River Engineering
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Lecture – 23
River Equilibrium-II

Good morning all of you today let us have a next lectures on river equilibriums in which we will talk about the next part of the river equilibriums is that will revisit regime relationship. We will talk about downstream hydraulic geometry and river meandering and also the basic concept to the advanced levels. How the river equilibrium concept has evolved with the time that is what I will today I going to present you.

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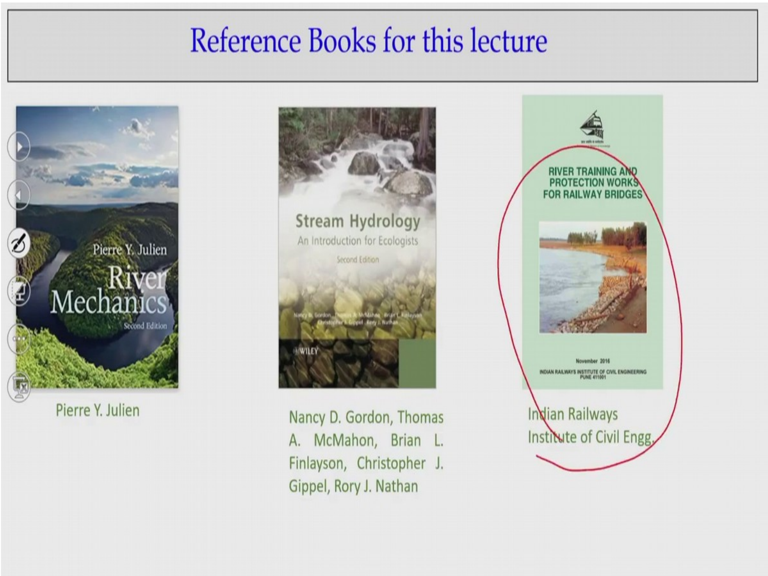

So if you look at the next part it is very interesting that I have taken a new book concept which is a river training and protections work for railway bridges by Indian railways of institute of civil engineers which is published in 2016. Probably we will have some cross reference of this book about Indian knowledge about river equilibriums, river morphology that the concept river characterization regionalizations of river characterizations.

These are the things are very detail is given in this book and I am going to follow this book as well as PY Julian books as you know it many of the study has been done for the university of many study has been done for the river Mississippi and lot of experience on the Mississippi rivers and elsewhere's. The combinations of both I am going to deliver the lectures for you.

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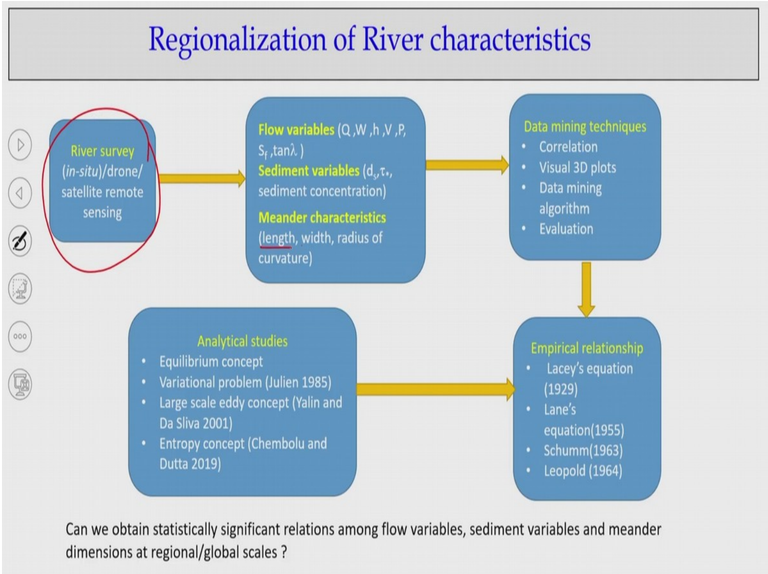

Now if you quit the concept if I liquid the river has a n number of degree of freedoms that means we can visualize the rivers as the n number of degree of freedoms in terms of flow variables in terms of sediment variables in terms of meandering channels the river bend it has the variability. So how do we do it we start doing the the river survey so we look it to the river survey which earlier used to go to the field conduct the river survey measure the velocity depth width the perimeters of discharge sometimes may be the bed shear stress, bed material movements.

All we can sediment load, the bed load but we can measure it also they use the satellite imagery to know it the bend characteristics in terms of the river bend length, meander width, the radius of curvatures and what could be the tanλ the stream line deviations in the river bend the sediment characteristics like ds the shield number sediment concentrations all either you compute direct measured directly in the river or we can estimate from other data when you have that.

So the definitely the river survey plays a major roles to find out the river the variables in terms of flow variables sediment variables and the meander variables that that is what we get it data and if you look at the in terms of degree of freedoms what are there in the flow that the discharge, width, flow, depth, velocity, perimeters, slope and also the for the river bend you can have a stream lines deviations.

For the sediment part we can have particle size distribute value shield number sedimentary concentrations the meander length width radius of curvatures. So we can get a large number of data if I do the rivers survey using go to the field collect the data or we can use a satellite imagery to estimate some of these characteristics from satellite data. Nowadays you know it it is quite easy to get the satellite data as a Google earth, Mobas or Google earth is there and many others satellite data providers are giving a free data set to characterize in the river in terms this.

Now if you look at that what did they do it the basically targeting the regionalization's can we establish the relationship between independent dependent variables. Anyway you can expect it that the independent variable like discharge, the dx and the shield numbers can be the independent more than that we do not know it so that way if you look it by just looking this data so discharge which is easy to measure it.

And you can have a ds value you can have a τ^* the shield numbers and we can try to locate whether we can establish the relations with other dependent variable like flow width, depth, the velocity, the perimeters or the sediment concentrations or we are looking at it what could be the meander plan form in terms of radius of curvature in terms of the length width whether we can have established the relationship there.

And the questions comes that can you obtain a statistically significant relationship among the flow variable, sediment variable, meander dimensions at a regional or the global scales. If I talk about the regional scale can you develop the relationship for the Ganga, Brahmaputra meghana systems. Can you develop the relationship for the Peninsula Rivers or can you develop a relationship which can hold good for at the global scales.

So all these bigger questions mark people lot of research has been going on to find out whether there is no what you generally do it there are regionalizations if I summarize that the basically it is a data mining concept. This is data mining concept people nowadays talk so much. So data mining concept you have a huge data measurement of the flow variable sediment variable the measuring characteristics at different part of the rivers different rivers at different time intervals at the equilibrium stage.

The stage where the banks are quite stable or the there is not a significant order of change is happening it. If you look at that part we can establish the relationship using the data mining concept very basic is correlations analysis visual 3d plots that a lot of data mining algorithms nowadays available and those things we can integrate it and evaluate the relationship. What it happens? What is the known empirical relationship with us? Lacey's equations we will talk about that lane’s equations 1955, 1929 Schumm 1963 all these relationship I will talk about.

Leopold relationship 1964, so these are the relationships we got it after doing a data mining of huge data what we collected from the river level at the reach levels at the different part of the world. And we try to integrate it either the regional scale or the global scale try to look it whether we can establish empirical relationship between dependent variables and the independent variables of a river systems.

If you look at that what we try to look at that this river is behaves differently there has a concept of equilibrium concept is there so it is a lane’s concept or the lacey’s equations concept will come. Variational problems also there they consider minimize the energy dissipation concept follows through the variations is the Julian 1985. The large scale eddies concept nowadays people are talking about all these forces what it happens it that due to the extreme flood events it creates a large scales eddies.

The turbulent structures what we discuss previous classes that that structure is responsible to have a formations of that. So that is the reasons there are the large scale eddy concept which is Yalin and De Sliva. Recently we also introduced an entropy concept for the river morphology which you can follow it and some of the papers also we will discuss in the next class that how we are we have brought it a concept of entropy into the river morphology analysis that what we will discuss it.

But if you look it as look at as a summary what we are understanding that we need to have a river survey we should have a quality river survey data that is what is matter to us if data is not a having a quality data we can land up with empirical equations which are not statistically significant. We should identify the variables flow variables, sediment variables, mandarin characteristics and much more we can look it.

Recently there are a lot of data mining algorithms are there and the correlations visual 3 dimensional plots which are there nowadays any spread sheets Microsoft spreadsheet and you can establish the empirical relationship what we got in almost 70 years back those things we can look it but there are new concepts which is are coming it starting from equilibrium to entropy. That is the basic idea when you do a empirically relationship.

So try to understand it the empirical relationship of a river systems talks about the river behaviors which we do not understand at the particular time scale or the spatial scale that the idea is if it is there is a empirical equations. Let us I repeat it lacey's equations again I want to revise this lacey’s equations for you to because this is the equations we so frequently we have been using it river protections work.

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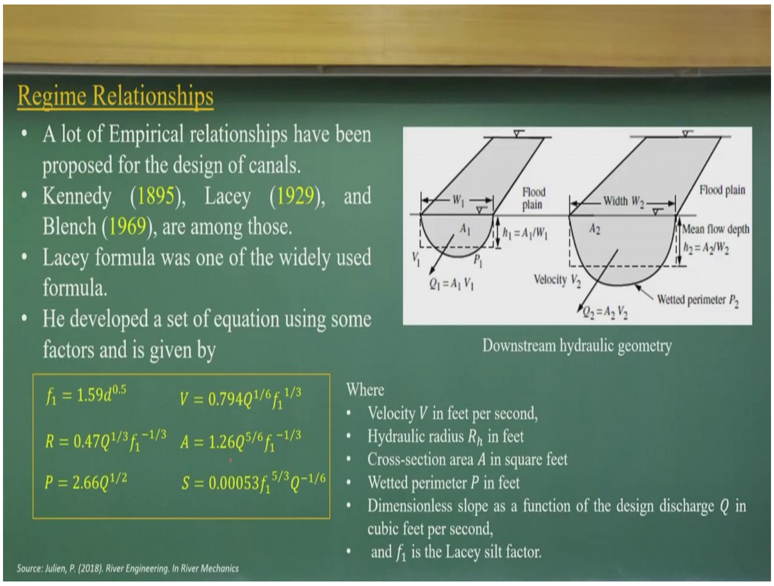

So lacey’s equations if you look at that it identified the basically the velocities area the hydraulic radius and the P which are dependent variables is a functions of discharge and silt factors. The silt factor is a function of particle size d50 value functions of particle size distribution. So this is a silt factors and these are all conducting a series of experimental data from the canals in Indian subcontinent undivided Indian subcontinent.

So if you look at that if you look at this lacey’s formulates what you widely use it it has still has a strength like manning’s equations it has represent the lumped response of a equilibrium reach of the river or the straight reach of the rivers where the dependent variables like the velocity, hydraulic radius, area, perimeter and the slope is a functional of Q and f 1. Q is discharged f 1 is the silt factor it is just a data mining concept.

The equation has not come up just like that they have done thorough analysis of the data using way back in 1929's okay we did not have a much computer that times. But is that data analysis concept the same concept we are using it with super computers now but there is a data analysis concept where it has established the relationship between dependent variables and the independent variables.

Independent variables here define is about the sediment transport the d50 values and the discharge the Q representations and that what you have the velocities hydraulic radius, area and the parameters. So just you look it, the velocities depends upon for equilibrium channels is a Q as a power relationship with 1/6 and there is a factors f 1 factors are there which is 1/3. Same way if you look at that hydraulic radius has this coefficients.

If you look at this most of the coefficients are simplified in terms of 1/6, 1/3, 5/3 or 1/2 that is basically the perimeters representing $Q^{½}$ it is too easy to remember it the p is equal to $2.66Q^{1/2}$ its very easy. If you look at this equations what we rewrite it the P is equal to the perimeters is equal to wetted perimeters is equal to 2.66 times of this square root of this discharge.

So that means it is just depends upon the flow. So the perimeter of the river wetted perimeter of f equilibrium channels it depends upon your only the discharge value only the discharge value. So if you look at that and that what is a power of 1/2.5 square root of this. If this very wide river the P will be close to the width of the rivers so that means for a wide river like a Brahmaputra or Ganges the width is a just a functions of the discharge that is all.

It does not depend upon the particle size. So how can it happen it but it is the relationship after doing the data mining. We do know it because these are the data the canal level data is collected from the field levels then done the statistical analysis like the meanderings equation the Lacey’s equation has a lot of strength. And if you look at that part the same way for the velocity, the hydraulic radius will be for a wide river it will be close to the flow depth.

So that means the flow depth has a function of Q and f and this having functions of Q 1 by 3 and f 1 -1 by 3. See if you try to understand it how these functions has come up and these are data mining after doing it so called todays we talk about data mining concept similar way they collected data they did the outlier analysis they did visually all these equation fitting and then they try to bring it the relationship which might have taken few years to bring this equation it is not a few days like what we have now computing facilities with Microsoft excel spreadsheet or any statistical tools.

There was no tools no computers but how they derive this concept through the data mining collecting relevant data, conducting all these things and this is still holds good still in India we can see the regional equations it is quite valid for the Ganges, the Brahmaputra alluvial systems we use this equations as it being develop for a regional scale. Let we will discuss much more about this when you go for next levels of regional equations.

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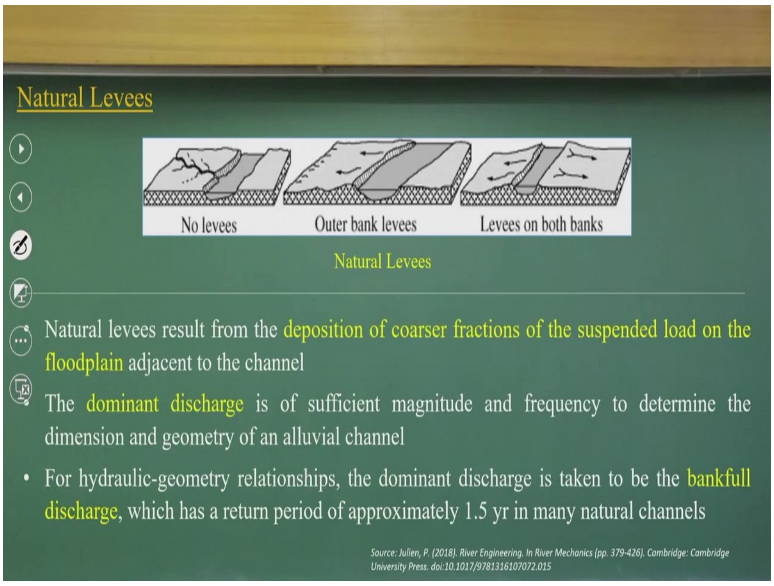

Now if you look at the next part when how you define it in the bank full discharge. If you look at that you can have rivers like this where you have the plodding and that bank is not at all having any levees. But there will be the conditions that levee you within both the banks because the water will flow it during the floods both the banks. If it does not flow those both the banks then you will have outer bank levees or if I have a levees on the both the banks.

This is a natural levee natural levees processes are there no levees natural levees forces in the both the banks and the outer bank levees. So if these the conditions now we have to look at what is the bank full discharge, the lateral levees resulted from depositions of course of the suspended loads on the floodplain adjacent to the channels that is what it happens it when extreme flood events comes the flood of 2 years, 5 years return period now most of the water goes to the flood plain area.

As it goes to the flood plain area thus also it goes with the sediment loads and that sediment start the depositing. And because of that depositions it creates a natural embankment that is what is called natural levees it could be a both on the bank or outer bank or there are no levees for that matter. Now if you look at that we also call about dominate discharge because the single discharge may not represent it.

That it depends upon sufficient magnitudes and frequency to determine the dimension geometry of alluvial channels just trying to repeat it. The dominant discharge is that the sufficient magnitudes and frequency the occurrence to determine the dimension and geometry of alluvial channels in this lecture. So we are not going more detail about dominate this chats but the hydraulic geometry relationship the dominant discharge can do bank full discharge which is having a return periods about 1.5 years that is what is there.

So that means the bank full discharge by conducting a thorough analysis is found to be a 1.5 return period flood discharge what does it indicate? It indicates is that if it is a bank full discharge this happens in the return period of 1.5 years that every 2 years we are supposed to be in a natural rivers we should have flood in the floodplain. Every 2 years intervals you should have that is nature of the flow.

We should have the floods on the flood plains so when you do the embankments you try to understand what we have been doing it because when confining the rivers. And as we confined the rivers you know that how the sediments happen but naturally the river creates its flood plains and flood plain inundations it happens at a rate of a 2 year return periods that means every 2 years if we are living in the flood plain if a river as it in natural conditions.

We should expect 1 flood event. So if you look at that that is what the natural conditions but as we modify the condition that is what we should try to understand what we are doing it. But naturally what it shows that the bank will discharge is equal to 1.5 return period flows that means 2 year return period flow, flood in a rivers it is supposed to inundate the flood plain area supposed to inundate the flood plain area 3 years 5 years and 20 years no doubt it will indicate a larger area.

So this concept can help us to understand how things are happening it at the rivers scales and that is what is a regionalization idea that it has a return period of 1.5 years but no doubt we should do regional studies to find out whether it is a 1.5 years or 2 years for Brahmaputra river or Ganges or the peninsula rivers those research studies to be done it to look at what is happening it whether it is 1.5 year return period that is for us.

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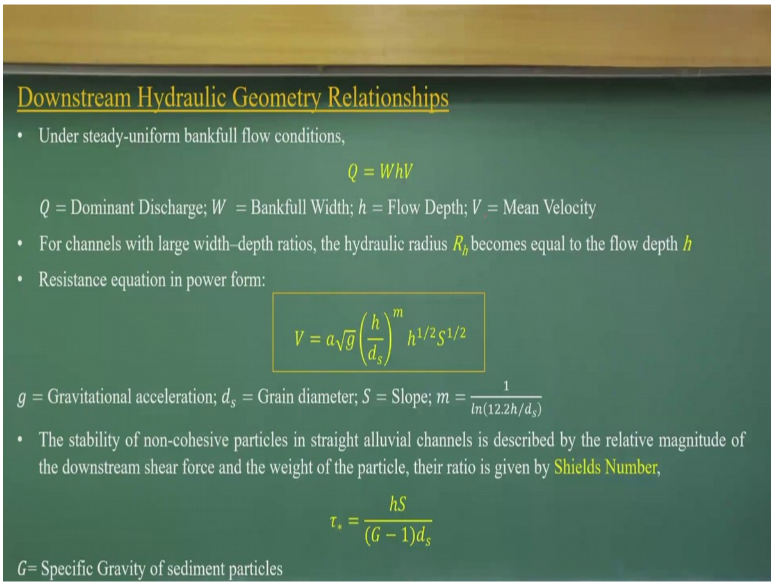

Now if you look it if I go for next levels we try to look at the relationship the basic relationship again we look at a simple continuity equations and the flow resistance equations. If you look at this simple continuity equations which is a discharge is area into the velocity here the W is a width W is width of the river and h stands for a flow depth V is the velocity then you will have the discharge due to W h P.

So area into velocity but if you look at the flow resistance equations which takes care of all the near boundary nearbed turbulent structures and all we can establish a relationship with a velocity with h by d s so that means d s indicating for us if it is a river bed these are the river bed it is the flow depth and d s is the particle size if you look at the stones or boulders are there for hilly rivers. You are looking a submerged relative submergence h by dx to the power exponent of m which also depend upon h by d s.

It depends upon the relationship between this with the whether it is the submerged how what is that it is h is much, much larger than d s this values will be the larger value is a less you will have these things. Just you look at the relative submergences value indicating first. Then you have the slope you have a flow depth then you have the coefficients indicating for us the resistance flow.

So we have a continuity equations we have the assuming the velocities going on as a flow resistance equations you can have this c and this power exponent m is depends upon relative submergence. Banks are the non cohesive materials which is too easy to have a simplifications no alluvial rivers is full of the sand, it is a mixture of silt clay and compositions of that.

But if you are considered a non cohesive materials as we discussed earlier we can define a shield numbers which are functions of 2 components 1 is the downstream shear force and weight of the fluid sediment particles that is what is the shield numbers or shield shear stress we talk about that is what we discussed earlier.

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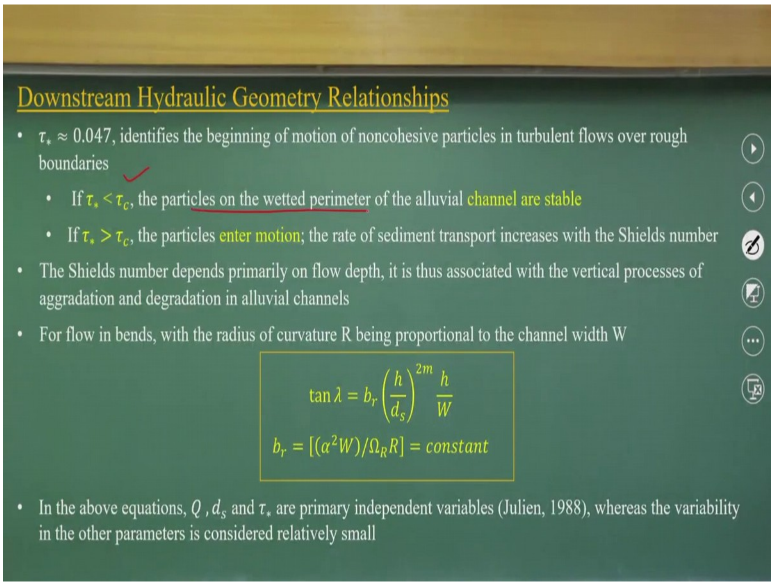

Now we try to have a relationship that is what is look at that you know wait these things the particles on the wetted perimeters of algebra channels if you see that if τ* is less than critical shear stress if it is more than that then you will have a have motions it will start entering the motions and the rate of sediment transport increase with the shield numbers. The shield number primarily depends upon the flow depth.

Because d s does not change it the g does not change it so specific gravity does not change it only this h and s value so that is the reasons it is primarily depends upon the flow depth and vertical process of the aggregation degradations in alluvial channels. But if you flow in a bends as we discussed earlier there will be centrifugal forces there will be stream line deviations upper stream line deviations will be there.

And those things if you would relate the relationship you will get it again h/d_s somewhat relative submerged depth h/W, W is a width h is the flow depth. So that ratio and it has a depending upon the br ratio which is a constant for us. So if you look at that how the flow variables are coming. So if you look at all these things the dependent variables primary dependent variable is considered is discharge d s representing of the bed settlements and the τ* the shield numbers indicating that a ratio between the 2 forces.

One is a shear forces by the weight of the sediment particles. So these 3 consider as independent variables and others we are talking about and the Julian 1988 establishes that variability of other parameters relatively small that is the they are data analysis and data their data mining concept what they got it these are the 3 are primary independent variable for all them to establish relations with the dependent variables.

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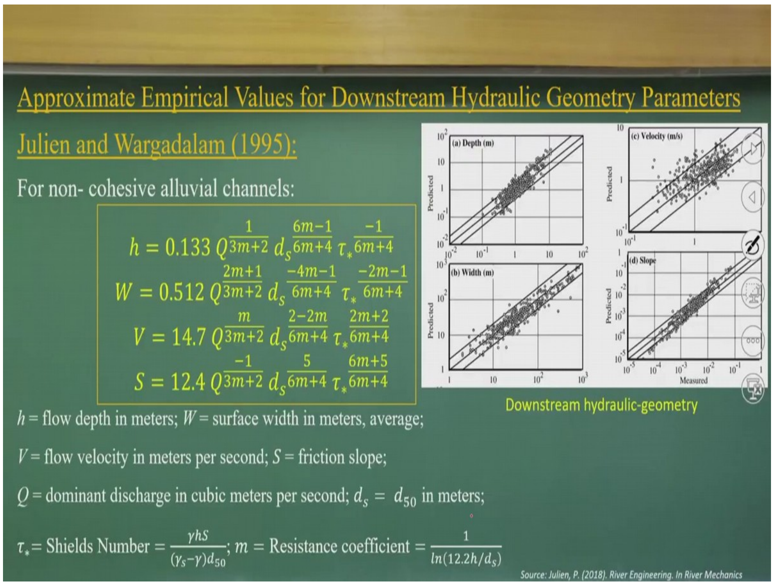

Now if you look at the next part it is a quite interesting which is given by Julian and Wargadalam1995 the relationship between flow depth, width, the velocity and slope is a functions of now it is a higher versions than the lacey's equations is a functions of Q d_s τ*, Q d_s and τ* it is a functions and the power exponent is depend upon the m value. So m is a resistance coefficient which also have a relationship with relative submergence depth.

So as compared to the lacey equations now we are going more details which is now not only depends upon only the Q and d s it depends upon the shield numbers it also depends upon your power x point like in earlier case we have a width is equal to 2.66 Q into half. So width of the river wave but in this case the width of the rivers has a (2m + 1), (3m + 2) plus there is a functions of dx and τ^*.

As we do a data mining advance data mining concept we suppose refine the equations we get it more independent parameters as compared to the lacey's equations. So if you look at that we have this part which is are indicating for us and s is a friction slope what we have or the energy gradient. And the flow velocity Q is a dominant discharge in cumecs, d s is a d50 in meters and shield numbers τ^* and the resistance that it is.

So what they did it they established these equations then they have a relationship between measure and predicted. So that is the reasons when you develop the original scale things you need to have a huge data set that is what is the statistical analysis. If you look it this is a measured one versus predict for the flow width. So if it is follow in a 1 is to 1 line it is a perfect but it does not happen for a river database is predictions and the measures should not have a 1 is to 1.

Because that is the natural variability is there but their equations is perfect and that is what is they have the prediction and the width in meters with from 1 meter to 1000 meters it is 1 meter river width to go to 1000 meters still you can have a relationship of width in terms of discharge d s and τ^* and it can follow these functions and it also showing this statistical significance band.

The same way flow depth which varies from 10^{-2} to 10^{2} whenever you see the data in a river case please try to interfere then you can have a interesting knowledge about the rivers these are rivers speaks out the truth through this data. So we should interpret the data more extensively look at the range. The major is at 10^{-2} which is a centimeter a level goes to the 100 millimeter and most of the rivers are in this range.

Most of the rivers are up to 10 meters or the 12 meters not more than that and that data set it is false is here and which is a predicted range and that is the presence. So with this the a way Julian Wargadalam relationship in terms of flow depth, width and velocity and friction slope we can; the velocity has a much more variability's which is a meter per second it goes up to 10 m/s that is what is maximum velocity can happen it ok.

This is a 1 meter per second and it can have a 4 meter, 5 meter per second. So that is what I I said it earlier the maximum velocity you can design for a reward training works we look interpreting this data we can consider from this data as its measure you can have a roughly 5 meter for seconds. Because we design for a stream because many of the times in a rivers system we do not have the data and we cannot wait for another 30 years to collect the data measure the velocity.

But we can have interpret the knowledge about the rivers from elsewhere as a regional studies like as its indicating here the river velocity which we need it many of the times it can go as high its 5 meter per second or 7 meter per second not more than that as the data recording is so great because we look for maximum. And similar way the flow depth also in this and if you look at that way the slope also if you look at the predicted and these things which is more statically significant band its follow it as compared to velocity.

So it all says that how much of uncertainty is there from the scatter plot when you try to establish this relationship the original relationship in terms of flow depth, width, velocity, energy slope with respect to Q d_s and τ^* and these are the data is collected at the river levels at the field levels and with their comparisons with a major and predicts. So does that how good the relationship if you look in these things you can say that the velocity can have a lot of uncertainty in measurements and the predictors.

If you look at this equation as well as the measurement squared but in terms of depth and width and the slope we can have a not much that significant order of uncertainty is involved.

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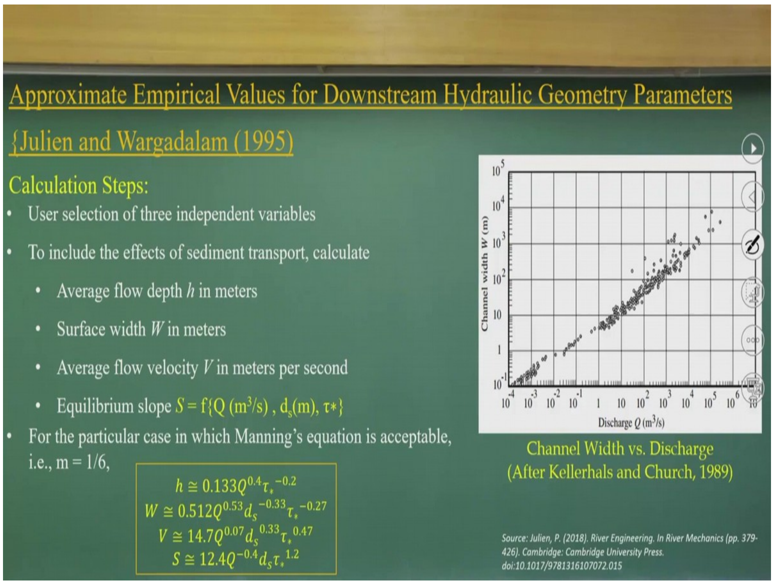

Now if you look it other very interesting things are there if you look at this channel width this is very interesting figures if I plot it this discharge versus channel width which varies meter 10^{-1} its almost a centimeter levels the width can go to 10^5 that means almost a 10 kilometer width like Brahmaputra rivers 10 kilometer width and it can have a one kilometers and it can go to the 10 kilometers width.

So if you look at that part what is indicating your discharge if you look at that just look at the distance 10^4 so that means discharge can go up to 10000 cumecs this is very good in relationship and we can interpret a lot of things these are the data at the river compiled all over the world plotting between channel width and the discharge. So if you look at that if the width of the river is 1 kilometers it can go as high as 10000 cumecs which is normal for Brahmaputra rivers.

And if a width is increasing it up to 10 kilometers the discharge can go as a level of 10 times that means 0.1 millions or 1 lakh cumecs that is the strength of the Brahmaputra rivers as we can see the width of the rivers. And you just see the width of the rivers and we can know it approachment range of the discharge because these are the data is plotted for original river.

So if I have a 10 meter width you can say that you can have a n log scale with the 10 meter cube per second. So these are very interesting data which is compiled in 1983 by Kellerhals and Church for a rivers specialist the width of the river we can measure from satellite data and we can know it what could be the average discharge is flowing through that is this plot we can use it to know it estimated discharge ranges that is what is a scale as I intentionally representing you try to interpret this date the discharge versus the channel width.

As its width varies from centimeters to go to 10 kilometers or 100 kilometers which is not possible so maximum range is 10 kilometers more than lesser than that and you have a discharge with the 10^5 cumecs 1 lakh meter cube per second so Brahmaputra discharge is 72000 meter cube maximum highest 100 year return periodic time is much larger than that.

So if you look at that this data across the global level it indicates for us to interpret the knowledge the relationship between channel width and the discharge. That is what if you look at that the average flow depth is h in meter surface width W and if you have average velocity v equilibrium slope if I establish is a functions of Q d_s τ^* and if you use the m equal to 1/6 using this manning's equations.

These equations again you can modify it you will get a relationship approximate relationship between flow depth width velocity and the energy slopes and the energy slope which is a functions of that. But just tend to have a representing you that if you look at that the lacey's equations talk about the width is a functions of a constant and functions of 1/2 that is power function of 0.5 the same thing here is a 0.53 no doubt.

We improve the equations but more or less the power exponent of this relationship it remains more or less the same that is the things you can try to understand it with the different things. So in time we are evolving regional river relationship but more or less the power experts are within the ranges that is what is the lacey's equations is 0.5 and where is the Julian equations is 0.53 is not significant difference. But there is a τ^* and d_s is there which may have a slight bit difference is there.

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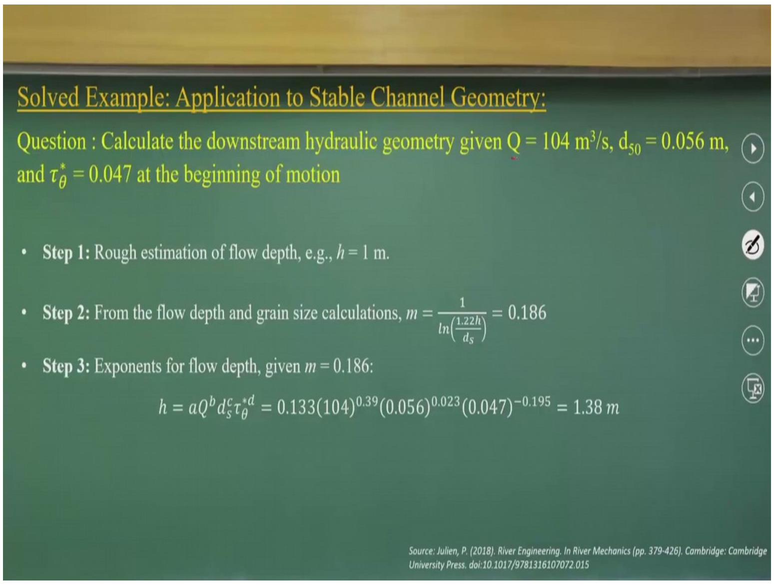

Now if you look at the next level to interpreted it or many of the times we if you know the discharge and d50 value and we know the shield numbers at beginning of the motions can we compute the downstream hydraulic geometry. That means we need to compute depth, width, the perimeters and the velocity and the slope. This side is known d50 is known to us the problem is here m is a function of dx and the h m is a functions of relative submergence depth which is a function of h/dx.

So that is the reasons we will assume a flow depth compute the m value then again you recheck it whatever the h values are coming are the same. In this case we first resume the h equal to 1 meters compute the memory values then you put the regional equations of that m value compute the h. So we found it the assumed values is 1 meter which is assume it but estimated this that means there is a lot of difference.

So we again hit and trial methods we change the h value compute m value again you compute the h from the regional equations whether that 2 difference are there or not there. If not there then you can assume that h value that is we do it. So if you do it this repeatedly calculations of these still it converts the h equal to 1.49 m equal to 0.17 and which is give h equal to 1.51 the difference is not much difference.

If that is the conditions we can fix up that and then we can compute m equal to 0.172 flow depth width velocity and the slope what we get it using this empirical equation. So this is what we can use it from d50 values and all to compute is the flow width the velocity and the energy slope gradients that is for this high downstream of hydraulic geometry.

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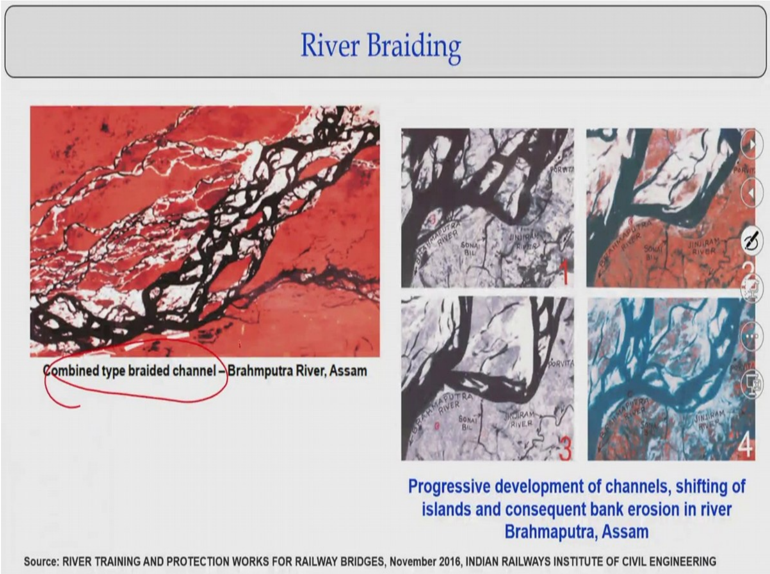

Now if you look at very interesting part graphs which is we many other times we just you to show it the rivers 1 of the river where everything changes very fast river plan or river geometry, sediment transports these are too dynamic you can see this combined type of braided channels. Nowadays is not a difficult any satellite imagery is Google earth imagery is you can see it how dynamic is from the rivers in terms of series of channels.

In terms of series of channels what we have it makes us is the very interesting part the how the channels are changing it, still you have a challenging task to understand this rivers in a sand bed braided river systems in the wold this is a typical rivers and if you look it, how this progressive development of channels if you look at that part really it is indicating for us just try to interpret these figures.

You just check it these are the channels there is a channels and there is a island formations next what you look at the channel is here there are lot of sand depositions the islands are not there then further you come it these two channels are activated there are island again forming in between that. And you go for this again this is again channel formations all these things are happening again island formations are happening.

If you look at this time history lines of timelines of river Brahmaputra plan forms which is too dynamic and that is what is makes us to understand the spreader rivers whether does it follow any science or does it follow any energy dissipations concept all these are big questions. So the basic idea is like if you look at that how the river has a dynamicness and how this cut off the island, consequent the bank erosion process which is happens so dynamically in Brahmaputra rivers if you can look it. These are quite interesting and quite challenging for us.

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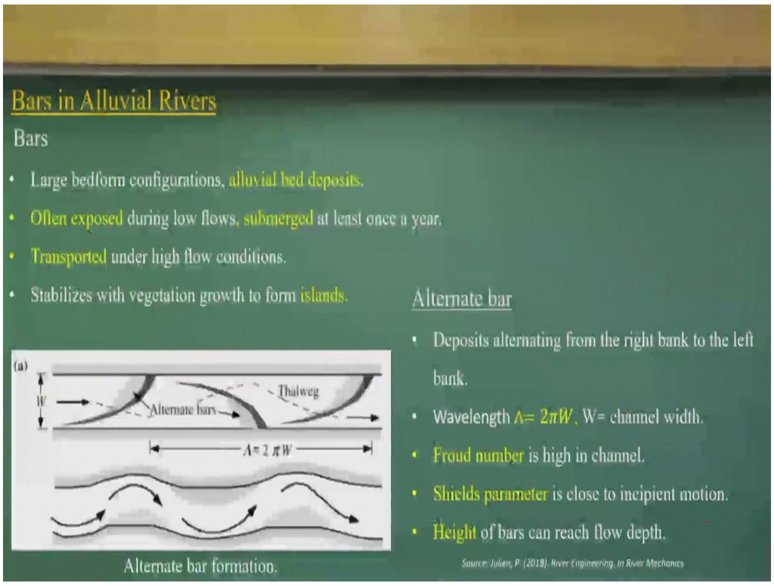

Now if you look at how does formations happens as a bars in alluvial rivers. If you look at that the bars generally a large bed form configurations in a level bed deposits. So if you look at that if have this channels if you look at these figures the channels will not have a straight there will be a meanders. Because of these meanders you will have a bar formations these are called point bars alternative point bars.

And this is the Thalweg line the defaced channels this is the thalweg line and you can have a alternate bar formations will be there and these bar transformations can have a wavelength can have a wavelength which is a 2 pi times of channel width closely 7 times or 3.6 times of width. You just try to understand it the formations of alternative bars with a 2 time of phi of W or we can say it as close to the sixth time of W do not go to too precise.

So 6 times of width of channels you can see this the length from this to this points if you look at that length formations of this wavelength formations of alternating bar which is a as close to the 6 times of width of the; So that is what is accelerating part. So if you look at that there will be high flow conditions that will be transport the stabilized with the vegetation grow from the islands as I saw the photograph of Brahmaputra rivers it it is a Froud numbers which is high in these channels.

And the shield parameter is a close to incident motions the height of the bar can reach to the flow depth. So height of bar can actually expose into the higher levels that is the conditions can happen it.

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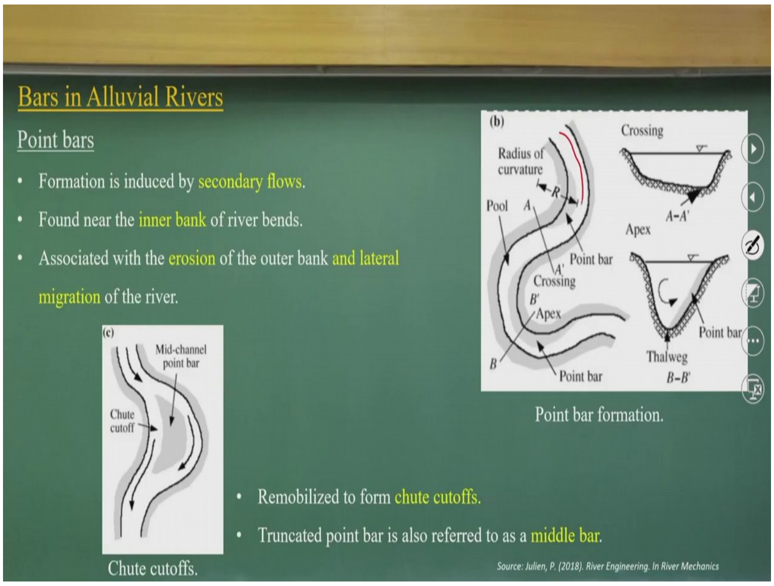

Now if you look it next 1 very interesting if you look at this point bar formations again I need to tell you to just case the figures to understand the river mechanics is that if I have a river you will have a point wire formations point bar formations will be there. There will be pool there will be the point bar formations river crossings point will be there. And if you take a cross section at a dash which is just crossovers you can have a as close to the parabolic set.

But when you have a near the thalweg line near this point bar you can see the depositions you can have a secondary current and you can have a defaced service. So as we discussed earlier so you can see that lot of sedimentary deposits happens it the formation induced by the secondary current. That is what we try to show in many times how the secondary current formations are play the major rules.

Inner bank will have this point bars is found in the inner banks associated with the erosions of outer bank and lateral migrations of the rivers. So river also have a lateral migrations and if you look at this part it also go for a cut off, it will have a cut off. So then this island becomes the mid bar island meet channel point bars and then you can have the cut off's. The cut off chute of will you credit and truncated the point bar also referred there is a middle bar.

So we can have these conditions and just case the figures of the rivers plan forms and try to understand it how the secondary currents are happening how the plan forms are happening how the Thalweg line shifting are happening and the cross section that is we should understand it looking the river plan form.

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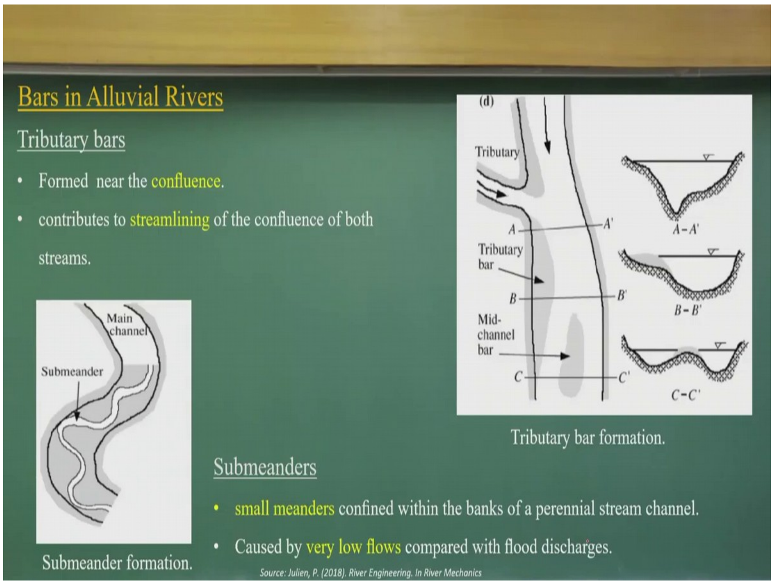

Now if you look it many of the times we have the river and the tributaries are joining it so we can have the depositions which is called the tributary bar formations. Like for example if you look at these cases ok 2 rivers are joining it and if you draw the stream lines and all the flow will come like this flow will become like this. So there will be a erosions the depositions also deter.

So because of this joining the 2 alluvial rivers both are feeding the sediments to this reach and there are the Thalweg line the shifting of the channels and because of that there will be a erosions and the depositions and there will be a tributary mouth depositions will happen it also the tributaries once will be there and because of so much erosions depositions happens it it will also create a mid channel bar.

If I take a cross sections if I just take a cross sections if you look at that a dash bb dash and c c dash the 3 cross sections. If I look at that the shape of the a is coming like this so there is a phthalate line bb dash there is a depositions tributary bar formations then these at the cc dash you can see that mid channel depositions are having it so 2 channel formations are there. So the tributaries we can have a sometime middle channel bar formations.

So the tributary junctions can have these conditions. So we should try to understand how the flow sediments the erosions are depositions are aftering it at the 2 confluencing with the river and the tributary in alluvial zone. Not only that; if you look at that this is a confluencing and streamlining of confluences of both the streams. And if you look at the like a Brahmaputra rivers also in the top we see it is not a 1 channels it has a lot of sub meanderings there within the menders there is a meander.

So you can see the river in the top but at the bottom levels there are the sub-meanders are happening which if you do not have a cross section data analysis properly you cannot find it there are smaller meanders are wrapped in it. So it is quite interesting and quite to look at research study that how does it happen it the meanders and the sub menders and those sub meanders how the morphologically they are active.

Whether these sub meanders also accelerates the bank erosion process. Does it the sub meanders play a role for morphology all the big questions still we do not have answer for that because there is not much study has been done it for and these sub meanders are visible in Brahmaputra river in many parts of the rivers stretches that is the reasons it says still it is a complex rivers morphologically to try to understand it.

How the compositions of meander sub meanders the braiding are happening in this complex river.

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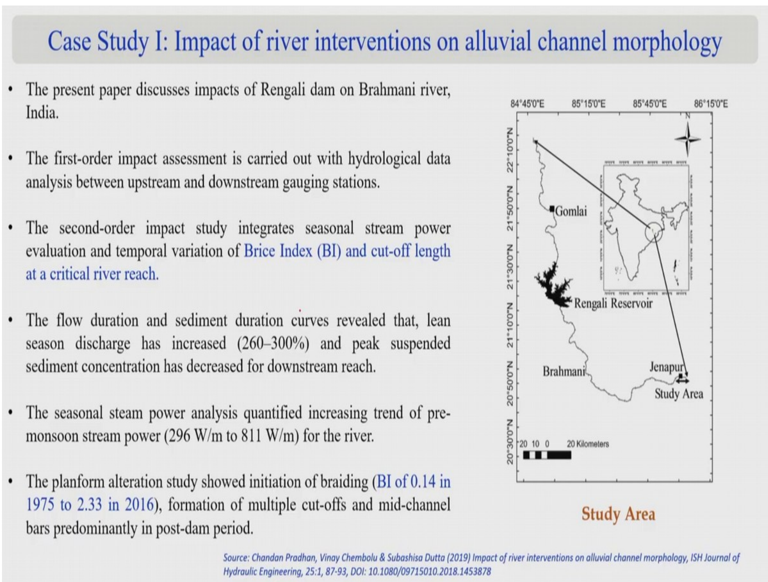

Before leaving these lectures today let me talk about the case study 1 with impact of the river interventions of alluvial channel morphology. So we conducted a study and we published in ISH journal of hydraulic engineering in the last years. We try to look it what is the impact of Rengali dam the dam structures on the Brahmani river morphology. We try to locate first order analysis to do between upstream and downstream gauging stations.

Second order analysis which looks at these seasonal steam powers evaluations with the temporal variations of Brice index and the cut off length of a critical river reach. What we found is that if I do these flow durations and sediment durations curve analysis the lean season discharge has increased 300 times because of this Rengali dam the lean flow discharge has increasing trend that is almost say 300 times.

The peak suspended load sediment concentration has decreased at the downstream rates which expected because its reservoirs are there. So because of the reservoir the peak sediment, sediment concentration has decreased the downstream rates. The sediment decreases the seasonal flow, flow is increasing trend. The flow is increasing trend where it so you can have these things.

And what is it with that the seasonal steam power analysis increasing trend of pre monsoon stream 256 or 300 watt per meters to 800 watt per meters. So energy dissipation has increased pre monsoon steam powers. The plan forms alternation study shows that there is a braiding initiations which is earlier its breeding index is 0.14 in 1975 it has gone to 2.33 in 2.201 so in almost 40 years.

After the 40 years the braiding index which is indicating the brice index which are indicating for us how much a river is braiding it that is what it happens a little is not a braided rivers and it is going towards the braiding after the 40 years implementing this dam. And there is a cut off mid channel bar predominantly post dam periods. These are where summarizing these things if you are interested you can refer to this paper.

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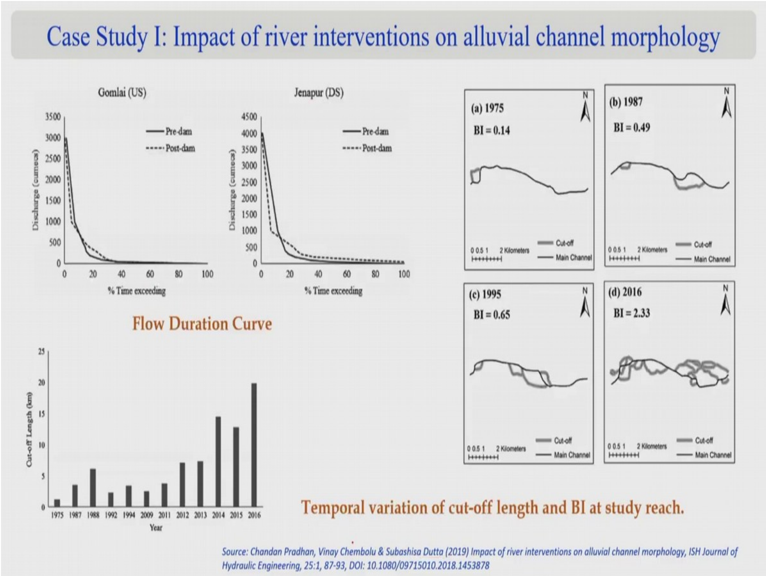

Next part how this is the upstream, the sediment discharge and all not change much but there is a downstream if you look at the discharge and the flow distribution curve has changed it not only that it has significantly increased the brice index 0.14 to 2.3 and you can visually look it how braided channel formations happened. And if you look at the cut off length which is increasing still like this so that is the curve.

So river meanders to its going to the braiding forms. So we should try to understand it faster or second order analysis because of the dam structures what we are creating it. We have done some interventions and that in one intervention how the river is responding that is the questions we always should ask it and we should monitor the river at the different levels.

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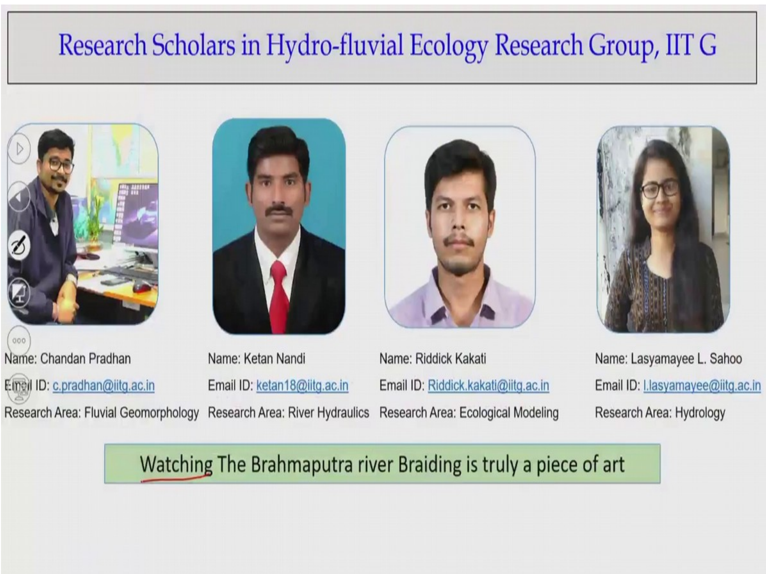

Just let me conclude this lectures talking about that the watching the Brahmaputra river braiding is a truly a piece of art which we partly understood partly not understood, thank you very much for this lectures.