate that peak discharge and runoff volume increase significantly from 1972 to 2000. Liu et al (2004) presented a distributed hydrologic modeling and GIS approach for the assessment of land use change on flood processes. WETSPA (Water and Energy Transfer between Soil, Plants and Atmosphere) and GIS techniques were used to predict flood hydrograph to evaluate storm runoff from different land use areas and to assess the impact of land use changes on flood behaviour. Three hypothetical scenarios namely urbanization, deforestation and afforestation were considered. They concluded deforestation has a fair negative impact and afforestation has a moderate positive impact on flooding.

Bengaluru District Profile

Bengaluru district is situated in the heart of the South-Deccan plateau in peninsular India to the South-Eastern corner of Karnataka State between the latitudinal parallels of 12° 39' N & 13° 18' N and longitudinal meridians of 77° 22' E & 77° 52'E at an average elevation of about 900 meters covering an area of about 2,191 sq. km (Bengaluru rural and urban districts). Bengaluru is the sixth largest metropolis in the country and an epicentre for the various cultural, social and religious activities. Bengaluru urban district with a population of about five million consists of three taluks namely Anekal, Bengaluru North and South. The city apart from being the political capital of the state is also a very important commercial centre for some of the major industrial establishments. The district supports about 9.41% of the state's total population and 27.41% of the total urban population of the state.

Topography

The Bengaluru North taluk is more or less a level plateau and lies between 839 to 962 meters above mean sea level. In the middle of the taluk there is a prominent ridge running NNE-SSW. The highest point (Doddabettahalli 962m) is on this ridge. The gentle slopes and valleys on either side of this ridge hold better prospects of ground water utilization. Bengaluru South Taluk represents an uneven landscape with intermingling of hills and valleys with bare rocky outcrops of granites & gneisses raising 30-70 meters above ground level are common in the southern portion. The highest point is 908m above mean sea level and the lowest at 720 meters above the mean sea level. Southern and Western portions present a rugged topography composed of Granitic and Gneissic masses. The eastern portions of the Taluk form an almost featureless plain with minor undulations.

Hydrology

The Bengaluru district supports about 461 tanks serving the irrigation needs to various capacities (Bengaluru Gazetteer, 1981). Most of these tanks are seasonal and carry water for six months during a year. (Bengaluru: North - 98 tanks, South - 166 tanks , Anekal - 197 tanks). The total surface water potential created by these tanks is about 12,541 hectares accounting to about 54 % of the total water resources of the district.

Rivers

Bengaluru has no major rivers flowing in the district. The Arkavati River flows in the district for a small distance in Bengaluru North taluk and the Dakshina Pinakini touches the borders of the district to the North-East of the Anekal Taluk. The Vrishabhavati, a tributary of Arkavathi that takes its birth in the Bengaluru City at Basavanagudi, flows in the district before joining the Arkavati near Muduvadidurga and the Suvarnamukhi from Anekal Taluk joins the tributary before joining the Arkavati.

Ground water

Ground water in the district occurs under water table conditions in the weathered mantle of the granitic gneisses & in the joints, crevices and cracks of the basement rock. Ground water is developed largely by means of open wells. Open wells as well as bore wells can both yield between 70 to 90 meters of water per day.

Climate

Bengaluru is considered to be climatically a well-favoured district. The climate of the district is classed as the seasonally dry tropical savanna climate with four seasons. The dry season with clear bright weather is from December to February with summer from March to May, followed by the southwest monsoon season from June to September. October and November constitute the post-monsoon or retreating monsoon season. The main features of the climate of Bengaluru are the agreeable range of temperatures, from the highest maximum of 33°C in April to the lowest minimum of 14°C in January. The two rainy seasons, June to September and October to November, come one after the other but with opposite wind regimes, corresponding to the southwest and northeast monsoons. The climate of the district is Dry tropical savanna with four seasons.

1. Dry Characterised with bright weather from Dec to Feb
2. Summer Characterised by high temperatures, from March - May
3. Monsoon South-West monsoon, Jun - Sept
4. Post-monsoon October – November

The mean annual rainfall is 859.6 mm, with three different rainy periods covering eight months of the year. June to September being rainy season receives 54% of the total annual rainfall in the S-W monsoon period and 241-mm during the N-E monsoons (Oct. - Nov.)

Geology

Bengaluru District is entirely underlain by Precambrian granite and gneiss of the Indian Precambrian Shield and which are part of the peninsular granitic complex. Migmatite and gneiss are dominant, but there is a zone of granite and granodiorite some 20 km wide trending in a north-north-west direction across the far western part of the district. The weathered zone is of considerable importance to the groundwater occurrence, because the fresh granitic and gneissic rocks have no primary porosity. They can only store and transmit water via open fractures, and a universal characteristic of such aquifers is that they mostly have very low hydraulic conductivity and a high degree of lateral inhomogeneity. The “hard rock” aquifers, or “fissured aquifers”, that are present near the surface (within the first 100 m below ground surface) are considered as “discontinuous aquifers”, as a consequence of their discrete hydraulic conductivity.

Bengaluru has a natural elevation of 920 metres and this means that the water can percolate on its own down the slopes. Encroachment, illegal construction, blockage of storm water drains, breaching of tanks and lakes and deliberately blocking the natural flow of water causes impediments in the flow of water.

Poorly Managed and Inadequate Drainage Network

More than half the sewage generated in Bengaluru is directly discharged into stormwater drains and lakes, contaminating water bodies and ground water, a CAG report revealed. Reduction in stormwater system capacity increases flood significantly. The existing sewage network covers only 40% of Bengaluru Metropolitan Region (BMR) and the sewage treatment plants receive only 47% of the sewage generated, says the report of the CAG (comptroller and auditor general of India) for the year ended March 31, 2010. Also the remaining 53 percent was discharged directly into stormwater drains and lakes, contaminating water bodies and groundwater. Lack of capacity of cross drainage works causes localised and widespread flooding. Construction of services (water, telecommunication, power etc) above invert and below flood level obstructs flow and aggravates flooding.

Solid Waste Management

Dumping of solid waste and building waste in the drainage causes blockage and pollution in the drainage system. These channels which are supposed to allow free flow of water are blocked with debris and most times refuse and sewages. These substances increase the bed load of the drainage channels causing them to rise. The result is channel overflowing its bounds into adjourning flood plains. Bridges and culverts (blockage) are also constructed across channels and this obstructs river flow and cause occasional flash floods. Therefore a need for implementation plan for solid waste management is required.

Land Use Land Cover Change

According to data contained in the Bengaluru Mahanagara Palike Master Plan, 40.4% of the land in the city is used for residential purposes. Transport uses 24.3% of the land, while land used for industrial, and commercial purposes comprise 6.9% and 2.7% respectively. As the city of Bengaluru expands, the BMP expects the percentage of land used for industrial purposes to decrease, while it expects the percentages of land used for residential, commercial and public and semi-public purposes to increase.

Poor and often short sighted urban planning has resulted in Bengaluru rapidly losing its green cover and water bodies, so much so that they have become the prime reason for almost all of the City's ills. Bengaluru is the only city among the big four metropolis of India-Mumbai, Kolkata, Delhi ad Chennai-not to be located in or near a water source. If Mumbai has the Arabian Sea, Kolkata the Ganges and Madras the Bay of Bengal, Delhi has the Yamuna but Bengaluru has no such water body. Yet, Bengaluru has seen a massive urban influx over the last five decades and there has been a 637 per cent increase in urban areas in Greater Bengaluru area from 1973 to 2009 and it is still growing. The rise in built up area from 16 per cent in 2000 to around 24 in 2009 and almost 30 per cent today has seen a corresponding decrease in wet lands, breaching of lakes and tanks and decrease in green cover, leaving water with no natural course to flow off. This has been exacerbated by the presence of 542 slums with many of the lacking basic facilities in sanitation and hygiene and straining the natural resources.

Model Setup

Model Area

The model domain for flood modeling covers the Bangalore Urban District. The extent of the boundary layer is Lat 12^{0}38’8.0304’’ to Lon 77^{0}15’1.375’’ and Lat 13^{0}14’18.0636’’ to Lon 77^{0}52’11.024’’ covering the all possible watershed boundaries contributing to the Bangalore city. The Model area comprises the entire metropolis region of Bangalore figure 1 below shows the study area map with study domain processed in ArcGIS.

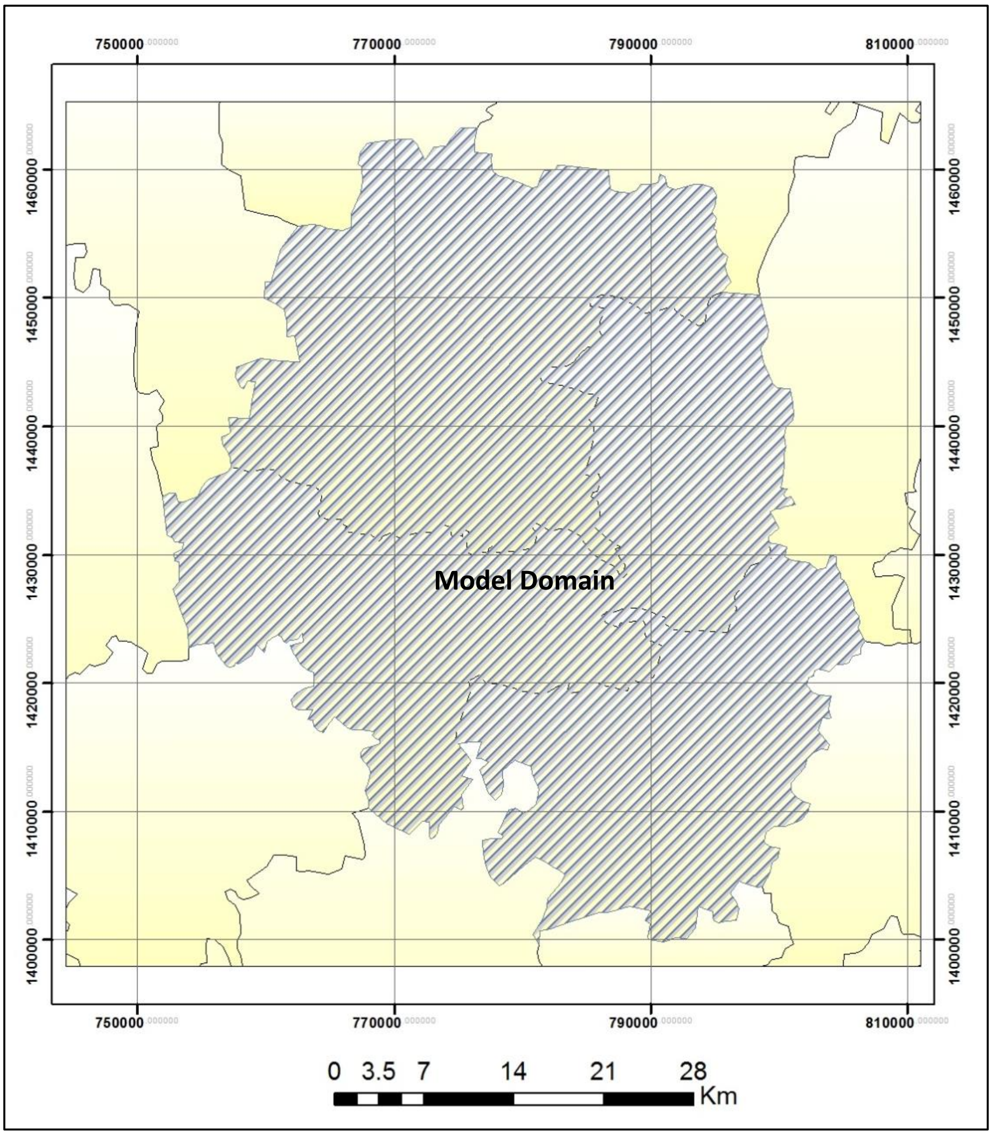


Figure 1 Bangalore: Model Domain

MIKE 21

The hydrodynamic model in the MIKE 21 Flow Model (MIKE 21 HD) is a finite-difference general numerical modelling system for the simulation of water levels and flows in estuaries, bays and coastal areas. It simulates unsteady two dimensional flows in one layer (vertically homogeneous) fluids and has been applied in a large number of studies. The model is based on the very basic mass balance equation and conservation of momentum equation. These two equations together, describe the flow and water level variations. These equations are in the form of Saint Venant equation used in MIKE 21. (DHI, 2011)

Mass Balance Equation

$$\frac{\partial \xi}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t}$$

Conservation of Momentum Equation in x-direction:

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x}\left(\frac{p^2}{h}\right) + \frac{\partial}{\partial y}\left(\frac{pq}{h}\right) + gh\frac{\partial \xi}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2.h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial x}(h\tau_{xx}) + \frac{d}{dy}(h\tau_{xy}\right] - \Omega_q - fVV_x + \frac{h}{\rho_w}\frac{\partial}{\partial x}p_a = 0$$

Conservation of Momentum Equation in y-direction:

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q^2}{h}\right) + \frac{\partial}{\partial x}\left(\frac{pq}{h}\right) + gh\frac{\partial \xi}{\partial y} + \frac{gq\sqrt{p^2+q^2}}{C^2.h^2} - \frac{1}{\rho_w}\left[\frac{\partial}{\partial y}(h\tau_{yy}) + \frac{d}{dx}(h\tau_{xy}\right] + \Omega_p - fVV_y + \frac{h}{\rho_w}\frac{\partial}{\partial y}p_a = 0$$

The following symbols are used in these equations:

h(x,y, t) – water depth =ξ-d, m
d(x,y,t) – time varying water depth , m
ξ(x,y,t) –surface elevation, m
p,q (x,y,t)- flux densities in x- and y-directions (m 3 /s/m) = (uh,vh);
(u,v) = depth averaged velocities in x- and y-directions
C(x,y)- Chezy resistance (m ½ /s)
g- acceleration due to gravity (m/s 2)
f (V)- wind friction factor
V, Vx, Vy (x,y, t)- wind speed and components in x- and y-directions (m/s)
Ω(x,y)- Coriolis parameter, latitude dependent (s -1)
Pa (x,y,t)- atmospheric pressure (kg/m/s 2)
Pw- density of water (kg/m 3)
x,y- space coordinates (m)
t- Time (s), τxx, τxy, τyy- components of effective shear stress

Methodology

Two different rainfall intensities, duration and frequencies are selected in this modelling approach; DHI MIKE21 was used to simulate the rainfall events. The AWS 5 minute time series rainfall Data for the year 2015 obtained from open archived source (Yuktix open weather project), followed by quality check with IMD hourly data with return period of 10 years (164 mm) and 100 years (266 mm) were selected for hydrodynamic calculation on 2D flow model. CartoSAT DEM procured from NRSC (national remote sensing centre) with 10 m spatial resolution was used for the surface elevation. Other spatial information such as Road network, water bodies are obtained from OSM metro extract data set in the form of shapefiles. These shapefiles has been gone under quality test in Google earth to rectify the errors in the network datasets and then merged with the Landuse map for the creation of surface roughness in ArcView grid data. The topographic data (DEM) was first converted in ArcGIS to ASCII format to be used in MIKE 21 simulation to determine the water level. Figure below schematises the overall approach of the study. The detail description of data processing is provided in the section Pre-processing of data section in the report.

Modelling Approach

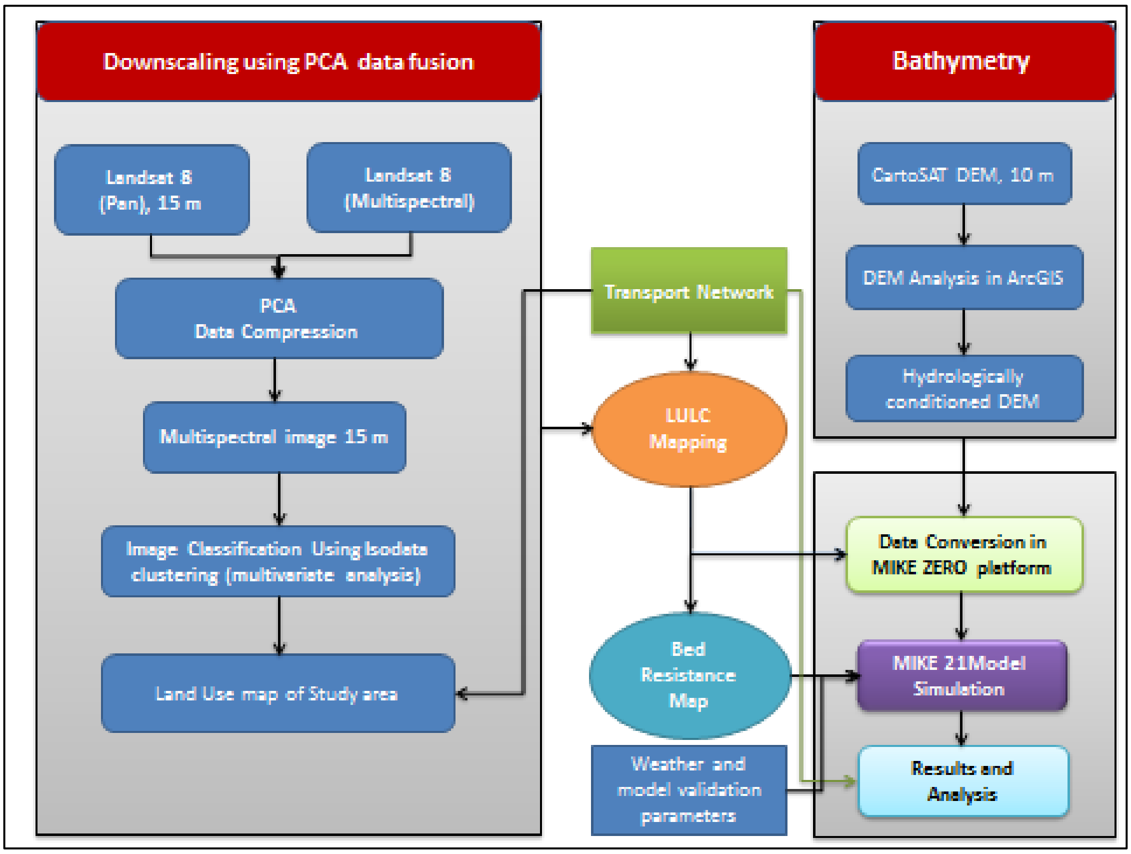


Figure 2 Schematic Diagram of Model using Spatial-Numerical Model

Data Collection and Pre-Processing of data

Rainfall Data

Rainfall is the main driving parameter of urban floods in Bengaluru. Since, rainfall intensity, duration and frequency determine the extent and severity of flooding, it is important to analyse the rainfall for the selection of events in the modelling process. The rainfall data can be analysed and presented in many ways. Here, we have analysed the rainfall data of Bengaluru provided by IMD. 25 year daily rainfall data (1990-2014) obtained from IMD station (BANGALORE; BNG, LAT 13.0, LON 77.6, ELEVATION 921m) is analysed using Gumbel probability distribution function for calculation of return period and frequency analysis. The Gumbel method of frequency analysis is based on extreme value distribution and uses frequency factors developed for theoretical distribution. The Gumbel extreme value distribution is most accepted and widely used method for flood frequency analysis. It can be observed from the graph bellow that on the whole observed data fits the frequency curve satisfactorily.

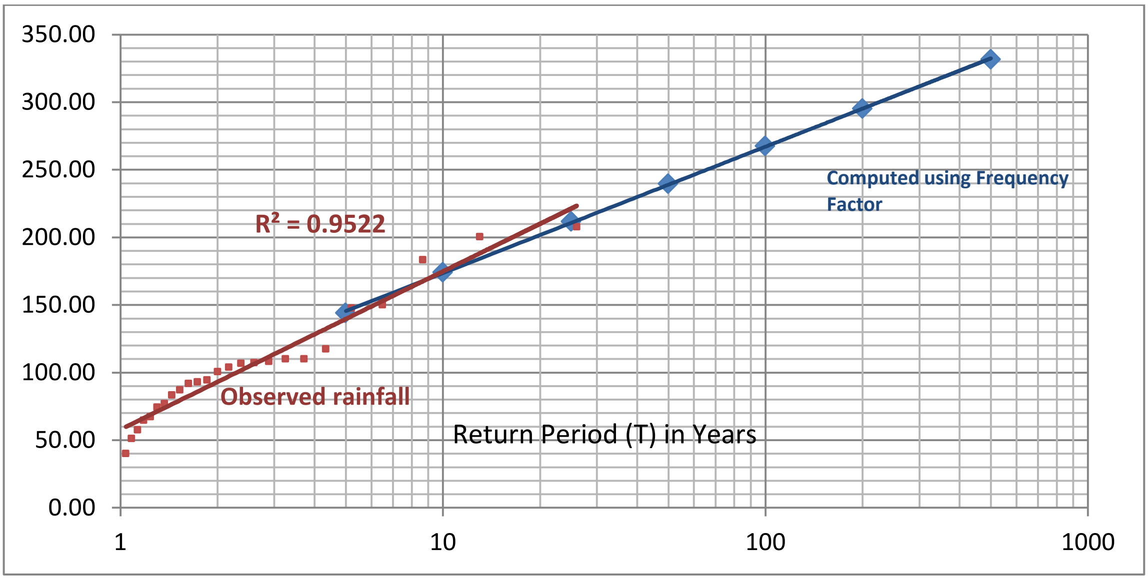


Figure 3. Gumbel Extreme Value frequency distribution adjustment of rain intensities and return periods

Table I: Calculated Rainfall and Return period using Gumbel distribution

Return Period T (in Years)	Annual Maximum Rainfall
5	144.04
10	173.86
20	202.07
50	239.52
100	267.34
200	294.96
500	331.45

Rainfall being a driving force in this case to simulate the surface runoff requires a time series data of rainfall intensity/rate with temporal variation in a model domain. In general either historical rainfall series or designed storm. In this study the earlier option is considered. Two different rainfall intensities, duration and frequencies are selected in this modelling approach; DHI MIKE21 was used to simulate the rainfall events. The AWS 5 minute time series rainfall Data for the year 2015 obtained from open Yuktix open weather project source (http://www.yuktix.com/m/aws/), followed by quality check with IMD hourly data with return period of 10 years (164 mm) and 100 years (266 mm) for hydrodynamic calculation on 2D flow model

Table II Selected Rainfall events for HD simulation

Rainfall Event	Total Rainfall (mm)	Total Duration	Return Period (T)
23-04-2015	164	2 hr 10 minutes	10
03-11-2015	266	4 hrs 10 minutes	100

Processing of Hydrologically Conditioned Depressionless DEM

Hydrologically conditioned DEM is a DEM whose flow direction defines expected flow of water over the terrain. The flow pattern and flow direction are important and it should be correcting before going for any kind of hydrological assessment using DEM. The Hydrologically conditioned Dem is a function of analysis being performed and the analysis would be different for different assessments. For flood analysis, surface storage can be avoided as they store water and get and will contribute to downstream catchments during the rainfall event eventually. (ESRI UC, 2014)

CartoSat DEM with 10 m spatial resolution is processed in ArcGIS to make it Hydro Conditioned. First all the tiles (25) of CartoDem have been joined together using Mosaic tool in ArcGIS. The resulting layer file then get filled to form a depression less DEM. The resulting DEM file was converted from Raster to Point vector data using raster to vector tool in ArcGIS followed by removal of specific point removal. The grid points which has unrealistic elevation they could be a natural depressions or manmade trenches. These depressions form sink in the model and have to be removed from the DEM as they results in changes in flow path of the flood water (Anon, 2010). These sinks have to be removed as during simulation these grid points will show unrealistic and high water depth. All no data values and unrealistic elevation points in land has been deleted. Interpolation tool is used for assigning values to those points. The processed Point data file then gets converted to DEM raster. The resulting raster data is used for defining flow pattern and flow direction. The process of making a hydro conditioned DEM is an iterative process and the correction technique run several times to make the Hydro DEM which can be used in the model. The Resulting Hydro DEM (figure 4) was used to create bathymetry data for MIKE 21 model.

Figure 4 Hydrologically Conditioned CartoSat DEM processed in ArcGIS

Bathymetry

The bathymetry file was created in MIKE21 using the Mike Zero toolbox. The tool Grd2MIKE was used to convert the ASCII file to dfs2 file which can be used in MIKE21. For the boundary in MIKE 21 either elevation or the flux can be assigned at the boundary position (DHI, 2011). In this model elevation has been given at the boundary. When importing GIS surface data for a MIKE21 bathymetry, it is recommended to ensure that the *'True Land'* value is set to a sufficiently large value as these nodes never become active computational nodes within the model domain (DHI, 2011). The grid spacing of 30 m was used in this model Bathymetry file. In the model it is important to have same geographical datum and projection system for entire study domain.

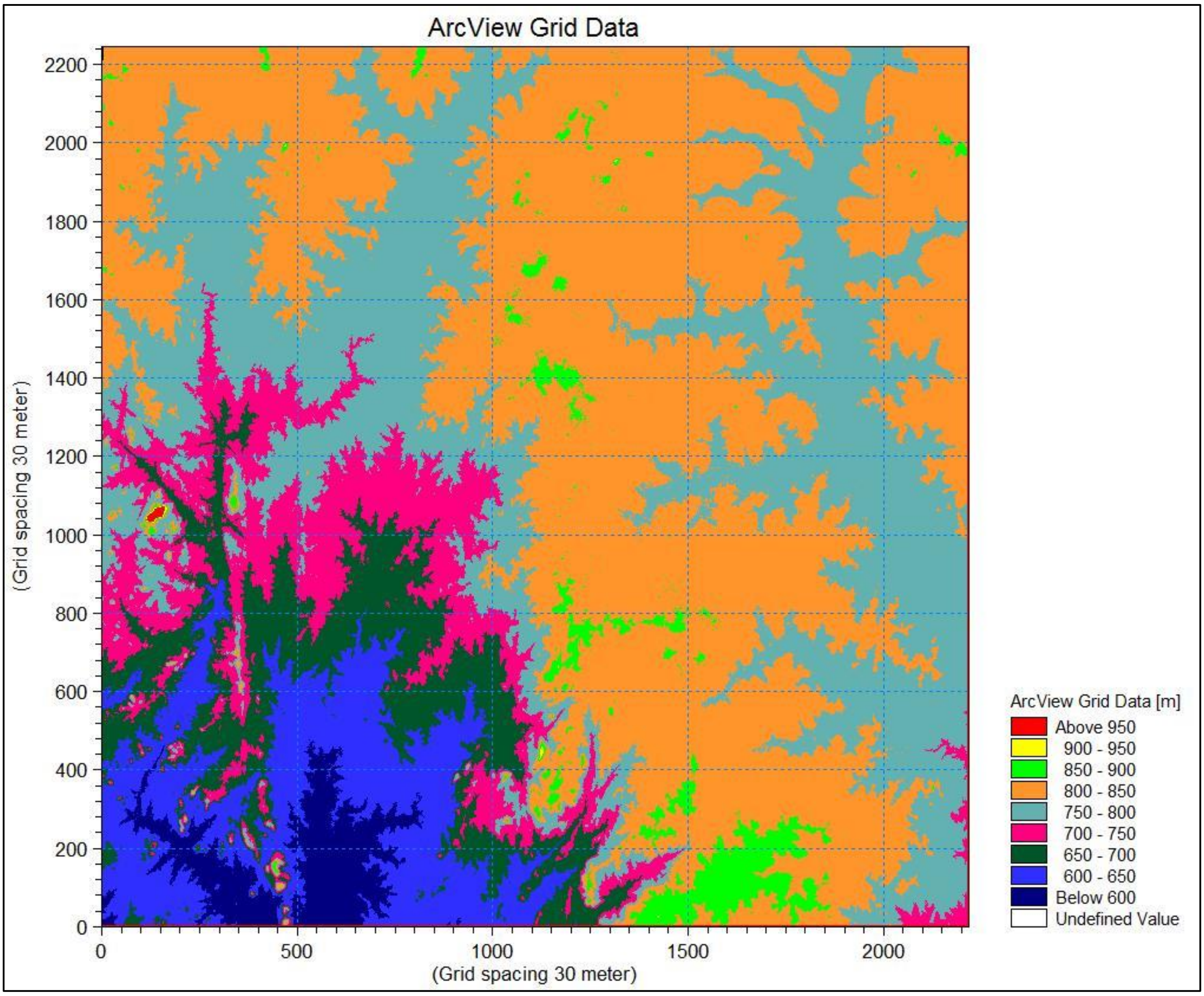


Figure 5 Bathymetry File in ArcView Grid data processed in MIKE Zero toolbox

Processing of Surface Roughness Data

The bed roughness values can be specified as Chezy or Manning numbers in the model. Either a constant value can be used for the whole area or different values for the different Land use can be considered for better simulation. In this study Grid file of the manning number has been created for better simulation.

The satellite imagery of Landsat 8 having 30 m spatial resolution was merged with 15 m panchromatic band to produce 15m resolution multispectral image by data fusion through PCA in ArcGIS. The 15 m multispectral image then classifiesd using isodata clustering technique of unsupervised data classification through multivariate analysis. 50 classes were made with the aid of Dendogram. Reclassification into seven classes namely, water bodies, forest/tree, built up, sparsely vegetated surface, cropland, fallow land and lastly roads consisting of primary, secondary, tertiary and link roads obtened from OSM metro extract was prcessed in ArcGIS. The water bodies and road network shapefiles being in vector format were converted to raster format using polygon to raster tool and merged with the classified image in ArcGIS. These seven classes were then allotted the manning's coefficient. Roughness coefficients represent the roughness of the surface in channels and flood plains.

The results of Manning's formula, an indirect computation of stream flow, have applications in flood-plain management, in flood insurance studies, and in the design of bridges and highways across flood plains.

Manning's Equation

$$V = \frac{R^{2/3} S^{1/2}}{n}$$

Where,
V is Average velocity (m/s)
R is Hydraulic radius (m)
S is Energy slope (m/m)
n is Manning's roughness coefficient

The land use land cover classification consisting of seven classes were converted to ASCII format. The tool Grd2MIKE was used to convert the ASCII file to dfs2 file which can be used in MIKE21. LULC data file processed in ArcGIS is used to create Gridded data for the bed roughness. Different manning number values are assigned for different land cover. The recommended manning number values for different land cover is given bellow in table.

Table III Manning's roughness coefficient used in the model (Chow, 1959)

Surface type	Manning's n	Manning's Number M = (1/n), [m^(1/3)/s]
Forests/Tree	0.1	10
Water Bodies	0.045	22.2
Built up	0.083	12
Cropland	0.04	25
Sparsely Vegetated	0.06	16.7
Fallow land	0.03	33.3
Roads	0.016	62.5

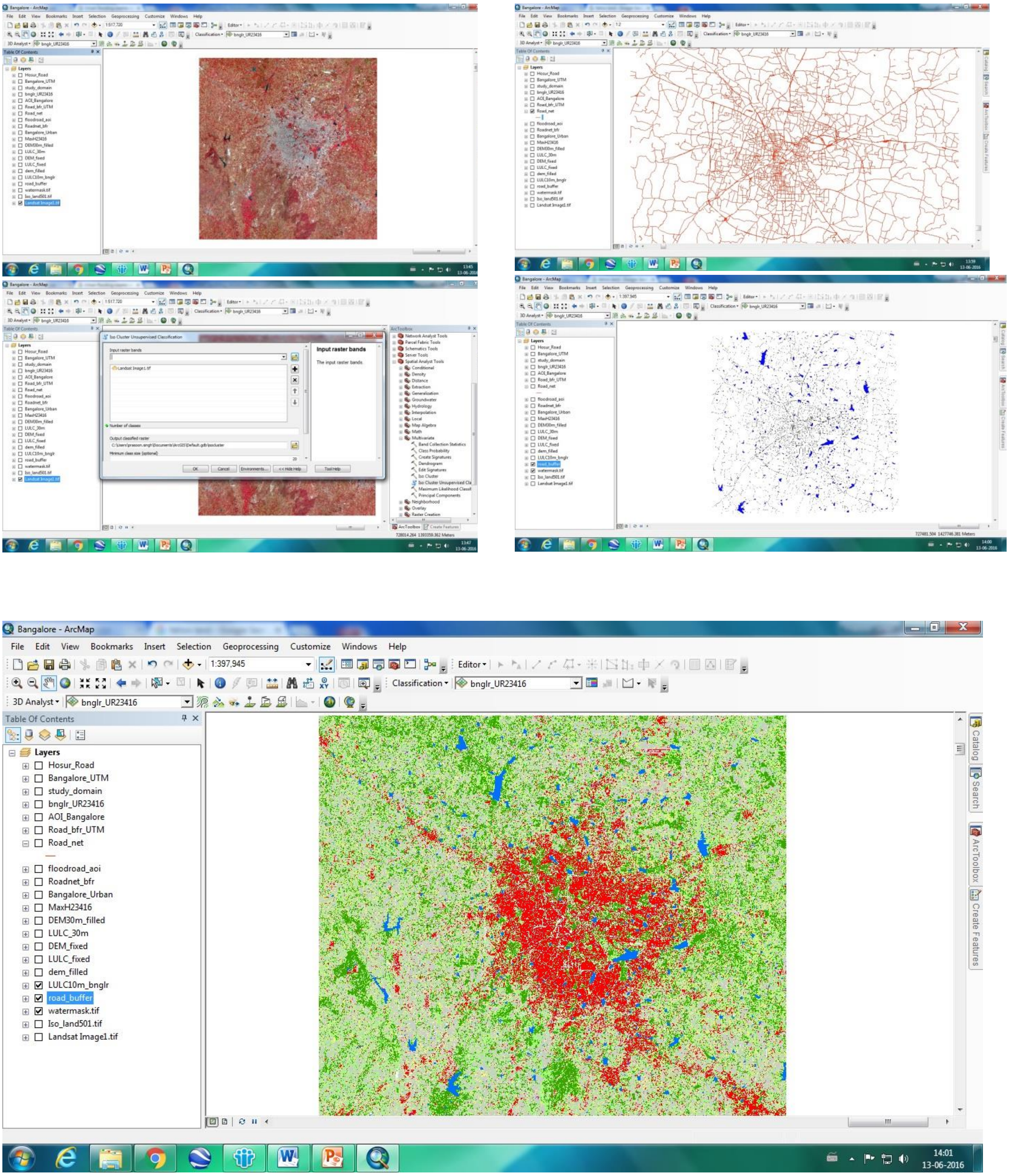


Figure 6 Process of data fusion and image classification in ArcGIS

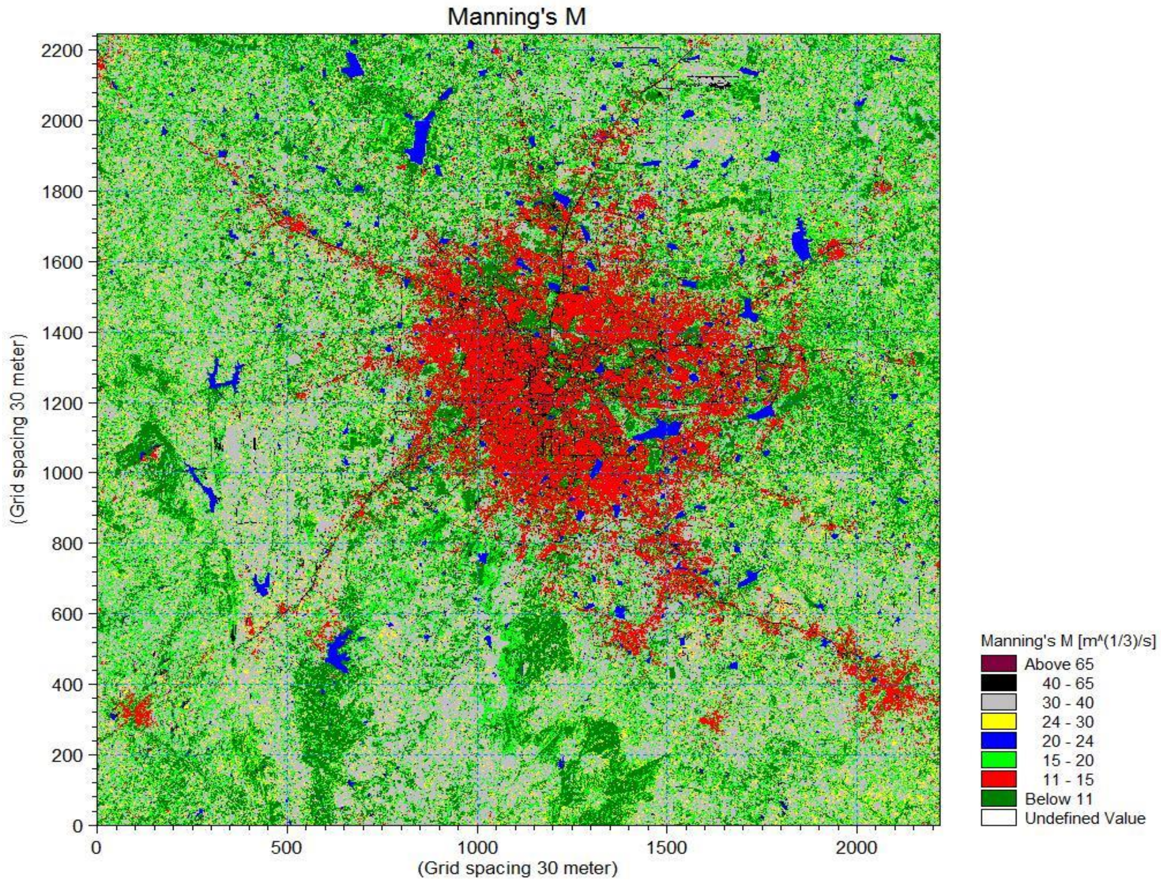


Figure 7 Bed Resistance Map (Manning number)

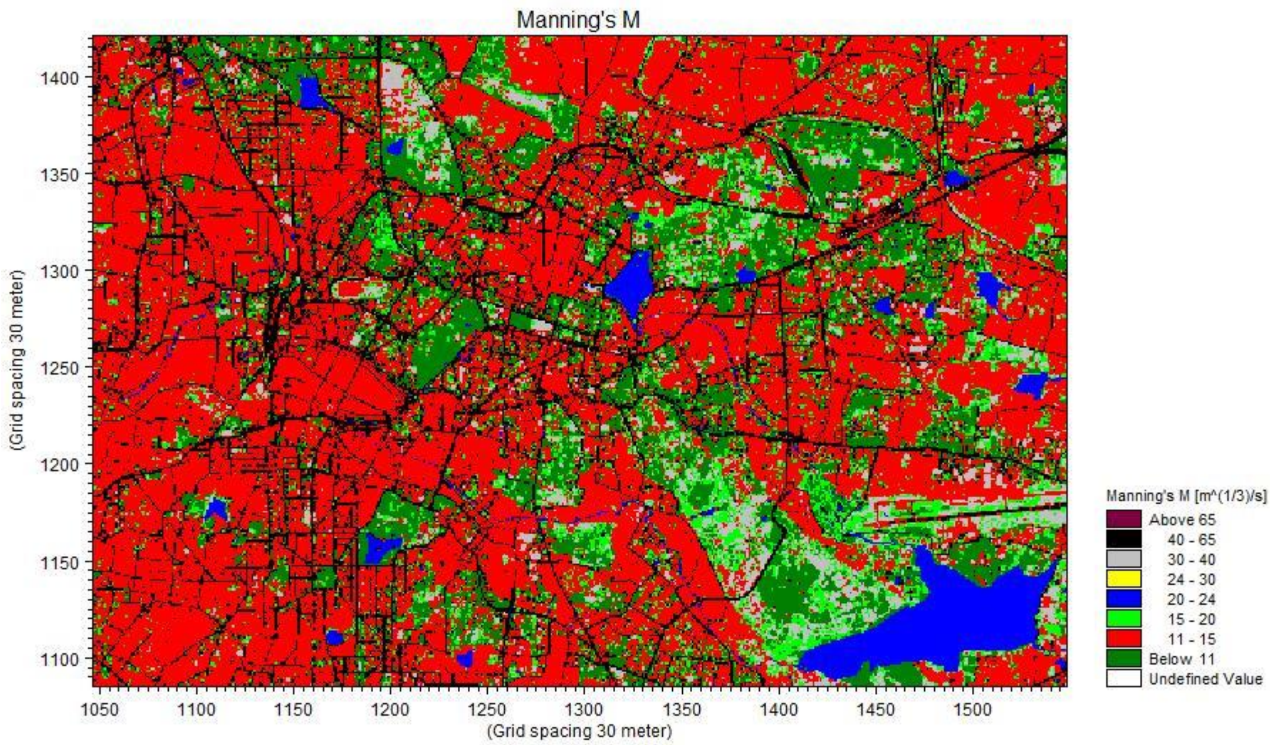


Figure 8 Enlarged View of Bed Resistance Map (Manning number)

MIKE 21 HD SIMULATION

The hydrodynamic model in the MIKE 21 Flow Model (MIKE 21 HD) is a general numerical modelling system for the simulation of water levels and flows in estuaries, bays and coastal areas. The model has been used successfully in overland flow modelling for flood plain applications. It simulates unsteady two dimensional flows in one layer (vertically homogeneous) fluids and has been applied in a large number of studies. The model is based on the very basic mass balance equation and conservation of momentum equation. These two equations together, describe the flow and water level variations. These equations are in the form of Saint Venant equation used in MIKE 21. (DHI, 2011).

In MIKE 21 flow model simulation two type of model parameterization is required. First, the basic parameters which include selection of models, Bathymetry data, Simulation Period, Boundary conditions, defining Source and Sink in the model, Mass Budget and flood and dry depth as per the application. The other is hydrodynamic parameters like The MIKE 21 hydrodynamic (HD) module is a mathematical modelling system for calculation of the hydrodynamic behavior of water in response to a variety of forcing functions, e.g. specified wind conditions and prescribed water levels at open model boundaries. (DHI, 2011). The following HD related parameters one has to define to validate and simulate the model; Initial Surface Elevation, Boundary as per the bathymetry, Source and Sink wherever applicable with the discharge value, eddy viscosity, resistance using a constant value or in gridded form, wave radiation and wind conditions. After having all defined parameters HD simulation has been run and resulting flood level maps were generated for selected two rainfall events in every10 minute interval. Also, a maximum flood level map was also generated in the process and the results were analysed for both the events. The complete series of maps are placed in the Annexure section

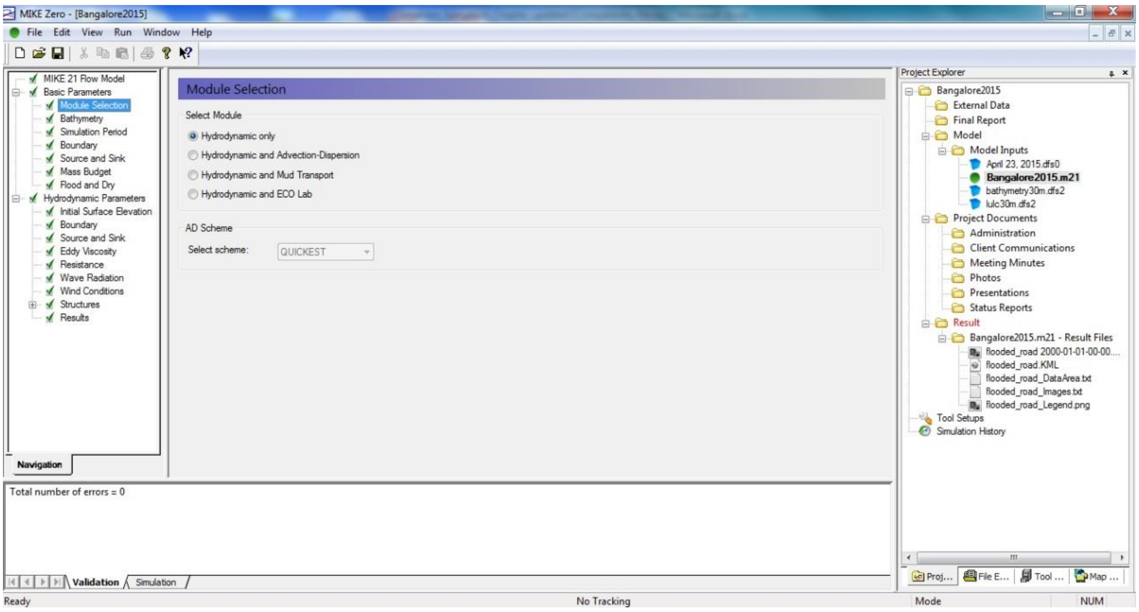


Figure 9 MIKE 21 Interface

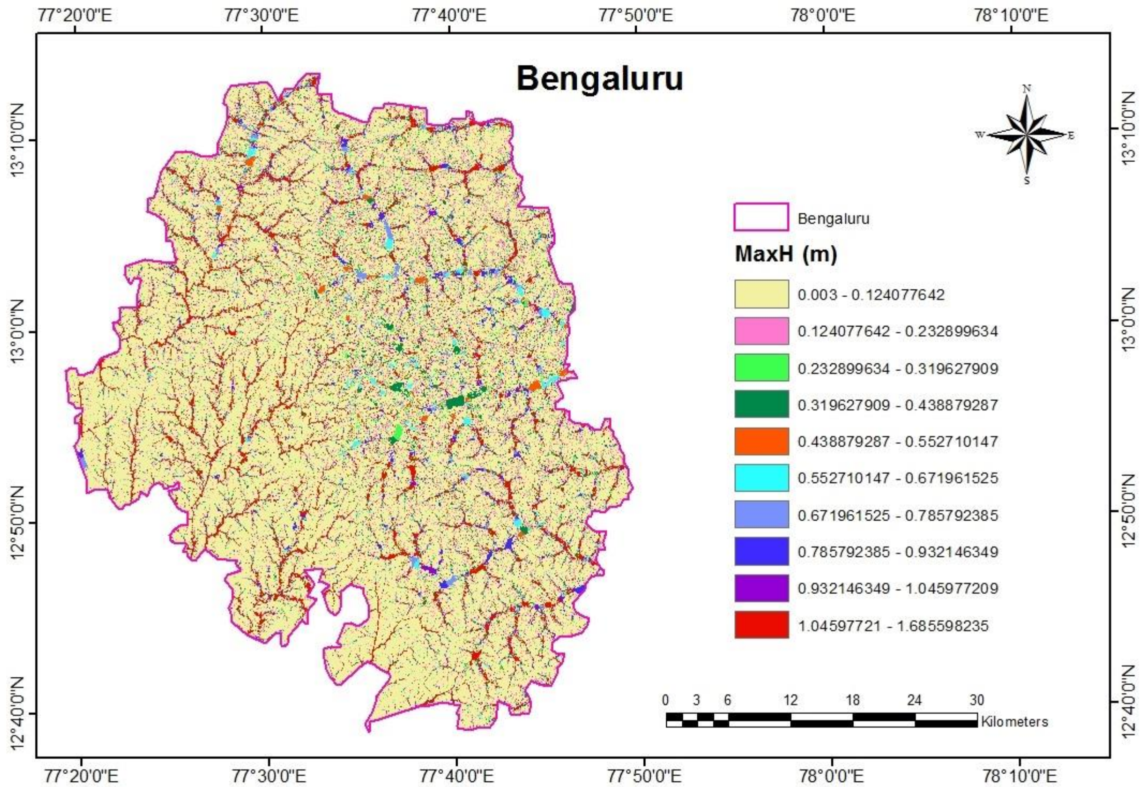
Results and Analysis

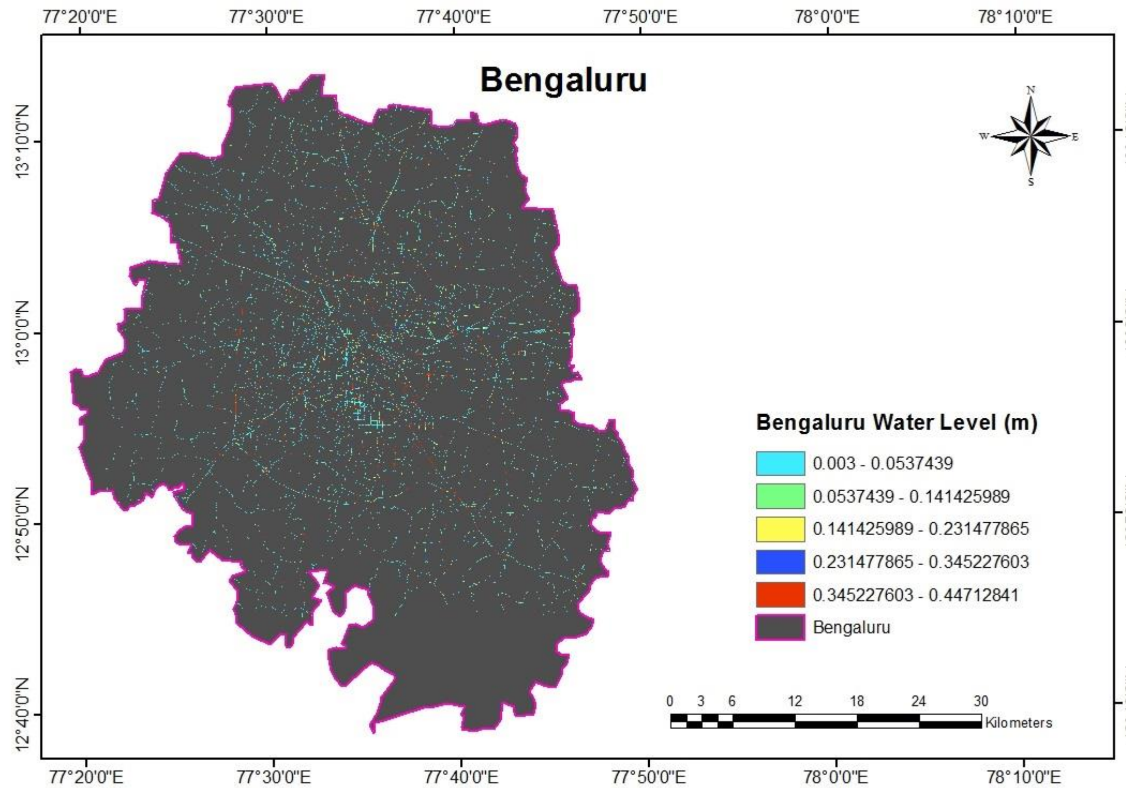
The model is simulated and the results were obtained for every 10 minute interval. The maximum flood level map at the end of the simulation has been analyzed for both the events selected for simulation. Flood map of Bengaluru Urban distric has been created and spatial information of flood level is calculated for the entire area of interest. Flood on road networks has been anlysed as per the administrative boundary of east, west, north and sout Bengaluru and also a complet analysys of Bengaluru as whole.

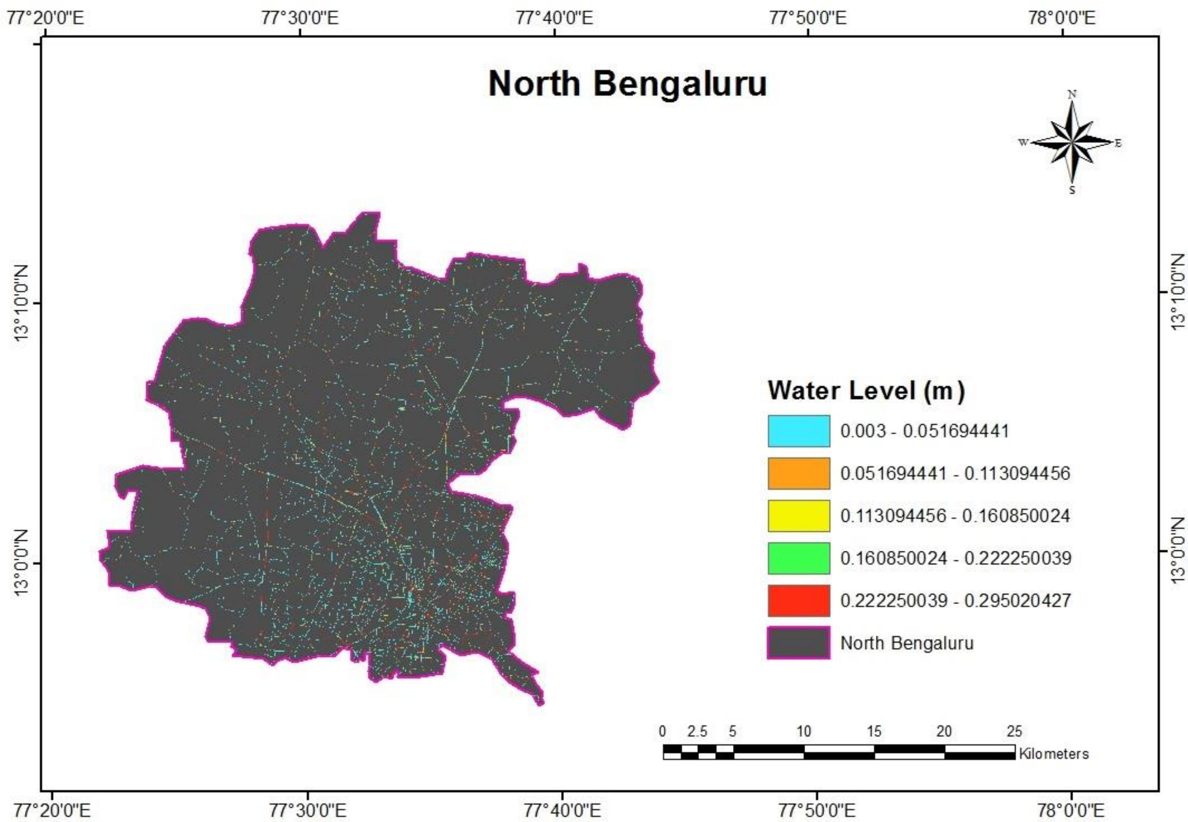
Resulting Flood maps below shows the spatial information of flood level and extent of flooding both on overland and flood on Road networks. The results indicate that the extent of flooding is wide spread and in some places the water level are alarmingly high. Areas nearby the drainage lines are most affected followed by the road cross sections and low lying areas. **The North and the East Bengaluru** are worst flood affected areas both in terms of spatial extent and flood level height.

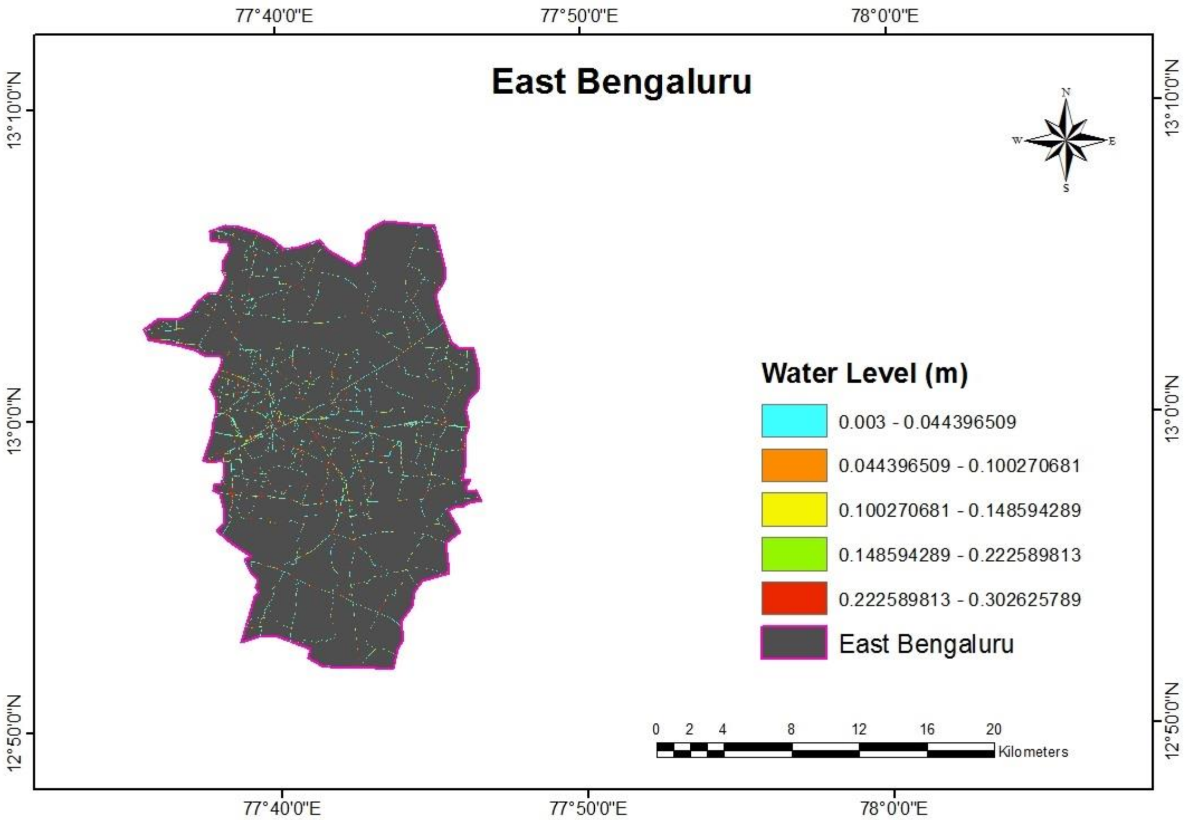
Event of April 23, 2015

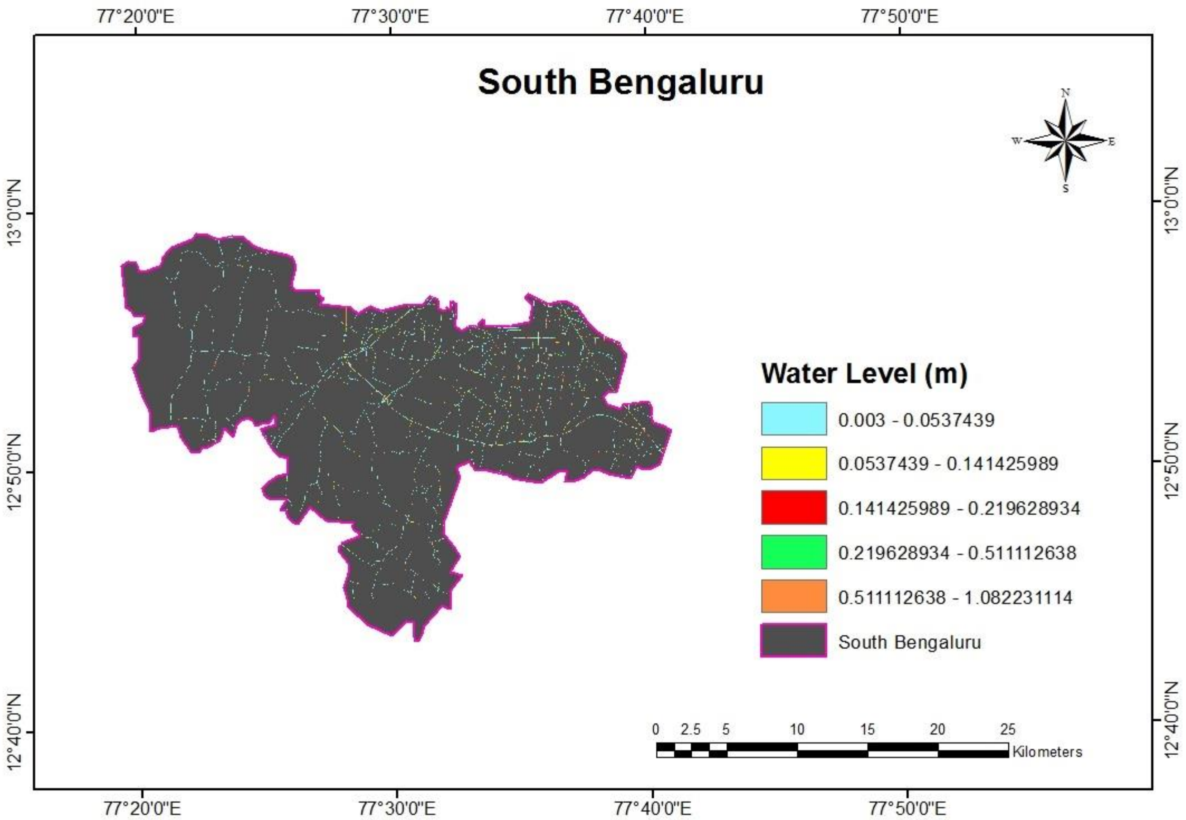
Maps showing the maximum flood extent over land as well as on road networks in Bengaluru Urban district. Further, the zone wise maps has also been created to provide more details of flood level and its extent.

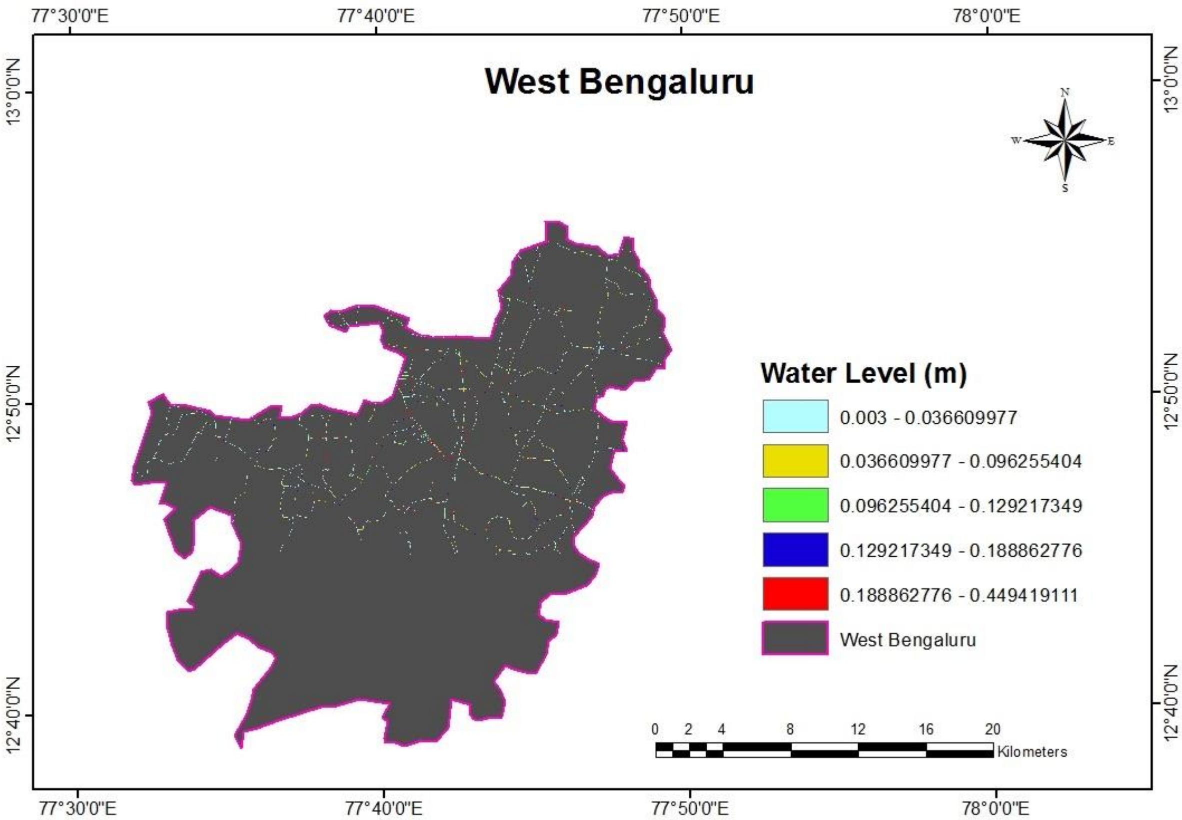


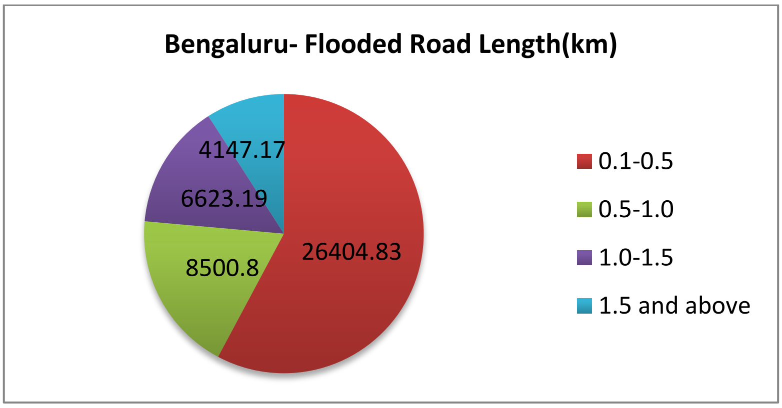

Bengaluru
Bengaluru Water Level (m)
0.003 - 0.0537439
0.0537439 - 0.141425989
0.141425989 - 0.231477865
0.231477865 - 0.345227603
0.345227603 - 0.44712841
Bengaluru
0 3 6 12 18 24 30
Kilometers
77°20'0"E
77°30'0"E
77°40'0"E
77°50'0"E
78°0'0"E
78°10'0"E
13°10'0"N
13°0'0"N
12°50'0"N
12°40'0"N


North Bengaluru
Water Level (m)
0.003 - 0.051694441
0.051694441 - 0.113094456
0.113094456 - 0.160850024
0.160850024 - 0.222250039
0.222250039 - 0.295020427
North Bengaluru
0 2.5 5 10 15 20 25
Kilometers
77°20'0"E
77°30'0"E
77°40'0"E
77°50'0"E
78°0'0"E
13°10'0"N
13°0'0"N

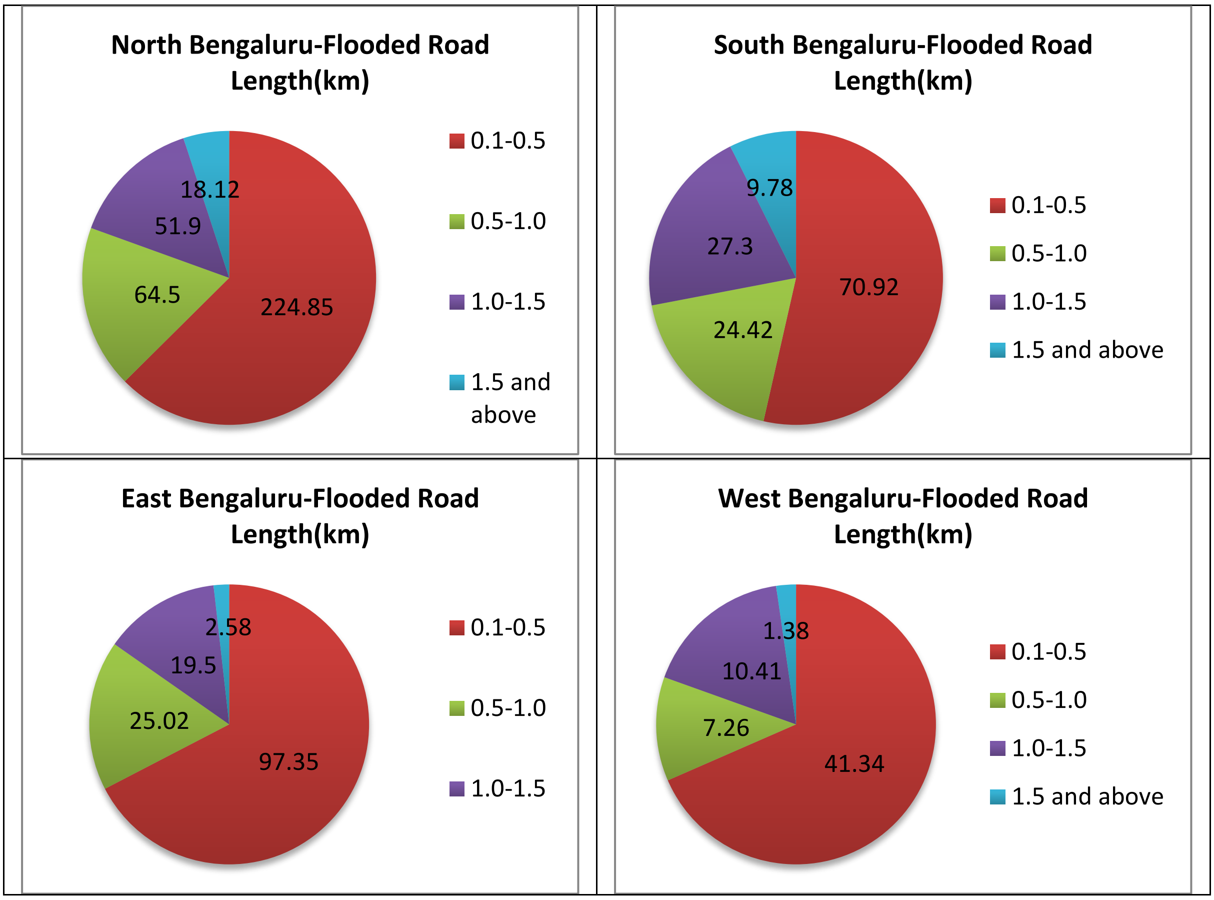

East Bengaluru
Water Level (m)
0.003 - 0.044396509
0.044396509 - 0.100270681
0.100270681 - 0.148594289
0.148594289 - 0.222589813
0.222589813 - 0.302625789
East Bengaluru
0 2 4 8 12 16 20
Kilometers
77°40'0"E
77°50'0"E
78°0'0"E
13°10'0"N
13°0'0"N
12°50'0"N
N
S
E
W


South Bengaluru
Water Level (m)
0.003 - 0.0537439
0.0537439 - 0.141425989
0.141425989 - 0.219628934
0.219628934 - 0.511112638
0.511112638 - 1.082231114
South Bengaluru
0 2.5 5 10 15 20 25
Kilometers
77°20'0"E
77°30'0"E
77°40'0"E
77°50'0"E
13°0'0"N
12°50'0"N
12°40'0"N
N
S
E
W





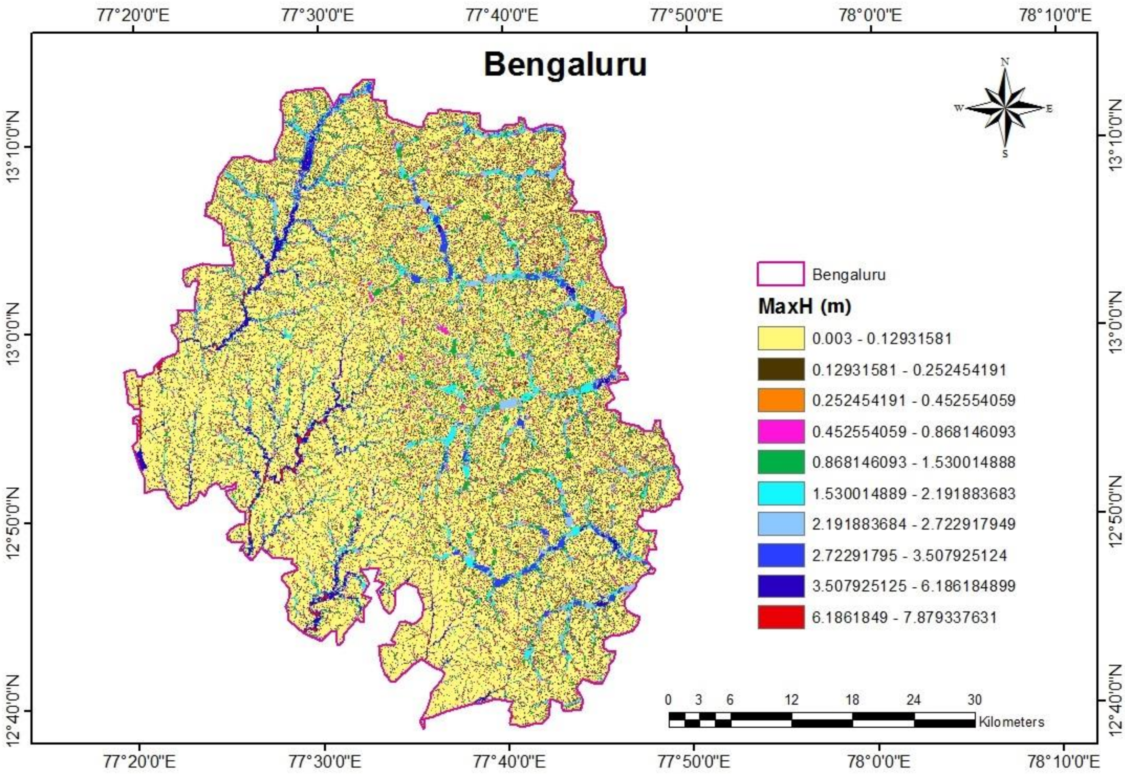
Bengaluru city recorded maximum flooded road length of 26404.83km in the range of 0.1 to 0.5 m water level. These road length may be considered as dry areas as the flood level on these networks are closee to drying depth only few roads have water level which is close to 0.4 m. It is followed by 8500.8 km in the range of 0.5 to 1.0m water level and 6623.19km of road length in the range of 1.0 to 1.5m water level. Lastly, about 4147.17km of road length has the water level range of 1.5m and above and can be considered as hotspot.

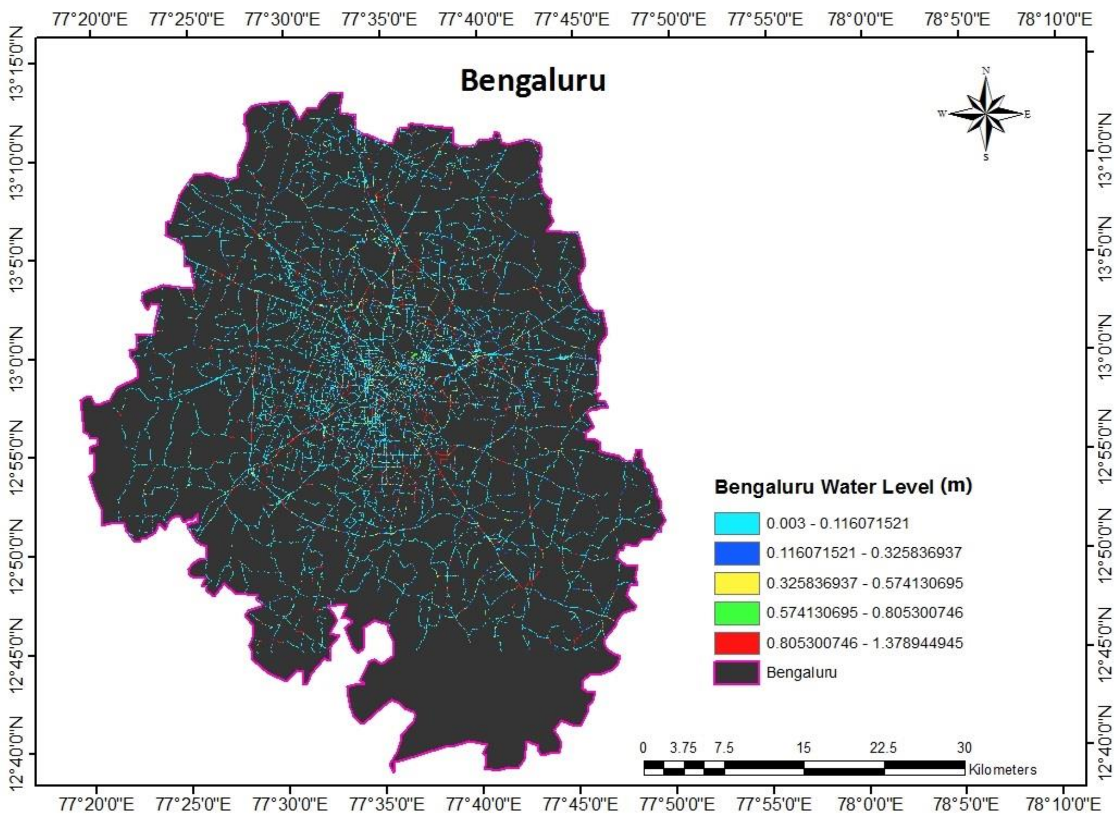


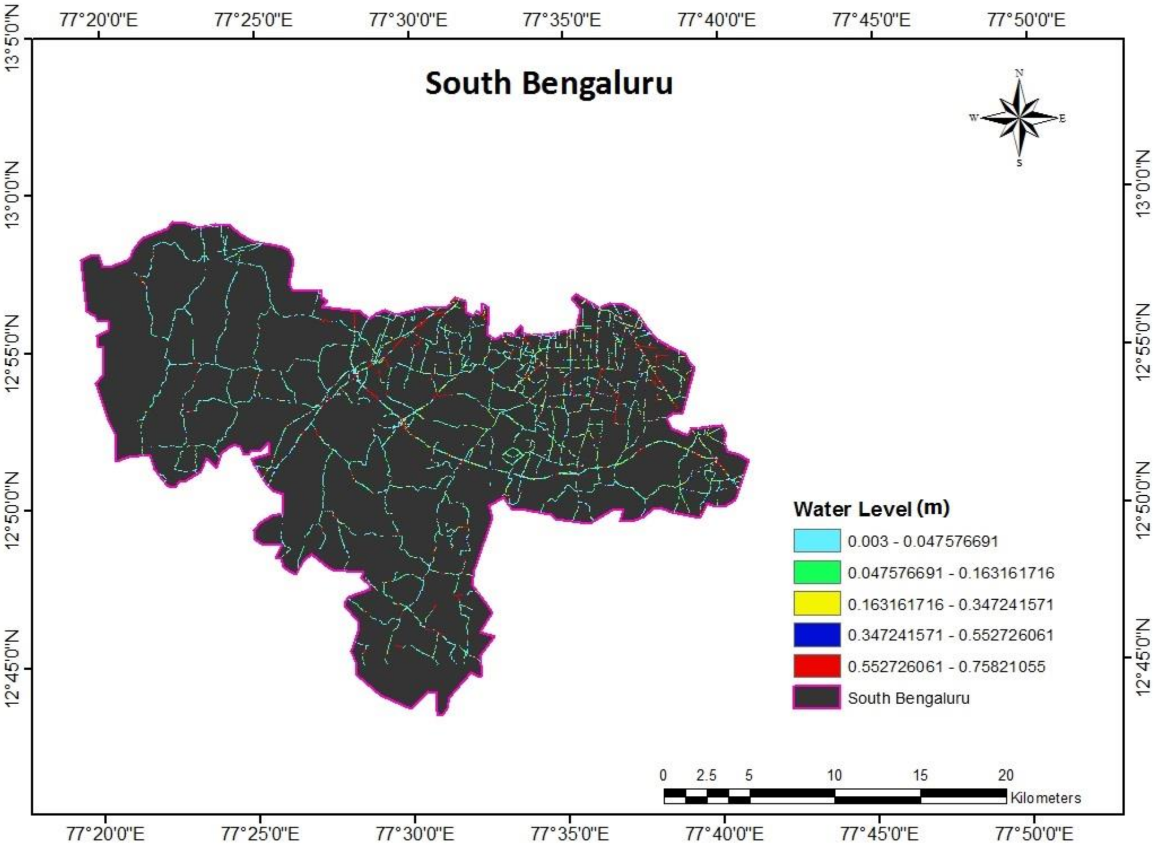
North Bengaluru recorded maximum flooded road length of 224.85km in the range of 0.1 to 0.5 m water level. It is followed by 64.5km in the range of 0.5 to 1.0m water level and 51.9km of road length in the range of 1.0 to 1.5m water level. Lastly, about 18.12km of road length has the water level range of 1.5m and above and can be considered as hotspot. South Bengaluru recorded maximum flooded road length of 70.92km in the range of 0.1 to 0.5 m water level. It is followed by 24.42km in the range of 0.5 to 1.0m water level and 27.3km of road length in the range of 1.0 to 1.5m water level. Lastly, about 9.78km of road length has the water level range of 1.5m and above and can be considered as hotspot. East Bengaluru recorded maximum flooded road length of 97.35km in the range of 0.1 to 0.5 m water level. It is followed by 25.02km in the range of 0.5 to 1.0m water level and 19.5km of road length in the range of 1.0 to 1.5m water level. Lastly, about 2.58km of road length has the water level range of 1.5m and above and can be considered as hotspot. West Bengaluru recorded maximum flooded road length of 41.34km in the range of 0.1 to 0.5 m water level. It is followed by 7.26km in the range of 0.5 to 1.0m water level and 10.41km of road length in the range of 1.0 to 1.5m water level. Lastly, about 1.38km of road length has the water level range of 1.5m and above and can be considered as hotspot.

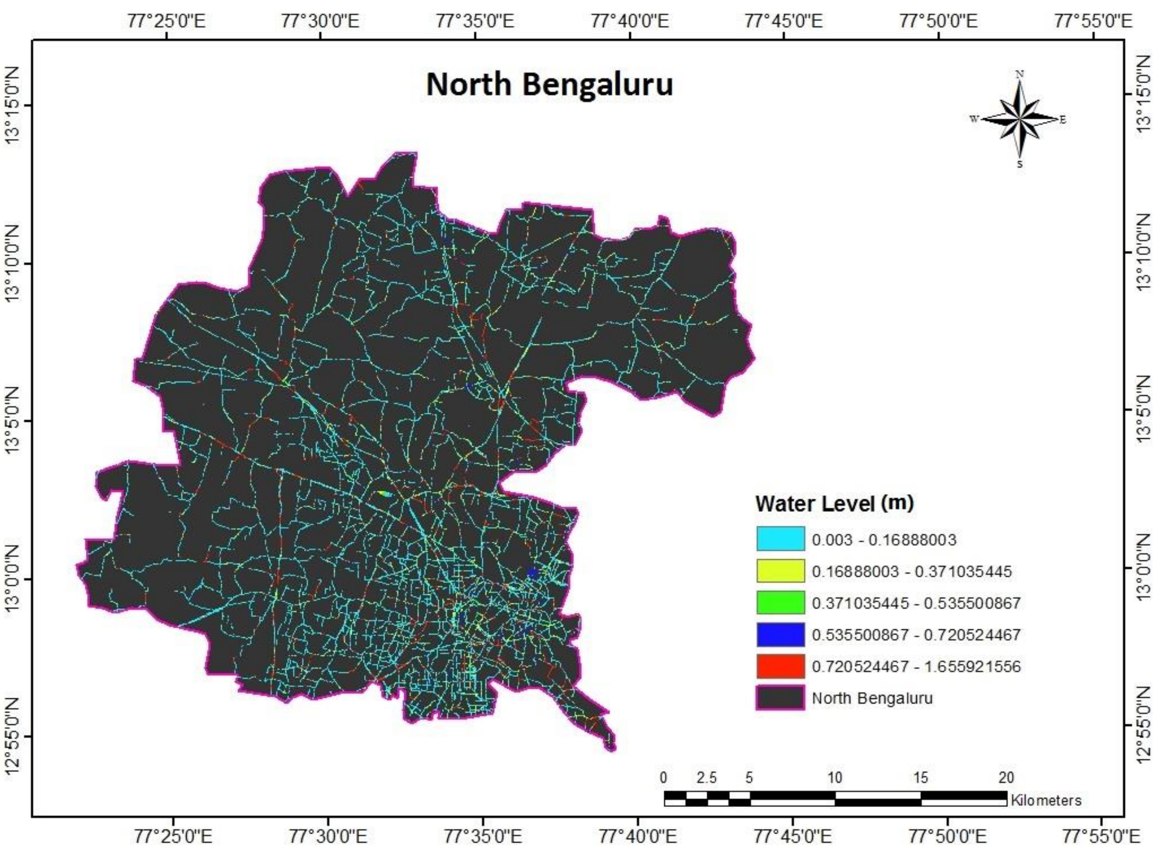
Event of November 04, 2015

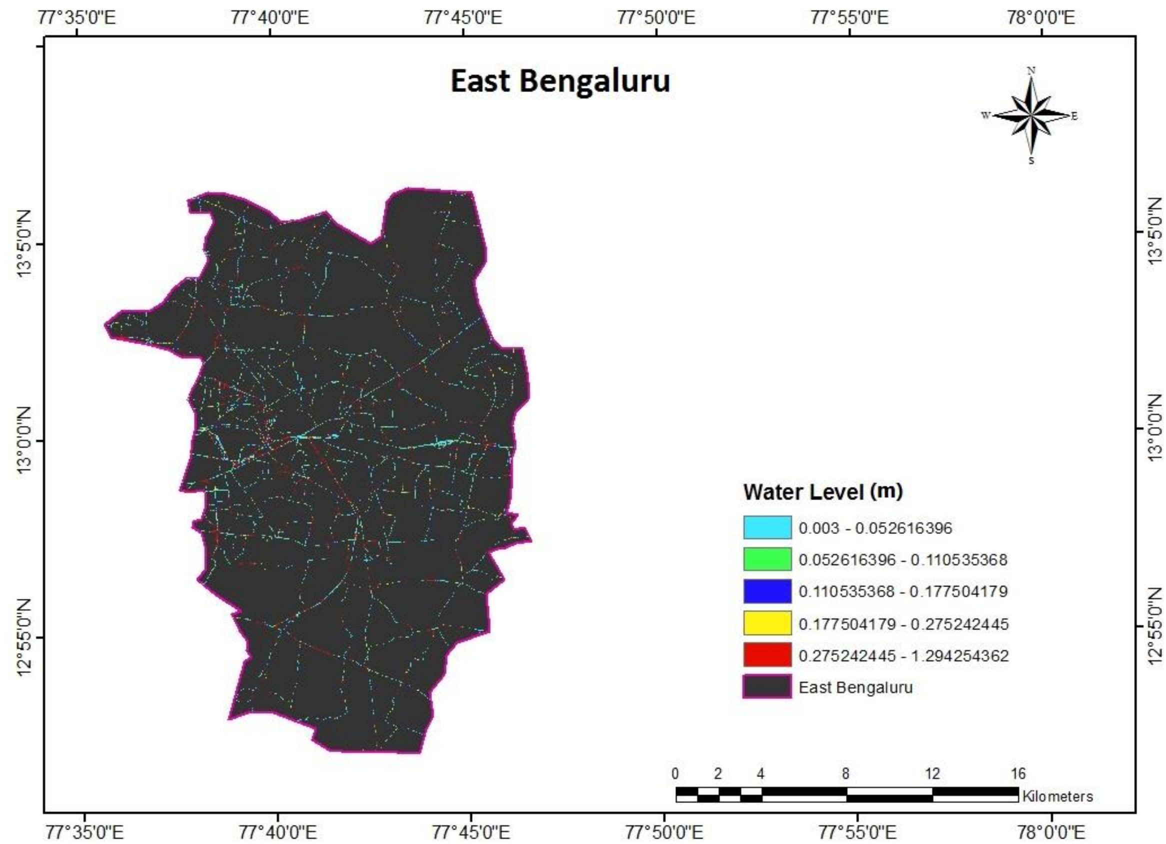
Maps showing the maximum flood extent over land as well as on road networks in Bengaluru Urban district. Further, the zone wise maps have also been created to provide more details of flood level and its extent.

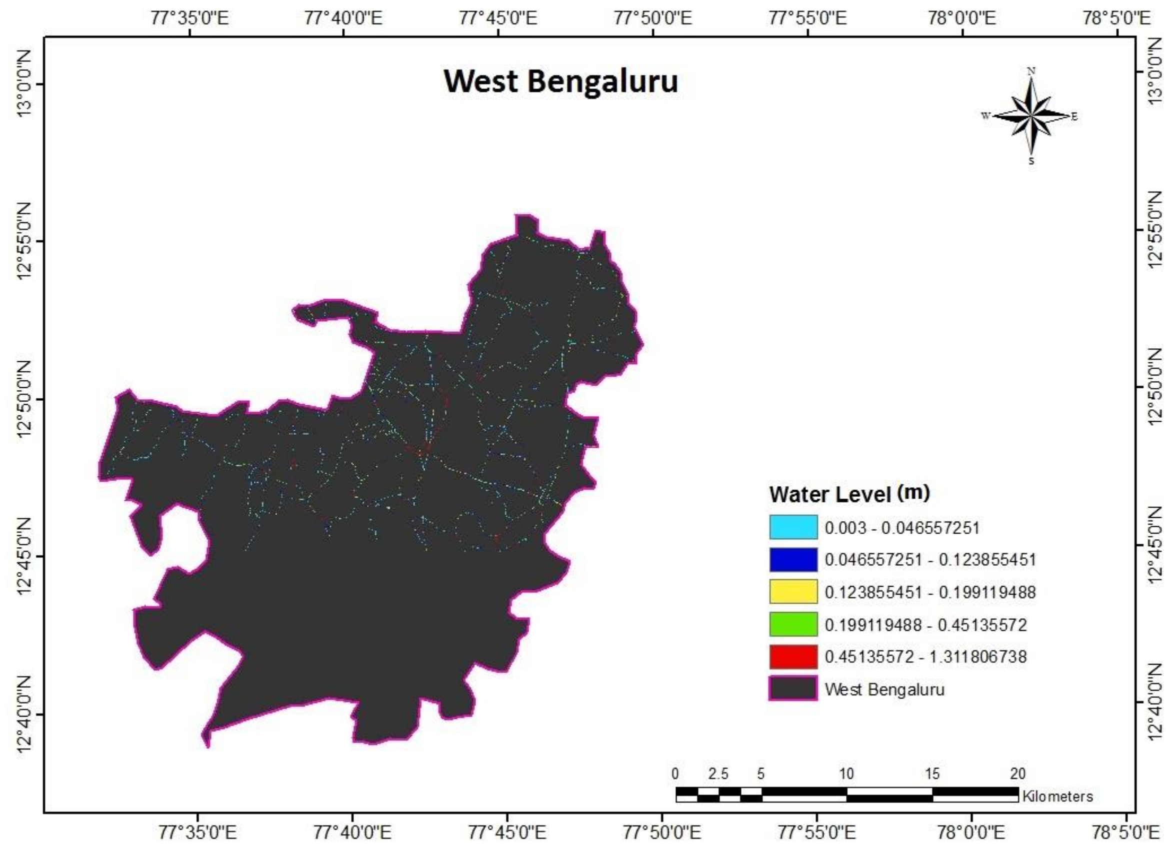


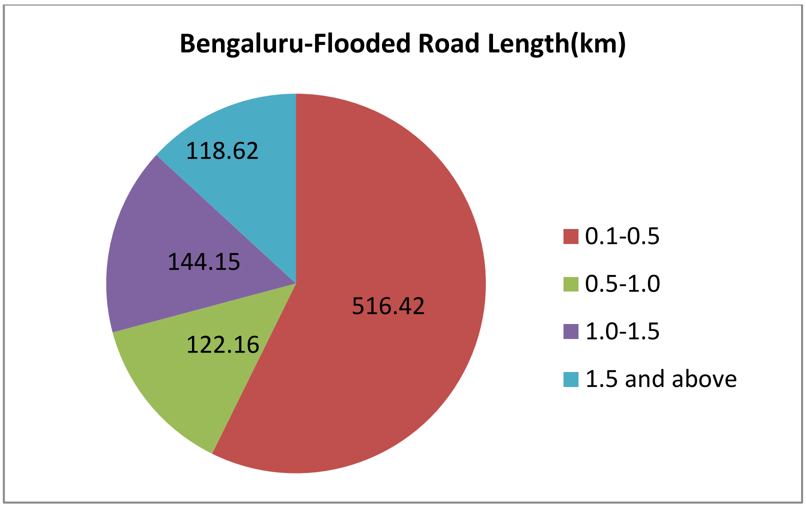



South Bengaluru
77°20'0"E
77°25'0"E
77°30'0"E
77°35'0"E
77°40'0"E
77°45'0"E
77°50'0"E
13°5'0"N
13°0'0"N
12°55'0"N
12°50'0"N
12°45'0"N
N
S
E
W
Water Level (m)
0.003 - 0.047576691
0.047576691 - 0.163161716
0.163161716 - 0.347241571
0.347241571 - 0.552726061
0.552726061 - 0.75821055
South Bengaluru
0 2.5 5 10 15 20
Kilometers

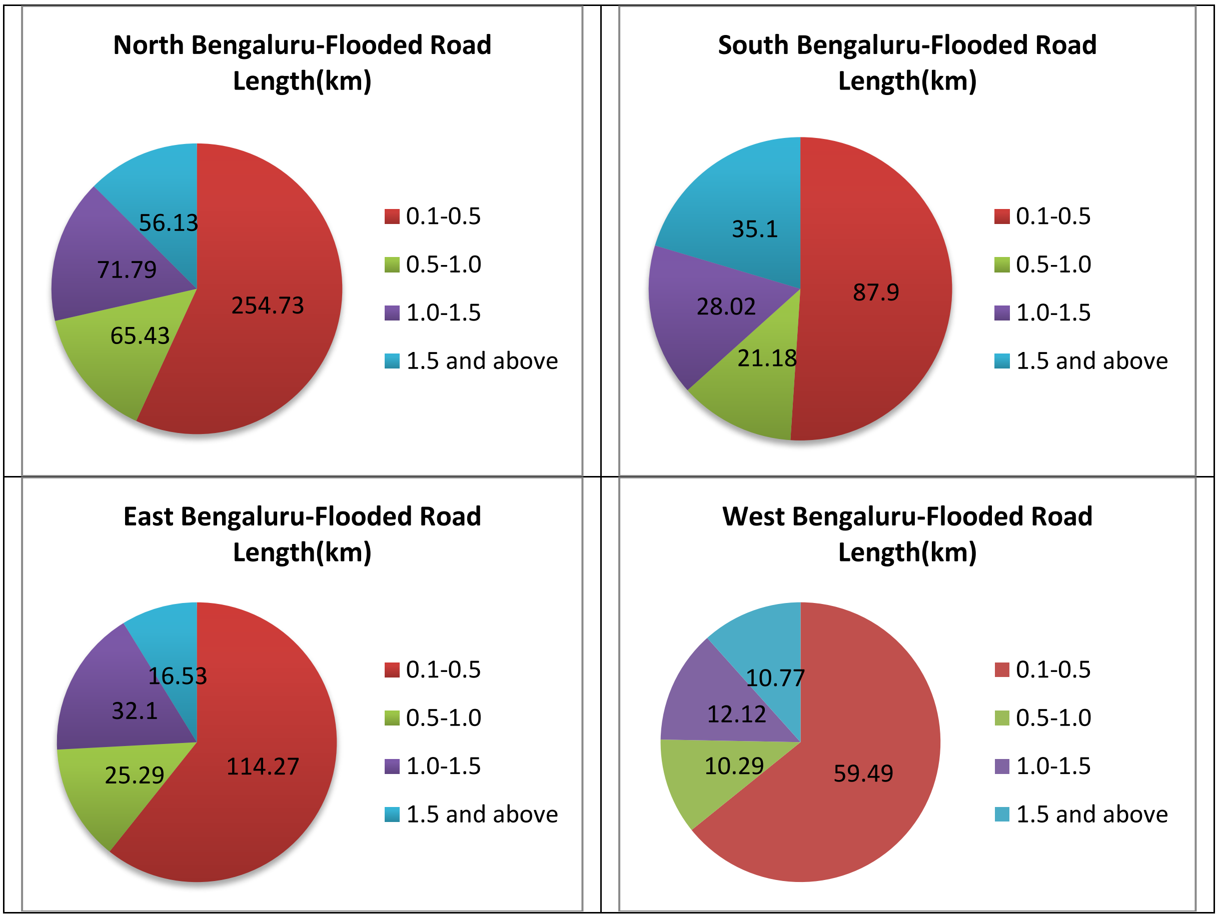

North Bengaluru
77°25'0"E
77°30'0"E
77°35'0"E
77°40'0"E
77°45'0"E
77°50'0"E
77°55'0"E
13°15'0"N
13°10'0"N
13°5'0"N
13°0'0"N
12°55'0"N
N
S
E
W
Water Level (m)
0.003 - 0.16888003
0.16888003 - 0.371035445
0.371035445 - 0.535500867
0.535500867 - 0.720524467
0.720524467 - 1.655921556
North Bengaluru
0 2.5 5 10 15 20
Kilometers


East Bengaluru
Water Level (m)
0.003 - 0.052616396
0.052616396 - 0.110535368
0.110535368 - 0.177504179
0.177504179 - 0.275242445
0.275242445 - 1.294254362
East Bengaluru
0 2 4 8 12 16
Kilometers
77°35'0"E
77°40'0"E
77°45'0"E
77°50'0"E
77°55'0"E
78°0'0"E
13°5'0"N
13°0'0"N
12°55'0"N


West Bengaluru
Water Level (m)
0.003 - 0.046557251
0.046557251 - 0.123855451
0.123855451 - 0.199119488
0.199119488 - 0.45135572
0.45135572 - 1.311806738
West Bengaluru
0 2.5 5 10 15 20
Kilometers
77°35'0"E
77°40'0"E
77°45'0"E
77°50'0"E
77°55'0"E
78°0'0"E
78°5'0"E
13°0'0"N
12°55'0"N
12°50'0"N
12°45'0"N
12°40'0"N



Bengaluru city recorded maximum flooded road length of 516.42 km in the range of 0.1 to 0.5 m water level. These road length may be considered as dry areas as the flood level on these networks are closee to drying depth only few roads have water level which is close to 0.4 m. It is followed by 122.16 km in the range of 0.5m to 1.0 m water level and 144.15 km of road length in the range of 1.0 m to 1.5 m water level. Lastly, about 118.62 km of road length has the water level range of 1.5 m and above and can be considered as hotspot.



North Bengaluru recorded maximum flooded road length of 254.73km in the range of 0.1 to 0.5 m water level. It is followed by 65.43km in the range of 0.5m to 1.0m water level and 71.79km of road length in the range of 1.0m to 1.5m water level. Lastly, about 56.13km of road length has the water level range of 1.5m and above and can be considered as hotspot. South Bengaluru recorded maximum flooded road length of 87.9km in the range of 0.1 to 0.5 m water level. It is followed by 21.18km in the range of 0.5m to 1.0m water level and 28.02km of road length in the range of 1.0m to 1.5m water level. Lastly, about 35.1km of road length has the water level range of 1.5m and above and can be considered as hotspot. East Bengaluru recorded maximum flooded road length of 114.27km in the range of 0.1 to 0.5 m water level. It is followed by 25.29km in the range of 0.5m to 1.0m water level and 32.1km of road length in the range of 1.0m to 1.5m water level. Lastly, about 16.53km of road length has the water level range of 1.5m and above and can be considered as hotspot. West Bengaluru recorded maximum flooded road length of 59.49km in the range of 0.1 to 0.5 m water level. It is followed by 10.29km in the range of 0.5m to 1.0m water level and 12.12km of road length in the range of 1.0m to 1.5m water level. Lastly, about 10.77km of road length has the water level range of 1.5m and above and can be considered as hotspot.

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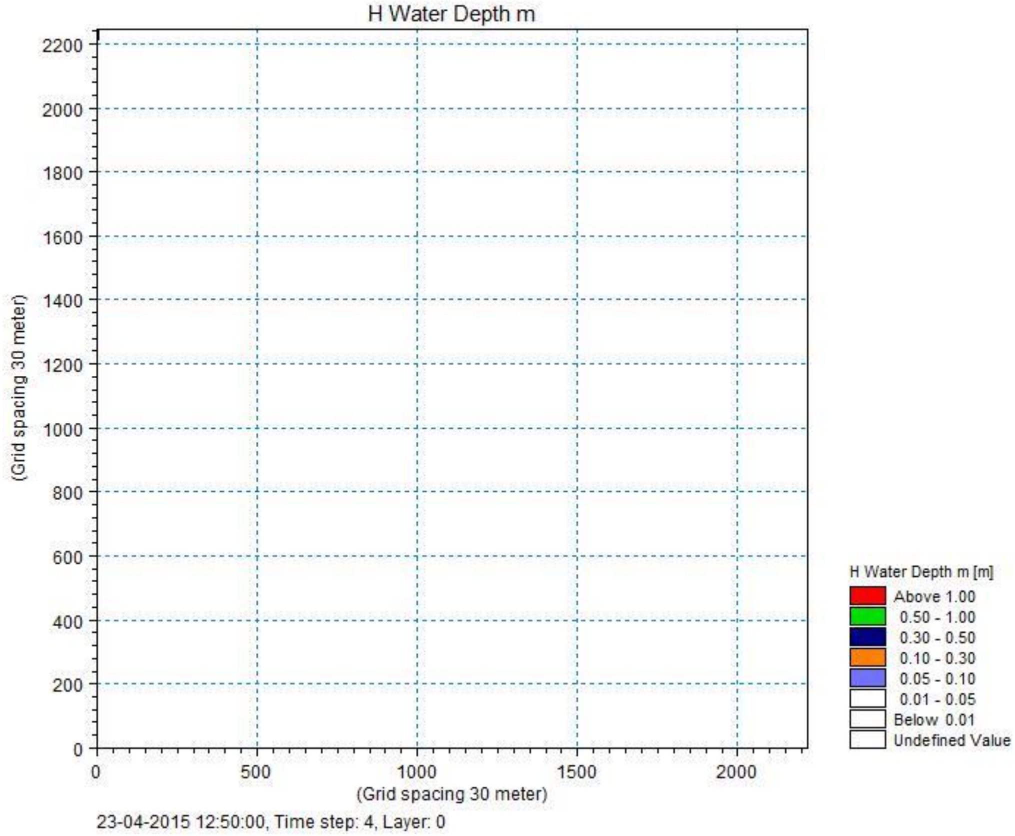
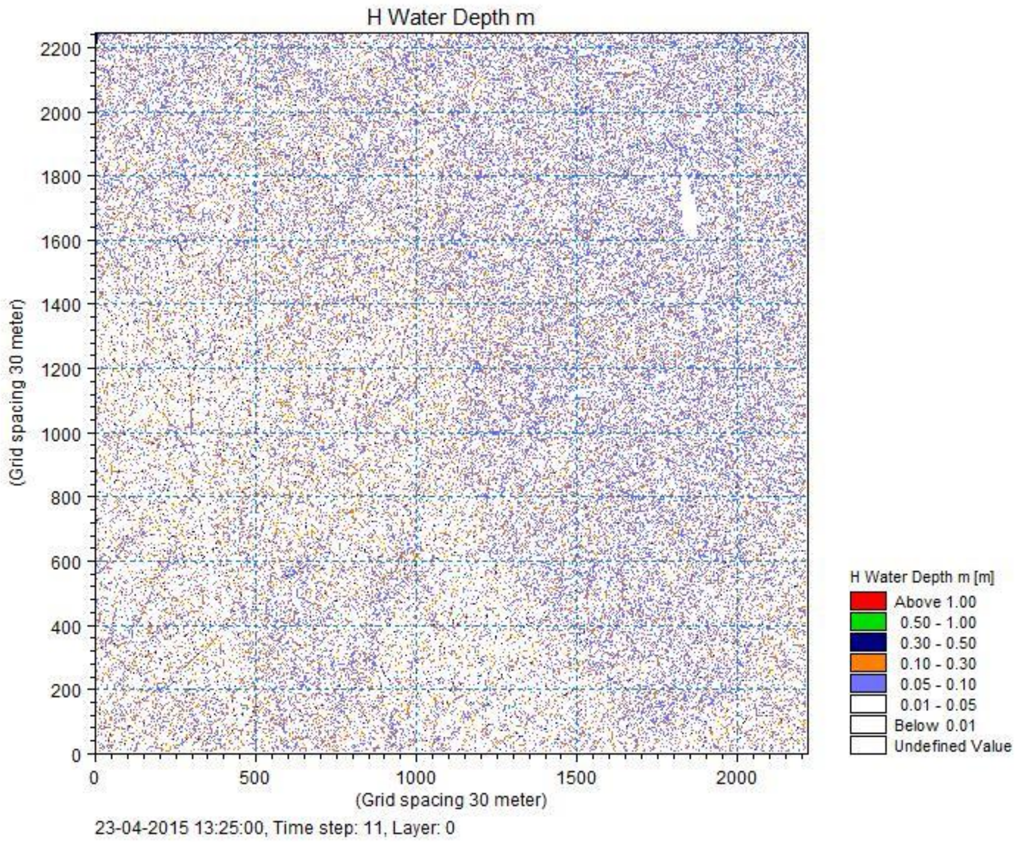
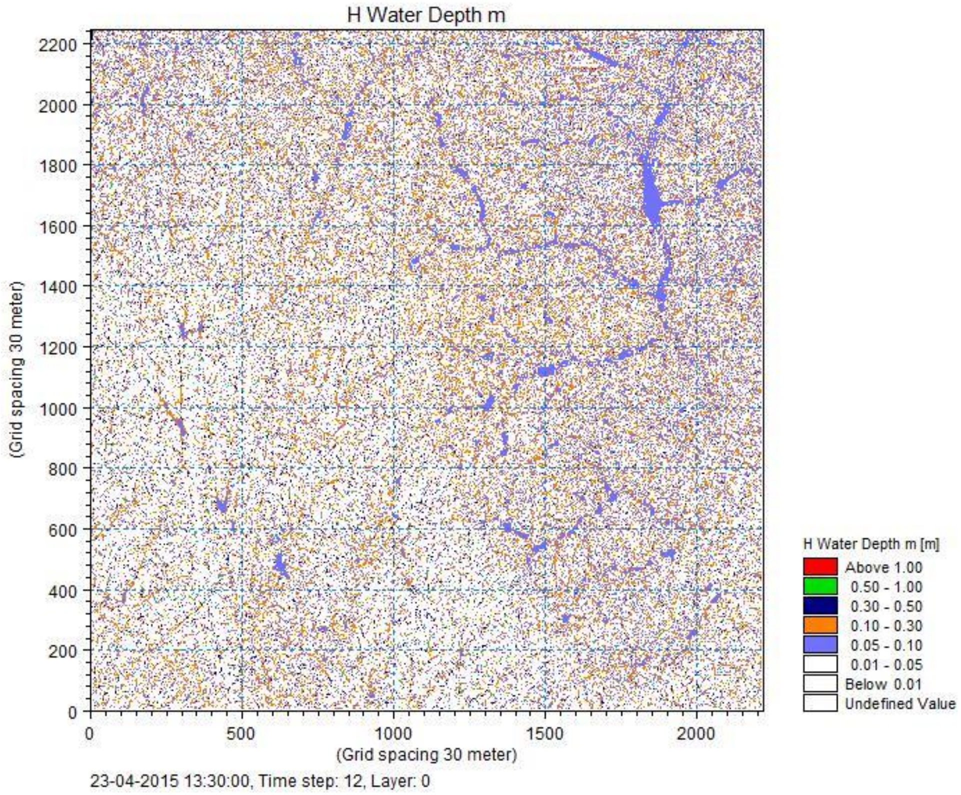
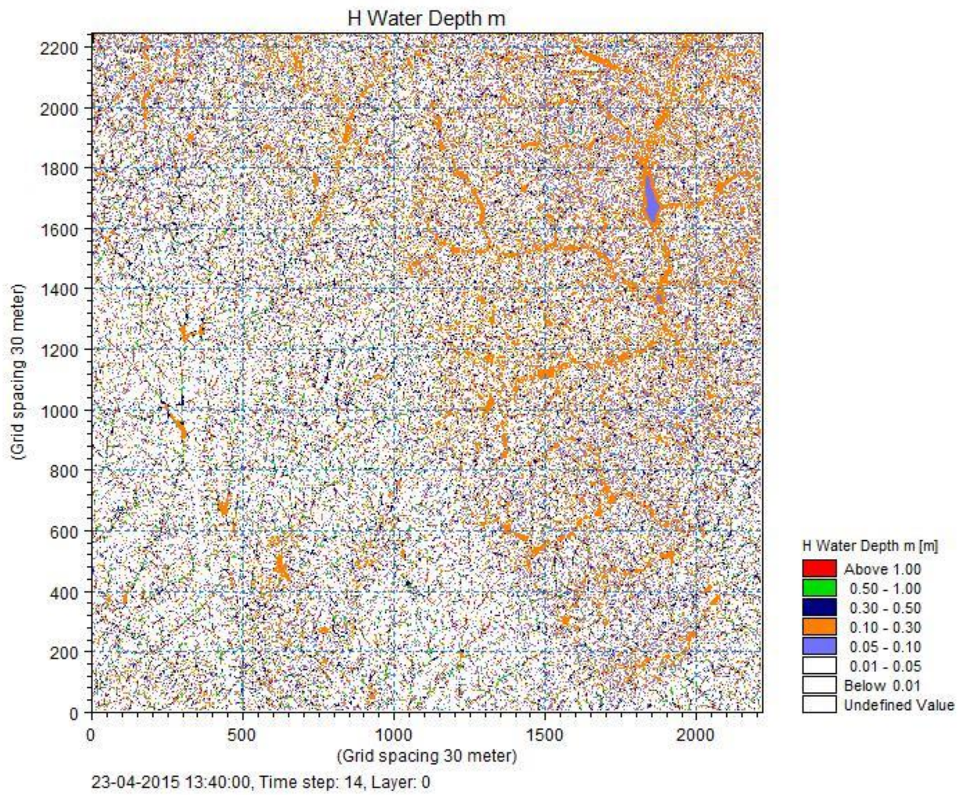
Annexure

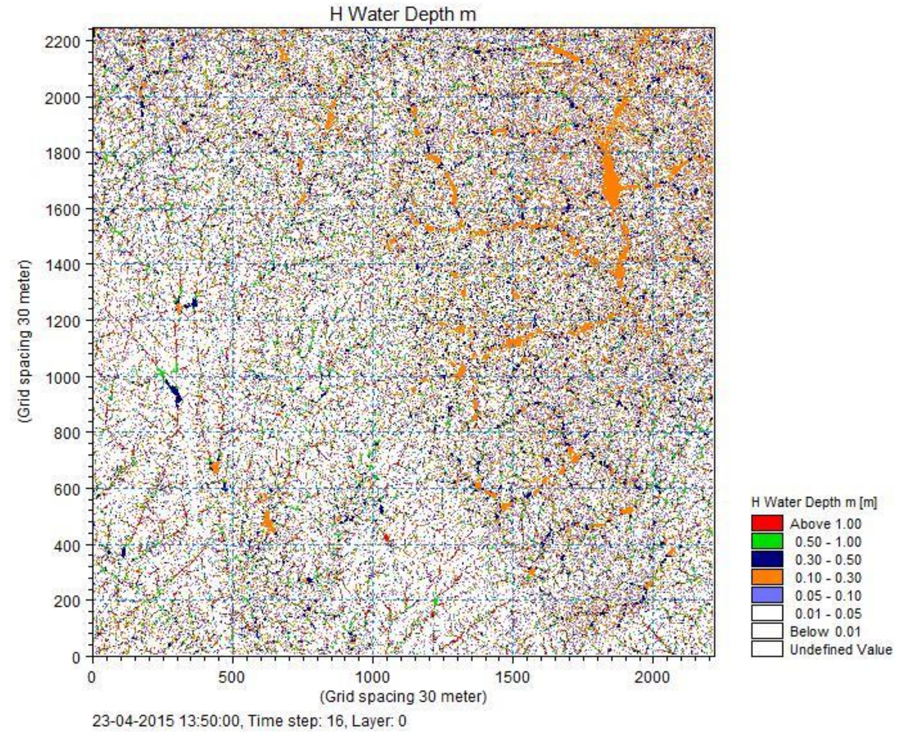
Time Series of flood Maps for 23-April-2015

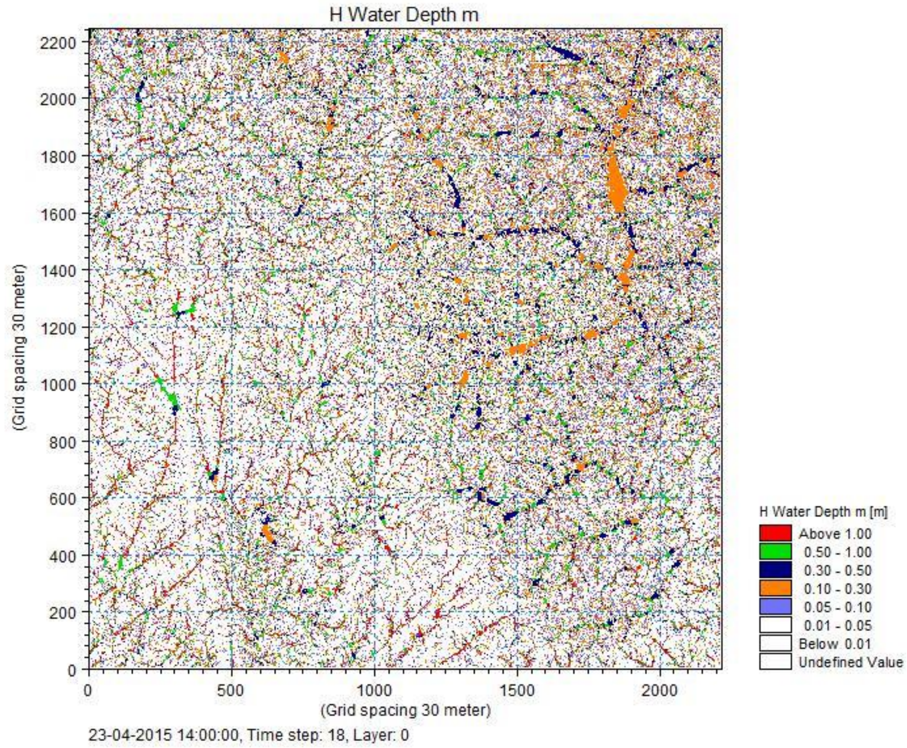


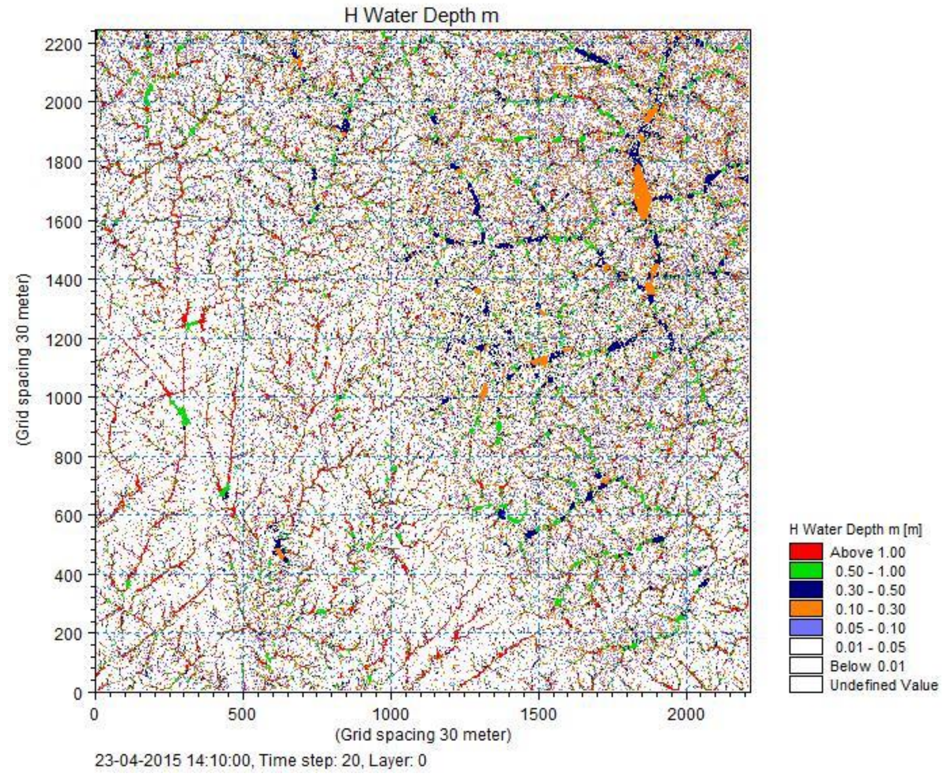


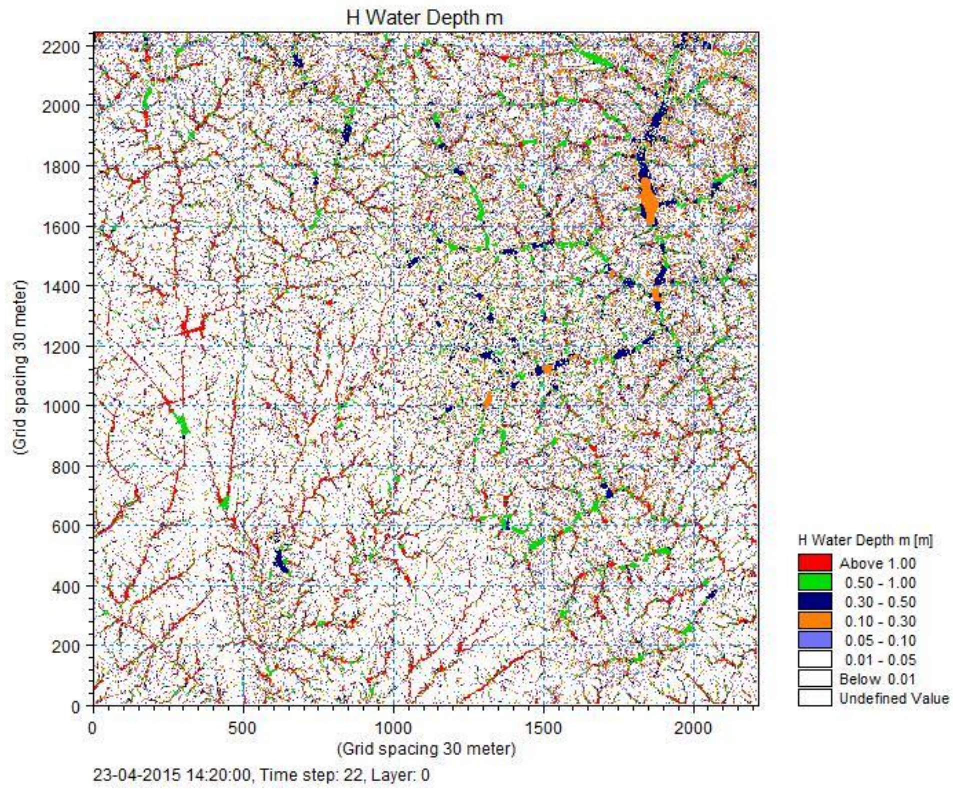

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value
23-04-2015 13:30:00, Time step: 12, Layer: 0

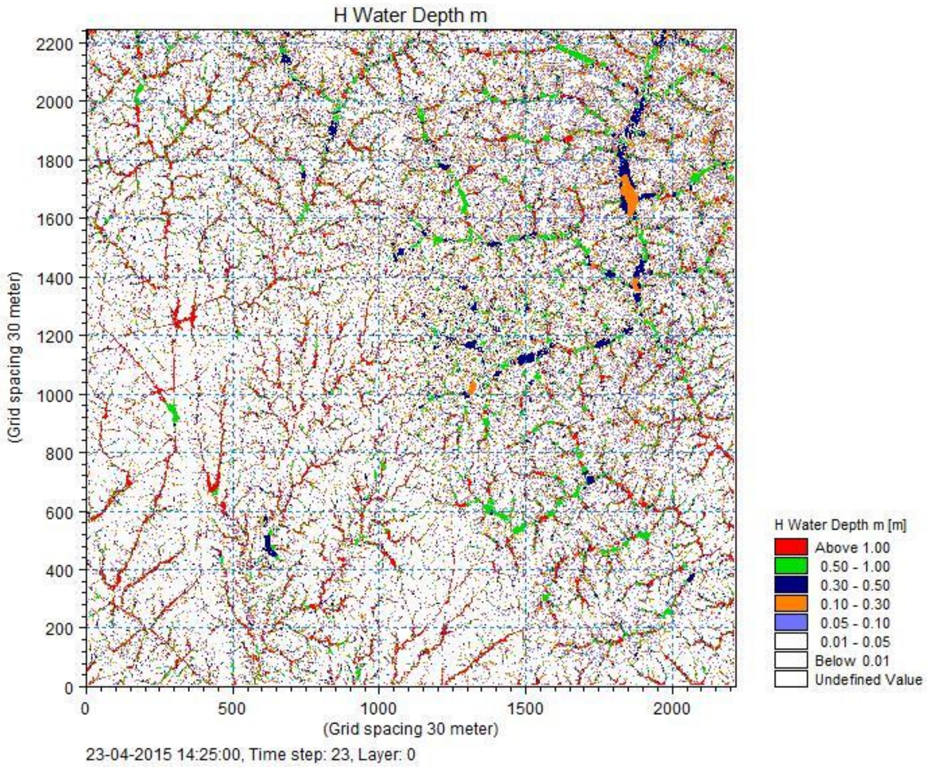

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value
23-04-2015 13:40:00, Time step: 14, Layer: 0

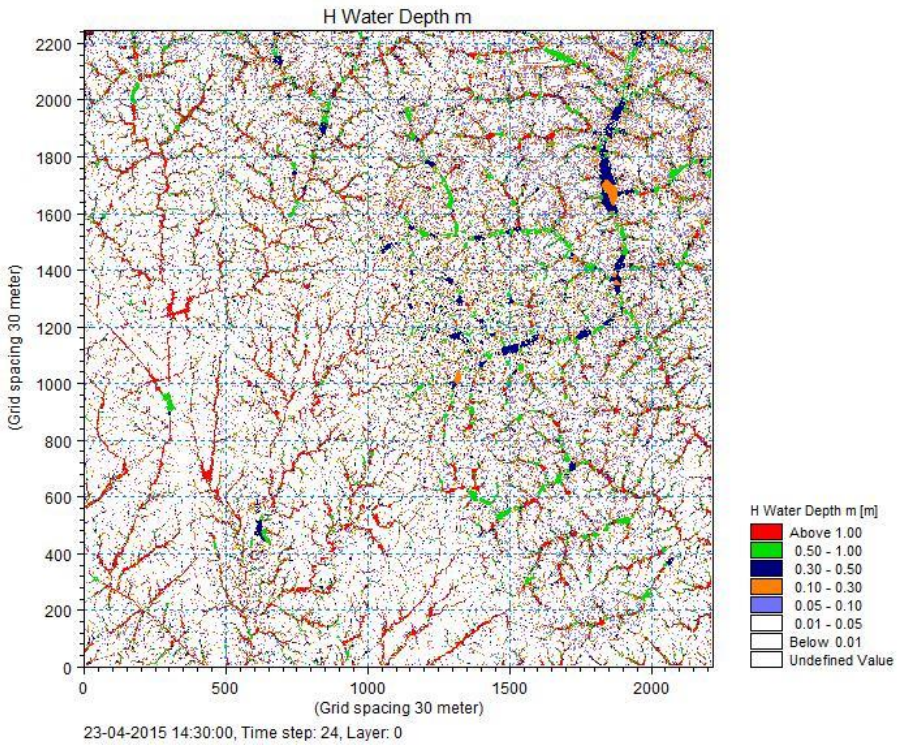

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
23-04-2015 13:50:00, Time step: 16, Layer: 0
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value

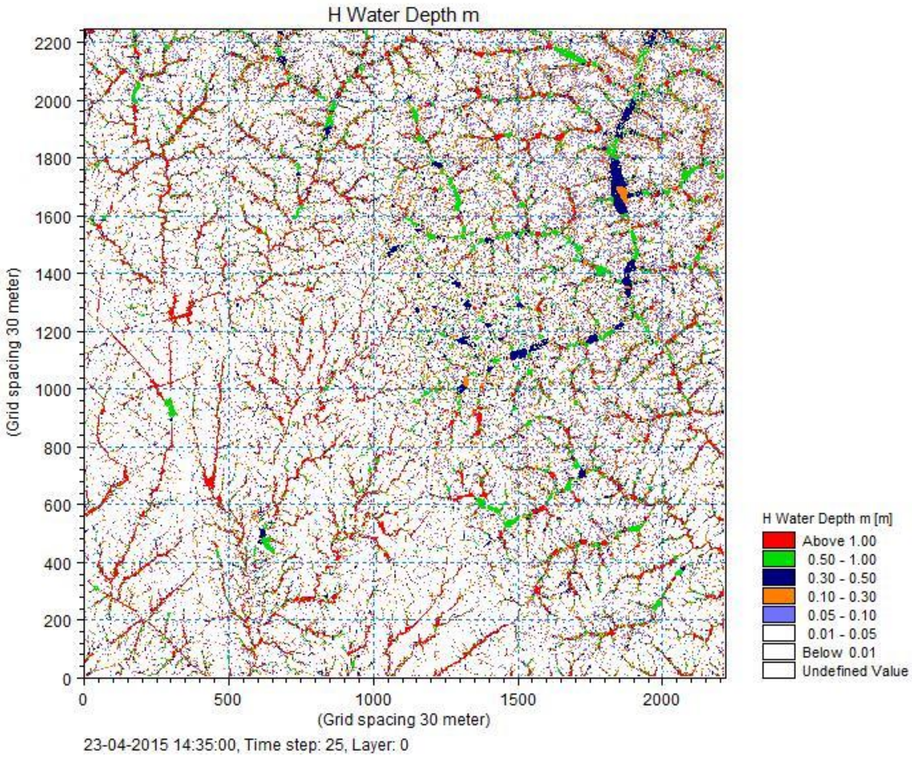

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
23-04-2015 14:00:00, Time step: 18, Layer: 0
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value


H Water Depth m
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
23-04-2015 14:10:00, Time step: 20, Layer: 0
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value

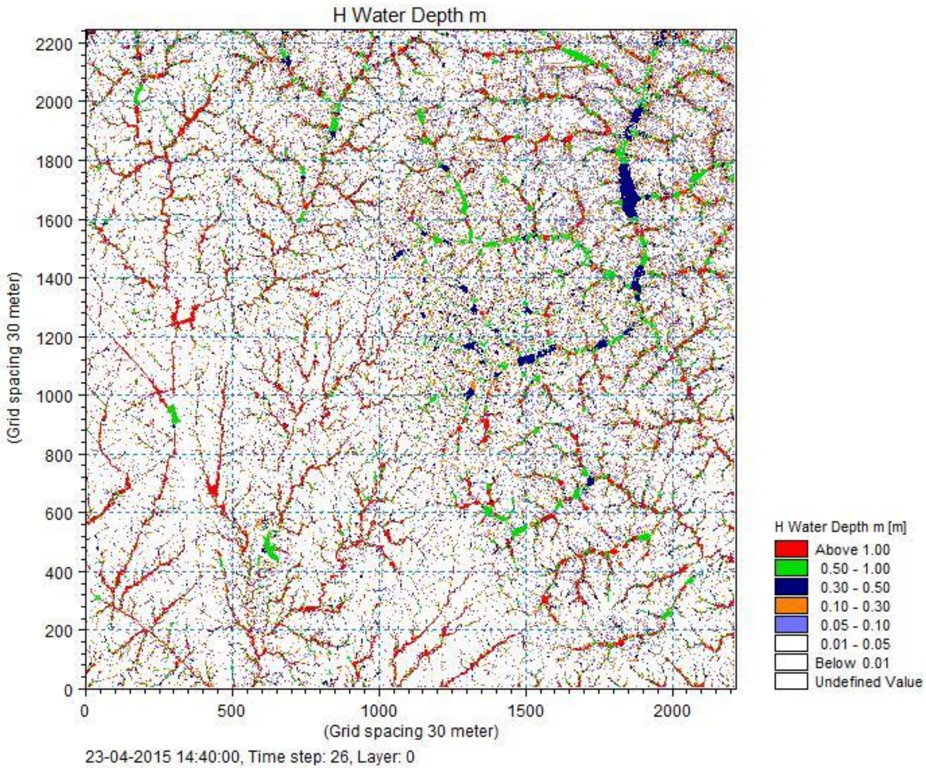

H Water Depth m
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
23-04-2015 14:20:00, Time step: 22, Layer: 0
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value


H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value
23-04-2015 14:25:00, Time step: 23, Layer: 0


H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value
23-04-2015 14:30:00, Time step: 24, Layer: 0

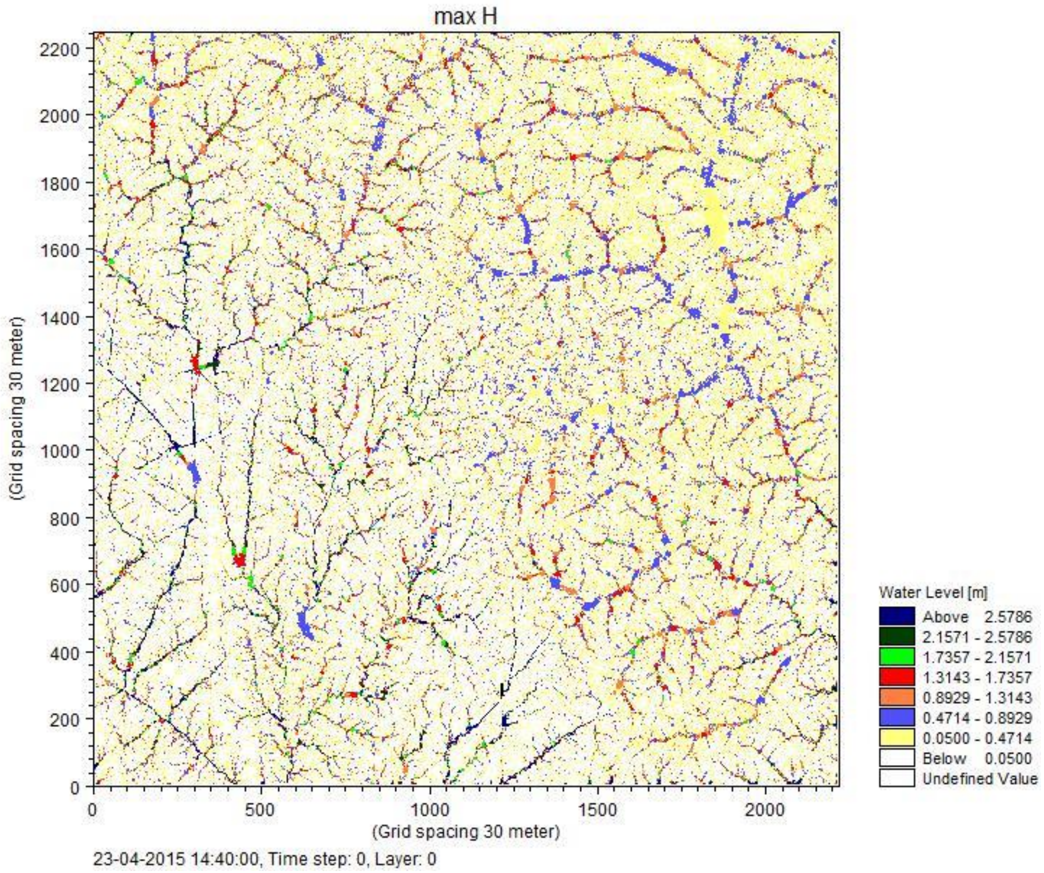


H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
23-04-2015 14:35:00, Time step: 25, Layer: 0
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value

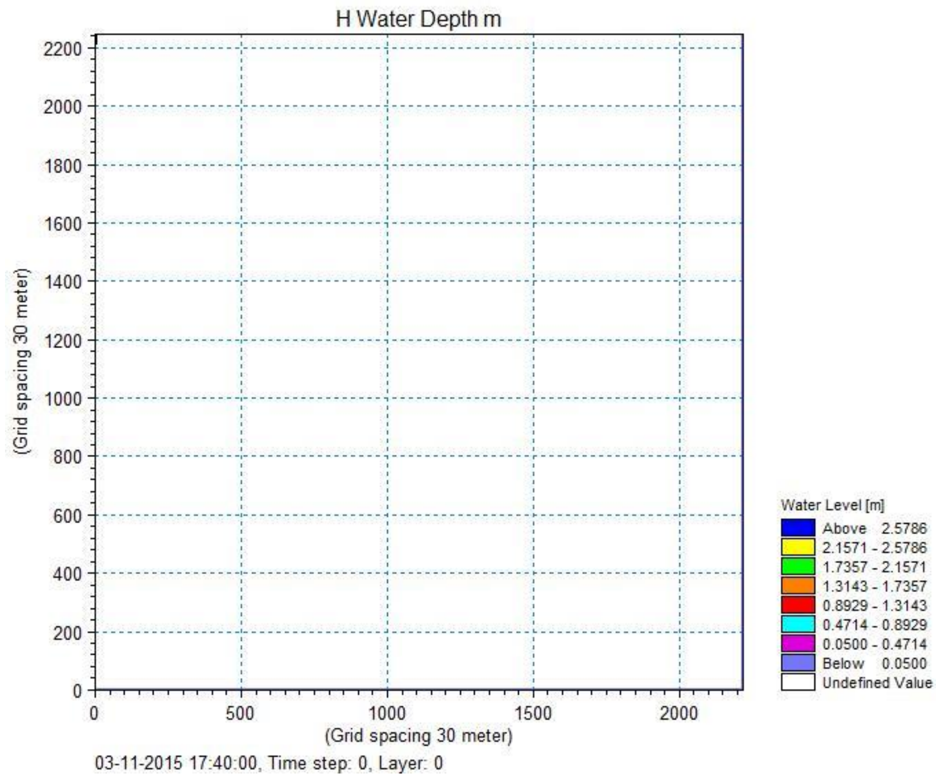


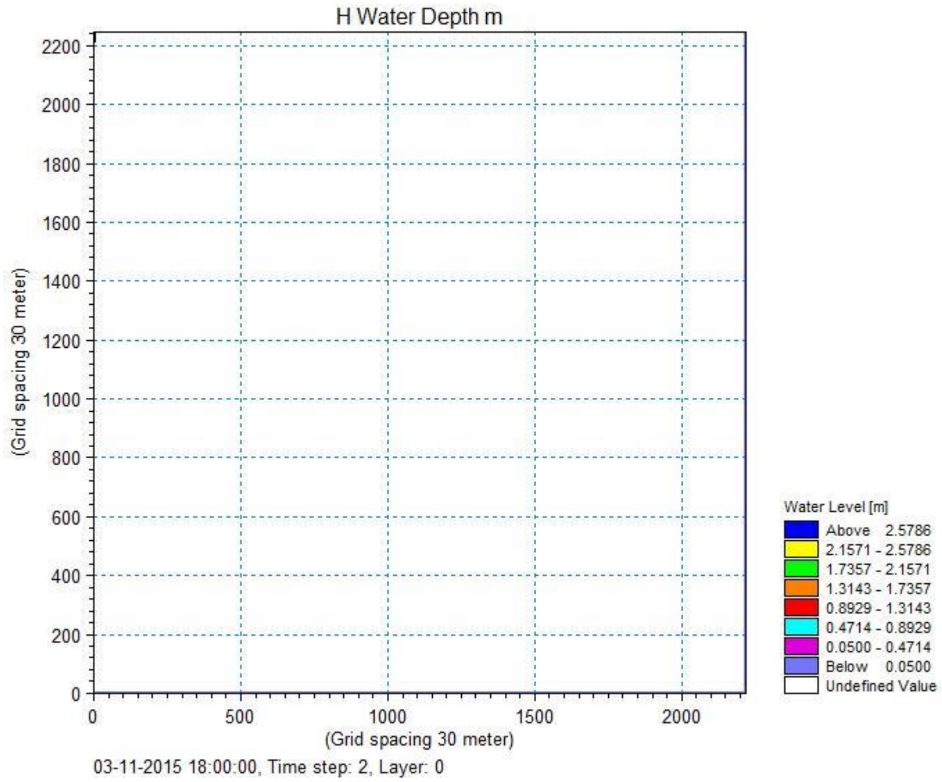
H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
23-04-2015 14:40:00, Time step: 26, Layer: 0
H Water Depth m [m]
Above 1.00
0.50 - 1.00
0.30 - 0.50
0.10 - 0.30
0.05 - 0.10
0.01 - 0.05
Below 0.01
Undefined Value

teri

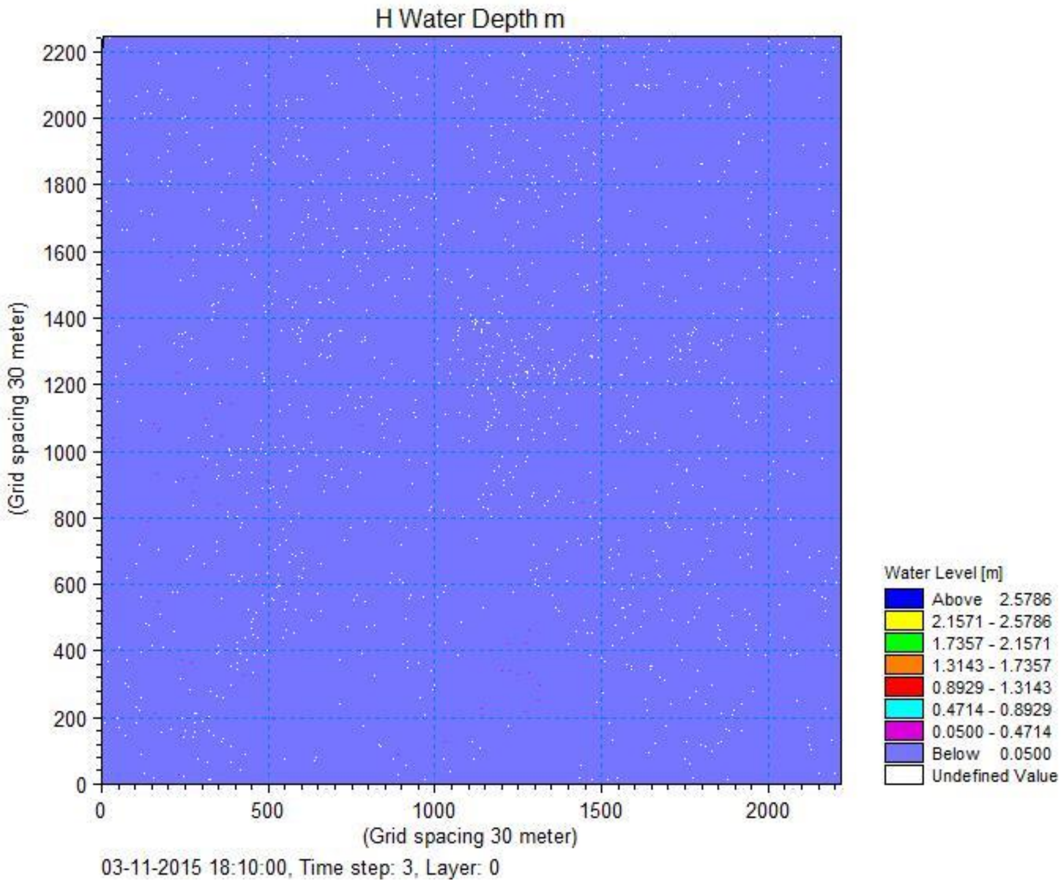


Time Series Maps for 03-November-2015

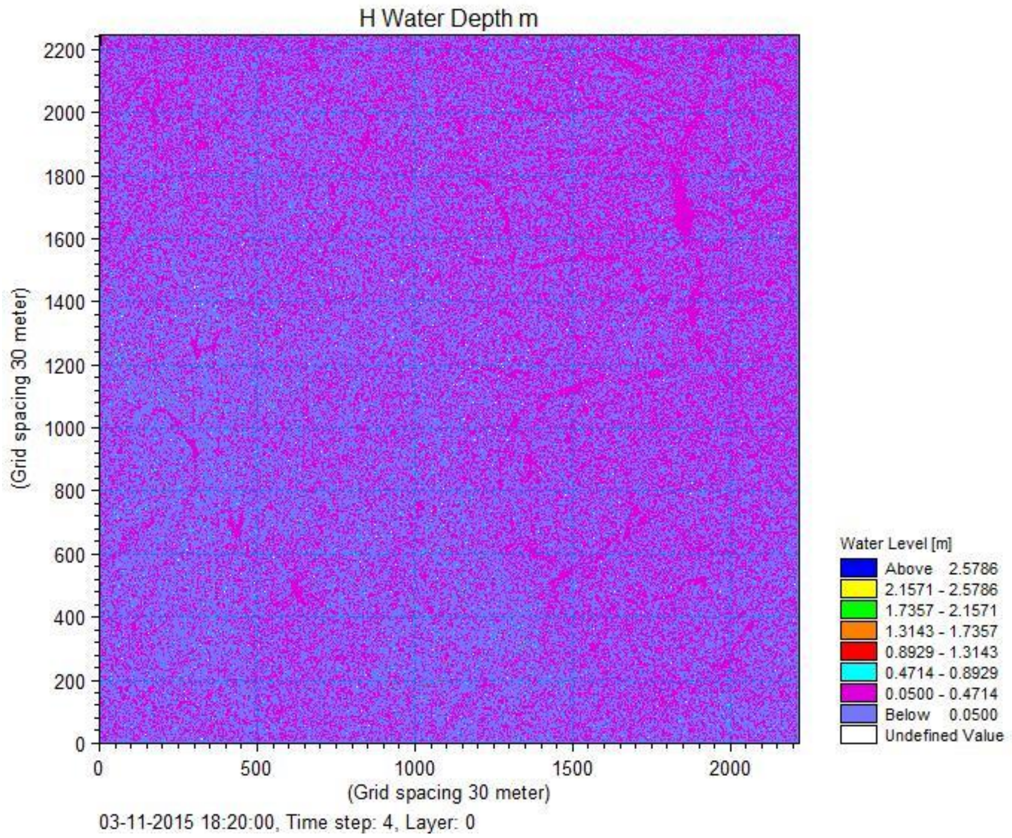


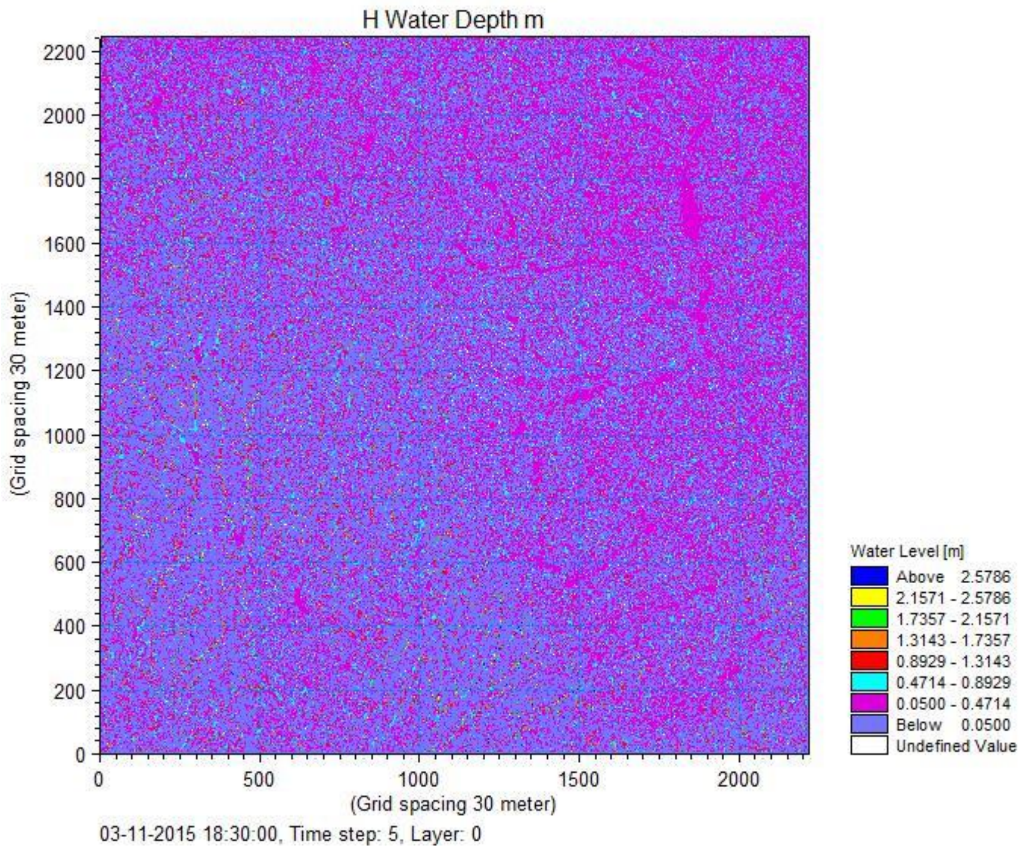


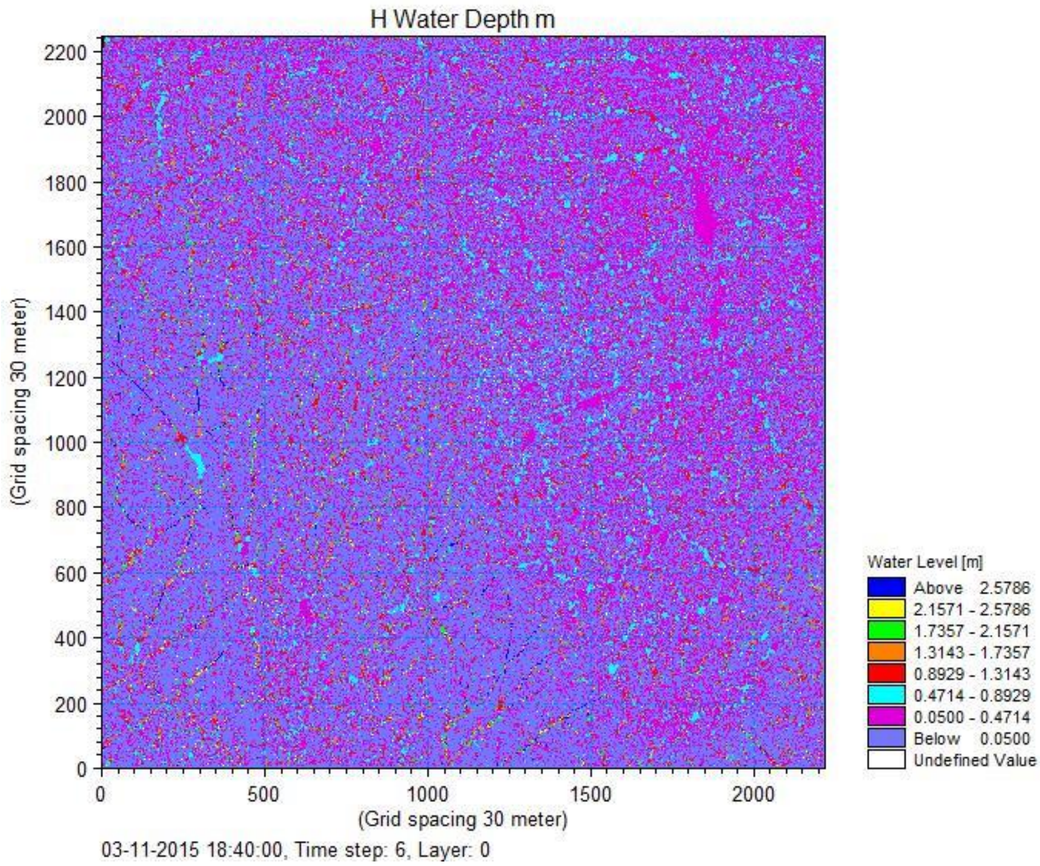
H Water Depth m
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
03-11-2015 18:00:00, Time step: 2, Layer: 0
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value

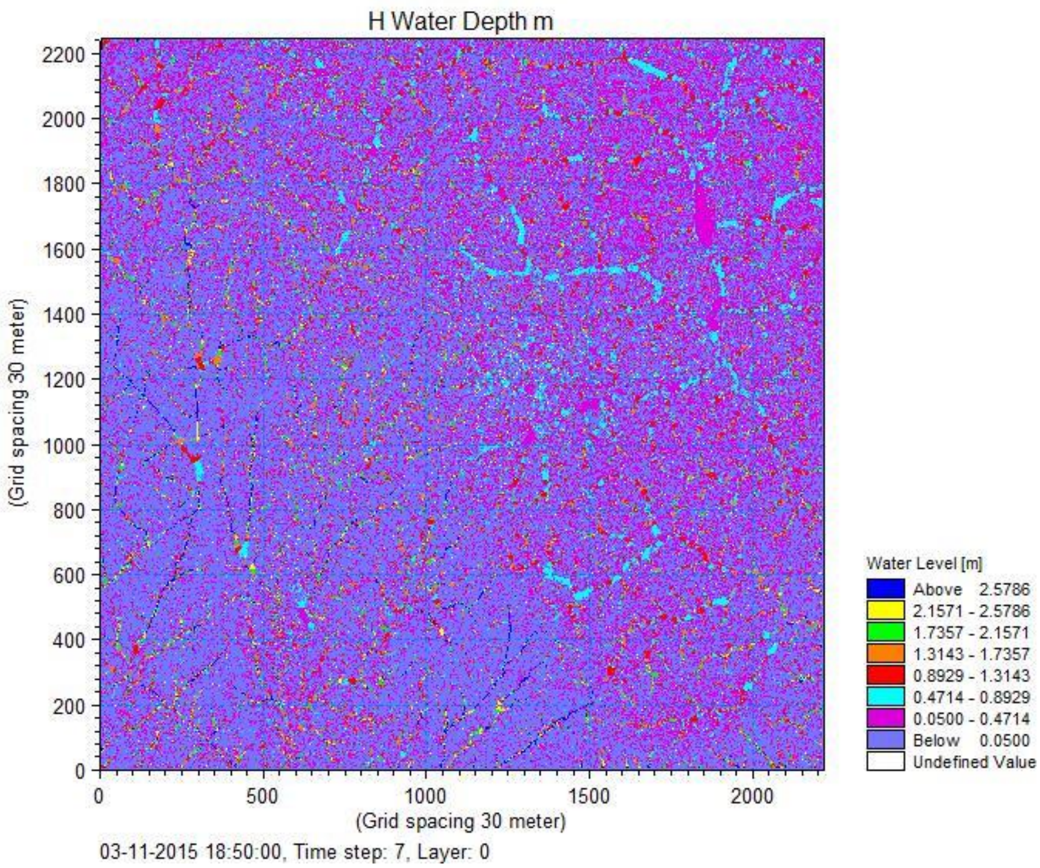


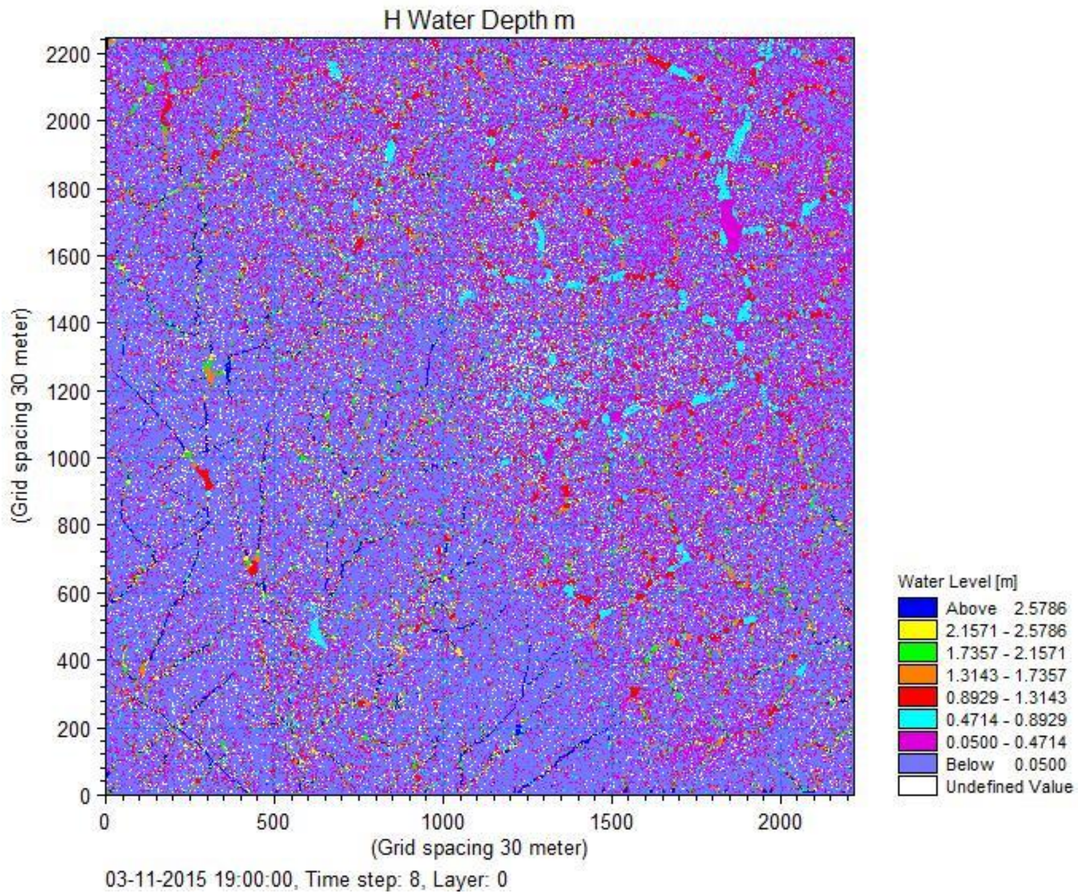
H Water Depth m
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
03-11-2015 18:10:00, Time step: 3, Layer: 0
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value

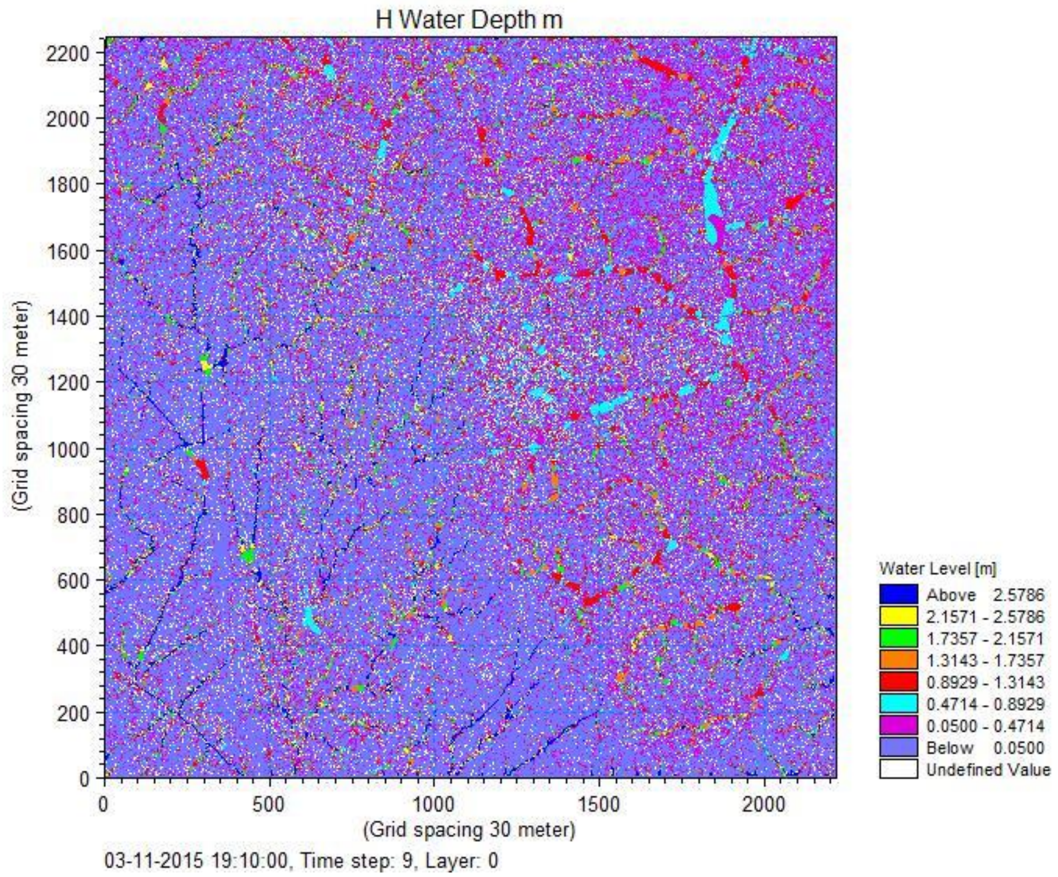

H Water Depth m
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 18:20:00, Time step: 4, Layer: 0

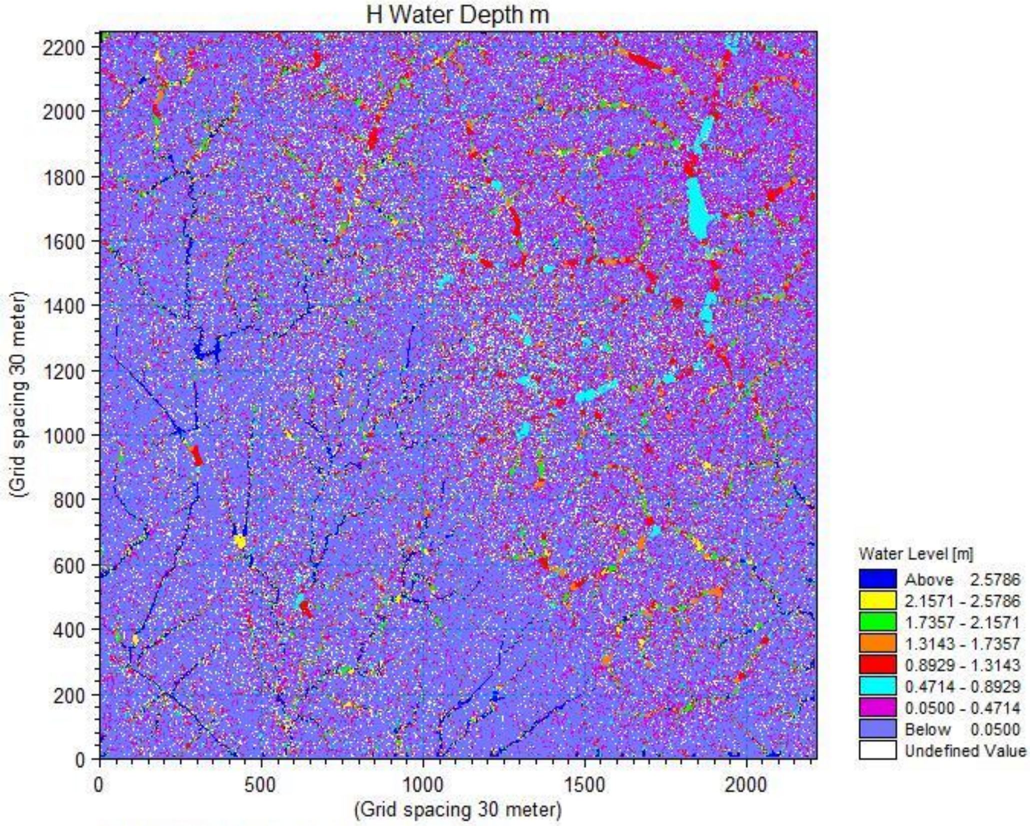

H Water Depth m
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 18:30:00, Time step: 5, Layer: 0


H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 18:40:00, Time step: 6, Layer: 0

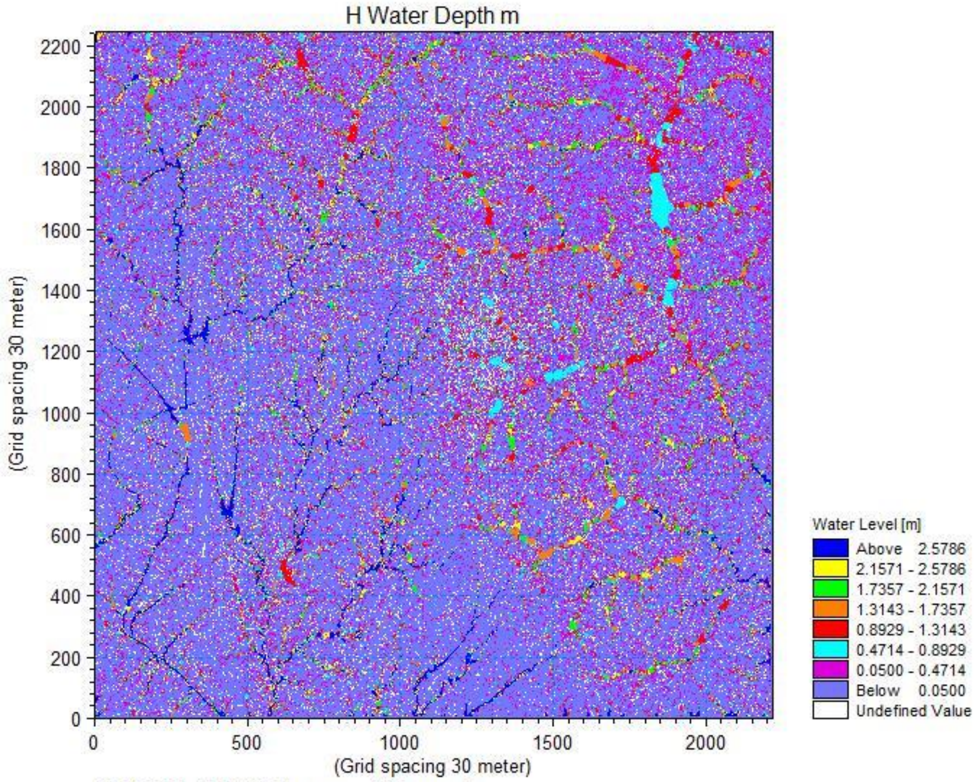

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 18:50:00, Time step: 7, Layer: 0


H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 19:00:00, Time step: 8, Layer: 0

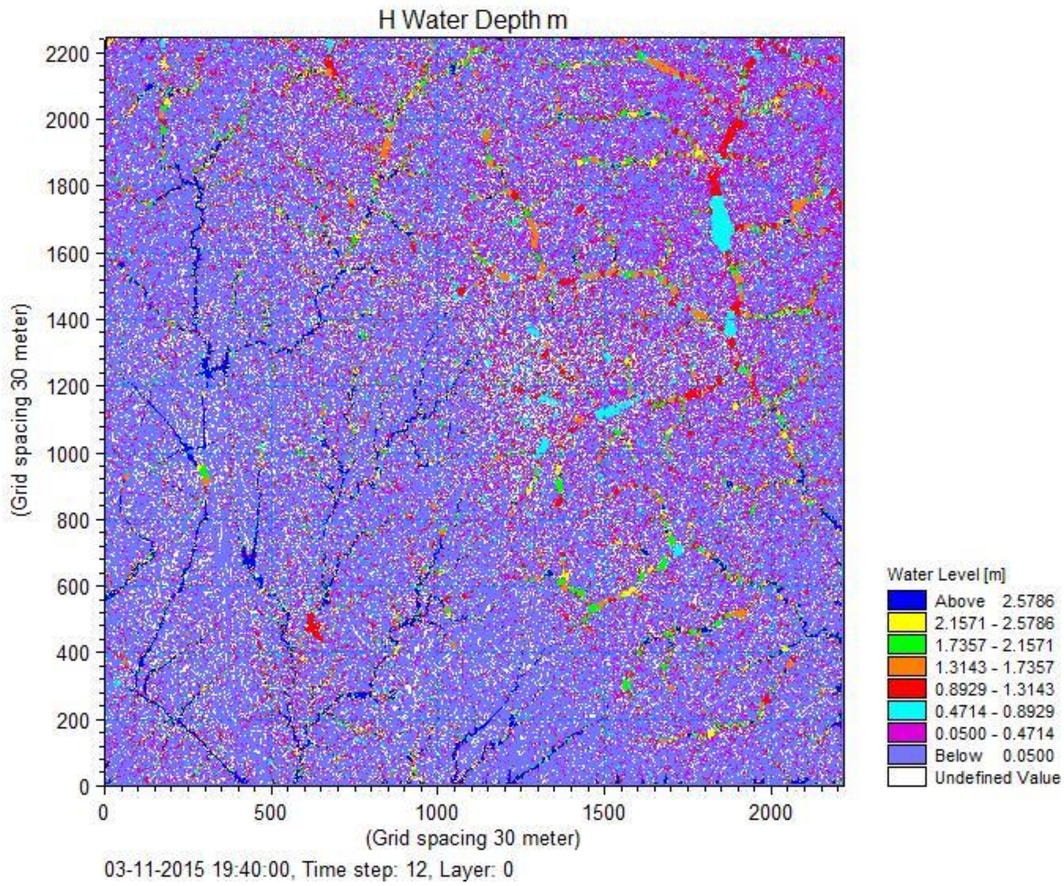

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 19:10:00, Time step: 9, Layer: 0

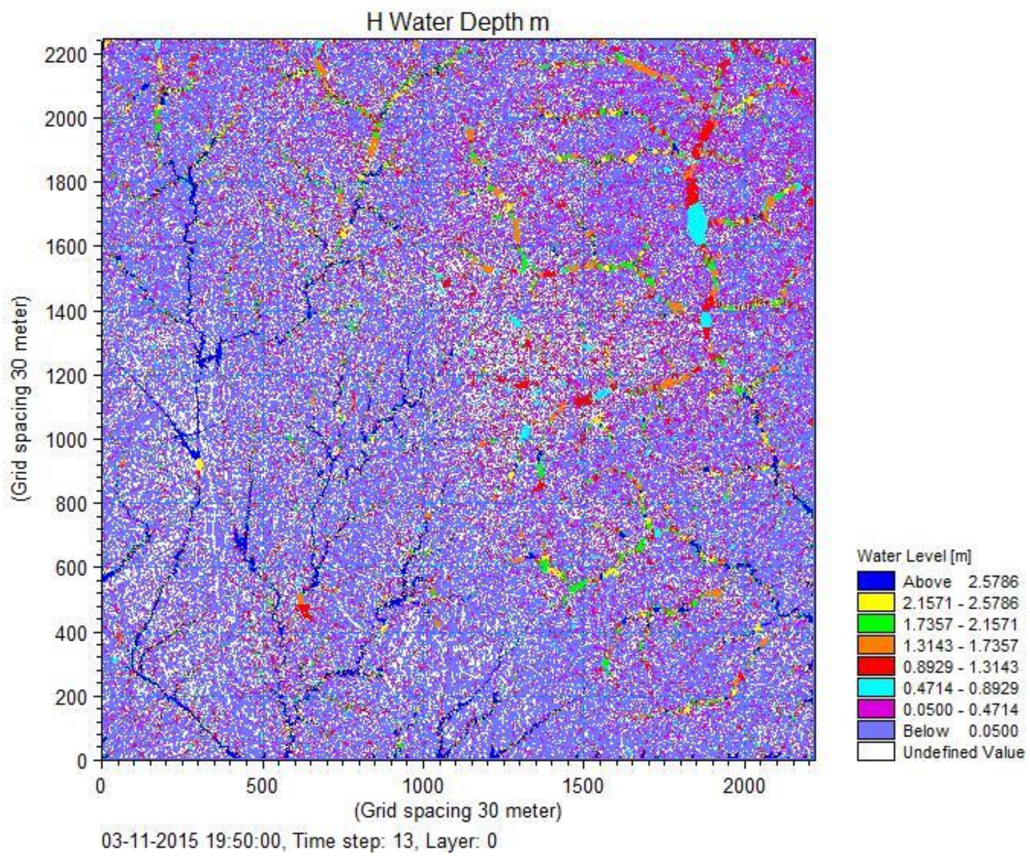


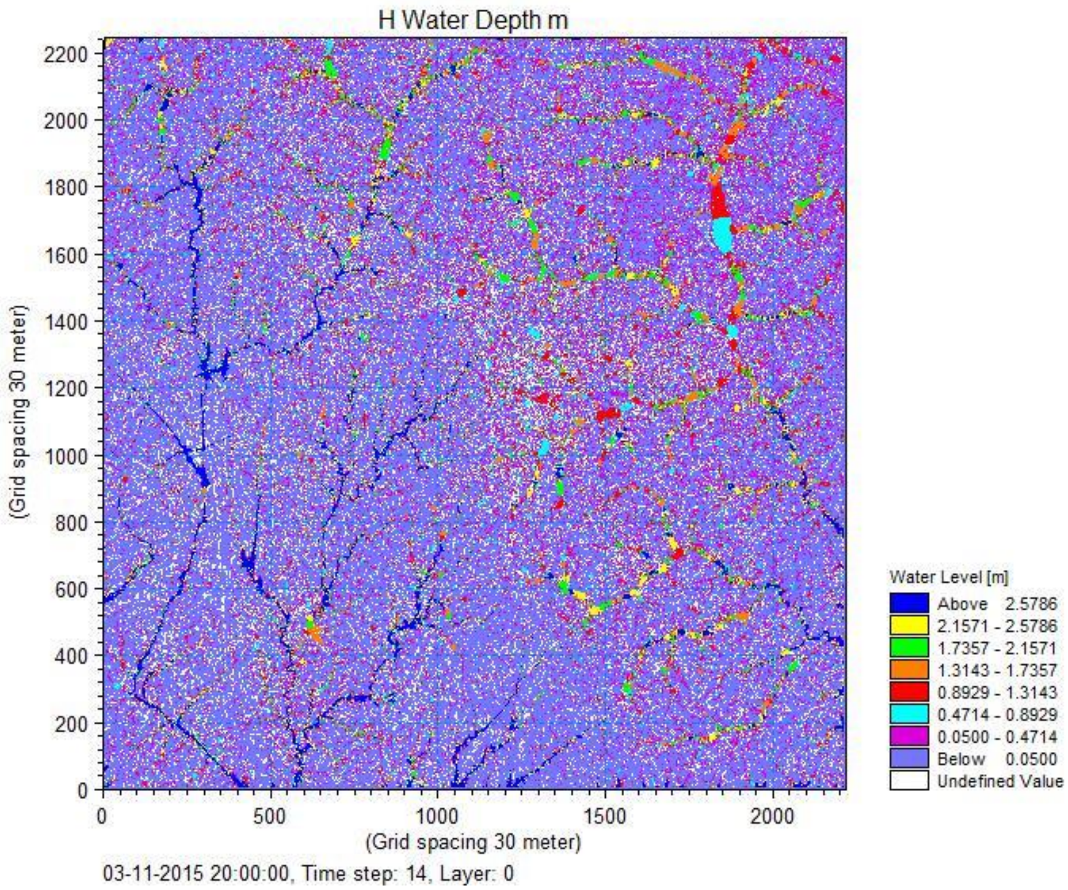
03-11-2015 19:20:00, Time step: 10, Layer: 0



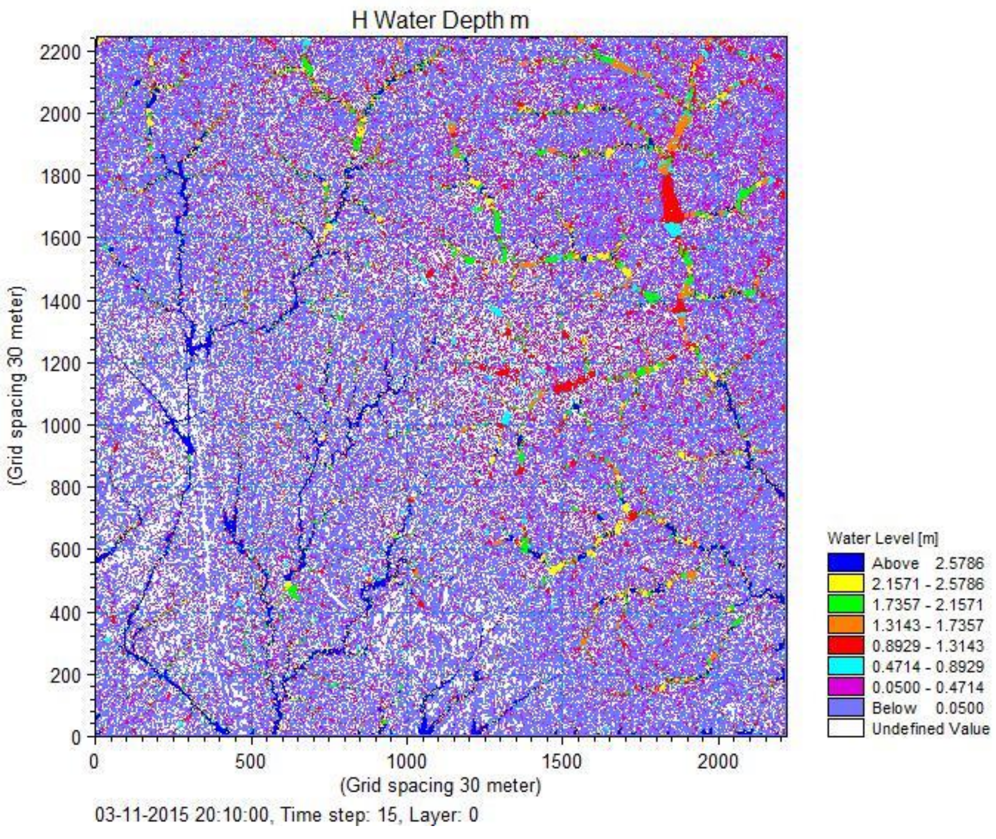
03-11-2015 19:30:00, Time step: 11, Layer: 0


H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 19:40:00, Time step: 12, Layer: 0

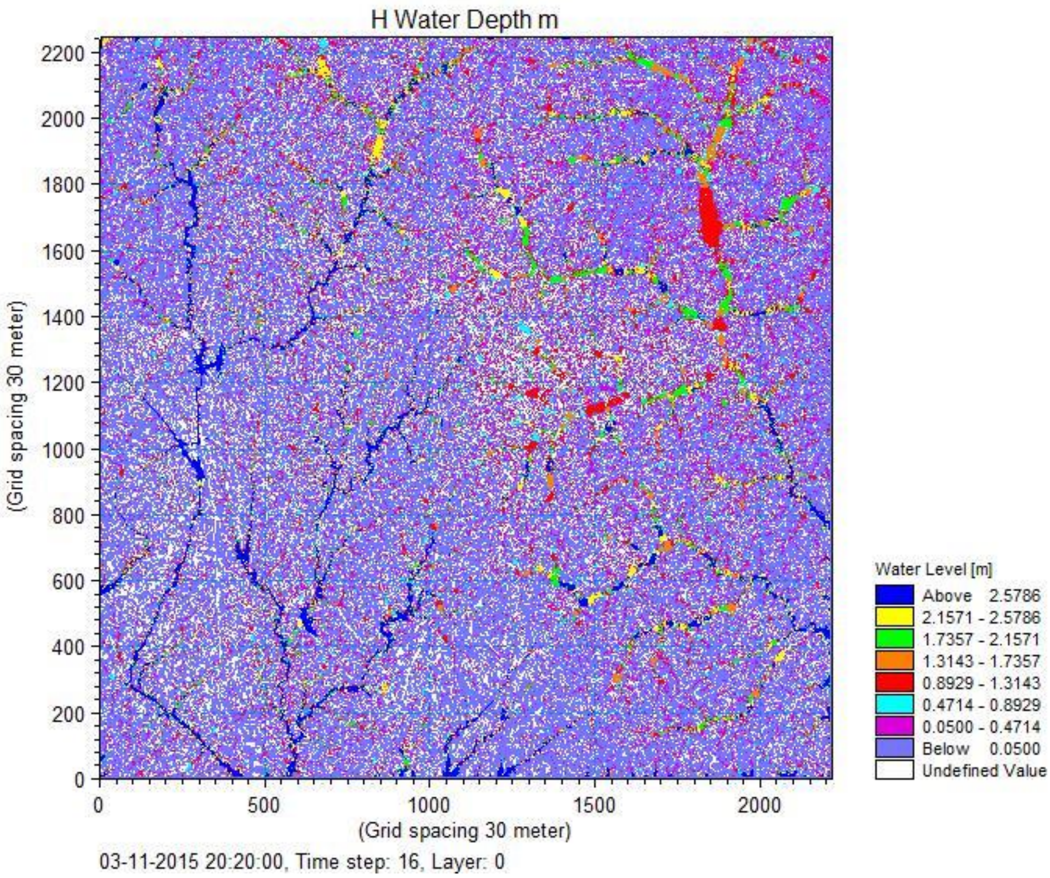

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 19:50:00, Time step: 13, Layer: 0

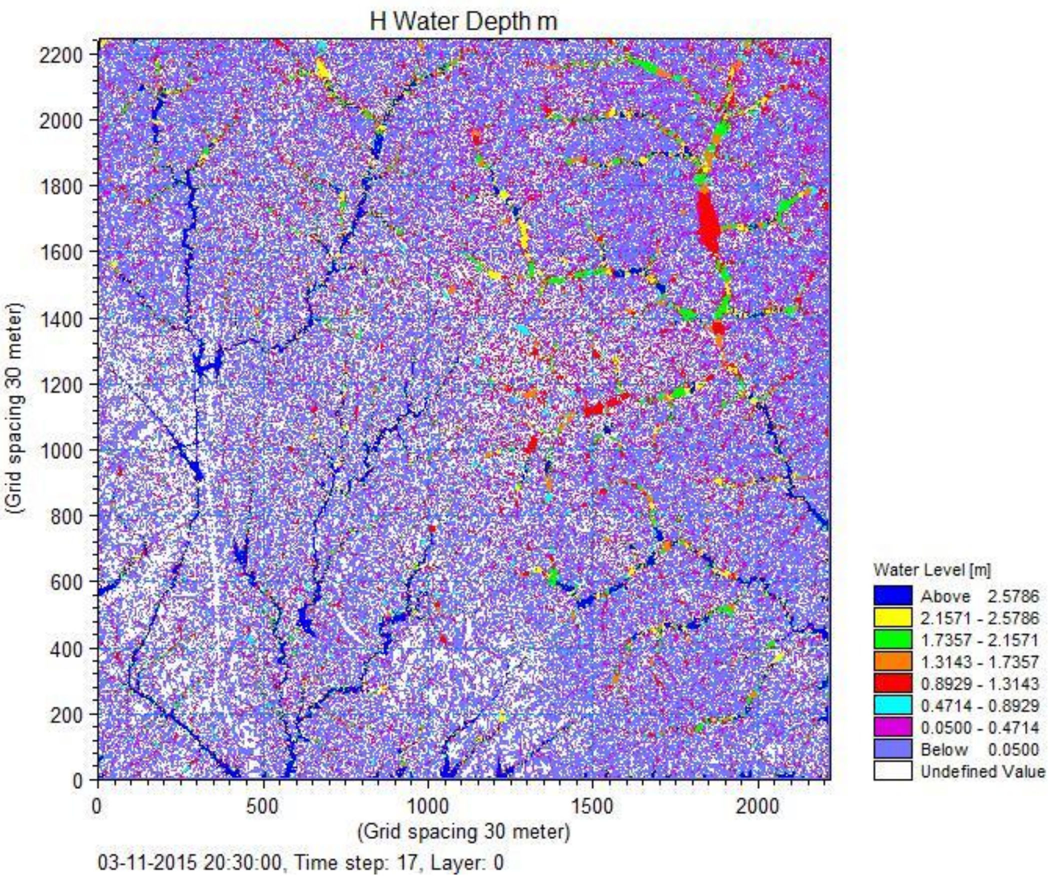


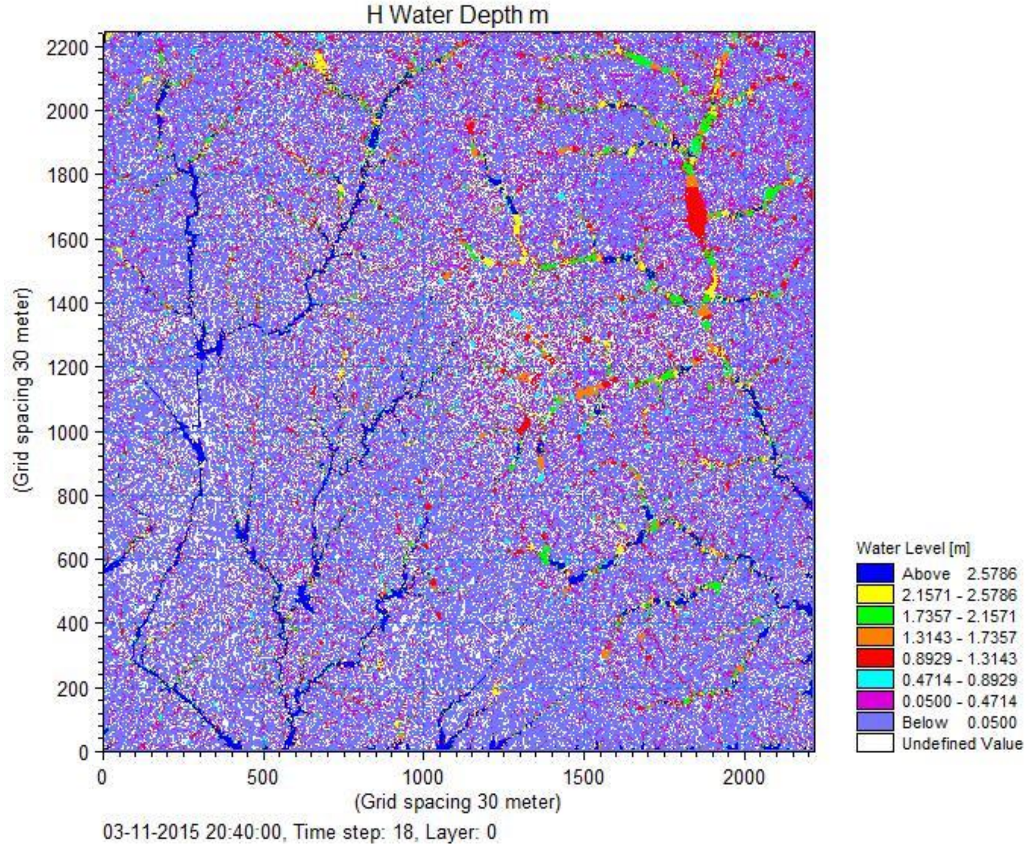
H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 20:00:00, Time step: 14, Layer: 0

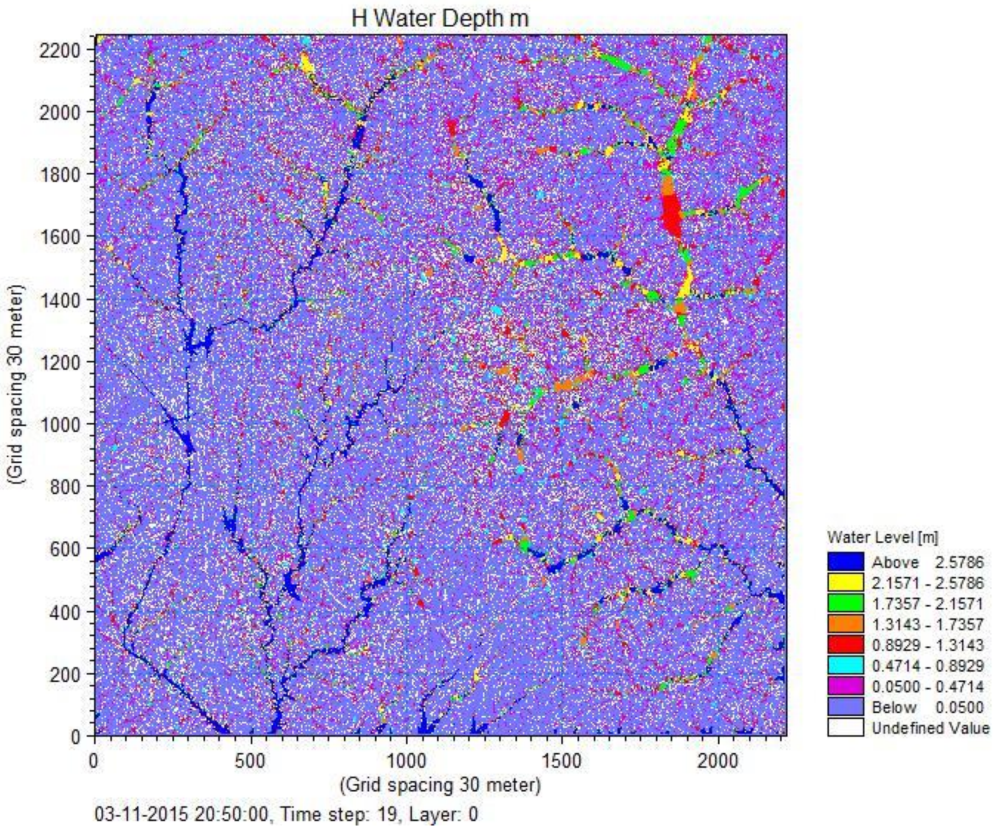


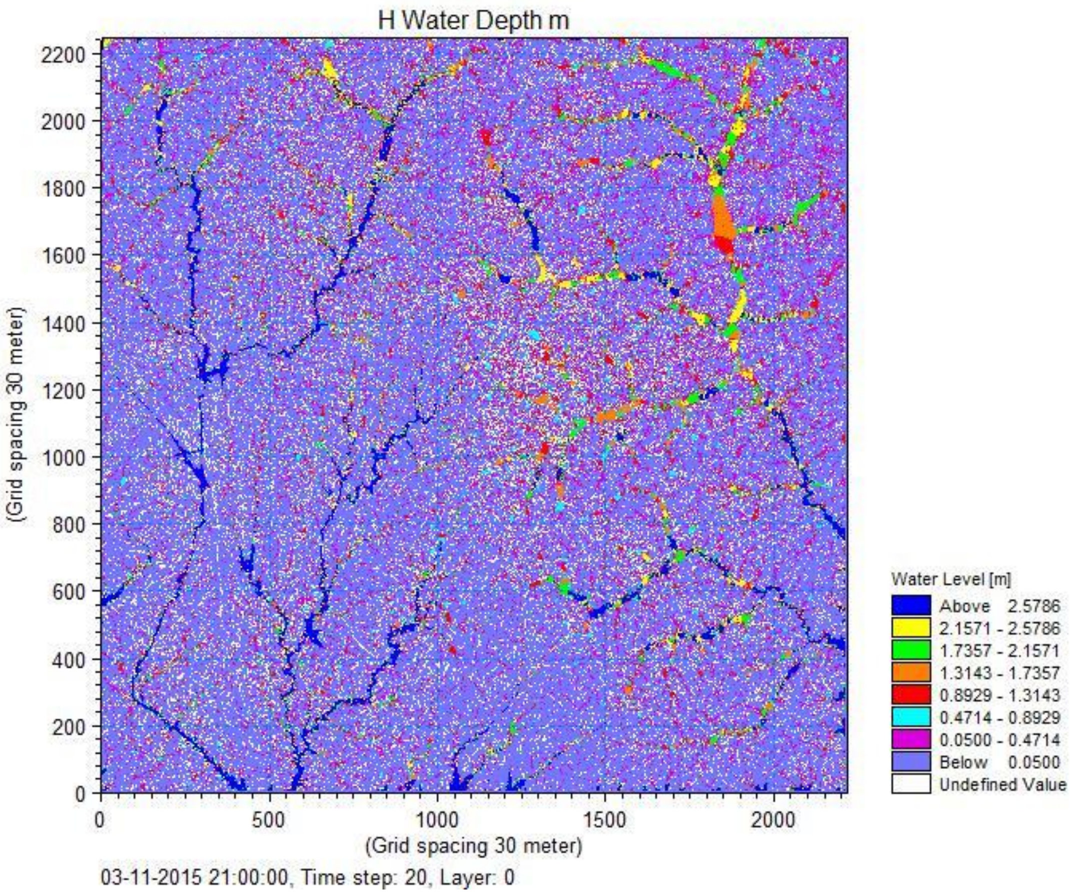
H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 20:10:00, Time step: 15, Layer: 0

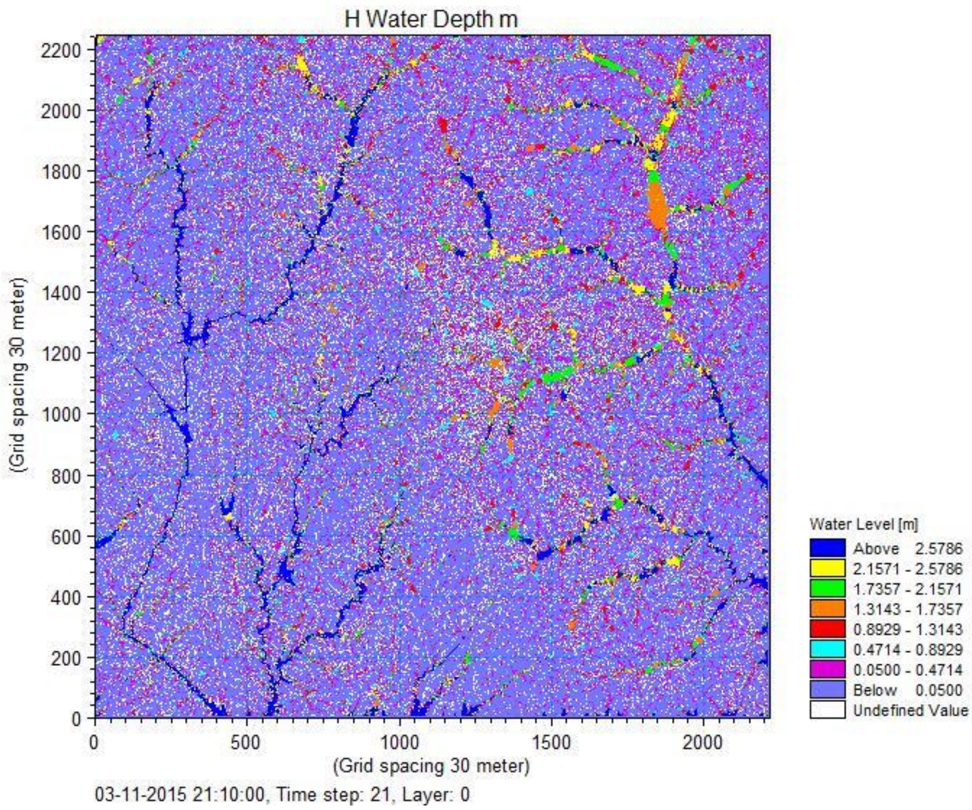

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 20:20:00, Time step: 16, Layer: 0

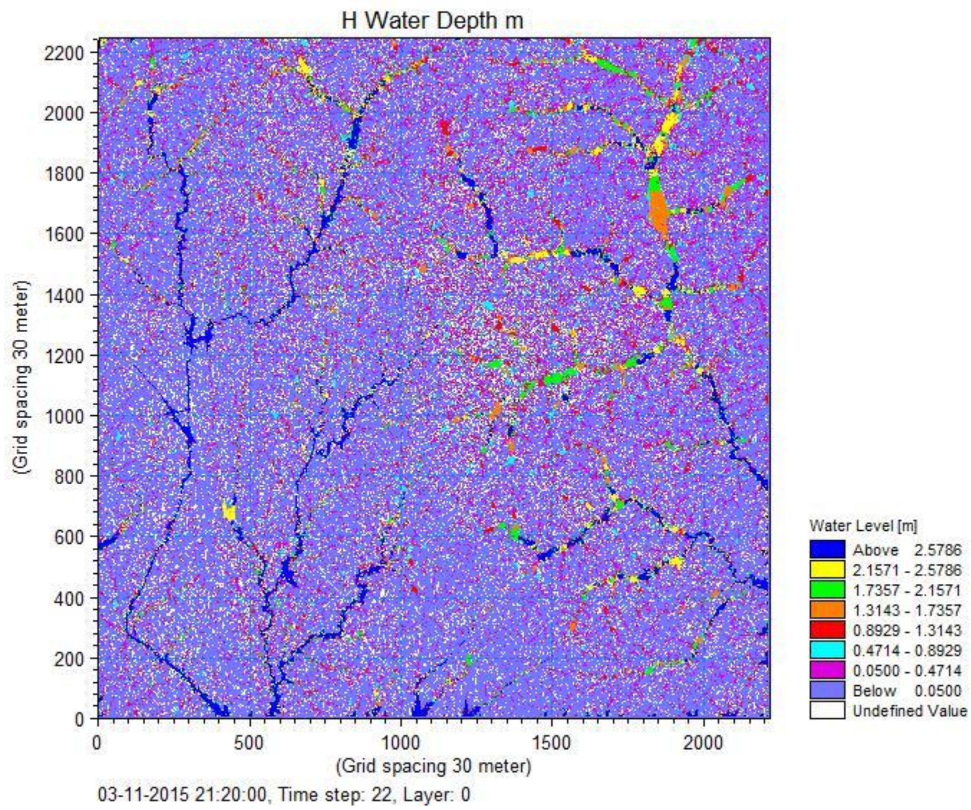

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 20:30:00, Time step: 17, Layer: 0


H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 20:40:00, Time step: 18, Layer: 0

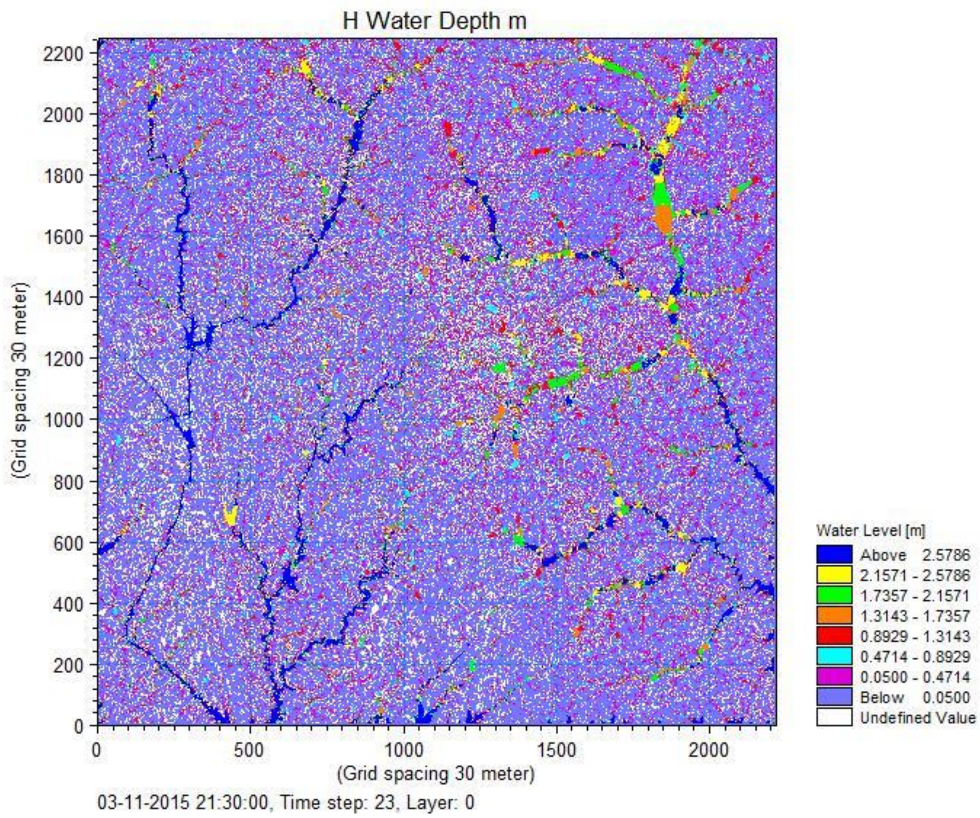

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 20:50:00, Time step: 19, Layer: 0


H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 21:00:00, Time step: 20, Layer: 0

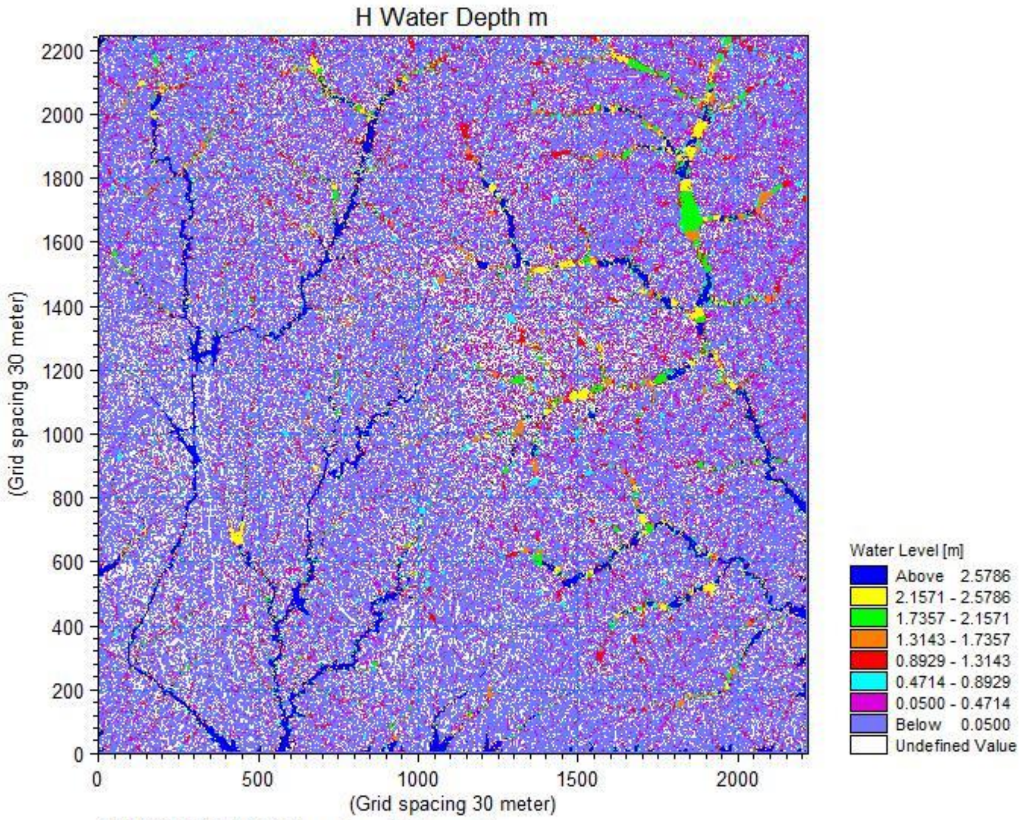

H Water Depth m
(Grid spacing 30 meter)
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 21:10:00, Time step: 21, Layer: 0



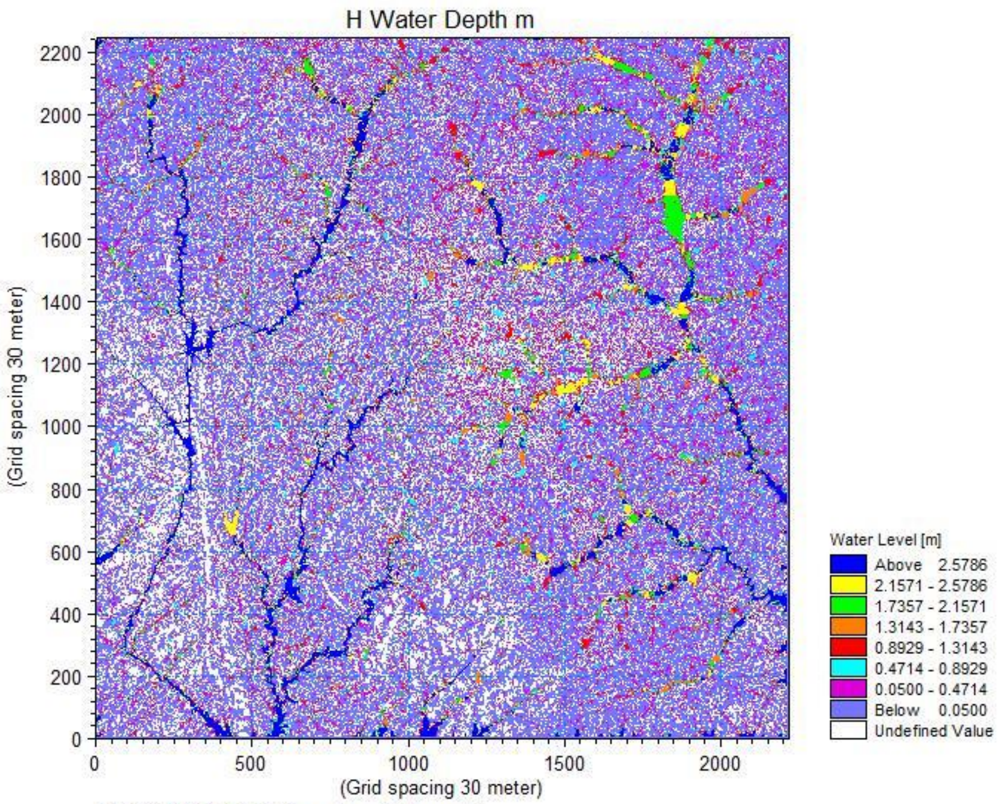
H Water Depth m
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 21:20:00, Time step: 22, Layer: 0



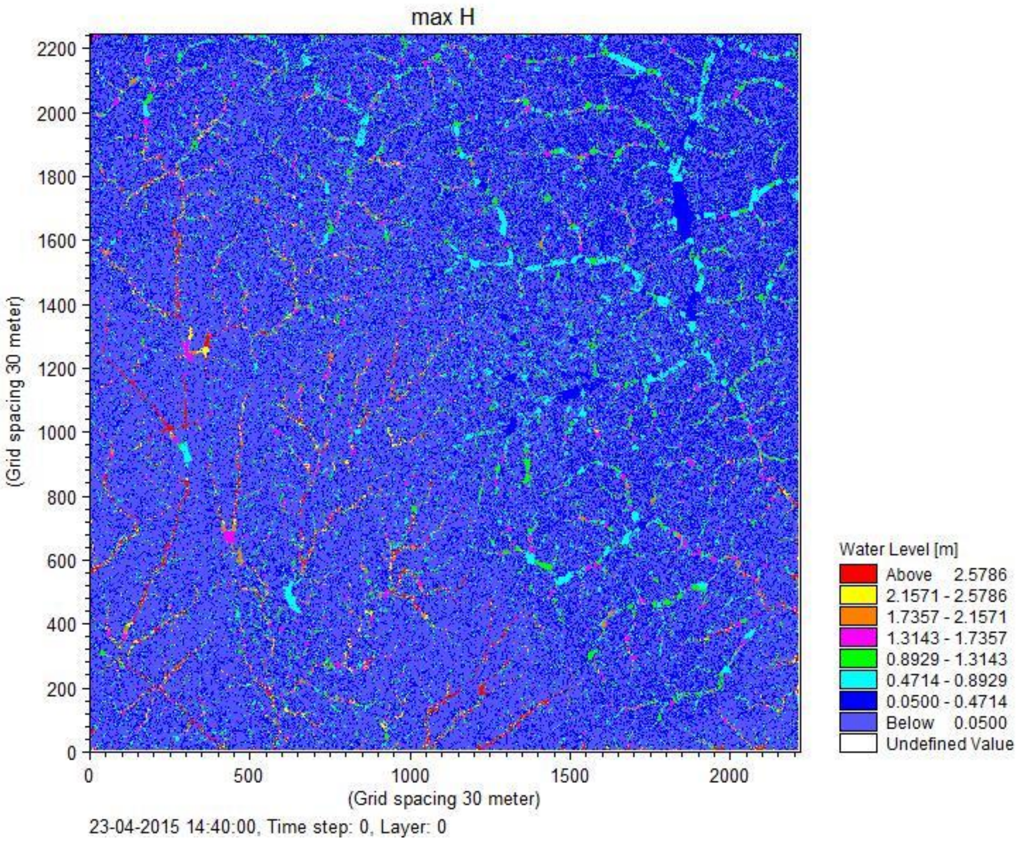
H Water Depth m
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
03-11-2015 21:30:00, Time step: 23, Layer: 0



03-11-2015 21:40:00, Time step: 24, Layer: 0



03-11-2015 21:50:00, Time step: 25, Layer: 0



max H
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Grid spacing 30 meter)
0
500
1000
1500
2000
(Grid spacing 30 meter)
Water Level [m]
Above 2.5786
2.1571 - 2.5786
1.7357 - 2.1571
1.3143 - 1.7357
0.8929 - 1.3143
0.4714 - 0.8929
0.0500 - 0.4714
Below 0.0500
Undefined Value
23-04-2015 14:40:00, Time step: 0, Layer: 0