Urban Utilities Planning: Water Supply, Sanitation and Drainage
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Module - 03
Collection of water
Lecture - 11
Rainfall, Runoff and Ground Water

Welcome back. Today, we will start module 3 Collection of Water. And in lecture 11, we will start with Rainfall, Runoff and Ground Water.

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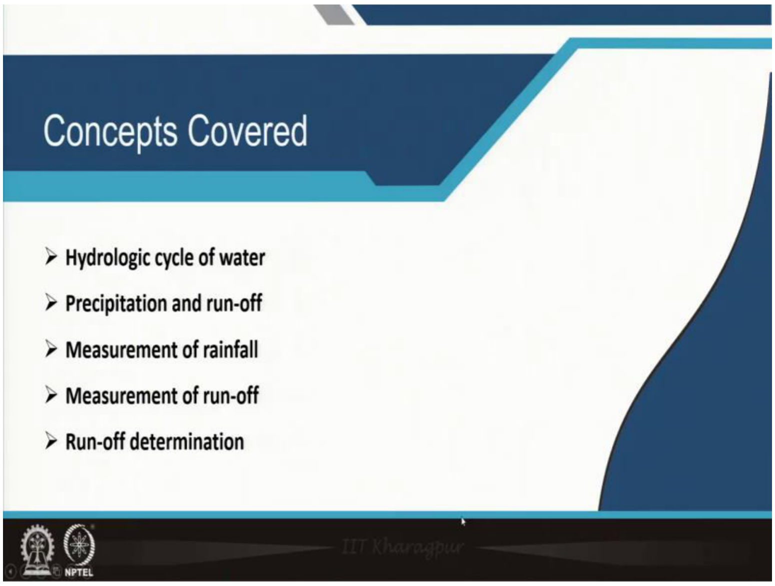

So, the different concepts that would be covered in this lecture are hydrologic cycle of water, precipitation and run-off, measurement of rainfall, measurement of run-off, and run-off determination.

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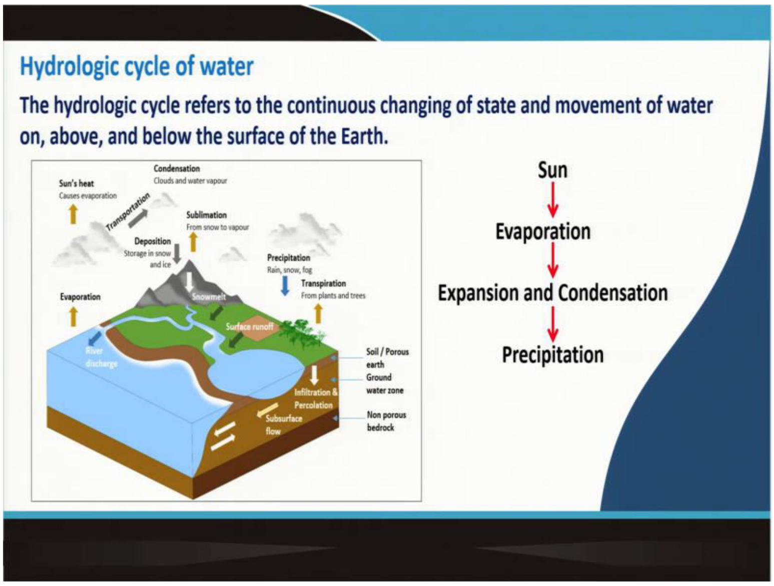

So, the hydrologic cycle of water is something we have all been taught in our schools. It refers to the continuous changing of both the state of water and the movement of water, both on above and below the surface of the earth. The state of water changes from liquid to vapor due to sun's heat, moves up and gradually expands because of low pressure in the upper layers and then condensation takes place. At dew point, precipitation happens and water reaches the ground as rain or snow. This is a cyclic process which goes on continuously. So, there is both change of state as well as movement of water.

And once the water falls back on the earth it again moves in different ways. For example, some of it percolates inside the earth surface and then moves within the earth surface, some of it moves above the earth surface and goes towards the different rivers, streams and the different water bodies from where it evaporates. So, this entire process is the hydrologic cycle of water which is a continuous process.

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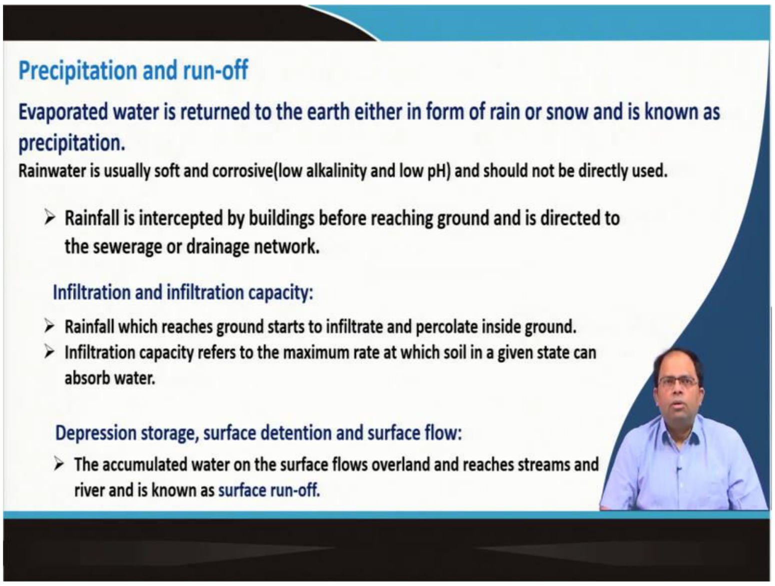

Precipitation and Run-off

The evaporated water which is returned to the earth, in the form of either rain or snow is known as precipitation. Both snow and rain are usually measured separately as they are in different states.

For example, when there is rainfall, the rainwater collected is used directly for certain purposes. It is soft and hence can be used for household purposes such as cleaning clothes. But it is also a little bit corrosive. Why? Because it has got a low pH value and low alkalinity; that means, it is a bit acidic in nature. So, it is recommended to treat the rainwater before being used for potable purposes.

During the rainfall, the water falls on different surfaces; such as paved surfaces, green surfaces, on the rooftops of buildings as well. The rainfall that falls on the roof top usually is drained from the roof, by means of rain water pipes and then this water directly goes into the drainage network and its drained through the drainage network of the city or the sewerage network and is transported towards the treatment plants or to the final disposal points which could be streams or rivers. Since this water enters the drainage channel, it doesn't contribute to run-off.

The rain water which falls on the ground and flows over it constitutes the run-off. Depending upon the porosity of the surfaces, rainwater percolates inside the ground. Once it reaches the ground, it starts to infiltrates into the soil and starts moving inside the soil. Therefore, some amount of rainfall can move below the surface as well above the surface in the form of run-off.

The infiltration capacity refers to the maximum rate at which soil in a given state can actually absorb water. So, depending on the infiltration capacity certain percentage of the rainfall will percolate into the ground, and certain percent remains above the ground.

The amount of rainfall that remains above the ground fills up all the different smaller holes or pores that are around. And so, this is called depression storage. After all the smaller undulations are filled, the excess amount of water starts flowing in form of a laminar flow over the surface. And this accumulated water on the surface once it flows over the land, it eventually reaches the streams and river and this is known as the surface run-off.

Apart from these, there is sub surface run-off; the water that flows just below the surface in the direction of the streams and eventually flows into the stream and contributes to the water in the stream. But surface run-off is the one which concerns us at this point.

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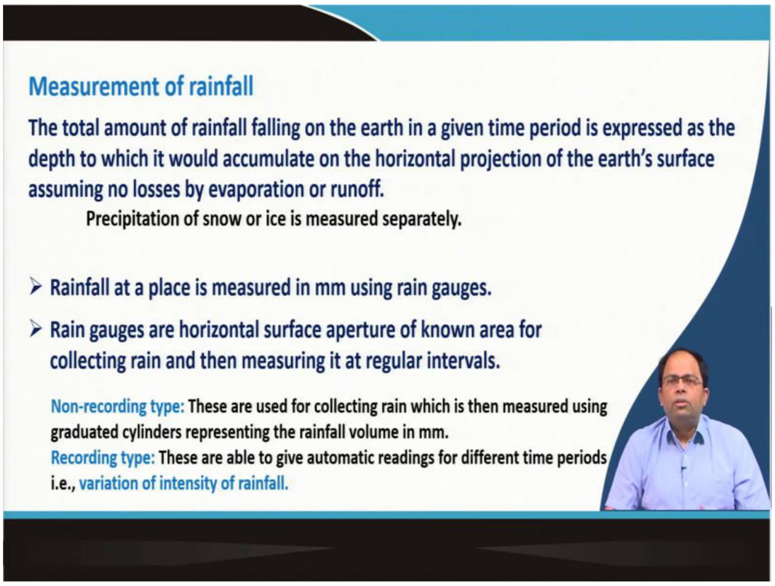

If we cannot control the surface run-off, it will lead to floods in urban areas. We have to control this particular flow by either taking them into certain drainage channels or determining the size of the drainage channels appropriate to take this flow and so on. So, that is how we should manage the different amounts of run-off that is generated in urban areas.

Measurement of Rainfall

Before determining the amount of run-off, we need to determine the amount of rainfall that occurs. The total amount of rainfall falling on the earth in a given time period is expressed as the depth to which it would accumulate on the horizontal projection of the earth surface assuming no losses by evaporation or run-off. In order to measure rainfall, we take an unit area and determine the amount of rainfall that has happened in terms of the height of the water that is accumulated over that particular surface. We need to be careful about the fact that whenever rainfall happens, there is evaporation and some amount of water reduces. So, we should assume that evaporation doesn't occur and no run-off is being generated from this particular point and that the entire water is measured as the total amount of water that is falling as rain. In addition to this, we need to measure snow and ice separately since these are in different states.

Let's look into the measurement of rainfall. The rainfall is measured in millimeters and the equipment or the instrument used to measure rainfall are called rain gauges. Rain gauges are horizontal surface apertures of known area for collecting rain and then measuring it at regular intervals. So, it is a cylinder of known area where we allow the water to accumulate and we know the area of the cylinder. This helps us to determine the amount of rainfall that is generated within that time period. It is measured at regular intervals so that we can measure the intensity of rainfall at different time periods.

There are two types of rain gauges, one is a non-recording type rain gauge and other is a recording type rain gauge. The non-recording type rain gauge is used for collecting rains which is then measured using graduated cylinders representing the rainfall volume in millimeter as a static measure. It constitutes of graduated cylinders whose content will give us the actual height of rainfall in millimeters. Since it is graduated, for a particular volume, the height of rainfall can be readily read.

Then we have the recording type rain gauge, which is dynamic, gives us automatic readings for different time periods and also measures the variation of intensity of rainfall. That is during different time periods if you are able to measure how much rainfall happens, we are automatically measuring the intensity of rainfall at different time periods.

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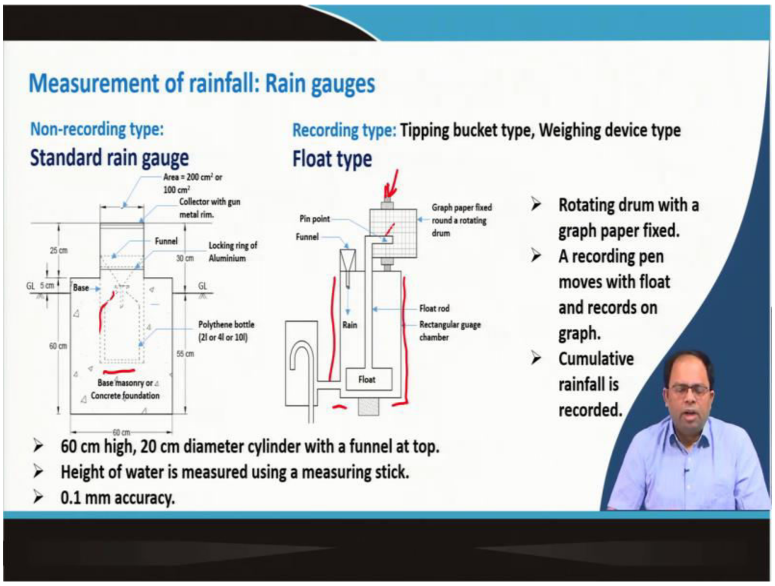

So, let us look at two of these figures given over here. The first figure shows our standard rain gauge which is a non-recording type rain gauge, and as you can see over here it is a cylinder and it has got a funnel at the top.

So, whatever rainfall falls within this particular area rainfall is collected into this particular container. This cylinder here is 60 cm high with a diameter of 20 cm and a funnel at the top and height of water is measured using a measuring stick which is graduated. That is, it will show us exactly how many millimeters of rainfall has happened because we have already calibrated or graduated that particular cylinder. It can measure up to an accuracy level of 0.1 mm. So, this is the standard rain gauge with no moving parts. These standard rain gauges could be set up in any points, at any locations. But it has to be measured at certain intervals otherwise you would not be able to understand any change in the intensity of rain fall.

Similarly, we have got other kinds of rain gauges which are recording type. The image actually shows of a float type of rain gauge. And as you can see over here it has a container, a box, a cylinder and there is a funnel over here as well.

So, whatever rain falls on the funnel gets inside and this float gradually goes up. And there is a cylinder over here and this rotates, and this has got a graph paper attached to it for measurement. Graph paper is fixed into the cylinder and as the cylinder rotates this arm goes up because of the float. There is a recording pen fixed with the float which gradually moves up as the float rises up. And because this cylinder is rotating you will see that there is a change in the height of this line and you can understand what is the intensity of rainfall. So, following this graph, we can determine how the intensity is changing during different time periods.

So, once the water reaches a certain height within this container, because of the siphon effect it gets out, i.e., the entire water goes out, and then the water rises up again until this level goes out and then again, we start recording for the next time period. So, in this way we keep on recording and this is an automatic system.

To summarize, this is a rotating drum with a fixed graph paper. Recording pen moves with the float and records on this particular graph, and cumulative rainfall is recorded. So, this is how you can automatically record the rainfall at different time periods.

So, in addition to float type rain gauges, there are other kinds of rain gauges such as the tipping bucket type and the weighing device type. In tipping bucket type, the container is filled, and once it is full, it tips and lets out the liquid and again it comes back and gets filled. So, the number of times the container gets filled and emptied records the total amount of rainfall during different time periods. Similarly, weighing device type depends on the weight of the rainfall. These are the different instruments that can be used to measure the amount of rainfall that falls in a particular urban area.

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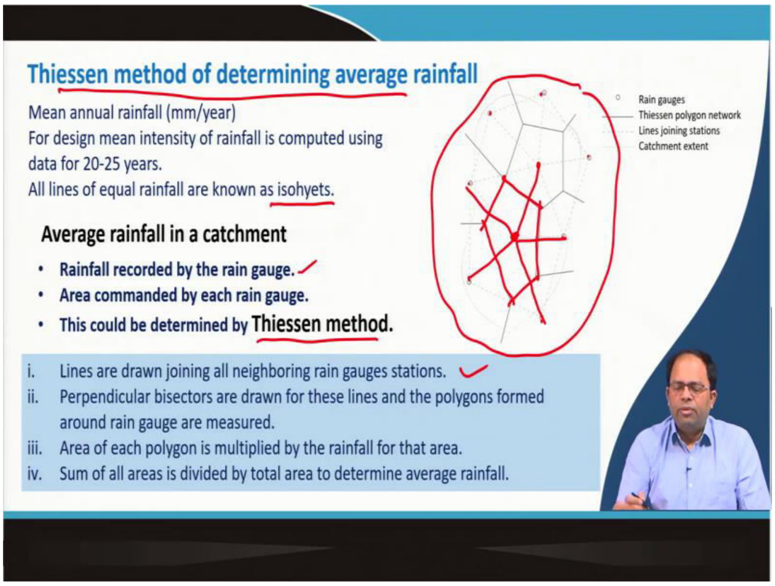

Thiessen method of determining average rainfall

Consider this example, in this particular drawing. You can see the points where the rainfall is measured. We need to determine the total amount of rainfall that happens in a particular area. In this particular area, there could be several rain gauges and the rainfall is not uniform throughout during a certain rainfall event and different points will have received different amounts of rainfall. That is, there are differences in both the intensity of rainfall as well as the event of rainfall that also may happen in one area, in another area it may not happen.

Suppose we have to design a drainage network for an entire area. For this, we need to understand the amount of rainfall happens at certain time periods measured by these rain gauges for different areas. So, what we require is to measure the average rainfall for this particular area.

So, how do we determine the average rainfall? We can take the rainfall readings of each of this particular weather stations and divide by the number of weather station to get the average. This method may not be accurate because we do not know exactly how much area is being represented by a particular weather station.

So, we follow a method called the Thiessen method. It refers to creation of polygons around the weather station in such a way that there are continuous polygons. And there is no area which is unrepresented; that means, each area is assigned a weather station.

To summarize, first we need to determine the mean annual rainfall for a particular area which is done by adding all the different rainfall events that has happened in that area.

And if we want to determine mean annual per day, we can divide by the number of days for that particular area or for a particular season. And then using this mean annual rainfall we have to design different kind of infrastructure that is required. Infrastructure refers to the drains and drainage channels and so on.

For design we usually look into the data of rainfall for the last 20-25 years and sometimes even more. Because rainfall does not happen uniformly every year, some year it is high, some year it is low and the amount varies. And sometimes the variation is pretty big. Hence, we take an average of around 25-30 years and we try to find the intensity of rainfall during this period what kind of rainfall event is possible.

If I design my infrastructure like drainage channel, detention basin, based on a lower value, then during the actual event there may be chance of flooding. So, we need to determine the extreme rainfall events during the last 20-30 years and then based on that we will design our infrastructure.

Sometimes we also try to determine areas which could be assigned similar amount of rainfall where isolines and isohyets come into picture. All lines of equal rainfall based on point data is connected via contours to form isohyets.

So, to determine average rainfall in a particular catchment area which is required to design the drainage infrastructure for this particular zone or catchment, first of all we have to record the rainfall using a rain gauge and the next step is to determine the area commanded by each of these rain gauges which can be determined by the Thiessen method. For this, we join all the different neighboring rain gauges using lines and draw perpendicular bisectors to the line joining two stations, continuing the process for all stations and we end up with polygons with a station in it. The polygon’s area is multiplied with the rainfall recorded in this particular weather station and that gives us the total rainfall for this particular area. When we do it for all the different polygons that has been formed around each of the weather stations, we get the total volume of water that has been collected because of rain in this particular catchment.

And then if we want to determine the average rainfall in this particular catchment, the value divided by the overall area gives the average rainfall intensity. Based on these values we can determine the sort of infrastructure required.

So, this is the Thiessen method for determining average rainfall.

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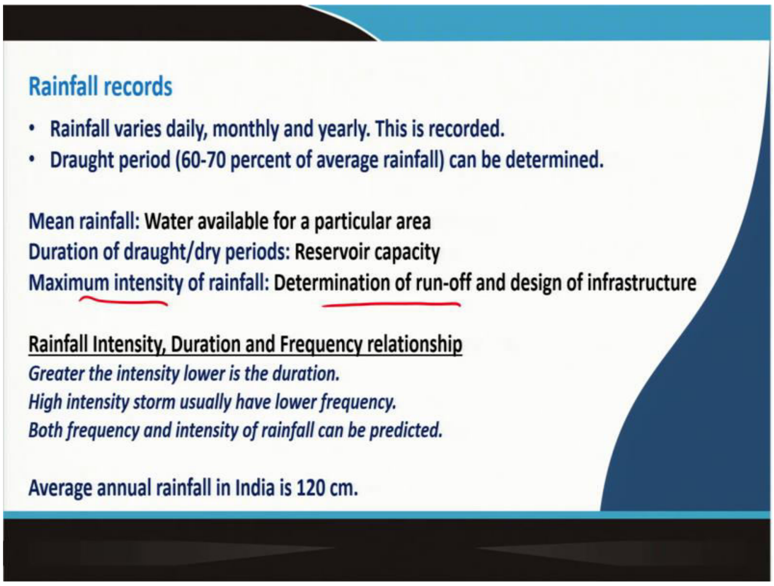

Rainfall records

So, why is rainfall records important? Why do we measure rainfall? Why do we keep this records?

Rainfall records are important because rainfall varies daily, monthly, yearly, and keeping these records help us understand the variations in rainfall during different seasons.

We also need to determine the draught periods, that is, whenever the rainfall is 60 to 70 percent of the average rainfall, it is denoted as a draught period. Maintaining these records help us determine when the period of draught occurs. This is pertinent because of climate change, India is looking at severe draughts in the coming years.

So, we need to keep a record and assess if there is a cycle of draughts; that means, at certain intervals draughts are returning so that we will be prepared for it. This is why we need to keep rainfall records.

So, what are the kind of data we keep? One is mean rainfall that is average rainfall. So, using this we would be able to determine what is the total amount water available for a particular area. We also need to understand the duration of draught and dry periods, because if we know that the drought will be there for a 1-year period, then we will determine the reservoir capacity or the storage capacity for water, and then accordingly create our infrastructure.

We also need to understand the maximum intensity of rainfall and based on that we have to determine our drainage channels and so on. We have to determine the run-offs and design the infrastructure, so that it does not cause floods. As floods cause a lot of monetary damage, we need to maintain such records of data sets in regards to rainfall.

Also, there is a relationship between rainfall intensity duration and frequency which is complex, but there are some general trends. For example, greater the intensity lower is the duration of rainfall. So, if we have a very intense rainfall, it is of lower duration. High intensity storm usually has lower frequency, and both frequency and intensity of rainfall can be predicted.

In India, we usually get an average annual rainfall of around 120 centimeters. So, this is not uniform in all over India, some places it is more, some places it is less. So, average rainfall in India is around 120 centimeters per year; that means, per year we receive this amount of rainfall.

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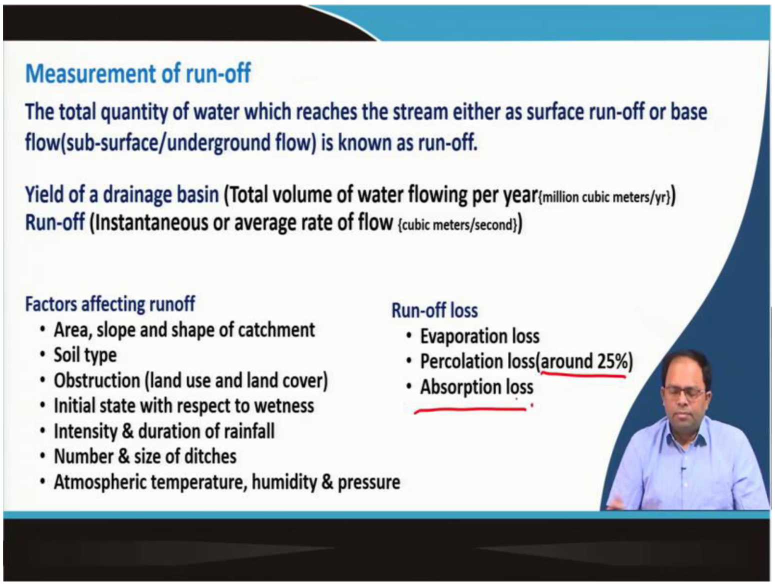

Measurement of run-off

So, similar to measuring rainfall we can also measure run-off because that determines what kind of infrastructure we will actually construct.

The run-off is considered as a total quantity of water which reaches the stream either a surface run-off or base flow; that means, sub surface or underground flow together is known as run-off.

So, yield of a drainage basin and run-off are two different terms that we use interchangeably. But the problem is these two are different terms. For example, when we talk about run-off it is instantaneous or average rate of flow is given in cubic meters per second. Run-off is expressed in cubic meters per second and that actually refers to that flow during that particular period.

The yield of a drainage basin refers to the total volume of water flowing per year from that particular drainage basin. So, that is where we actually have the entire catchment, annual rainfall for that particular catchment or we have multiple weather stations where we use Thiessen method and determine the total volume of water flowing from that particular catchment in million cubic meters per year. In both cases the unit is cubic meters divided by time. One is for year, another is for second. First one is called run-off whereas the other is the yield for a particular drainage basin.

What are the factors effecting run-off? We discussed that the water that falls on the ground, some of it goes below, and then it flows below the surface. That means, it not depends on the amount of rainfall, it also depends on the slope of that area, kind of soil, kind of land use which actually determines what amount of rainfall will go below and what amount will flow on the surface. So, all these affects the run-off that is generated for a particular area.

So, area, slope and shape of catchment determines the run-off that is generated. Then depending on what kind of soil the infiltration is determined. Next, obstructions, that is due to the land use and land cover which also determine run-off.

If a area is already receiving lot of rainfall and a new rainfall event happens. Then, little amount of water would be able to infiltrate because the pores in the soil are already filled with water and the infiltration would be low. Another factor is intensity and duration of rainfall. If intensity of rainfall is pretty high and the duration is low, most of the water goes off as run-off. But if the intensity is low and it goes on for a longer period, maybe more water percolates or infiltrates inside the ground. Then it depends on the number and size of ditches in area, atmospheric temperature, humidity, and pressure which determines some amount of evaporation loss and temperature and so on.

So, these are the different factors which effect run-off. And these factors result in certain kinds of losses. First is the evaporation loss, the amount of water that is evaporated from the surface itself. Then, the percolation loss which is the amount of water which goes below the ground and becomes ground water eventually. And we can assume something around 25 percent, but it varies of course. And then, there is absorption loss which is by the plants; that means, the plants will take away some of the waters and then eventually let it out by evaporation or transpiration.

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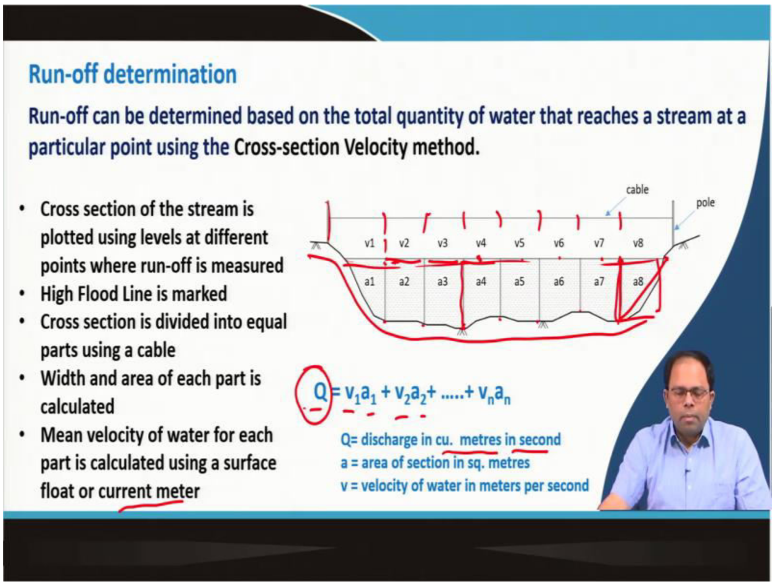

Run-off determination

Run-off can be determined in many ways. But one the most authentic or easiest way to determine run-off is to determine it by the cross-section velocity method.

<u>Cross-section velocity method</u>

It is determined based on the total quantity of water that reaches a stream at a particular point and we can measure the total amount of run-off that happens in that particular catchment. So, there is a stream originating from a catchment, and if we can measure the amount of water present in that particular stream coming from this catchment area.

If we can measure the flow of water in the stream, it is basically the run-off coming from the surrounding areas which falls into the catchment both by surface flow and subsurface flow and that we can determine as the run-off.

The first job is to understand the profile of this particular stream i.e., we need to determine the cross section of the stream. For this, we measure the level/depths at different locations along the channel and that helps us to determine the cross section.

And then, we measure the high flood line and the maximum water level. We then divide this entire cross section into different zones using a cable. A cable is stretched between both banks. And then at equal intervals of the cable we get equal divisions in the cross section.

Now we have got equal divisions and the depth of each of this divisions which help us to calculate the area of each of these divisions. In case of a very large streams, we assume that the corners as squares, but in case of very small streams, we can take them as a triangle and we can measure their area as well.

After the area of each part is calculated, the mean velocity of water for each part is calculated using a surface float or current meter. So, this is the next step, that means, for each of these zones or each of these sections we determine the velocity of water in this section. The velocity varies at different parts of the river; that means, at the sides the velocity is different compared to the centre of the river, right or the centre of the stream. We measure the velocity for each of these particular sections and then we multiply with area.

We can measure velocity using a current meter or we can use something like a float and the time taken by the same to cover a fixed distance at that part of the cross-section. So, once we know the velocity of each of these sections, we multiply with the area of each of these sections and we can get the total discharge in cubic meters in second for this particular stream.

$$\mathbf{Q = v_1a_1 + v_2a_2 + \ldots.. + v_na_n}$$

Where, a is the area of section, each section in square meters. V is the velocity of water in meters per second for each of this section. We just multiply both of them and then we add up for all those sections, we get the total discharge for this particular stream, which is the run-off for this particular catchment.

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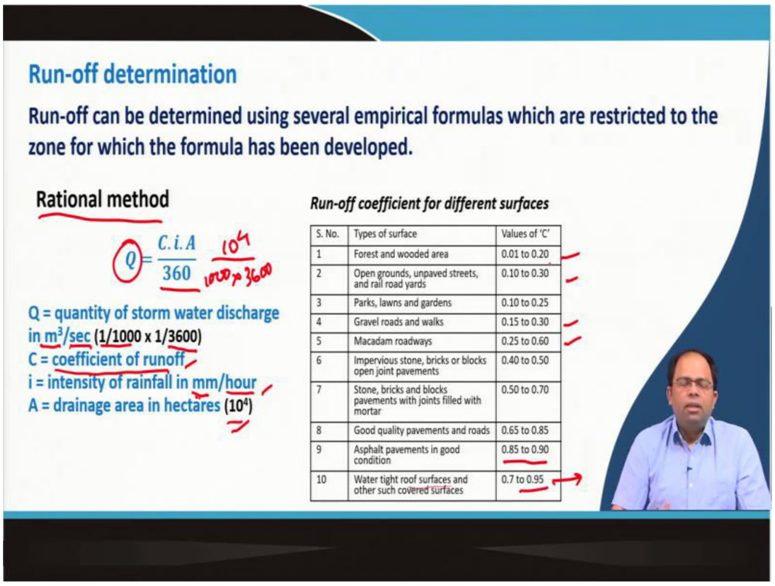

So, this is one method which is a bit crude as it not always easy to carry out these measurements.

Rational Method

Many researchers have developed several empirical formulas which are restricted to the zone for which the formula has been developed. So, that means, each of these researchers have developed certain equations through which you can measure run-off but it is specific for that particular area. There is one method which is a rational method which can be utilized in different areas and which is given as:

$$\mathbf{Q = C.\,i.\,A/\,360}$$

where C is basically the coefficient of run-off, i is the intensity of rainfall in millimetre per hour and A is the drainage area in hectares.

So, that means, we have the area, we multiply it with the intensity of rainfall that is millimeter per hour of rainfall, as we are doing it in the Thiessen method. So, this gives us the total volume. And then we divide by time, time is in hours and, but when we determine the discharge we determine in second. So, that is why we divide it by 3600 because we have to convert hour to seconds. And this 1 by 1000 is because we are converting millimeter into meter cube. And then drainage area is in hectares which is 10 to the power 4 meter square.

That is why we end up with meter cube and these are the factors which are going into this particular equation, 10 to the power 4 goes to the top divided by 1000 divided by 3600. So, in this way we end up with this C i A divided by 360.

So, this is the equation that we use and we can change the coefficient of run-off to determine the surface this particular rainfall event is happening and based on that we can determine the run-off for that particular surface or that kind of surface.

Now, let us see the values of C, like for forest and wooded areas it is around 0.01 to 0.2 which determines the amount of rainfall that either gets into the soil and other kinds of losses. For open grounds and unpaved street, it is 0.1 to 0.3, for parks lawns and garden it is 0.1 to 0.25, gravel roads and walk is 0.15 to 0.3, macadam roadways is 0.25 to 0.6, impervious stones bricks and blocks is 0.4 to 0.5 and so on.

The more impervious the surface, higher is the run-off coefficient. For example, asphalt, value of C is around this 0.85 to 0.9, whereas, roof surfaces are almost like 0.95 or you can even ignore that because roof surface is usually drained to the surface drains or to the drainage network. So, it actually does not create much of any run-off until unless there is no rain water pipes or the rain water pipe is not fitted to a drainage network. In that case, 95 percent is generated as run-off. Whereas, for other places like forest and wooded area, most of it is goes into the ground and only a little bit comes as runoff. So, that is how we can determine the run-off for a particular area.

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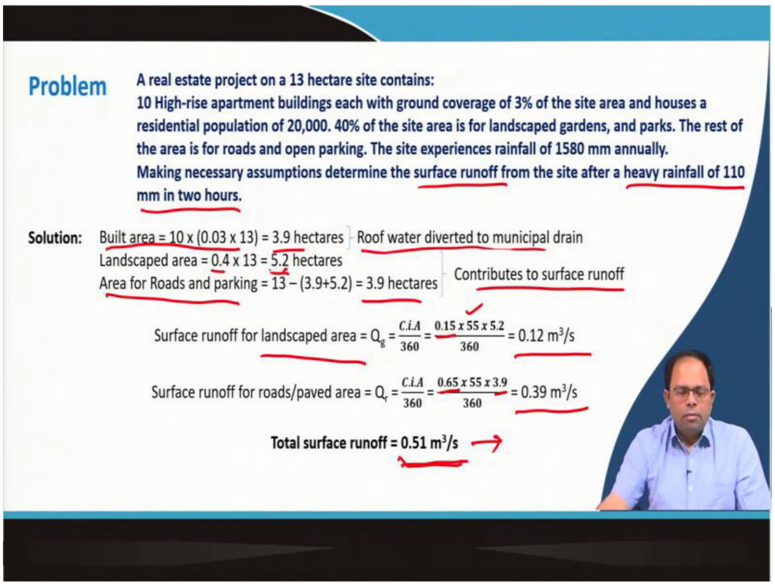

Problem:

Question: A real estate project on a 13 hectare site contains: 10 High-rise apartment buildings each with ground coverage of 3% of the site area and houses a residential population of 20,000. 40% of the site area is for landscaped gardens, and parks. The rest of the area is for roads and open parking. The site experiences rainfall of 1580 mm annually. Making necessary assumptions determine the surface runoff from the site after a heavy rainfall of 110 mm in two hours.

Solution: Lot of information is given, but maybe we do not need to all the information We need to determine the surface run-off, from this site after a heavy rainfall of 110 millimetre in 2 hours. So, how do we solve that? Let us see.

So, first of all we find the total built up area is 10 x 0.03 x 13 hectors which comes to around 3.9 hectares. We can assume that roof water is diverted to municipal drains directly. So, it does not creates any kind of surface run-off.

$$\text{Built area} = 10 \times (0.03 \times 13) = 3.9 \text{ hectares}$$

Second is the landscape area which is 40 percent of 13 hectors which comes to around 5.2 hectors and then areas for roads and parking which comes to when we subtract both of this from 13 we get 3.9 hectares. So, both of these contributes to surface run-off. So, this is our first assumption.

$$\text{Landscaped area} = 0.4 \times 13 = 5.2 \text{ hectares}$$

$$\text{Area for Roads and parking} = 13 - (3.9+5.2) = 3.9 \text{ hectares}$$

Then, using the rational formula we can put all the figures in this equation C i A / 360, where we can estimate runoff for landscape area where the coefficient is 0.15 and we multiply with the intensity of rainfall which is 110 in 2 hours. So, 110 in 2 hours is basically 55 millimetre per hour. So, that is what why we put 55; multiplied by 5.2 which is the total area in hectres and we get 0.12 meter cube per second.

$$\text{Surface runoff for landscaped area} = Q_g = \frac{C.i.AC.i.A}{360\;360} = \frac{0.15 \times 55 \times 5.20.15 \times 55 \times 5.2}{360 \qquad 360} = 0.12 \text{ m}^3/\text{s}$$

And surface run-off from roads and paved area everything is same except the coefficient is different. And of course, the area is different. We get a total run-off of 0.39 meter cube per second. So, total surface run-off comes to around 0.51 meter cube per second.

$$\text{Surface runoff for roads/paved area} = Q_r = \frac{C.i.AC.i.A}{360\ 360} = \frac{0.65\ x\ 55\ x\ 3.90.65\ x\ 55\ x\ 3.9}{360 \qquad 360} = 0.39\ m^3/s$$

Total surface runoff = 0.51 m^3/s

So, that means, if we have to design a drainage channel or a storage area, we have to design a storage area which can take this kind of flow that is generated in that particular site. But as we will discuss in later lectures that designing a drainage channel is not that simple. It is not based on the overall values of run-off that is generated or the average flow that we are getting, but depends on many other things. We will discuss that later. So, roughly we can say this is the total volume of run-off per second that is generated from this particular site.

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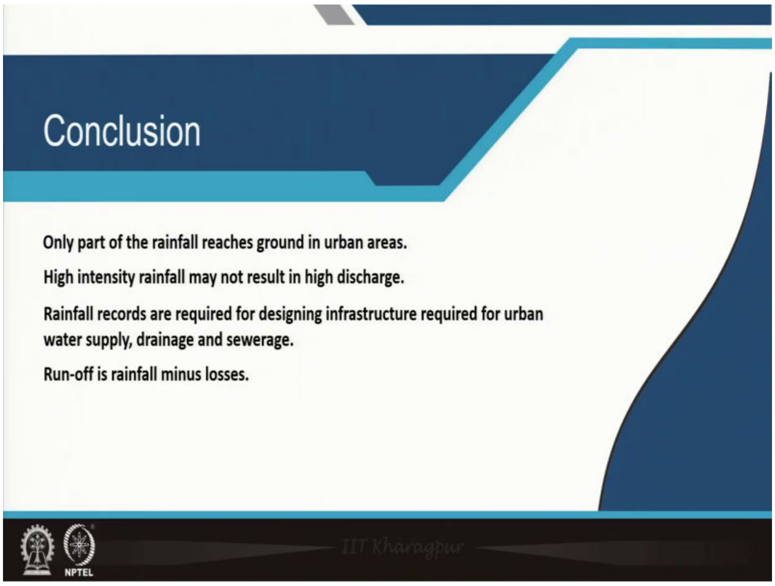

Conclusion

So, to conclude from this particular lecture, only part of the rainfall reaches the ground in urban areas which was explained in the previous problem. High intensity rainfall may not result in high discharge. So, we say that high intensity rainfall may be for a shorter duration, so it may not result in very high discharge. Rainfall records are kept, as they are required for designing infrastructure, required for urban water supply, drainage and sewerage. And finally, run-off is rainfall minus the losses.

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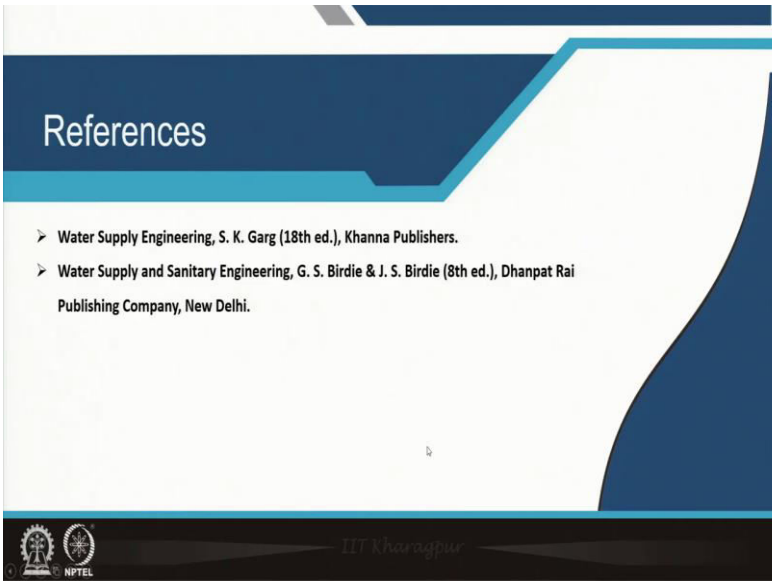

So, these are the references. These are two text books which we will be following throughout the course, and in addition to other materials as well. So, this you can follow. So, that is the end of this lecture.

Thank you.