Water Resources Engineering

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Lecture No # 11

As a water resources engineer, we are interested in looking at the runoff generated, so that we can find out the amount of surface water available. Sometimes we are interested in knowing the amount of ground water available, but we first concentrate on the surface water. Out of the total precipitation, which is the driving force behind the runoff, some part of it is lost, if we consider the runoff. Now this loss depends on the aspect we deal with, for example if we look at it from surface water point of view, then the amount of water that infiltrates or evaporates is loss to us. If we look at it from irrigation or engineering point of view, then the infiltration is not a loss. In fact this is will drive the soil moisture. The loss will be defined differently depending on the aspect we are taking. Right now we will start from a water resource engineering point of view. What are the losses or abstractions?

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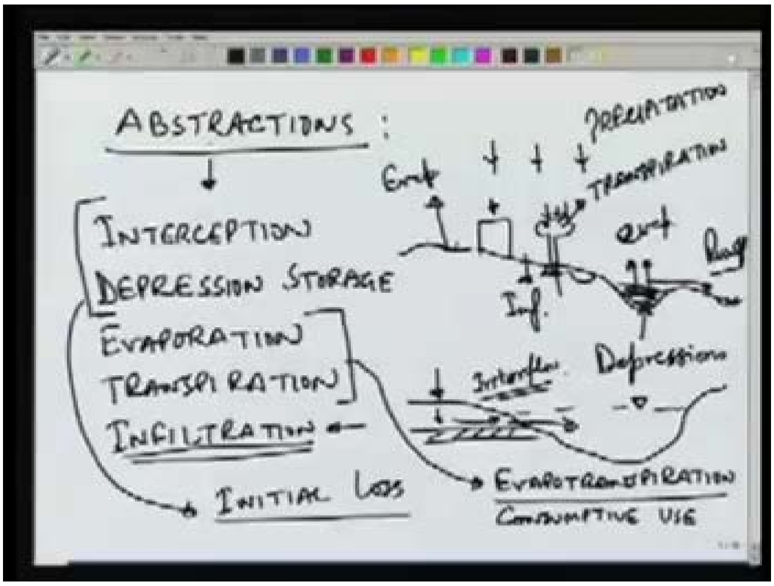

If we look at the precipitation over certain area where there may be trees and buildings, out of total precipitations, a part of it will be detained on the roof top or on the tree leaves. A part of it will infiltrate, a part of it will evaporate once it reaches the surface. So evaporation is followed by infiltration. There is some storage on the tree leaves and the building then we may have small depressions where water may be stored. These are not the streams but they are small depressions which have to be filled and then water will move towards the river. If we consider the runoff, so this part which is runoff (Refer Slide Time: 02:50) water, when falls on the ground, all of it will not reach the streams as runoff. Whatever is abstracted, will be called as abstractions. As we have seen here, there are various components of the abstractions and these can be written as interception, which is the amount of water intercepted on maybe say buildings or trees. Then we have the depression storage which is nothing but small surface depressions which will store water before it goes for the runoff. We have evaporation, transpiration which may be from the land surface or from small depressions also. There will be transpiration when the plant roots take water from the soil and then transpire it through their leaves back to the atmosphere. We have infiltration which is the amount of water that goes below the ground surface.

Out of this infiltration, some part may come back to the surface as runoff. For example if we have an impermeable layer close to the surface, then part of the infiltration may run over this impermeable layer and contribute to the stream. That part will also contribute ultimately to the runoff but for now we shall consider that all the infiltration is an abstraction from the rainfall or the precipitation. Interception and depression storage occur in the early part of the rainfall and therefore they are together called initial loss. Similarly evaporation and transpiration are very similar in nature and the factors affecting evaporation and the transpiration are almost identical. We combine them and call it evapotranspiration or sometimes consumptive use. So evapotranspiration includes both evaporation and transpiration from the plants. Then infiltration can be considered as a loss. Since we have discussed the interflow or sub surface runoff, we will for the time being not consider it. Let us look into the mechanisms of these processes and see the factors which affect them. We shall look at them one by one. Let us start with the interception.

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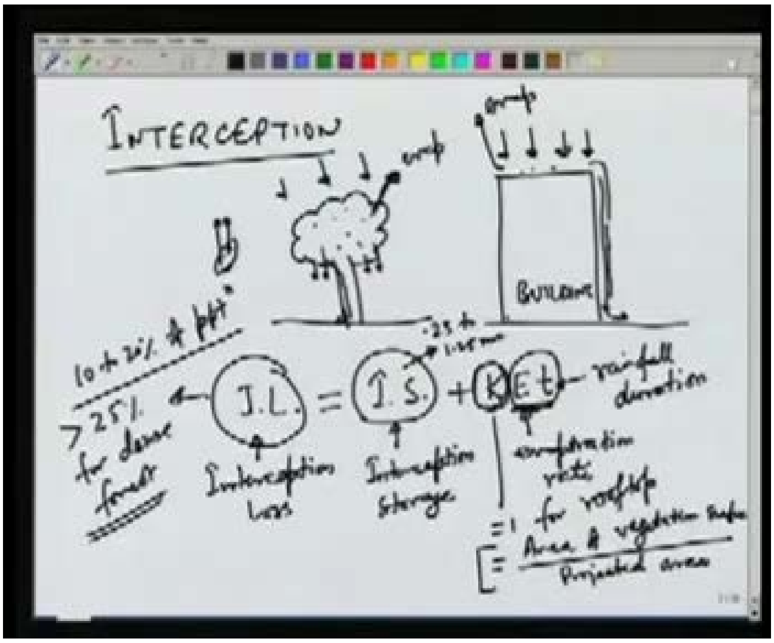

Let us suppose precipitation occurs over a roof top. This is a building and on the roof when the precipitation occurs, some amount of water will be stored on the roof before it is carried through the drains down to the ground level. Some amount will be stored on the roof top or it will be intercepted by the roof top. Similarly when there is a tree, some amount of precipitations falling on the tree will be detained or intercepted by the leaves and that will be called interception. Out of this interception, there will be evaporation, similarly from the roof top there will be some evaporation. From roof top, water may go through the drain and ultimately reach the ground surface. Similarly from the tree some water may fall down out of the intercepted water. Some water may directly fall down from the tree or some of it may go over the stems and then again reach the ground level. These parts are not really lost but the part which is evaporated is a loss as far as runoff is concerned. Now for a building if the rainfall intensity is very small almost all of it may be intercepted. Similarly for the trees also if the intensity is small the leaves will be able to store all of the precipitation. But when the intensity becomes large then there is a limited capacity of the roof top or the tree leaves to store water and therefore we write the interception loss equal to some storage initial value which can be stored on the roof top or the tree leaves. Also, there is some factor kE and t where E is the evaporation rate and t is the duration of rainfall. This factor k will be discussed in little while. But let us first look at the roof top when there is some initial storage, the interception storage.

Now there is an evaporation going on while the rain is occurring. So depending on the rate of the evaporation and the duration of rainfall, this additional amount which is evaporated from the roof top can also be lost due to interception and for roof top k will be equal to 1, a flat area or roof top. If you have leaves then the leaves are not horizontal. They have some inclined surface and the evaporation from this whole area will occur. So k will represent the ratio of the area of the leaf to the projected area or the horizontal area. I will call it vegetation surface divided by the projected area. This will be the horizontal area. This will be greater than 1, so from a tree leaf surface, we have some initial storage then we have this ratio K and multiplied by t gives us the evaporation loss dividing the rainfall. This gives us the entire interception loss from a structure or vegetation and this is about 10 - 20 percent, of the rainfall or precipitation. If we have vegetated area, then it is 10 – 20 percent. But sometimes if you have a very dense forest, it may be more than 25 percent. The interception storage is generally around 0.25 - 1.25 millimeter and this represents the depth of water that can be stored without it flowing off from the tree or from the roof top into the drains.

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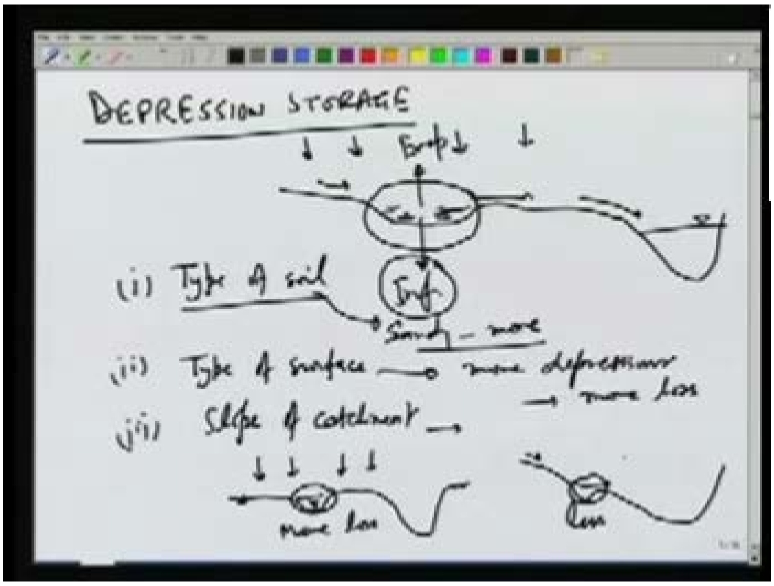

Now the next abstraction that we consider is the depression storage and as we discussed there may be a small depressions on the surface. So when the rain occurs, these depressions have to be filled before the water runs off to the stream. The amount stored in the depression is lost through infiltration and evaporation. So the depression storage will depend on the presence of depressions on the surface. It will also depend on a lot of other factors and we can look at some of these factors:

1. The type of soil: This because, the depression storage or the loss from depression will depend on the infiltration and therefore the type of soil which will affect the infiltration rate will decide the loss through the depression storage. For example if you have sandy soils, then you have more loss due to depression storage. Of course the ground surface is important because if they are more depressions, then there will be more depression storage.
2. Type of surface: More depressions would mean more loss.
3. Slope of the catchments is another important parameter. If you consider 2 cases in one, the catchment is very flat than their depressions and in the other is catchment is sloping than their depressions. There will be more loss in flat catchments and less in steep catchments because the water will be flowing faster. There will be more time for infiltration here and less here.
4. The fourth factor which affects the depression storage is the initial soil moisture.

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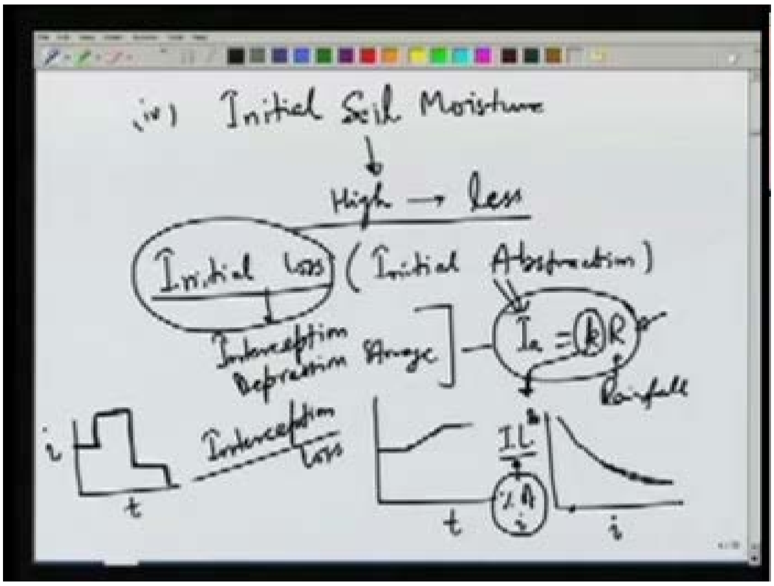

If you have high initial soil moisture, then there will be less infiltration and therefore less depression loss. Therefore, these factors tell us that the depression storage and similarly the interception also depend on a lot of factors. It is very difficult to estimate the effect of all these factors individually. We assign some percentage of the precipitation as the initial loss which includes both interceptions also called initial abstraction and depression storage.
Generally we say it is initial abstraction or I_a. It is some percentage. Let us say K times the amount of rain rainfall and this is the initial abstraction I_a. k is some fraction which will depend on catchment characteristics and will typically be obtained by observing the conditions. This initial loss varies with time.

Let us talk about the interception and see how it varies with time and when we say with time, the rainfall intensity is also an important parameter. The rainfall intensity may be changing with time as it may be idealized like this. If the rainfall intensity is less than the capacity of the interception in that area, then all of it will be intercepted. What we can show is with rainfall intensity, suppose we say I here and interception loss here as typically as a percent of I_a. If initially the rainfall intensity is smaller, then interception loss would be a larger percent of the rainfall and the general curve which we get is something like this. When the intensity is small, more percent or in fact it may be typically about 80 percent of the rainfall can be intercepted and then it loses through evaporation but as the intensity increases the capacity of the structures and the trees is limited to store water. Interception loss remains almost same as it increases a little bit because of the evaporation as we have seen here. With time it will increase slightly because of evaporation, but more or less we can assume that interception loss is almost constant so, with the fraction of the intensity of rainfall, it will go on decreasing as the intensity is increased. When we say that with time, we have initially a small intensity which then becomes large and again it becomes small then we would get interception loss. The interception loss would be limited to the rainfall.

It may be equal to the intensity of rain in the beginning if the intensity is smaller than the capacity of the area for interception. Then when we have rainfall which is higher than the capacity of interception, then we may have slight increase because of the evaporation occurring from the surfaces and then again when the rainfall becomes smaller, it will increase at a constant rate. It may become like this. The interception loss is not constant with time. It changes with time, but what we do is we assume that it is some fraction. The overall interception loss is some fraction of the total precipitation which will depend on the catchments characteristics and also on the distribution of the rainfall and whether there is more number of storms or whether there is less number of storms.

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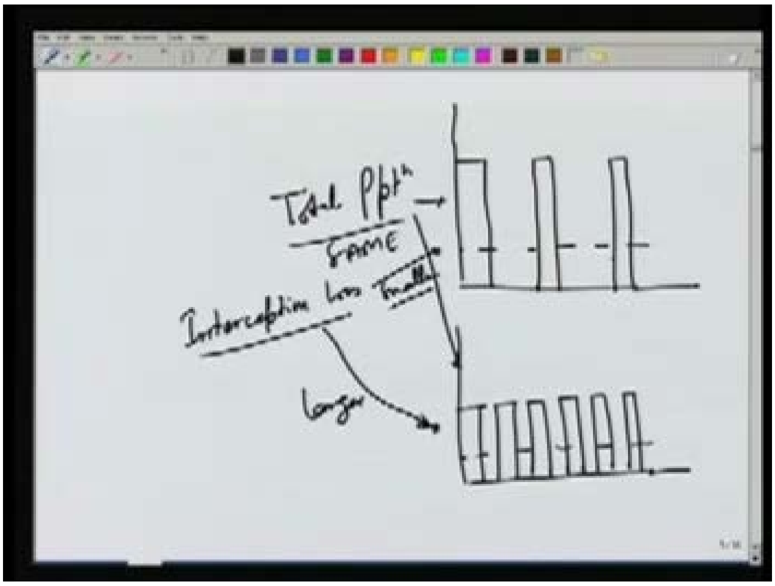

For example over a certain period we may have a few storms of very high intensity or over the same period we may have lower intensity storms, but they may be more in number. Suppose we look at this distribution, where there is more intensity of storms but there are only 3 and here there is ½ the intensity, but there are 6 of them. The total amount of rainfall, the total precipitation is same in both these events but the amount of interception loss as the percentage of total precipitation, if we look at interception loss, will be much more because for each storm event, the interception loss will be almost same as initial storage.

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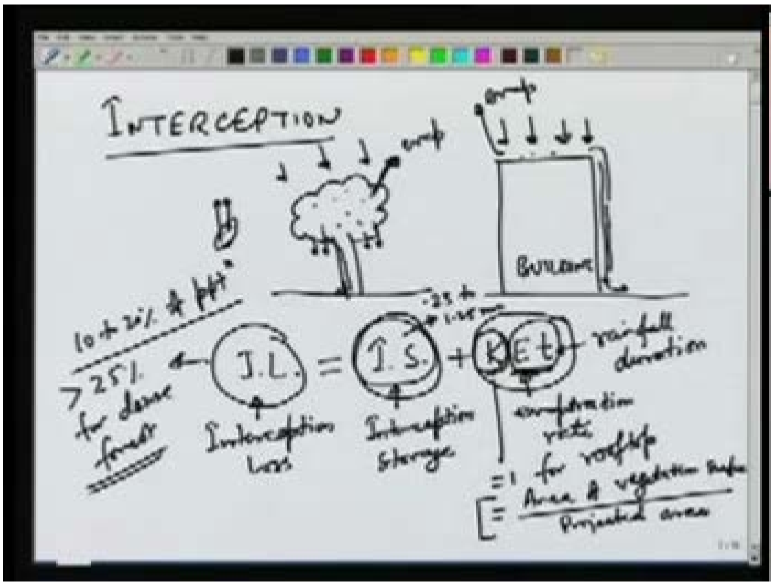

So if we look at this equation there is interception storage which would be fixed. There will be some change with time but if we say that more or less, the interception storage is same, interception loss is almost equal to interception storage, we can say that in the second event, the total interception loss will be 6 times interception loss for a single storm. While here it will be only 3 times the interception loss for a single storm. The interception loss will be much higher, if we have more frequent storms for the same amount of precipitation.

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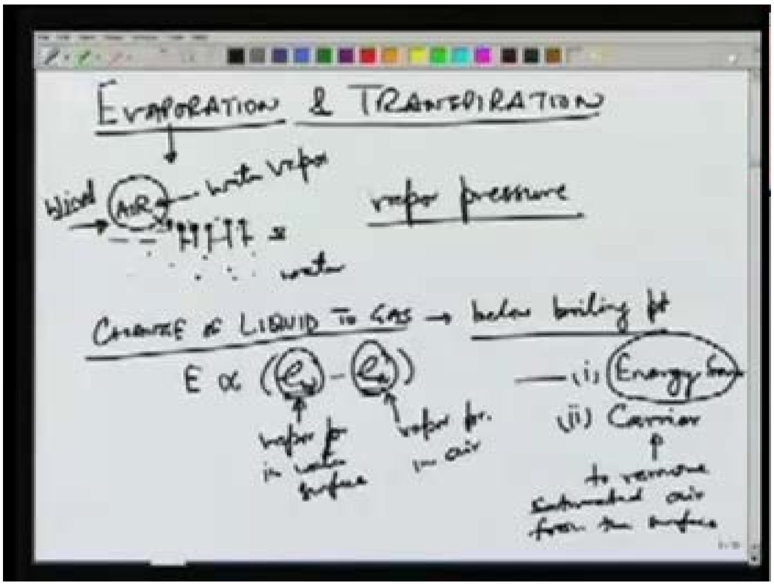

The other abstraction we may want to look into is evaporation and we combine the transpiration also with this and call it evapotranspiration for consumptive use. If we look at the evaporation, the process of evaporation is there is a water surface, filled with water. Let us look from water surface, how the evaporation occurs above water level. There will be air which contains water vapor. There is water vapor present in the air. There is water below the surface, so there will be some vapor pressure in the air as well as on this water surface.

Depending on the difference of this vapor pressure, water molecules will go either from the water into the air which is called evaporation or from the air into the water which is called condensation. If we can write the process of evaporation as change of liquid to gas below boiling point, of course we have one change which is due to boiling that when the liquid is converted to gas below boiling point, change of liquid to gas occurs because of the difference in vapor pressure and this vapor pressure difference. So we can say that this evaporation rate E will be proportional to vapor pressure in water vapor pressure in the air. The water surface vapor pressure will be higher in order to cause infiltration, so the gradient of the vapor pressure is the one that drives the evaporation and for this, we need some energy. There are two things which are important for evaporation.

One is energy source and the second is some agency to carry this water away from the water surface, carry the air away from the water surface, so some carrier to remove saturated air from the surface. The energy source is needed to cause this evaporation but if we have the evaporation without any mechanism to lead this air away from the water body, then the air here will become saturated and generally slowly the vapor pressure in the air and water will tend to be equalize because as more water molecules evaporate the vapor pressure in the air will increase and it may become saturated above this water body. There has to be some agency like wind to carry this water away from the water surface and once the saturated water is carried away from this, there will be unsaturated air or less saturated air replaced here on the top of this water surface. Therefore it will again create a gradient of vapor pressure causing more evaporation otherwise the evaporation will be limited and once the air becomes saturated, the evaporation will be reducing with time. This tells us that there will be a number of factors on which the evaporation will depend upon. Let us look at these factors.

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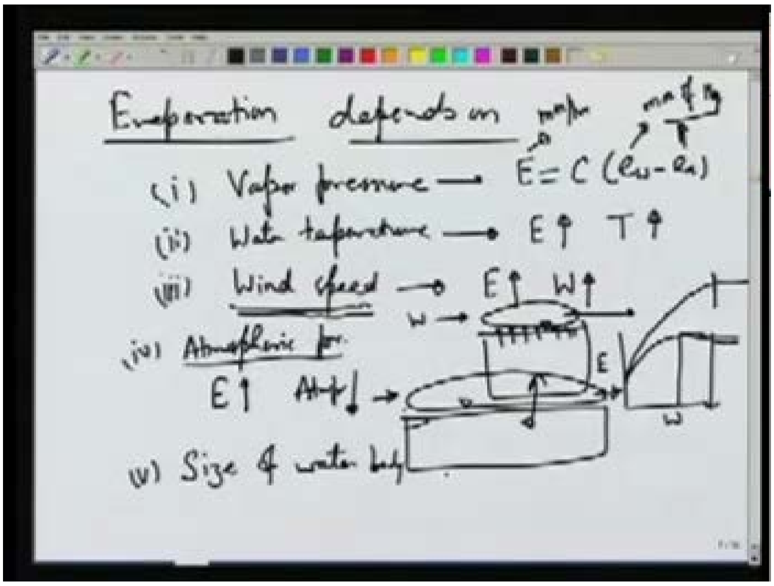

Evaporation depends on the foremost factor, the water vapor pressure in air and water surface. We have already discussed that the difference of the vapor pressure on the water surface and in the air will decide the amount of evaporation or the rate of evaporation. Since the vapor pressure depends on the temperature, the temperature also denotes the amount of energy present. Water temperature is another factor which affects the evaporation vapor pressure. We have already seen that e is proportional to or we can write E equal to some constant into $e_w - e_a$. This vapor pressure is represented in millimeter of mercury, both of them are represented in millimeter of mercury and E is the evaporation rate in millimeters per hour. The water temperature E is increasing as water temperature increases, so E is directly related to the water temperature. As T increases, E also increases. Then the next factor which we have discussed is if we have wind speed. If there is no wind, evaporation will continue for some time and then almost become negligible. If there is wind then we have a continuous process going on, so evaporation again will increase with increase in wind speed. Let us call it w, but it will not keep on increasing because there is a critical value beyond which the wind speed will not affect evaporation. For example we take a water body like this and there is a wind velocity w here. When wind velocity becomes sufficient to carry this air away from the water surface at the rate (at which depending on the rate of evaporation), and cause or maintain the evaporation rate.

Beyond that speed, there will be no change in evaporation rate. Suppose we draw a curve, the wind speed versus evaporation, and the wind speed is small, the evaporation will also be small because air becomes saturated very soon and it will increase as the wind speed increases. Beyond the critical value, evaporation will more or less be constant because that wind velocity is sufficient to carry air away from the water body and this wind velocity, critical wind velocity will depend on the size of the water body. So if we have a water body which is very long, the critical wind speed would be higher because then we need a larger velocity to carry all this air away from the water body. Wind speed is an important parameter because this is the mechanism which will carry saturated air away from the water surface. The next parameter which will affect evaporation is the atmospheric pressure and in this case we have inverse relationship E, that increases as atmospheric pressure decreases and this is due to effect of vapor pressure. The other factor that affects the evaporation size of water body is the size. It affects the critical wind velocity.

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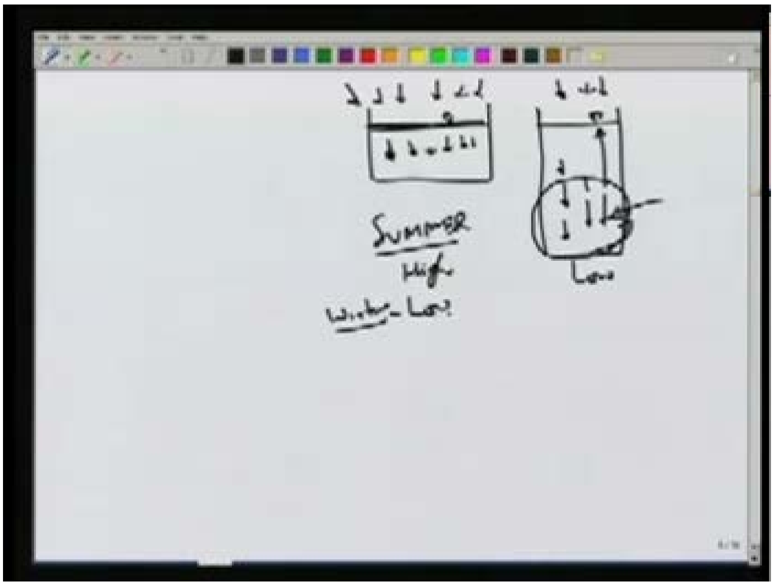

But the size itself will affect the evaporation in the sense that if we have a water body which is shallow or a water body which is deep, the mechanism or the process of evaporation will be affected by the depth of the water body. In this case, the solar radiation which is hitting the surface, the heat energy will be absorbed by this body. But in this case, the heat energy will be absorbed by the lower layer. In summer months, when there is high radiation, the water here at the lower level will get heated or will absorb the radiation and in winter this radiation will be released to the upper layers to cause evaporation. In summer this will have high shallow body, high evaporation because the absorption by the lower layer has not been there. Here some of the heat energy gets transferred to the lower layers and therefore the energy available for evaporation from the upper layer is smaller but in winter, the shallow body will have a lower evaporation. So as we have seen evaporation and transpiration are quite similar.

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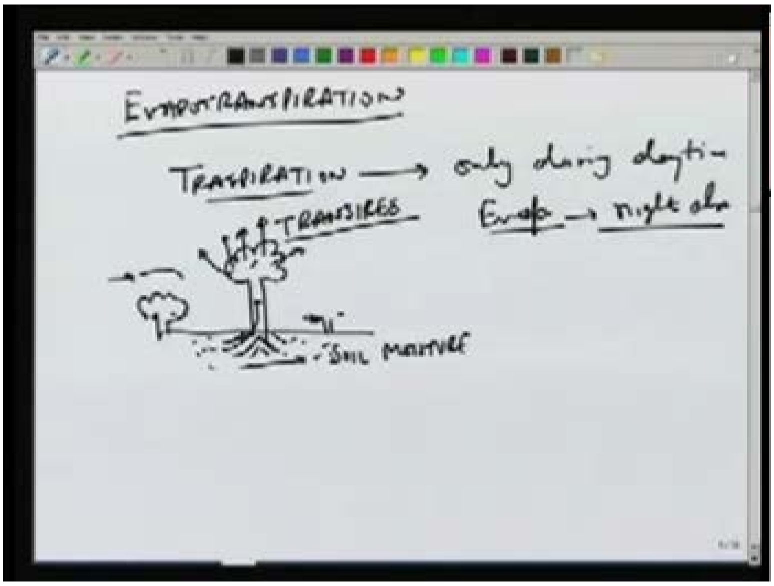

We combine them in evapotranspiration, but transpiration has a basic major difference when compared to evaporation. It is that transpiration occurs only during the day time. If we look at some vegetation roots, extending into the ground, it will require water during its growth which is generally taken from the soil moisture. There is some moisture present in the soil. The root zone which can be taken up by the tree then breathes it out. Breathing out means it is transpiring, so the tree transpires or breaths out the water in terms of vapor but this process occurs in presence of sun light so this is a day time process. In night time, it does not happen while evaporation also takes place during night too. That is the major difference between transpiration and evaporation although the rate of evaporation is slow during night but still happens. Naturally the amount of vegetation present will affect the transpiration if there are more trees or fewer trees. Transpiration has the factors which affect evaporation, for example the wind velocity will carry saturated air L from above this tree. All the factors which affect evaporation will also affect transpiration. In addition, the vegetation density, the nature of vegetation, its stage in growth will be the factors which will affect the transpiration. Evapotranspiration or the consumptive use is affected by a number of factors and we have looked at some of these factors. The next process which we look at is the infiltration.

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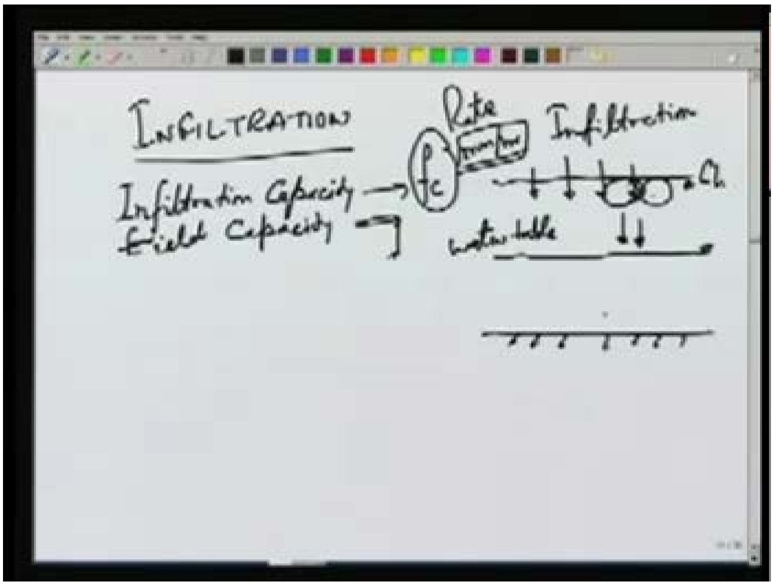

An infiltration can be thought of as the movement of water below the ground level. So it is really passing the surface ground water, the ground level and going below the ground surface. Below the ground surface there is an amount of soil here which is saturated with water and this saturated water is called ground water. This is the water table and the water below this is known as the ground water. Once this infiltration goes below the ground level then it may be retained by the soil near the top or it may percolate deeper and contribute to the ground water. As far as the ground surface is concerned there is (Refer Slide Time: 40:15) at which infiltration can occur.

We can define these two terms and find out the maximum rate at which infiltration can occur and then beyond what volume of storage within the soil, will it go deeper and contribute to the water table or the ground water. So there are two terms which are commonly used, infiltration capacity and field capacity. Infiltration capacity is the capacity of the soil to transmit or allow infiltration. Either we can say that this is the maximum rate at which water can be infiltrated and we denote it by f_c and field capacity. f_c is rate which is millimeter per hour.

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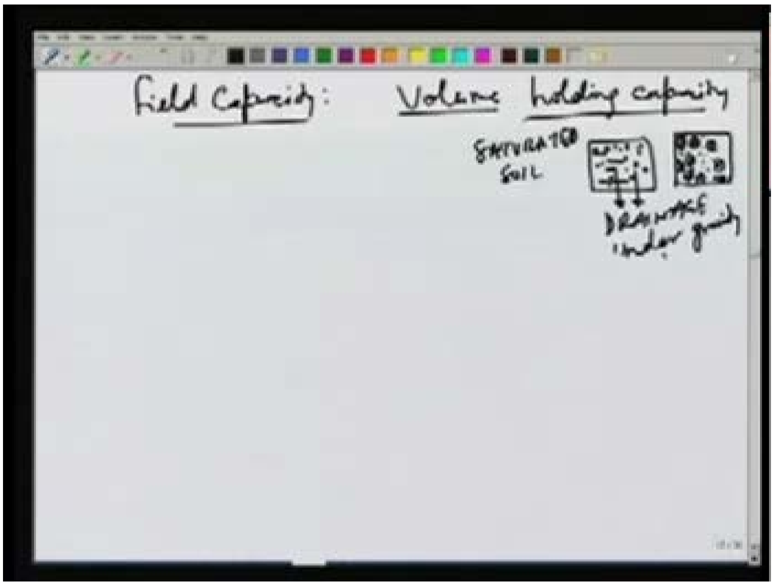

Field capacity is the volume which the soil can hold before allowing it to go deeper, so this can be very simply thought of as volume holding capacity of soil. So if you have soil present here and let us say it saturated with water so this is saturated soil and allows it to drain under gravity. If we allow this soil to drain under gravity after drainage it will again have these soil particles and there will be some water. It will not be saturated with water so there will be some air also but what about water is able to hold that will be called its field capacity. Once the field capacity is satisfied then a recharge to ground water will occur.

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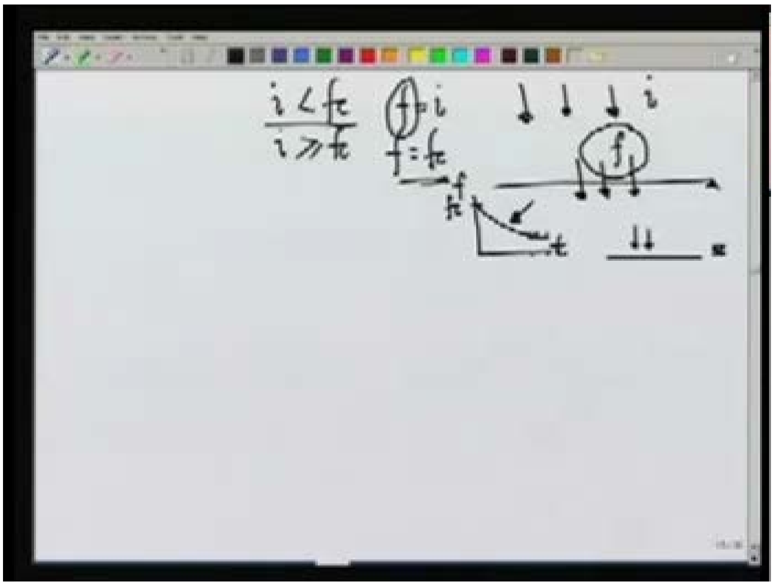

So we have rain occurring at intensity I_a and this is the ground level then we have infiltration occurring at a rate of f and then we have the ground water and there will be some recharge to this. We can look at various conditions, for example if i is less than f_c that means the rainfall intensity is smaller than the infiltration capacity, it means that all the rainfall can be infiltrated and therefore f will be equal to i. This tells us that the ground depending on the soil conditions has a certain capacity to infiltrate water which is called the infiltration capacity f_c. As long as the rainfall intensity is less than this, the entire rain can infiltrate but when the rainfall intensity becomes larger than $r = f_c$. Then f will be limited to f_c so the rate of infiltration will have its maximum value as f_c and if the rain is more than that even then, it would be limited to f_c. Infiltration rate f which is the actual rate of infiltration will vary with time, so initially it will be high, so, time versus f and let us say that the rainfall is more than f_c. Initially the infiltration rate will be high because the soil may be dry but then when rain occurs, the soil becomes wet and the capacity to infiltrate goes down. Other factors which affect the infiltration capacity or the infiltration rate is that, because of rain drop impact, some of the soil surface will become rearranged and therefore the infiltration capacity might reduce. Also some of the fine particles can clog the force on the surface thereby reducing infiltration rate. Infiltration rate will show a variation like this, where it will start with a high value and with decrease with time.

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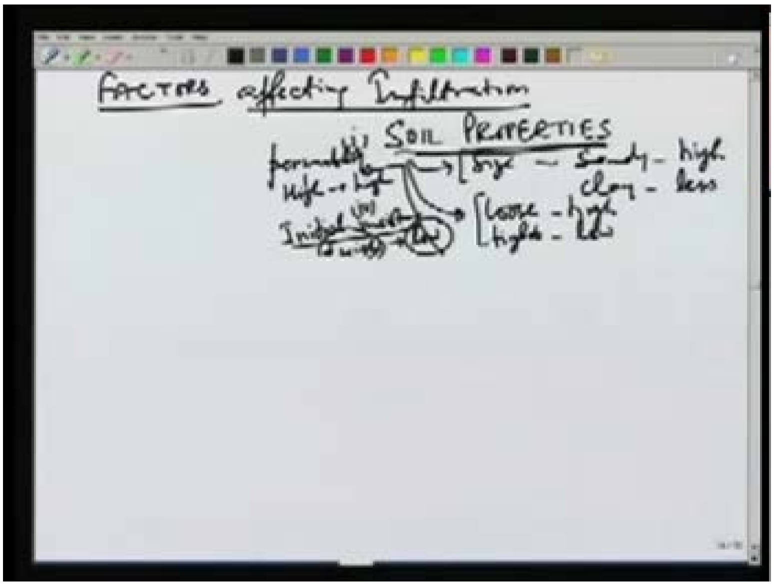

We shall look into some factors on which the infiltration depends. These can be thought of as soil properties and soil properties mean size of the soil whether it is loose or tightly packed. Generally sandy soils are the soils with larger grain size. They will have high infiltration rate, so sandy soils will have high infiltration rate and clay will typically have a lower infiltration rate. Then loose soils have high infiltration and tight soils will have low infiltration rate. So larger size particles have high infiltration packing and if it is loose, it will have high infiltration. Then we have high permeability which would mean high infiltration and generally if we have initial condition, let us say initial moisture. If initial moisture is high then we will have low infiltration. If we have high initial moisture, we will have a smaller infiltration because if the pores are already saturated with water there will be smaller capacity to absorb further water. These are some of the soil properties which affect infiltration.

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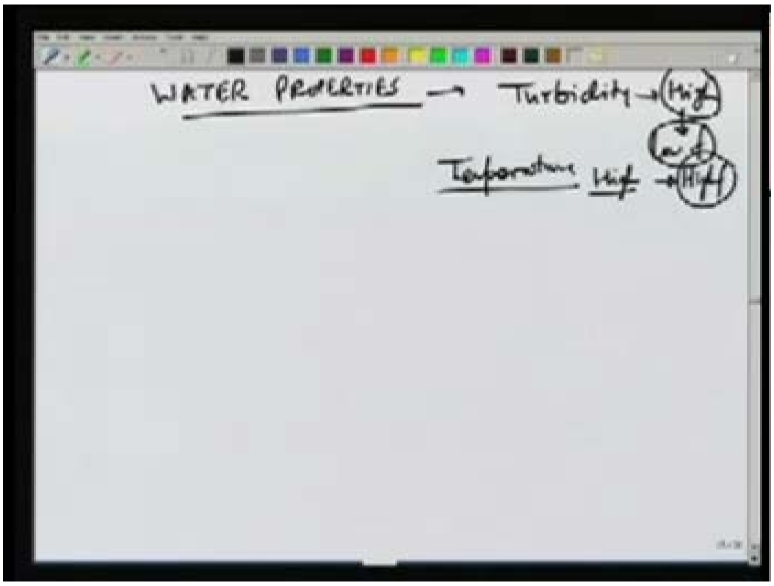

There are some water properties also which affect infiltration. For example turbidity, if we have high turbidity which means water contains a lot of other materials; solid material that may clog the pores and will reduce, so high turbidity means low air. Then temperature of the water will also affect the viscosity of water and viscosity affects the permeability. If temperature is high, it will mean the viscosity is smaller and therefore water can easily go inside the pores, so it will cause high f. We have seen high turbidity which means smaller infiltration; high temperature will mean lower viscosity and therefore higher infiltration. So these are the soil and water properties which affect infiltration.

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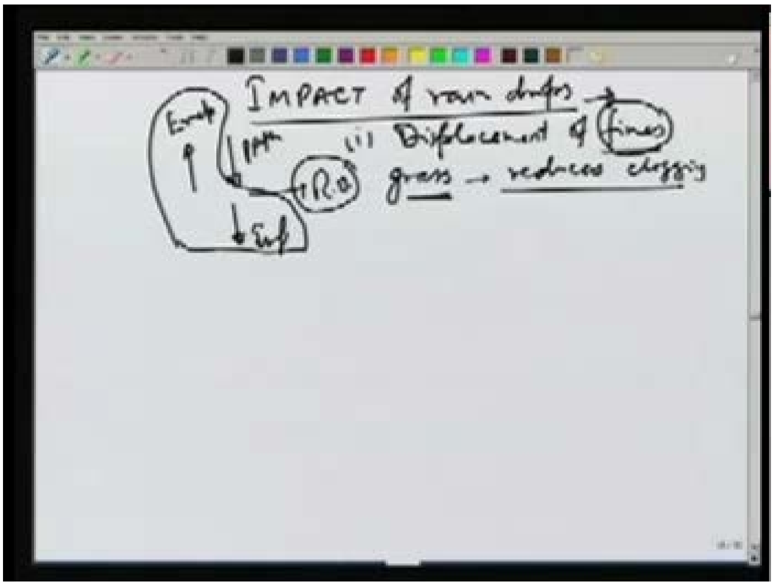

But in addition to these there are other important parameters which are impact of rain drops. In addition to the water property and the soil property, impact of rain drops will also cause infiltration to vary. There are really 2 effects which we can look into. One is displacement of fines, so the fine particles on the soil surface can be displaced by the impact of rain drops and they may clog the larger pores reducing infiltration. If we have grass it reduces clogging, so if there are fine particles, they can be displaced by the impact of rain drops and they may clog the pores but if grass is present on the surface, it will reduce the clogging because the impact of rain drops will not be able to displace that many fines. These are the factors which affect the infiltration and what we have seen today is the abstractions from the precipitation. We say that the runoff generated by a precipitation will depend on the amount of water taken out of the precipitation, allowing the rest to go as runoff. The amount of water which we have taken out of the precipitation depends on what we use. If we look at it from a water resource engineer's point of view, then anything which does not go into runoff will be called an abstraction. For an irrigation engineer point of view, anything which is not going for not infiltrating or recharging ground water or contributing the soil moisture can be thought of as an abstraction.

So if there is some precipitation and there is some runoff, let us say there is some infiltration and evaporation, then from water resources subsurface engineering point of view, surface engineering point of view and through irrigation engineering point of view all these will classify different things as abstractions. From surface water resources point of view, evaporation and infiltration would be abstractions. If we talk about ground water resources then runoff would be an abstraction and transpiration will be an abstraction. For irrigation engineering point of view, evaporation and runoff both can be thought of as abstraction and the deeper collation towards the ground water will also be an abstraction. We have looked at that section from the point of view of surface water resources. So we have classified abstraction as evaporation, transpiration, which are combined as evapotranspiration.

We have looked at the interception storage or the interception laws and the depression storage which we have combined as initial loss and then we have looked at infiltration, the factors affecting all these processes, the mechanism of all these processes and next we shall look at the measuring techniques. So we can measure some of these processes, the amount, so that we have a better idea of how much water will be abstracted, so that we can find out from the total precipitation, the fraction which goes as runoff.