Course Name: Watershed Hydrology

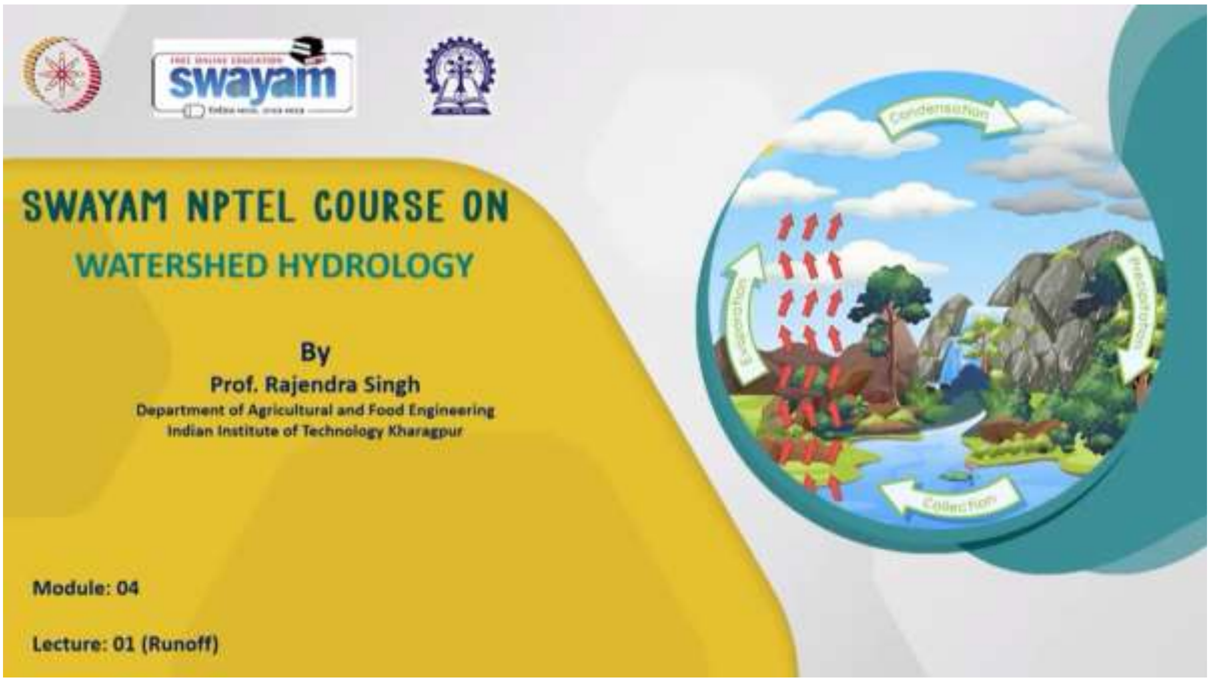
Professor Name: Prof. Rajendra Singh

Department Name: Agricultural and Food Engineering

Institute Name: Indian Institute of Technology Kharagpur

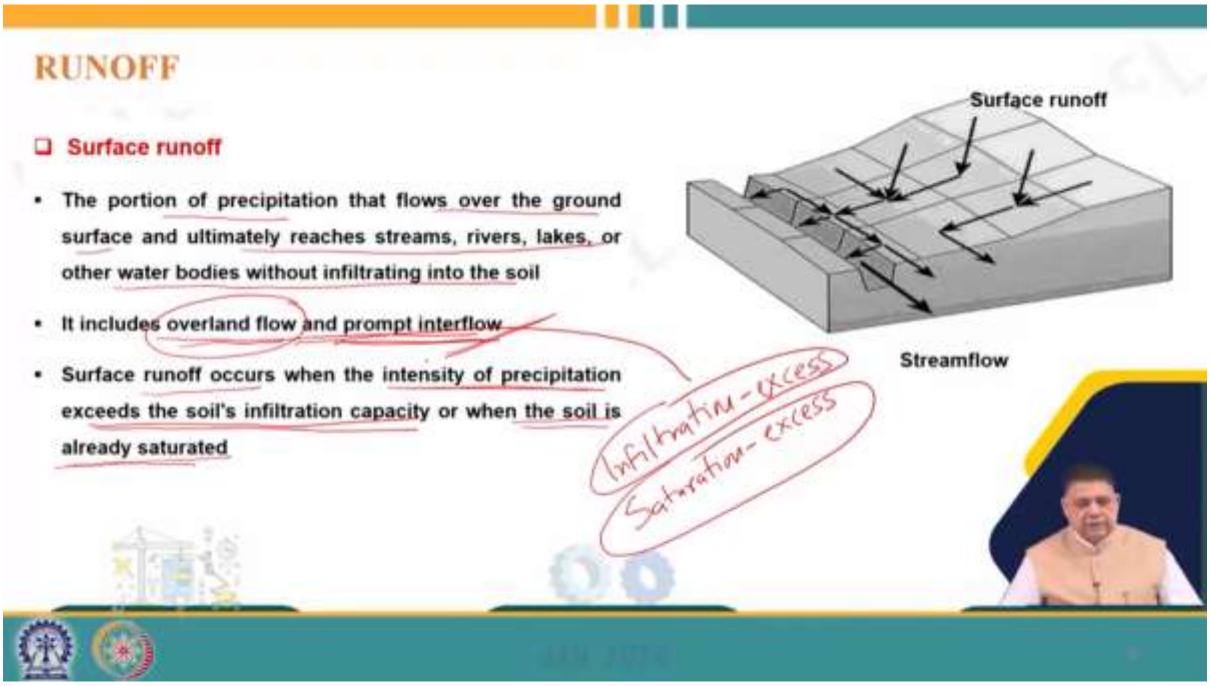
Week: 04

Lecture 16: Runoff



Hello friends, welcome back to this online certification course on Watershed High Hydrology. I am Rajendra Singh, a professor in the department of agriculture and food engineering at Indian Institute of Technology Kharagpur.

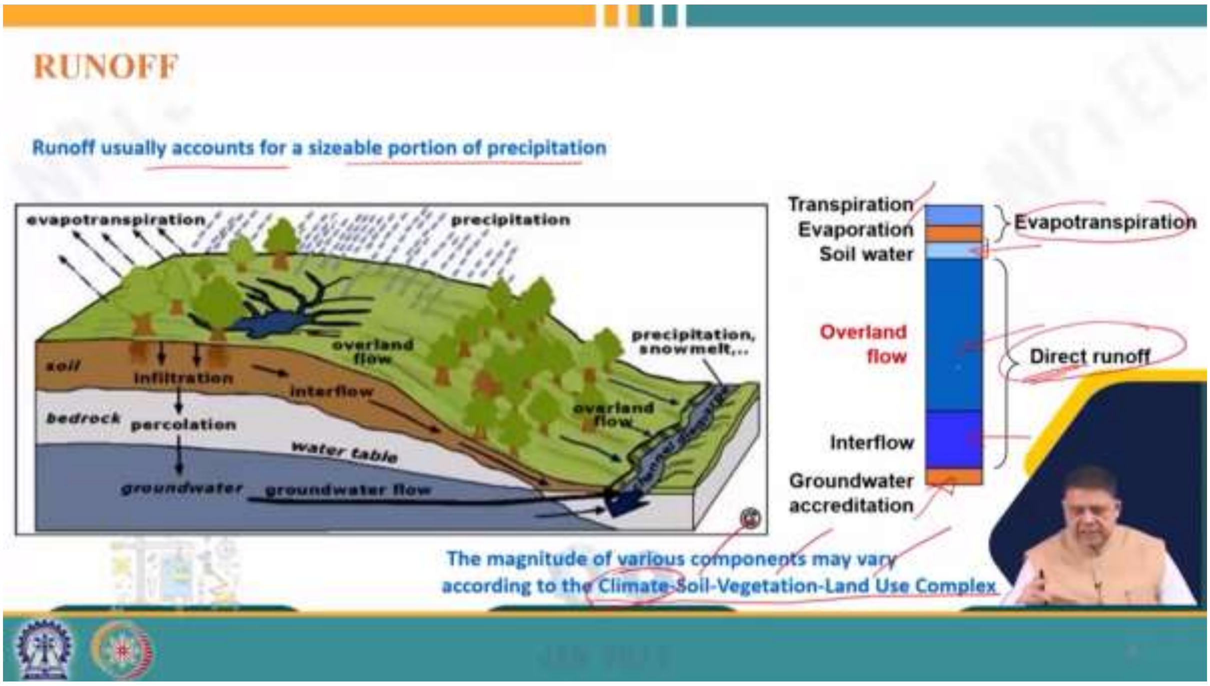
We are beginning with module 4 today, and the first lecture is runoff. The contents of this lecture include surface runoff, factors affecting runoff, and estimation of runoff.



To begin with surface runoff, it is the portion of precipitation that flows over the ground surface and ultimately reaches streams, rivers, lakes, or other water bodies without infiltrating the soil. It includes overland flow and rapid interflow. When precipitation occurs, it first meets the infiltration requirement. Whatever excess rainfall is there, or effective rainfall in excess after meeting the abstractions including infiltration, starts flowing on the surface as overland flow.

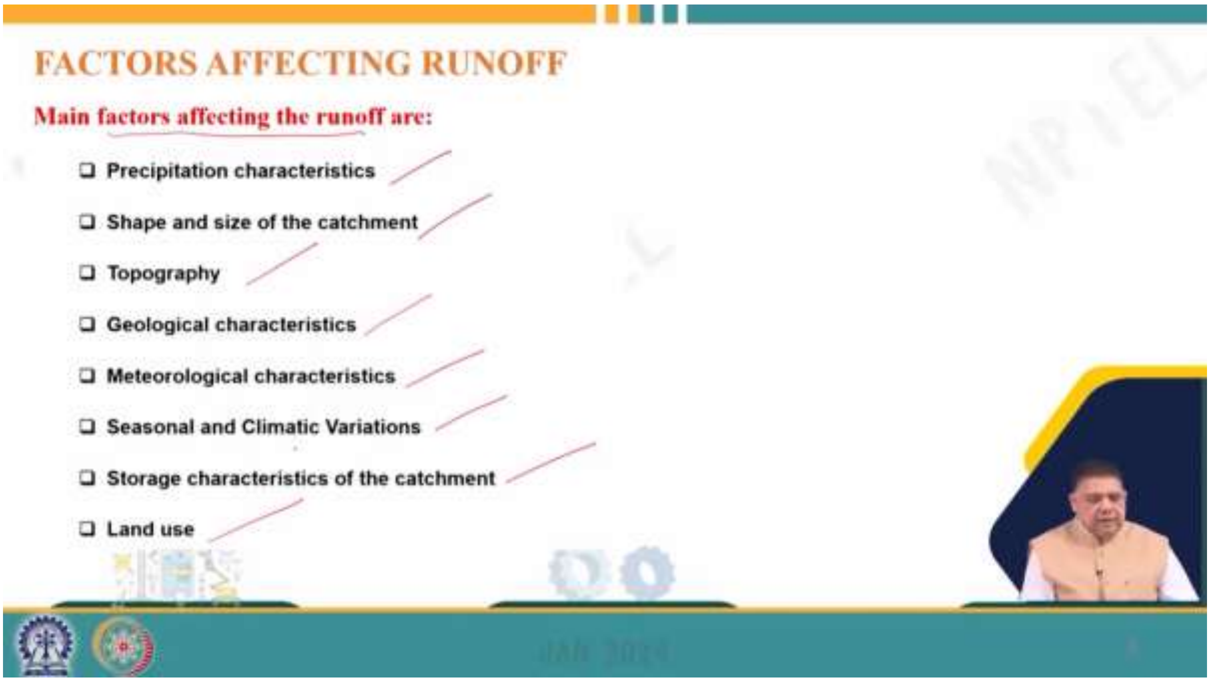
In discussing stream flow, we also found that the rapid interflow, which is the part of infiltration that goes into but flows parallel to the topsoil surface, might reappear on the surface as rapid interflow. So, overland flow and the rapid interflow constitute surface runoff. Surface runoff occurs when the intensity of precipitation exceeds the soil's infiltration capacity or when the soil is already saturated.

Earlier, while discussing, we mentioned infiltration excess overland flow and saturation excess overland flow. Infiltration excess occurs when the intensity of precipitation exceeds the soil infiltration capacity. Saturation excess occurs when the soil is already saturated from the bottom, and the rainfall on the saturated soil flows out as saturation excess overland flow. In both these situations, including rapid interflow, it is known as surface runoff. It is a major component of stream flow.

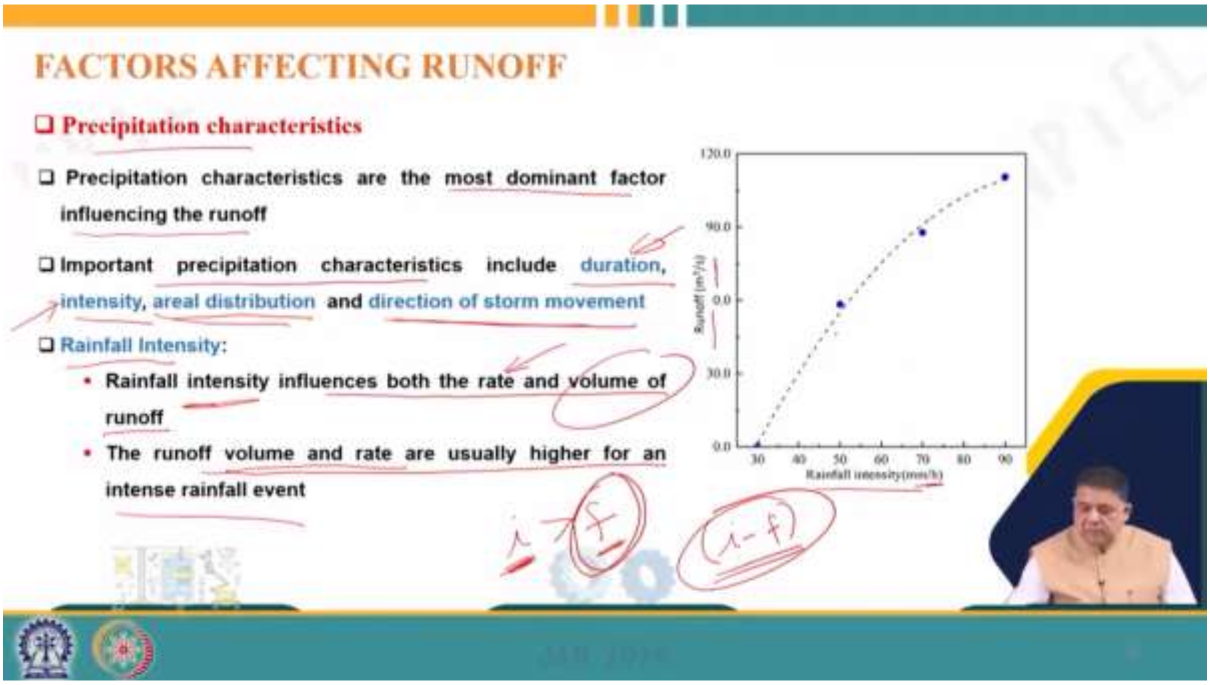


So, this is the one which is quite visible, and we can see it with our naked eyes, and it usually accounts for a sizable portion of precipitation. If you look at various processes of the hydrological cycle, this vertically tells us the proportion of various processes. Here on top, we have evapotranspiration, which includes transpiration and evaporation. Then we have a soil water component, and on the bottom, we have groundwater accretion, interflow, and overland flow, which is a direct runoff. Of course, the entire inflow is not direct runoff; a part of that could also join the delayed interflow or it may join the base flow or the groundwater flow. But as you can see, a major component of precipitation is direct runoff. This magnitude may differ and will vary according to the climate, soil, vegetation, and land use complex.

So, in a place, how the soil is, what kind of soil is there, what kind of vegetation is there, what kind of land use exists, and of course, the climate, because that determines the precipitation. So, based on these combinations, the proportions might change, but even then, direct runoff, overland flow, will have a sizable portion of precipitation at any place.



Now, coming to factors affecting runoff, there are several factors which play a significant role in the runoff process, and these are listed here: precipitation characteristics, shape and size of the catchment, topography of the catchment, geological characteristics of the catchment, meteorological characteristics of the catchment, seasonal climate variations at the place, storage characteristics of the catchment, and of course, the land use in the catchment. These are factors which affect runoff, that is, its timing and magnitude, and we will see these factors one by one.

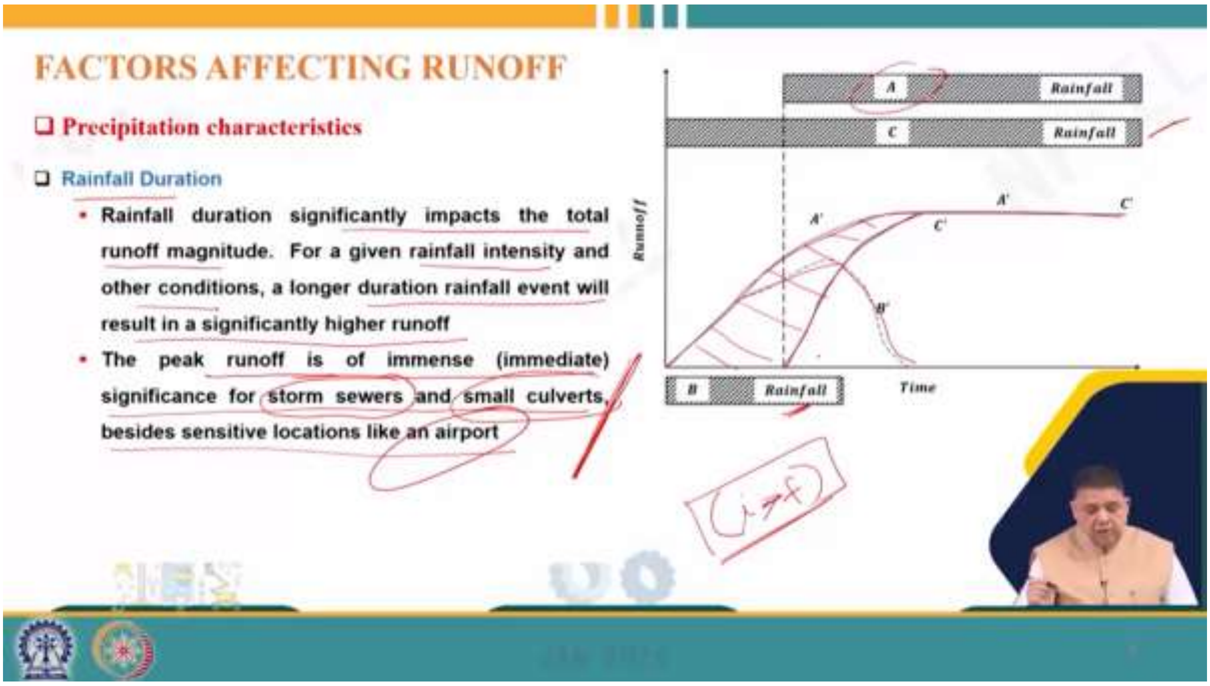


Beginning with precipitation characteristics, these are the most dominant factors influencing runoff. We know that the entire process, either the infiltration excess overland flow or saturation excess overland flow, which constitute mostly surface runoff, precipitation is the most important factor. If the precipitation amount is significant and greater than the infiltration capacity of the soil, then only infiltration excess overland flow will take place, or even if precipitation occurs, then only saturation excess overland flow will take place.

And important precipitation characteristics include duration, intensity, aerial distribution, and direction of the start movement. That means, what is the duration of this term, what is the intensity, how it is distributed aerially over the catchment, and in what direction the stop is moving with reference to the outlet, whether outlet to upstream end or upstream to downstream end. That will all impact the runoff generation.

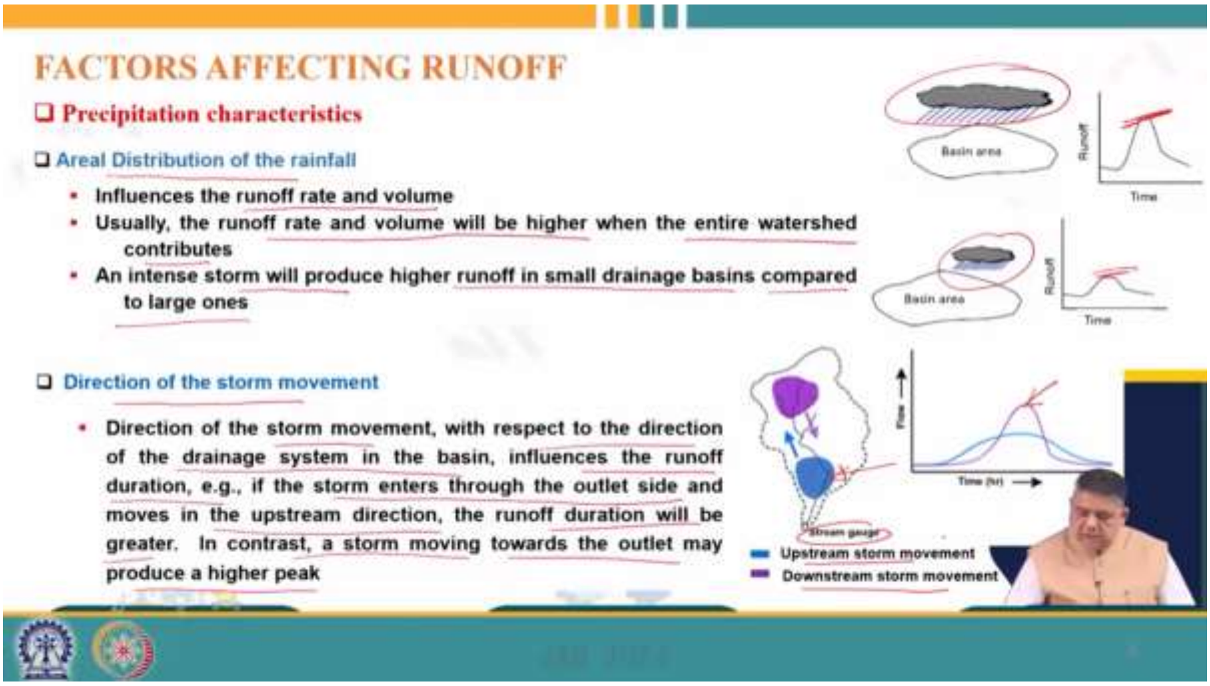
And within this, of course, rainfall intensity influences both the rate and volume of runoff. We have already seen that if you remember when we were discussing the Hortonian overland flow, then we decided that when $i > f$ where i is the rainfall intensity and f is the infiltration capacity of the soil, then only Hortonian overland flow occurs. So, that is why the rainfall intensity with respect to the infiltration capacity of the soil will determine at what rate the overland flow takes place or surface runoff takes place, and what is the total volume of runoff, of course. The runoff volume and rate are usually higher for an intense rainfall event. So, of course, if i is greater than f, and we Hortenian also said that $i - f$ is the excess runoff, excess rainfall that gets converted into overland flow.

So, obviously, the higher the intensity, the more will be this magnitude, and thus the rate and volume will be higher. And this is the plot which shows the variation of runoff rate against the rainfall intensity. This is millimetres per hour, and this is in cumec, and as you can see, with the intensity, the runoff rate varies, increases exponentially. So, there is an exponential increase in runoff with an increase in the rainfall intensity.



Then, of course, the rainfall duration significantly impacts the total runoff magnitude. So, for a given rainfall intensity and other conditions, a longer duration rainfall event will result in significantly higher runoff, which goes without saying because if intensity is let us take that it. So, $i - f$ that return this covers the rate, and of course, if the duration of the storm is longer, then obviously, at this rate overland flow will occur, and then obviously, the total volume will be much higher. The peak runoff is of immense significance for storm sewers and small culverts, besides sensitive locations like airports. So, of course, knowing the volume, if both the rate as well as the volume are very important for designing various kinds of structures, be the storage structures or discharge disposal structures. So, if it is a discharge disposal structure, then of course, the peak runoff is very important because what should be the capacity of storm sewers or culverts, so that the flow water could be carried smoothly. That, of course, will be governed by that, and also sensitive locations like airports, which cannot sustain the water retention on the surface. So, for them also, this is very important.

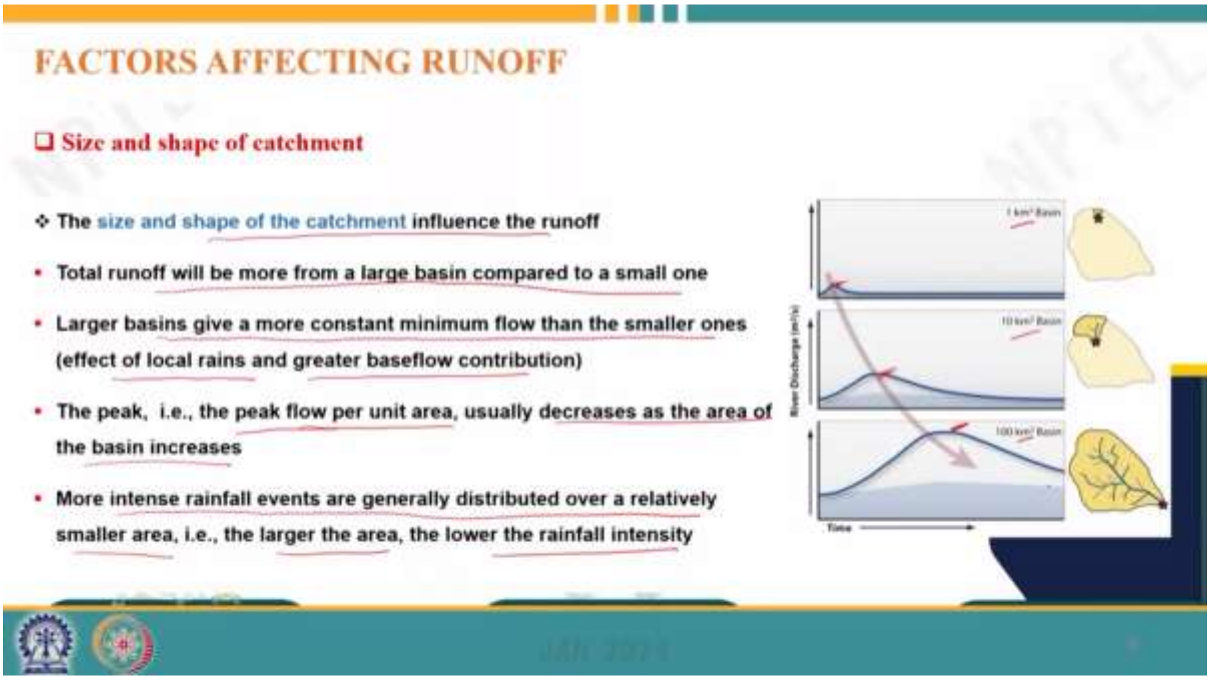
And of course, this picture just tries to show here that if the same intensity rainfall occurs, that say, for example, C and B started at the same time, but the duration was very little. So, as you can see, for C, the flow is continued, the runoff is continuing here starting from this point, it is continuing like this, but for B, it just stops here. Similarly, a storm which started much later as compared to storm C, then obviously, you can see that because storm runoff starts here, their magnitude will be significantly lower. So, this is the difference between A and C, and of course, you can find out the difference between B, and C also. So, of course, the duration makes a significant impact on the total runoff that is generated.



Then comes the aerial distribution of rainfall, which again influences both the runoff rate and volume. Usually, the runoff rate and volume will be higher when the entire watershed contributes. So obviously, if a storm is occurring all over the basin area, that means, the total flow will be much larger. Also, the total flow rate at the outlet will be significantly high as you can see here, hydrograph is a much higher peak compared to this because here the flow is only limited to a part of the basin area. And an intense storm will produce higher runoff in a small dredge basin compared to large ones which is quite obvious because a large basin means storage requirement will be much larger. So, if a small basin area is there, then it will produce more flow compared to a large flow if the duration of the storm is shorter.

Then comes the direction of the storm movement. So, as we discussed, the storm could move in an upstream direction, that is, starting towards from out is the outlet. So, from the outlet to upstream end or downstream, storm movement, that is, from upstream end towards the outlet.

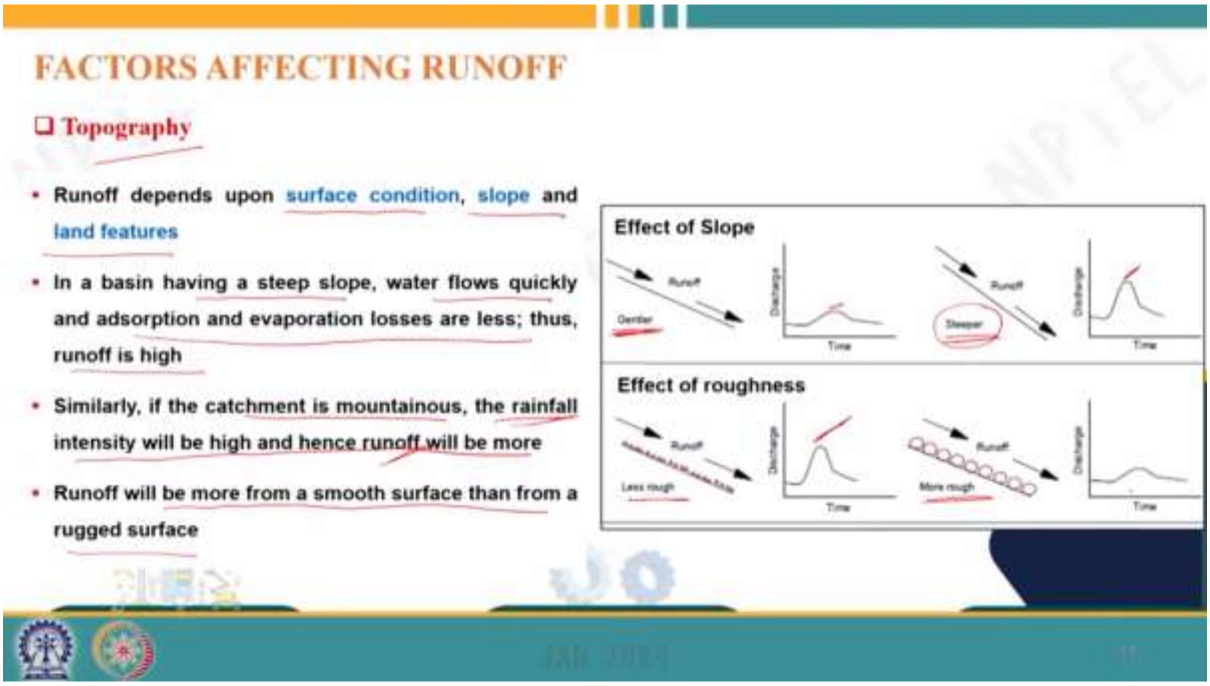
So, the direction of the storm movement with respect to the direction of the drainage system in the basin influences the runoff duration. If the storm enters the outlet side and moves in the upstream direction, the runoff duration will be greater because runoff will start continue right here when the storm is taking place and it will continue for a longer period of time till the system goes out of the basin. And in contrast, a storm moving towards the outlet may produce a higher peak. So, one which is coming in this direction will have a higher peak as compared to the one, but the total flow, I mean, the flow duration will be much larger for the storm which is moving upstream.



Now, we come to the size and shape of the catchment. The size and shape of the catchment influence the runoff, that is, total runoff will be more from a large basin compared to a small one, which is quite obvious because the total flow area will be more if the same storm occurs in a large area compared to a smaller area, then obviously, the total flow will be much higher from a large basin. A large basin gives a more constant minimum flow than the smaller ones, and that is because of the effect of local rains and greater base flow contribution. Even because it is the largest basin, so there may be localized precipitations. So, that will keep on producing rainfall, which may not be true for a small basin.

The peak flow or the peak flow per unit area usually decreases as the area of the basin increases, which is quite obvious because of the size and more intense rainfall events are generally distributed over a relatively smaller area. Larger the area, lower will the intensity of rainfall. So, obviously, lower intensity of rainfall, but because the area is considerably large. So, it is 1 square kilometre, 10 square kilometres, 100 square kilometres. So, as you can see, a peak flow which is significantly high, the larger basin also, the flow is continuing for a longer period of time, and the minimum flow level is also high because the base flow or the localized precipitations will be significant in this case.

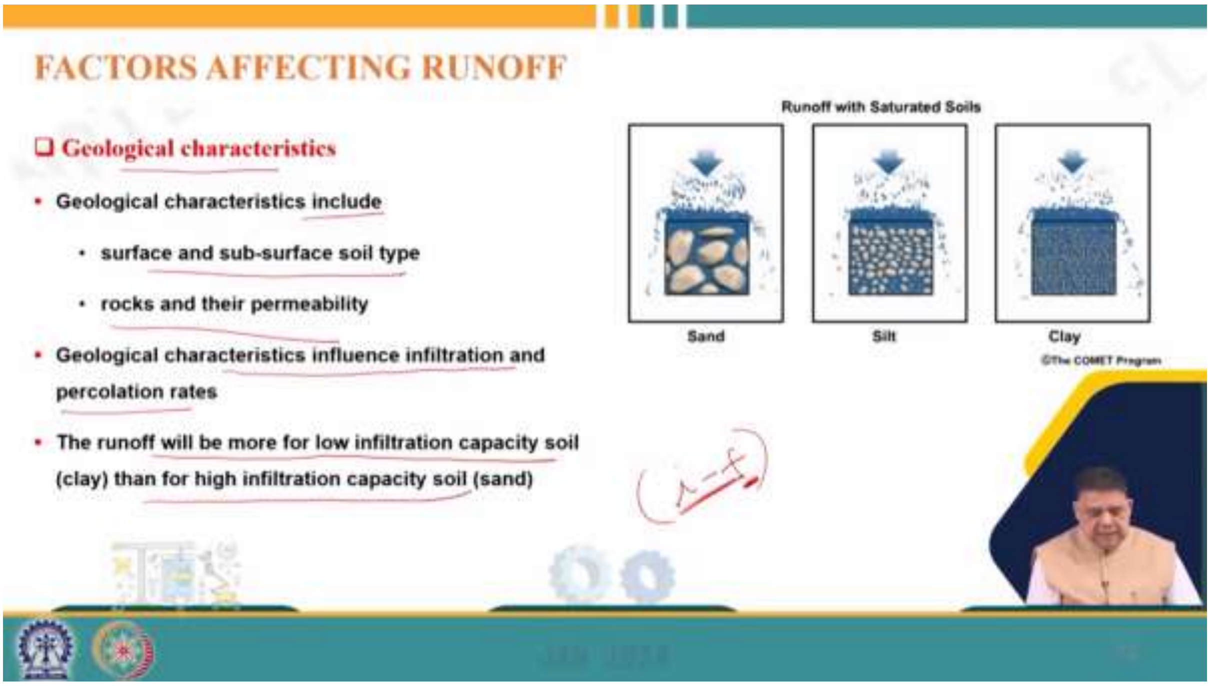
Then a fan-shaped catchment gives greater runoff because tributaries are nearly of the same size, that the time of concentration of runoff is more or less. So, if you take a fan-shaped catchment which is here, then obviously, as you can see that the flow time for water from this point to this point and this point and then they are not significantly different. That means, the entire basin, the peak flow will be reaching at the same time at the outlet. So, that is why the peak flow will be much higher. On the contrary, discharge over a first-leaf arrangement of tributaries is distributed over a long period because of the different length of tributaries. So, here in this case, if it is a fun leaf kind of. So, obviously, this flow here or here will be reaching the outlet much quicker as compared to the flow which is taking, which is starting from here. So, because of that, this flow will continue for a longer time, but peak will be higher in the case of a fan-shaped catchment.



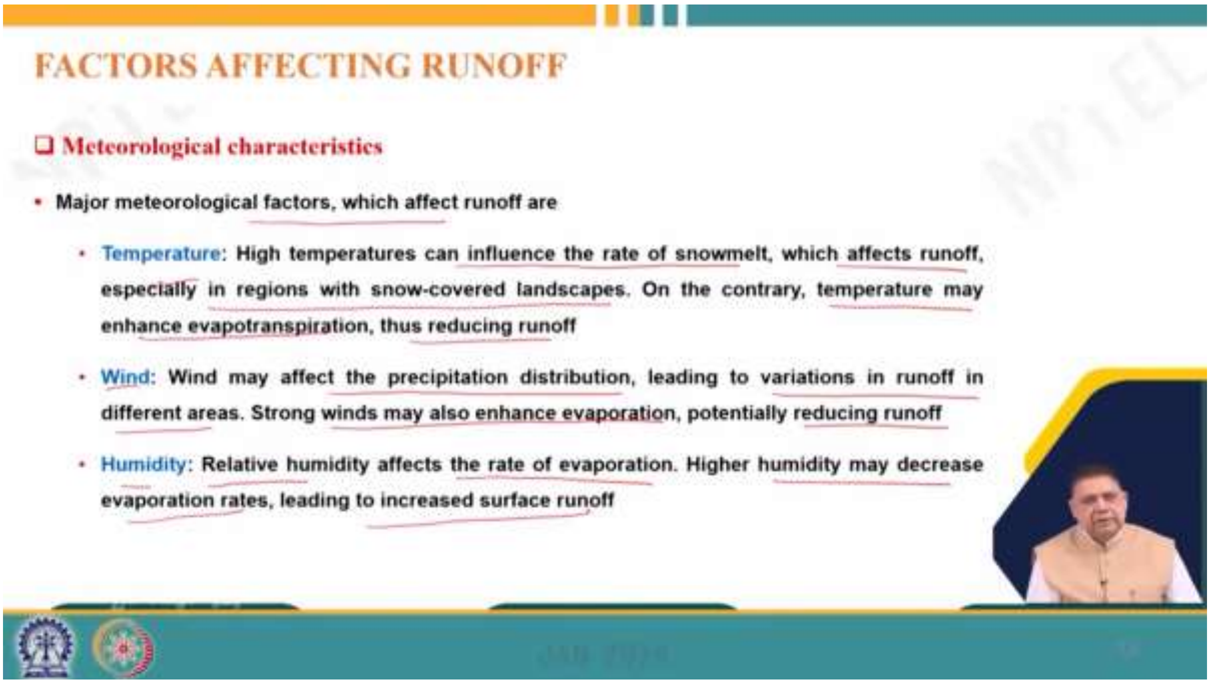
Then we come to topography runoff depends on the surface conditions slope and land features. If a basin has a steep slope, water flows quickly and jobs and evaporation losses are less, thus runoff is high. So, obviously, if it is a steeper slope, the velocity of flow will be very high as compared to a topography, a basin having a gentle slope.

So, obviously, because of that the flow will be reaching the outlet much faster. So, obviously, the peak will be much larger as compared to a flat or gentle slope basin, generally sloped basin, but flow will continue here for a longer time as compared to a steeper slope. Similarly, if the catchment is mountainous, the rainfall intensity will be high and hence runoff will be more. So, obviously, steep slopes also are mostly found in mountainous areas. So, there the rainfall is also expected to be high hence runoff will be more, and runoff will be more from a smooth surface than from a rugged surface.

So, if it is a rugged surface, that is a rough surface, then obviously, the velocity of flow will be more, the storage will be more as compared to a smooth surface where the velocity of flow will be much higher. So, the conditions will be just reverse because the higher velocity here on steep slope we get peak volume here on the smooth surface will get a much larger peak flow, but on a rough surface, the peak will be lower, but flow duration will be much larger.

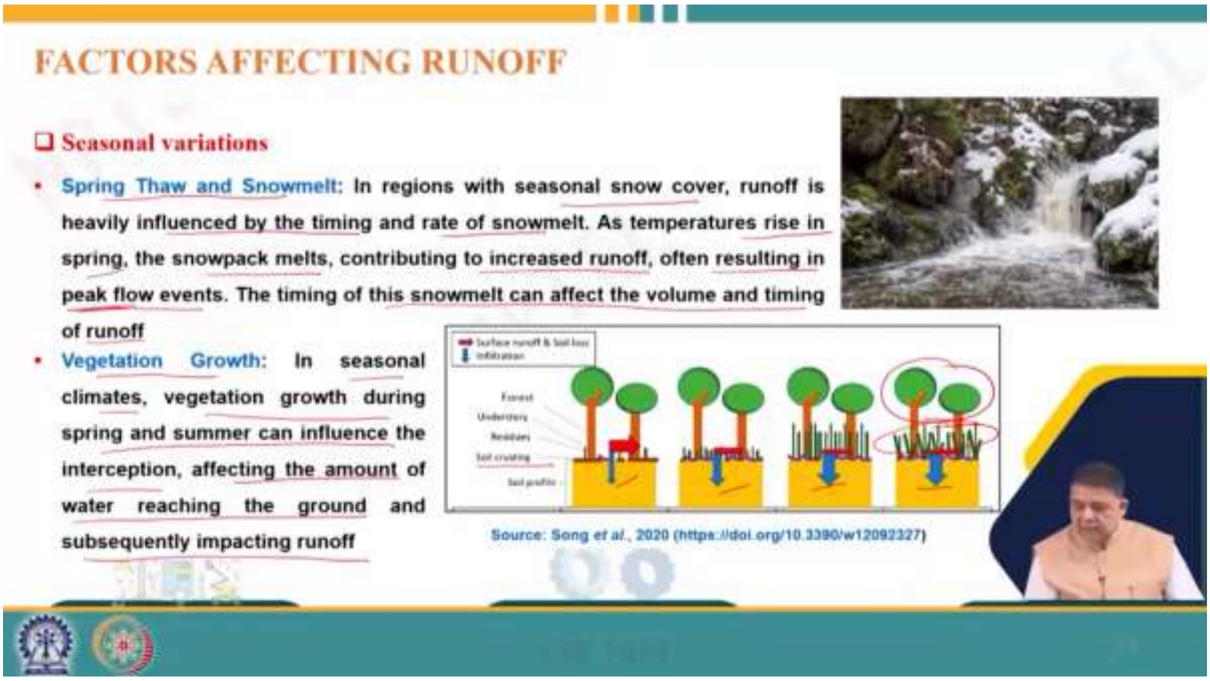


Then, geological characteristics, they include surface and subsurface soil type and rocks and their permeability, and of course, geological characteristics influence infiltration and percolation rates and runoff will be more for low infiltration capacity soil than for high infiltration capacity soil that we have already seen that $i - f$ gets converted into overland flow. So, obviously, if f is low for the same intensity, there will be the overland flow rate will be much higher as compared to a soil where f value is high. So, it goes without saying.



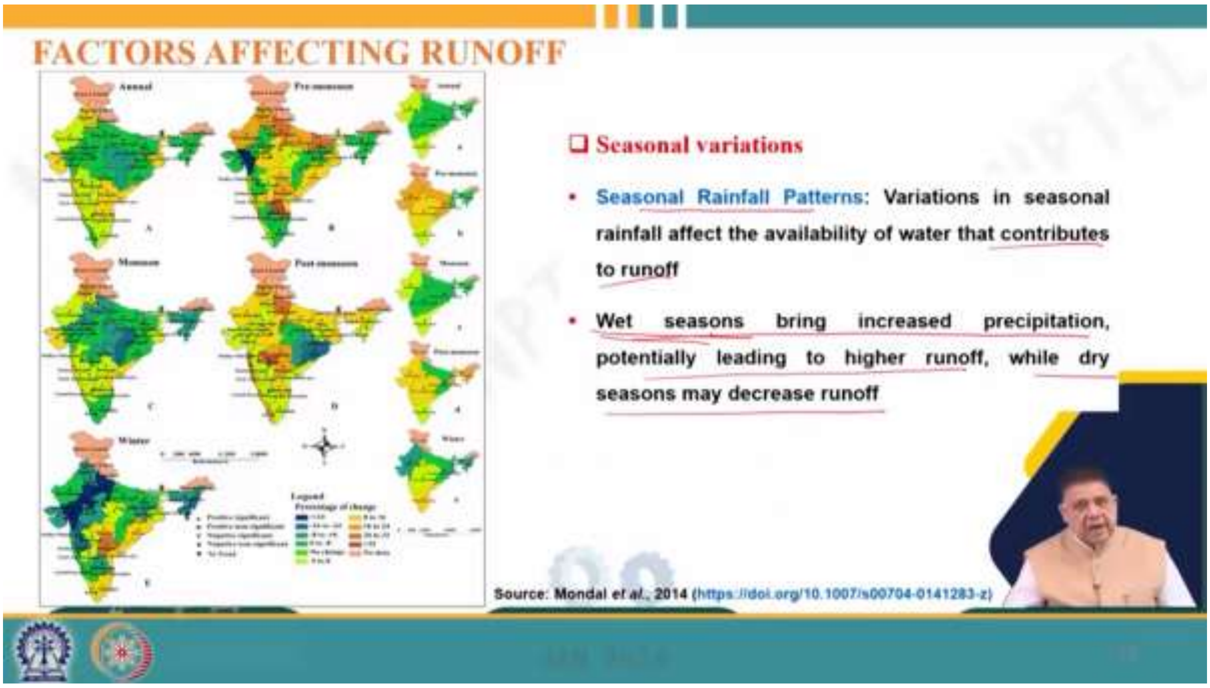
Then, metallurgical characteristics, of course, the metallurgical factors like temperature, wind, and humidity have a significant role in runoff generation. High temperatures can influence the rate of snowmelt which affects runoff especially in regions with snow-covered landscapes. So, obviously, as you see that perennial rivers they keep on getting water during even the lean period or non-monsoon period because of the snowmelt. On the contrary, temperature may enhance evapotranspiration losses and thus reducing the runoff. So, depending upon which season and which time we are talking about, based on that temperatures effect can be seen.

Wind may affect the precipitation distribution because the winds may take away precipitation from the catchment or they can bring and similarly that means it variation in runoff will be there. Similarly, strong winds may be although enhanced evaporation losses and thus runoff could be reduced. Humidity, we know that evaporation relative humidity plays a significant role. So, relative humidity affects the rate of evaporation, higher humidity may decrease evaporation rate leading to increased surface runoff and vice versa.

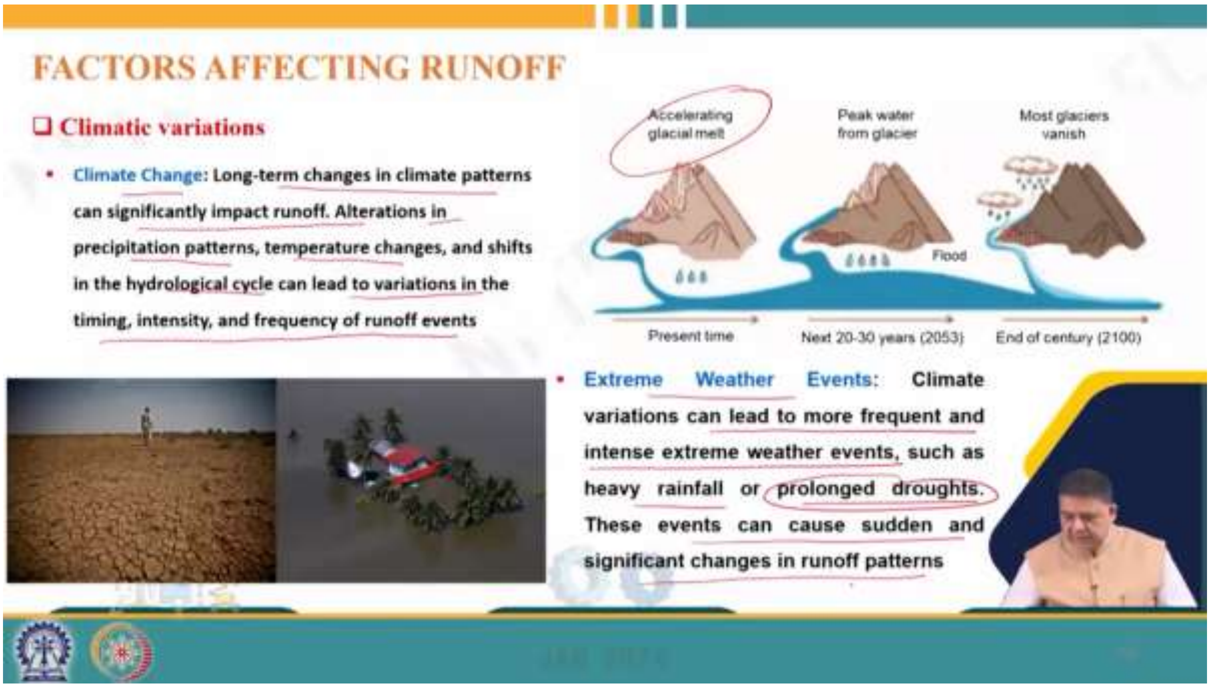


Then if we talk about the seasonal variations then these are more location-specific. So, spring thaw and snow melt in the regions where seasonal snow cover is there runoff will be heavily influenced by timing and rate of snow melt as temperatures rise in spring the snow pack melts contributing to increase runoff often resulting in peak flow event. So, in a heavily snowed area areas or basins the peak flow will be coming in spring and the timing of this snow melt can affect the volume and timing of runoff which is quite obvious. Then of course, the vegetation growth that will also affect runoff in seasonal climates vegetation growth during spring and summer can influence the interception affecting the amount of water reaching the ground and subsequently impacting runoff. So, obviously, there are many factors in a forest area that could affect for example, the forest the forest itself then the density the understory that means, the coverage the residues that are lying on the surface which we saw that in soils which are in forest areas because of the litter the runoff generation is very low and of course, the soil crust and soil profile. So, accordingly as you can see that infiltration will keep on changing.

So, infiltration will be much higher when there is the forest same forest if their understory or the vegetation is much more because that will also result in the soil crusting. So, infiltration will be much less and rainfall runoff will be lower.

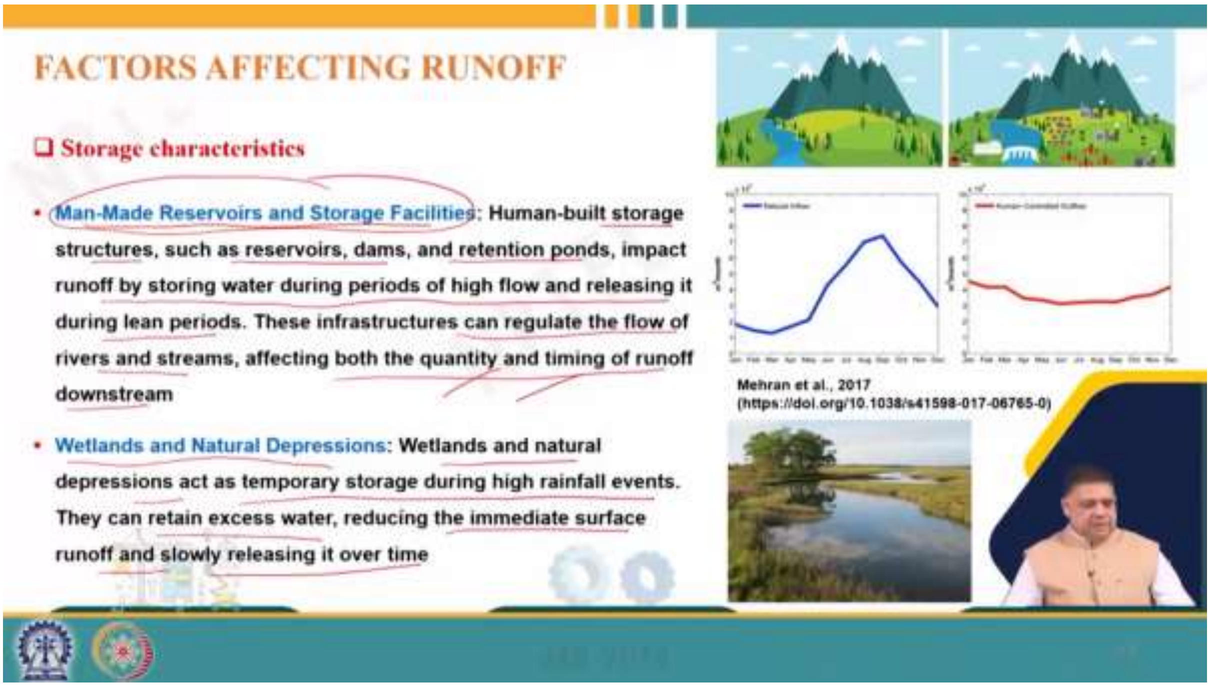


Within seasonal variation the seasonal rainfall patterns will also impact the runoff generation and the runoff distribution and wet seasons bring increased precipitation potential leading to higher runoff while dry seasons may decrease runoff and that we have seen that when we discussing about the various types of streams. So, we saw that there are ephemeral streams or intermittent streams which carry water only during a rainfall event or immediately after rainfall event or only during monsoon seasons. So, obviously, wet seasons we expect can expect higher runoff as compared to a dry season.



Then of course, the climatic variations the climate change long term changes in climate patterns can significantly affect runoff. Alternations in precipitation pattern temperature changes, shift in hydrological can lead to variation the timing intensity and frequency of runoff event. So, obviously, as we saw temperature is higher evaporation will be higher. So, obviously, the rainfall the runoff will be lower, but at the same time if temperature is higher the melts the glacier melt will be much higher and that means, the runoff will be coming frequently into the stream. And of course, the extreme weather events the climate variation can lead to more frequent and intense extreme weather events such as heavy rainfall or prolonged drought.

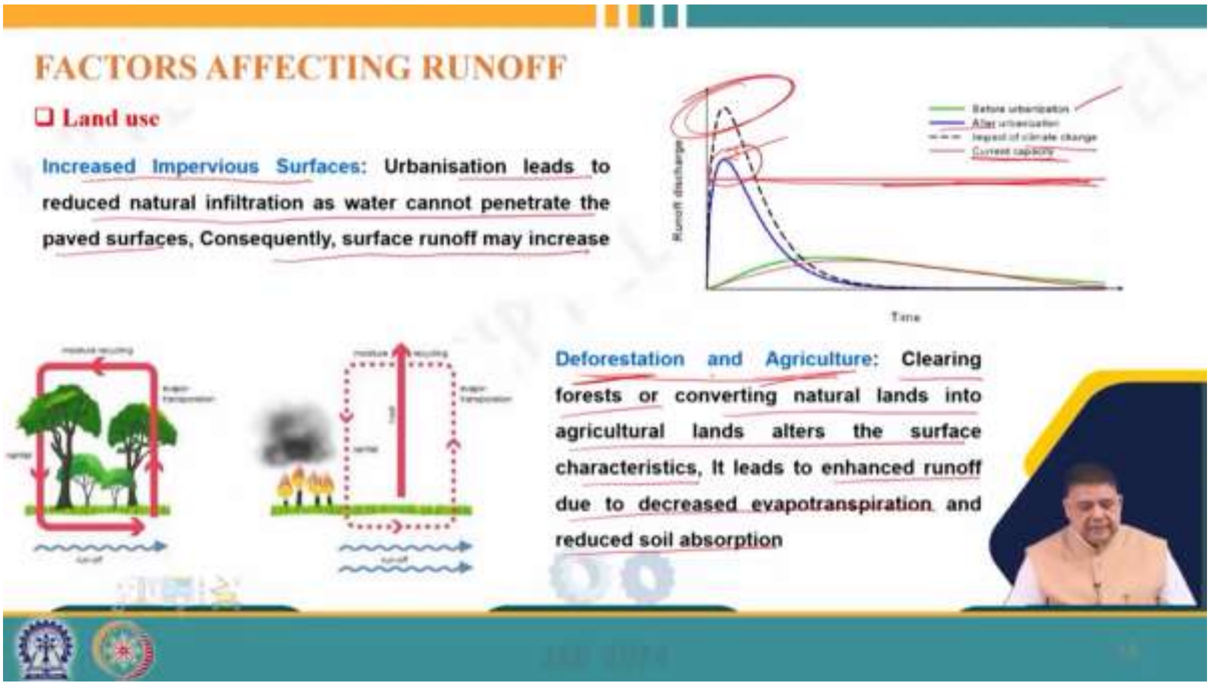
And of course, when we have heavy rainfall then we will get a lot of flood water and if it is a prolonged drought then of course, there will be no runoff. So, these events can cause sudden and significant changes in runoff pattern as we can expect.



Then of course, the storage characteristics also make a lot of difference like if they are manmade reservoirs in storage facilities. So, human built storage structures such as reservoirs dams and retention pond, they impact runoff by storing water during the period of high flow and releasing it during lean periods. It is structures can regulate the flow of rivers and streams affecting both the quantity and timing of runoff downstream.

So, of course, if we have reservoir built or dams built or retention pond built for storing water. So, obviously, during the high rainfall events these there will be lot of storage and thus runoff will be much lower. And of course, these storages as we discussed in previous lecture about the reservoirs and the storage requirement of reservoirs. So, obviously, these reservoirs are the retention ponds they store water for a particular purpose in order to meet demand during a lean period. So, obviously, this will be stored not get converted to runoff and used during the dry period to meet the various demands for which a particular storage structure is built.

So, obviously, whenever there is a manmade structure storage facility in the catchment. So, that will affect the runoff generation the quantity and timing of the runoff. Similarly, for wetland and natural depressions also. So, if there are wetlands and natural depressions they also act as temporary storage during high rainfall events they can retain excess water reducing the immediate surface runoff and slowly refitting over time. So, obviously, if the wetlands are there or natural depressions are there then also, we saw that when water starts flowing it will if it reaches the wetlands or in the depression natural depressions it will be retained there and then obviously, the magnitude of runoff will be much lower in that case.



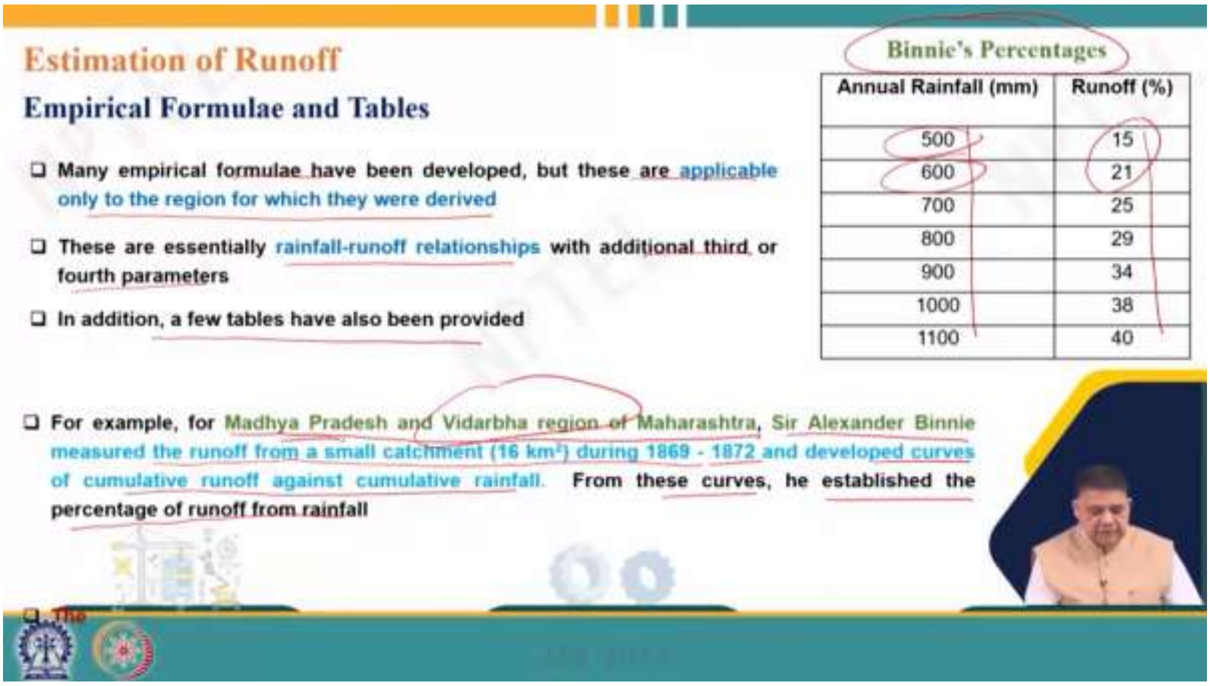
Now, we come to the land use and obviously, if there are increased impervious surfaces for example, the urbanization leads to reduced natural infiltration as water cannot penetrate the paved surfaces consequently surface runoff may increase. So, as you can see here if for a typical urbanized area before run before urbanization this was the green colour was the flow pattern the runoff pattern, but once urbanization took place then you can see the peak went very high that is blue colour pink went very high and of course, the duration became shorter. So, obviously, as you already we already known and we already see that in most of the Vega cities there are lot of building and road constructions are there we always find that even a small amount of rainfall can cause flooding in the towns and that is a on only because of the urbanization because we do not have enough capacity like here the red colour says that current capacity for the drainage capacity which is available. So, as you can see that this peak because of urbanization has crossed so obviously, because enough drainage capacity is not there. So, there will be flooding in the city or urbanized areas.

Similarly, nowadays there is an impact of climate change because of which there is a weather extremes or climate extremes are increasing extreme events are frequent. So, because of that there might be much higher rainfall and then obviously, as you can see because we do not have enough capacity. So, lot of runoffs will be discharged and that means, flooding will take place in urbanized areas. On the other side deforestation in agriculture that will also impact runoff like clearing forests or converting natural lands into agricultural lands alter the surface characteristics it leads to enhanced runoff due to increase evapotranspiration and reduced soil absorption. So, obviously, as we have seen that if it is a forest area then obviously, lot of water stored on the surface itself because of the litters and all, but if that is converted into agricultural land then obviously, the evapotranspiration which was much higher because of the plantation and all that will also go down and of course, so runoff will be and of course, there will be no storage on the surface because there are no litters and all. So, obviously, there will be more runoff generated if there is a deforestation or conversion of land into agricultural land.

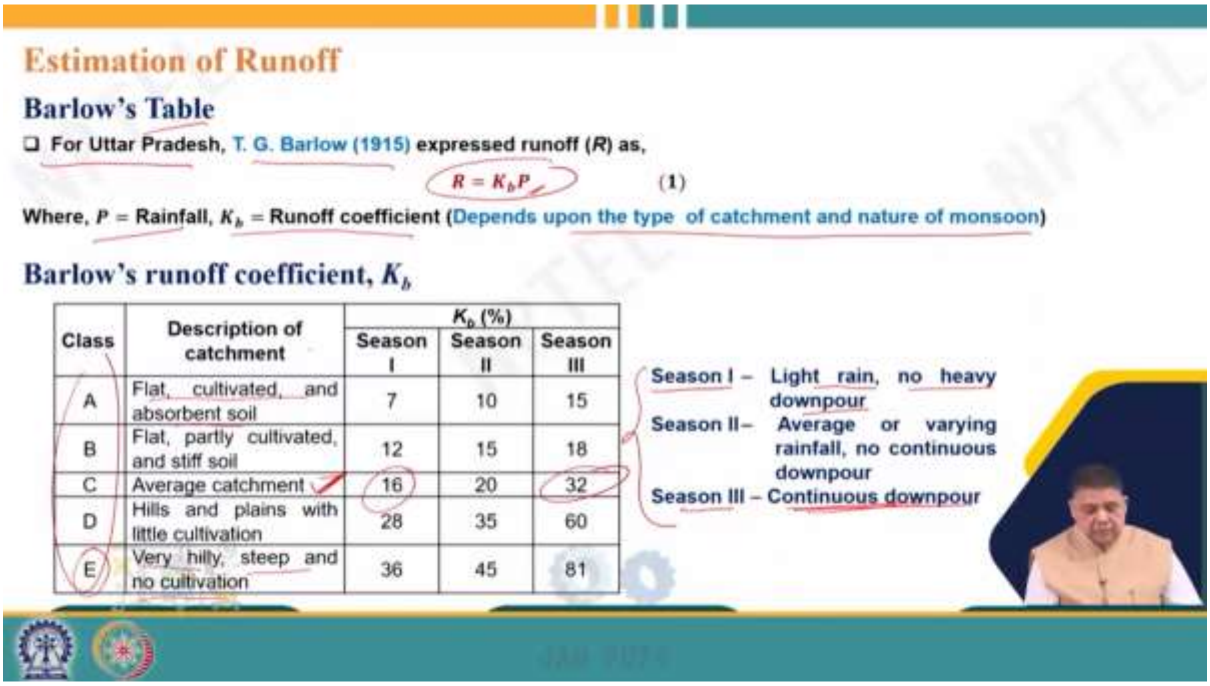
Similarly, land cover changes that is changes in agricultural practices like cover cropping or contour farming that may influence runoff. So, if there is a cover cropping or contour farming then obviously, these are meant towards water conservation. So, more of the water will be conserved and that means, runoff will be lower. So, changes in the natural drainage pattern altering the natural landscape such as road construction or the installation of drainage systems may influence the flow velocity and total runoff.

So, if they have instead of natural drainage you have artificial drainage. So, obviously, because they are designed to carry a particular amount of flow to a particular place. So, natural flow process in the drainage basins will definitely be affected.

Now, we come to estimation of runoff and there are different methods of runoff estimation like for example, there are some empirical formulae in tables there are methods which are based on estimating losses there are method which are based on finding out infiltration or average infiltration then there are three standard methods Cook's method rational method and SCS curve number method and in today and coming lectures we will see all these methods one by one.



Starting with the empirical formulae in tables many empirical formulae have been developed, but these are applicable only to region for which they are. So, they are empirical in nature quite obvious they cannot be used anywhere and these are essentially rainfall runoff relationship with additional third or fourth parameter. So, people might have used temperature or other factors and also few tables have been provided for example, for Madhya Pradesh and Vidarbha region of Maharashtra Sir Alexander Binny measured the runoff from a small catchment during 1869 and 1872 and developed curves of cumulative runoff against cumulative rainfall and from these curves established the percentage of runoff from rainfall. So, these are this is popularly called as Binny's percentage. So, based on the annual rainfall we know what percentage will be converted into runoff. So, if a Vidarbha region where the rainfall is usually in the tune of 500 to 600 mm in a year. So, only 15 to 20 percent of the rainfall will be convert into runoff age per Binny's percent, but as we have seen that this is only applicable for Madhya Pradesh and Vidarbha region.

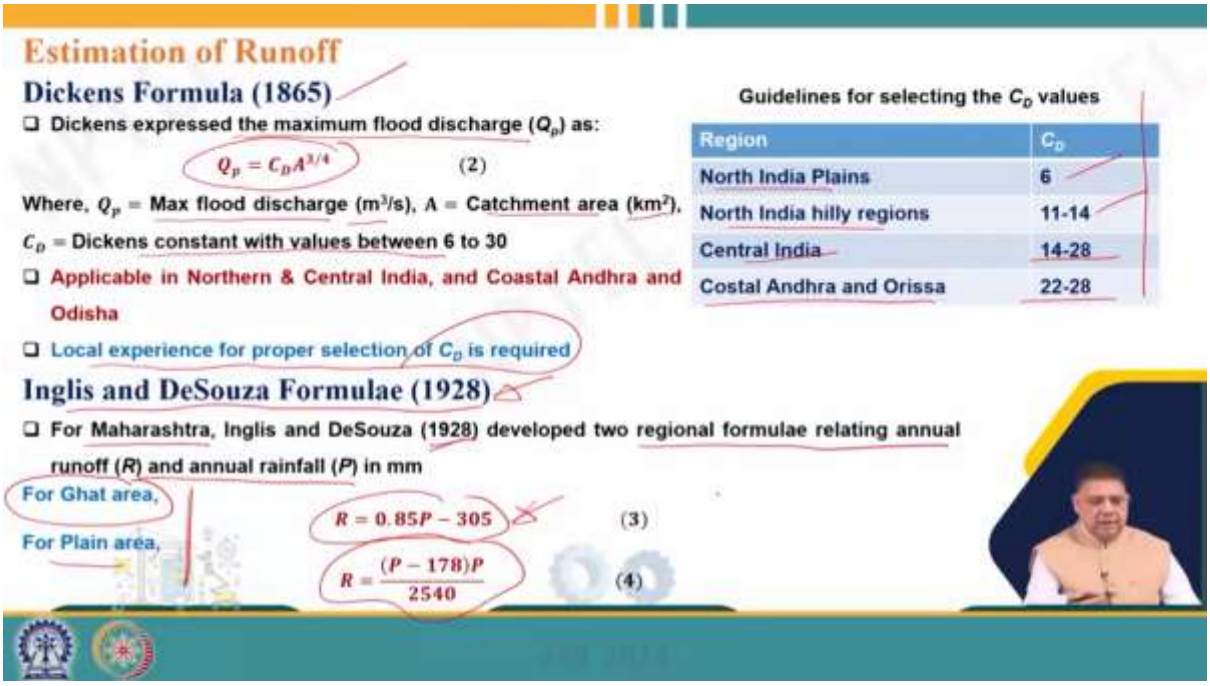


Then we have a Barlow's table which was developed for Uttar Pradesh by T.G. Barlow in 1915. He expressed runoff in this form

$$R = K_b P$$

where P is the rainfall and K_b is the runoff coefficient which depends upon the type of catchment and nature of monsoon. So, basically, he divided the catchment into different classes A, B, C, D, E having different descriptions.

So, A is flat cultivated and absorbent soil where in extreme other extreme E is very hilly steep and no cultivation. He also divided the season into 3 components season 1 where the rain is light and there is no heavy downpour and season 3 which has continuous downpour. So, depending upon which catchment you are and which season you are talking about for example, average catchment in season 1, 16 percent of the precipitation will get converted into runoff whereas in season 3 where there is continuous downpour 32 percent of the rainfall will get converted into runoff and this is only applicable for Uttar Pradesh.



Then we have Dickens formula which was developed in 1865. Dickens expressed the maximum flood discharge Q_P in this form

$$Q_P = C_D A^{3/4}$$

where Q_P is maximum flood discharge in cubic meters per second A is a cost catchment area in square kilometres and C_D is a Dickens constant with values ranging from 6 to 30 and of course, then he gave this table.

So, these are the areas for which the applicable. So, in the north plane India plains, the C D value is 6 north India hilly regions 11 to 14 central India 14 to 28 and coast Landra and Orissa is 22 to 28 and of course, based on local experience one has to select the C D and according we can then determine what will the maximum flood discharge knowing the catchment area.

Lastly, we will discuss today the English and D'Souza formula which was developed in 1928 and this it is made from Maharashtra. English and D'Souza in 1928 from Maharashtra they developed two regional formulas relating annual runoff and annual rainfall and that means, for ghat areas

$$R = 0.85P - 305$$

and for plane area

$$R = \frac{(P - 178)P}{2540}$$

So, depending upon which area you are in ghat or in plane area for in Maharashtra then of course, knowing the precipitation runoff value can be calculated.

So, we saw that there are certain empirical formulas and tables that are available. So, in this lecture we discussed the we defined runoff and discussed the factors of vector runoff and we started with discussing the methods of estimating runoff and today we saw a few empirical formulas and tables we will continue to discuss these methods in next lectures. Thank you very much please give your feedback and also raise your doubts or questions in so, that can be replied in the forum. Thank you.