Course Name: Watershed Hydrology

Professor Name: Prof. Rajendra Singh

Department Name: Agricultural and Food Engineering

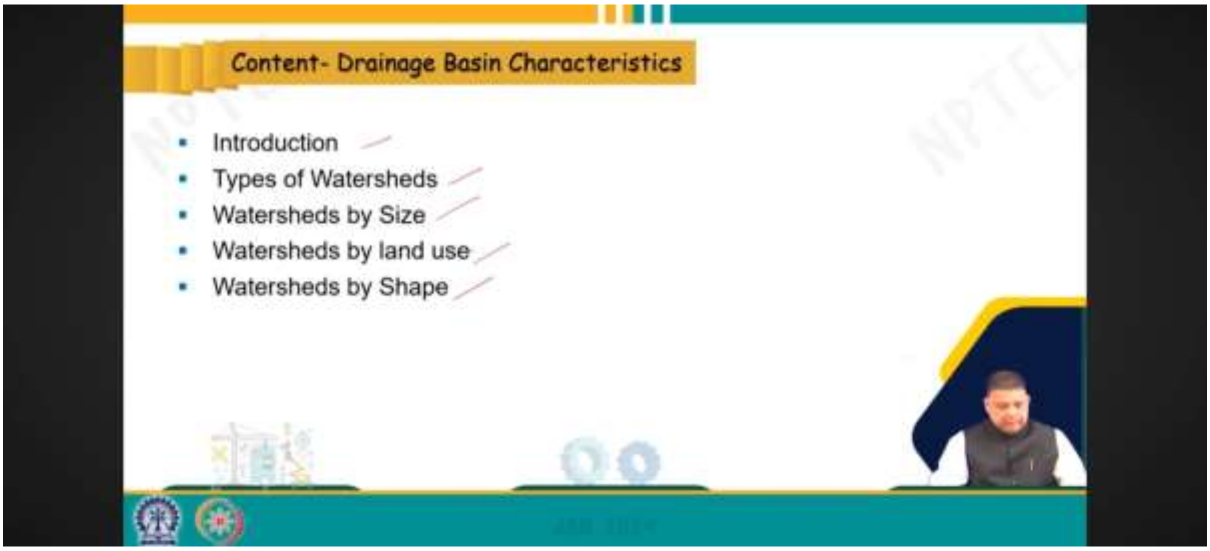
Institute Name: Indian Institute of Technology Kharagpur

Week: 07

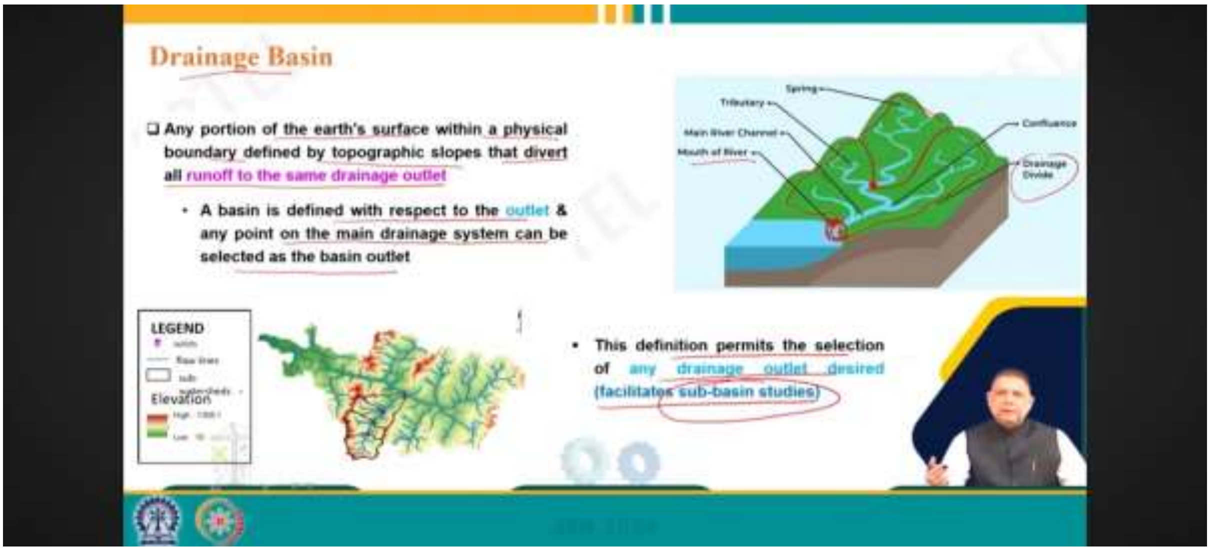
Lecture 31: Drainage Basin Characteristics

Hello friends, welcome back to this online certification course on Watershed Hydrologic Technology. I am Rajendra Singh, a professor in the Department of Agriculture and Food Engineering at the Indian Institute of Technology Kharagpur. Today, we are beginning Module 7 with Lecture 1, focusing on Drainage Basin Characteristics.

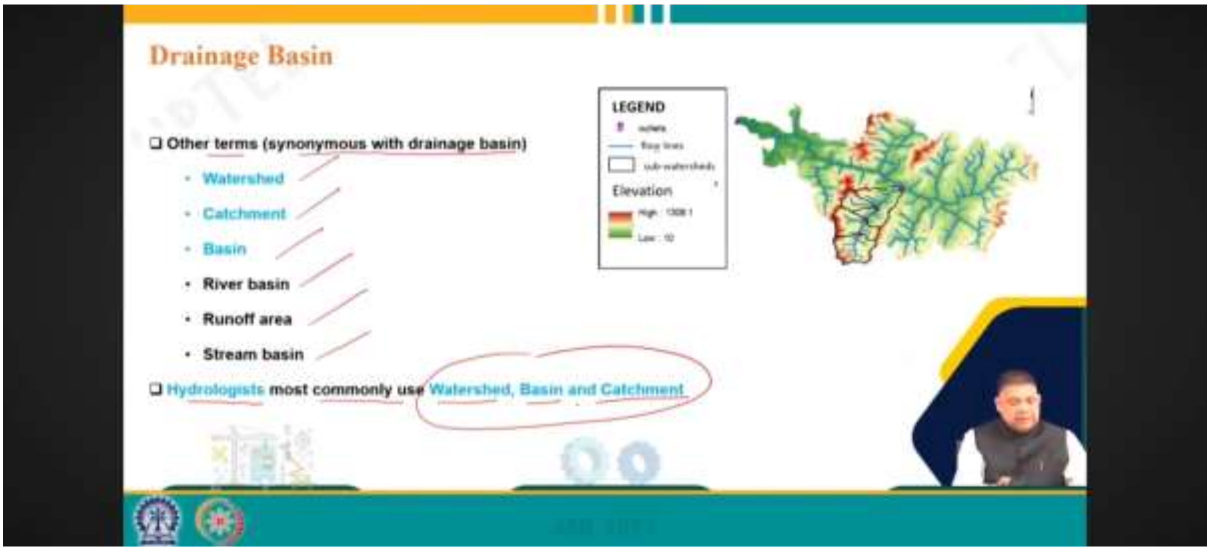
In this lecture, we will introduce drainage basins and their characteristics. We will discuss the types of watersheds categorized by size, land use, and shape.



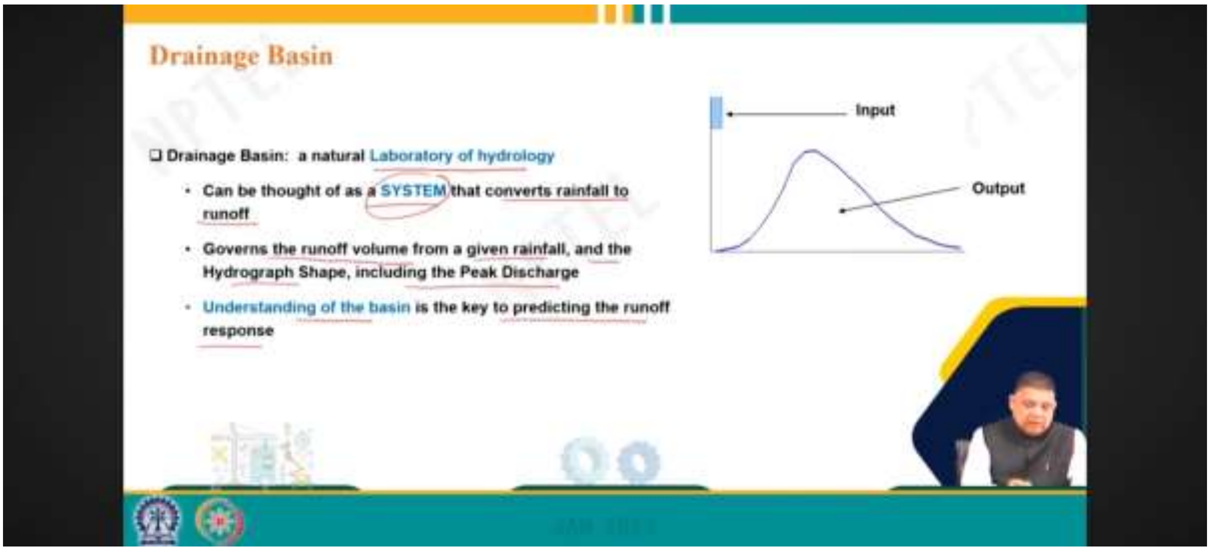
Now, let's delve into drainage basins. We previously defined a drainage basin in the introductory lecture as any portion of the Earth's surface within a physical boundary delineated by topographic slopes that directs all runoff to the same drainage outlet. Furthermore, we mentioned that various terms such as "watershed" can also be used interchangeably. Typically, we use "watershed" more frequently. As you can observe, the slope governs the flow of water. Hence, we utilize topography to delineate watershed boundaries, ensuring that all water within that area flows to a single outlet. Here, you can see a watershed boundary depicted by a dotted line, indicating the drainage divide based on topography. All the flow converges towards the outlet, which we refer to as the mouth of the river. A basin is defined concerning the outlet, and any point on the main drainage system can serve as the basin outlet. And this definition permits the selection of any desired drainage outlet, facilitating sub-basin study. So, here we observed that this is the main outlet of the watershed or the drainage basin. However, the definition states that the basin is defined with respect to the outlet. Thus, we may select any point as an outlet. For example, I may designate a specific point as my outlet of interest and then further utilize topography to delineate this watershed into sub-basins. So, if I can delineate these sub-basins based on watershed, they become the focus of my study, with the desired outlet as a reference. Therefore, when we use this definition - that the basin is defined with respect to the outlet, meaning the drainage area that directs water to a single outlet - it permits us to conduct sub-basin studies. Within the basin, we can establish different outlets and delineate various sub-basins, allowing for relative studies within them.



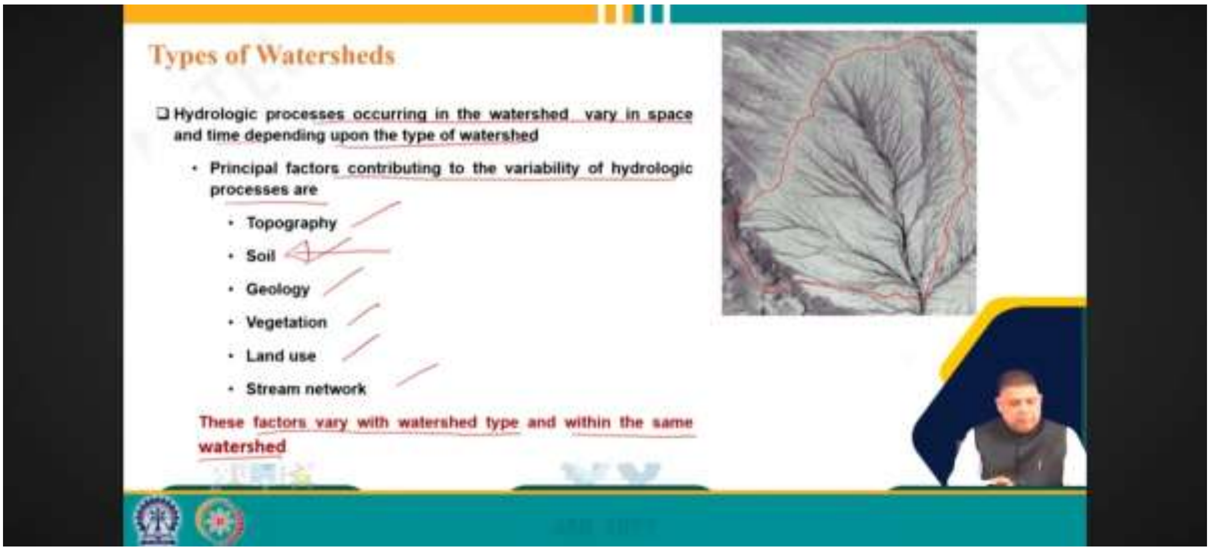
Regarding other synonymous terms used with drainage basin, such as watershed, catchment, basin, river basin, runoff area, and stream basin, they all denote the same concept. In hydrology, watershed, basin, and catchment are the most commonly used terms. Hence, we will interchangeably use these terms in our discussions, as they all refer to the same concept of a drainage basin.



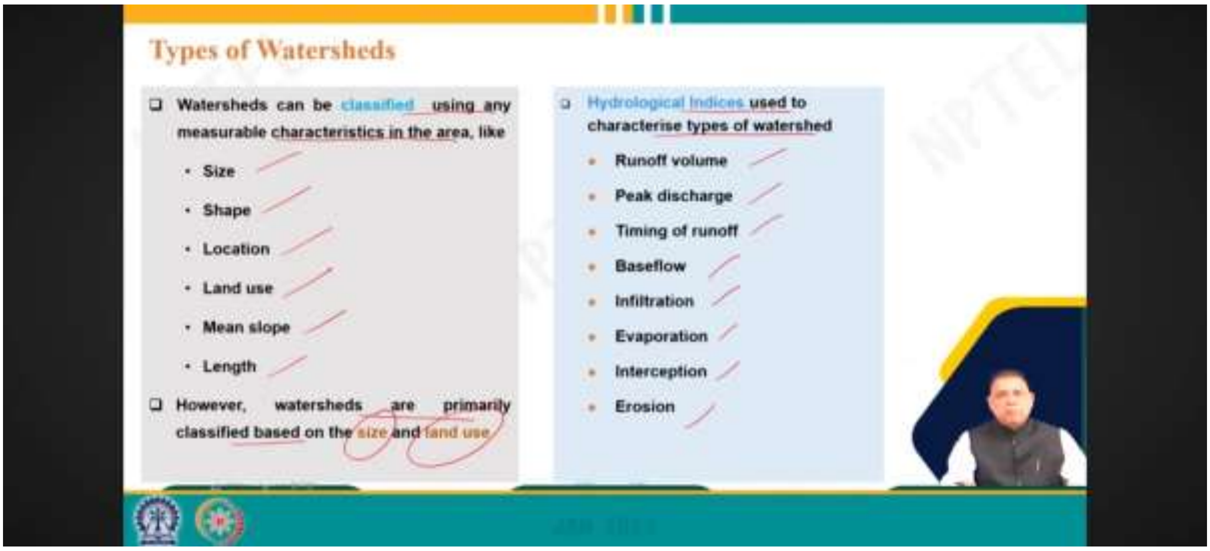
Now, a drainage basin serves as a natural laboratory for hydrology, conceptualized as a system converting rainfall into runoff. As we've previously discussed, the fundamental goal of hydrology is rainfall-runoff conversion. Hence, the drainage basin can be regarded as a laboratory or a system dedicated to this conversion process. It determines the volume of runoff generated by a given rainfall event and shapes the hydrograph, including its peak discharge. Therefore, the characteristics of the basin, such as its shape, directly influence the hydrograph's elements, including the peak, time base, and others discussed earlier. Understanding the basin is pivotal in predicting the runoff response. To study the rainfall-runoff transformation process effectively, it's imperative to comprehend the basin and its characteristics. This is why we're focusing on this topic.



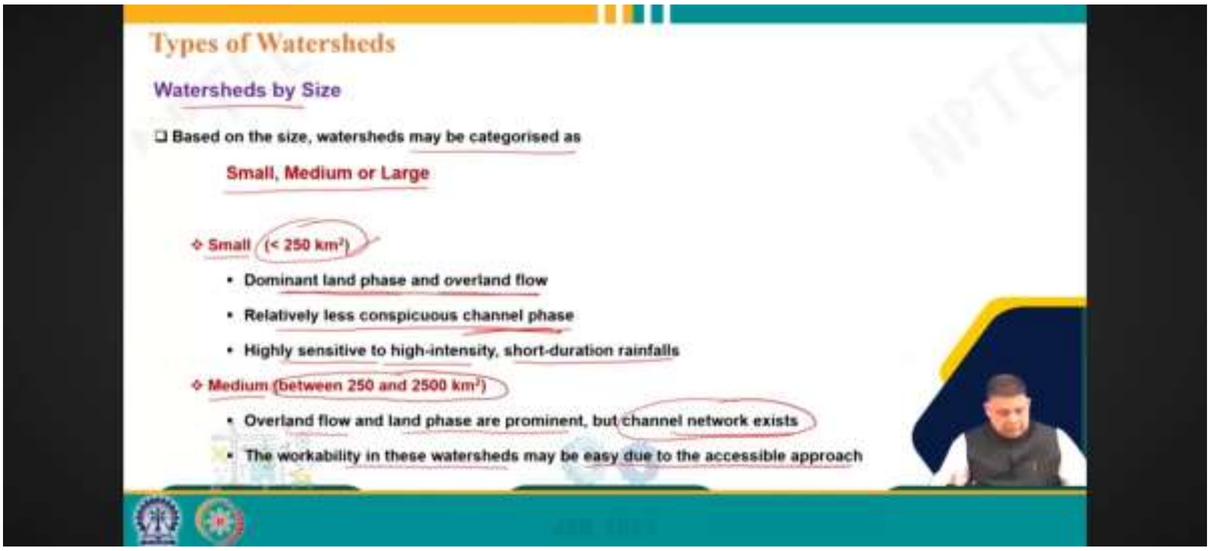
Moving on to the types of watersheds, the hydrological processes within a watershed vary spatially and temporally based on its type. Essentially, the type of watershed dictates how specific hydrological processes unfold. The primary factors contributing to the variability of hydrological processes include topography, soil composition, geology, vegetation cover, land use, and the stream network. These factors vary among watershed types and within the same watershed. As you may recall, we previously discussed the factors influencing runoff, which also affect the rainfall-runoff transformation process or the hydrograph. We observed that these factors influence the shape of the hydrograph and how runoff is generated. For instance, soil characteristics significantly impact the infiltration capacity of the watershed. The infiltration capacity, in turn, affects overland flow and consequently influences runoff generation and the shape of the hydrograph. Therefore, these characteristics are crucial from the perspective of rainfall-runoff transformation.



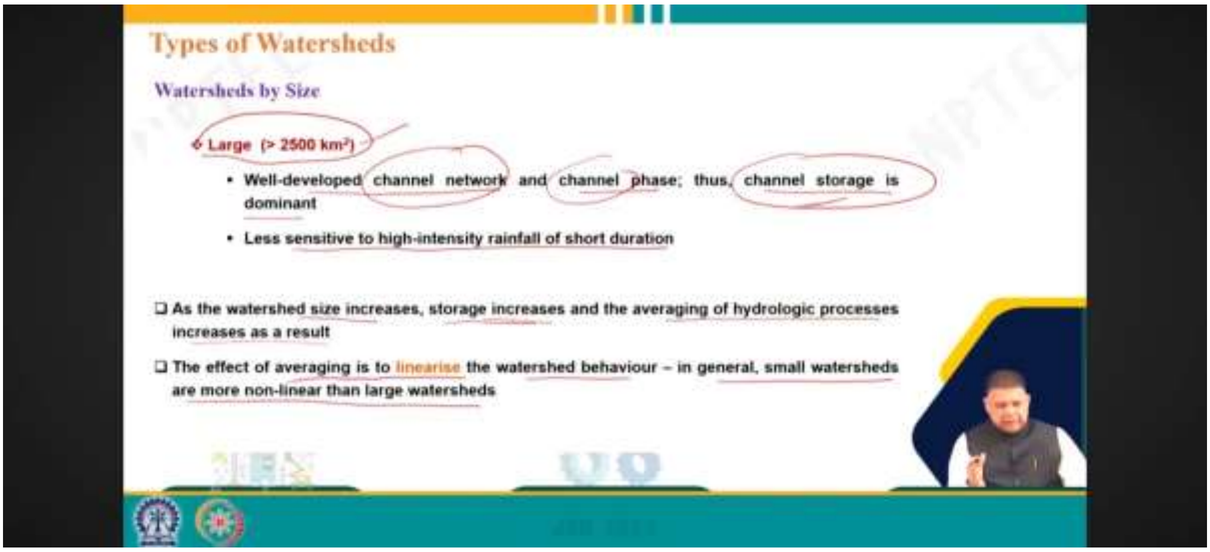
Watersheds can be classified based on various measurable characteristics within the area. For example, classification can be based on size, shape, location, land use, mean slope, length, or numerous other measurable factors. However, watersheds are primarily classified based on size or land use, which are the two common methods of classification. The hydrological indices used to characterize types of watersheds include runoff volume, peak discharge, timing of runoff, base flow, infiltration, evaporation, interception, and erosion. As you can see, these indices represent the various hydrological processes occurring within the watershed. So, we may choose any or a combination of these to compare the performance of watersheds. For instance, if we consider watersheds of different sizes, we can analyse how runoff volume is affected. Similarly, if the land use within a watershed varies, we can examine how peak discharge is affected. Hence, these hydrological indices can be utilized to characterize the type of watershed and its specific features.



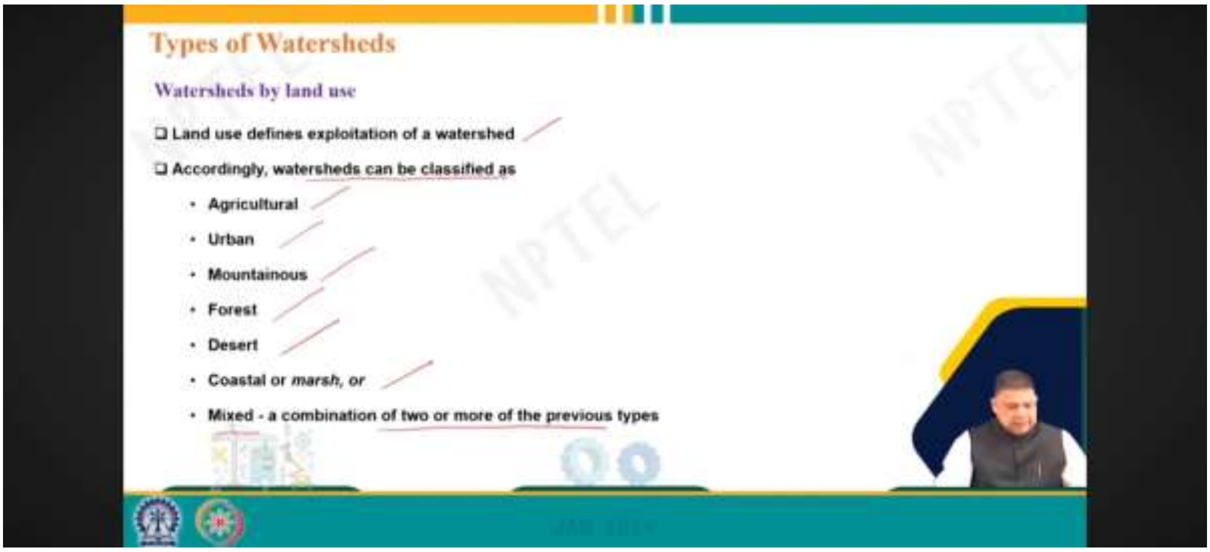
Now, moving on to classification, let's discuss watershed classification by size. Based on size, watersheds may be categorized as small, medium, or large, delineating three distinct characteristics. When we refer to a small watershed, it typically encompasses a geographical area of up to 250 square kilometre. Specifically, small watersheds exhibit certain features. They typically have a dominant land phase, with runoff primarily occurring over the land surface, and relatively fewer channel phases. If you recall our earlier discussion, runoff occurs in two phases: overland flow on the surface and channel flow through streams to the outlet. In small watersheds, the dominance lies in the land phase, with overland flow being prominent, while the channel phase is either absent or relatively minimal. Such watersheds are highly sensitive to high-intensity, short-duration rainfall events. Even if high-intensity rainfall occurs for a short duration, the flow at the outlet will be quickly affected, leading to the appearance of the peak. Hence, small watersheds are more sensitive in nature due to this rapid response to rainfall events. Moving on to medium watersheds, their drainage area typically ranges between 250 and 2500 square kilometre. In these watersheds, the overland flow and land phase remain prominent, but a channel network exists. Although the land phase still dominates, medium watersheds have a more developed channel network compared to small watersheds. Workability within these watersheds may be easier due to their larger size, making studying, conducting experiments, and analysing factors more feasible.



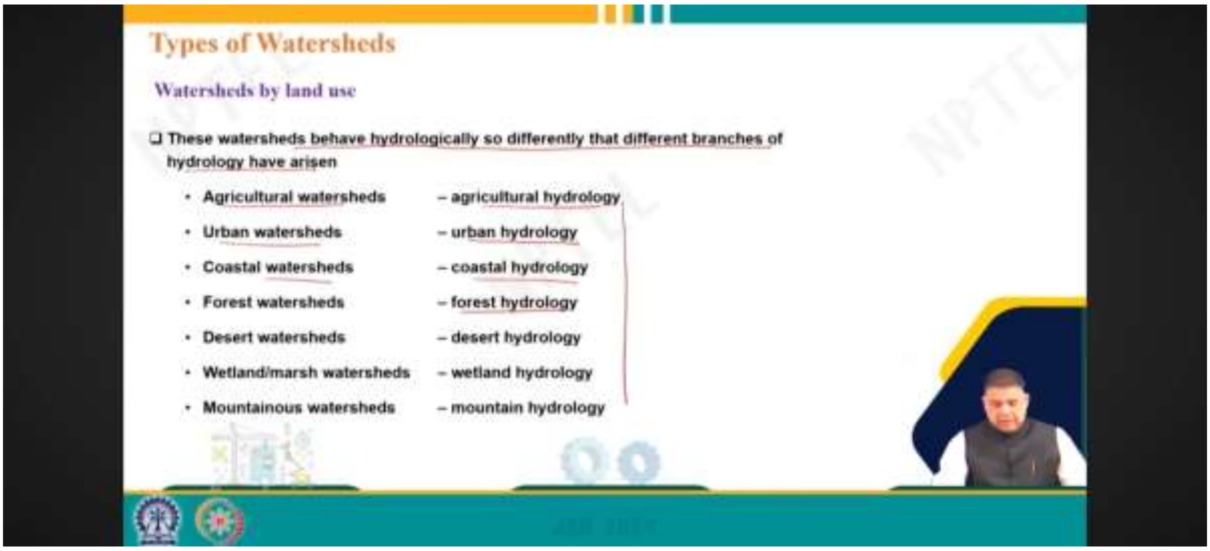
Lastly, watersheds can also be classified as large watersheds, with a drainage area greater than 2500 square kilometre. The typical feature of large watersheds is a well-developed channel network and channel phase. Channel storage is dominant, and these watersheds are less sensitive to high-intensity rainfall of short duration. Compared to small watersheds where the channel phase is almost missing and only overland flow occurs, large watersheds have a dominant channel network and significant channel storage. And that's because there's a significant segment of water stored within the channel. Consequently, they are less sensitive to high-intensity rainfall of short duration since rainfall can be absorbed within the channel phase to a large extent. As the watershed size increases, storage also increases, leading to an increase in the averaging of hydrological processes. As we transition from small to large watersheds, we observe that channel storage is significant, particularly in large watersheds. Therefore, the storage within the basin is much larger in large watersheds, resulting in a lesser effect of short-duration events and an increase in the averaging of hydrological processes. The effect of this averaging is to linearize the watershed behaviour. In general, small watersheds are more nonlinear compared to large watersheds. Essentially, the rainfall-runoff transformation process tends to be more linear in large watersheds than in small ones.



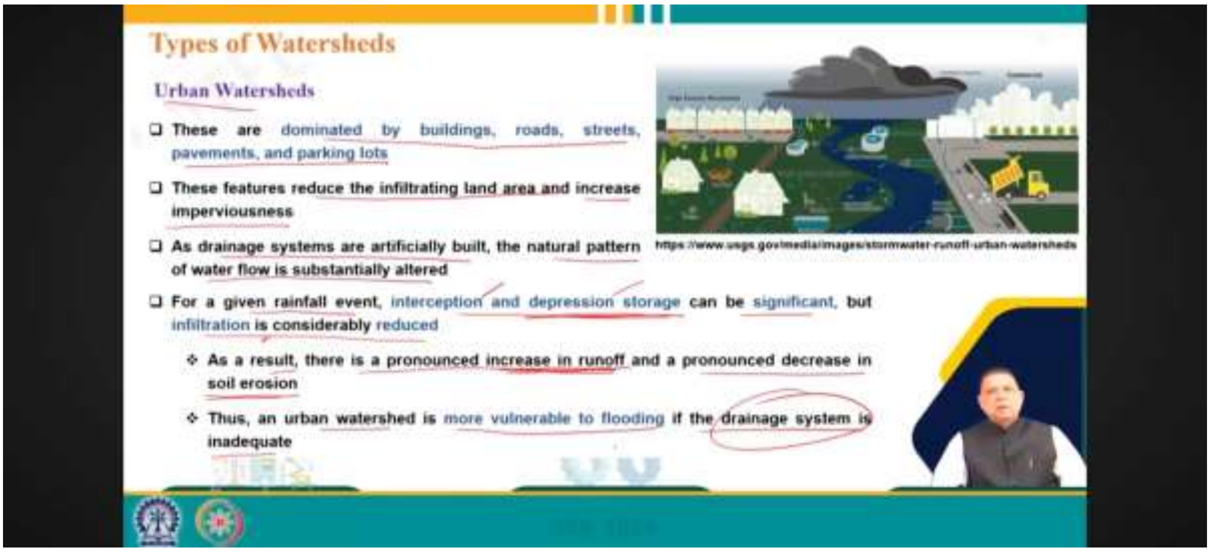
Moving on to watershed classification by land use, land use defines the exploitation of a watershed. Accordingly, watersheds can be categorized as agricultural watersheds, urban watersheds, mountainous watersheds, forest watersheds, desert watersheds, coastal watersheds, or mixed watersheds, which are combinations of two or more of the aforementioned types. All of these types can be considered as various classifications of watersheds based on land use.



These watersheds exhibit hydrological characteristics so diverse that different branches of hydrology have emerged. For instance, agricultural watersheds have agricultural hydrology, urban watersheds have urban hydrology, coastal watersheds have coastal hydrology, and forest watersheds have forest hydrology, among others. Each of these branches is extensively developed, with textbooks dedicated to each specific topic. This indicates that each type of watershed has well-established hydrological principles associated with it.

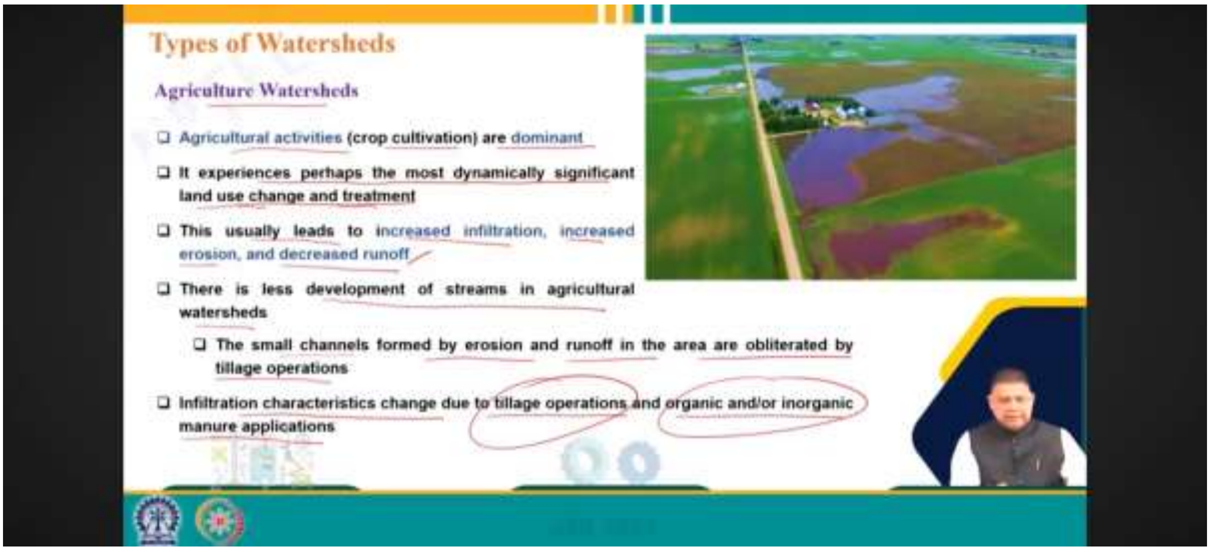


Now, let's delve into each type of watershed starting with urban watersheds. These watersheds are predominantly characterized by buildings, roads, streets, pavements, and parking lots. This means that most of the area is paved or cemented, resulting in reduced infiltration and increased imperviousness. As a consequence, infiltration becomes almost negligible due to the impervious nature of the land. Additionally, the presence of artificially constructed drainage systems significantly alters the natural flow patterns of water within the basin. Constructing buildings, roads, streets, and pavements impacts the natural drainage system of the basin. In urban areas, artificial drainage systems are commonplace, leading to a complete alteration of the natural water flow patterns. Although interception and depression storage can be significant for a given rainfall event, infiltration is considerably reduced due to the paved surfaces. Thus, urban watersheds present unique hydrological challenges characterized by altered flow patterns and reduced infiltration due to extensive urbanization and the presence of artificial drainage systems. Interception will also be more prevalent in urban areas due to potential depressions. Consequently, there is an increase in depression storage, but infiltration is considerably reduced because there is minimal exposed soil. This leads to a pronounced increase in runoff and a significant decrease in soil erosion, as there is little loose soil available. With reduced soil erosion and minimal infiltration, runoff is increased in urban areas. Consequently, urban watersheds are more vulnerable to flooding, especially if the drainage system is inadequate. This vulnerability arises because almost all the dire rainfall gets converted into runoff, resulting in significantly high flow rates. In instances where the drainage system is insufficient, the likelihood of flooding is heightened. Clogging of the drainage system presents a major problem in many Indian urban towns, as is well-known. Indeed, urban flooding incidents occur almost yearly.

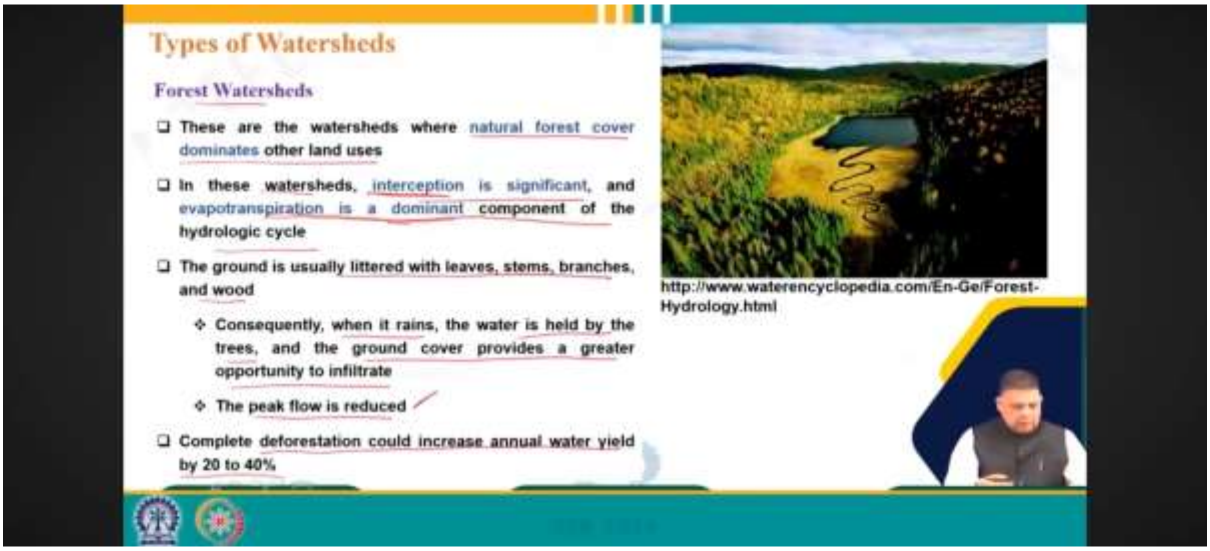


For example, in 2019, the mega city Mumbai experienced severe flooding. Similarly, in Patna in 2019, the National Disaster Response Force (NDRF) had to rescue people from flooded areas. Additionally, in Delhi last year, in 2023, flooding affected various parts of the city, including hospital wards, as seen in the image. Certainly, this clearly demonstrates that the clogging of the drainage system is a major issue, and urban watersheds are prone to urban flooding.

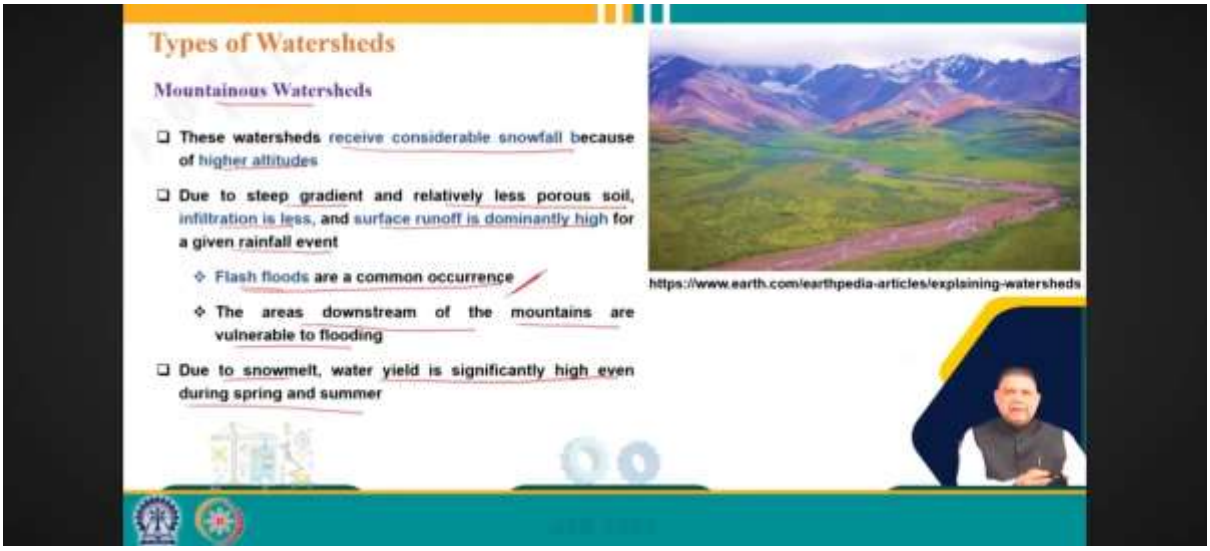
Moving on to agricultural watersheds, as the name suggests, agricultural activities or crop cultivation dominate the land use in these areas. Agricultural watersheds undergo perhaps the most dynamically significant changes in land use and treatment. This is quite evident due to the presence of 2 to 3 cropping seasons, during which numerous primary and secondary tillage operations occur. Consequently, the soil gets disturbed each time, leading to dynamic changes in land use and treatment. These changes typically result in increased infiltration, erosion, and decreased runoff. Infiltration increases because the loose soil on the surface can absorb most of the rainwater, which is beneficial for agricultural crop production. Erosion, on the other hand, increases due to the presence of loose topsoil resulting from primary and tillage operations. This loose soil has a tendency to flow out during rainfall events. However, runoff is significantly decreased in agricultural watersheds, primarily because bunding are often utilized. Additionally, there is less development of streams in these watersheds. This is understandable since even the small channels formed by erosion and runoff in the area are impacted by tillage operations, which continuously disturb the landscape. Even during the dormant season between cropping cycles, any channels that may have formed are likely to be smoothed out during the next round of tillage operations. So, obviously, the development of channels and streams is almost non existent. Infiltration characteristics change due to tillage operations and the application of organic and inorganic manure. Since tillage operations are consistent and manure application is ongoing, the infiltration characteristics and soil composition undergo continuous changes in agricultural watersheds.



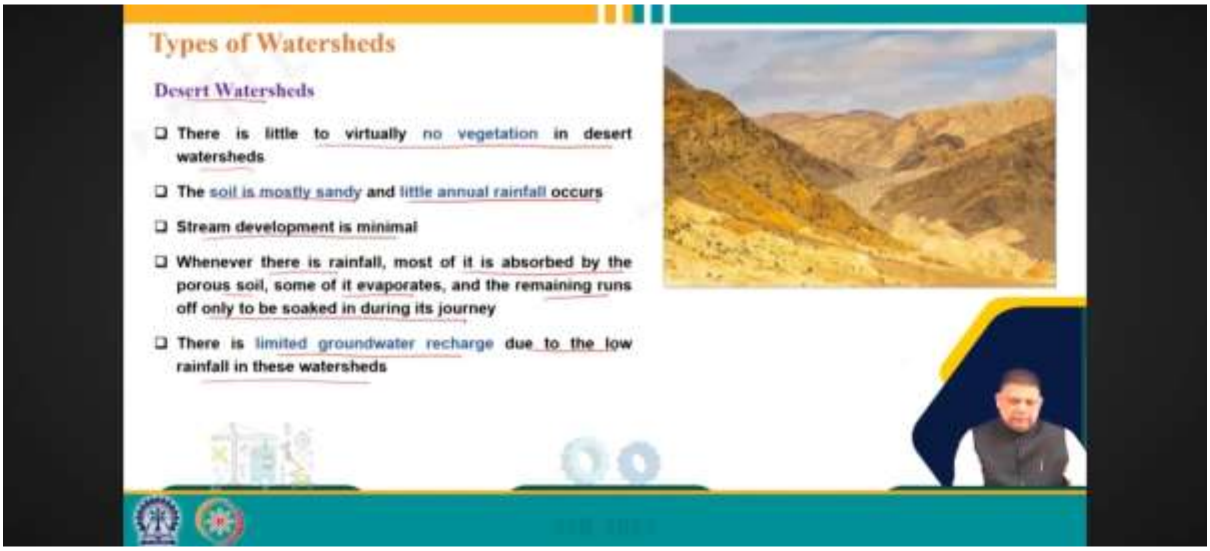
Next, we have forest watersheds, where natural forest cover predominates over other land uses. In these watersheds, interception plays a significant role, and evapotranspiration is the dominant component of the hydrological cycle. This is quite evident due to the presence of dense forests and tall trees, which contribute to significant interception as most of the area is covered by the canopy. Additionally, evapotranspiration is dominant because transpiration rates are high in forested areas. The forest floor is typically littered with leaves, stems, branches, and roots. Consequently, when it rains, the water is held by the trees, and the ground cover provides ample opportunity for infiltration. So, obviously, the peak flow will be much lower. Consequently, the infiltration opportunity time will be much higher due to the litter and other factors, resulting in reduced peak flow. Studies show that complete deforestation could increase annual water yield by 20 to 40 percent. This suggests that forests, or forested watersheds, absorb 20 to 40 percent of the rainfall due to their characteristics.



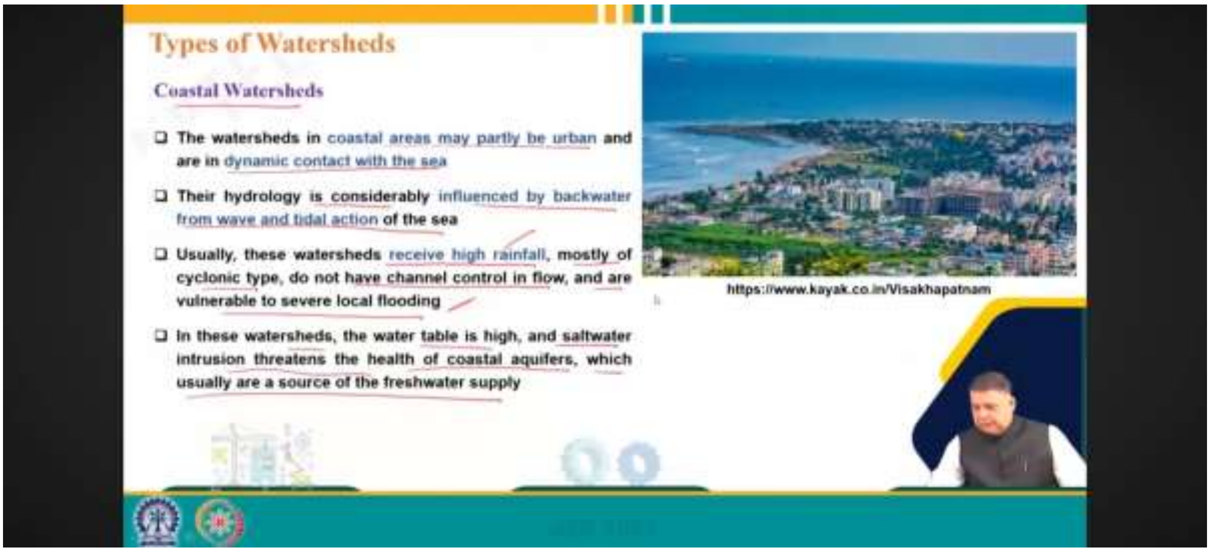
Next, we have mountainous watersheds. These watersheds have a characteristic feature of receiving considerable snowfall and precipitation due to their higher altitudes. Additionally, due to steep gradients and relatively less porous soil, infiltration is minimal on mountainous surfaces, which may consist of rocks. As a result, surface runoff is predominantly high for a given rainfall event, leading to common occurrences of flash floods. Because infiltration is negligible and slopes are steep, overland flow tends to quickly flow down at high velocities, contributing to the prevalence of flash floods. Consequently, areas downstream of mountains are vulnerable to flooding due to the nature of flash flooding, making downstream areas prone to flooding. Due to snow melt, water flow is significantly high even during spring and summer in mountainous watersheds. Unlike other watersheds where flow is more prominent during the monsoon season, in mountainous watersheds, flow remains significant during spring and summer due to snow melt.



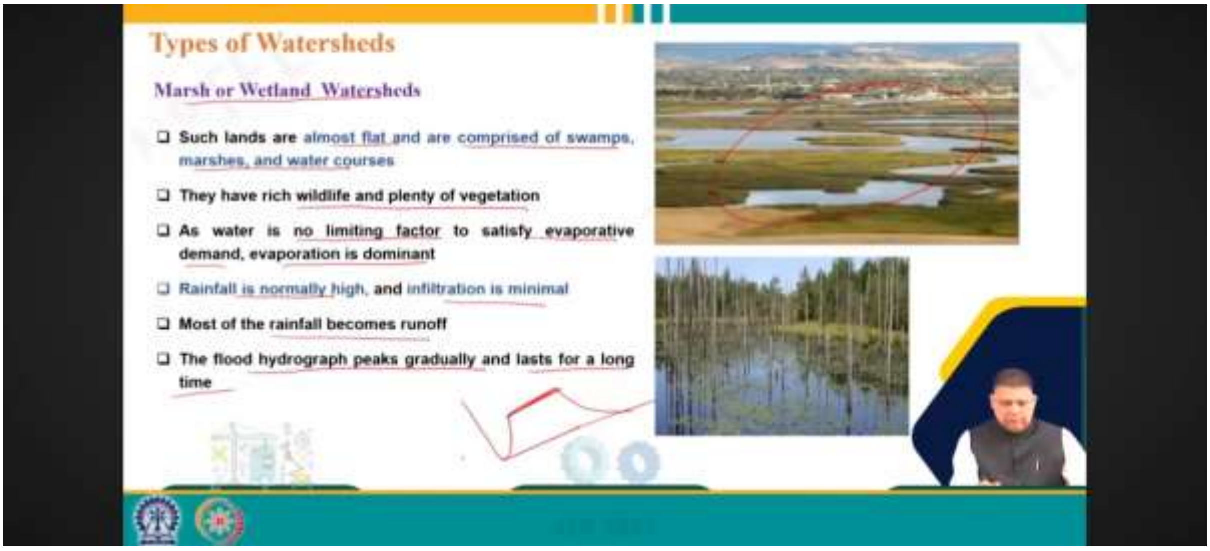
Moving on to desert watersheds, there is little to virtually no vegetation, which is quite evident. The soil in desert watersheds is mostly sandy, and there is minimal annual rainfall. Due to these factors, stream development is minimal in desert watersheds. Whenever there is rainfall, most of it is absorbed by the porous soil, some evaporates, and the rest runs off, only to be soaked up during its journey. Consequently, there is not much flow for stream development. Occasionally, ephemeral streams may be generated for a short distance or period of time during rainfall events. Moreover, there is limited groundwater recharge in desert watersheds due to the low rainfall. Since rainfall itself is scarce, groundwater recharge is also low in these areas.



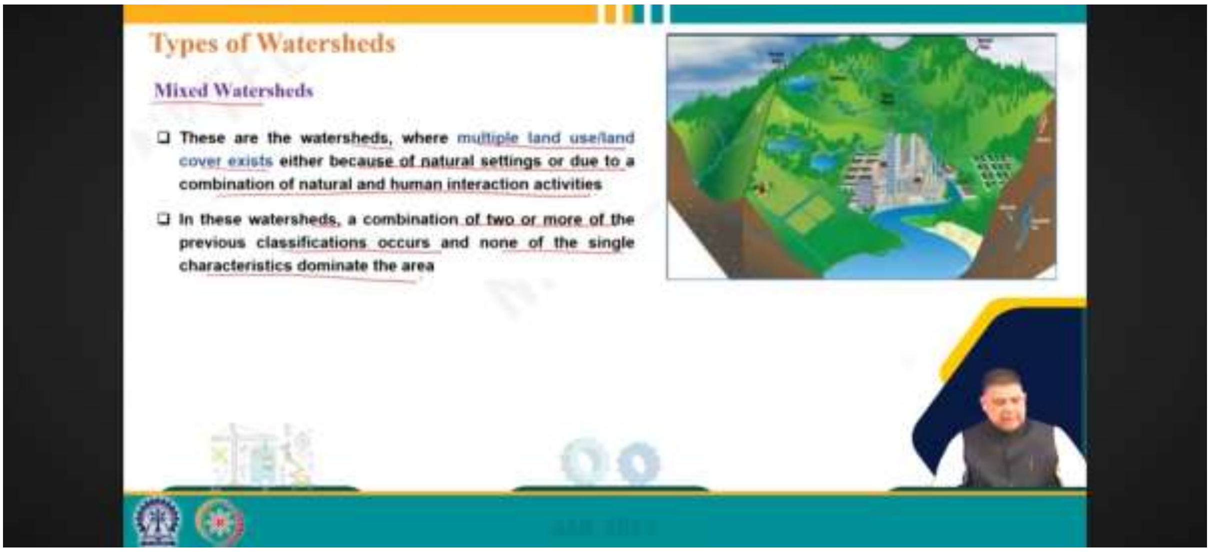
Next, we have coastal watersheds, which are located in coastal areas and may partly consist of urban areas. These coastal towns often serve as tourist spots, leading to significant development. Consequently, they have an urban nature and are constantly in dynamic contact with the sea. The hydrology of coastal watersheds is considerably influenced by backwater from wave and tidal action of the sea. This impact extends to groundwater, which can be affected by saltwater intrusion due to its connection with the sea. Due to these factors, backwater is a significant concern in coastal watersheds. Typically, these watersheds receive high rainfall, especially of cyclonic type, and often lack channel control in flow. As a result, they are vulnerable to severe local flooding, particularly during cyclones. Flooding is a common occurrence in these coastal areas. Moreover, in coastal watersheds, the water table is high, and saltwater intrusion poses a threat to the health of coastal aquifers, which are typically a source of fresh water supply. Therefore, maintaining the quality and integrity of these coastal aquifers is crucial for ensuring a sustainable freshwater supply in coastal regions. Saltwater intrusion is indeed a major problem for these kinds of watersheds.



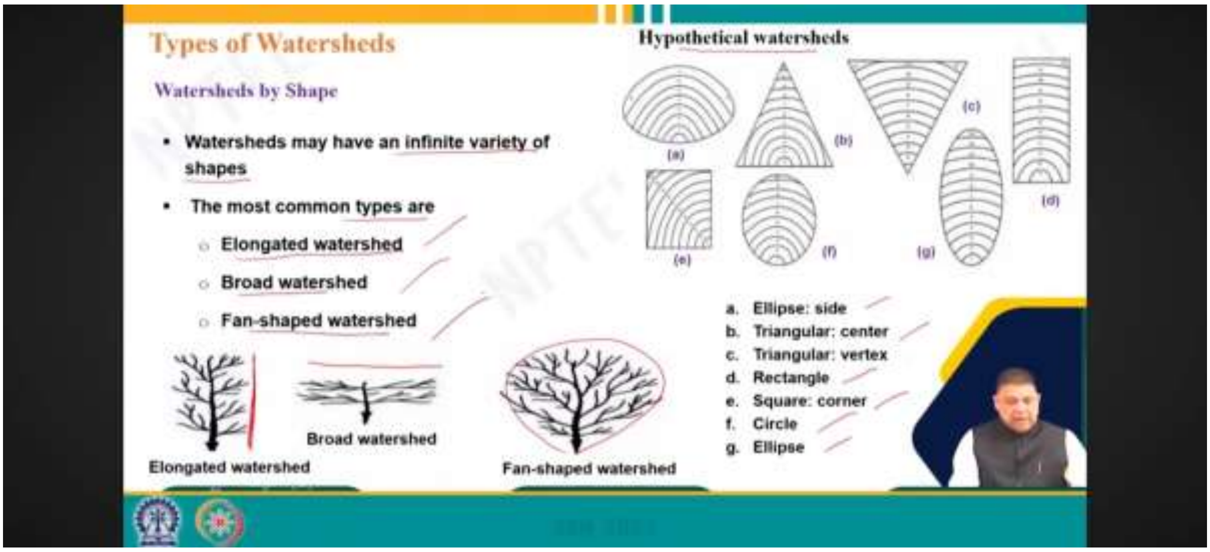
Now, let's discuss marsh or wetland-type watersheds, which are almost flat and comprised of swamps, marshes, and watercourses. These areas are rich in wildlife and vegetation, with numerous water bodies, swamps, and marshes present. Water is not a limiting factor in satisfying evaporative demand in these environments, so evaporation is dominant across the entire surface, resulting in high potential rates of evaporation. Typically, rainfall is high in marsh or wetland watersheds, and infiltration is minimal due to saturation. Consequently, most of the rainfall becomes runoff, translating directly into runoff. The flood hydrograph peaks gradually and lasts for a long time. As rainfall intensity increases, the flow increases, and the peak flow occurs as long as rainfall persists. This type of hydrograph is characterized by an elongated peak due to the prolonged duration of rainfall, as illustrated here.



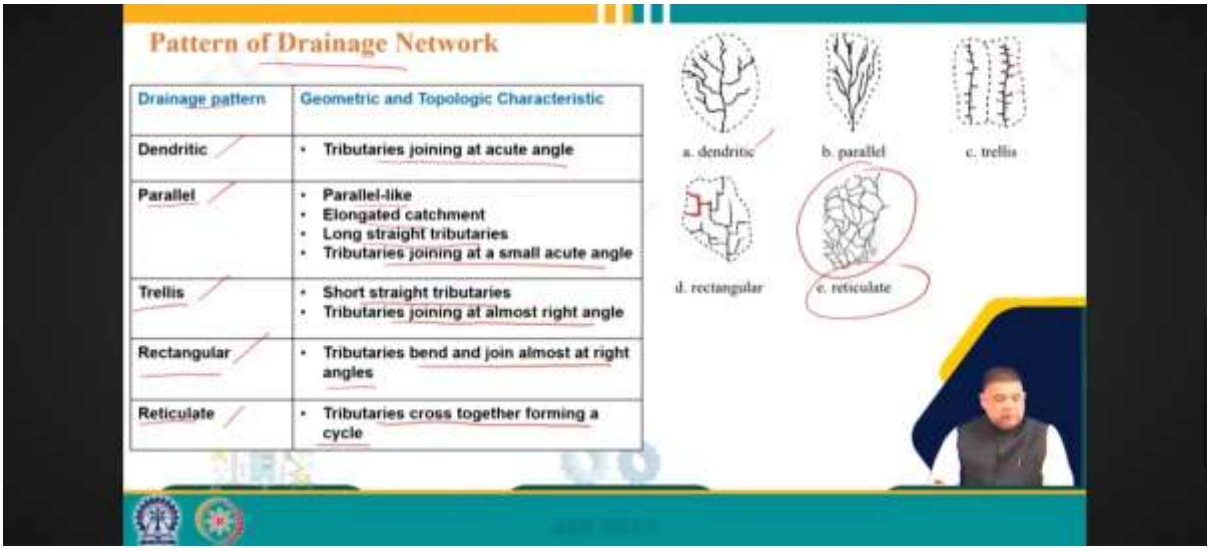
Lastly, let's consider mixed watersheds, which involve multiple land use and land cover types. These watersheds may feature a combination of natural settings and human intervention activities, resulting in a diverse landscape with various land uses. This combination can include both natural and manmade elements, depending on the specific characteristics and history of the watershed. And in these watersheds, a combination of two or more of the previous classifications occurs, and none of the single characteristics dominate the area. Consequently, they exhibit combined characteristics of the types of watersheds mixed within the basin.



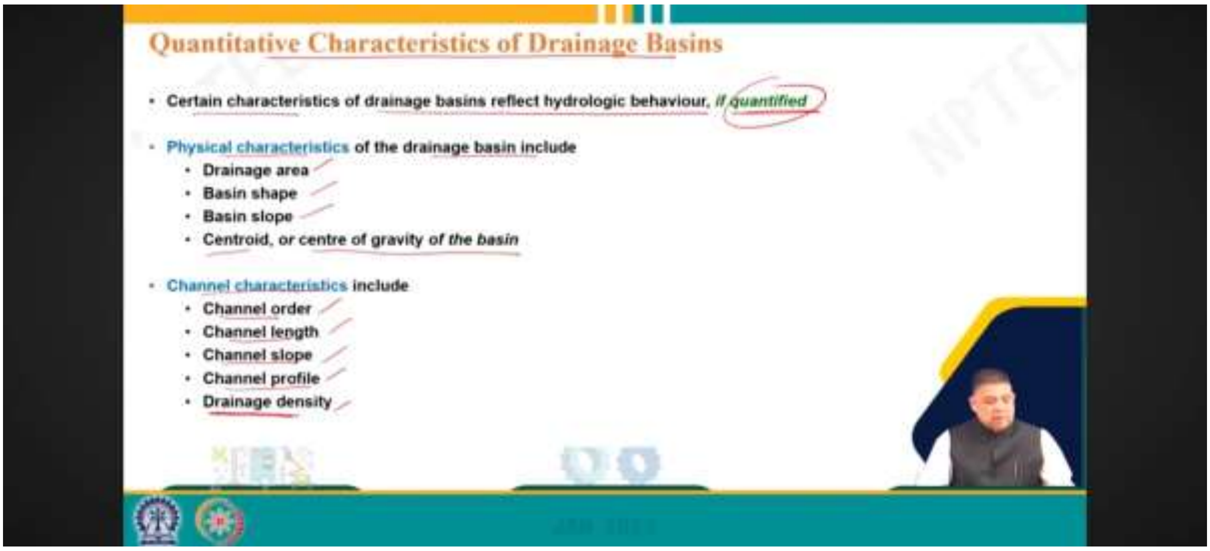
Lastly, we consider watersheds by shape. Watersheds may have an infinite variety of shapes, but the most common types we find are three: elongated watersheds, broad watersheds, and fan-shaped watersheds. Elongated watersheds have a much higher length compared to their width. Broad watersheds, on the other hand, have significant width in comparison to their length. Fan-shaped watersheds are almost elliptical but very close to a circle. These are the three common types of watersheds encountered. However, in numerical model, we can have an infinite variety of shapes. Therefore, several hypothetical watershed shapes, such as elliptical, triangular, rectangular, square, and elliptical, have been imagined and model during mathematical model. Nevertheless, in field conditions, these three types of watersheds—elongated, broad, and fan-shaped—are typically encountered.



Moving on to the pattern of the drainage network, we observe that the types of drainage patterns vary along with the types of watersheds. Different kinds of networks can be encountered. For instance, we may encounter dendritic drainage patterns, parallel drainage patterns, trellis drainage patterns, rectangular drainage patterns, and reticulate drainage patterns. These represent various possibilities in drainage network formations. In a dendritic drainage pattern, tributaries join the main channel at acute angles. As depicted here, all the tributaries join the main channel at acute angles, allowing for connections at various angles. Parallel drainage networks, on the other hand, consist of parallel networks, as shown. These networks are typically found in elongated shapes of watersheds. They feature long, straight tributaries that run parallel to each other. Tributaries in parallel drainage networks can also join at small acute angles, similar to dendritic patterns. Next, let's discuss trellis drainage patterns. These patterns feature short, straight tributaries, as illustrated here, where both the main channel and tributaries exhibit short, straight segments. And tributaries join at almost right angles. As you can see, the tributaries join the main channel almost at a right angle, indicating a trellis-like network. Next, we have a rectangular network where tributaries bend and join almost at right angles. Typically, as seen here, they almost form right angles before joining the main tributary. In a rectangular drainage pattern, almost all tributaries join at right angles. Lastly, we have a reticulate pattern where tributaries cross each other, forming a cycle. This crisscross network is characteristic of the reticulate pattern. Thus, the drainage network can exhibit specific patterns within a particular basin or drainage network.



Now, let's discuss the quantitative characteristics of drainage basins. Certain characteristics of a drainage basin reflect hydrological behaviour when quantified. In the upcoming lectures, we will discuss how to quantify these characteristics. The typical characteristics could be physical characteristics of the drainage basin or channel characteristics. Physical characteristics include the drainage area of the basin, basin shape (as we have seen, different shapes result in different hydrological behaviours), basin slope, and centroid or centre of gravity of the basin. The centroid or centre of gravity is sometimes used to describe certain hydrological behaviours. Similarly, channel characteristics play a crucial role. We observed there are different channels within the basin, including the channel phase, where most of the water is carried to the outlet. Channel characteristics such as channel order, channel length, channel slope, channel profile, and drainage density are important. Drainage density, which we will define in the next lecture, also plays a significant role. Channels of different orders, lengths, or slopes affect flow velocity and depth, and drainage density considers the number of channels in relation to the area, which we will discuss in later lectures. So, we will discuss all these quantitative characteristics of the drainage basin and how they can be used in hydrological analysis, including the use of models.



With this, we come to the end of this lecture, where we have attempted to categorize and define a drainage basin. We also characterized watersheds based on their shape, size, or land use pattern, and discussed drainage patterns. Lastly, we summarized by listing certain quantitative characteristics, which we will study in the next lectures. Thank you very much. Please provide your feedback and feel free to raise any doubts or questions, which we will be happy to address on the forum. Thank you very much.