Water Resources Engineering

Prof. R. Srivastava

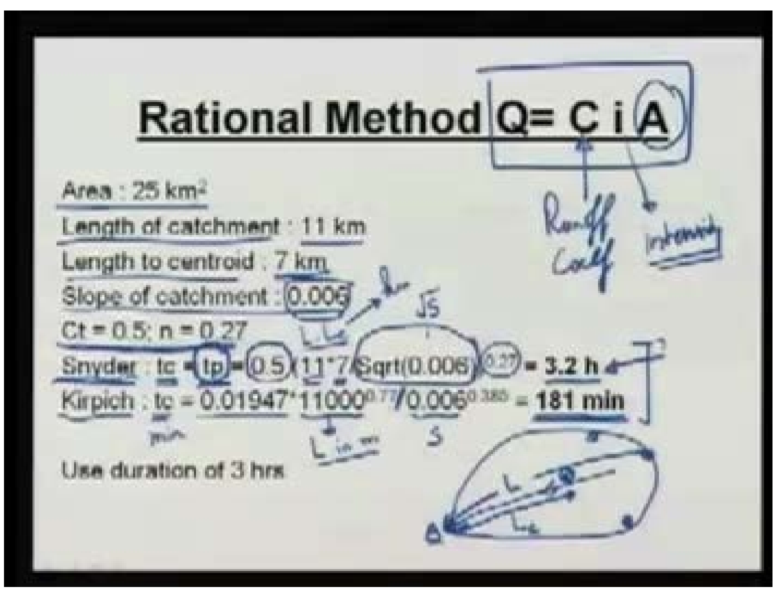
Department of Civil Engineering

Indian Institute of Technology, Kanpur

Lecture No. # 24

We have looked at some methods of finding out the flood for a given catchment. Some of these methods are rational method in which we use enough coefficients and some intensity of rainfall and use the discharge as C into i into A where i is the intensity, A is the area and C is runoff coefficient. The other methods which can be used to find out the flood due to a particular storm or the design value are the unit hydrograph method which we have already seen in detail, how to find the hydrograph for any given rain, if we know the unit hydrograph for a particular duration. The other methods which are normally used are empirical methods, based on certain area, for which we develop those equations and therefore they will be applicable only to those areas or other areas. We can also do such frequency analysis. If we have a gauged catchment, and we measure the annual flood, let us say for a period of 30 years or 40 years, based on that, we can extrapolate and estimate the flood value for let us say 100 year period or 200 year period.

(Refer Slide Time: 01:33)

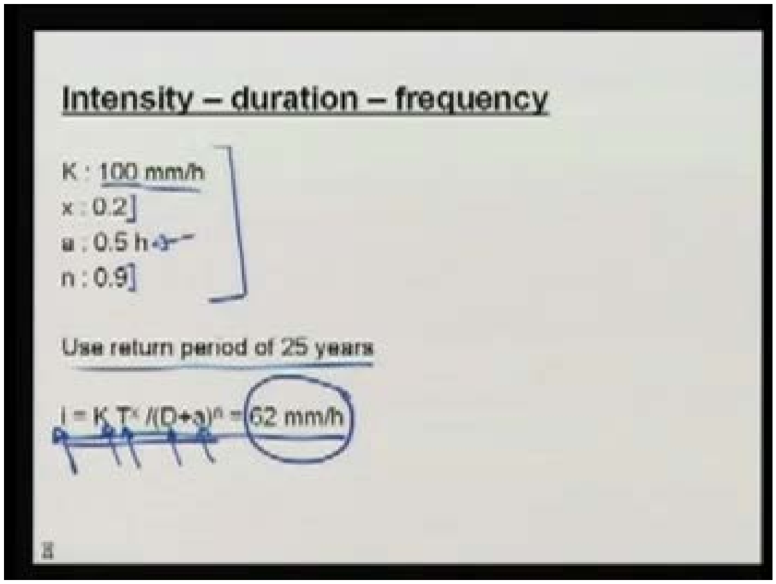


So we will look at some examples of these methods. We will start with the rational method which expresses the flood as Q = C (runoff coefficient), i (the intensity of rainfall and we will look at methods to determine this i) and A (the catchment area). Let us say that we have the catchment which is given. The area of catchment is, 25 kilometres square. The catchment which is given has 25 kilometre square area. The other parameters which are given for the catchment are the length and the length to centroid, so the length along the water course L and then centroid of the area may be somewhere here (Refer Slide Time: 02:26). The point directly opposite direct on the water course, can be written as L_C, so length of the catchment is given as 11 kilometres and the length to centroid from the outlet point, can be called point A. It is 7 kilometres. Slope of the catchment is 0.006. Generally it is taken as the difference between the points furthest away from the outlet point and the outlet point is divided by the length L. This 0.006 is also known. Now can we find out the intensity of rain if we know what duration of rainfall to use, and the purpose?

We know that as the duration increases, the intensity decreases. We should take the minimum possible duration and we have also seen that the duration should not be less than the time of concentration because then the entire area will not be contributing to runoff for some time period. Therefore that intensity should be taken for a duration corresponding to the time of concentration and we should find out the time of concentration for the given catchment. The time of concentration can be obtained based on empirical equations. For example in the equation which is similar to Snyder's equation in the Snyder's synthetic hydrograph, we have the time to peak which is equal to some constant C_t into L and L_c which are the lengths of the catchment and the length of centroid. This factor was not present originally in the Snyder's equation. But we use this square root of S term. This is the square root of the slope of the catchment. This is L into L_C and this is power n. Again the C_t and n values differ from catchment to catchment. But for this catchment let us say that we are given these values as 0.5 and 0.27. Using a relationship similar to Snyder, we can estimate time of concentration by assuming it to be equal to the lag and for small basins, this assumption may be valid. If we use this equation L and L_C (of course this equation is in kilometres), slope is dimension; the value which we get will be in hours.

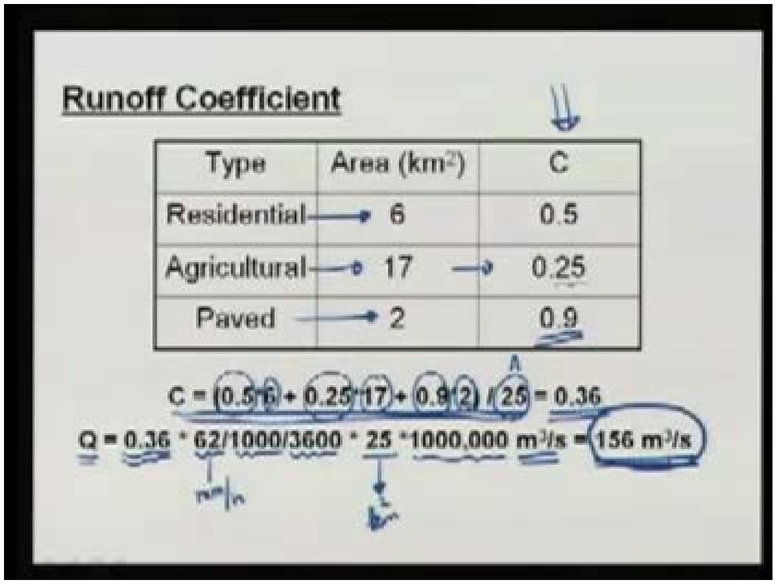
So we get a time of concentration of 3.2 hours which means that raindrop is falling here or here which is the farthest really from a travel point of view, we will take about 3 hours to reach the outlet A. Now this is one equation which we can use to find out the time of concentration. There is another commonly used equation known as the Kirpich equation. It says that t_c in minutes will be equal to 0.01947 into this is L in meters. This is the slope which is dimensionless. So the Kirpich equation says that t_c in minutes will be 0.01947 times the length of catchment (in metres) to the power 0.77, divided by the slope to the power 0.385. If we put the values of L and S, we get a value which is 181 minutes. If you look at these two in this case, they are not very different. So to be on the conservative side we can take t_C which is smaller than this and therefore we will use a duration of 3 hours. It means rainfall for duration of 3, hours we have to find out the intensity and as we have seen earlier, there are equations which relate the intensity with the duration and the return period.

(Refer Slide Time: 06:21)



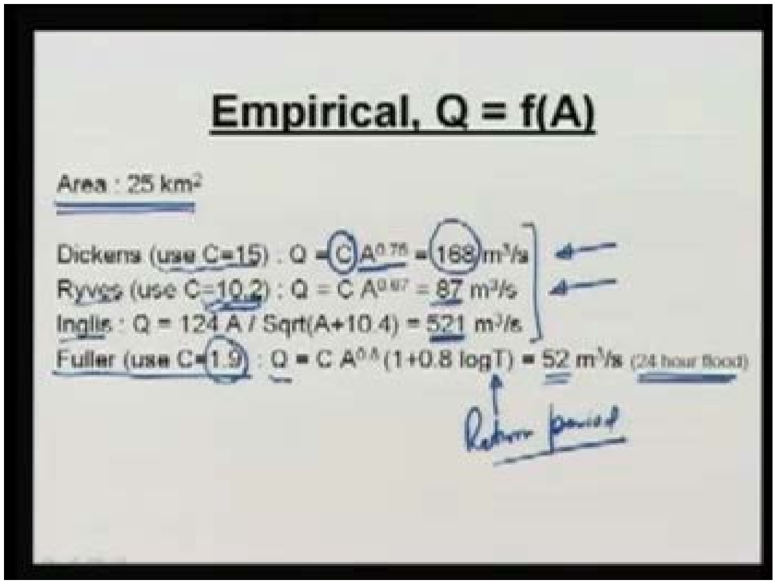
One of the equations which we had looked at, both of this form is i = intensity = K, which is a factor depending on the catchment, T is the return period in years x and n are exponents. D is the duration in hours and a, is another constant which depends on the catchment. So assuming these values for K, x, a and n, we can find out what will be the intensity of a three hour rainfall, for a return period of 25 years. We put the value of K as 100 millimetres per hour, the exponent x as 0.2 and n as 0.9 and then a as 0.5 hours using D of 3 hours, we get intensity of 62 millimetres per hour. So in the relationship Q = C i A i is obtained based on the time of concentration and the catchment properties. A is given as 25 kilometre square. Now we have to find out runoff coefficient. We have already seen that runoff coefficient depends on the type of area in this case. Let us say that this 25 kilometre square area has 3 different types of area or land users.

(Refer Slide Time: 07:34)



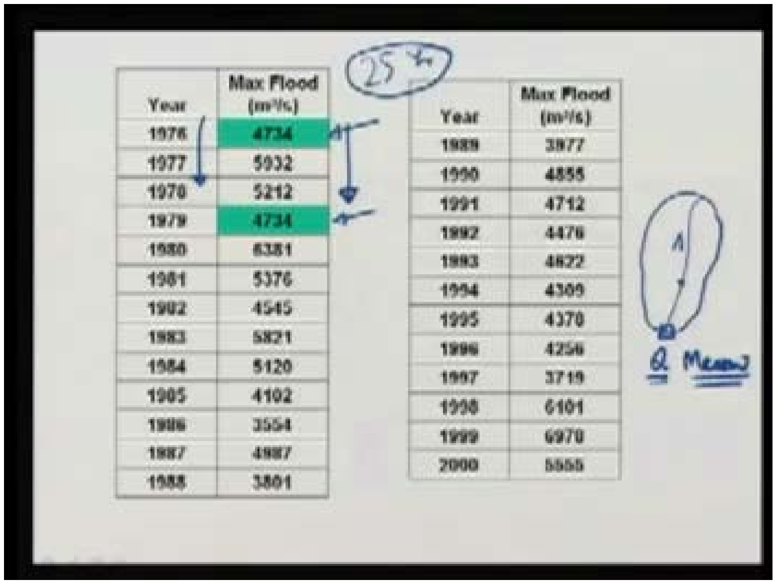
Here we have listed the values of residential area as 6 kilometres square. Agriculture can be taken as 17 and there is 2 kilometres square of paved area. The runoff coefficient C for these areas is given in tabular form in various books. We can take the representative values of C as 0.5 for residential, 0.25 for agriculture. It depends on the soil too. In this case, we may assume it to be a little sandy and therefore the runoff coefficient C will be a little smaller. So point 0.25 is okay and then paved. We can use a value of 0.9. The runoff coefficient is generally very high for paved areas closer to 1. We will take a value of 0.9. Now we have to find a mean value of C for the entire catchment. So we can give a weight which corresponds to the area, which is occupied by the corresponding land use and therefore we can write a weighted mean of C as 0.5 for residential area, 6 area occupied by residential, 0.25 again, C for agricultural area paved C and paved area divided by total area of the catchment which is 25 kilometre square. So we get a weighted value of C as 0.36 and now we can obtain the value of Q, 0.36 is C, 62 is in millimetre per hour. So we will convert it into meters by dividing it by 1000 and per second by dividing by 3600. 25 is the area in kilometre square, so we multiply it by a million to get it in metre square. Therefore the resulting value will come out to be in metre cube per second and it turns out to be 156 metre cube per second. Over this catchment of area 25 Kilometres Square, if a rainfall occurs of intensity 62 millimetres per hour for 3 hours then the maximum discharge which can be expected will be 156 metre cube per second using the rational formula. There are empirical equations also which can be used to find out the flood discharge. We would look at some of them.

(Refer Slide Time: 10:06)



For example, the same catchment area of 25 kilometres square we have seen these equations which are given for a particular area. For example Dickens equation is northern India, early regions, central India, the value of C is different for different areas and we will use let us say C of 15 for this case which typically is the higher limit for hilly areas in Northern India or in central India, all over limits. So let us use 15 areas in kilometre square to the power 0.75. It gives us the value of 168 metre cube per second. Similarly there are other equations like Ryves equation, Inglis equation which are derived for Tamil Nadu or Maharashtra. They are derived for a particular area and they should be used only for that area or a similar area. But if we use them using some coefficients, we can get an estimate of the flood discharge. In this case 87 Inglis gives us 5 21 which is very high and then in the U.S, the Fuller's equation is commonly used which accounts for the return period. Also the other equations do not have any return period. Term included there, but Q here for Fuller's equation accounts for the return period and using a C of 1.9 which is on the higher side. We get a value of 52 metre cube per second and this is a 24 hour flood. So using empirical equations, we can obtain a 24 hour flood or flood for any given duration. But typically these are giving us daily floods and not the 3 hour flood which we obtain from the rational method.

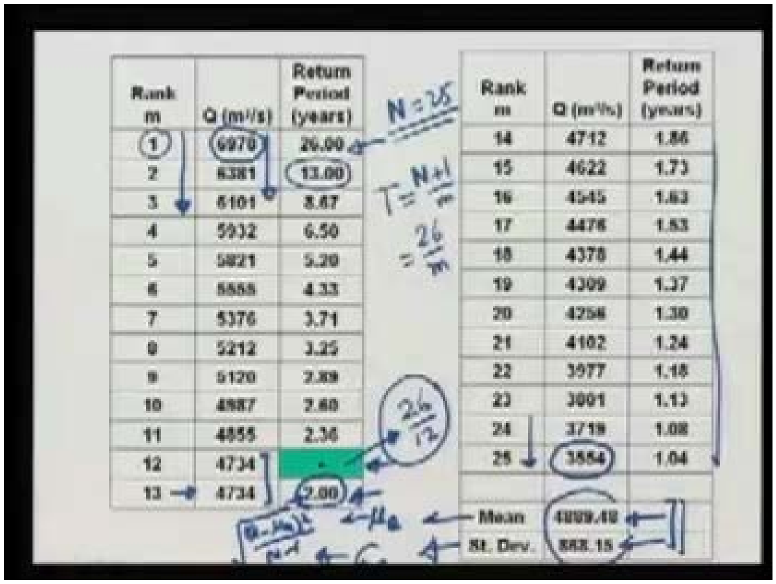
(Refer Slide Time: 11:59)



We would then look at the frequency analysis in which suppose, we have a gauged catchment and we have the data of the flow available. Let us consider Delhi flow data we have, so again suppose we look at the same some catchment area A and suppose we have this gauging station here, Q is known or measured. Now from this measurement, we can get for each year, what is the maximum flood? This table shows you the year versus maximum flood and using this data we can do a frequency analysis. Note that these two values are same.

When two values are same, when we rank them, they will have to be careful so what we do first in the flood frequency analysis is arrange the data in decreasing order.

(Refer Slide Time: 13:11)

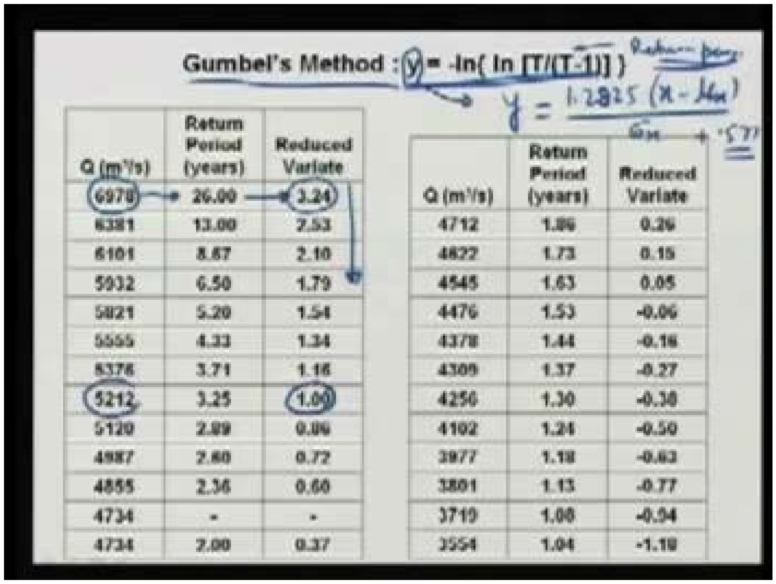


Rank m	Q (m³/s)	Return Period (years)	Rank m	Q (m³/s)	Return Period (years)
1	6970	26.00	14	4712	1.86
2	6381	13.00	15	4622	1.73
3	6101	8.67	16	4545	1.63
4	5932	6.50	17	4476	1.53
5	5821	5.20	18	4378	1.44
6	5555	4.33	19	4309	1.37
7	5376	3.71	20	4254	1.30
8	5212	3.25	21	4102	1.24
9	5120	2.89	22	3977	1.18
10	4887	2.60	23	3801	1.13
11	4855	2.36	24	3719	1.08
12	4734		25	3554	1.04
13	4734	2.00			
			Mean	4889.48	
			St. Dev.	868.15	

So this data which corresponds to 25 year period from 1976 to 2000 can be arranged in decreasing order and given a rank. In this table we are showing the rank from 1 – 25, Q is arranged in the decreasing order and here you will notice these two values 47, 34 are the same. The first value is not assigned any return period this return period in this case N is 25 because we have 25 years of data.

So the return period would be N + 1 divided by m or in this case 26 divided by m. So for the first, it will be 26 divided by 126 divided by 2 and so on. We can compute the return period for each flow and since this return period represents the flow being equalled or exceeded, when the 2 values are same, we assign it to the lower value. In this case the higher ranked value is 13 and gets a return period of 2 for this case. So for this case the value which we will actually obtain would be 26 by 12, but we will not write it here because these two are the same and the both will have a return period of 2 years. This table completes up to 25. This is the minimum annual maximum flood which has been observed. This is the maximum you can see. It goes from about 3500 to 7000 mean of these flows is 4889 and the standard deviation we will be using these 2 in the probability distributions later on. So we can compute the mean of the Q's and the standard deviation which is so mean let us write as mu of Q and a standard deviation sigma of Q mean of course is sum of all sigma Q divided by N and this is based on square root of Q – mu q square divided by n – 1. So that formula gives us the values of mean and the standard deviation.

(Refer Slide Time: 15:33)



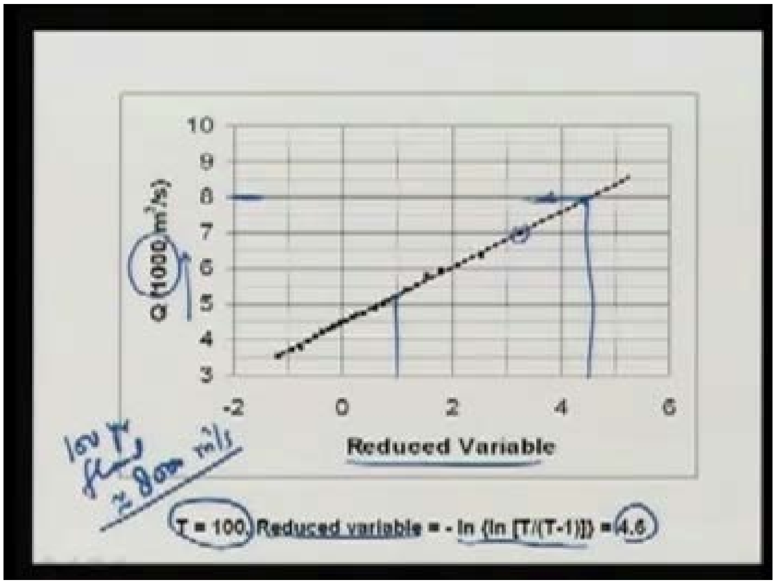
Gumbel's Method : $y = -\ln\{\ln[T/(T-1)]\}$

Q (m³/s)	Return Period (years)	Reduced Variate
6978	26.00	3.24
6381	13.00	2.53
6101	8.67	2.10
5932	6.50	1.79
5821	5.20	1.54
5555	4.33	1.34
5378	3.71	1.16
5212	3.25	1.00
5120	2.89	0.86
4987	2.60	0.72
4855	2.36	0.60
4734	-	-
4734	2.00	0.37

Q (m³/s)	Return Period (years)	Reduced Variate
4712	1.86	0.26
4622	1.73	0.15
4545	1.63	0.05
4476	1.53	-0.06
4378	1.44	-0.16
4309	1.37	-0.27
4256	1.30	-0.38
4102	1.24	-0.50
3977	1.18	-0.63
3801	1.13	-0.77
3719	1.08	-0.94
3554	1.04	-1.18

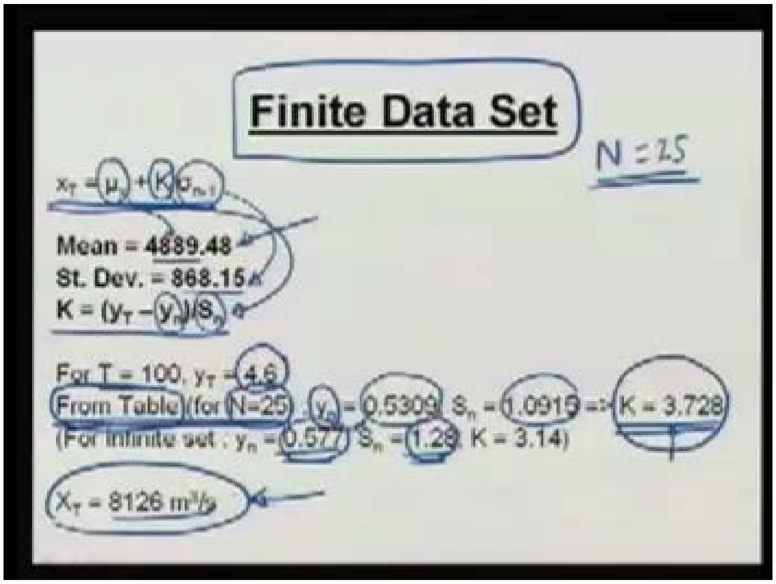
Now there are various frequency distributions which have been used for annual maximum flood. We will discuss 2 of them. One is the Gumbel's method and the other Log-Pearson type three distributions. So we start with the Gumbel's method in which the reduced variable Y is dependent on the actual variable X or in this case Q as 2825 X – mu x divided by sigma x + 0.577. So a reduced variable has been defined which has a return period of T. So T again in this case is the return period. So for any particular Q, we can obtain the return period which is the same as we have shown here. This Q 6978 a return period of 26 and for this return period, we get the reduced variate using this equation and therefore this reduced variate versus Q plot can give us a method of extrapolating the value of Q for a higher return period.

(Refer Slide Time: 17:04)



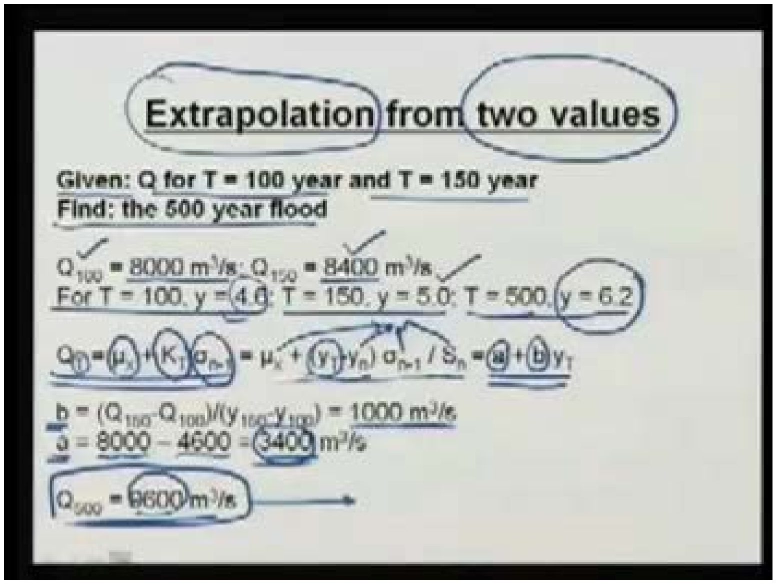
So in this case we have plotted the here the reduced variable versus Q. We notice that this Q is in 1000 metre cube per second and so for example for 6978, the reduced variate comes out to be 3.24 which corresponds to return period of 26 years. So, that 6978 point is shown here with a return reduced variate of 3.24. Similarly if we look at reduced variate of one Q is 5212, so that it corresponds to this point. All the points can be plotted and in this case if the data follows the Gumbel's distribution, they come on a very nice straight line which can be extended to extrapolate the value for any return period. For example if we want a 100 year return period, for example we want 100 year flood, then we can find out the reduced variable corresponding to that T. Using this equation which comes out to be 4.6 and then using this data at 4.6, we would estimate the value of the 100 year flood. So 4.6 will be somewhere here and then corresponding to this we can estimate the value and obtain it graphically. From this, it comes to be close to 8000 metre cube per second. So we can say that the 100 year flood is roughly 8000 cube per second. Most of the times the data is not infinite because Gumbel's distribution values which have been used were derived for an infinite set of data but if we have a finite set of data then we need to make some corrections in the method.

(Refer Slide Time: 19:06)



If we have a finite data set in this case, since we had only 25 year of data we must modify the equation. This is the equation which we use. Saying that this factor K which depends on the reduced variable mean and standard deviation this mu x we have all ready obtained from the data but now this K instead of having a value Y_n S_n which we are earlier given as 0.577 and 1.28. Instead of these values, now they will depend on how many years of data we have. So from the table which is again given in various books, we obtain a value of Y_n for 25 year data as 0.5309. If we have large number of data's set then 0.577 is the value. So there is some change here. Similarly S_n for infinite data set 1.28 and for 25 years required 1.09. This gives us a value of K. Let us say we want 100 year flood reduced variable. We have already seen will be equal to 4.6. So 4.6 – 0.5309, divided by 1.0915 will give us the value of K equal to 3.728 and then using this equation where mu is known sigma n – 1 is known, K is also obtained from here. We can get a 100 year flood as 8126 metre cube per second which is very close to what we had been obtained graphically at about 8000 metre cube per second. For finite data set, we need to correct these tables which will be available in various references or books and we need to correct it and then obtain the value of the flood. In this case we obtain 8126. Earlier we had obtained 8000 metre cube per second. They are very close to each other. Now in Gumbel's method since it is a linear relationship, if we know the flood for any 2 return periods, we can extrapolate for any other return period.

(Refer Slide Time: 21:42)

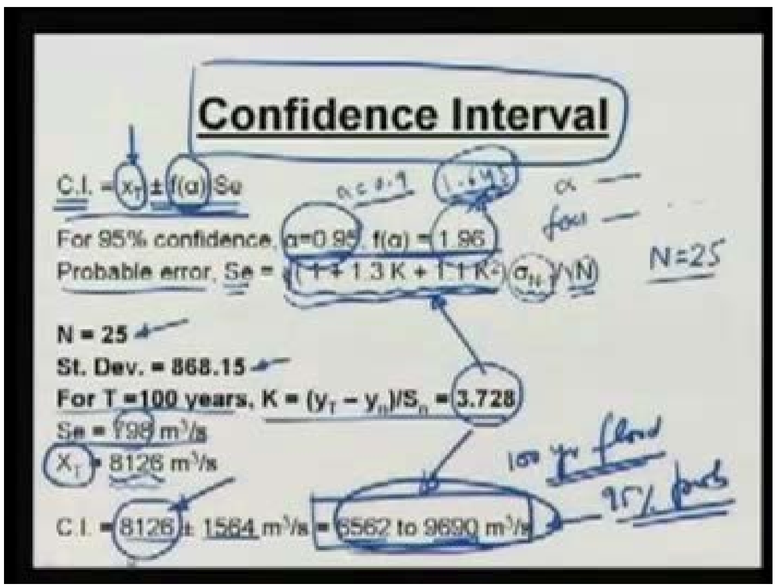


So we will take an example in which from two values, we can extrapolate 2 any other value. So the example which will be taken as let us assume that the given data is for 100 year flood and 150 year flood. We know what is the flood discharge and using that we have to find the 500 year flood. The same thing can be done using the graphical technique and also in which we would extend this line and find out for 500 what will be the reduced variable Y? Using this equation and then corresponding to that Y, we can find out what is the flood. But using computations too we can estimate that. For example let us say that Q_{100} is given as 8000 metre cube per second and Q_{150} is given as 8400 metre cube per second. So on an average, 8000 metre cube per second of maximum flood annual flood can be expected once in 100 years 8400 metre cube per second expected once in 150 years and what we want is what will be the flood which can be expected once every 500 years? So for T = 100, we have all ready seen Y is 4.6 for T is equal to 150, we can obtain Y as 5.0 and for T = 500, Y is 6.2. So using this 6.2, we could have extrapolated this value (Refer Slide Time: 23:13) and obtain so 6.2 will be somewhere here. So we can see that it will be close to about 9500 or so but using the calculations too, we can look at how to compute this. The equation which will be ready have seen is that Q for any return period T will depend on the mean of the discharges.

So mu x which represents the mean of the discharges and sigma which is a standard deviation these two are constants they are dependent on the data set available they don't change with the return period. K changes with the return period and as we have seen all ready the equation for K is Y_t – Y_n divided by S_n so Y_n S_n sigma n – 1 and mu x. These values do not change with t the only thing which changes with t return period is the value Y_t. We can write this as some constant a plus some other constant b into Y_t because everything else is constant except Y_t and it is a linear function of Y. So if we write Q_t equal to a + b Y_t we have really two unknowns a and b if the values of Q_t and y_t are known for two different values then we can estimate these a and b values in this case Q_{100} is given and Y_{100} is given similarly Q_{150} is given and Y_{150} is given. So using these two, we can obtain b as delta Q divided by delta y which comes out to be 1000 metre cube per second. So 8400 – 8000 divided by 5 – 4.6 will come out to be 1000 metre cube per second and similarly it can be obtained from any of these equations as 8000 – 4.6 into 1000. It turns out to be 3400 metre cube per second and then using the value of Y for 500 years, we can obtain Q_{500} as 3400 + 6200 which is 9600. It comes very close to the value which we obtained from the graphical method. But this can be obtained directly without the need of plotting the graphs. So a 500 year flood for the given data can be taken as 9600 metre cube per second. Using the frequency analysis we can estimate the return period, the flood for a particular return period, but since these are all uncertain values, we should have some idea about not only our predicted value of flood for a return period but, what is the confidence level.

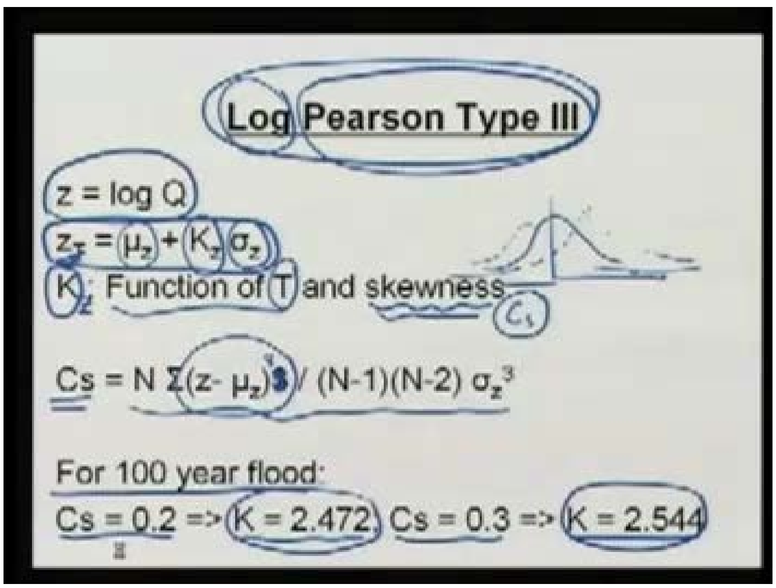
Typically we will analyse let us say 95 percent confidence intervals. So we will predict a range of discharge values and say that there is a 95 percent chance that the actual 100 year floods or 500 year flood would be within those values. So we will look at the confidence interval in this case.

(Refer Slide Time: 26:25)



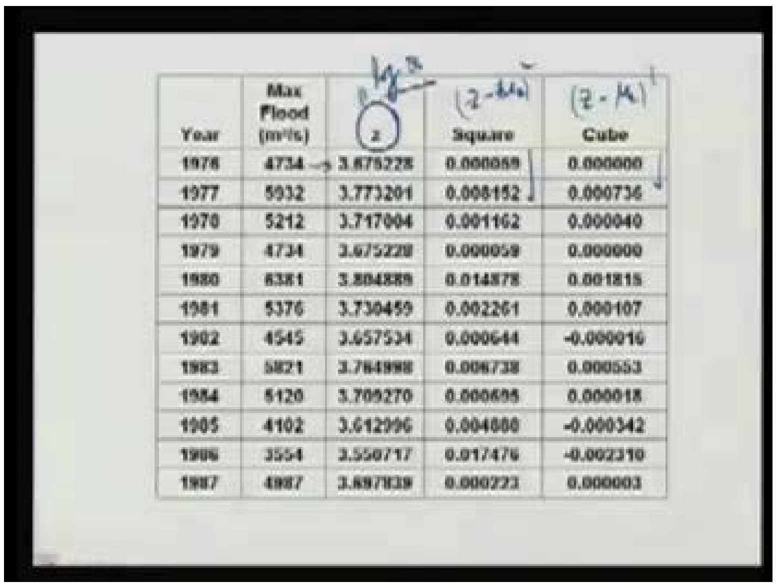
The confidence interval is given as the value we predict for T year return period and then there is a + – or there is a range about the mean or the predicted value, within which we have 95 percent or 80 percent confidence interval. If alpha is a function of the confidence interval, for example, alpha = 0.95, we get f alpha 1.96. So there is a table of values. Alpha versus f alpha which is again given in various references and from that we can pick up the value of f for any given alpha. S_e is a probable error which is given as some constant. That constant is related with K and this square root sign is over all this. So this term is a function of K and we have this standard deviation and square root of N. N is the number of data, in this case we have 25. K can be obtained using the same equation for T = 100 years. It can be obtained as 3.728 with given values of N N sigma. So using this data, we can obtain the probable errors. Using K we can obtain this constant. This is known, this is known (Refer Slide Time: 28:01), so we get the value of S_e, to be 800 metre cube per second, XT which we have estimated 100 year flood earlier was 8126 metre cube per second. If you want to find out the 95 percent confidence interval, we will use this equation with XT of 8126 f alpha of 1.96, S_e of 798 and we get 8126 + – 1564 metre cube per second. So this gives us a range for 100 year flood. So what it tells is that a hundred year flood will be between 6562 metre cube per second and 9690 metre cube per second. If we make this assessment we are 95 percent confident that the data actual flood will lie within this range. Instead of predicting a single value which earlier we had taken as 8126, we have now predicted a range. This means that actual flood will be between 6562 and 9690. There is a 95 percent probability that the actual flood which will occur once every 100 years. It will be within this range. Now if we just want to have a different probability or confidence interval, for example if we take alpha to be 0.9, then the only thing we need to change is f alpha which comes out to be 1.645. When we put that, we will get a range here which will be smaller than this range because f alpha has become smaller. So a 90 percent confidence interval would be smaller. But again it will centre on the mean 8126, but the band will be smaller. As we reduced the confidence interval, the band will get narrower but 95 percent confidence interval is typically used and therefore in this case, we can say that the design value of flood should be between these values. We can estimate the flood and we can also estimate the confidence interval that within that interval, the flood is likely to be 95 percent certain.

(Refer Slide Time: 30:13)



The other distribution which we used is known as the Log Pearson type three distributions. This is commonly used in the US where Pearson type three is a distribution which is assumed. Log means that instead of the variable following the Pearson type 3 distributions; log of the variable follows the Pearson type three distributions. We use a variable Z which is defined as log of Q and then we say that Z will follow a Pearson type three distribution and for any return period T, Z value will be given by mean, again a constant K and the standard deviation sigma z. Now in this case, the distribution is supposed to be skewed. It is not a symmetric distribution. But it can be skewed like this or it can be skewed like this (Refer Slide Time: 31:30) where there may be a long tail in the negative side or there may be a long tail on the positive side. That will give us some skewness and the function KZ which we have; KZ is a function of the return period T and the skewness of the distribution which we call Cs. The Cs value is computed by using this equation where Z – mu z cube will be 0 if that skewness is symmetric. This is because, if it is symmetric, then positive and negative values of the (Refer Slide Time: 32:18). This is cube, the positive and negative values of the cubes will cancel each other and Cs will become 0, but usually it will not be so. For example in this case we can compute Cs from the given data. There are tables given for Cs. So for example, for a 100 year flood, if Cs is 0.2, Kz is 2.472, if Cs is 0.3, K is 2.544, and we have taken these two values of Cs because when we compute Cs for this data, we find it to be between these two. That is the reason why from the table these two values can be taken.

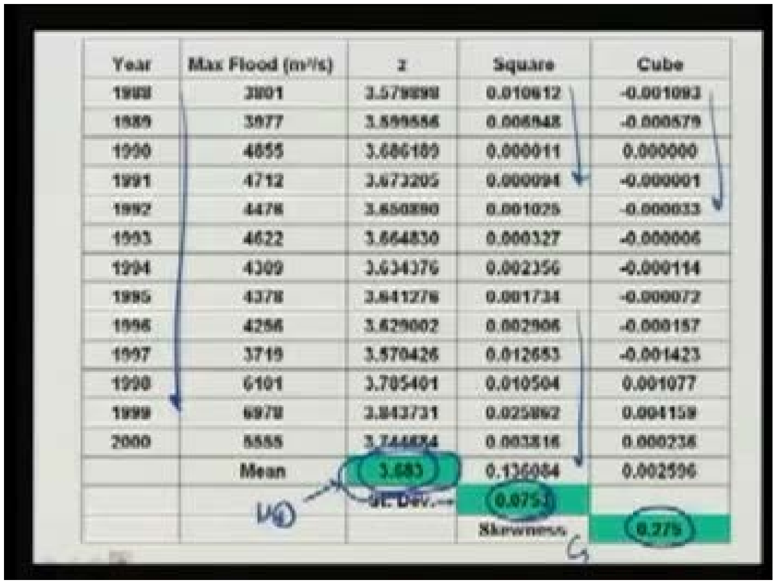
(Refer Slide Time: 33:01)



Year	Max Flood (m^3/s)	z	Square	Cube
1976	4734	3.675228	0.000059	0.000000
1977	5932	3.773201	0.008152	0.000736
1978	5212	3.717004	0.001162	0.000040
1979	4734	3.675228	0.000059	0.000000
1980	6381	3.804889	0.014878	0.001815
1981	5376	3.730459	0.002261	0.000107
1982	4545	3.657534	0.000644	-0.000016
1983	5821	3.764998	0.006738	0.000553
1984	5120	3.709270	0.000696	0.000018
1985	4102	3.612996	0.004880	-0.000342
1986	3554	3.550717	0.017476	-0.002310
1987	4987	3.697839	0.000223	0.000003

The data is shown here.

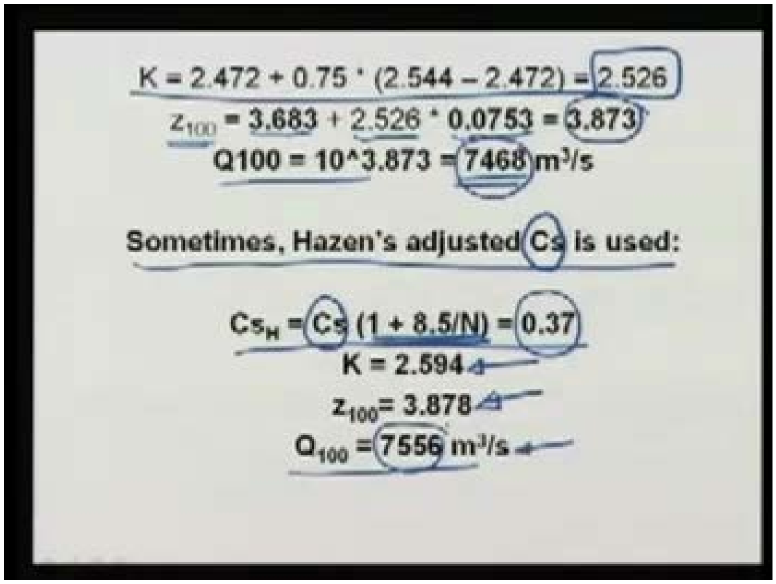
(Refer Slide Time: 33:04)



Year	Max Flood (m^3/s)	z	Square	Cube
1988	3801	3.579898	0.010612	-0.001093
1989	3977	3.599556	0.006948	-0.000579
1990	4855	3.686189	0.000011	0.000000
1991	4712	3.673205	0.000094	-0.000001
1992	4478	3.650890	0.001025	-0.000033
1993	4622	3.664830	0.000327	-0.000006
1994	4309	3.634376	0.002356	-0.000114
1995	4378	3.641276	0.001734	-0.000072
1996	4256	3.629002	0.002906	-0.000157
1997	3719	3.570426	0.012653	-0.001423
1998	6101	3.785401	0.010504	0.001077
1999	6978	3.843731	0.025862	0.004159
2000	5555	3.744674	0.003816	0.000236
	Mean	3.683	0.136084	0.002596
		St. Dev.	0.0753	
			Skewness	0.275

The same data given, 1976 to 1987 in this figure, then up to 2000 this figure is shown. So from this data, we first transform it. This is log of Q, so we transform the Q to its log, and then this is a difference of a square. So Z – mu z square and this is cube Z – mu z Q. We find out the squares and the cubes for all the data and then we add them up. This is the mean of the log Q0Q, so it comes out to be 3.3683. The standard deviation from the summation of these squares divided by N – 1square root will give us 0.0753 and skewness Cs is obtained from the equation shown here (Refer Slide Time: 34:04), where this Z – mu z cube is the sum of the column and sigma z has already been obtained here. Using this sum and sigma z and mu z, we get a value of Cs as 0.257, corresponding to this Cs, as we have seen here in this table, K is given for 0.2 and 0.3.

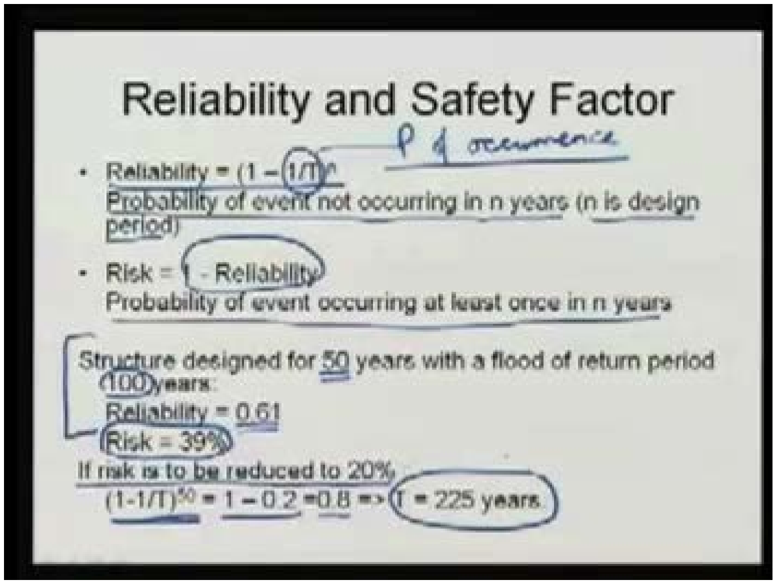
(Refer Slide Time: 34:32)



We can use the linear interpolation between these two values and obtain the K value for a given Cs as 2.526. Using this value of K, we can estimate Z for 100 year return period as the mean, K and sigma. We have already seen mean and sigma from the table, the mean, standard deviation K, we have obtained here. The C_{100} comes out to be 3.873 and Q_{100} is nothing but 10 to the power Z, so in this case it will come out to be about 7500 metre cube per second. Using Gumbel's distribution, we had obtained the value close to 8000 here. We are getting almost 7500 metre cube per second. Both of them are quite close now. Sometimes since it is a finite data set, the Cs value is adjusted. Hazen has proposed this modification in which the Cs is modified by this factor of 1 + 8.5 over N.

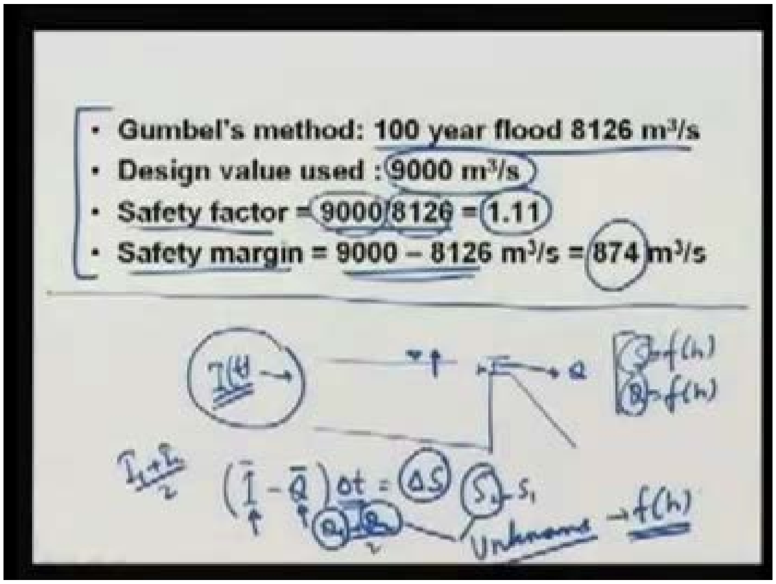
N is the number of years of record, in this case it is number of data that is 25, so 1 + 8.5 divided by 25 into Cs will give us value of 0.37. For this value again, from the tables, we can obtain the value of K, Z hundred and Q_{100}. In this case it becomes a little more than this value, but still close to 7500. So using either the Gumbel's method or the Log Pearson probability distribution, we can obtain the value of the flood. We can obtain an estimate of the confidence interval. The next thing which we can do is to find out what could be the risk or reliability of a structure.

(Refer Slide Time: 36:28)



For example if we suppose we design a structure which is of a useful life of 50 years and we design it for 100 year flood. What will be its reliability or what is the chance that it will not fail in the next 50 years. That is what we call as the reliability probability of the event not occurring in years, where n is the design period. What we say, is we have designed a structure for, let us say 100 year flood and the useful life or the designed life of this structure is 50 years. What will be its reliability? In this case we can find out 1/T is the probability of the event occurring. So 1 – 1/T will be probability of event not occurring in 1 year and to the power n will give us probability of the event not occurring in n years, n consecutive years. In this case using n = 50 and T of 100 years, we get a reliability of 0.6 which means the risk which is one minus reliability is the probability of the event occurring at least once in n years or there is a probability of failure of the structure which will be 39 percent. Now 39 percent risk may be too high in some cases. So if you want to say that we want to keep a risk of let us say, 5 percent, and then we can find out the corresponding return period. For example if we say that the risk is to be reduced to 20 percent, then what should be the design discharge and for what return period? We can use the same equation 1 – 1/T to the power 50 = 1minus risk equal to 0.8 which gives us a T of 225 years, meaning that if we want to have a 20 percent risk only then we should take a 225 years flood or 225 years event to design that 50 year structure.

(Refer Slide Time: 38:40)

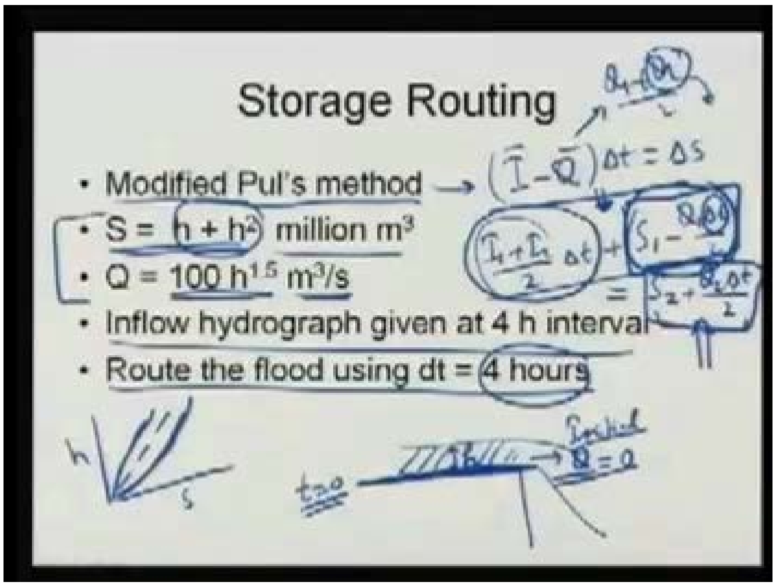


We have seen the risk and reliability. There is another term which is also commonly used to define the safety of a structure, safety factor and safety margin. These are quite straight forward that suppose we have a 100 year flood of 8126 metre cube per second and the design value which is used is 9000, then the safety factor will simply be the ratio of the actual value to the estimated value. The used valued is 9000 and the estimated value of the variable is 8126. Then we have the safety factor which is 1.11 and sometimes we use safety margin which is the difference of these two. We have a safety margin of 874 metre cube per second. We have looked at how to estimate the design flood, how to obtain the reliability or the risk. In all these cases, we have assumed that there is some method of estimating a design flood at that location where we want the structure to be built. It may be a dam or a bridge in some cases the flood may not be available at a particular location or in some cases we may have to design a structure by passing that flood through that structure. For example in case of a spillway we have a flood coming in and there will be some storage and then there will be some outflow. We need to know what will be the rise in the water level and there is going to be a flood because the inflow and the outflow will be same due to this storage effect.

In some other cases, suppose there is a river at one point, we may know the flood hydrograph. We want to estimate what will be the flood hydrograph at another location, downstream of that point. This is known as the routing or the flood routing. We will discuss in terms of storage routing where the flood is being routed through a reservoir. So storage routing or reservoir routing or level pool routing is because we assume that the water level in the reservoir remains horizontal and sometimes we would also look at channel routing in which there is a flow coming into river or a channel. The question arises, how it will move downstream. It aims to find out how the inflow hydrograph gets changed from the outflow hydrograph because outflow hydrograph will be different from the inflow hydrograph and we need to find out how it will be different. For example if we have let us say a dam here and there is some inflow coming in this water level here, the discharge over the spillway queue will depend on what the water level here is or what is the height h. The storage within the reservoir will also depend on the height h and I as a function of time which is the inflow hydrograph will be given to us. Given this inflow hydrograph, we want to estimate how this water level will change in such a way that the storage and outflow account for whatever inflow is coming in.

The equation which is used for this case is the continuity equation which says that in any time period, the net inflow should be equal to the change in storage. So if we have some time $t = t_1$ and $t = t_2$ then delta t during that time, there is mean inflow and mean outflow because inflow is changing with time. So we can use some mean value between t_1 and t_2. Typically it is done as $I_1 + I_2 /2$ where I_1 and I_2 were the inflows at the beginning and at the end of the time period, these will be known because inflow hydrograph is known to us. Similarly Q bar is taken as $Q_1 + Q_2 / 2Q_1$ is known to us at the beginning of the time step but Q_2 is not known to us. Similarly delta s is $s_2 – s_1$ s_2 and Q_2. These are the 2 unknowns. They are both functions of Q, functions of h and our aim of the routing is to find out how Q, s and h change with time. The method which we use in this case will be modified Pul's method.

(Refer Slide Time: 43:18)



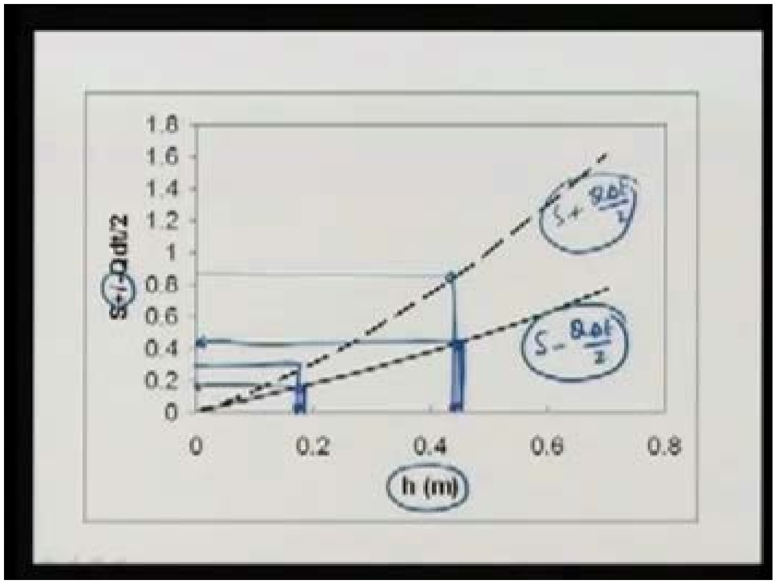
It uses the same form I – Q mean value delta, t = delta s which is converted in terms of $I_1 + I_2/2$delta t known quantity plus another known quantity $S_1 – Q_1$ delta t/2. This is equated with the unknown which is $S_2 + Q_2$. What we do is this Q contains Q_1 and Q_2. Q_2 is not known. So we transform the equation in such a way that the known quantities come on one side and the unknown on other side. Then suppose in this case, we assume that the storage above the reservoir level can be given by h + h square million cubic meters. Just for our computation sake, we will assume this equation. But typically it will be given in the form of a graph, as h over S and generally the form of the equation will depend on the topography of the area and the nature of this variation may be linear, or quadratic. So in this case, we have assumed a quadratic distribution S has h + h square. Similarly the outflow Q will also depend on h and we have assumed that generally it varies as h to the power 3/2. So we have assumed that Q is = 100 h to the power 1.5 meter cube per second. If suppose the data given to us includes that S and Q varies with h as the given functions, then the inflow hydrograph is given at 4 hour intervals. Now we want to route the flood using a delta t of 4 hours.

(Refer Slide Time: 45:41)

h (m)	S (M m³)	Q (m³/s)	S-Q dt/2 (M m³)	S + Qdt/2 (M m³)
0.00	0.000	0.000	0.000	0.000
0.05	0.053	1.118	0.044	0.061
0.10	0.110	3.162	0.087	0.133
0.15	0.173	5.809	0.131	0.214
0.20	0.240	8.944	0.176	0.304
0.25	0.313	12.500	0.223	0.403
0.30	0.390	16.432	0.272	0.508
0.35	0.473	20.706	0.323	0.622
0.40	0.560	25.298	0.378	0.742
0.45	0.653	30.187	0.435	0.870
0.50	0.750	35.355	0.495	1.005
0.55	0.853	40.789	0.559	1.146
0.60	0.960	46.476	0.625	1.295
0.65	1.073	52.405	0.695	1.450
0.70	1.190	58.566	0.768	1.612

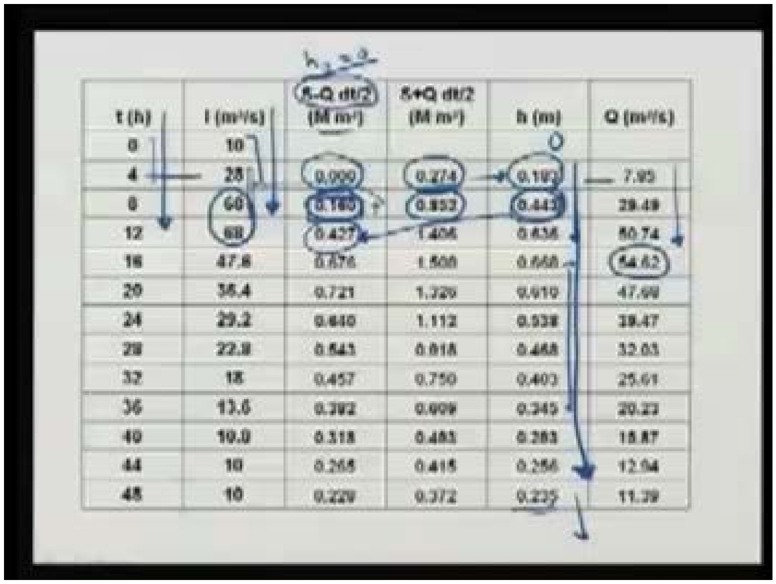
If we look at this table, we have prepared a curve or we have obtained data which relates S – Q delta t /2 and S + Q delta t/2 with h. If we look at the Pul's modified equation, this is S – Q delta t/2, S + Q delta t/2. Both these quantities can be related with h because S and Q both are functions of h for any given delta t which we have assumed here as 4 hours. We can prepare a curve between h and these 2 quantities and that is what we have done here. We have computed S– Q dt/2 and S + Q dt/2 versus h. For any given h, S is obtained as h + h square. Q is obtained as 100 S to the power 1.5. We have taken a range up to 0.7. We could go higher also but in this case, we have stopped at this because the outflow does not go above this value the reason which we will see later.

(Refer Slide Time: 46:57)



Once we have obtained these two columns, we can plot it and show the variation of h versus S plus minus Q delta t by 2, so S minus delta t by Q delta t by two and S plus these two curves can be plotted and Pul's method consist of graphically doing the computations. When we start $I_1 + I_2$ by 2 delta t we can compute S – Q delta t/ 2, we can obtain from the graph for the given h. In this case we will assume that when the flood starts the inflow hydrograph starts at t = 0 and that time, the water level in the reservoir is at the top of the spillway. So this is at time t = 0.We have this which is the Pul level and therefore Q is 0 initially let's assume that Q is 0. We could assume some other value, but let us assume that since the water level is here, there is no outflow. We could have assumed a different water level also. Now S – Q delta t/ 2 will be known for the starting value of h, I bar delta t can be obtained from the inflow hydrograph and therefore we can get this value of S + Q delta t/2 and once we know this, the corresponding value of h can be obtained from this figure so that calculations proceed like this (Refer Slide Time: 48:41)

(Refer Slide Time: 48:41)



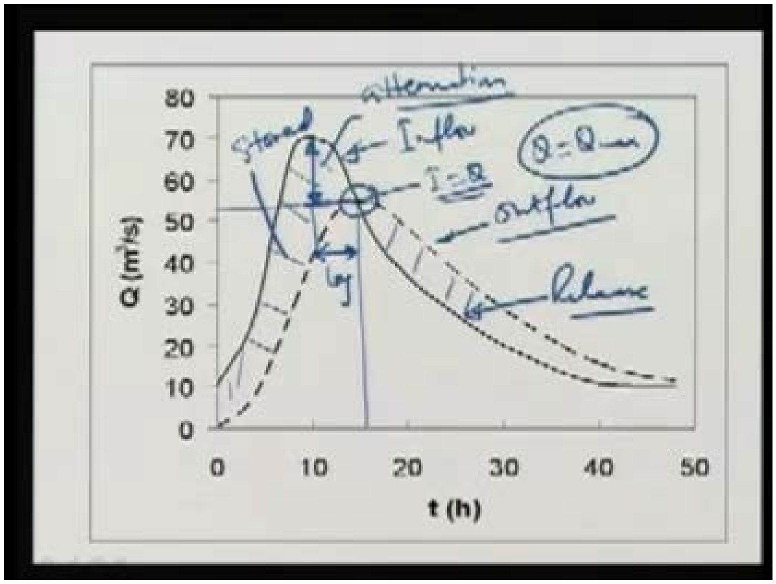
t (h)	I (m³/s)	S–Q dt/2 (M m³)	S+Q dt/2 (M m³)	h (m)	Q (m³/s)
0	10			0	
4	28	0.000	0.274	0.183	7.93
8	60	0.160	0.852	0.443	29.49
12	68	0.427	1.404	0.636	50.74
16	47.8	0.676	1.500	0.668	54.62
20	36.4	0.721	1.320	0.610	47.68
24	29.2	0.640	1.112	0.538	39.47
28	22.8	0.543	0.818	0.468	32.03
32	18	0.457	0.750	0.403	25.61
36	13.6	0.382	0.609	0.345	20.23
40	10.0	0.318	0.483	0.283	15.87
44	10	0.265	0.415	0.256	12.94
48	10	0.229	0.372	0.235	11.39

t in hours and inflow in metre cube per second is given to us. S – Q delta t/2 is 0 because our initial h is assumed as 0. h_0 is assumed as 0 therefore both S and Q are 0. This term comes from S – Q delta t /2 plus the mean inflow into delta t, so 28 + 10 divided by 2 which will be 19 metre cube per second into 4 hours that we will convert into million metre cube and get a value of 0.274. Corresponding to this 0.274, we would look up from the graph and see the value.

So 0.274 would be somewhere here (Refer Slide Time: 49:41) and from the graph we can look up the value of h. It turns out to be around 0.183. We start with 0.274, get 0.183. Now for this 0.183, we can obtain the value of S – Q delta t /2 again from this figure. So S – Q delta t /2 for the next step will turn out to be about 0.16. So that is what we have done here in this value. We will however add again the mean inflow during that time period. So we will get a new value of S + Q delta t/ 2 as 0.852 and for 0.852, again we can get the corresponding value of h as 0.443 from this figure.

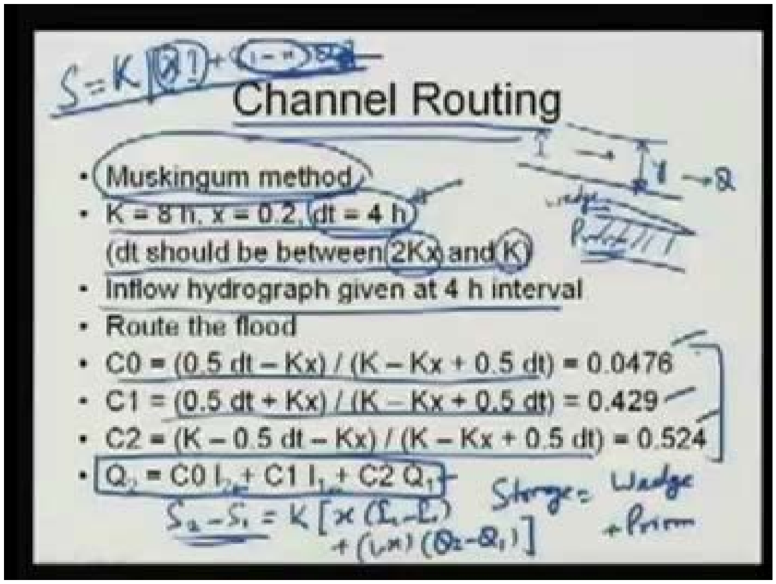
Then for .443, we can get the value of S – Q delta t/2. So for 0.443, we get 0.427 as S – Q delta. Basically we just go from one curve to the other so we come to this point get to this curve (Refer Slide Time: 51:33) then similarly once we obtain the value here we come to this point and get the value for S – Q delta t/2. Then again add the mean inflow to get S + Q delta t/2. In this way by doing the computations, we can obtain at the end of each time interval, the value of h and therefore Q, because Q is the function of h. We have already seen and we can plot this time versus Q as the outflow hydrograph.

(Refer Slide Time: 52:08)



This is shown in this figure. This is inflow (Refer Slide Time: 52:14) I and outflow, so a few things can be noted from this figure. One is that, at this point where the inflow and the outflow cross, it means inflow is equal to outflow. At this point, the outflow is also maximum (Refer Slide Time: 52:40) and as we have discussed earlier, it will be maximum because at this point the storage is at the maximum. Before this, the water goes to the storage, after this, it is being released. This amount of water goes into the storage (Refer Slide Time: 53:07), this point. Water level reaches the maximum because Q is also maximum, storage is also maximum and then beyond this, the water will be released from the storage and therefore outflow will be more than the inflow. The peak of the outflow as we can see from this figure is this table (Refer Slide Time: 53:27) is about 55 metres cube per second. The peak of the inflow is around 68. There is attenuation or a decrease in peak of about 13 metre cube per second and it is also shifted. The peak shifts or there is a lag and there is an attenuation in the outflow hydrograph. In this way we can perform the storage routing and obtain the outflow curve and also the way the water level in the reservoir is changing with time can be obtained too. So we can see that initially it starts with 0, then it increases up to about 0.668 and then it starts again decreasing and in this case, it has gone down to point 235. It will go down further if we continue the computations.

(Refer Slide Time: 54:25)



In the storage routing, we have the storage dependent on head. Channel routing basically means if there is a flood coming in a channel, there is some depth of flow occurring. They really do not find the storage in this case. But there is a change in the storage and we have already seen that we can write this storage change, storage as wedge plus prism. If we have this change in water level like this, then we have prism storage and wedge storage. We will be discussing the Muskingum method of routing. In the Muskingum method, we assume a linear reservoir or linear storage as S (Refer Slide Time: 55:36). The storage in the channel, the wedge storage is proportional to the inflow. The prism storage is proportional to the outflow and the total storage is given by sub factor K which is the time constant. Some weightage X to I and 1 – X_2 Q. In this case let us assume that the values which are given are 8 hours for K, 0.2 for X and let us use the same inflow hydrograph with a duty of 4 hours.

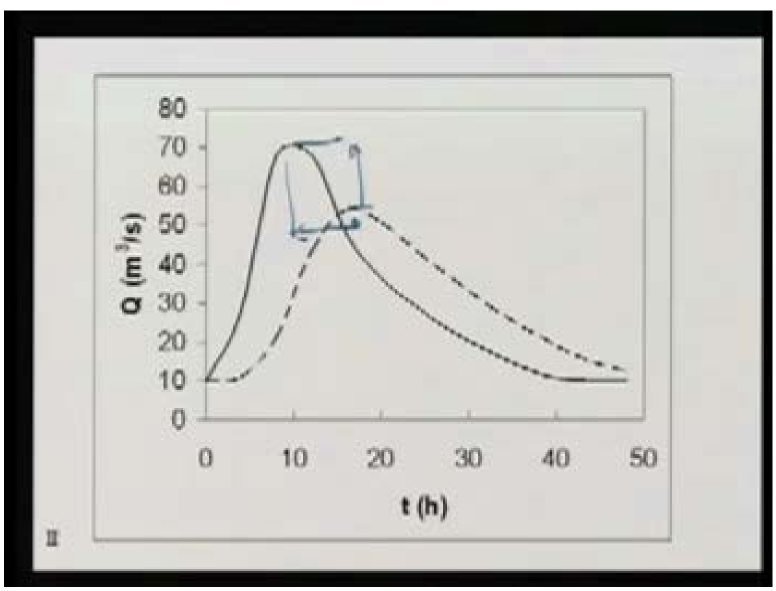
There is a requirement that dt should be between 2 K_X and K in this case is 8 and 2 K_X is 3.2. So we use 4 hours which is good for this case. Inflow hydrograph as we have seen is given at 4 hour interval. Now in the Muskingum method, we use the same equation but the change in storage is written as (I_2 – I_1 + 1 – x) (Q_2 – Q_1) and using this storage we can write an expression relating the Q at the end of a time period with inflow I_2 at the end of the time period, I_1 at the beginning and Q_1 at the beginning. This Q_1, I_1 and I_2 are known C_0, C_1, C_2 are constants which are obtained by these relationships and the numerical values of these constants is obtained as 0.0476, 0.429, 0.524 and therefore the competitions are rather straight forward in this case for the time given, inflow is given.

(Refer Slide Time: 57:35)

t (h)	I (m^3/s)	Q (m^3/s)
0	10.0	10.00
4	28.0	10.86
8	68.0	20.93
12	68.0	43.34
16	47.6	54.11
20	36.4	50.48
24	29.2	43.43
28	22.8	36.35
32	18.0	29.87
36	13.6	23.90
40	10.0	18.06
44	10.0	14.99
48	10.0	12.61

Q_2 is obtained from this equation where C_0, C_1, C_2. I_2, I_1 and Q_1 are obtained from this. For example, in this case I_1 is 10, I_2 is 28 and Q_1 is 10. These 3 values will give us 10.86. When we go to the next step, then we use I_1, I_2 Q_1, these 3 values will give us and this way we can proceed with calculating the outflow hydrograph and that is plotted here (Refer Slide Time: 58:21).

(Refer Slide Time: 58:21)



In this case we have assumed that initial outflow is 10 metre cube per second. It is a channel routing. So we assume that initially inflow and outflow are same and therefore again you can see that there in attenuation here and there is a lag here but in this case the peak is roughly 54.11, while in the other case we had seen 54.62. So they are not very different in this case. We have seen how to move the flood or how to route the flood from one point to other. If the inflow hydrograph is given at one point and if the storage characteristics of the channel or the reservoir are known, then we can obtain the flood hydrograph at any point in the out stream.