Water Resources Engineering
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Lecture No. 15

Today we will continue with our discussion on estimation of the flood discharge. As we have seen the flood expected in a channel or a river would depend on a lot of factors. One of the most important factors is the rainfall and based on the rainfall we can convert that into runoff using various techniques. For example the unit hydrograph method which we have already discussed will convert a given rainfall into runoff using the unit hydrograph or we have also seen that if we have various data available for previous years about the flood magnitude in different years we can extrapolate that data and predict the flood for a return period which is longer than the duration of the given data. There are lots of methods of estimating the flood and lets list them. The first method which we saw was based on the unit hydrograph theory. The second method which we discussed was dependent on the flood frequency and we analyzed it based on the available data while the first one is based on the rainfall runoff conversion.

Two other methods which are sometimes used in absence of other kinds of data are the rational method and in absence of all these data which are required for other methods we can use some empirical methods to obtain the flood discharge in which we use some empirical equation.

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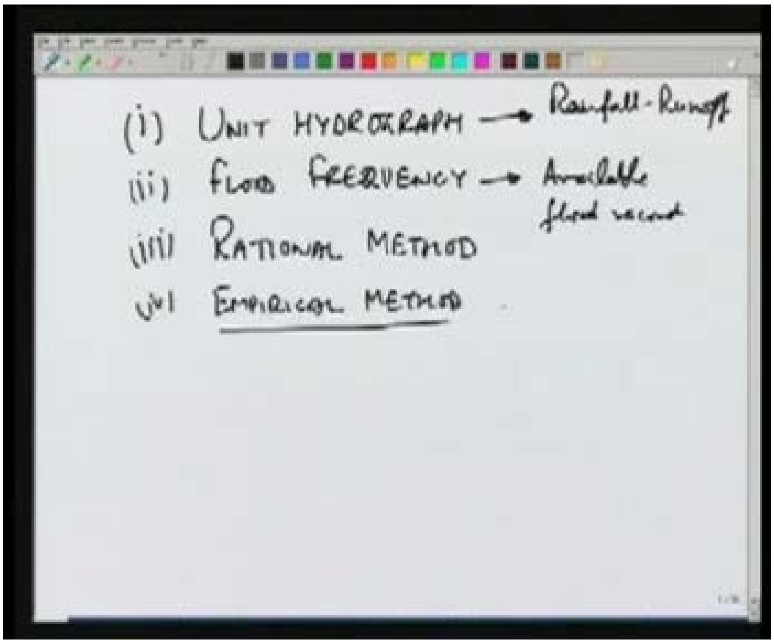

In the rational method we also relate the rainfall with runoff. But compared to the unit hydrograph theory where we have a hydrograph denoting the effect of a unit rainfall, finding out the runoff and then using it for actual rainfall and predicting the actual runoff, this is a little different. In the rational method we relate this using a coefficient. Rainfall given intensity of i, occurring over the area A will produce some runoff where C is an empirical constant which will depend on the area. Here we have a direct relationship like C into iA while in the rainfall runoff relationship using the unit hydrograph we have a unit hydrograph which we apply to the excess rainfall and predict what will be the actual flood in the river.

The unit hydrograph theory we have already discussed in detail. We will see the excess rainfall; we'll take for different projects little later on. We have also seen flood frequency studies in which we say that there will be some kind of frequency distribution for the floods and if we plot the return period versus the flood discharge for example return period may be in years flood discharge may be in meter cube per second we would get a line like this based on the available data. Based on the available data we can plot let's say we have data available for 50 years we may have a return period close to 50 years here and then may be 2 years. We can extrapolate this and predict may be a 100 year flood or a 1000 year flood by extending this line and getting the value of Q.

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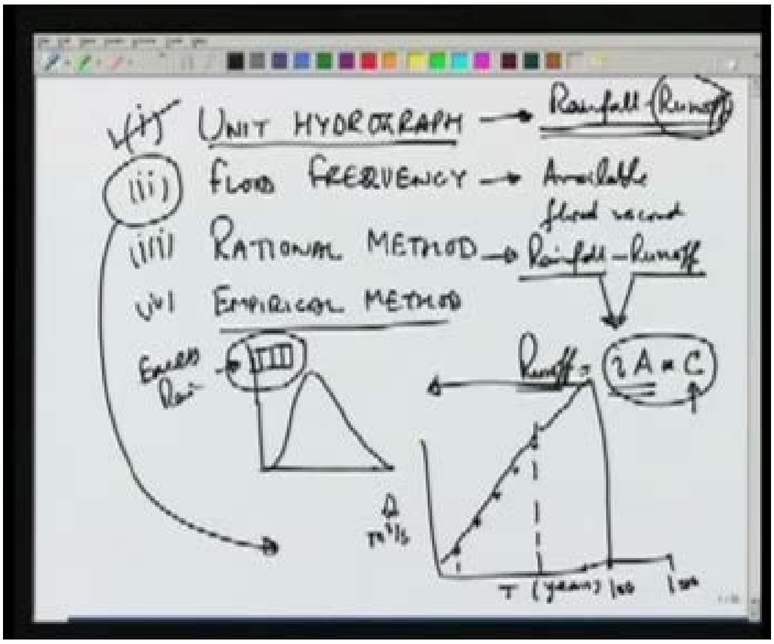

We have already seen some distributions like Gumbel's distribution Log Pearson type III distribution and how to use them to obtain return period let's say 100 year return period flood or 1000 year flood like that. This we have discussed. Let's start today with the rational method. The idea behind rational method is quiet straight forward. If you have a rainfall let's say rainfall intensity is i and this is the time typically in hours rainfall intensity typically will be in millimetre per hour and let's say that this is the intensity i. If the catchment area, A typically in square kilometres is given we know that how much volume of precipitation will occur for an intensity i over the catchment area A. The volume of precipitation would be i into A and it has to be converted into proper units. For example if i is in millimetre per hour and A is in kilometre square we will have to take care of the units by adding some constant term here. We will not discuss these constants we will just take i into A with proper units. Out of this total volume of precipitation some fraction will go as runoff. That fraction we can say that the C into i into A where C may be thought of as runoff coefficient. If intensity i rainfall occurs over an area A, at steady state it will create a discharge of i into A and some fraction of that discharge C we can take as the runoff coefficient giving us the maximum flood discharge equal to C into i into A.

Now let us look at the temporal distribution of the runoff. On the same figure we can plot a curve which will show us runoff per unit area. This runoff per unit area will increase with time, will attain a constant value, remain constant and once the rainfall stops it will decrease with time. The shaded area here and the shaded area here would be same such that the total volume of runoff is equal to some fraction C into i into the area. This time where the runoff reaches a constant value is known as the time of concentration. Under very simplified conditions let's look at a catchment. We have a stream with tributaries and Tc is the time for a raindrop to reach the outlet from the farthest point of the basin. A rainfall which occurs here will move to the channel and then go towards the channel and reach the outlet after sometime. Similarly a raindrop falling at this point will reach the channel and then follow the stream to the outlet point. Whatever is the maximum time out of these will be known as the time of concentration. At that time the entire area would be contributing to runoff and the runoff will reach a maximum value. It will remain at that level till the rainfall stops because beyond this point, beyond the point t_c we say that the entire area of catchment is contributing to runoff and it remains constant and then this empirical constant C we use to denote what fraction is going as runoff so this time t_c is important.

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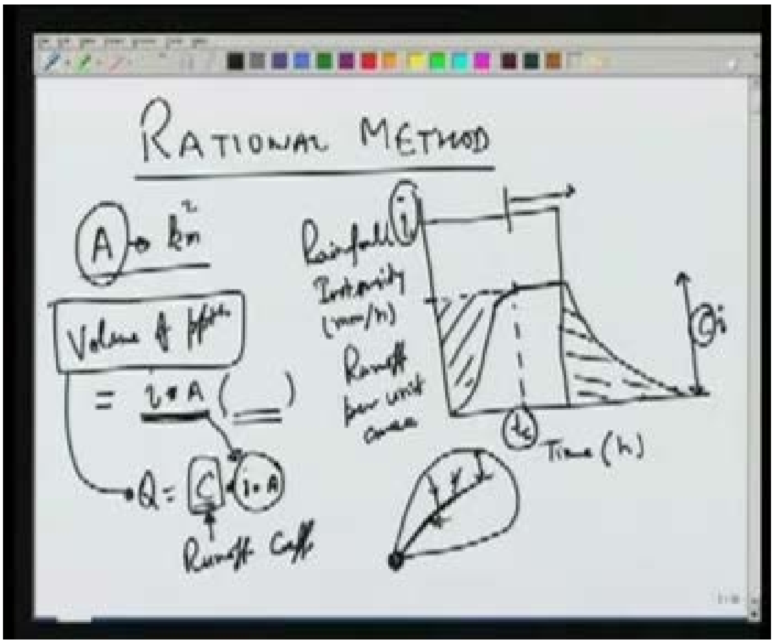

Our rainfall duration should be more then t_c in order to achieve this constant runoff. Using this we write our rational formula equation as Q equal to C i A and in this we will express this i and A in consistent units so that we get Q in meter cube per second or whatever units we desire. i will depend on what is the return period and what is the time of concentration. The duration of the rainfall should be t_c because we know that beyond t_c duration if the rainfall occurs the peak discharge will not change and if we take a duration which is larger than t_c then intensity would correspondingly reduce. We want the maximum intensity and therefore the duration should be taken as the minimum allowable which is t_c. If it is less than t_c the entire area will not be contributing to the runoff and therefore the runoff value will be smaller. Any duration less then t_c will not reach the maximum flow and we want a duration of rainfall which is equal to t_c.

The other term which we want is the return period. What is the return period of this rainfall i? Return period as we have seen will depend on the importance of the structure. So T depends on the importance of structure. Whether we are designing a storm water drain or whether we are designing a dam the return period T would be larger for a more important project. Once we decide on the duration t_c and the return period T we have seen various equations which relate the intensity with the duration and the return period and the equations are typically of this type KT to the power n t_c plus A and raised to the power some factor m. The values of K, n, a and m will depend on the catchment properties. There are some values given for these parameters for different areas. For example for Indian conditions typically the values taken are K is about 40 to 120. Then n is roughly 0.1 to 0.7. These values are generally used for Indian condition depending on the catchment. So there is a wide variation in these parameters. For a particular catchment if we are considering the intensity in that catchment we'll have to come up with what are these coefficient values. Using that we can find out the intensity.

The return period T as we have discussed will depend on the type of project. For example if we are designing storm water drains T may be 10 to 20 years. If it’s a structure which is more important then it may be a 100 years or 50 years. Once we get the value of i, the other parameter is C which is an empirical constant. Again it will depend on the type of catchment and after designing the return period based on the importance of the structure we need t_c, time of concentration.

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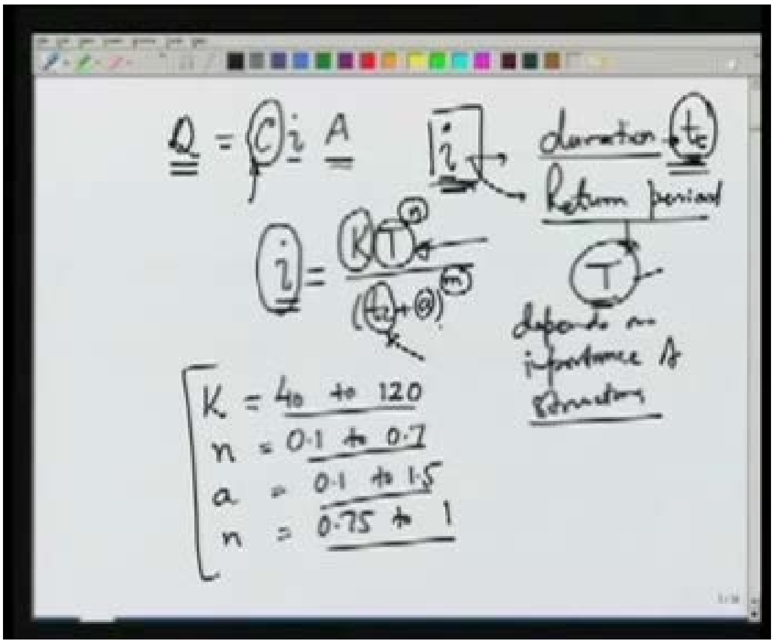

The time of concentration again will depend on the catchment properties and there are lot of empirical equations given for estimating the time of concentration. For example one of the equations which is given as we have seen in instantaneous unit hydrograph theory also is of this form in which L is the length of the catchment. In this case L may be taken as the length along the stream. Then L is the catchment length. L_c is up to the centroid of the catchment. If the catchment centroid is let's say some where here, then L_c would be along the stream. What is the length of the catchment? S is the slope. L_c is length to centroid which really means along the stream. If the centroid is here a point opposite to that on the stream the length to that point will be L_c. n is an exponent which is generally taken as about 0.38. S is the slope which can be obtained from a topographic map of the basin and C_t is an empirical constant. The value of C_t typically ranges from about 0.5 to 11.7. For example if it's a valley then typically we use about 0.5. If it's a mountainous area then we use 1.7. This will give us the value of t_c. The C_t value will depend on units which we are using. Typically t_c is taken in hours and the lengths are taken in kilometres. So we get the time of concentration in hours using this equation.

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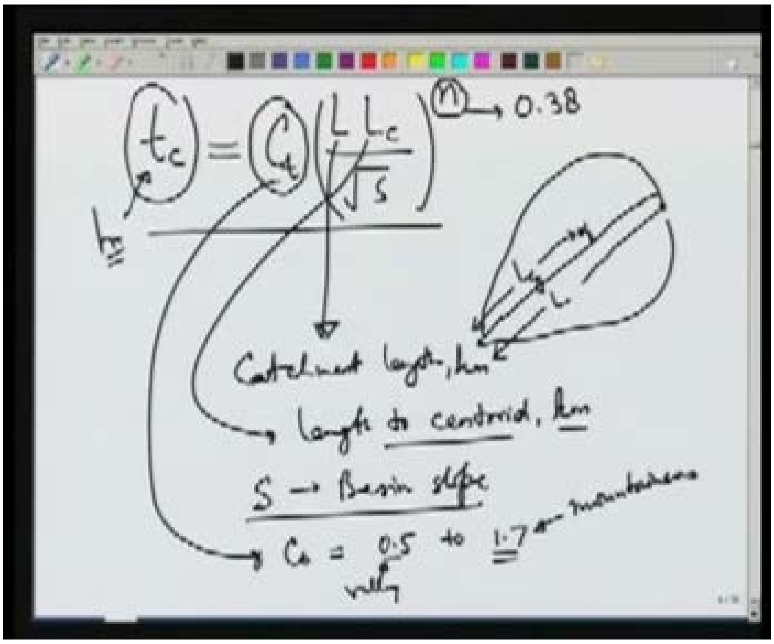

Using that time of concentration, using the values of a, m, n, K and the design value of T we can obtain the intensity of rainfall i and then using Q equal to CiA, we get Q provided C is known. This C, the runoff coefficient is again dependent on a lot of properties. For example surface of the catchment. If the surface is impervious then C would be higher because more runoff will occur. If the surface is pervious then lot of infiltration will occur and less runoff will occur. Slope also; large slope means the velocity will be higher and therefore less chances of infiltration, less time for infiltration and then land use will also affect. An industrial area will be paved little bit, agriculture area may not be. Depending on that we can have values of C and an example we can give as a table which says that for sandy soil depending on the slope for example if it's a flat slope which typically we say is less than 2% slope or steep slope which we say about 7%. So for a flat slope the value of C would be ranging from about 0.05 to 0.1 and for a steep slope typically 0.15 to 0.2. Similarly if you have residential area value of C is taken as about 0.3 to 0.7. If you have industrial area then C is normally taken as about 0.5 to 0.9. If the area has lot of streets then naturally in the streets are impervious, most of the precipitation will go as runoff and C will be very high. In this case C may be taken as almost 1. That is about 95% of the precipitation goes as runoff.

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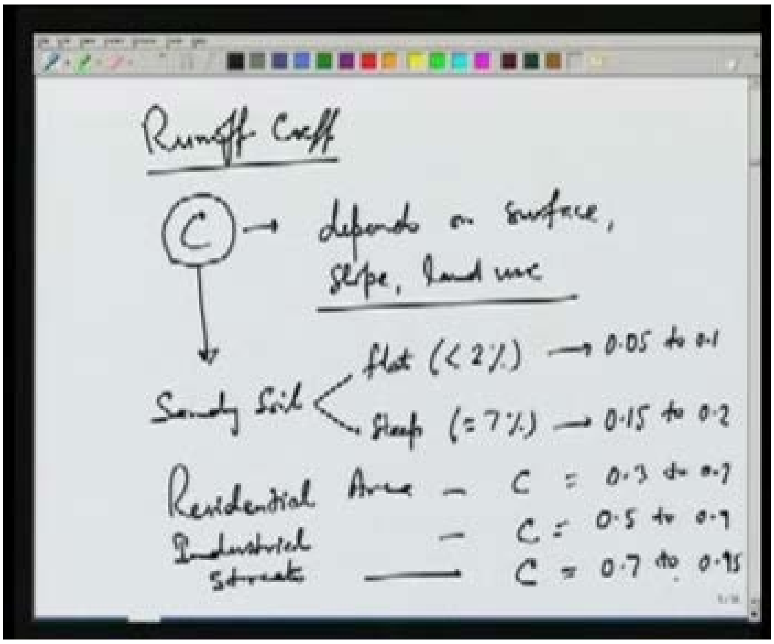

Similarly if we have agricultural area the value of C will depend on the type of soil. For example if we have loam then again depending on the whether the slope is flat or steep the value of C can be taken as 0.1 to 0.2 for flat slopes and 0.3 to 0.4 for a steeper slopes. If you have clay then since infiltration is smaller the runoff coefficient will be higher and again depending on what is the slope the values of C can be taken little higher; for example 0.4 to 0.5 and 0.6 to 0.7. Knowing the type of surface, the slope of surface we can estimate what will be the runoff coefficient and knowing the intensity and the area of catchment we can estimate what is the flood discharge by using the rational formula.

Sometimes the catchment may not consist of a single type of soil or slope. In that case we may have to sub divide the catchment area into different areas. For example there may be some area here which is agriculture and there may be some area here which is residential. If we say that there are sub areas let’s say Ai's, i going from 1 to n. So we have this n sub areas Ai which have different coefficients Ci. Then we can find out an effective runoff coefficient by taking weighted average of all the C's and use that C in the rational formula. The C which we can use let’s say C bar would be equal to sigma Ai Ci over sigma Ai or …… equal to the area. so this can be used to have the rational method applied to an non homogenous catchment.

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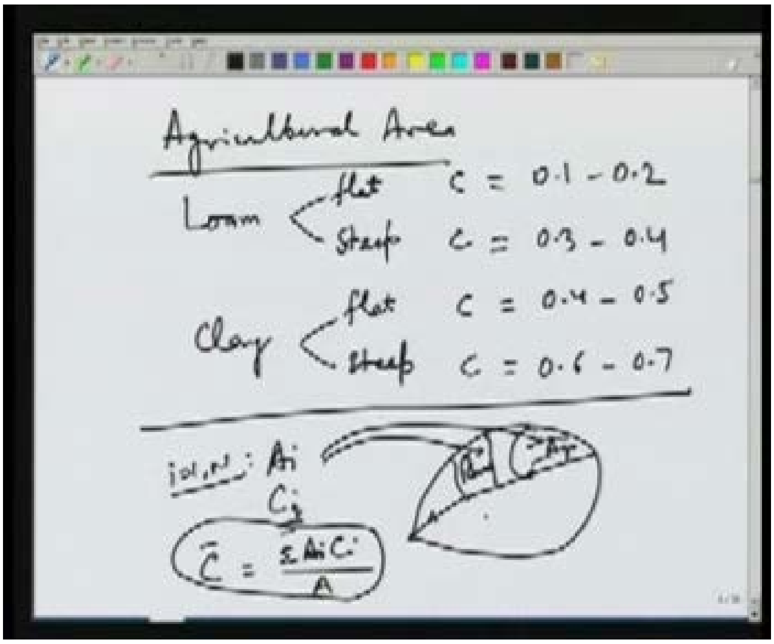

One more equation which we sometimes use for t_c which I have not discussed. It is just one of the methods which we use to estimate the time of concentration. There are some other methods also. For example there is an equation known as Kirpich equation which relates t_c as a function of length and the slope. If we see this equation this uses the length of the catchment, length of the centroid and the slope of the catchment.

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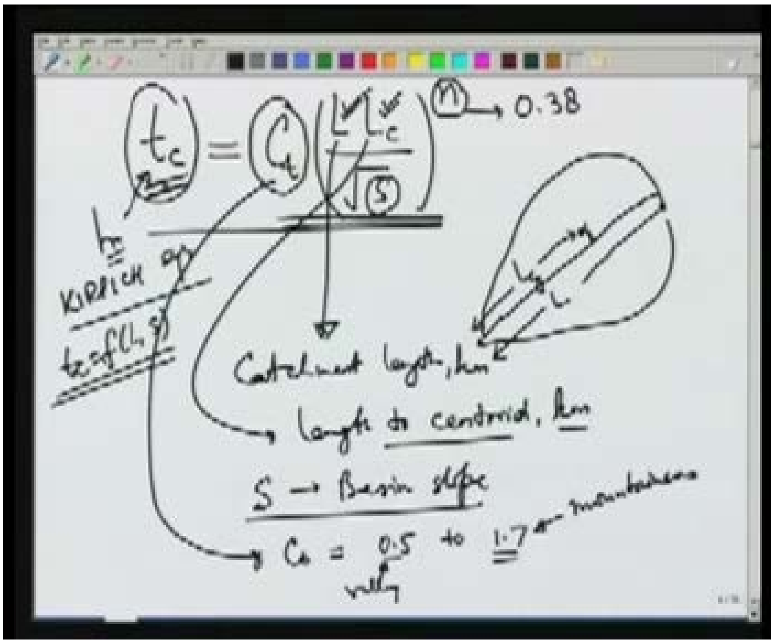

In the Kirpich method t_c is given as function of length and slope and the function which is used is t_c equal to a constant 0.0195. The units in this case are minutes for t_c and meter for length. This is a little different from the previous equations where we had t_c in hours and L in kilometres. The slope as per this method is given by delta H over L where delta

H is the elevation difference between the farthest point or remotest point and outlet. The slope is computed based on the elevation of the remotest point in the basin and the outlet divided by the length. So that slope is used in this equation to get t_c.

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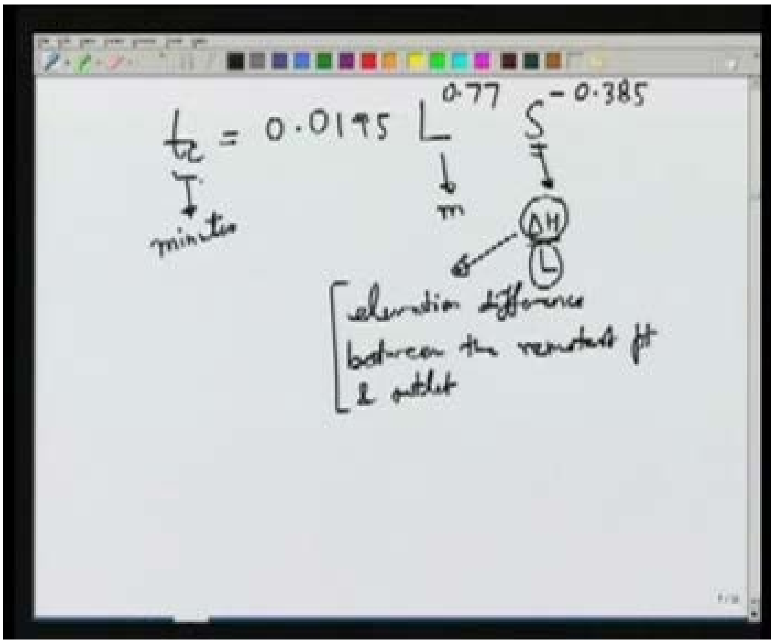

We can use any of these methods to estimate the time of concentration. The rational method is one of the methods. There are some other empirical methods which correlate the maximum discharge typically with the catchment area, generally catchment area to some power for example 0.75 or 0.66. Generally they are of the form C into A to the power n where n is typically about 3/4 or 2/3 or 0.8. There are different formulae which use different values of A. In the rational method there is limitation to applicability. The area should be small enough. Typically less than 50 square kilometer the rational method can be applied easily. Beyond that having a constant intensity of rainfall over the entire area is not a very good assumption. So the rational method may not be applicable. Empirical methods are applicable over larger areas also. So this A can be quiet large also; sometimes thousands or even more than that. Some of the empirical equations which we will discuss here are derived for Indian conditions, some for US conditions and some have used data from all over the world. We can look at some of them here.

For example Dicken's formula which says that the flood discharge would be given by some constant C into area to the power 3/4 or 0.75. Most of these empirical formulae have these two values which are different. They will be using a different exponent for area and a constant which would depend on the type of area. For example Dicken's formula …. C, which is equal to 6 for north Indian rivers. For rivers in north Indian plains the C value which is used is equal to 6. Then for some other conditions for example if you have north India hilly areas then we increase the value to about 12. Because the slope is larger, runoff will be higher because of less infiltration and similarly there are other values given for example 20 for central India and about 25 for coastal Andhra Pradesh. Depending on which area you want to apply the Dicken's formula the C value will be different, catchment area will be known to us. Generally in all these equations we will be taking the catchment area in kilometre square and the flood discharge in meter cube per second.

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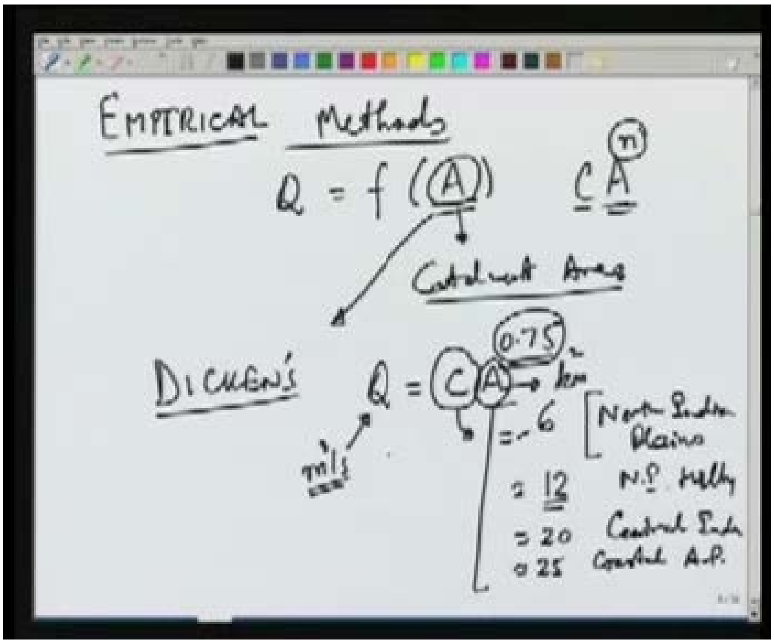

Some other equations which have been used are Ryves equation. Similar to the Dicken's equation this also uses Q equal to C but now the power becomes 2/3 and for this case the coefficient C is about 7 for areas within 80 kilometres from coast. This equation itself is valid or has been derived for Tamilnadu, Andhra Pradesh and Karnataka areas. So it should not be used for other areas directly. For the areas which are within 80 kilometres from the coast C is about 7. Then it's about 8.5 for areas which are more than 80 but less than 160. So distance x between 80 and 160 kilometre we can use 8.5 and near hills it can be increased to value of 10. Knowing the catchment area, knowing the type of area and location of the area we can estimate C and therefore Q.

Similarly Inglis has suggested using an equation of this type. This is also a local equation applicable to Western Ghat's in Maharashtra. So this should also be used only in that area. For other areas we may use a similar form of equation but then we may be using different constants. So either a power equation like this or a equation like this can be used but these coefficients 2/3, the exponent and the coefficient will depend on the type of area on which we are applying it. If we are within some of the areas which are covered by these equations we can directly use these equations. If not we may have to develop our own equation and apply that. In Maharashtra Western Ghats we can directly use this equation. Sometimes we use this with little modification in the coefficient or in the southern part of India we can use this equation with these coefficients.

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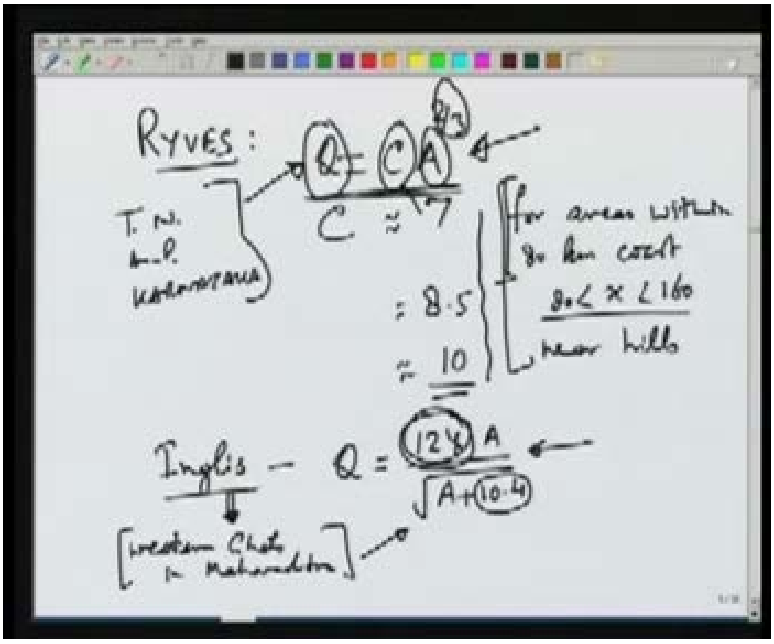

For some other areas for example Fuller has suggested an equation which says Q equal to some constant again a power of area. But he has added one more term to account for the return period of the flood. T here denotes the return period in years, A and Q have the usual meaning. C is a coefficient which varied from about 0.2 to 1.9 for US conditions. In the United States the value of C was found to vary from about 0.2 to 1.9 and this equation had advantage that it accounted for the return period of the flood also. Similarly there is an equation developed by Baird and McIllwraith which uses data from all over the world and the form of relationship it uses is Q. This gives a very high value of Q. We can compare it with the Inglis formula and note that it is of similar form. But it gives very large value of Q which we can say is for a very large return period.

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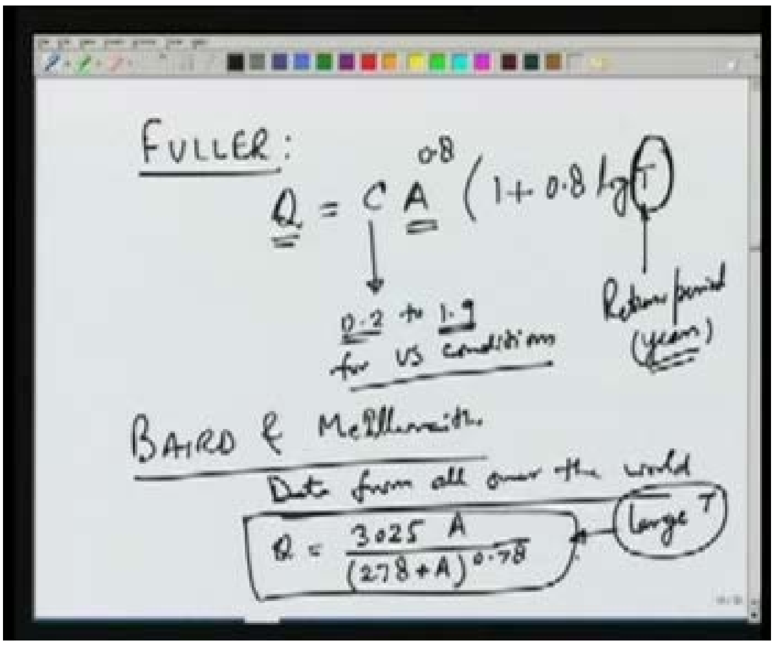

This can be used to obtain the maximum possible flood for a given area and since it uses data from all over the world it represents a very high return period flow or the maximum excepted flow anywhere.

Another method which is used is known as the envelope curve method. If the data is available for some basins which are similar to the basin under consideration and suppose this flood data for different catchment areas is available to us what we do is we draw a curve which envelopes all the data and we use this as our design curve. So knowing the catchment area we can estimate what will be the maximum flood. These envelope curves have been developed by some investigators for different areas in India and using that we can get the maximum flood. To estimate the maximum flood discharge at some point in the channel we can use any of these four methods that we have discussed. Unit hydrograph method, flood frequency method, rational method or empirical method.

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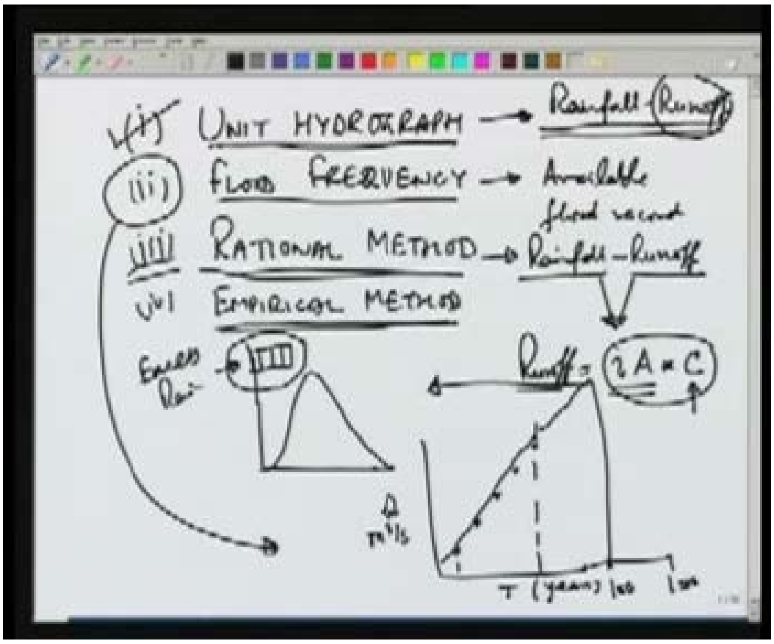

We have seen in the flood frequency method we should have data available about the flood magnitude for different years at least a 30 year record is normally required. Sometimes even 10 years or 15 years data has been used but it’s not advisable to use less than 30 years. The more data available to us for flood frequency analysis the more accurate or the more reliable will be our predictions and we can extrapolate using the flood frequency distributions our flood values to 100 years or 200 years or even 1000 years flood. The time required, the time period T or the return period T is the average difference between two floods of that magnitude. So the return period T will depend on the importance of the structure. Once we decide T using the flood frequency we can estimate the value of flood.

In the rational method we saw that we need to estimate the time of concentration which we can estimate using some empirical equations as we have done in synthetic unit hydrograph method. In the empirical method the methods are developed for a particular area. They use some coefficients which are applicable only in that area and if we want to apply them to other areas we should be careful. In the unit hydrograph method which we have discussed in detail earlier we already have developed a rainfall runoff relationship in form of unit hydrograph which tells us for a rainfall of certain duration of unit volume what will be the resulting runoff and then knowing the actual rainfall causing flood we can obtain the flood discharge. But the actual rainfall which causes flood will have certain intensity and to find out that we need to know what is the importance of the structure and what maximum intensity can be expected in that area and for that intensity duration frequency curves which we have discussed ah under precipitation they will be useful

These curves, the intensity duration curves are typically of the form giving intensity and duration, duration generally in hours, intensity generally in millimeter per hour and then for different return periods we will have different lines for example T equal to 100 years, may be 20, 10. If we are interested in the maximum flood discharge then the duration should be equal to the basin lag or the time of concentration. But sometimes we may be interested in the total volume of runoff. In that case the duration should be as large as possible and probably should be equal to the maximum duration which we have observed in that area. So duration will depend on what is the purpose of the analysis? If we are interested in the peak then the time of concentration or the basin lag should be used as the duration. If we are interested in the volume then maximum observed duration should be taken as the duration of rainfall. The return period will depend on the importance of the project. For example if we are designing storm water drainage 20 years may be sufficient; for more important 100 or even 1000 years should be needed.

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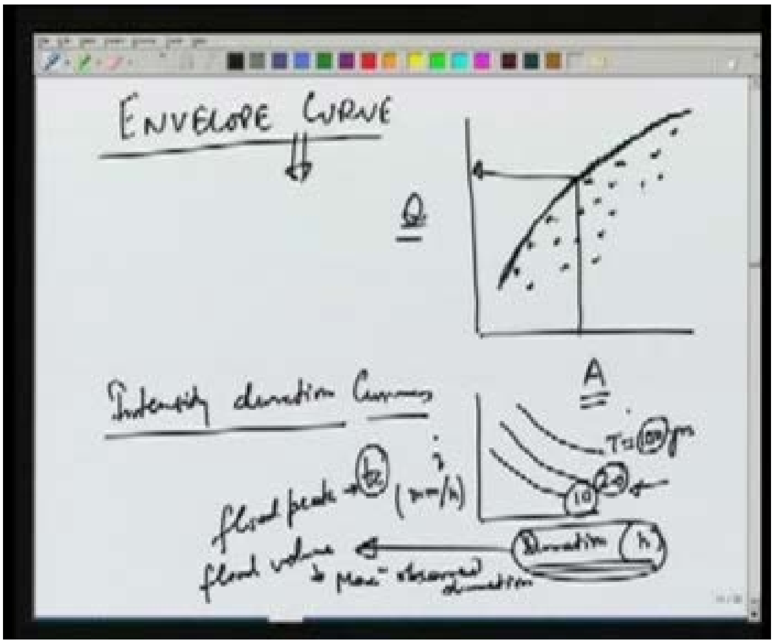

Once we estimate the flood it is really not sufficient to just estimate it because lot of people are living downstream of that point and they may be affected by the flood. So there should be some advance warning given to them and that's why flood forecasting becomes very important and then when we say flood forecasting what it means is that we give some advance warning to people who are affected by that flood in order to be able to either vacate that area or go to some higher grounds nearby. So flood forecasting is quiet important from the point of view of saving lives and property and typically we would have a short range forecasting, medium range or some long range forecasting. Short range typically means about a day or half day to 2 days, medium range means we are predicting the flood or forecasting that flood will occur quiet in advance typically about 2 to 5 days and long range is generally of the order of weeks; a week or 10 days or more than that. So these are all important. They need different kind of information they use different kind of data.

For example a short range prediction will typically monitor the river stage and suppose we are looking at a river going like this. Let's say this is the area if we monitor the stage at this point A we can correlate and we are interested in predicting or forecasting a flood at point B. The factors which will affect the flood volume or flood peak at B will be what is the stage at A? Then what is the precipitation in the area between A and B? Also important will be the soil moisture condition in this area. The correlation would typically be that if the river stage is high at point A the flood peak will be higher at point B. If the precipitation is high in the area between A and B even then the flood peak will be higher at B and if the soil moisture is high it would mean less infiltration and more runoff so that will also cause an increase in the runoff at B. Typically we will correlate it and river stage is one of the main parameters. So at A the water level at the river at certain time combined with these two will give us some idea about the excepted flood at point B after a few hours or may a day or two.

With all these forecasts we should make sure that there is sufficient warning and also they should be reliable. Sufficient warning means that we have enough time for the people to move away from that area and reliable means that if we say that the flood is going to be there in 2 days or 5 days the flood should actually occur. If there is no flood then people will lose faith on the predictions and next time they may not take it very seriously. Since reliability is dependent quite a bit on chance, high river stage at A sometimes may be combined with soil moisture which is very low. So there will be lot of infiltration and not much runoff. So predicting it exactly will not be possible. We will have to have some degree of uncertainty there but we should try to minimize that uncertainty a lot.

In the medium range we typically predict 2 to 5 days in advance and these are based generally on rainfall runoff correlation. We develop rainfall runoff correlation for that area. Rainfall generally is measured every day and then using rainfall records for the past few days which will give us an idea about the soil moisture conditions we can predict what will be the runoff after 3, 4 days or 5 days. In the long term forecast generally the satellite data is used or sometimes radar data is used and what we do using this data is try to predict a weather system; how it is moving and how much water it is carrying? Knowing the direction of movement and amount of water in that particular weather system using a satellite or radar data we can predict things much in advance. So we can develop circulation model, a global circulation model which can predict where the storm will be after, 4 days, 5 days or weeks and using that prediction we can estimate when and how much flood will occur at a given point. All these methods whether we are using short range, medium range or long range are based on different kinds of data and the reliability of this data and the correlation between the data which we have used should not be very uncertain in order to have reliable estimates.

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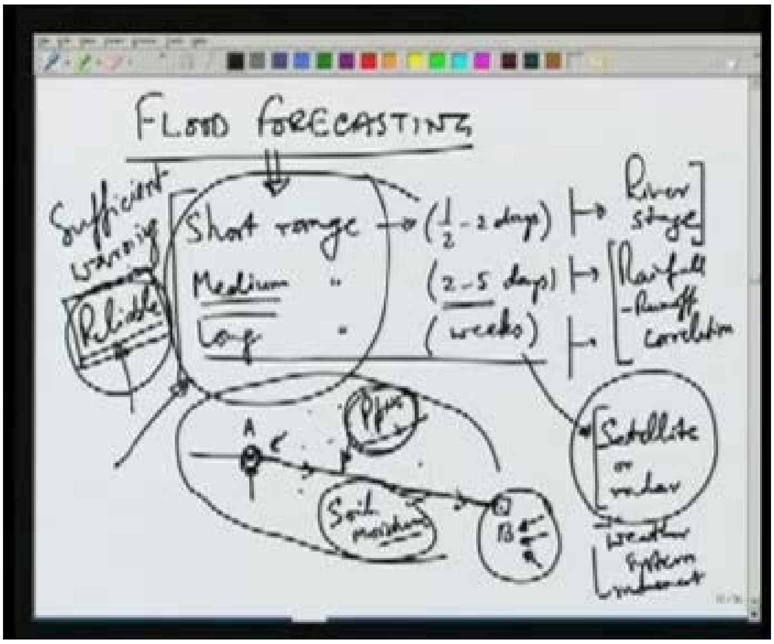

In today's lecture we have seen various methods of estimating the floods. The magnitude of the flood can be estimated based on either the unit hydrograph theory or the frequency studies or the rational methods or some empirical methods and then we have also seen various ways of predicting or saying when the flood will occur and how much flood will occur with some reliable estimates a few days or a few weeks in advance to give people living downstream of that portion enough time to vacate that portion and minimize the loss of property and life.