Water Resources Engineering

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Lecture No. # 01

In this module we will talk about water resources engineering. Now all of us are aware of the importance of water and the scarcity of water resources. So we must use the resources available to us optimally and before doing that we must know how or in what forms water is available, its special and temporary distribution and for that the first thing which we will discuss is the hydrologic cycle.

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As you can see in this figure, the hydrologic cycle or the water cycle consists of various forms and movements of water. Now let us start with this ocean. In the ocean due to the southern radiation, there is a lot of evaporation of water. When it goes up it condenses and then there is some precipitation in the form of either rain or snow. We will discuss these forms little later.
When the rainfall occurs, there might be some evaporation directly from the rain and the rest of it when it falls on the surface either goes into the ground as infiltration or it runs off in the rivers or deposits in the lakes. Now these rivers then run to the ocean and this cycle continues. There are lot of components of these this cycle which we are interested in. For example if we are working in the field of irrigation engineering we would like to know how much water is going into the

ground and from where the plants can take their water? For example, for this module concerned about the water resources, then we should know how much water is going into the rivers so that we can control the floods or we can avoid a lack of water for irrigation other areas. So let us look at some components of this precipitation.

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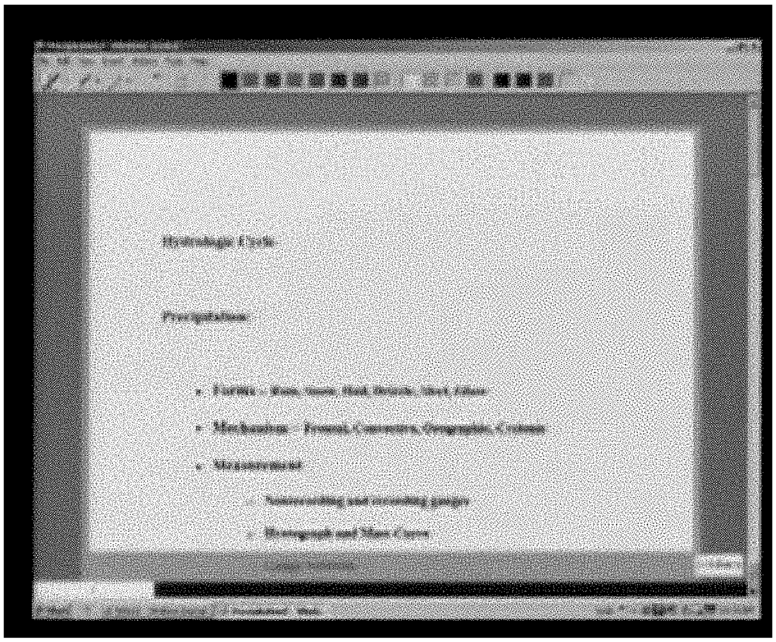

We will start with discussion of precipitation, its various forms. In India we would typically worry about rain, snow and hail. All of us know what is rain snow of course we have seen India it's not lot but in some of the western countries and colder climates snow is also an important part of the precipitation. Hail, drizzle, sleet and clays are all different parts of precipitation. In your chemistry classes you must have seen the precipitation of solids and liquids. So in similar form you can think of rain as precipitation of liquid in gas. So in the atmosphere there is lot of water vapour, when it cools down, the condensation causes that water vapour to drop in the form of rain or snow or hail depending on the temperature at that time. Various forms have sub classifications. Also for example rain can be classified as light medium or heavy depending on how much rain is falling in let us say 1 hour.

When we study the mechanisms of rain, it can be caused by various different kinds of mechanisms. The important thing is that there is a mass of water vapour which should cool down so that the water condenses and then falls down. So for cooling, we have lot of different mechanisms. For example the frontal mechanism where a front which is a surface or a surface of contact between 2 different air masses of different temperature, when a warm front or warm air for example,

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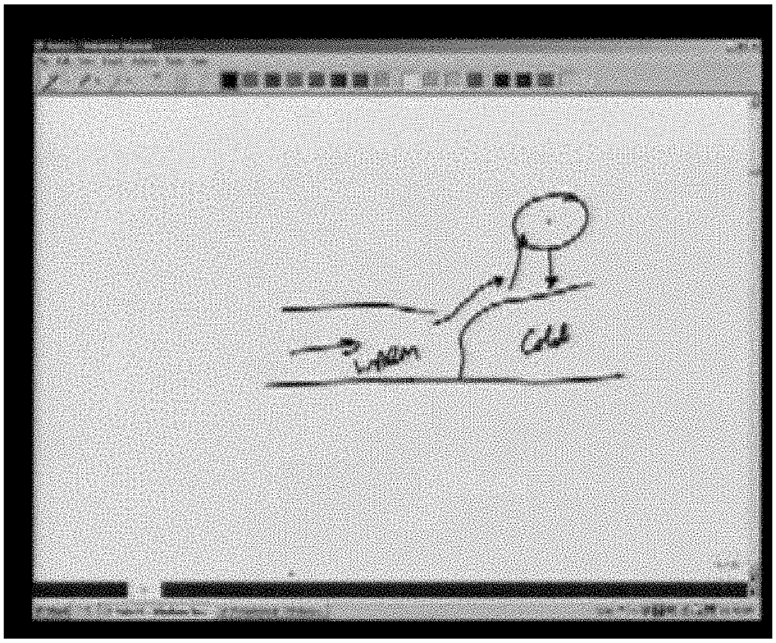

this is the ground surface and there is warm air going from the side and encounters a cold front here. Then this warm air tends to rise above the cold air, because of its smaller density and therefore as it goes up due to adiabatic rate of cooling, this water vapour will condense and will fall down as rain, so this is called frontal precipitation.

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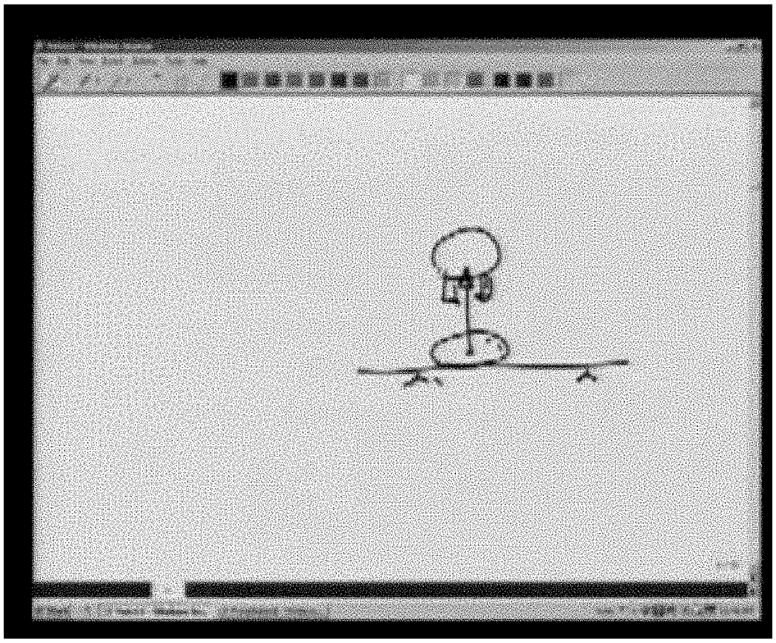

The surface of the earth may be warmer and therefore the air which is in contact with the surface because of it is high temperature and low density tends to rise and sets up the conductive current. Now when this air rises again, it goes up, it goes down and therefore there will be some precipitation in the form of rain. The third mechanism is called Orographic precipitation.

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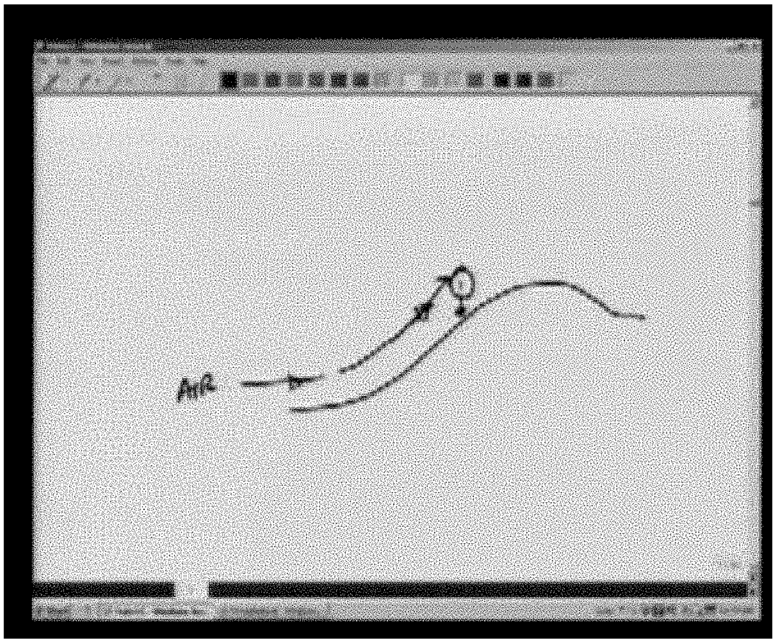

In this form if we have a mountain and air coming in, it will raise because of the rise in the ground elevation. As it rises up again, the temperature decreases and there will be some precipitation which is known as the orographic precipitation and then finally cyclonic precipitation.

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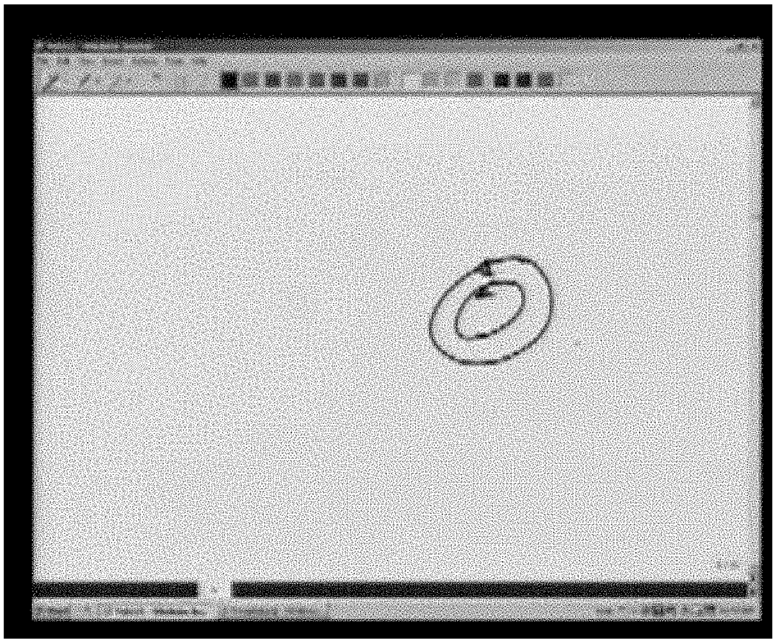

This occurs especially in coastal areas where from the sea cyclones which are winds of very high magnitude and rotating about the centre, they carry a lot of moisture from the sea and then they come on land and will cause precipitation. Now precipitation is important, and to know how much precipitation is occurring at a certain time, we shall discuss the measurement of precipitation in the next topic. There are basically 2 different types of instruments, which are known as rain gauges. One is a simple non recording and the other is recording. Non recording means that it will not record with time of the continuous variation of rainfall. We will go manually and may be once a day see the instrument and see how much rain has collected and in recording type gauges, we have a continuous record of rainfall. As it is falling, it is being recorded in the non recording rain gauge.

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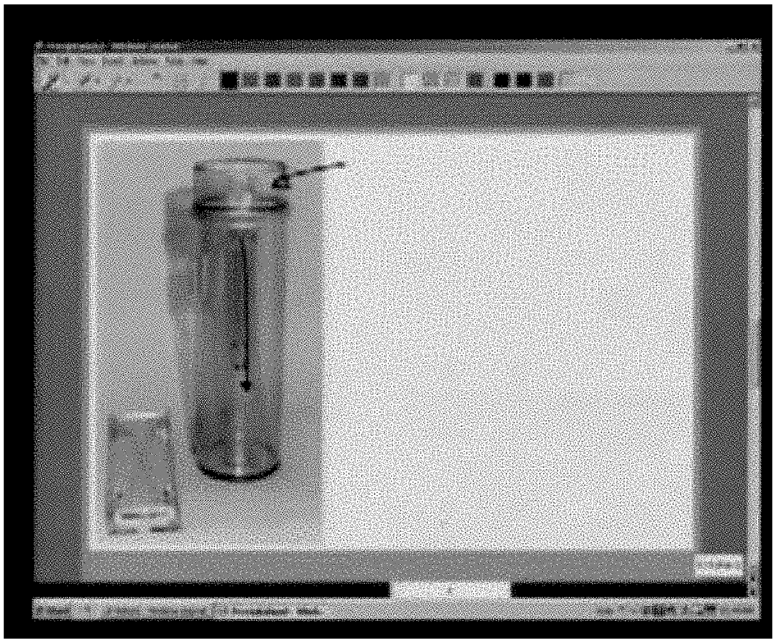

This figure shows a non recording. Typical non recording rain gauge in which on the top we have a funnel to carry the rain water falling on it. This funnel then carries water into a graduated cylinder on which we can see the markings which tells how much rain has fallen in that period. Typically in India around 8 – 8.30 AM, a person goes and looks at this rain gauge and finds out how much rainfall has occurred in the previous day. So at a fixed time, every day somebody goes and watches the amount of rainfall in the recording gauges. We have a continuous record. There are 3 different types of rain gauges commonly used here. The most common one is known as a tipping bucket.

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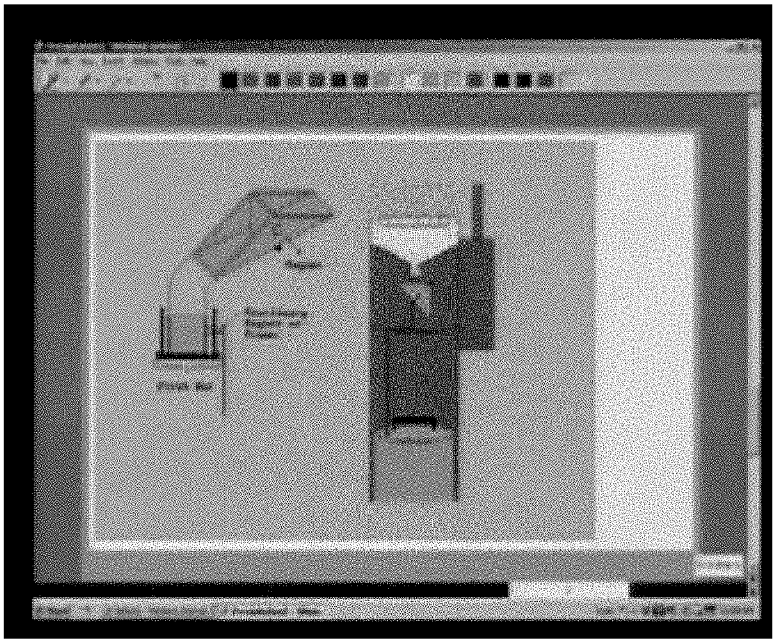

In the tipping bucket rain gauge which is shown here we have a funnel which collects rain fall and there is an arrangement here which is known as the tipping bucket which has 2 compartments as shown here (Refer Slide Time: 09:30). One of the compartments is below the funnel, so it collects all the water and then a fixed amount of water has entered into this bucket it tips over. So then it rotates and the other compartment comes below the funnel, so this will go here and the other compartment will come below the funnel and then it will start collecting and when it tips, there is a magnet here which will send the signal to some recording device and we will know how much time it took to fill one side of the bucket and we know how much rainfall has been collected in that time. So that way it records these tips which tell us the intensity of rainfall. The data which we obtained from these non recording and recording gauges can be expressed or displayed in a form of a hyetograph or a mass curve.

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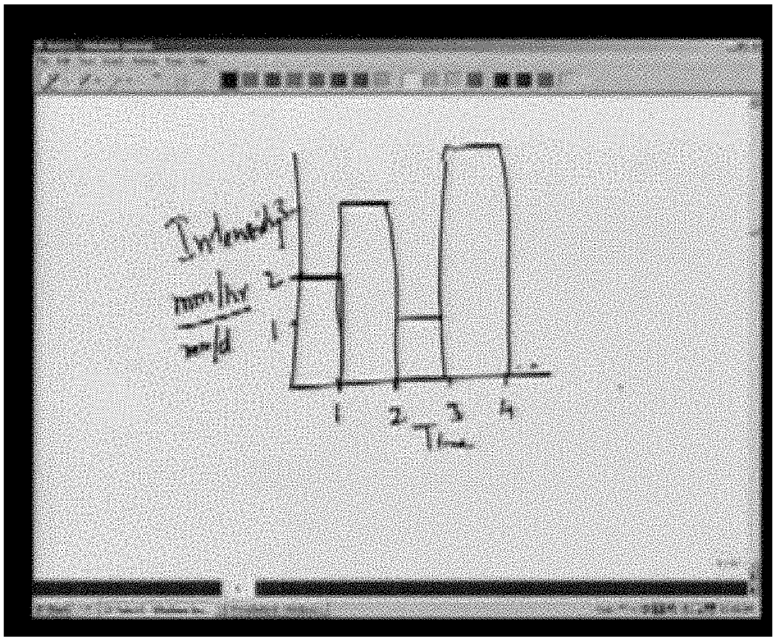

Now a hyetograph is a plot of time versus intensity. Intensity of rainfall is typically expressed in terms of mm per hour and sometimes cm per hour. If we have a non recording rain gauge, then this data can be expressed as daily values of intensity. For example in the first day, if we collect 2 mms of rain, we can express the intensity and it would be better in that case to change it to mm per day. So we have 2 mm in the first day, then suppose in the second day we have 3, and then it will look like this. Since we do not know when in the day this rainfall occurred, because we are collecting data every 24 hours, we cannot show the variation within that one day. So this typically will look like this and so on. So this is known as a hyetograph. How does the rainfall intensity vary with time? The second type of curve which we use to show the rainfall intensity variation is a mass curve.

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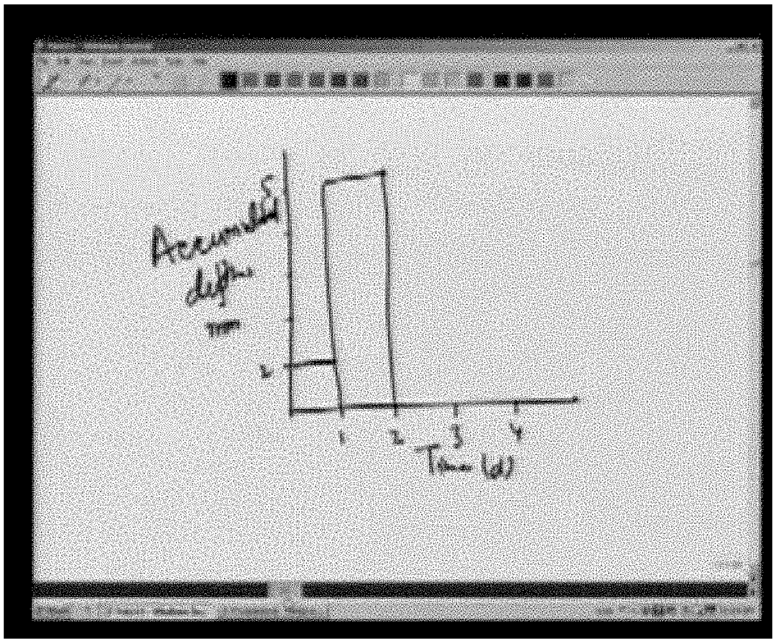

The mass curve again with time shows the accumulated depth, so the intensity shows how intense the rainfall is, how many cm or mm is per hour and a mass curve shows how much depth has accumulated from the starting. So again we say that at this time and day, this accumulated depth may be in mm s or cm, so in the first day if we have 2 mm of rain, it would be 2 then in the second day suppose we have another 3, then this would be 5. So this curve is continuously increasing because it tells you the accumulated mass or depth of rainfall. For recording gauges, we typically get a curve which directly gives us the accumulated depth. In the recording gauge we have come across the tipping bucket. There is another one which is not so common because it is more expensive and this is known as a weighing type in the weighing bucket. As the rain falls on the bucket or on the rain gauge, it gets collected and a signal is sent immediately to record how the weight is increasing with time.

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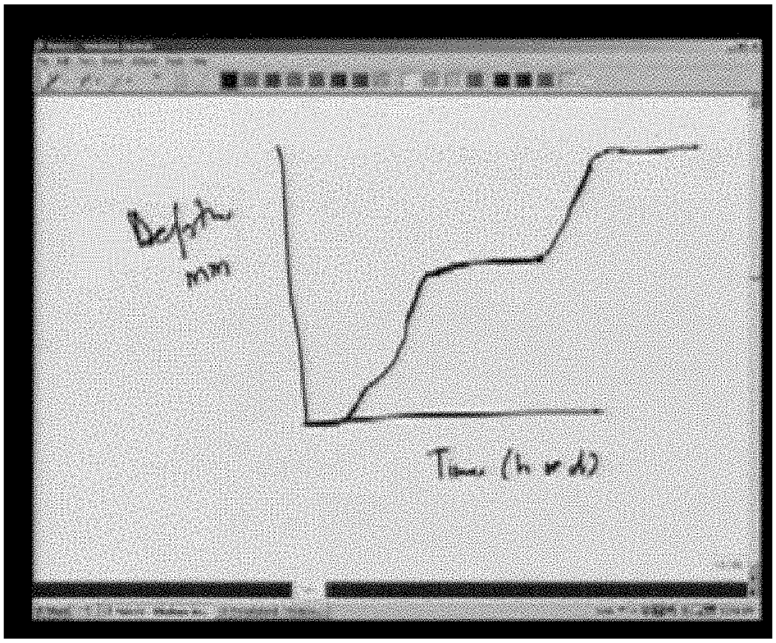

So what we get is directly a mass curve of rain which would look like this. Again this depth may be mm s or cm. Time may be in hours or day. This shows the accumulation of rain in the rain gauge over time and if you look at this curve it tells you that there is no rain from this point. At this point, there is some rainfall. The slope of this curve will show you the intensity of rainfall. So wherever the slope is largest, for example here or here the intensity of rainfall is very high and there it is flat. There is almost no rainfall or very low intensity rainfall. So the mass curve slope will give us the hyetograph. Now to collect the data we need to put these rain gauges in the field and therefore it becomes important to know what should be our network.

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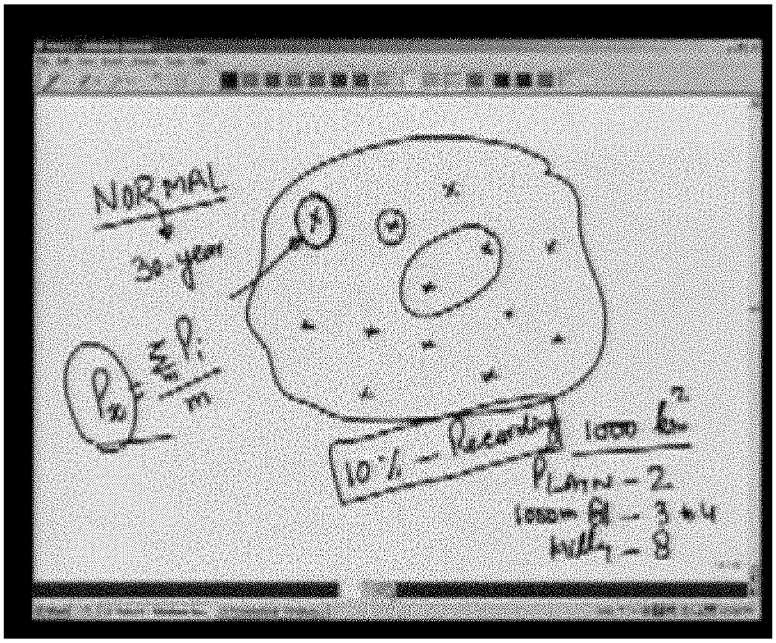

For example, if we want to find out the rainfall over a certain area, how many rain gauges should be put and where should they be located, then for example one option would be to locate the gauges here (Refer Slide Time: 15:03) or you may add more gauges here. So there are some guide lines which tell you, in how much area how many gauges should be used. Now for example in India the guidelines are for a 1000 km square area. If we have a plane area, 2 rain gauges are sufficient. If you have moderate elevation for example a 1000 m elevation, then you may need 3 to 4 rain gauges in a 1000 km square area. Because the variation of special variation of rain is likely to be more than in the planes and for hilly areas typically we need to use 8 rain gauges for 1000 km squared area. So these guide lines should be followed whenever we are designing a rain gauge network and another guideline is that 10 percent of the rain gauges should be of recording type. So if we have lets say 15 gauges in this area, 1 or 2 should be recording and based on the record. Of those 1 or 2 we can estimate the temporal variation of rainfall. On the other stations that is why this 10 percents recording gauges are to be used.

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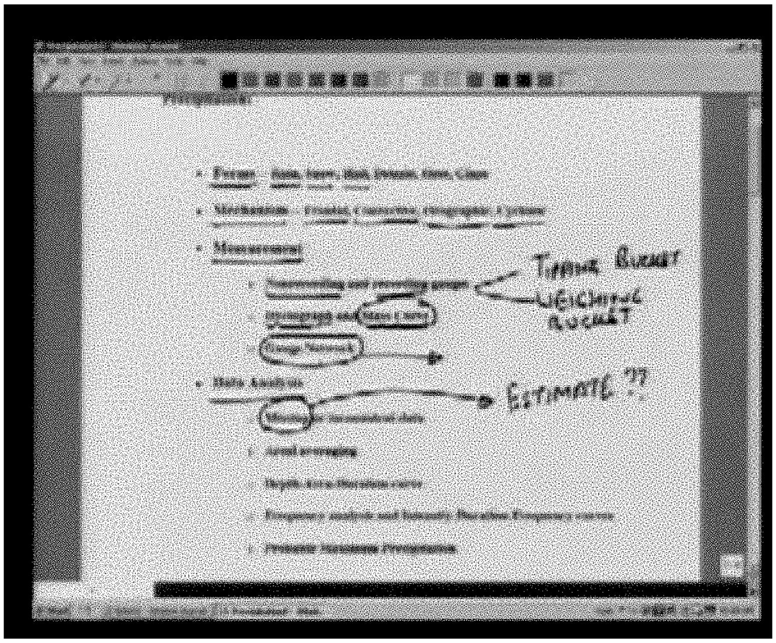

Once we collect the data from these gauges, we have to analyse the data, so the next thing we will discuss is the data analysis. Suppose we have a network of rain gauges like this and we have collected a data over let us say a period of a year, then some of the data may be missing. For example there may be a rain gauge here where we have data for every day. But one day the person who was supposed to collect the data could not go there and therefore we have a missing data. So the first thing we will see is how to estimate or how to take care of the missing data. If we have collected data for a number of days but have missed 1 day, how do we estimate that missing value? The easiest thing of course is to see if we have missed values at 1 station but we have the values available at all the other stations we can take mean of all the other values and say that will be the value at this point.

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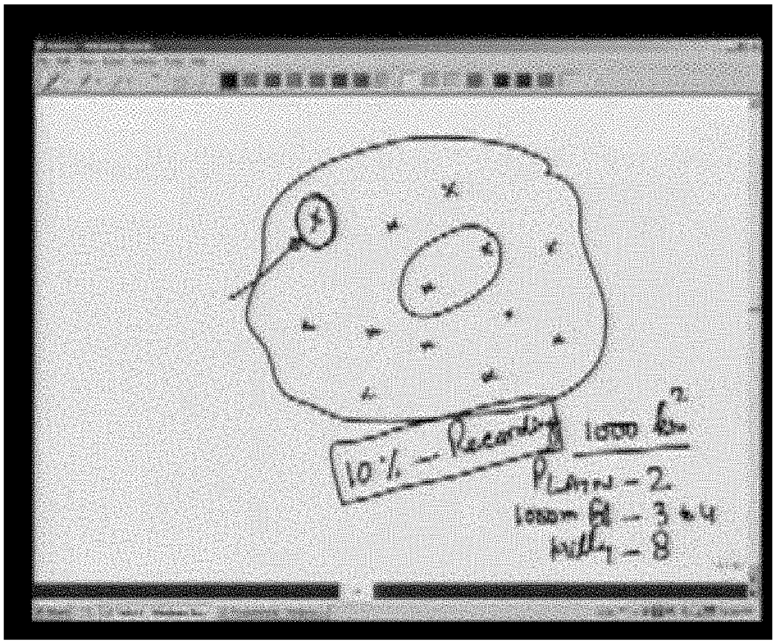

So if we have m other stations, then we can say that the missing value at x could be the mean of all the other values of precipitation on that day, and we estimate our missing value of Px using this. But there is a problem with this method when there is a wide variation of rain over the area. For example this gauge may be recording a higher rainfall than this gauge in general. This is the reason why we have to look at normal precipitation at various gauges. When we say normal precipitation, typically normal is taken as a 30 year average. So if we are looking at let us say May 18th then we would consider what the rainfall at those stations on May 18 over the past 30 years was and the average of those values would be called the normal precipitation for that rain gauge for that day. So if we are measuring the precipitation at this station on May 18th, we can estimate it based on the mean precipitation on that day for all the gauges and they are normal values.

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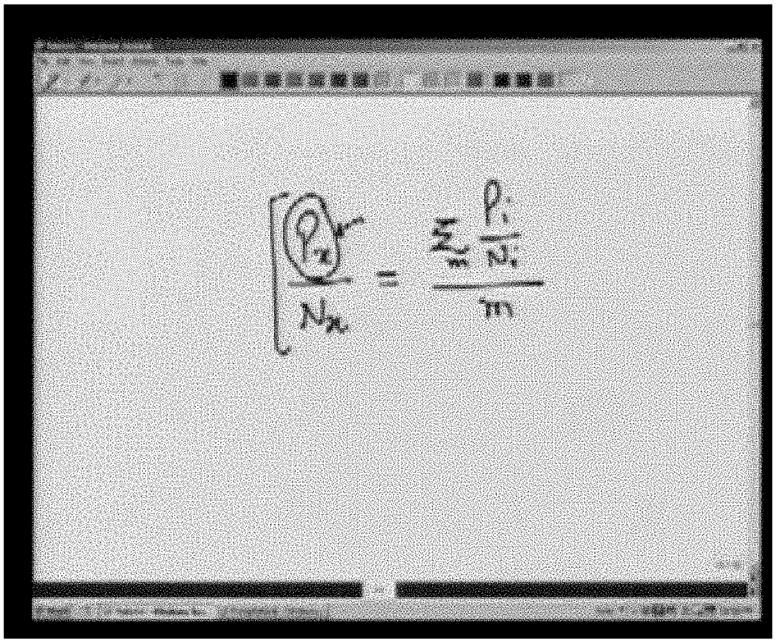

So the formula which we use in this case takes care of the variation in the normal rainfall at other stations also. So it is a similar formula but now instead of estimating the rainfall, we estimate the ratio of the rainfall with the normal rainfall and that way we can estimate the missing value P_x. The next important thing to look for is whether the data is consistent or there is some inconsistency in data for this purpose.

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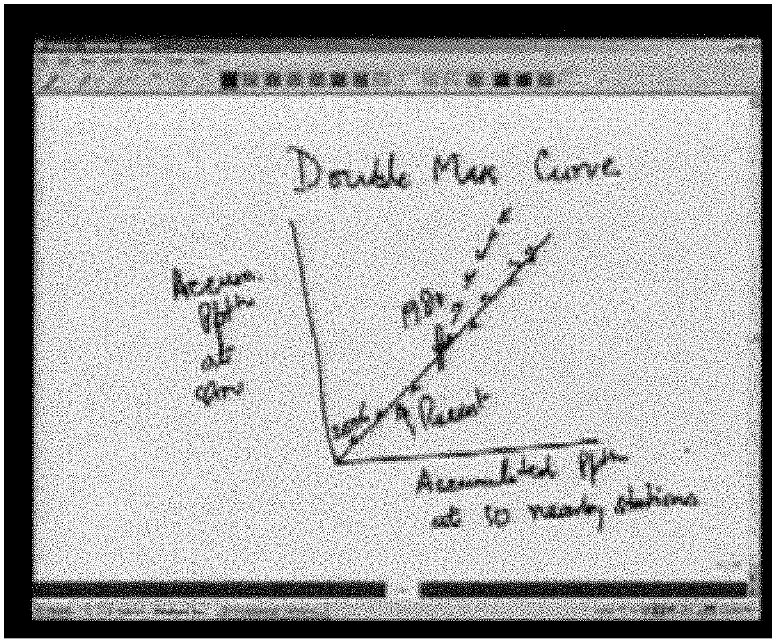

We use what is known as a double mass curve. The assumption is that if the data is consistent it should follow the same trend over a number of years compared with the other stations in that area. So we plot a double mass curve which is accumulated precipitation, suppose 5 or 10 nearby stations versus the precipitation at the station where we want to find out whether the data is consistent or not and if the data is consistent, typically it would follow a straight line with minor variations. But if there is some change in the characteristics of the catchment or if the gauge has been shifted and there is some inconsistency, then we would see that the data does not follow a single straight line and it may deviate from that position. So if we plot the most recent data here and if there is a break somewhere, let say we are starting from 2006 and then we find that in 1980 there was a break in the curve.

So it will tell us that the data is not consistent and there is some problem. Either before 1980, the gauge was in different location and then it was shifted or there was some change in the precipitation pattern because of some natural factors. For example there may be lot of vegetation which was removed. So there could be a number of factors causing this behaviour but any inconsistency in data can be obtained by the double mass curve analysis by plotting accumulated precipitation at one station versus accumulated precipitation at a few nearby stations. Now once we estimate the data and check that is consistent, we go for ariel averaging.

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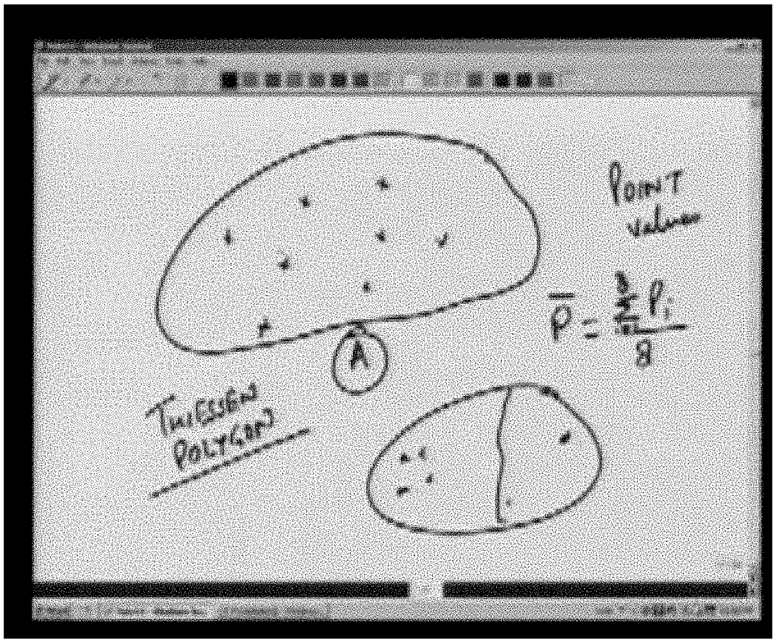

So if we have a certain area and we want to find out rainfall over this area, the values which we have for precipitation is only at these rain gauges and these are called point values. Out of these point values, now we want to estimate what would be the average rainfall over this whole area. So let us call this area A. So the problem is, given the point rainfall values at the rain gauges, how to estimate the average rainfall over the entire area?

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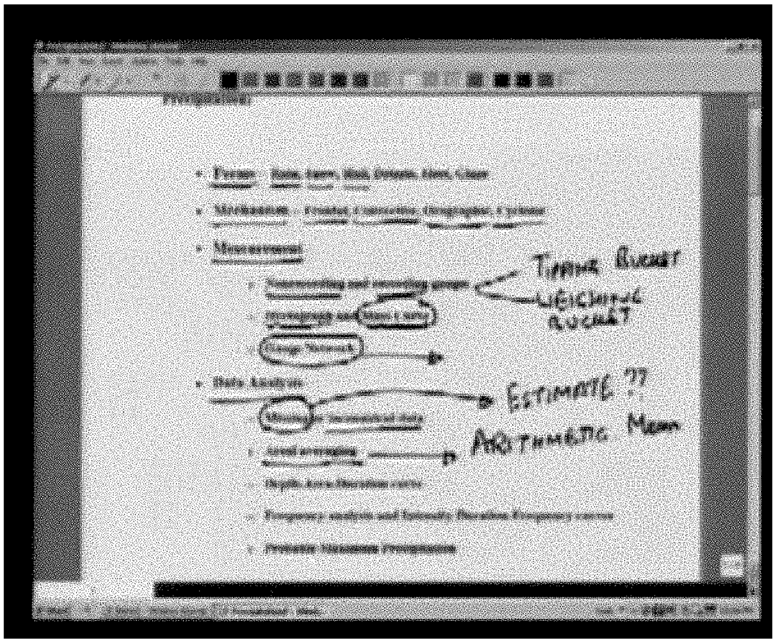

There are a number of techniques. The simplest one is known as arithmetic mean and as it is clear, arithmetic mean means we just take the mean of precipitation values at all the stations.

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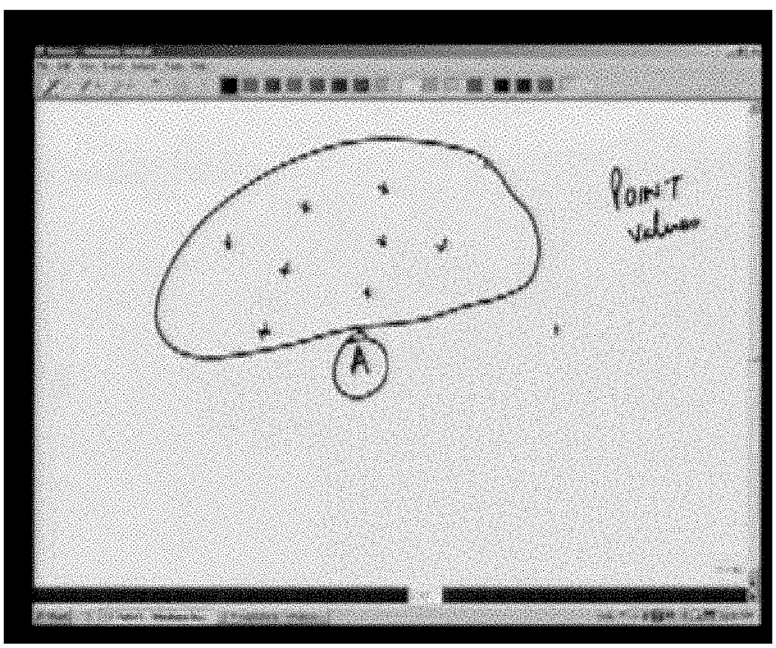

Let us say we have these 8 stations. We will say that arithmetic mean or mean precipitation or the area would be sigma of pi over 8, i = 1 to 8. So it will take the mean of all the precipitation over the entire area. The draw back with this method although is very simple is that we do not give any weight to the location of the gauges in that area.

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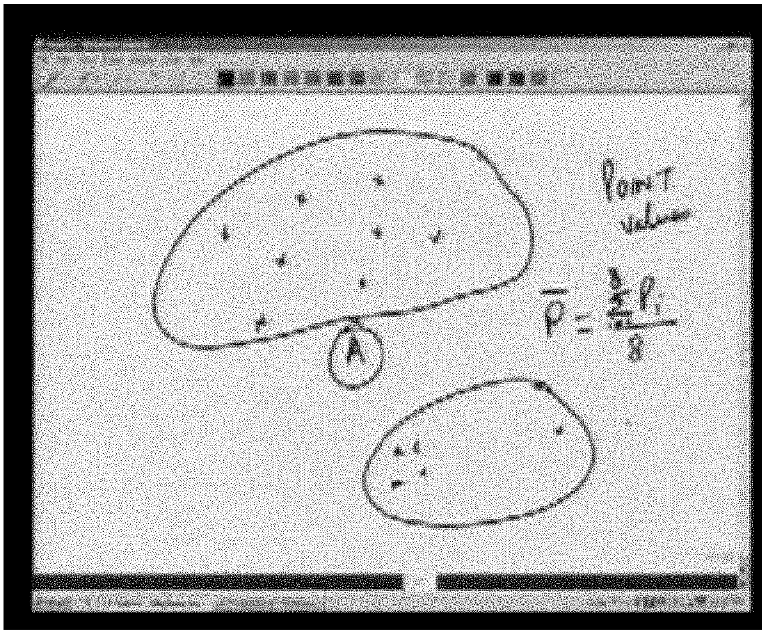

If we have an area where let us say 4 gauges are here and 1 gauge is here, we take the mean without considering that these 4 are very near. So they do not represent as much area as this one here. So how much area does it represent? It is not accounted for in the arithmetic mean method. So a modification or an improvement over this was proposed by Thiessen and this is known as the Thiessen polygon method in which the relative position of various gauges is also considered.

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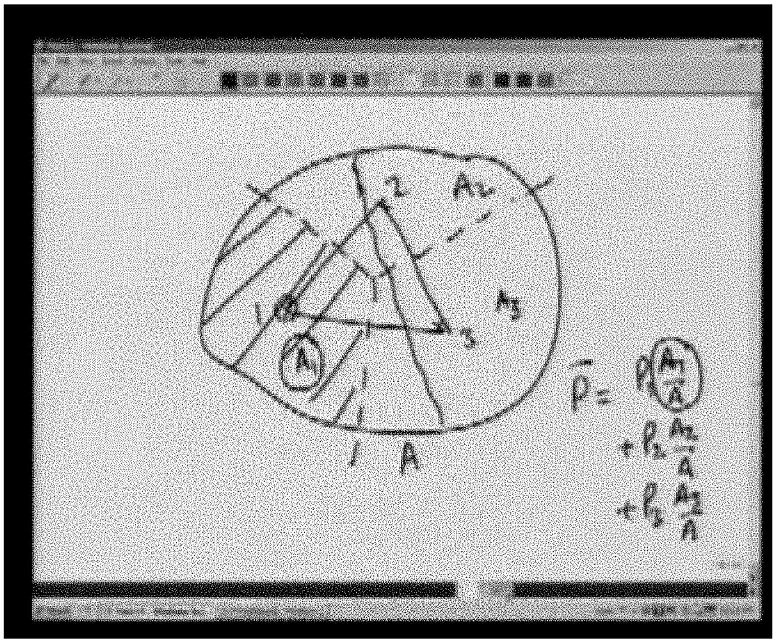

If we have rain gauges in an area like this, we draw perpendicular bisectors of the lines joining the rain gauges and then we assign suppose this is rain gauge, 1, 2 and 3, we say that area A_1 is an effective area for the rain gauge 1. Similarly area A_2 and area A_3 and then we compute the average precipitation. We give the weight to individual rain gauges. So $P_1A_1/A + P_2A_2/ A$, this tells us that a certain rate A_1/A depending on what area is covered by rain gauge 1 is assigned to the precipitation of each rain gauge. So this takes care of some of the draw backs of the arithmetic mean method in that it accounts for the position of the gauges. But it does not account for variation in topography. For example there may be mountainous area here and there may be plane area here, so if this is a sharp change in elevation, the thiessen polygon method will not be able to account for it.

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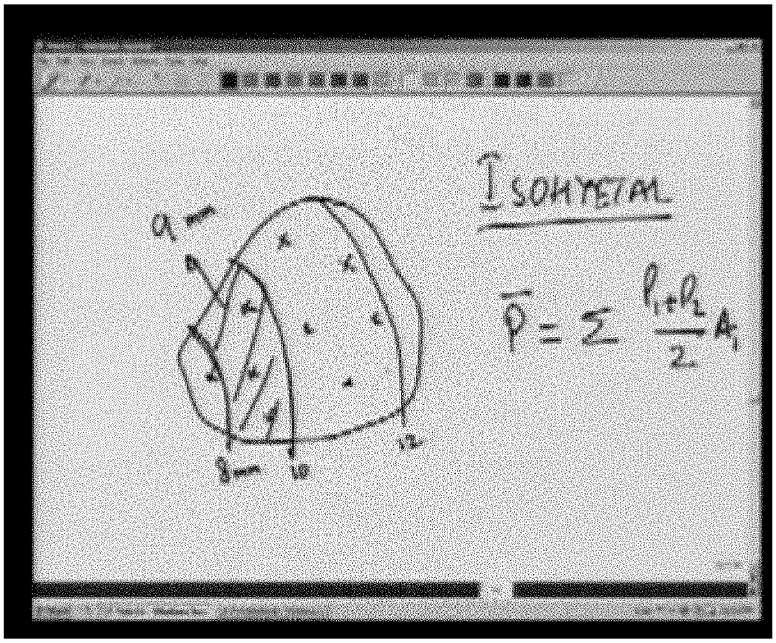

and therefore we have another method which is called Isohyetal method which accounts for the variation of topography. Also by looking at individual precipitation values, I am drawing isohyets. Isohyets are nothing but lines of equal precipitation. So if we have the precipitation values at all these stations, we could look at those values and using those values we could draw isohyetal lines. For example this rain gauge, may be 8 mms, 10mms, and 12mms, depending on the values of these rain gauges. So these all these rain gauges will have values between 8mm and 10mm. This will have less than 8mm, this within 10mm and 12mm. So we will draw the isohyets and then we will assume that the area between 2 isohyets has a rainfall which is equal to the mean of the values of these 2 isohyets. So this area will have a rainfall of 9 mm and by summing up the area and the rainfall over the respective areas, we can get the average rainfall over the area in terms of P bar. Suppose P_1 and P_2 are the surrounding isohyetal values and A is the area between them, then we simply sum up the average precipitation into the area for all the isohyets in the area. Now once we get the ariel average, we can know what is the depth of rainfall over certain area and then we can prepare what are known as depth area duration curves.

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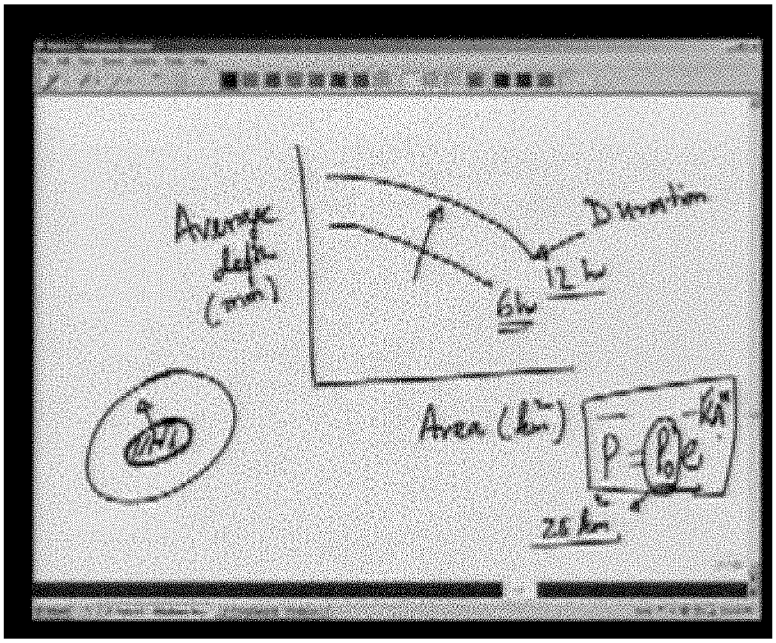

Now these curves look like this. This is the area which may be in Km square and average depth of rainfall which may be in mm or cm and this will show the duration of rainfall which may be 6 hours, 12 hours and so on. So this is the duration. Now if you look at a typical storm, the intensity will be the largest at the centre of the storm and therefore the depth will be very high. As you increase the area, it means you are moving away from the storm centre. The intensity decreases and therefore the depth also decrease over the area. Now if the storm is of larger duration the depth will increase. So these kinds of curves will tell us how much of the average depth of rainfall is to be expected over a certain area if the rainfall occurs for a certain time which is 6 hours or 12 hours or any given time. There is sometimes an imperical equation also given for variation of rainfall. Average depth with area is – K k to the power n exponential where P_0 is the point rainfall value, which we obtain from the rain gauge. But since the rain gauge will not always be at the centre of the storm we say that this rain gauge value represents the rainfall over a 25Km squared area. This kind of equation tells us, for any given duration the average depth decreases with area. These values of K and M will depend on the catchment area and some typical values are given in various text books about different areas. The other aspect which is important is to have some kind of frequency analysis or risk analysis to see the chances of rainfall occurring in the next 10 years or next 100 years or so. The frequency analysis is also very important from this point of view.

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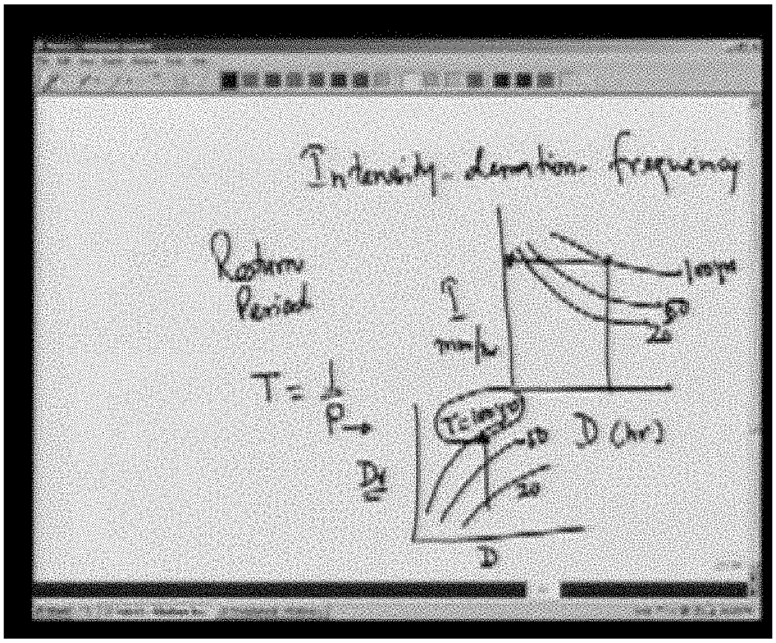

So frequency analysis is nothing but deciding how frequent a rainfall would be and typically what we do is present an intensity duration frequency curve in which we say how frequent will the rainfall of certain intensity and certain duration be. The curve would look like this. This is the intensity of rainfall which may be mm per hour duration typically in hours and this denotes the frequency or the return period which may be a rainfall of once in 100 years or once in 20 years or once in 50 years. The frequency of course would be reverse of the time period, so we can write the time period as one over the probability of occurrence of a rainfall and when we discuss the intensity using frequency curve, they will help us in knowing or designing a project or some structure against a given probability of occurrence. So if you want to design something which needs to be very safe, we may go in for 100 year precipitation and based on that 100 year precipitation, we can find out the depth of precipitation and those curves.

We can prepare, in terms of duration, depth of rainfall and the time period. So what this curve indicates is that for a given duration of rainfall, what will be the depth for a given time period. One should be aware of the fact that time period of 100 years does not mean that this rainfall will occur every 100 years. In general if we take a very long period of record, for example 400 - 500 years, this event is likely to occur 4 or 5 times. It is not that it will occur only once in any given 100 year period. Related to this there is a concept of probable maximum precipitation which can occur over a given area and this probable maximum precipitation is used in very extreme cases where we have to design something which is very critical. For example a large dam the future of which will be catastrophic so in that case, we can find out what the PMP is.

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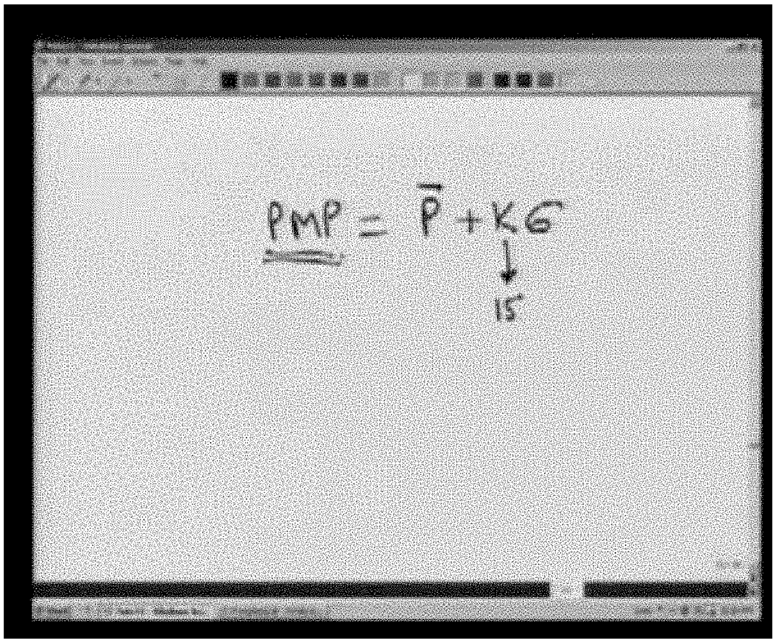

PMP or the probable maximum precipitation which is typically written as some factor multiplied by the standard deviation plus the mean rainfall and generally the value of K is taken as above 15. So the mean rainfall plus 15 times standard deviation which is normally taken as the probable maximum precipitation for that area and this is used in critical design to estimate what will be the maximum flood which can occur in the given catchment. So in this lecture we have seen various aspects of precipitations but we must realise that as water resource engineer, it is not the precipitation which is of importance to us.

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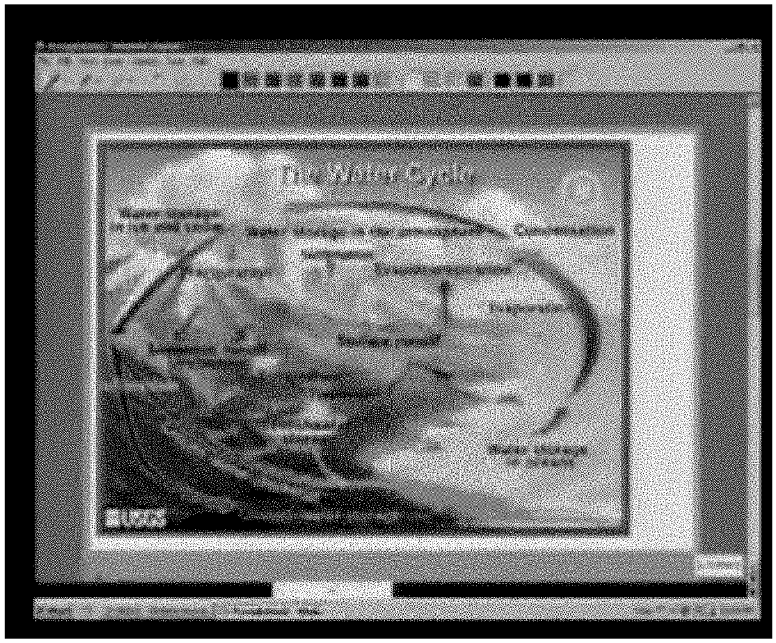

It is really the run off or how much water is going into the river which is more important to us. Although you are an agricultural engineer, the water which is going underground may be more important to you but most of the water resources engineering projects deal with construction of dams, canals and other things from the rivers and therefore the volume of water going into the river is more important although it depends on precipitation. But we are more concerned about the run off. So in today's lecture we have looked at the precipitation. Out of this precipitation, part of it will go underground which is called infiltration, part of it will evaporate from the surface; part of it will be lost as transpiration from the plants. So we combine them and we call that evapo transpiration. So evapo transpiration and infiltration are the 2 abstractions from the precipitation and most of the rest goes to the streams or over the surface as surface run off. Part of it goes inside the ground and again goes to the streams and ocean as underground run off or what we call base ground.

So after today's lecture in which we studied precipitation, we will look at what are the various abstractions with infiltration, evapo transpiration and also there is some 'storage on the surface' to see the quantity of water taken out of the precipitation and that will help us in finding quanitity of the water going into the rivers and lakes.