Urban Utilities Planning: Water Supply, Sanitation and Drainage
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Module - 08
Water carriage system
Lecture - 39
Storm Water Drainage Planning Part II

In lecture 39, the 2nd part of the Storm Water Drainage planning will be discussed.

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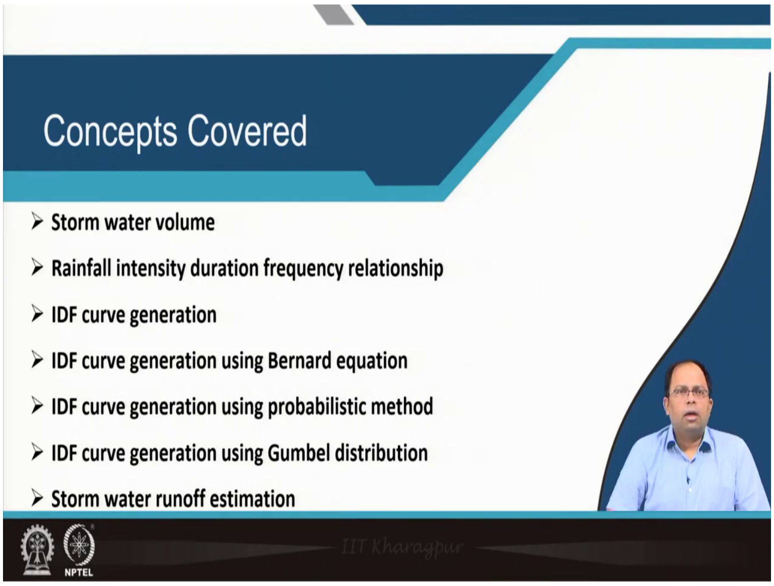

The different concepts that will be covered are on storm water volume, rainfall intensity duration frequency relationship. Then, storm water drainage planning, IDF curve generation, IDF curve generation using Bernard equation, IDF curve generation using probabilistic method, IDF curve generation using Gumbel distribution, and storm water runoff estimation.

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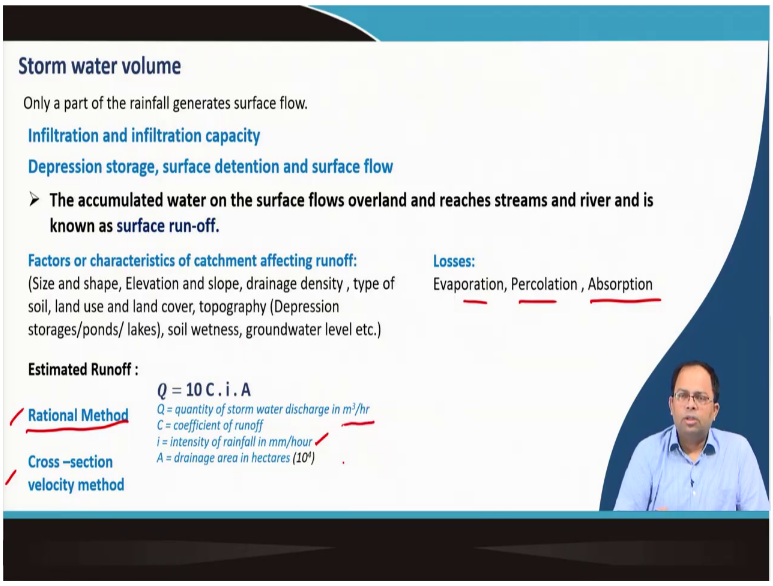

Storm water volume

When we try to determine storm water volume, we have to understand that only a part of the rainfall generates the surface flows or the eventual storm water volume. This is because of infiltration. This means some of the water infiltrates into the ground. This depends on the infiltration capacity of that particular soil.

It also depends on the depression storage; i.e., some amount of water is accumulated in depressions on the ground and once these depressions are filled, then only the water starts flowing outwards. Also, there is some amount of surface detention as well as the surface flow. The accumulated water on the surface flows overland and reaches streams and river and is known as surface runoff.

This surface runoff is actually what generates the total flow or the storm water drainage volume. The water flows over land and then reaches the point of disposal. This means, it travels over the land, or the catchment. Thus, there are certain things in the catchment which affects the runoff.

The size and shape of the catchment has an affect on the quantity of runoff that is generated. The elevation and slope of the catchment will also play a role. The more the elevation, more is the slope, the faster would be the travel time. In addition, the drainage density, type of soil (type of soil may influence percolation more for certain soils), also affects the runoff.

Land use and land cover imperviousness also play an important role. Topography, the depression storages(ponds, lakes and certain undulations in the ground) affects the runoff. The soil wetness is also an important factor. It means that when rainfall happens, soil becomes wet but if the rainfall happens again, then amount of infiltration will be less and thus the runoff will be more.

Groundwater level in that area also plays a role in determining the amount of runoff that is generated by a particular area. Some of the losses that are experienced are the evaporation losses from the catchment, percolation losses from the catchment and absorption losses by trees leaves by the catchment. So, these are the main sources of water losses from the catchment.

Rational method can be employed to determine the amount of runoff or quantity of storm water discharge in meter cube per second. The equation is given as follows:

$Q = C.\ i.\ A$

Q = quantity of storm water discharge in meter cube per hour

C = Coefficient of runoff that is the based on different characteristics which determines the percentage of water that becomes runoff

i = Intensity of rainfall in millimeter per hour (if the rainfall event is for a longer duration, then the intensity may be different as compared to the rainfall event for a shorter duration)

A = Drainage area in hectares

Cross section velocity method can also be applied to determine the volume of runoff when the water goes to a stream and then flows along the stream. We can measure the profile or the cross section of the stream and then, based on the velocity of water in that stream we can determine the quantity of flow or the quantity of runoff.

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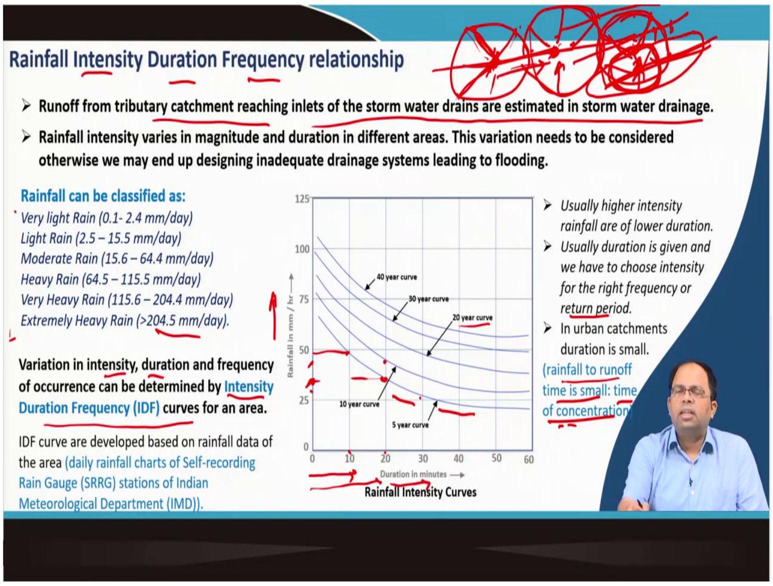

Rainfall Intensity Duration Frequency relationship

The three terms; intensity, duration and frequency are related and there is a need to have an understanding of the relationship between them. However, prior to that, few basic things needs to be understood. Runoff from the tributary catchment reaching inlets of storm water drains are estimated in storm water drainage. From different parts of a particular catchment area, some streams are generated and comes to the main storm waterline or the storm water drainage line.

That means, water flows along some channels which can natural such as natural depressions or valleys and then reach the inlet point of the drain. This is this runoff from tributary catchments reaching inlets of the storm water drains and is estimated in storm water drainage.

Once it enters into the drain, it goes underground into the sewer network or the storm water drain which can be closed drain or sewer.

One need to understand how these flows generate and how it flows in the catchment. This is where one needs to estimate the catchment's effect on the quantum of water that flows over it. Rainfall intensity also varies in magnitude and duration in different areas. Rainfall does not fall uniformly on a particular area. Neither is the intensity uniform throughout the rainfall event. This variation needs to be considered otherwise we may end up designing inadequate drainage systems leading to flooding.

Rainfall could be classified as very light rain, light rain, moderate rain, heavy rain, very heavy rain and extremely heavy rain. Extremely heavy rain is greater than 204.5 millimeter per day, heavy rain is around 64 to 115 millimeter per day. These are different classifications but we need to work with the exact figures of the rainfall to determine the storm water drainage. So, variation in intensity, duration and frequency of occurrence needs to be measured for any rainfall event and it is determined by this intensity duration frequency(IDF) curves for a particular area.

IDF curves are developed from rainfall data of that area using data from rain gauges that measure the rainfall continuously over every day for each area for each rain gauge station that is present in a given urban area.

These daily rainfall charts of self recording rain gauge stations of Indian Metrological Department are used to generate the IDF curves. This is a record of what kind of rainfall event happened and the intensity of rainfall per hour for everyday.

The Figure shows the rainfall intensity curve with rainfall intensity in y axis (in millimeter per hour) and duration (in minutes) in x axis. There is a 5 year curve, 10 year curve, 20 year, 30 year, and 40 year curve. These depicts the frequency.

Duration means the time period for which the rainfall happens. For example, 10 minutes or 20 minutes. The intensity of rainfall is the maximum of all rainfall events within a certain time period. So, that time period is the frequency.

To determine the maximum rainfall that happened of 20 minute duration in the last 5 years, we will use the lowest curve for the corresponding value which is approximately 35. This is the maximum intensity that has been recorded in the 5 year period. Similarly, one can determine the maximum intensity recorded in the 10 year period or 20 year period. So, the more is the frequency, higher is the intensity because chance of this kind of extreme event happening is even more.

The lesser the duration, higher is the intensity. For 10 minute duration, the intensity is 50, whereas, for 20 minutes duration, the intensity is 35, for 30 minutes, it is around 22. Similarly, it goes down when the duration increases. Usually duration is given and one need to choose intensity for the right frequency or return period. For example, 5 year return period or 20 year return period. In urban catchments, duration is small because drains are provided at certain intervals which receives the water at the inlet point from the surrounding catchment within limited time.

The time taken by water to travel from an extreme point to this particular inlet point is the travel time of water along this particular catchment. This may depend on the slope of the catchment, etc. This helps to determine the intensity of rainfall(maximum intensity possible for a particular return period). Whatever is the travel time, it is the time period when rainfall can happen. To determine the maximum intensity of rainfall during the given duration(say 10 minutes), we can use the IDF curve.

Usually urban catchments are very small, so the intensity or travel time should be at least 10 minutes. This is also known as time of concentration. It is basically rainfall to runoff time.

In a particular catchment, water comes to a inlet in sewer line and then water flows along the sewer lines from this inlet. So, time of concentration for a point is the total time taken by water to travel from the extreme point in the catchment to the inlet and then the time it takes to travel from the inlet to this point.

The first part of the time is the overland flow time, whereas the next is the gutter flow time. For every inlet, the time of concentration is different. Similarly, the area is also different and also includes the entire area before that.

This is how we estimate the time of concentration for each of this inlet. It helps to determine the storm water volume that is considered for a particular point.

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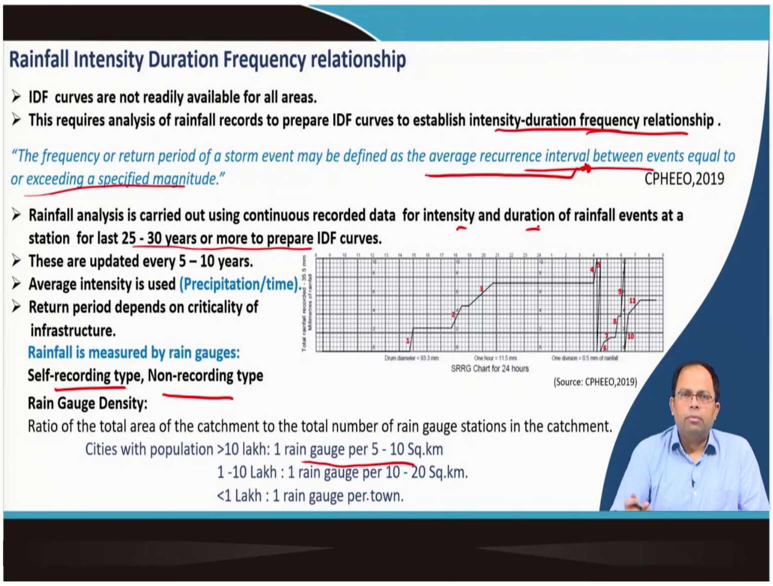

Rainfall Intensity Duration relationship

The understanding of IDF curves is very important. IDF curve help us to understand the maximum rainfall that is possible for certain duration for a certain return period.

It is used for designing pipelines because whenever we are designing pipelines for storm water drainage, we have to design it for extreme cases. IDF curves are not readily available for all areas. This requires analysis of rainfall records to prepare IDF curves to establish intensity duration frequency relationship. Thus, if IDF curves are not available, it needs to be prepared.

The frequency or return period of a storm event may be defined as the average recurrence interval between events equal to or exceeding a specific magnitude. So, if we have a particular intensity of rainfall, the frequency or return period of a storm event may be defined as the average recurrence interval between events equal to or exceeding a specific magnitude.

There is a need to determine the average recurrence interval for a particular event or extreme event. The return period actually determines the maximum possible intensity that is possible in that return period. Within that time period, the maximum frequency is observed.

Thus, whenever IDF curves need to be generated, we need to have information about the kind of frequency, kind of return periods, and rainfall data that has been recorded over time for that particular area. Rainfall analysis can be carried out using continuous recorded data for intensity and duration of rainfall event at a rain gauge station for each day of last 25 -30 years or more to prepare IDF curves. These curves are updated every 5 to 10 years.

For a particular time duration, we take the average intensity and return period depending on criticality of infrastructure. For more critical infrastructure like an airport, we will consider 100 year return period; that means, the storm recurrence interval has to be 100 years.

The rainfall is measured by rain gauges. These are of types: self-recording type and non-recording type but usually self-recording type measures both the intensity and duration.

As seen in this graph, the given line measures the total rainfall and based on this, we can actually determine the intensity. It is not only the intensity that varies over a particular rainfall event, but rainfall also varies area-wise. This can only be determined by putting rain gauge stations in every area. So, the rain gauge densities also play an important role. The ratio of the total area of catchment to the total number of rain gauge stations in the catchment gives us the rain gauge density. Cities with population greater than 10 lakh need to put 1 rain gauge per 5 to 10 square kilometers. For population 1 to 10 lakh, this is 1 rain gauge per 10 to 20 square kilometers and for 1 lakh, 1 rain gauge per town.

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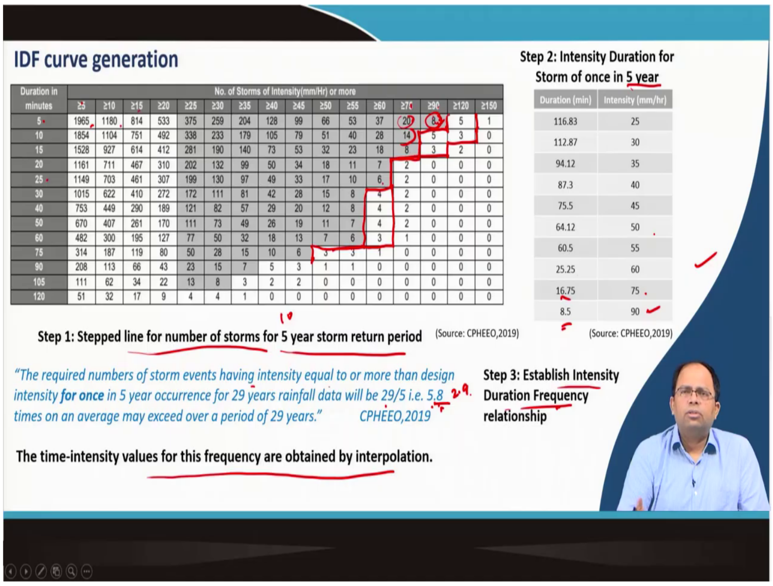

IDF curve generation

In the Table shown here, the duration is in minutes (5 – 120 minutes) and the rainfall intensity (≥5 - ≥120) is given. Corresponding to this data, an array of the number of events that has happened is given. This chart is prepared based on the data that is already available. We have to summarize the data and perform a cumulative addition both horizontally and vertically, and then only we get these figures.

This means around 1965 rainfall events of duration 5 minutes had intensity greater than equal to 5 millimeter per hour. Similarly, for a duration of 120 minutes, 51 events were recorded where the rainfall intensity was greater than 5 millimeter per hour. Greater than 10 mm/hr of intensity was observed for 32 events for 120 minutes. For 2 hours of duration of rainfall,17 events were observed with rainfall intensity greater than 15. For smaller duration events like 5 minute, the rainfall intensity greater than 5 is 2000 events. Greater than intensity of 90 millimeter per hour, 8 events were observed. Greater than 75 millimeter per hour, 20 events were observed, but of duration 5 minutes. Thus, lesser the duration higher is the intensity.

Using this table, we can create a step line for number of storms for 5 years storm return period. This is a collation of data for 29 years. There is a separate step line for 10 years storm period.

The required number of storm events having intensity equal to or more than the design intensity for once in 5 year occurrence for 29 years of rainfall data will be 29 divided by 5 that is 5.8 times on an average may exceed over a period of 29 years.

As we are considering a 5 year return period and the total data is for 29 years, there is a chance that 5.8 times on an average the rainfall intensity may exceed for over that 29 years. If I take the value of 8 which is for 5 minute duration and this is for 90 millimeter per hour, 8 times the event has occurred. At least this is more than 5.8. Then 14 times 75 mm intensity has happened for 10 minutes.

This process continues and 45 millimeter of intensity is observed for a 75 minute period which happened 6 times. The intensity values for given frequency are obtained by interpolation. After interpolation, we get this table where we have intensity duration for storm once in 5 years. For 90 millimeter per hour intensity, this duration is 8.5 minutes.

For 90 millimeter intensity, duration was 5 minutes, but we interpolated and the value to be 8.5. Similarly, for 75 mm, this value became 16.75. For 60 mm of rainfall this value became around 25.25.

This is how the data could be correlated together and we can establish the relationship between intensity and duration and frequency using this data. The frequency is already chosen which is 5 year period. If we consider 10 year period, then we would have divided by 10 which is 2.9.

For different time periods for different frequency, we can have different steps and accordingly we can generate this table from where we have to establish a relationship between intensity and duration. This could be done through any sort of regression.

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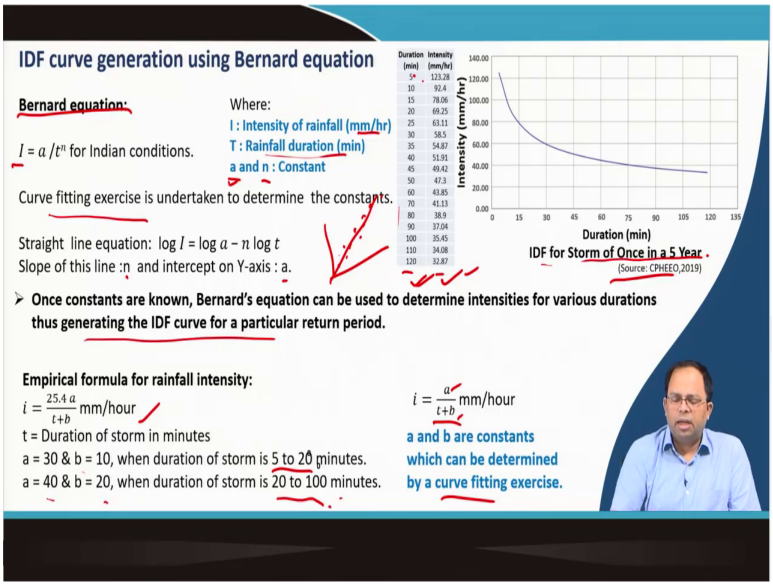

IDF curve generation using Bernard equation

In Indian condition, we use this Bernard equation for generating IDF curves where the relationship that is proposed is given as follows.

$$I = \frac{a}{t^n}\ for\ Indian\ conditions$$

where

I = Intensity of rainfall (mm/hr)

T = Rainfall duration

a and n = Constant

We need to calibrate based on the data that is available. For example, in this particular case, the data is 5 minutes duration, intensity is 123.28 millimeter per hour; 120 minutes duration, 32.87 millimeter per hour. Once this rain gauge data is obtained from the metrological data, we can fit these particular values and we can determine the values of a and n.

Curve fitting exercise is undertaken to determine the constants by taking the log of both sides as shown below:

Straight line equation:

$$\log I = \log a - n \log t$$

Slope of this line: n

Intercept on Y-axis: a

We can fit a linear line between these points and can determine the value of a and n based on the intercept and the slope of the line. Using this relationship, we can plot the intensity and duration in a graph. From this graph we can have the IDF relationship or IDF for storm once in 5 year period. Once constants are known, Bernard's equation can be used to determine intensities of various durations, thus generating the IDF curve for a particular return period.

Already lot of researchers have developed several empirical relationships which have resulted in various formulas. One of the formula is given below:

$$i = \frac{a}{t+b} \; mm/hour$$

a and b can be determined by curve fitting exercise.

An example is given below:

$$i = \frac{25.4\, a}{t+b} \; mm/hour$$

Where

t = Duration of storm in minutes

a = 30 and b = 10, when duration of storm is 5 to 20 minutes

a = 40 and b = 20, when duration of storm is 20 to 100 minutes

The value of a and b is not fixed, but it varies as per the duration of the storm. So, we can directly use this formula as well. Bernard's equation is common in Indian context. However, apart from this, there are other methods as well.

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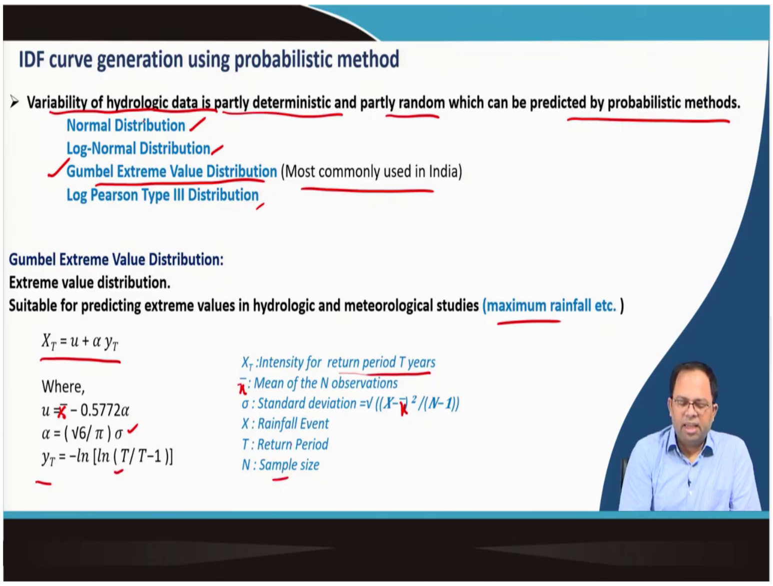

IDF curve generation using probabilistic method

As rainfall events are probabilistic, we can use a stochastic approach as well. There is variability of hydrologic data that means, we are taking the maximum, but there is variation in the data. So, it is partly deterministic and partly random which can be predicted using probabilistic methods.

We can use the equation such as Bernard's equation which was following a certain formulation. Similarly, we can use a normal distribution to determine the probability distribution or a log normal distribution or a Gumbel extreme value distribution or the log-Pearson type III distribution. Out of these distributions, Gumbel extreme value distribution is the most commonly used one. This is basically a curve which needs to be fitted with the data.

It is suitable for predicting extreme values in hydrologic and meteorological studies like maximum rainfall and it is given by following equations.

$$X_T = u + \alpha y_T$$

Where

X_T = Intensity for return period for T years

$\bar{X}$ $\bar{X}$ = Mean of the N observations

σ = Standard deviation = $\sqrt{\left(\frac{(X-\bar{X}^2)}{N-1}\right)}$ $\sqrt{\left(\frac{(X-\bar{X}^2)}{N-1}\right)}$

X = Rainfall event

T = Return period

N = Sample size

$$X_T = u + \alpha y_T$$

$$u = \bar{X} - 0.5772\alpha$$

$$\alpha = (\sqrt{6/\alpha})\sigma$$

$$y_T = -\ln[\ln(T/(T-1))]$$

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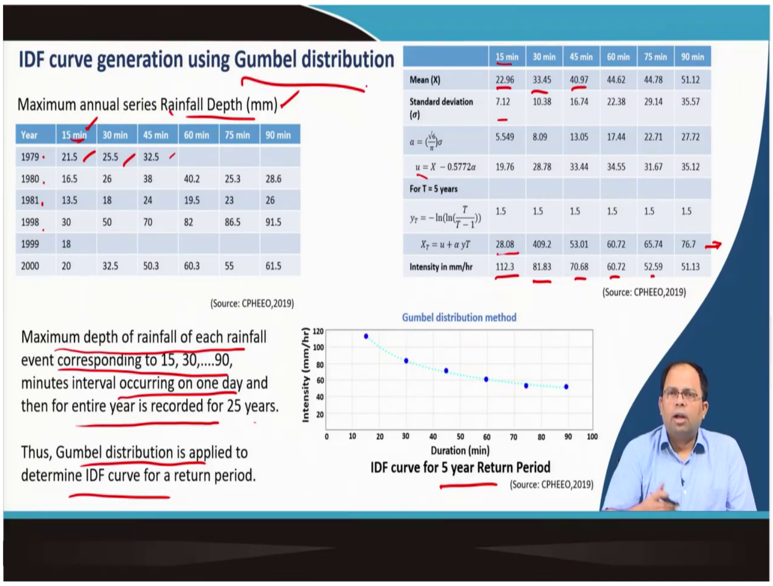

The Table shows the maximum annual series rainfall depth data in millimetre for year 1979, 1980, 1981, and 1988. For duration of 15 minutes, maximum value observed was 21.5; for 30 minutes, it was 25.5 millimetre; and for 45 minutes, it is 32.5 millimetres. For 15 minute duration, if we take all the observations, it becomes the number of samples that can be put in the formula. This is maximum depth of rainfall event corresponding to 15, 30, 90 minutes interval occurring on one day and for entire year recorded for 25 years.

The Gumbel distribution is applied to determine the IDF curve for a particular return period. Let us assume that in this particular case, we are considering data for a 5 year return period. We calculate the mean for 15 minutes which is 22.96 out of all this data, for 30 minutes it is 30.45..

Similarly, we calculate the standard deviation using the formula in the previous slide. Then, we calculate value of a, u and T equal to 5 year periods based on the given data. We can calculate value of y_T and then X_T value which is given in millimeters of rainfall. For the given duration, we get a maximum rainfall intensity of 28.08 millimeter of rainfall.

Now, we need to convert it into intensity which is millimeter per hour. So, we will multiply this by 60 minutes and then divide by 15 minutes which becomes 112.3.

The results are plotted in the curve to create the intensity curve which follows the Gumbel distribution. This is how the intensity curves are created using the Gumbel distribution or a stochastic approach.

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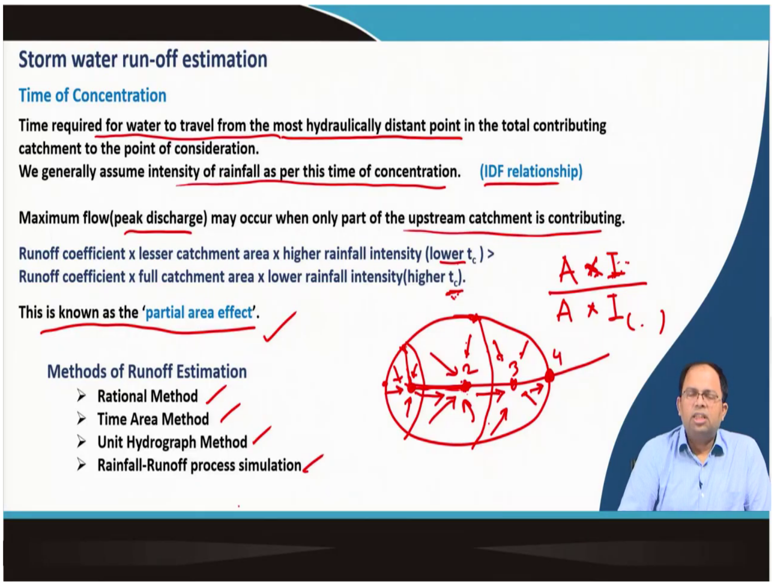

Storm water run-off estimation

The time of concentration is the time required for water to travel from the most hydraulically distance point in the total contributing catchment to the point of consideration. In a catchment area, different direct areas contribute water to different inlets in the drain.

Usually, we can assume that water reaches an inlet from the surrounding area and via travelling along the drain.

Water coming from the surrounding area may take larger time than water travelling from upper catchment area entering via another inlet and then travelling along the drain. In any case, the intensity of rainfall is assumed as per the time of concentration from IDF relationship.

Maximum flow peak discharge may occur when only part of the upstream out of the entire catchment is contributing. Usually we assume that the entire catchment is contributing and whenever the entire catchments water reaches the particular point, we may have the maximum discharge, but it may not be true. That means, maximum flow may occur when only part of the upstream catchment is contributing. That is because the total flow that is being contributed depends on not only area but also on intensity.

If the entire area is considered, the flow takes a certain amount of time. Accordingly, intensity is determined. But if the area is less, the time required to flow is less but intensity may be higher because the time of concentration would be less.

Runoff coefficient x lesser catchment area x higher rainfall intensity is greater than runoff coefficient x full catchment area x lower rainfall intensity for higher time of concentration. This is called the partial area effect.

The total volume of water could be estimated via several methods.

One is the rational method to determine sewer volumes. Other methods include time area method, unit hydrograph method, and rainfall runoff process simulations.

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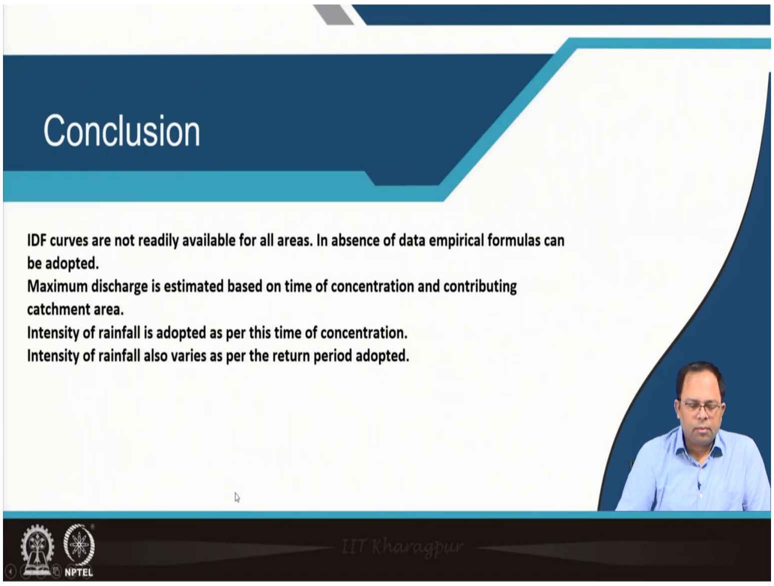

Conclusion

To conclude, IDF curves are not readily available for all areas in absence of data empirical formulas can be adopted. Maximum discharge is estimated based on time of concentration and contributing catchment area. Intensity of rainfall is adopted as per this time of concentration and intensity of rainfall also varies as per the return period adopted. These are the few points that can be considered while determining IDF curves time of concentration and the intensity of rainfall for that time of concentration.

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References

These are the references that can be used.