Urban Utilities Planning: Water Supply, Sanitation and Drainage
Prof. Debapratim Pandit
Department of Architecture and Regional Planning
Indian Institute of Technology, Kharagpur

Module - 12
Drainage and Recharge
Lecture - 58
Urban Flood Management and Drainage Plans Part I

Welcome back! In lecture 5, Urban Flood Management and Drainage Plans are discussed.

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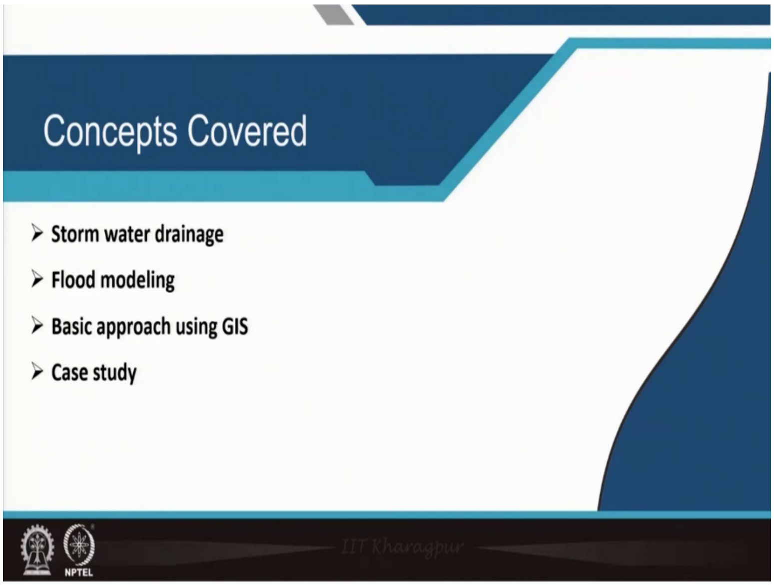

So, the different concepts covered are storm water drainage, flood modeling using basic approach with GIS and a case study.

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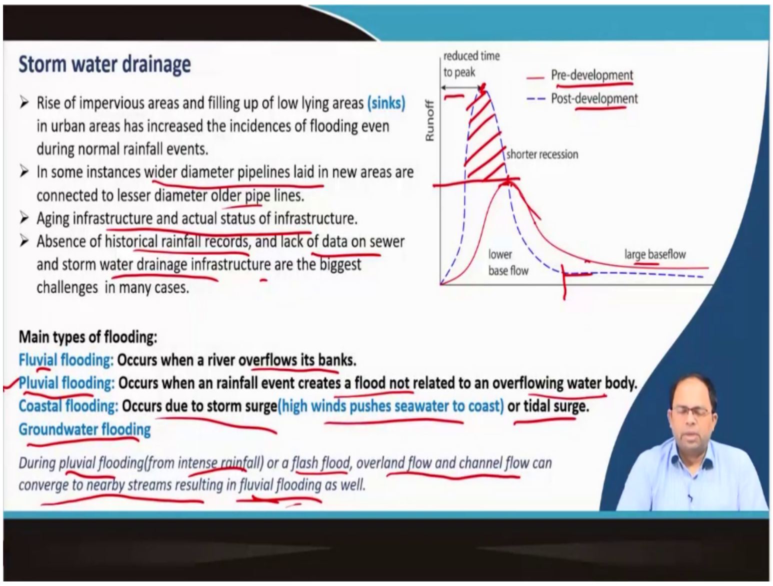

Storm water drainage

The main issue in our urban area is the rise of impervious areas and filling up of low-lying areas or sinks. There is an increase in the volume of runoff that is generated in an urban area and the time it takes for runoff to travel from the point where the rainfall falls on that catchment and then, to the point where it is being collected or a drainage channel that time has also reduced.

As a result, there is an increase in the incidence of flooding even during normal rainfall events with very little amount of rainfall. Before development the base flow is extended and larger. After development, the runoff volume is high and is generated much faster. Peak time is reduced and base flow is lower.

The drainage channel, cannot cater to this kind of runoff and the excess volume of water constitutes the flood. In addition, the time of this rainfall to the maximum peak runoff generation is also getting reduced.

In addition to the presence of impervious areas, there are other issues. For example, in some new areas wider diameter pipelines are being laid and they are connected to lesser diameter older main trunk lines. This also leads to flooding. The excess water will come out from the manholes and create floods in those particular nodes or areas. The aging infrastructure in most urban areas are also often blocked/choked with no sufficient information. This is reducing the quantum of flow along these channels which leads to flooding. In urban areas, the historic rainfall records are sometimes not available.

Lack of data on the sewer and the storm drainage infrastructure becomes a big challenge for preparing plans for storm water drainage in urban areas.

When we talk about floods in urban areas, there are different kinds of flood. The first type is fluvial flooding. Fluvial flooding is when a river overflows its banks. After a rainfall event the runoff that is generated can also result in flood within urban areas and this is not related to the water body or the river that is adjacent to that particular urban area. Then coastal flooding occurs during storm surges when high wind pushes sea water to the coast. And then there is ground water flooding when there is excess amount of ground water. When recharging a particular area, the aquifer may get filled and eventually there can be flooding. So, during pluvial flooding that is urban flooding from intense rainfall or a flash flood, overland flow and channel flow can converge to nearby streams resulting in fluvial flooding as well.

Pluvial flooding and fluvial flooding can also happen together, when too much amount of rainfall happens in an urban area and it all flows into the nearby channel thus creating some amount of fluvial flooding as well.

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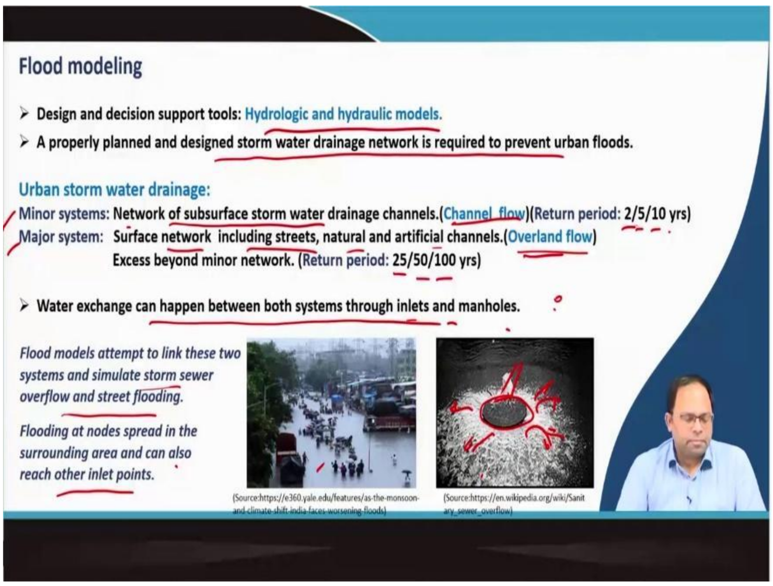

Flood Modelling

In order to determine the spread of flood or the occurrence of flood, we need to conduct flood modeling. For this purpose, we have different design and decision support tools that are the hydrologic and the hydraulic models.

We use those models to determine the extent of floods and so on, but there is a certain strategy to use these particular models. So, usually a properly planned and designed storm water drainage network is required to prevent urban floods. So, whenever we do flood modeling, we actually test if the existing infrastructure is adequate to cater to the runoff or what has to be done to prevent flooding.

So, urban storm water drainage is of made up of two systems; one is the minor system, another is the major system. Minor system is the network of subsurface storm water drainage channels. If there are sewers which can convey the storm water, then these are sub surface storm water drainage channels which forms the minor network.

We have already learnt how to determine the flow in a particular channel and that the return period is taken for 2, 5 or 10 years depending on where or for what purpose we are designing the particular channel.

Similarly major systems refer to surface networks in the urban area which are the streets, natural and artificial channels and this is also referred to as overland flow. The water flows over land and sometimes it may flow along the street, sometimes flows along the natural or the artificial channels and so on. So, in this case the return period is 25, 50 or 100 years.

The water that is collected enters into this minor system via the inlets and then it flows and we estimate the time of concentration and the rainfall intensity. We next determine the maximum volume/flow of water that comes to different nodes and then based on that, we design the channels.

Sometimes when there is more rainfall than expected and the water coming to a particular node is more than the design profile of that particular section that is when the flooding happens. This excess water coming out through the manholes will create flood in that particular area.

The excess water coming out of this node spreads over the surface and it will move along the streets or natural, artificial channels and this forms the overland flow.

Then, because water is flowing over land, then it will also come in contact with other inlets and then water will also enter into those particular inlets into the sewer network.

So, there is an exchange that can happen between both the major and the minor system through inlets and manholes. So, that means at certain nodes, we can estimate the amount of water which would be excess and that becomes overland flow and from here water can get inside the inlets as well.

The flood models attempt to link these two systems and simulate storm water overflow and street flooding. The complexity of this linkage actually determines what sort of model is used. We can have very simple models, but at the same time we can have very complicated models as well.

In the given image, the entire street has got flooded because the street is sometimes designed as a drainage network. Therefore, the surrounding water will come to the streets and then get into the sewer network via those particular inlets.

But because the sewer is totally filled, it is not able to take in this water and water remains on the street and that is what is creating the flood. The water spreads from the street to the surrounding areas. So, flooding at a node spreads in the surrounding area and can also reach other inlet points.

Even though there may be no rainfall in this area, flooding may happen due to rainfall happening in some other area because the capacity of the sewer is exceeded in this area.

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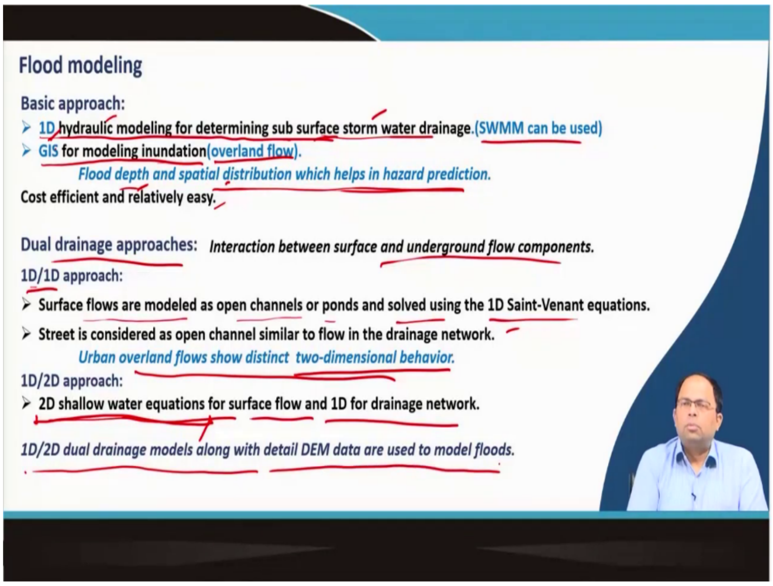

The basic approach is to consider the minor network that is the sewer network or the sub surface storm water drainage only. We use 1D hydraulic modeling for determining the sub surface storm water drainage and for this we can use the SWMM software that we have learnt earlier. We can use it for determining that how the water is actually travelling through a particular storm water channel. We can determine which are the nodes that are getting flooded.

We can also determine the total volume of water that is creating the flood and then we can use GIS to model the inundation or the flooding because of this water. This could be termed as the overland flow. Flood depth and spatial distribution helps in determining the hazard created by the flood. So, hazard prediction comes after we can determine flood depth and the spatial distribution of spread of this particular water. So, this approach is cost efficient and really relatively easy and that is mostly followed in most urban areas. But we can use other approaches as well.

This is called the dual drainage approach where interaction between surface and underground flow components are considered. So, we not only consider the drainage in the minor system, but also in the major system or in the overland system.

So, within dual drainage approach, we can again have two approaches. One is 1D 1D approach and the other is called 1D 2D approach. So, what happens in 1D 1D approach is that the surface flow is modeled using 1D.

Surface flows are modeled as open channels or ponds and solved using 1D Saint Venant equation. Whatever flooding happens at a particular node that actually spreads along the street. So, street is considered as an open channel similar to the flow in the underground sub surface drainage network.

Urban overland flows is however not that simple because it does not only passes along the street, it will spread in multiple direction and it is usually shows distinct two dimensional behavior.

So, that is where we go for 1D 2D approach where we use 1D for determining the sub surface storm water flow whereas, for we use the 2D approach for determining the surface flows. We use 2D shallow water equations for surface flow and 1D for the drainage network. So, 1D or 2D dual drainage models along with detailed DEM data are used to model floods.

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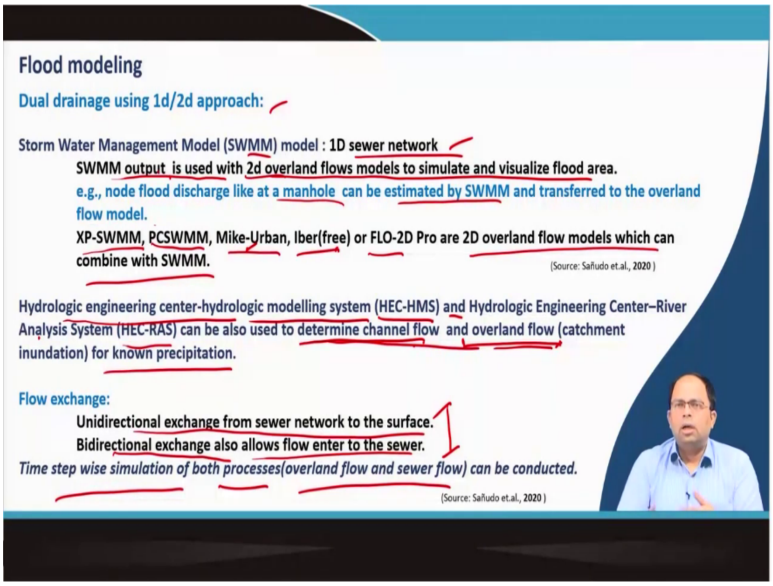

To do the 1D 2D approach, we use storm water management model for determining the flow in the sewer network. SWMM output is next used, that means, that node flooding data from SWMM is used with the 2D overland flow models to simulate and visualize flood area.

So excess volume of water getting out from particular nodes are taken as input for this 2D overland flow models and they show that how the water will spread over the surface from that particular node. Overland flow models like XP-SWMM, PC-SWMM, Mike-Urban, Iber which is also free and Flo-2D Pro can be used. These are 2D overland flow models which can be combined with SWMM.

The alternative is we can use two other softwares. Hydrologic engineering Center-hydrologic modelling system (HEC-HMS) made by US army and Hydrologic Engineering Center–River Analysis System (HEC-RAS) can be used to determine channel flows and overland flows that is catchment inundation for known precipitation events.

Here, both channel flow that is 1D as well as overland flow using 2D can be designed using these two software which are also freely available. So, flow exchange could be a unidirectional exchange from sewer network to the surface. At the node, the flood happens and we assume that from that point the water will spread in all directions or it could be a bi directional exchange, that is, it flows from the overland flow that is generated also enters into the sewer at other points. To model this, we need to do a time step wise simulation where both the processes overland flow and sewer flow can be conducted. First, we compute the values for the sewer flow based on the flooding generated at certain nodes and then we calculate the overland flow.

Some amount of water gets back into the sewer and contributes to the flow in the sewer. So, we can do it at multiple time intervals to see what are the effects. So, that is how some researchers have also modeled flooding in particular urban areas.

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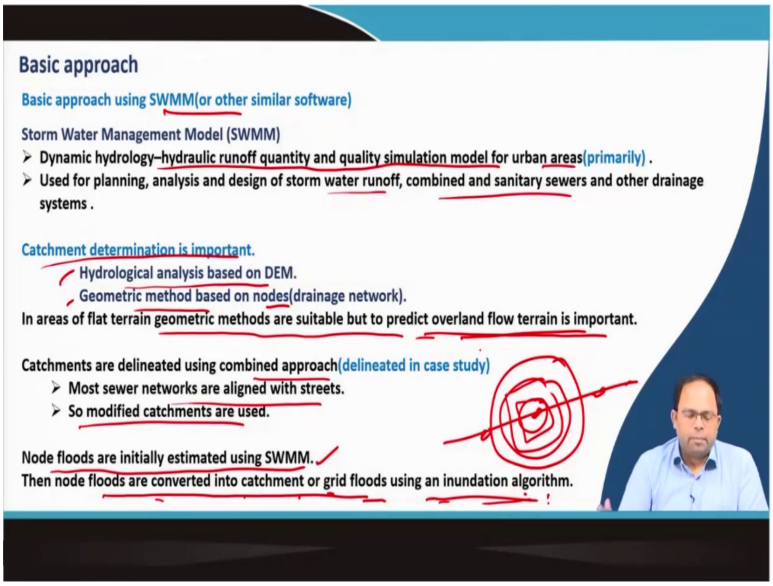

Basic approach

So, we will learn about the basic approach where we use SWMM. SWMM is a dynamic hydrology hydraulic runoff quantity quality simulation model primarily for urban areas. This could be used for planning, analysis and design of storm water runoff, combine and sanitary sewers and other drainage systems.

Catchment determination is done using hydrological analysis based on DEM to determine the natural stream orders in a particular area and the geometric method where we have considered important nodes or flooding points. Both the methods are used and in areas of flat terrain geometric methods are suitable. But to predict overland flow terrain is important.

Catchments are delineated using a combined approach of both this hydrologic and geometric method and most sewer networks are aligned with streets and so, we can modify the catchments as per that as well.

So, we have learned this basic process of determining a catchment for a sewer network earlier. So, we will follow the same process. So, node floods are initially estimated using SWMM. We have also learnt how to determine node floods earlier. And then node floods are converted into catchment or grid floods using an inundation algorithm.

So, suppose we have a sewer network. We determine what is the flooding in a particular node, then we determine the inundation that is the spread of flooding using some algorithm and node floods are converted into catchment or grid floods. So, we determine how much this node flood will spread in a particular area.

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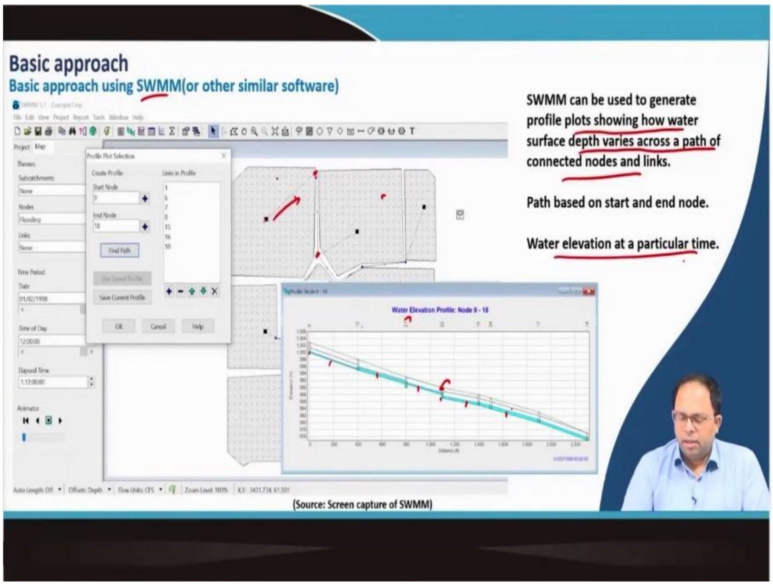

So, let us see the interface of SWMM. SWMM can be used to generate profile plots showing how water surface depth varies across a path of connected nodes and links. So, we determine that start node is maybe 1 and the end node is 18. So, these are the different links in the profile. So, we need to find the path in which water will flow from node 9 to node 18.

So, start node is 9, then it goes to node 10, then to node number 21, 22, 16, 24 and so on. And in each node, there is a manhole because there is change in direction or alignment and so on. So, we can see the volume of water in each of these sections and this could be determined in SWMM.

So, based on the rainfall event that has happened, we can run the simulation. Once we have put in all the data, we can determine the volume of water in each of the sewer sections and then based on wherever there is flooding, the water reaches the top of that particular manhole and water elevation at a particular time can be determined.

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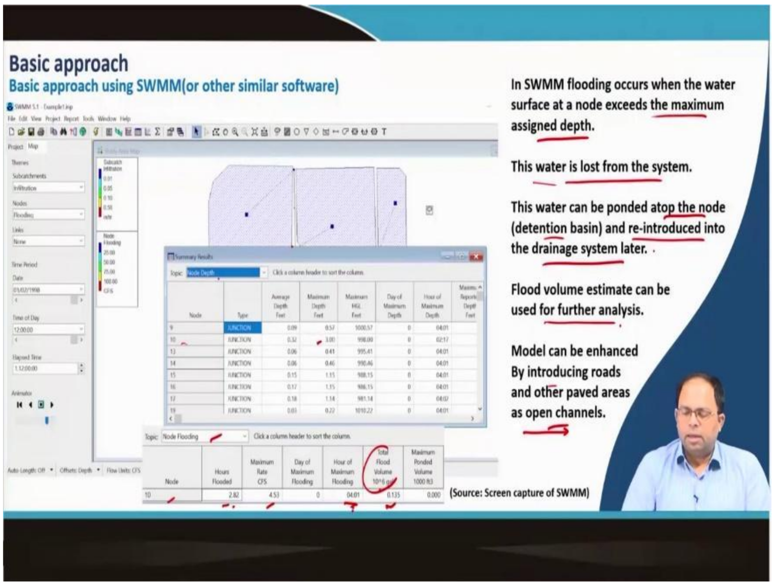

We can see that in SWMM flooding occurs when water surface at a node exceeds the maximum assigned depth of that particular node. So, we have already seen the node depths at every junction. The maximum depth is 0.3 feet and if it exceeds the ground level, then there would be flooding.

So, we can see that at node 10 flooded hours is 2.82 hours and the maximum rate is 4.53 cubic feet per second, and total flood volume is also given.

In SWMM further calculations are not dome and this the water is lost from the system. But this water can be considered as ponded, gathered on top of the node and reintroduced into the drainage system. So, flood volume estimate can be used for further analysis and models can be enhanced by introducing roads and other paved areas as open channels as well. Here also excess water flowing through these channels will create floods.

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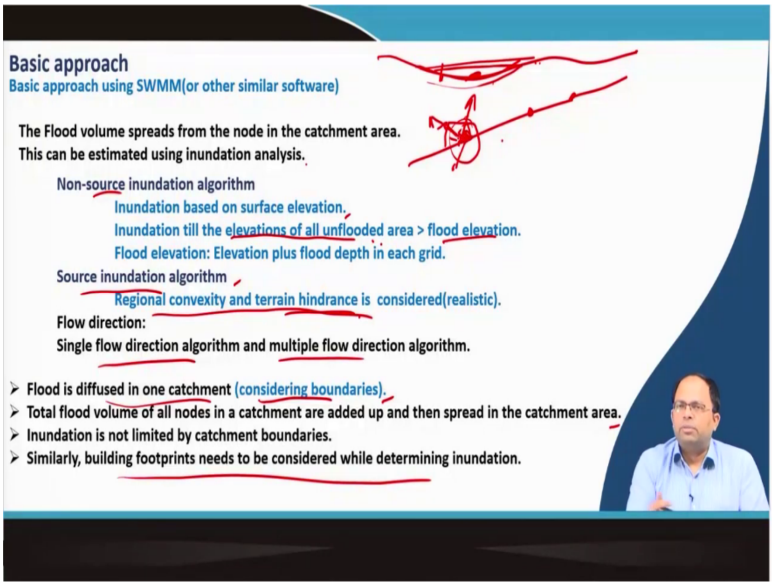

So, as we are discussing in the basic approach we assume the node flooding using SWMM and the flood volume spreads from the node in the catchment area and this can be estimated using inundation analysis. So, there are different forms of inundation algorithm.

Next, we have non-source inundation algorithm. Inundation is based on; inundation till the elevations of all unflooded areas greater is than the flood elevation or flood depth in each grid. We have contour profiles and we know the volume of water. So, based on the contour profile we will determine how much the water will spread in that area. In non-source inundation algorithm, we assume that the spread would be uniform as per the contour. We do not consider the hindrances such as the buildings. So, we need to understand how much the water would spread or what would be the height of that water in that particular reservoir.

Source inundation algorithm actually considers the regional convexity and the terrain hindrance which is a more realistic approach. As you can understand the terrain could be of different shape and water starts flowing from an area based on the slope of this particular land and the water may flow in one direction or it may flow in many directions as well.

So, we have learnt earlier when we have used the DEM models that water flows can be estimated using the D8 algorithm in which water flows in the direction which has got the highest slope, but sometimes water can flow proportionately to different direction based on the different slopes as well.

So, if I consider only one direction flow, that is 1D, if we consider multiple directions then it is 2D. So, in this case we can go for a source inundation algorithm where we can consider either 1D flow or a 2D flow.

But since it is source inundation, terrain hindrances and buildings are also considered. Flood water does not usually get inside the building because buildings are raised or sometimes they have some other productive measures.

So, when flood is diffused in one catchment, we consider the catchment as the boundary and whatever flood volume that we have estimated, we consider to be spread on the entire catchment and we determine the height of the flood, but that is not practically possible because the catchment is designed or determined based on our requirements, but flood water does not understand what is the catchment and it will spread till it can.

So, that means that consideration of boundaries becomes important. Thus total flood volume of all nodes in a catchment are added up and then they are considered to spread in the catchment area. So, this is a crude approach. So, these are the different considerations that you can also make while you determine how this flood volume will spread in that area.

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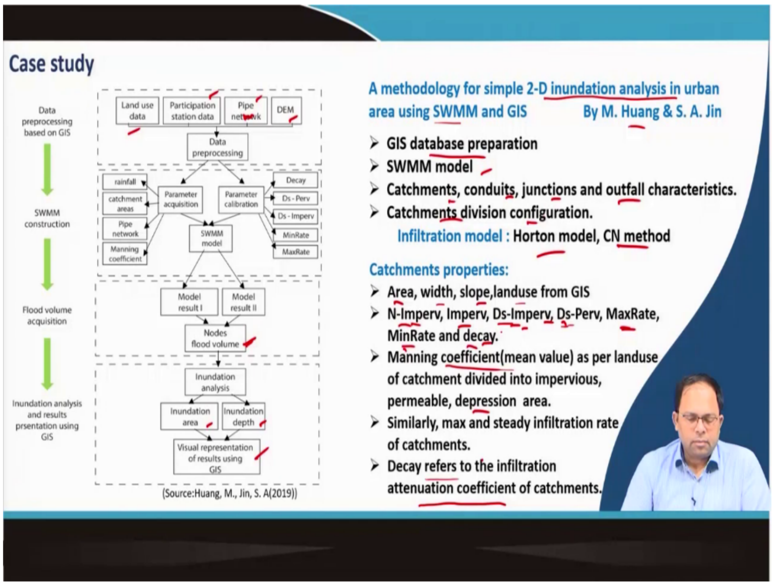

Case study

So, let us look at a case study of a research was conducted by Huang and Jin and this is a methodology for simple 2D inundation analysis in urban area using SWMM and GIS.

So, this is the basic approach that people use. First of all you have to create a GIS database for the area, catchments, conduits, junctions, outfall characteristics. Catchment divisions and their configuration has be fed as input into the SWMM model.

The infiltration model in SWMM can use CN method or Horton method. So, once you have the land, use data precipitation data pipe network data, then DEM data, then we can run the SWMM model. We can run the model for multiple scenarios or for multiple cases and then we can determine the node flood volume and once the node flood volume is determined, then we go for inundation analysis and we determine the inundation area, the total inundation depth of that particular area and we can make GIS map for visually representing that.

First the catchment properties were input into the SWMM model, the area of the catchment, width of the catchment, slope, land use of the catchment were entered. And Manning's coefficient as per land use of catchment divided into impervious and impervious areas were put in.

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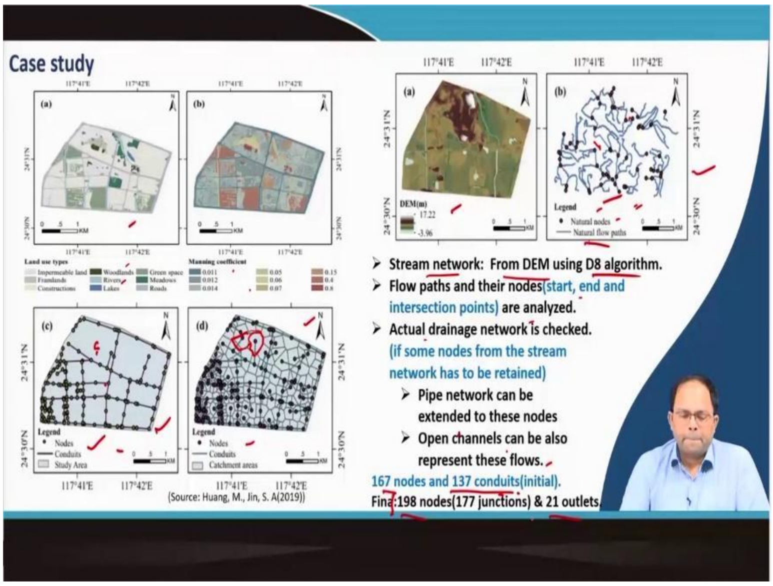

The land use type i.e., impermeable farmlands constructions woodlands rivers and the Manning's coefficient for each of these particular catchments were actually determined and once that is determined, then then based on the natural slope of that particular area or the DEM of that area, the natural flow channels were determined.

We can use ARCGIS to determine this from the DEMs. We can determine the natural flow paths in a particular area. This actually shows in which direction the water will flow and along which channels the water will flow, but this is good for larger catchments or for larger areas, but again in urban areas particularly in flat terrain areas, we have to depend on the node-based catchment i.e., geometric methods of catchment determination. The actual drainage network and the natural flow network both have been combined to create this final nodes and conduits for this particular catchment.

So, this is a hybrid approach where we combine both the approaches together and this gives a more realistic storm water network or catchment for a particular area. The D8 algorithm could be utilized from DEM to determine the stream network and flow paths. Nodes, start, end and intersection points are analyzed and compared with the actual drainage network. Some nodes from the stream network can be retained. Thus both can result in a combined pipe network and open channel can be also used to represent these new flows.

So, we can say that the sewer network could be extended along the natural channels or we can assume open drains for these particular channels, but overall, this together makes up the storm water drainage network. So, initially it was 167 nodes and 137 conduits in this particular case, but after the combined approach there is a total of 198 nodes.

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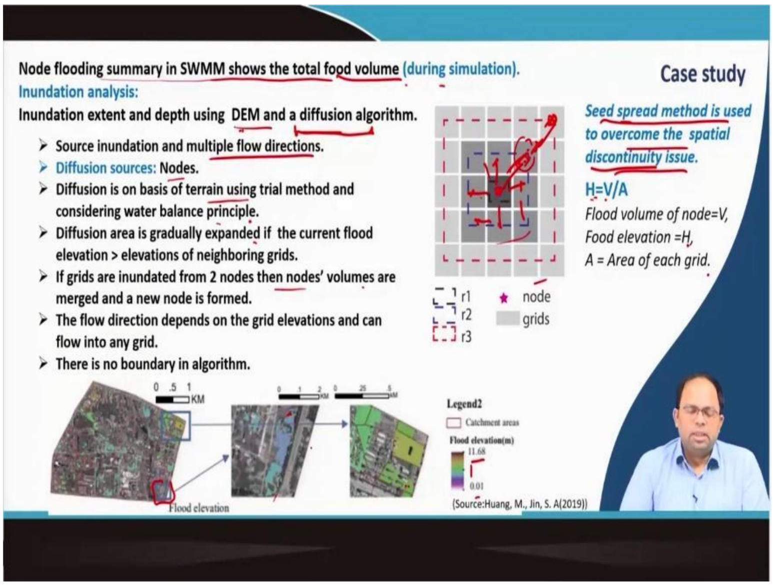

So, based on these nodes as well as the catchment data, the node flooding summary in SWMM was calculated.

So, after that the inundation analysis was conducted and inundation extent and depth using the digital elevation model and a diffusion algorithm was considered.

Multiple flow directions were considered. So, from diffusion sources or the nodes diffusion is estimated on a basis of terrain using trial method and considering water balance principle.

Diffusion area is gradually expanded if the current flow flood elevation is greater than elevations of the neighboring grid. This is a little bit modified approach, where first the node from where diffusion is happening is determined, then gradually it is expanded. That means, we expanded by one cell in each direction and we see that if the level of this area is higher than the flood level and if it is so, then we expand our area for where the flood is occurring.

Then, we keep on expanding in different direction. This is the new inundation algorithm that has been proposed in this particular paper.

So, this method is called seed spread method and it is used to overcome the spatial discontinuity issue. So, we can actually see for each zone how the flooding is spreading to the surrounding zone. If we were considering the overall area then we just divide the flood volume by the total surface area based on the contour profile and this gives the depth and extent of flooding, but discontinuities in certain direction are not considered.

Because of the presence of certain structures, we need to consider the discontinuity and this is possible if we are gradually spreading from one point to the different directions. The flood volume is given by the equation:

$$H = \frac{V}{A}$$

Where Flood volume of node=V, Food elevation =H, and A = Area of each grid

So, in case grids are inundated from two nodes, then node volumes are merged and a new node is formed. We can increase the catchment size as well.

So, the flow direction depends on the grid elevations and can flow into any grid and there is no boundary in the algorithm. This is an improvement on the simple GIS method, but at the same time it is still not over land flow following 2D approach. It is still a simple GIS approach.

So, finally, we can see that for a particular area, there is a spread of flood and the flood heights have been categorized and flood elevation is given in meters which in some areas, is 11 meters whereas, some areas it is as low as 0.01 meters. So, that is how the entire flood model has been determined.

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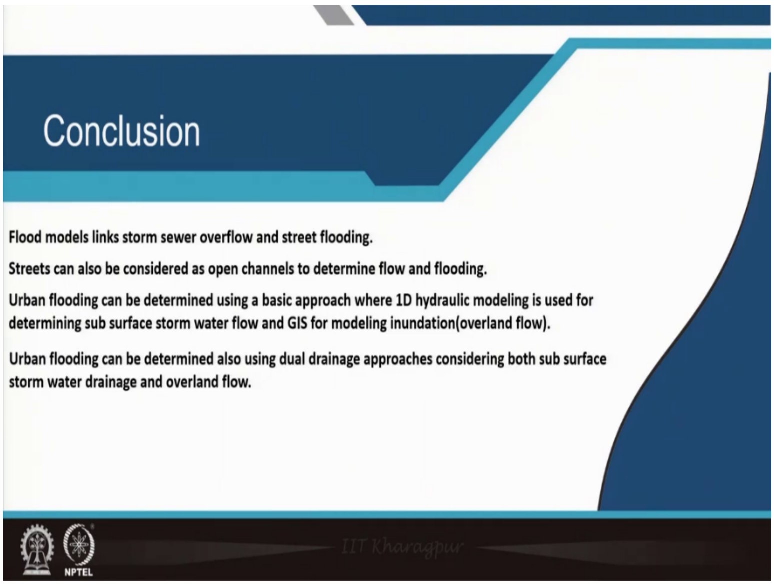

Conclusion

So, to conclude flood models links storm sewer overflow and street flooding. Streets can also be considered as open channels to determine flow and flooding. Urban flooding can be determined using a basic approach where 1D hydraulic modeling is used for determining sub surface storm water flow and GIS for modeling inundation that is overland flow and urban flooding can be determined also using dual drainage approaches considering both sub surface storm water drainage and overland flow.

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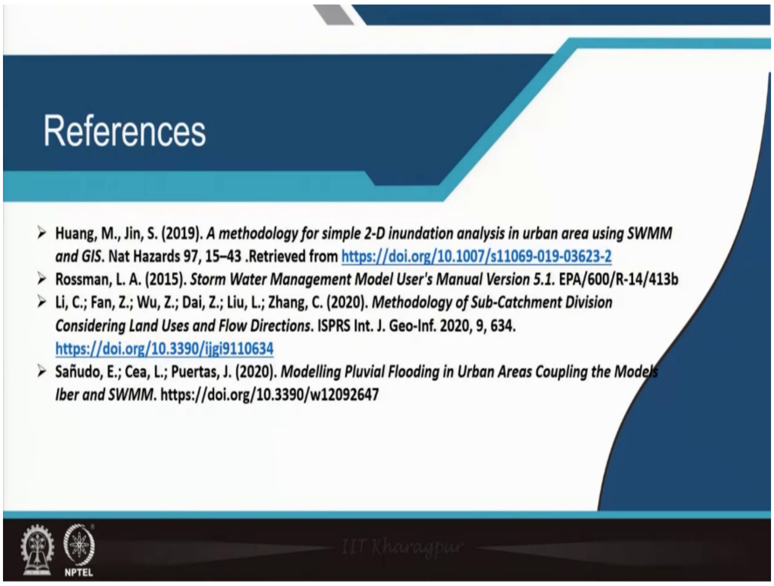

So, these are the references you can use.

Thank you!