Engineering Hydrology
Professor Doctor Sreeja Pekkat
Department of Civil Engineering
Indian Institute of Technology, Guwahati
Module 4 - Lecture 46
Overland Flow

Hello all, welcome back. In the previous lecture, we have started with the surface water and we have seen what is meant by surface water and the water which is flowing on the surface of the Earth is termed as surface water and after that we have seen different storage components. Once these storage components are satisfied, we will be getting the surface water and we have already seen the abstraction that is different losses which are taking place from the rainfall. Whenever there is a rainfall occurring we are having infiltration and also, we need to satisfy different storage components, after that whatever excess rainfall is coming that is coming as the overland flow or surface runoff. So, we have seen different techniques to calculate the initial abstractions. In those abstraction techniques we were discussing about the initial abstraction and also water lost due to infiltration. So, different abstraction calculation techniques we have seen and remaining water is considered as the excess rainfall or direct runoff depth that will be contributing to the direct runoff or overland flow.

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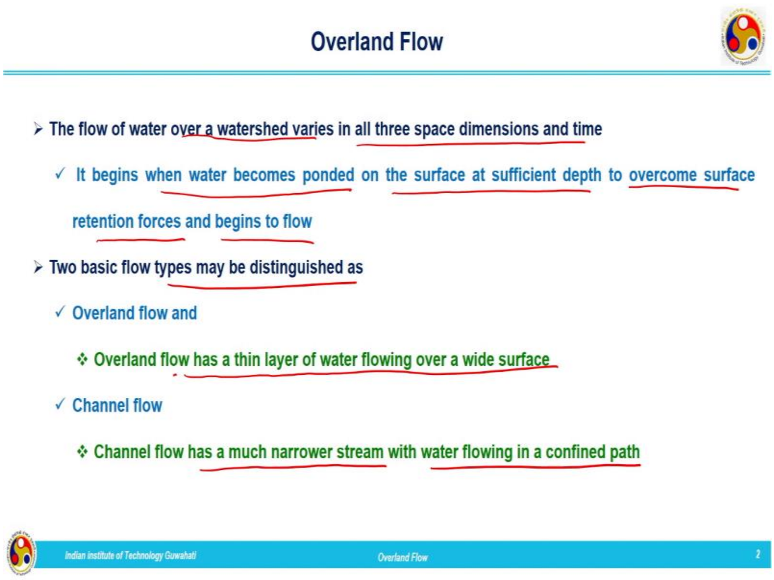

So, in today's lecture we will move on to overland flow. So, the flow of water over watershed varies in all the three dimensions. So, it is a three-dimensional phenomenon, in all the direction the flow of water on the surface of the earth will be taking place. It begins when water becomes ponded on the surface at sufficient depth to overcome surface retention forces and then begins to flow. That is whenever there is a storm or rainfall is occurring, we are having certain storages to be satisfied. Once the storage has been satisfied, the remaining water which is coming is termed as the excess rainfall. This excess rainfall will be initially ponded on the surface of the earth. Once it reaches certain depth, it will overcome the retention forces and it starts flowing on the surface of the earth. So, that is termed as the overland flow.

Two basic flow types may be distinguished as: one is overland flow and the other one is the channel flow. Overland flow is the flow which is having a thin layer of water flowing over a wide surface. Excess rainfall depth is attained to a certain depth it will be overcoming the retention forces and it starts flowing on the surface of the earth. So, that is the overland flow and once it has started as overland flow, it cannot flow as overland flow or sheet flow for a long time. As the area increases, it will be separated into small-small channels. So, then the channel flow starts. Both is overland flow that is the sheet flow and also the channel flow are considered as the surface flow and the channel flow has a much narrower stream with water flowing in a confined path. Overland flow it is spreading over the entire area and after that it will be concentrated into small-small channels.

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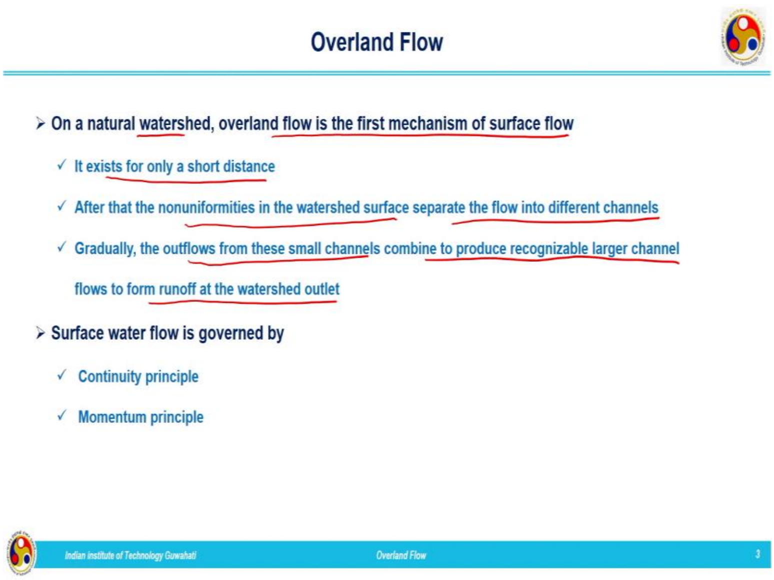

On a natural watershed, overland flow is the first mechanism of surface flow, that is initially different storage components will be satisfied. After that water will start accumulating on the surface certain depth it will be attaining, then the first flow process which is starting on the surface of the Earth is the overland flow and the importance of this is that it exists only for a short distance, it cannot go beyond a certain distance. After that what will happen non-uniformities in the watershed surface separates the flow into different channels, it will not be a plain surface. The land surface will be having so many undulations and non-uniformities it will be leading the overland flow to separate it into small channel flows. Gradually the outflows from these small channels combined to produce recognizable larger channel and it flows to form runoff at the watershed outlet.

Initially water depth and then it will be flowing as overland flow and overland flow again due to the non-uniformity separates into small-small channels and it will form recognizable channels and these channels will be contributing water at the outlet of the watershed, that is our runoff. Now, surface water flow is governed by continuity principle and also momentum principle. Here also we will be making use of our fundamental principle that is the continuity and momentum principles.

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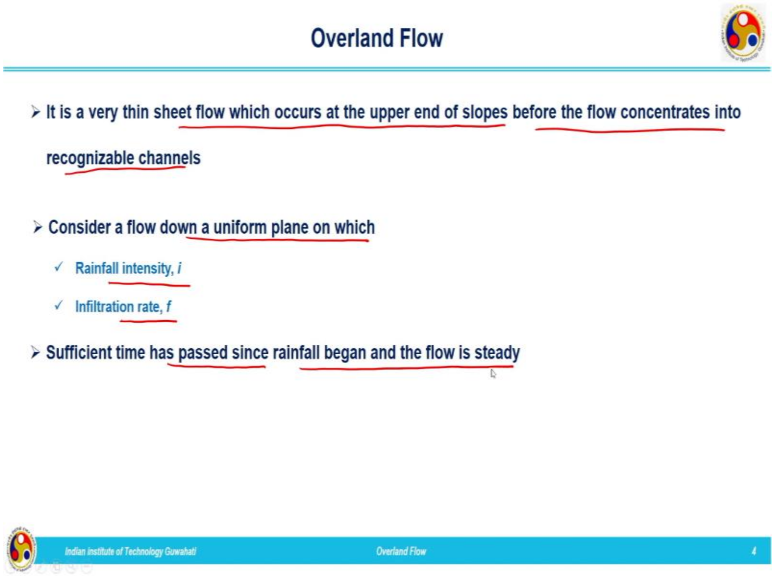

So, overland flow is a thin sheet flow which occurs at the upper end of slopes before the flow concentrates into recognizable channels. So, now consider a flow down a uniform plane on which rainfall intensity is *i* and the infiltration rate is *f*. So, we are going to find out the expression for quantifying the overland flow. So, for that what we are considering we are considering an inclined plane on which we are getting the rainfall which is having an intensity *i* and also infiltration *f*. So, these are the two inputs rainfall intensity *i* and infiltration rate *f*.

Now, sufficient time has passed since rainfall began and the flow is considered to be steady. So, here we are going to derive the expression for overland flow considering the flow to be steady and the expressions will be derived based on the fundamental principles of continuity and momentum equations.

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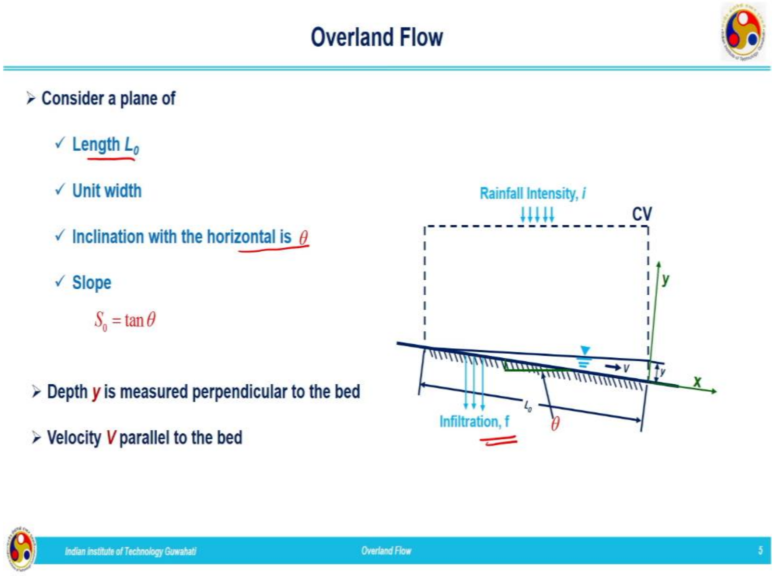

We are going to consider a plane which is having a length L_0. So, we can see the schematized representation of the plane. It is having a length L_0 and the x direction is considered as along the plane and y direction is perpendicular to the plane. So, you should keep in your mind that x is not horizontal, x direction is considered along the plane and y is perpendicular to the plane. We are considering the length of plane as L_0 and width in the other direction is considered as unity that is the plane is an inclined plane. So, it is making an angle of theta with the horizontal and based on that we will be having a slope that is given by $tan\theta$.

So, slope is given by $tan\theta$ because the inclination of the plane is θ with the horizontal. Now, for the analysis point of view we need to consider a control volume that is represented by means of this dotted line. This is our control volume and the rainfall are occurring within the control volume which is having an intensity of i and from this infiltration rate is represented by f is taking place and whenever a rainfall is occurring water is getting infiltrated into the ground and after that once the initial storage has been satisfied, we will be getting a ponded depth of water on the surface of the ground that is the excess rainfall will be causing the ponding depth and once it is free from the retention forces, it starts flowing as a thin sheet flow that is our overland flow which is having a depth of y. That y is measured perpendicular to the plane along the y-direction and the velocity is along the direction of x that is represented by V. So, the depth y is measured perpendicular to the bed and velocity is measured parallel to the bed.

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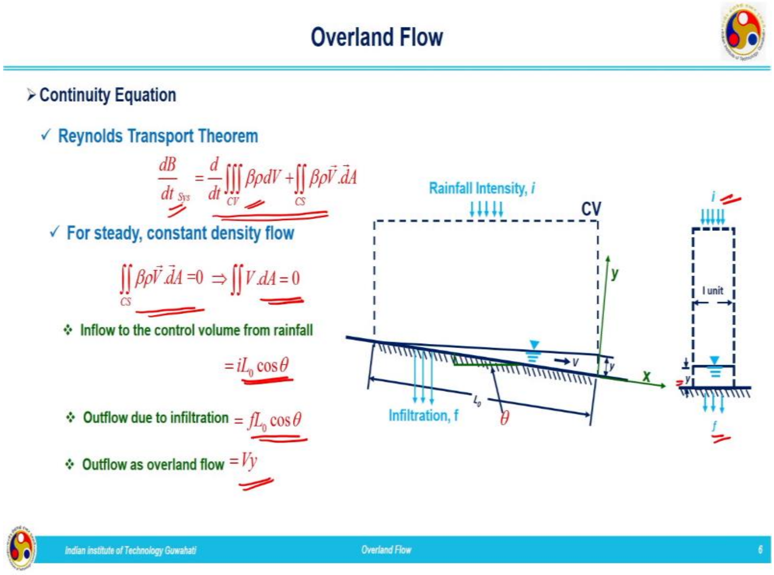

This is the same representation which I have shown in the previous slide. Now, we need to write the continuity equation, when we are going to write the continuity equation, we will be making use of Reynolds Transport Theorem which is given by this equation,

$$\frac{dB}{dt}_{Sys} = \frac{d}{dt}\iiint_{CV} \beta\rho dV + \iint_{CS} \beta\rho \vec{V}.\vec{dA}$$

This is very much familiar to you we have been using it continuously for different processes and in this case, we are considering steady state of flow. So, when steady state is considered with respect to time there will not be any variation. So, you look at the RTT we are having two terms: one is on the left-hand side $\frac{dB}{dt}_{Sys}$ and on the right-hand side the first term is also $\frac{d}{dt}\iiint_{CV} \beta\rho dV$. So, both are unsteady terms. So, for steady constant density flow, the equation takes the form across the control surface

$$\iint_{CS} \beta\rho \vec{V}.\vec{dA} = 0$$

So, β is the intensive property that intensive property is calculated based on the extensive property. In this case, this is the flow of water and while considering the extensive property and intensive property, this is mass conservation principle. So, the extensive property B is the mass of the fluid and corresponding intensive property is $\frac{dB}{dm} = 1$ and here we are considering constant density flow. So, density can be taken out of the integral sign. So, the equation takes the form,

$$\iint V.dA = 0$$

RTT has taken this simple form. What does it represent? It is representing the net outflux equal to 0 that means, inflow is equal to outflow. Now, before further proceeding we need to see the cross section of the control volume. So, the control volume is having a unit width and intensity of rainfall *i* entering into the control volume, *f* is the infiltration taking place from the ground surface and because of the sheet flow, sheet flow is having a depth. The depth of sheet flow is represented by *y* marked like this. Now, we can write the inflow and outflow. Inflow to the control volume from rainfall that is main inflow is from rainfall and outflows are due to infiltration and also overland flow. So, we can write expressions corresponding to inflow and outflow separately.

So, inflow to the control volume can be written as $iL_0 \cos\theta$. This is discharged per unit width because we are considering the other dimension as unity. In the similar way we can write the outflow due to infiltration that will be $fL_0 \cos\theta$. L_0 is inclined at an angle of θ. So, the component of that along the horizontal will be $L_0 \cos\theta$. So, that is why $L_0 \cos\theta$ multiplied by one into per unit width we are considering that is why it is $fL_0 \cos\theta$ and $iL_0 \cos\theta$.

Now, when we talk about the overland flow discharged per unit width is given by *V* multiplied by *y*. So, overland flow can be written as Vy. Now, we have written expressions corresponding to inflow and outflows, we can substitute in our Reynolds transport theorem.

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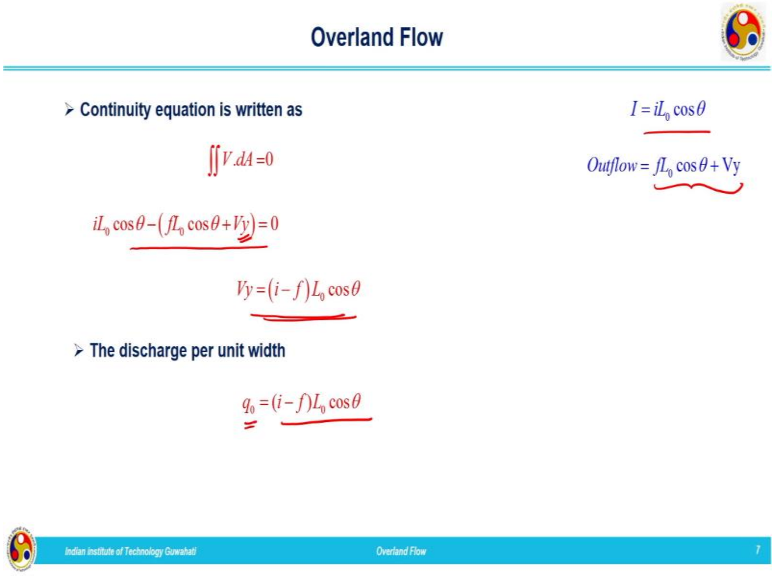

Inflow is

$$I = iL_0 \cos\theta$$

outflow together infiltration and overland flow together we are considering

$$Outflow = fL_0 \cos\theta + Vy$$

So, in this case inflow is equal to outflow because we are considering the steady state condition. So, continuity equation is written as

$$\iint V.dA = 0$$

$$iL_0 \cos\theta - \left(fL_0 \cos\theta - Vy\right) = 0$$

We need to quantify the overland flow. So, that quantities, corresponding to overland flow will be kept on the left-hand side other terms will be taken to the right-hand side. So, we can write

$$Vy = (i - f)L_0 \cos\theta$$

So, Vy is the is representing the overland flow discharge per unit width. So, we will be representing discharge per unit width as q_0 and it can be written as

$$q_0 = (i - f)L_0 \cos\theta$$

Discharge q_0 we have obtained and on the right-hand side we are having $(i-f)L_0\cos\theta$. So, for solving this we need to have one more equation that will come from our momentum equation.

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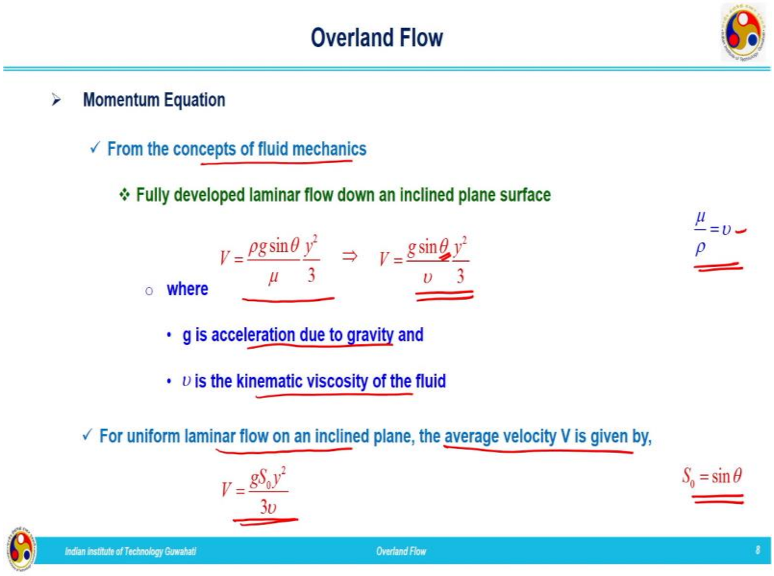

So, momentum equation when we derive, we are going to take some concepts from fluid mechanics that is from the concepts of fluid mechanics we can write for a fully developed laminar flow taking place over an inclined plane the velocity can be written as

$$V=\frac{\rho g\sin\theta}{\mu}\frac{y^2}{3}$$

So, this equation is coming from fluid mechanics you might have already studied in the course of fluid mechanics in the case of fully developed flow occurring over a fully developed laminar flow occurring over an inclined plane. So, for that flow the velocity is given by this expression., We are not going to derive that particular equation, we are directly taking it from fluid mechanics. So, here also in our case, we are considering a laminar flow over an inclined plane. So, in this equation $\frac{\mu}{\rho}$ can be substituted as υ. υ is nothing but the kinematic viscosity and the expression for velocity takes the form

$$V=\frac{g\sin\theta}{\upsilon}\frac{y^2}{3}$$

where g is the acceleration due to gravity and υ is the kinematic viscosity of the fluid and one more term is there related to $\sin\theta$. In the case of small angles from calculus, we know that $\sin\theta = \tan\theta = \theta$. So, here for $\sin\theta$ we can substitute as the slope. So, the expression takes the form, for uniform laminar flow on an inclined plane, the average velocity V is given by

$$V = \frac{gS_0 y^2}{3\upsilon}$$

Where $S_o = \sin\theta$. This assumption is applicable to very small angles only. So, for $\sin\theta$ we have substituted as the slope of the plane and the average velocity is given by $V = \frac{gS_0 y^2}{3\upsilon}$. So, this expression can be used for finding out the velocity of overland flow.

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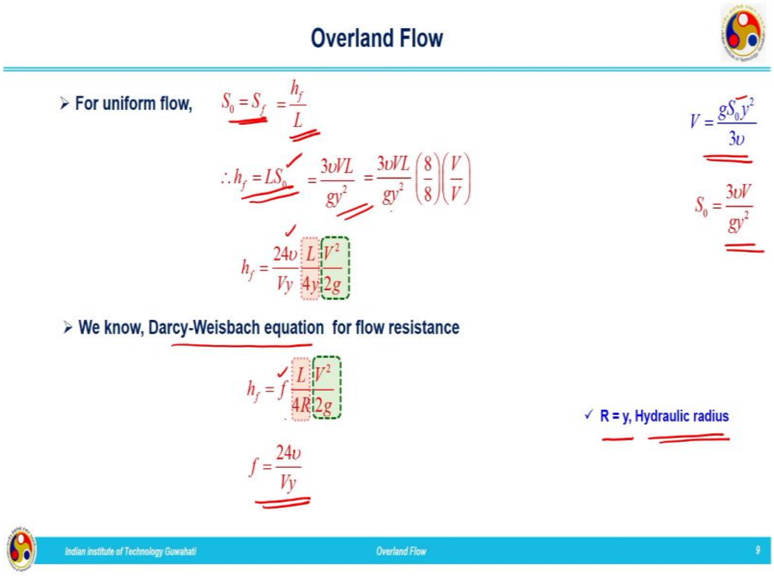

Now, what we are going to do we are going to combine the continuity equation and also momentum equation. For uniform flow we know $S_0 = S_f$, that is the bed slope is equal to friction slope, that can be written as $S_0 = S_f = \frac{h_f}{L}$. h_f is the head loss as the flow takes place from one location to another which is having a length of L. $\frac{h_f}{L}$ will be giving us the slope or the friction slope. So, from that we can write

$$h_f = LS_0$$

This will be giving you the head loss taking place during the travel of a distance of L. The expression for V we has already written i.e., $V = \frac{gS_0 y^2}{3\upsilon}$ and what we are going to do for S_0 we will substitute $S_0 = \frac{3\upsilon V}{gy^2}$ in this equation. So, h_f can be written as

$$h_f = LS_0 = \frac{3\upsilon VL}{gy^2}$$

This equation can be again modified as

$$h_f = LS_0 = \frac{3\upsilon VL}{gy^2}\left(\frac{8}{8}\right)\left(\frac{V}{V}\right)$$

We need to rewrite this equation in some other form that is why we are going to multiply and divide this particular expression on the right-hand side by *8V*. So, it will take the form

$$h_f = \frac{24\upsilon}{Vy}\frac{L}{4y}\frac{V^2}{2g}$$

Why we are writing this? We know already from Darcy-Weisbach equation, flow resistance h_f is given by

$$h_f = f\frac{L}{4R}\frac{V^2}{2g}$$

You compare these two equations. You can see that both these equations are of the same form. Here you can see $\frac{V^2}{2g}$ is there on both the equation and in the first equation we are having $\frac{L}{4y}$ instead of that in Darcy-Weisbach equation we are having $\frac{L}{4R}$ and R is equal to y, hydraulic radius.

So, by comparing this equation and the Darcy-Weisbach equation, we can conclude that R is the hydraulic radius, that is depth of overland flow can be considered as the hydraulic radius R, both are same and friction factor f can be written as,

$$f = \frac{24\upsilon}{Vy}$$

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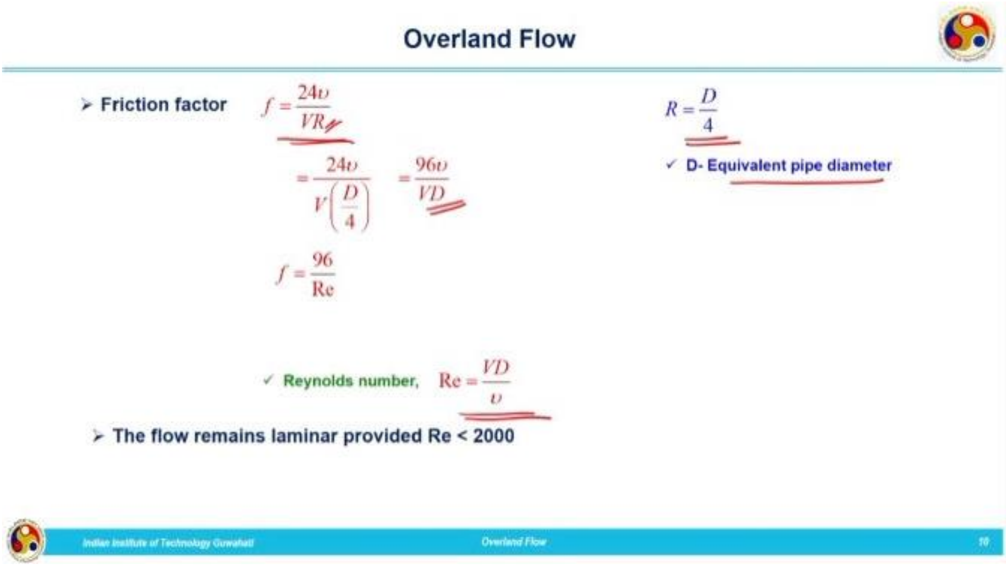

But we know in the case of pipe flow $R = \frac{D}{4}$. Hydraulic radius R can be written as diameter by 4. This is coming from the expression hydraulic radius is equal to $\frac{A}{P}$. Area divided by wetted perimeter and from that we can understand that R can be written as diameter divided by 4. So, D is the equivalent pipe diameter and here we are substituting for $R = \frac{D}{4}$. Then, friction factor f will be taking the form

$$f = \frac{24\upsilon}{V\left(\frac{D}{4}\right)} = \frac{96\upsilon}{VD}$$

Now you look at the equation, it is very much familiar to you. What is $\frac{\upsilon}{VD}$? $\frac{VD}{\upsilon}$ is nothing but our Reynold's number. So, this equation can be modified as friction can be rewritten as

$$f = \frac{96}{R_e}$$

R_e is nothing but the Reynold's number given by

$$\mathrm{R_e} = \frac{VD}{\upsilon}$$

For laminar flow, Reynold’s number should be less than 2000. So, initially when we were discussing we have considered the flow to be laminar.

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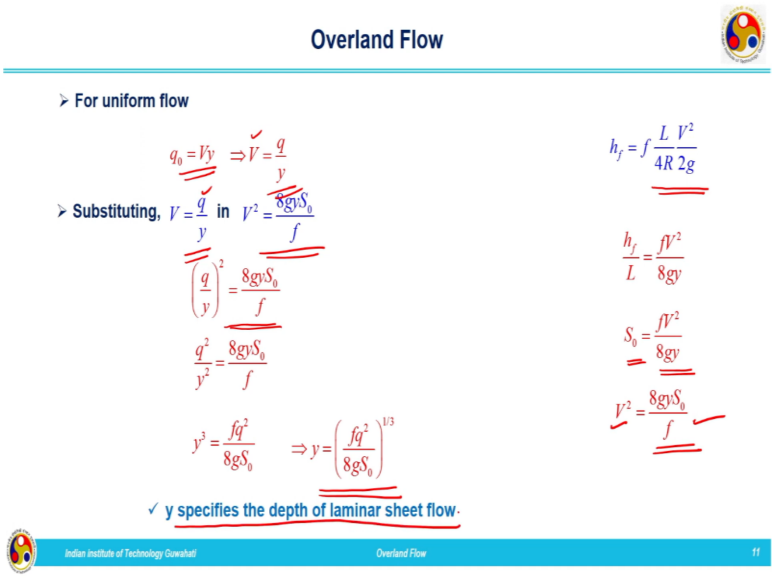

h_f is given by Darcy-Weishbach equation as

$$h_f = f\frac{L}{4R}\frac{V^2}{2g}$$

and for uniform flow

$$q_0 = Vy$$

Discharge per unit width (q_0) is given by V multiplied by y. That is an expression for overland flow. So, now what we are going to do

$$V = \frac{q_0}{y}$$

We know

$$\frac{h_f}{L} = \frac{fV^2}{8gy}$$

and from this we can write

$$S_0 = \frac{h_f}{L}$$

S_0 is the bed slope or friction slope. For uniform flow both are equal. S_0 is given by

$$S_0 = \frac{fV^2}{8gy}$$

V^2 is given by

$$V^2 = \frac{8gyS_0}{f}$$

So, we will substitute $V^2 = \frac{8gyS_0}{f}$.

In the equation i.e., $V = \frac{q_0}{y}$, we will substitute this. So, let us see how it will be coming that is

$$\left(\frac{q_o}{y}\right)^2 = \frac{8gyS_0}{f}$$

So, we can modify this equation

$$\frac{q_o{}^2}{y^2} = \frac{8gyS_0}{f}$$

and y^3 will be taking the form

$$y^3 = \frac{fq_o{}^2}{8gyS_0}$$

This will give us the value corresponding to the depth of overland flow y is equal to

$$y = \left(\frac{fq_o{}^2}{8gyS_0}\right)^{\frac{1}{3}}$$

So, this is the equation corresponding to the depth of overland flow. How did we get that? We have combined the continuity equation and momentum equation and while using the momentum equation, we have made use of the principle from fluid mechanics regarding the velocity of a fully developed laminar flow over an inclined plane. We have we have compared the head loss from that equation and also from Darcy-Weisbach equation, certain adjustments with the terms we have done and finally, we got the depth of overland flow given by this equation, y is equal to

$$y = \left(\frac{f q_o^{\,2}}{8 g y S_0} \right)^{\frac{1}{3}}$$

y specifies that depth of laminar sheet flow, this is the depth of laminar sheet flow because our assumption initially is flow is a fully developed laminar flow.

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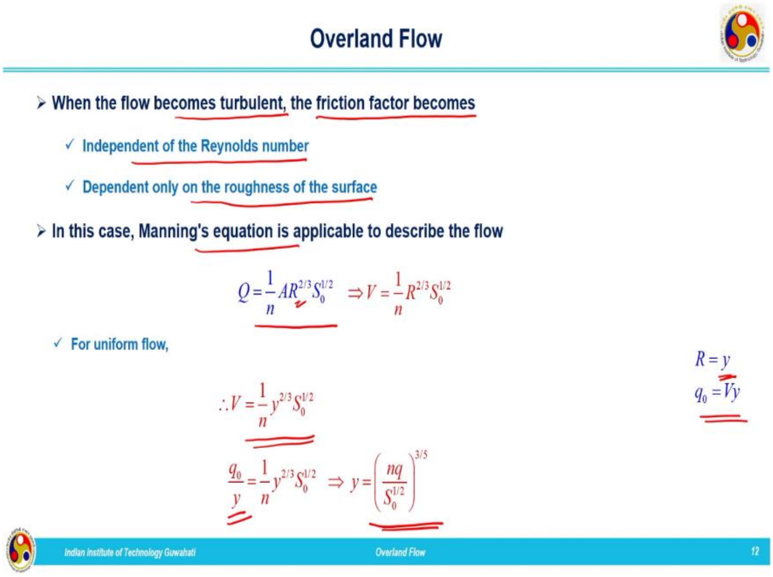

If flow is turbulent we cannot make use of that formula. Friction factor becomes independent of the Reynolds number. For turbulent flow, Reynolds number is not coming into picture. It is independent of Reynolds number and dependent only on the roughness of the surface. So, we can make use of Manning's equation in that case to describe the flow that is given by

$$Q = \frac{1}{n} A R^{2/3} S_0^{1/2}$$

So, if the flow is turbulent, we will not be making use of the previous expression for depth of flow, we will be making use of the Manning's equation and we will find out the depth of flow by making use of iterative techniques. Here in this case hydraulic radius is R can be taken as depth of flow, $R = y$ and $q_0 = Vy$ and V is given by

$$V = \frac{1}{n} R^{2/3} S_0^{1/2}$$

For uniform flow V can be written as

$$V = \frac{1}{n} y^{2/3} S_0^{1/2}$$

So, V is again written as

$$\frac{q_0}{y} = \frac{1}{n} y^{2/3} S_0^{1/2}$$

That gives y is equal to

$$y = \left(\frac{nq}{S_0^{1/2}} \right)^{3/5}$$

By comparing this equation for turbulent flow and also for laminar flow, you can make it in a general form, that I am not doing over here, that is if the flow is turbulent that you can understand by computing the Reynolds number: if it is greater than 2000 you can make use of this formula to get the depth of overland flow y. If the Reynolds number is less than 2000, it represents the laminar flow. So, in that case the expression which is derived based on the fully developed laminar flow we can make use for finding out the depth of overland flow. So, that much about overland flow. Now, let us move on to channel flow.

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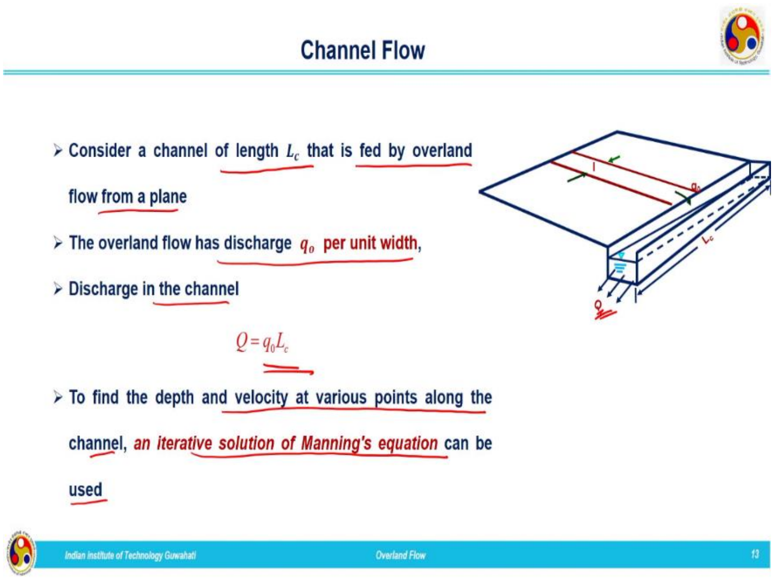

Consider a channel length L_c, L subscript c it is representing the channel length that is fed by the overland flow, that is initially itself we have understood that when an overland flow is formed, it will not be continuing for long distance. After certain time it will be separating it into small-small channels and finally, concentrating into a well-defined channel. So, here what we are assuming there is an overland flow that is contributing flow to the channel which is formed. So, that channel is having a length of L_c. So, here we are having the overland flow and within that overland flow, we have considered unit width only. So, the flow is entering into a channel, overland flow has a discharge q_0 per unit width that is discharging into a channel which is having a length given by L_c. This is the schematic representation of our channel flow and the channel is having a slope based on this slope flow is taking place and the total discharged from the channel is represented by Q.

Q is given by

$$Q = q_0 L_c$$

So, here we have considered the width as unity. In the similar way entire sheet flow is coming to the channel. That is why for getting the total discharge coming to the channel, we need to multiply discharge per unit width by the length of the channel. Here the total width of the sheet flow is the length of the channel, that is why $Q = q_0 L_c$. So, that is the outflow from the channel. That Q is given by the channel flow. To find the depth and velocity at various points along the channel, an iterative solution of Manning's equation can be used. So, here we are having a discharged q from the channel and we are assuming that it is a uniform flow. That q how it is produced? it has come from the sheet flow. So, entire sheet flow is contributed to the channel and we are considering the value of Q as small q multiplied by the width of the sheet flow that is nothing but the length of the channel. So, that Q can be assumed as uniform flow and by making use of the iterative techniques you can find out the solution to get the depth of channel flow. So that iterative technique I am not explaining over here. So that you can refer into any of the textbooks.

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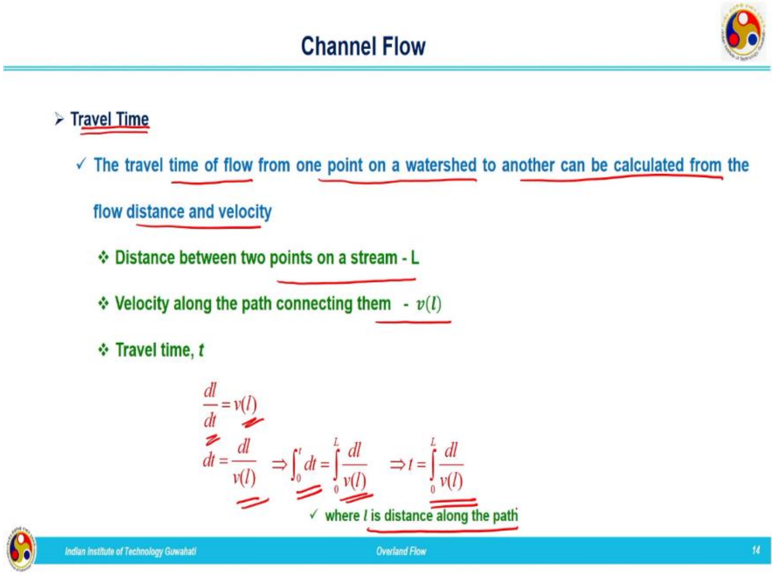

Now, coming to the travel time. How much is the time taken by the flow to travel from one point to another or when the flow will be reaching at the outlet point that is our next aim. So, travel time of flow from one point on the watershed to another can be calculated from the flow distance and velocity. That we all know if we know the distance travelled and the velocity which we have calculated from the previous expressions in the case of overland flow and also in the case of channel, we can calculate the travel time how much time the flow will be taking to travel from one point to the outlet of the watershed.

So, distance between two points on a stream be *L* and we are having the velocity along the path connecting them as *v(l)*. So, we can calculate the travel time *t* as $\frac{dl}{dt}$. $\frac{dl}{dt}$ is equal to

$$\frac{dl}{dt} = v(l)$$

We have computed and we know the length, so, then we can get

$$dt = \frac{dl}{v(l)}$$

So, *dt* is the time taken for traveling a distance of dl with a velocity of *v(l)*. So, *t* can be obtained by

$$\int_0^t dt = \int_0^L \frac{dl}{v(l)}$$

So, this can be written as

$$t = \int_{0}^{L} \frac{dl}{v(l)}$$

So, we can get the travel time, the flow has taken from one point to another if we know the distance and we know the corresponding velocity we can calculate the travel time, where l is the distance along the path.

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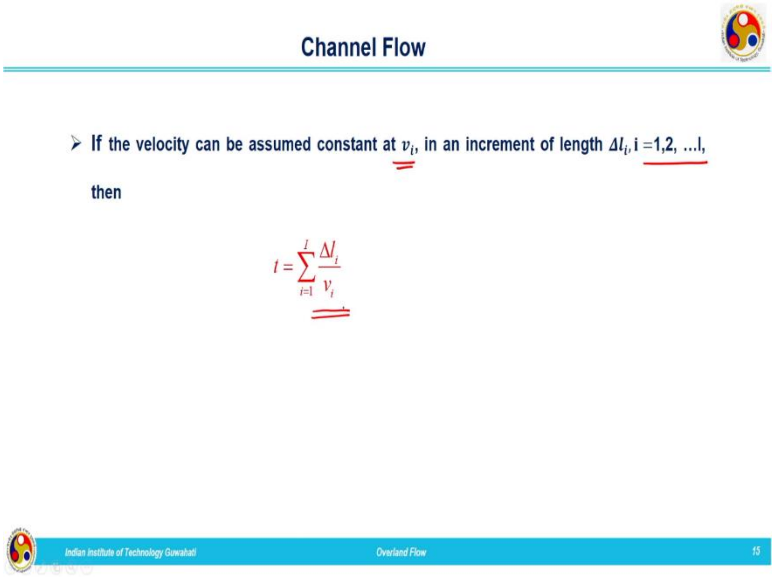

And if the velocity we are assuming constant at v_i that is we are considering different increment at the i^{th} think remain we are considering v_i as the constant velocity. In the similar way in all increments we are considering constant velocity. Calculating the time for each segment and finally total time is calculated by summing up the all the times for each increment i.e.,

$$t = \int_{i=1}^{l} \frac{\Delta l_i}{v_i}$$

So, that way we can get the total time taken by the flow to travel from a particular point to the outlet of the catchment.

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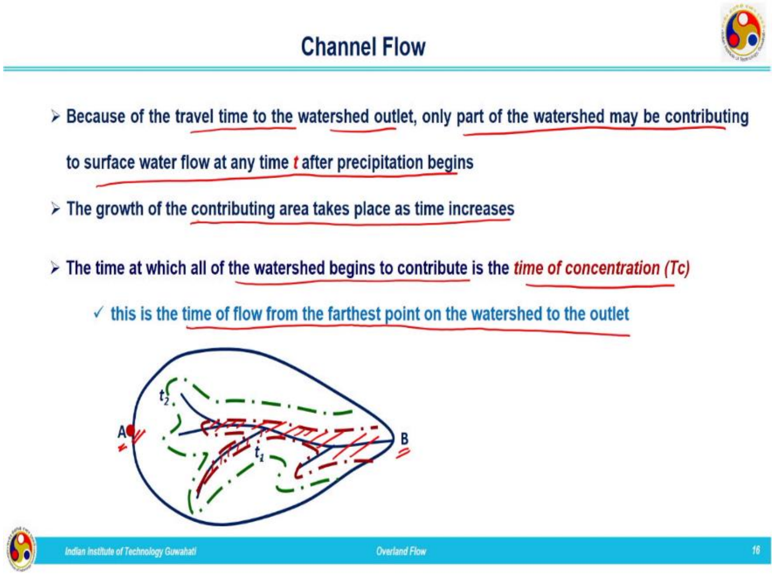

Now, because of the travel time to the watershed outlet, only part of the watershed may be contributing to surface water flow at any time once the precipitation begins. You can imagine we are getting a precipitation over the watershed, entire catchment would not be contributing flow at the outlet point initially. Extreme point will be contributing flow at the outlet point after taking some more time, more time is required for the flow to travel from the extreme point to reach the outlet point. So, initially certain part of the catchment will be contributing flow towards the outlet point.

We can have the schematic representation of that let this be a watershed and we are having the stream networks and the outlet of the watershed is represented by B and the extreme point is represented by capital A marked by this red dot. The growth of the contributing area takes place as time increases. Initially entire watershed would not be contributing water at the outlet point. The growth of the area takes place as time increases. So, initially at time t_1, this much area will be contributing water to the outlet point. Only this much area will be contributing and as time is increasing from t_1 to t_2, more area will be contributing water at the outlet point. The area contributing flow to the outlet point is marked by green dotted lines and it takes more time than that of t_2 for water to reach from this point to outlet point B, that is the remotest point to the outlet point B. So, the time at which all the watershed begins to contribute is termed as the time of concentration T_c. This time of concentration T_c is very important whenever we are talking about the flow taking place at the outlet of the watershed. So, the time of concentration is the time of flow from the farthest point on the watershed to the outlet which is the remote is point in the watershed that point will be contributing flow at the outlet of the watershed by taking a time of time of concentration.

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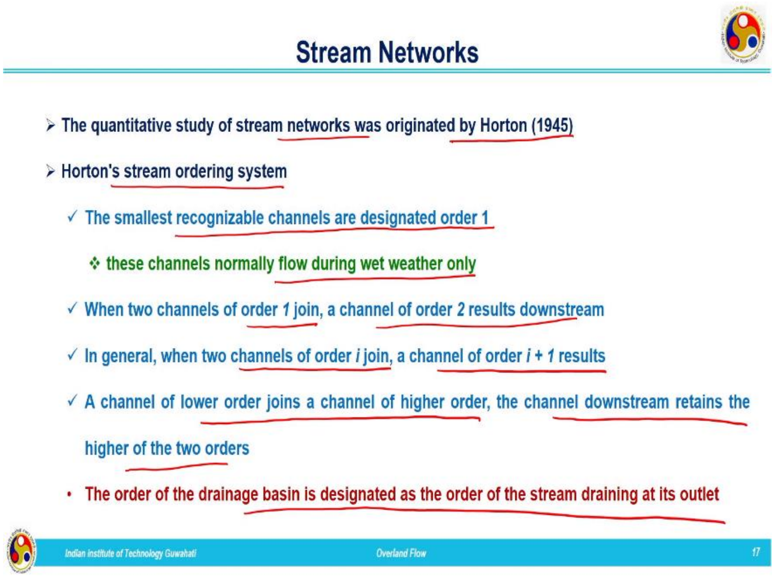

Now, we need to understand certain concepts related to stream networks. So, the quantitative study of stream network was originated by Horton in the year of 1945. It is based on Horton's theory and we need to understand the terminologies used by Horton, that is Horton stream ordering system. So, this is very important as far as watershed hydrology is concerned. So, Horton's stream ordering system includes: the smallest recognizable channel is designated as order one. So, in a watershed there will be so many channels present, smallest recognizable channel that is once the overland flow separates into channel flow small-small channels will be produced. Later on, as time elapses recognizability big channels will be produced. So, the smallest recognizable channels are designated as order one and these channels normally flow during wet weather only. Flow will be present in this channel only during the monsoon season and when two channels of order one joins, a channel of order two results. If two channels of order one joins together, we will get a channel of the order two, that is in general, if we are telling two channels of order i join, a channel of order i+1 results, that is when two channels are having order one, order one channel meeting another order one channel meeting together to form a channel which is having a stream order of two.

If we are generalizing two channels adding order i joined together then we will be getting a channel which is having a stream order i+1. A channel of lower order joins a channel of higher order, the channel downstream will be having an order of higher order. Out of the two orders highest order will be given to the channel which is formed out of these two. The order of the drainage basin is designated as the order of the stream draining at its outlet. Finally, these small-small recognizable channels will be meeting together to form a big channel and the order of the catchment or watershed is given as the order of the channel which is meeting at the outlet point of the watershed.

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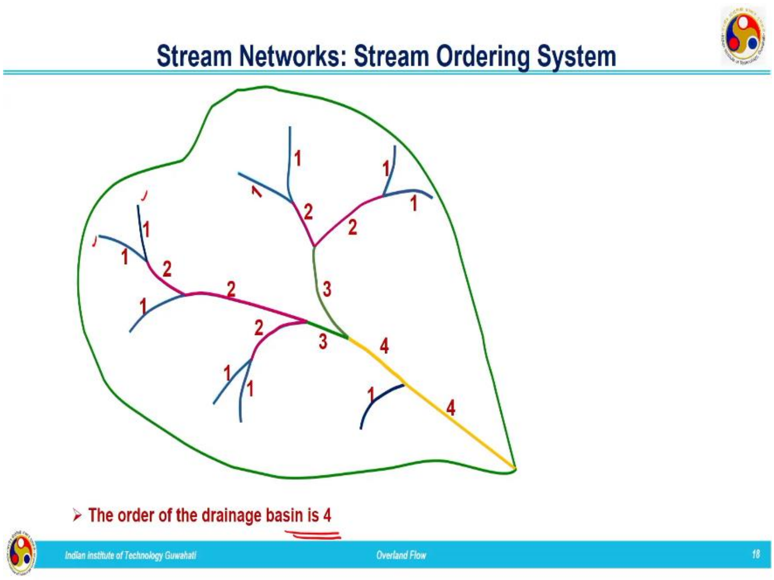

So, this can be more understood by means of a figure. Let this be a stream network in a watershed and in this we are going to do the stream ordering. So, these are the two channels which are having order 1, those two meeting together to form a channel of order 2. Then we are having another stream which is meeting this stream which is having order two, the order of this stream is one and these two streams are joining together, we are getting a new stream number that is nothing but order 2. We can continue like this. These two streams having order 1 will be joining to form a stream having ordered 2 and now we are having in the similar way there also order one order one channels join to form the channel to have stream order 2. Here also in the similar way it is formed and now, two channels which are having order two joining together to form a channel having a stream order three. In the similar way, here also we will get a channel of order 3. Now, these two channels will be joining to form a channel which is having an order 4.

Now, two channels are joining which is having order four and the other one is having one, the channel which is meeting at the outlet will be having order 4. So, stream order of this watershed is four. This way we need to order the streams. So, manually doing this will be difficult but this can be easily done in any of the GIS softwares. So, the order of this drainage basin is 4, that I think it is very clear with the help of this figure.

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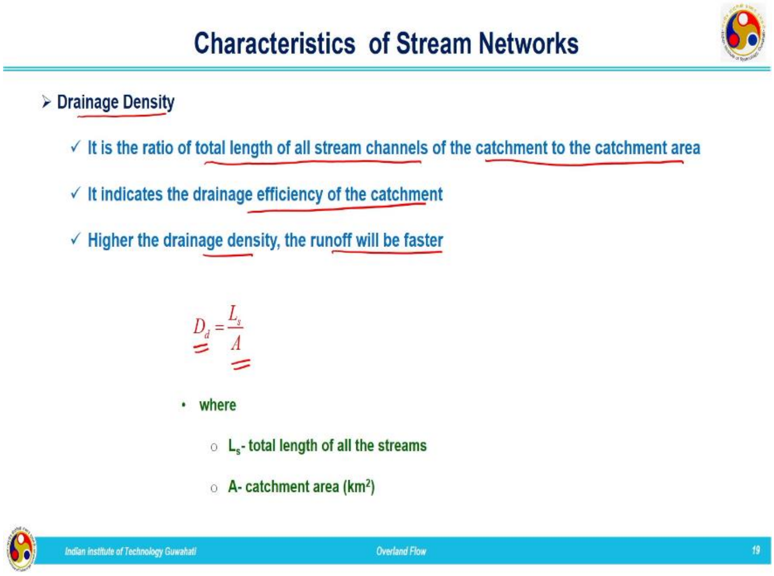

Now we need to understand the characteristics of stream networks. So, first one is the drainage density. Drainage density is nothing but the ratio of the total length of all stream channels of the catchment to the catchment area. So, it indicates the drainage efficiency of the catchment. If higher the drainage density, runoff will be faster. If you are having a watershed which is having higher drainage density, the runoff will be reaching at the outlet in a faster rate. Drainage density is represented by D_d. It is given by an expression

$$D_d = \frac{L_s}{A}$$

It is the ratio of the total length of the streams to the catchment area. L_s is the total length of all the streams and A is the catchment area in kilometres square.

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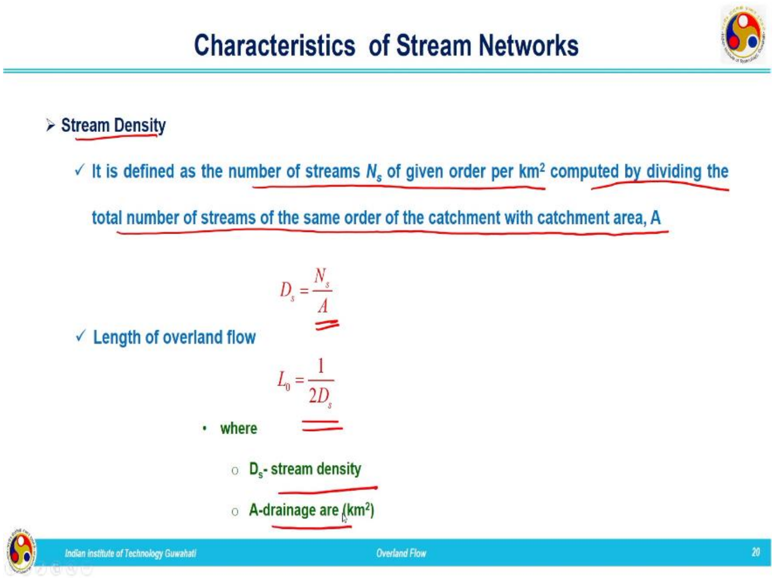

Next one is the stream density. It is defined as the number of streams N_s of a given order per kilometre square computed by dividing the total number of streams of the same order of the catchment with catchment area A. It is the number of streams divided by the area of the catchment. So, stream density D_s is given by

$$D_s = \frac{N_s}{A}$$

N_s is the total number of streams of given order and A is the area of the watershed.

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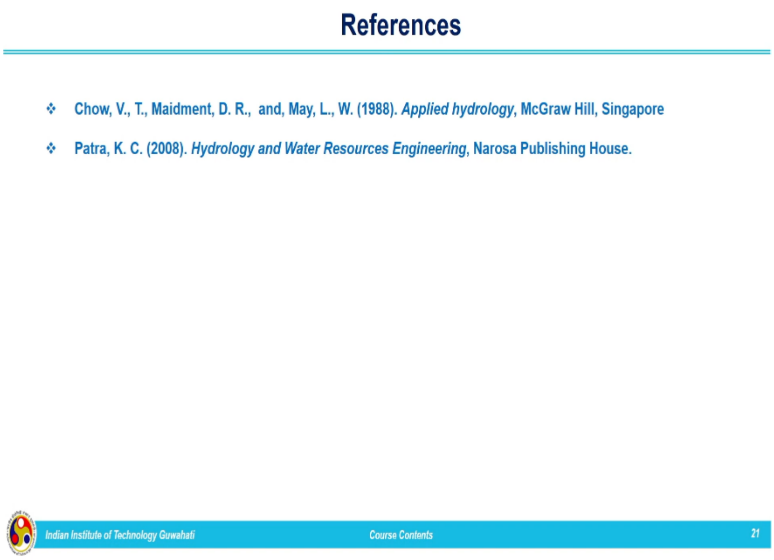

So, here I am winding up this lecture and the references related to this topic are given over here. Thank you.