Watershed Management

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Module No. # 08

Lecture No. # 31

Storm Water Management

[FL] and welcome back to the video course on watershed management. Today, we will start a new module; module number 8 on storm water and flood management. The topics covered in this module include storm water management, design of drainage system, flood routing through channels and reservoir, flood control and reservoir operations and some case studies.

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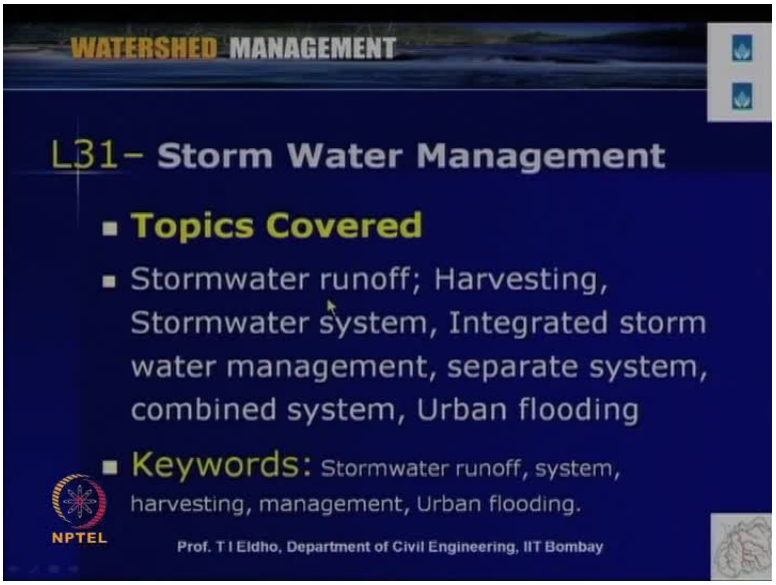

In today's lecture in module number 8, lecture number 31, we will discuss storm water management. Some of the important topics covered in today's lecture include stormwater runoff; harvesting, stormwater systems, integrated storm water management, separate system, combined system and urban flooding. Keywords for today's lecture: stormwater runoff, system, harvesting, management and urban flooding.

As we were discussing earlier, when we deal with watershed management, we have seen that there can be sometimes plenty of water due to heavy rainfall; or, sometimes there can be drought type situations. Depending upon the climatic conditions or the variations during monsoon season, when heavy rainfall takes place, there can be so much of water throughout the area – whether it is rural area or urban area. Especially in urban areas, when this water level goes beyond certain level, there will be huge problems like disturbance to the traffic, disturbance to the total life in that area, and then there will huge losses – economic losses. So, that means urban flooding is a major problem either in watershed scale or otherwise it is a major problem. This is caused due to the stormwater; I mean when the rainfall takes place.

As we have discussed earlier, we can classify into overland flow and channel flow. This over land flow component especially – all these will be collected through drainage system, various drains. Then, that will be joining into a stream or a channel. Then, finally, that will be routed to the major river or to the ocean. So, that way only generally the system will be working. So, that way this storm water management… Especially during the rainy season or monsoon season, the storm water management within the watershed is an important topic. Since in many aspects, it is related to the problems; that means like a flooding problem; or, it is related to the water harvesting; or, whether we can capture some of this water and then recharge or do some harvesting. So, that way also it is important. So, in today's lecture, let us discuss about the stormwater runoff, stormwater management, and then urban flooding related issues.

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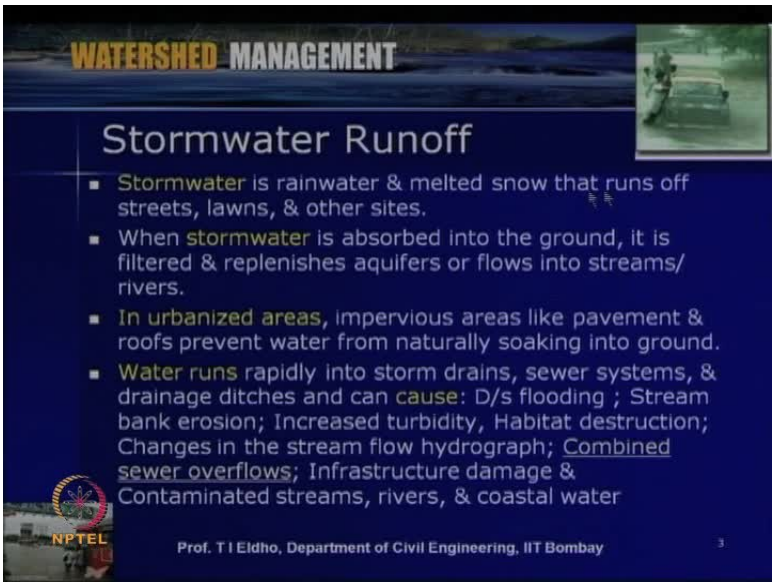

As I mentioned, stormwater is rainwater and melted snow that runs off streets, lawns, and other sites. So that way, somewhat we can that it is an overland flow. Whatever is due to rainfall or due to melted snow – coming off through the land, then coming to the streets, then lawns, and other sites. So, this is generally termed as stormwater. When stormwater is absorbed into the ground, you can see that wherever infiltration takes place, it is filtered and replenishes the aquifers or flow into streams and rivers. It can be either this – the stormwater can be recharge to the aquifers systems through infiltration process, or it can simply flow through the drainage systems to the streams and rivers. So, both ways it is possible, but as much as possible if it is infiltrating down that replenishes the aquifers system, so that we can use for future purpose by pumping the water from the aquifers system.

Then, when we consider the urbanized watershed or urbanized areas, especially impervious areas like a pavement and roofs, prevent water from naturally soaking into the ground. So, you can see that in a city like a Mumbai or Chennai or Kolkata or Delhi, we can see that most of the areas – especially pavement and lot of other areas are also paved or it is impervious. So, that way this impervious surface stops the water to percolate down to the ground. So, that way we can see that this water will be moving fast. So, this water runs rapidly into storm drains or sewer systems and drainage ditches, and then it can cause lot of problems as we discussed. Some of the important problems

can be like a downstream flooding. If heavy rainfall takes place and then all the stormwater is coming to the downstream areas, then there can be possibility of flooding.

Then, stream bank erosion – especially wherever this soil is a loose and then heavy rainfall takes place, there can be stream bank erosion. Especially wherever this water will be going to rivers and many times this water will be taken back for the municipal water supply, then there can be increased turbidity. So, another issue can be increased turbidity. Then, habitat destruction; changes in the stream flow hydrographs; that means especially in the urban areas due to the less time of concentration or time to peak will be less, then the peak also increases. So, that way there will be changes in this stream flow hydrograph.

Then, there can be combined sewer overflows. Wherever the sewage and then the stormwater drains combine system, there these can overflow; when especially mixed with sewage, then there can be more problems – environmental problems, then infrastructure damage. All these can cause contamination of the surface water like stream, rivers, ponds, or lakes. Then, the coastal water bodies will be also affected by the polluted stormwater. So, that way we have to manage the stormwater very scientifically. Then, we should appropriate plans and then appropriate drainage system. Then, if we can treat this stormwater to certain extent, so that the surface water including the groundwater will not be polluted due to the polluted stormwater. So, that way we have to plan the stormwater system appropriately. So, that way we can see that stormwater management is a very important topic, when we discuss about the watershed management.

Now, whether we can harvest this stormwater? We were discussing about the rain water harvesting earlier. Now, the question is – whether we can capture the stormwater, which can otherwise cause various problems like a flooding or the pollution to the surface water bodies. So, if we can harvest some of the water and then either we can use it or we can infiltrate down to the aquifers systems, then that will reduce the stormwater problems like flooding.

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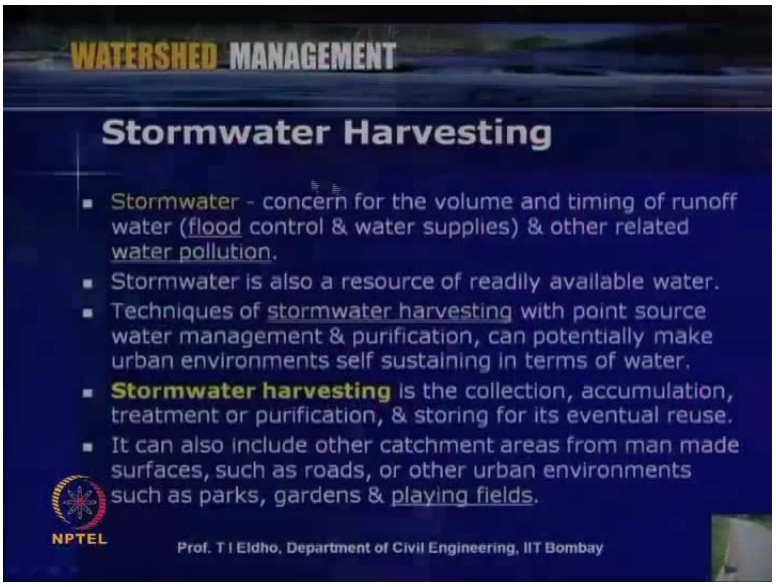

Let us look some important aspects related to stormwater harvesting. Stormwater – concern for the volume and timing of runoff water – that means flood control and water supplies – and other related water pollution. So, as we discussed, stormwater can cause flooding and then it can also cause surface water pollution. So, as I mentioned earlier, stormwater is also an important resource. Since this stormwater is not much polluted water, if we give some simple treatment like sedimentation or like settling tanks – that kind of treatment, we can directly utilize this stormwater. So, stormwater is a resource, which we can readily use for various purposes.

Techniques like a stormwater harvesting with point source water management and purification, can potentially make urban environment self-sustaining in terms of water – especially urbanized watershed. We can see that when the urbanization increases, more water is needed. So, that way, whatever water is available in that watershed may not be sufficient – especially if the stormwater is not harvested or stormwater is not properly utilized. So, that way if we can collect the stormwater and then either allow the stormwater to recharge to the aquifer systems or we can use to certain ways, then that will be very useful.

Stormwater harvesting is the collection, accumulation, treatment or purification, and storing for its eventual reuse. A storing can be either a direct storage like in ponds or in tanks; or also, we can recharge to the groundwater system. So, that way the stormwater

harvesting is very important. It can also include other catchment areas from manmade surfaces, such as, roads or other urban environments, such as, parks, gardens and playing fields. So, that way in all these areas, we can capture the stormwater and then we can treat it properly, purify it and directly utilizes it; or, we can recharge to the aquifer systems. So, that way stormwater harvesting is very important in terms of appropriate water resource utilization within a watershed.

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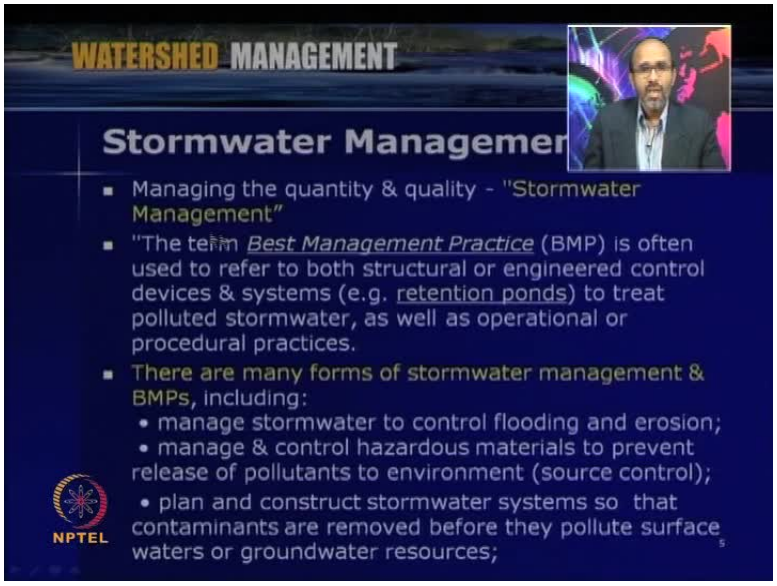

Now, let us look into various aspects of stormwater management. As we have seen especially in the rainy season or monsoon season, we have got so much of stormwater depending upon the rainfall condition. So, we have to deal with larger quantity of water. Then, as we discussed there will be pollution problems also. So, we have to deal with the quality of the water. So, that way when we have to deal with the quantity and quality of the stormwater, we call the process as stormwater management.

Generally, we have to go for the best management practices, which is best possible as far as the stormwater management is concerned. The best management practice is often used to refer both structural or engineered control devices and systems like a retention ponds or to treat polluted stormwater or storage within a pond as well as operational or procedural practices. So, this stormwater management is one of the best management practices; it can be for operational purpose or the procedure practices. There are many forms of stormwater management and best management practices – may include manage

stormwater to control flooding and erosion; then, manage and control hazardous materials to prevent release of pollutants to the environment, such as, source control from an industry or other sources. Then, plan and construct stormwater systems, so that contaminants are removed before they pollute the surface waters or the ground water resources.

When we look into the stormwater management, we have to deal two aspects: one is the quantity of the stormwater; second one is the quality of the stormwater. Quantities concerned mainly depend upon the rainfall pattern, the rainfall conditions, then how effectively we can capture this stormwater and use for various purposes. Then, quality issues are concerned from where the pollutant is coming and mixing with the stormwater; then, whether that will affect surface water sources like rivers, lakes, or other surface – water ponds and other things; or, this polluted water may infiltrate down to the aquifer systems and also cause the pollution to the ground water system. So, that way we have to see that best management practices are followed as far as stormwater management is concerned.

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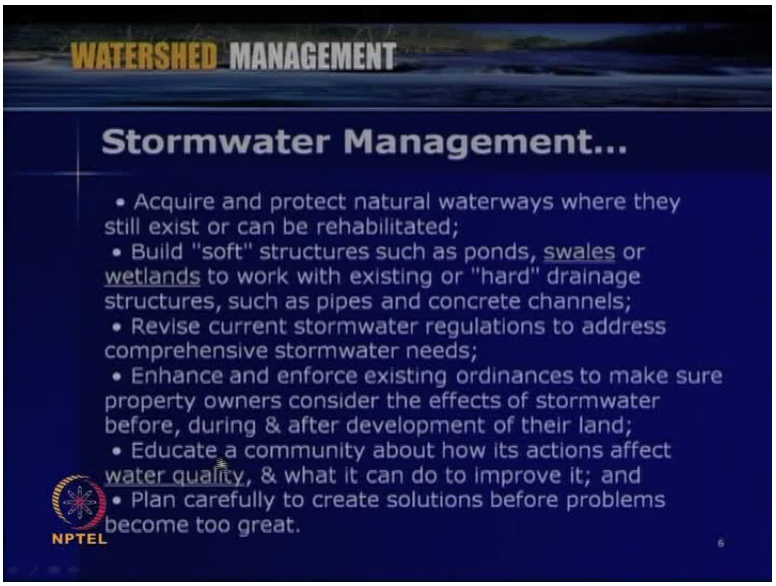

That way we have to acquire and protect natural waterways where they still exist or can be rehabilitated. If the development work is going on natural waterways areas, then how we can do best management practices? We can build soft structures, such as, ponds swales or wetlands to work with existing or hard drainage structures, such as, pipes and

concrete channels. So, as far as stormwater management is concerned, we can go for soft structures or we can go for hard drainage structures. Soft structures – generally in stormwater management, we call ponds, swales or wetlands. So, that can appropriately collect the stormwater and then it will be automatically treated like a sedimentation and a treatment within a wetland; or, we have to go for hard structures like we can collect all these stormwater through pipes, channels, and then we can give appropriate treatment.

Then, we have to revise current stormwater regulations to address comprehensive stormwater needs. As far as how we are effectively utilizing this stormwater –depending upon that we can have appropriate rules and regulations as far as this stormwater management is concerned. Then, we can enhance and enforce existing ordinances or lowest to make sure property owners consider the effects of stormwater before and after development of their land. All these depends – whenever a watershed basis or on a particular land wise – when we consider. It depends upon the developments taking place within that area. We should have certain rules and regulations as far as stormwater management is concerned, so that the private land owners or the property owners also go through these laws and then implement these rules as far as the stormwater is concerned.

Then, we have to educate a community about how its actions affect the water quality. Most of the time, as far as the private land owners are users, they may not bother about the water quality related to stormwater, but polluted stormwater is a major cause of water pollution. So, that way we should have strict rules and regulations and then we have to implement these rules and regulations. So, that way we have to plan carefully to create solutions before problems become too great. Especially in cities like Mumbai or Delhi and other areas, the urban stormwater pollution is a major problem – especially in places like Delhi, where the ground water is directly utilized back from the aquifers systems. So, that way when this polluted water infiltrates down to the aquifer system, the ground water system will also get polluted. So, that way we should be very careful to manage the stormwater with respect to the quantity and the quality.

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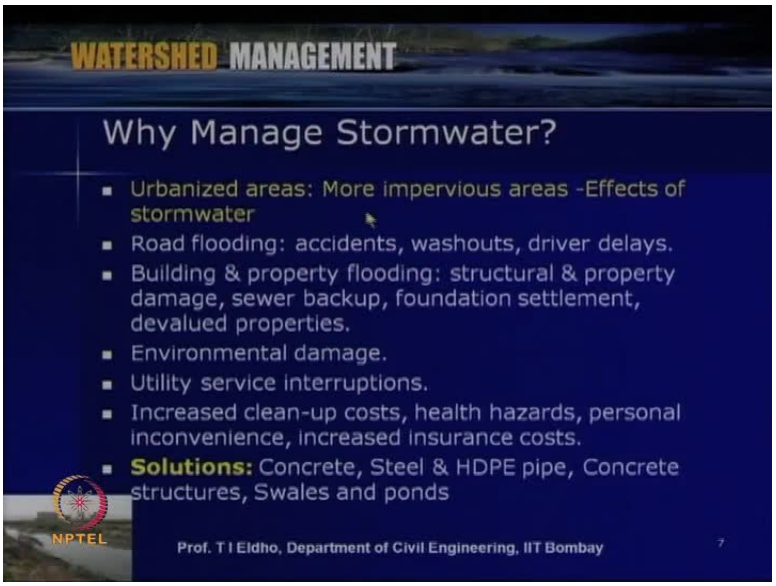

Now, let us look why we have to manage the stormwater. As I mentioned in the urbanized areas, when urbanization progresses, then the impervious area also increases. So, that way that affects the stormwater. So, as I mentioned, the pollution problem is one aspect. Then, the time of concentration and time to the peak of the hydrograph will be increased with respect to the natural watersheds. Some of the problems like if you do not manage the stormwater appropriately, a road flooding can takes place, and then related accidents, washouts, driver delays, etcetera. Then, other issues like building and property flooding – some of the buildings may get collapsed, property may be flooded, and then there will be structural and property damage. If the stormwater is going through the sewer systems, then sewer water will come there, backup will takes place. That will be another environmental problem. Then, there can be problems like foundation settlement, devalued properties, etcetera.

As far as the water quality is concerned, there will be major environmental damage. Then, many of the utilities will be affected. So, utility service interruptions like traffic interruptions; or, the internet or telephone lines can be cut; or, there can be related problems like – that kind of interruptions can take place. Increased clean-up costs – once after the rainfall, if these things are not done properly, then many areas will be – lot of mud will be there, lot of the solid wastes will be on the road and other places. So, we have to spend more money for clean-up after the rainfall events. Then, related health

hazards, personal inconvenience, increased insurance costs – all these are all major issues related to stormwater if we do not appropriately manage the stormwater.

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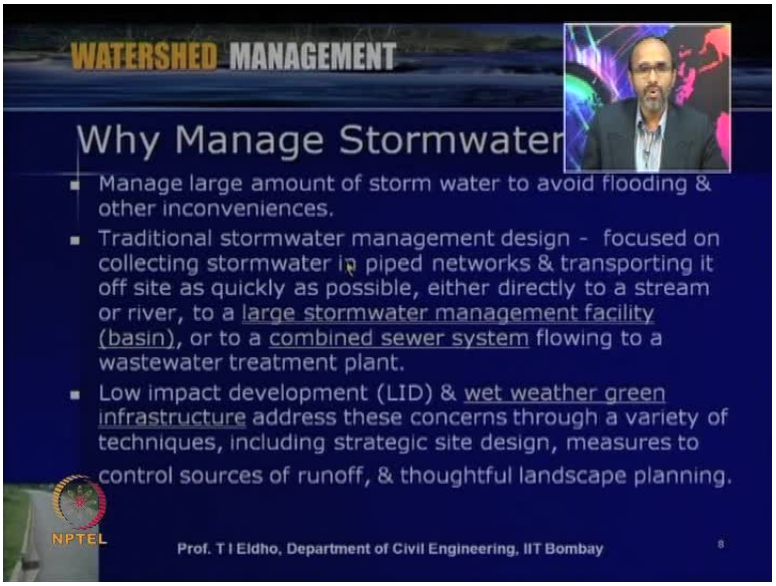

Some of the solutions – as we discussed, can be soft solutions like ponds, swales or wetlands; or, we can have hard solutions like concrete, steel, and HDPE pipes, concrete structures, etcetera, where this stormwater will be appropriately collected, stored, treated, and then released appropriately. So, that is why we have to go for stormwater management. Then also, as we discussed, depending upon the rainfall condition, we have to manage large amount of stormwater to avoid flooding and other inconveniences. Then, traditional stormwater management design – general trend is – we generally focus on collecting entire stormwater in piped networks like stormwater pipes; we transport this stormwater to offsite as quickly as possible, either directly discharge to a stream or river, either with some treatment or without treatment. Then, to a large stormwater management facility if its treatment is there or to a combined sewer system flowing to a waste water treatment plant. So, that is where we have to effectively manage stormwater since the quantity may be higher; then, the quality also we have to deal.

In recent times, in countries like United States of America, there are certain terms to deal with stormwater related issues or urbanizing issues; terms like low impact development or LID and then wet whether green infrastructure. These terms are coming to picture in the last few years. As I mentioned, there can be hard solutions as far as stormwater

management or soft solutions like an appropriate land management with respect to the construction of ponds, wetlands, etcetera. These low impact development and wet weather green infrastructure these times, which are coming to stormwater management in the last few years. These addresses the concerns through a variety of techniques, including strategic site design, measures to control sources of runoff, and thoughtful landscape planning. So, the main aim emphasis in the low impact development or the wet weather green infrastructure is mainly the landscape planning. The main emphasis to treat the stormwater wherever it occurs, instead of carrying entire stormwater to some centralized location, treat it, and then discharge to a river – instead of that, we would like to deal with stormwater at local level, it can be through landscape planning, or it can be some storage in some ponds or in some wetlands. Then, we should have appropriate plan. So, that way the terms like low impact development leads. Wet weather green infrastructure – these techniques are now in developing stage in countries like United States, Europe, and Australia.

These are found to be very effective to deal with the stormwater related issues. Overall environmental improvements have been observed in many of the small cities wherever this LID and wet weather green infrastructure things are being implemented. So, that way the main emphasis on… We are going for integrated stormwater management; it is not simply collecting the entire stormwater and then treating, but we are looking to an integrated system, where the stormwater management is done by considering various aspects of the land use and various other techniques.

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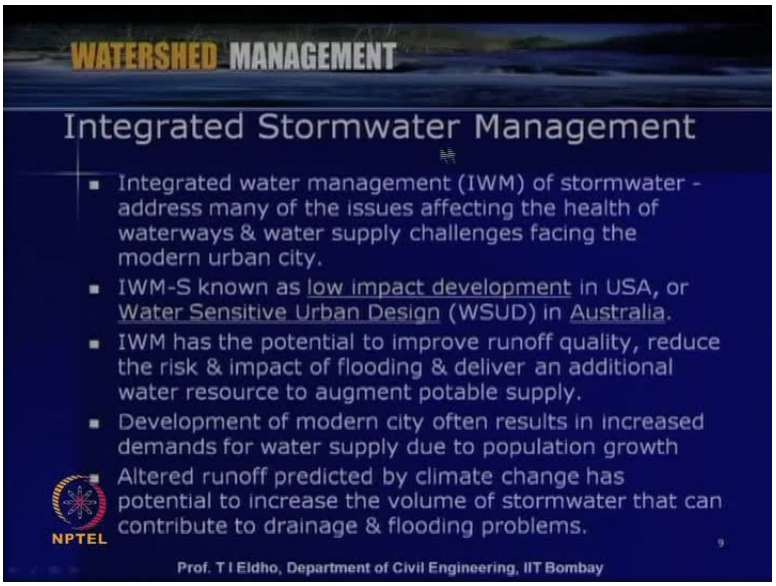

Let us look into what is integrated stormwater management. It is actually integrated water management only or IWM of stormwater. This addresses many of the issues affecting the health of waterways, water supply challenges facing the modern urban city. When we are effectively utilizing the water at local level wherever the stormwater takes place, we are actually reducing the water related problems, since we will be recharging the water or storing at local level. That can be directly utilized.

Integrated water management of stormwater known as low impact development in USA, or water sensitive urban design, WSUD in Australia; this integrated stormwater management is known as LID in USA or WSUD in Australia. IWM has the potential to improve runoff quality, reduce the risk and impact of flooding and deliver an additional water resource to augment the potable supply. So, the important terms here are – we want to reduce the risk, we want to reduce the flooding problem, and it will augment the potable water supply as far as the watershed is concerned. So, we are looking for development of modern city wherever the water needs will be made through these kinds of integrated water management.

Altered runoff predicted by climate change has potential to increase the volume of stormwater that can contribute to drainage and flooding related problems. So, this integrated stormwater management is a good option. We can reduce the problems like flooding or water quality issues. Also, we can improve the availability of the water on a

local level by site management or land use land cover management itself. So, that way this integrated stormwater management is adopted in many countries nowadays.

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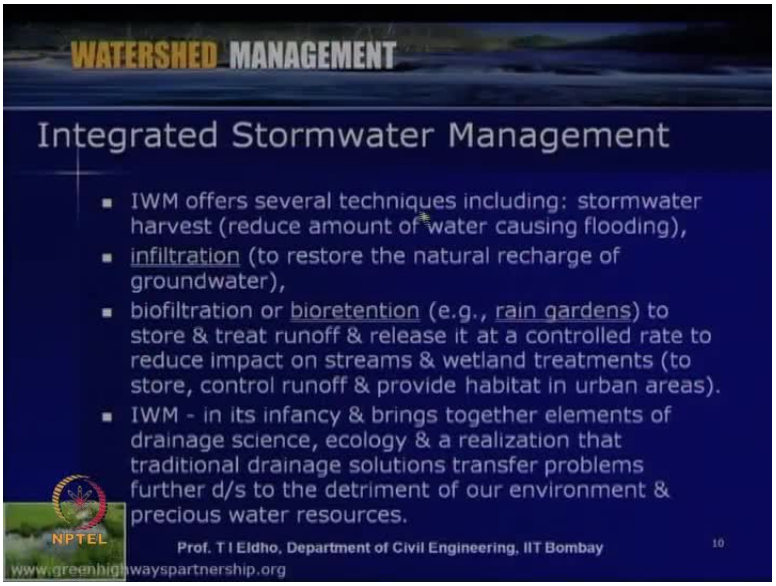

Further, this IWM offers several techniques like stormwater harvesting – as we have discussed, that reduce amount of water causing flooding. Infiltration – Infiltration means to restore the natural recharge of groundwater. Biofiltration or bioretention – that means just like rain gardens to store and treat runoff and release it at a controlled rate to reduce impact on streams and wetland treatments. So, the biofiltration or bioretention is same by making rain gardens or afforestation. By improving the plan covering, we can keep the rainwater for some more time and then it can be released in a control way, so that flooding will be reduced and then local water will be improved.

Integrated water management – in its infancy and brings together elements of drainage science, ecology and a realization that traditional drainage solutions transfer problems further downstream to the detriment of our environment and precious water resource. So, this integrated stormwater management is very important as far as the environmental management or environmental improvement – that means the water quality improvement; also, the water availability as far as the particular area is concerned.

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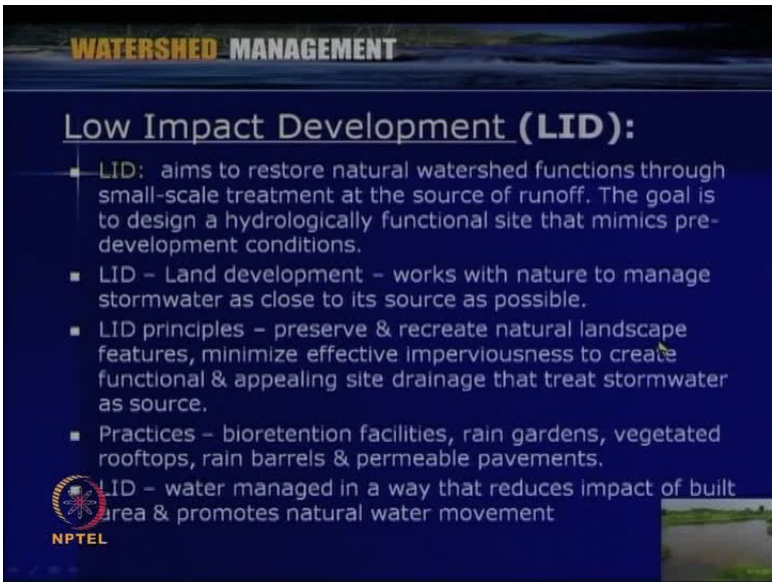

Now, let us further discuss some more aspects about this low impact development. Low impact development or LID aims to restore natural watershed functions through small-scale treatment at the source of runoff, as I already mentioned. The goal is to design a hydrologically functional site that mimics predevelopment conditions. Before the development, whatever the situations, we want to keep certain extent to that level itself by controlled development and various other needs. So, mainly, LID is related to land development and it works with a nature to manage stormwater as close to its source as possible. So, we do not want to take this entire stormwater to some central locations, treat it and then discharge to rivers, but we want to deal at local lever. So, that way it is a land development issue.

LID principles – the major principles are – preserve and recreate the natural landscape features and minimize the effective imperviousness to create functional and appealing site drainage that treat stormwater as source. So, this is the basic principle. So, we want to preserve and recreate natural landscape. Some of the important practices as far as LID is concerned, as I mentioned – bioretention facilities, rain gardens, vegetated rooftops, rain barrels and permeable pavements. So, these are some of the practices, which are adopted in countries like USA. This LID – water is managed in a way that that reduces impacts of built up areas and promotes natural water movements. So, that is the essence of LID. So, we are looking for natural water movement, so that more recharge will be

taking place, flooding will be reduced, and then there will be less possibility of water contamination.

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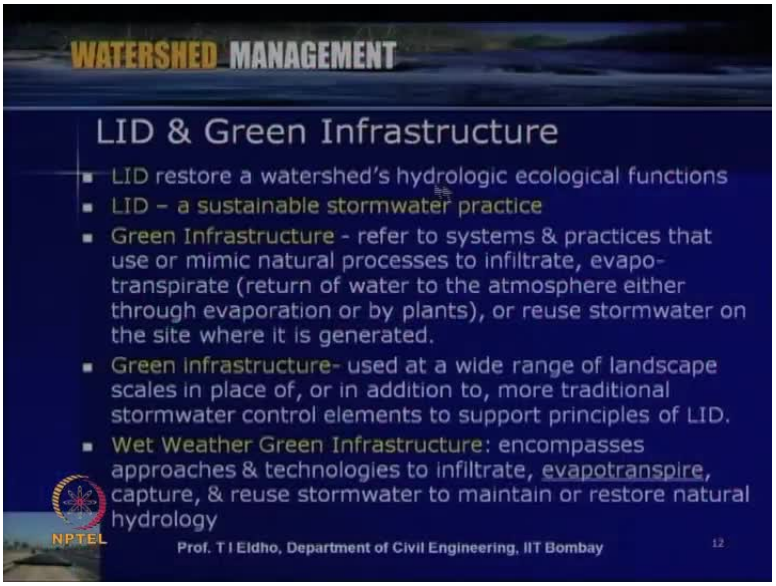

Another term as far as integrated stormwater management is concerned – green infrastructure. Let us look into some more aspects of this LID and green infrastructure. As I mentioned, LID restores a watershed's hydrological ecological functions. As we discussed, LID is a sustainable stormwater practice. So, that way the sustainability issues are there and that will be kept within the watershed, and then environment improvement also takes place. Green infrastructure – generally refers to the systems and practices that use or mimic natural processes to infiltrate, evapo-transpirate, or reuse stormwater on the site where it is generated. So, that way by improving the vegetation cover or through various means within the area itself, through green infrastructure, we are trying to increase the transpiration or evapo-transpirations. Then, we are also trying to reuse the stormwater by infiltrating down to the ground.

Green infrastructure – generally, used at a wide range of landscape scales in place, or in addition to, more traditional stormwater control elements to support principles of LID, which we discussed. Another term related to green infrastructure is wet weather green infrastructure – this encompasses the approaches and technologies to infiltrate, evapotranspire, capture and reuse the stormwater to maintain or restore the natural hydrology. So, in all these – LID or green infrastructure, the major emphasis is on

keeping the natural ecology with minimal developments, give the possibility of more recharge to the ground or to the aquifer systems, and then reduce the pollution.

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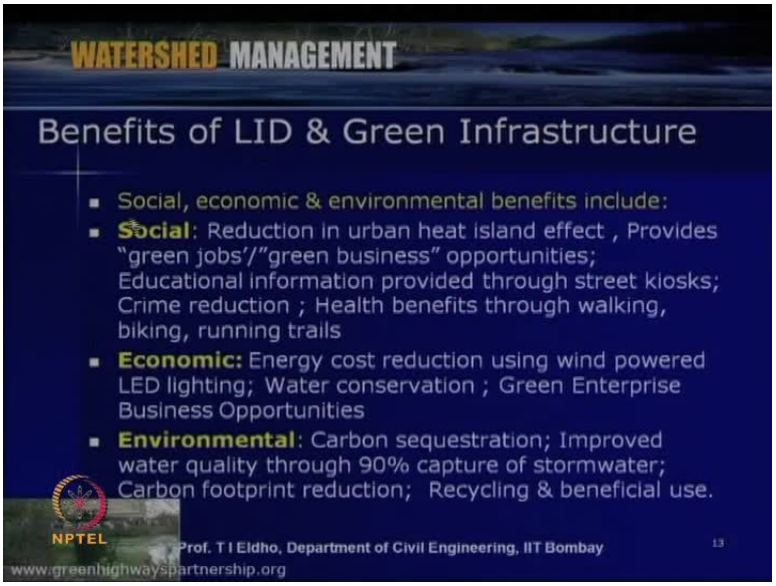

Some of the benefits of LID and green infrastructure includes – like benefits related to social, economic, environmental. Social means reduction in urban heat island effect, provides green jobs or green business opportunities. Whenever these kinds of planning takes place, more jobs are created. Then, educational information provided through street kiosks; crime reduction; health benefits through walking, biking, running trails, etcetera. So, there are some direct benefits and some of the indirect benefits also. Economic benefits include energy cost reduction using wind powered lighting, water conservation, green enterprise business opportunities, etcetera. As far as environment is concerned, the total environmental improvement will take place like carbon sequestration; improved water quality through 90 percent capture of stormwater; carbon footprint reduction; recycling and beneficial use, etcetera. So, these are some of the benefits of LID and the green infrastructure as part of the integrated stormwater management. Now, as we discussed, all these practices – it is better to do on a watershed scale since watershed is the hydrologic unit, as we were discussing in our lectures.

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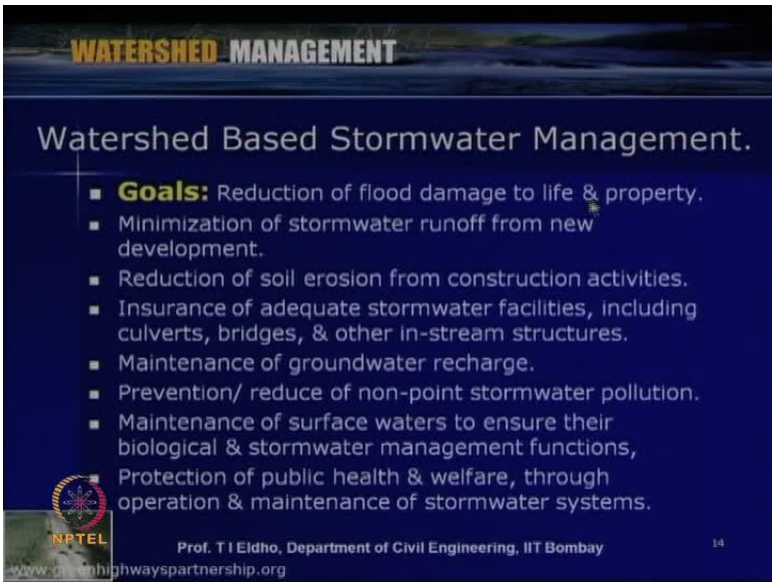

When we are looking into stormwater management on a watershed basis, some of the important goals include – like a reduction of flood damage to life and property, as we already discussed; minimization of stormwater runoff from new development; reduction of soil erosion from construction activities; insurance of adequate stormwater facilities; maintenance of groundwater recharge; prevention or reduction of non-point stormwater pollution; maintenance of surface waters to ensure their biological functions; protection of public health and welfare. So, like that we can set number of goals as far as the watershed based stormwater management is concerned. So, depending upon the area, depending upon the urbanization already took place, or what place the urbanization is taking place, we can set our goals and then we can try to achieve these goals. So, the main goal will be to capture the stormwater as much as possible quantity-wise, and then keep the best quality possible to improve the water quality as far as the stormwater is concerned.

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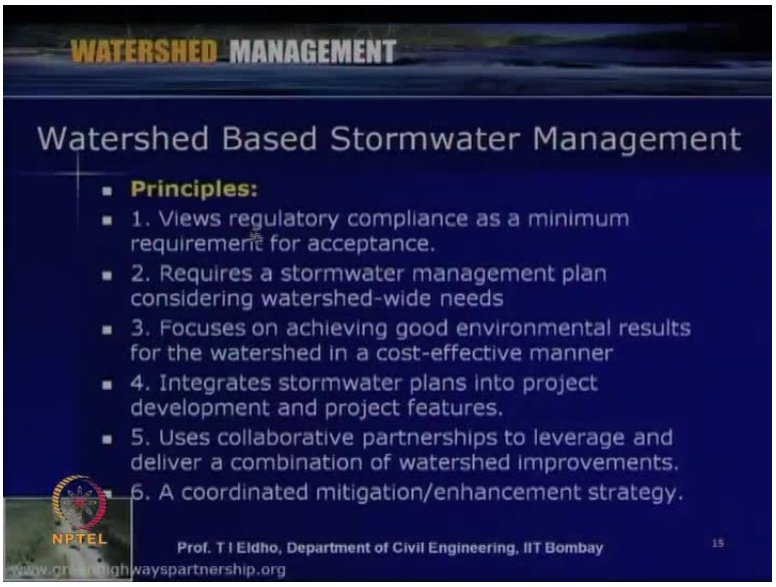

Some of the important principles, which we adopt for watershed based stormwater management includes – we can view the regulatory compliance as a minimum requirement for acceptance. Wherever rules and regulations are there, we have to see that they are implemented. Requires a stormwater management plan considering watershed-wide needs – when we consider the hydrology unit as the watershed based management, then we have to see what the other needs of the watershed are. So, accordingly, we can do the stormwater management.

It also focuses on achieving good environmental results for the watershed in a cost-effective manner. Integrates stormwater plans into project development and project features; uses collaborative partnership to leverage and then deliver a combination of watershed improvements; and then, a coordinated mitigation or enhancement strategy. So, when we deal with watershed based stormwater management, with respect to the goals, we can adopt specific technologies, which need with the regulatory compliance, so that there will be improvement as far as the total environment on a watershed basis. So, that way we look into the stormwater management.

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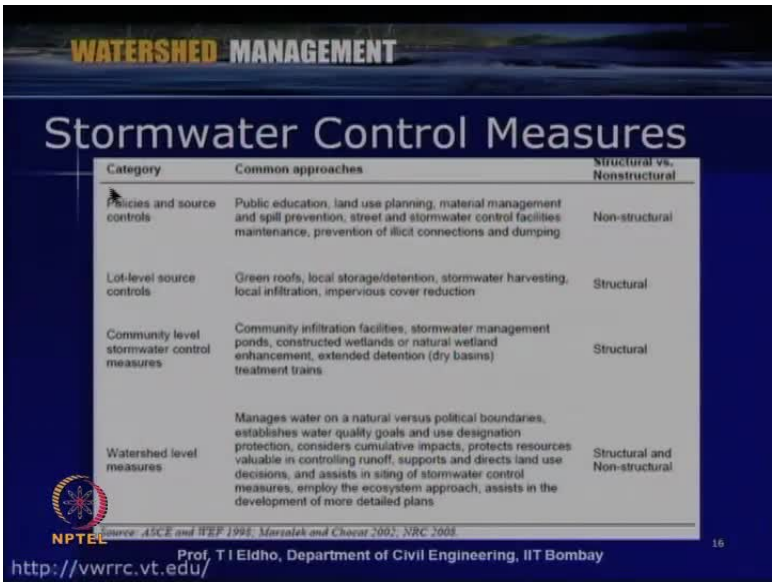

Let us now look into some of the important control measures. We can have various measures to deal with stormwater. So, let us look into various approaches as far as the stormwater is concerned. The policies and source controls are concerned – it can be public education, land use planning, material management, etcetera. Lot-level source controls are concerned – we can look for green roofs, local storage or detention stormwater harvesting, local infiltration, etcetera. Community level stormwater control measures are concerned – we can go for community infiltration facilities, stormwater management ponds, constructed wetlands or natural wetlands. So, these are all structural measures (Refer Slide Time: 36:21); actually, the policies and source controls concerned – which is non-structural measures.

Watershed level measures – can be structural or non-structural depending upon what we are adopting or what kind of control measures we are going for. The common approaches like – manages water on a natural versus political boundaries, establishes water quality goals and protects, and then considers cumulative impacts, etcetera. So, we can go for various systems depending upon what kind of category we are looking for or what kind of measures like – whether we are going for structural measures or non-structural measures. So, various norms, various approaches are possible. So, according to the set goals, specified principles, and the compliance with respect to the regulations, we can choose our appropriate approach for that location or for that watershed like – structural

measures or non-structural measures, and then we can go for the stormwater management.

As far as stormwater is concerned, when we deal with the urbanized watershed, most of the urbanized areas will have the sewage system also; we have to deal with the sewage systems, and then also, we have to deal with the stormwater. In many cities – small or large cities, there can be separate system: one system for only to deal with the stormwater, and then another piping or other kinds of systems to deal with the sewage or the waste water. So, as far as stormwater management is concerned, we can have separate systems; or, in some cities or some areas – especially there were countries – we can see that there can be combined systems, where for both the sewage systems or the waste water and stormwater, only one system is given. That kind of system is called a combined system.

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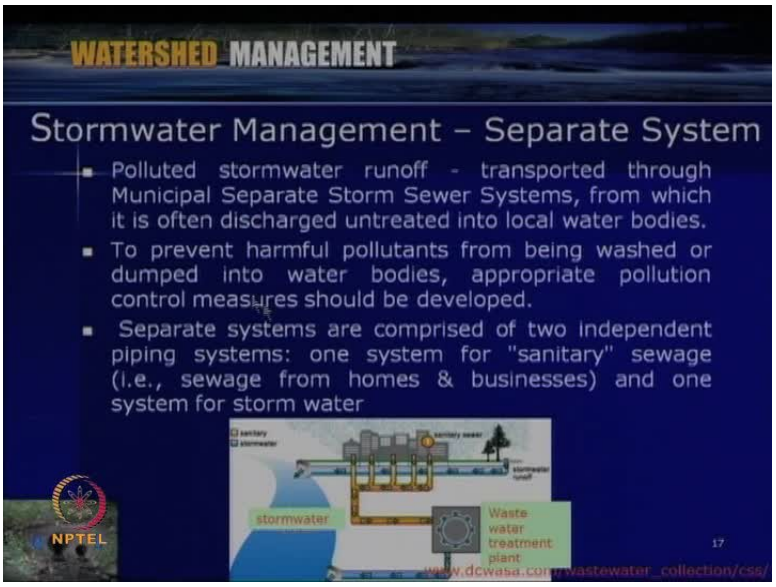

Let us look into some aspects of the separate system and combined system. In the separate system, the polluted stormwater runoff – we transport through municipal separate storm sewer systems, from which it is often discharged untreated into local water bodies. To prevent harmful pollutants from being washed or dumped into water bodies, we can also go for appropriate pollution control measures. Separate systems are comprised of two independent piping systems: one system for the sanitary or the waste water, and another for the stormwater system.

You can see here in this layout (Refer Slide Time: 39:07) – if these are some of the urbanized areas and then stormwater is concerned, it is now separately collected, and then it is directly discharged to a river like this. Then, the waste water is concerned – it is all collected through the pipelines and there will be a treatment facility like this; then, after treatment, it is discharged to the river or the stream. So, that is the basic principle of separate system.

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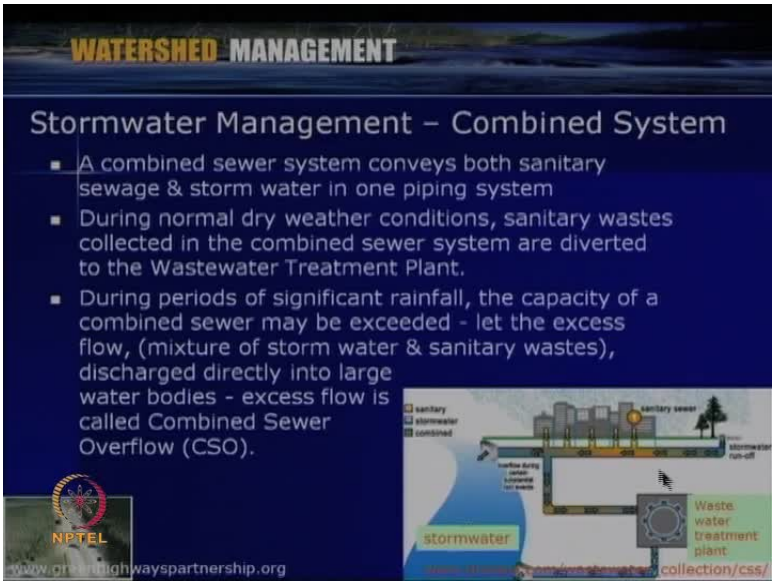

Now, let us look into the combined system. The combined sewer system conveys both sanitary sewage and stormwater in one piping systems. During normal dry weather conditions, sanitary wastes collected in the combined sewer system are diverted to the waste water treatment plant. During the periods of significant rainfall, the capacity of a combined sewer system may get exceeded; that is, so-called an excess flow. This is a mixture of stormwater and sanitary waste. This directly discharges into large water bodies; or, sometimes we call this excess flow as combined sewer overflow. So, the system is like this – when there is no rainfall, the entire waste water is collected, then it will be collected like this, then it will be treated at this location, and then it will be discharge to the river or stream. Then, during the rainfall season, this sewage water or the waste water and the stormwater will be coming. So, a mixed combination of stormwater and waste water will be there and that will be discharge to the… So, depending upon the condition, it may be treated; or, without treatment also, sometimes it will be discharged to the streams or rivers. So, this is so-called combined systems.

What we are discussing is – how to manage these stormwater, whether it is a combined system or separate system? So, that way we have to either collect through pipelines or the open drains; then, it can be – after treatment or without treatment, it will be discharged. Now, let us look into what are the effects of this, if we do not manage the stormwater properly. As we discussed, the main effect will be the flooding problem.

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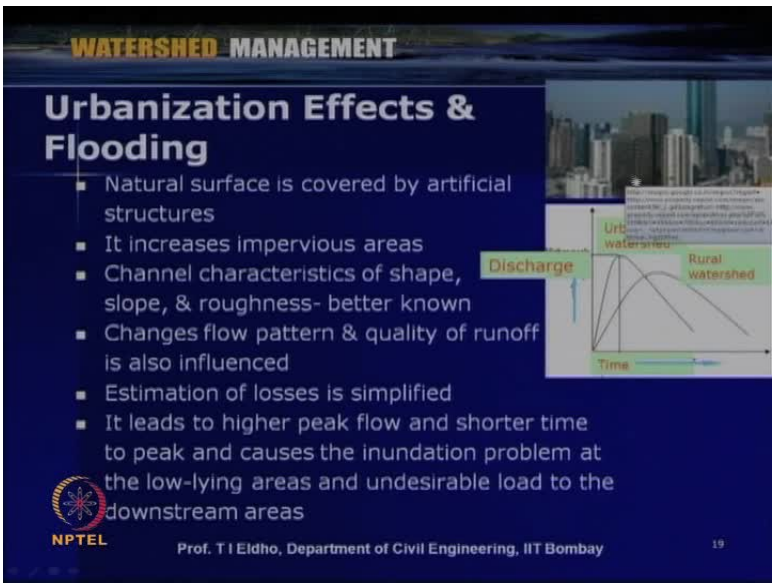

Let us look into the urbanization effects and the flooding problem. As we discussed, whenever the urbanization takes place within a watershed, so many structures will be constructed, roads will be constructed. The natural surface is covered by artificial structures. So, that way it increases impervious areas. Channel characteristics of shape like shape, slope, roughness – these are all better known as far as the urban areas are concerned. There will be changes in flow pattern and quality of runoff will be also influenced. Then, the losses are concerned – like infiltration losses – sometimes we can neglect. So, estimation of losses becomes simplified. However, this may lead to higher peak flow and then shorter time to peak and causes the flooding at the low-lying areas and undesirable load to the downstream areas.

You can see that if there is no urbanization – that means a natural watershed. So, generally, if you plot the hydrograph – that means time versus discharge, you can see that rural watershed, where there is not much urbanization, the hydrograph will be a flattened graph like this, (Refer Slide Time: 42:46) and the peak will be at this location.

However, in the same location, if urbanization takes place, then we can see that this hydrograph peak will be increased like this, and then time to peak will be reduced. So, that way we can see what happens – the time of concentration is reduced; time to peak is less, then, huge quantity of water will be coming to the drainage systems or to the streams or to the river; and then, that will rise the water depth, and then finally, the flooding will be the effect. So, the main urbanization effects will be like – the peak of the hydrograph, the discharge will be increased, and then time to peak will be reduced. So, within a short duration, there will be possibility of flooding. So, that is the main effect of urbanization.

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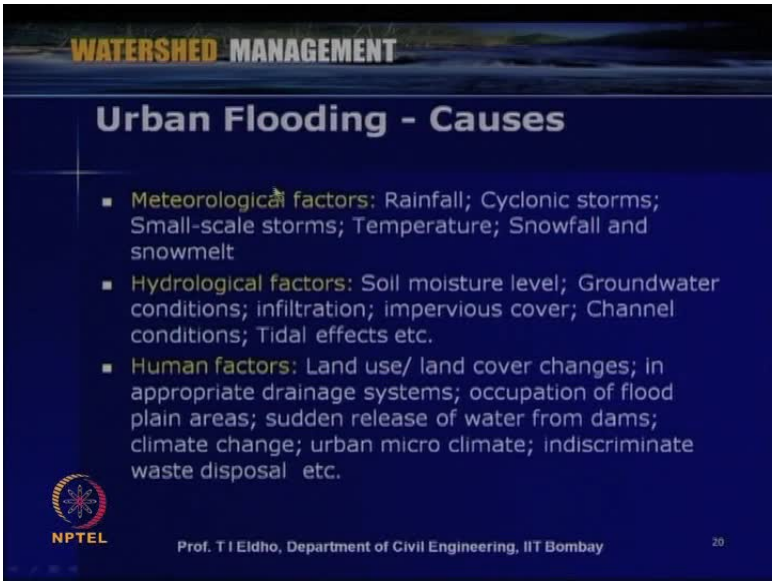

Due to urbanization and urban flooding, there can be number of reasons or number of causes. Some of the important causes are listed here. The causes can be due to meteorological factors, hydrological factors, or human factors. Meteorological factors like rainfall, cyclonic storms, small-scale storms, temperature increase, snowfall and snowmelt. Hydrological factors can be soil moisture level, groundwater conditions, infiltration, impervious cover, channel conditions, tidal effects, etcetera. Human factors like changes in land use; urbanization means – actually what is happening is a change in land use; so, land use or land cover changes; inappropriate drainage systems – there is no effective drainage systems or the drainage system is not effective; occupation of flood plain areas – like wherever the flood plain areas, that is, buildings are constructed, or it is enclosed; sudden release of water from dams due to the heavy rainfall conditions;

climate change effects; urban micro climate; or, indiscriminate waste disposal. So, these are some of the causes of urban flooding. Now, as we discussed, main issue is the flow depth increases and time to peak reduces. So, sudden flash flood can take place.

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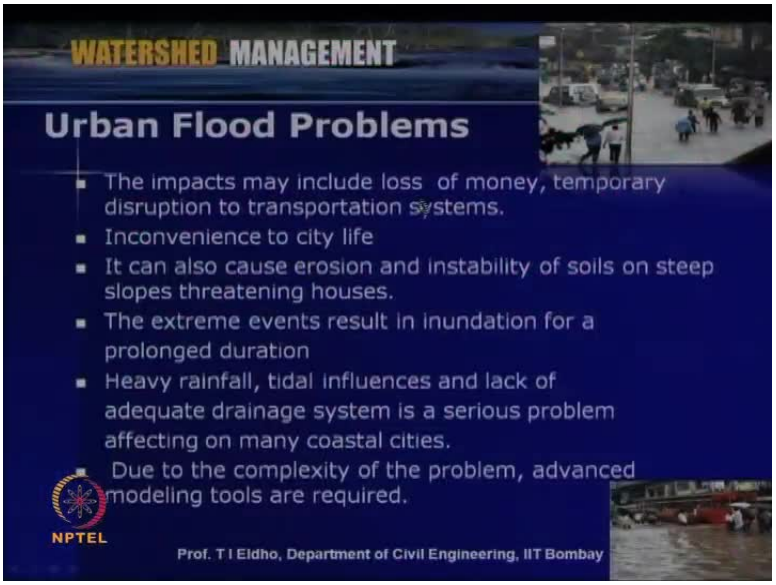

Now, let us look what are the problems related to urban flooding. In this slide, the impacts may include loss of money, temporary disruption to transportation systems, or the telecommunication systems. Then, inconvenience to city life. It can also cause erosion and instability of soils on steep slopes threatening houses; there can be land slide and other related issues. Then, the extreme events result in inundation for a prolonged duration. Heavy rainfall, tidal influences and lack of adequate drainage system – these are all some of the serious problems affecting especially in the coastal areas; simultaneously, with heavy rainfall, the tidal level also rises in a city like Mumbai. Then, you can see that heavy flooding problems – that will be prolonged flooding as happened in 26 July 2005. Due to the complexity of this problem, whenever we deal with urban flooding or urban flood prediction, we need sophisticated tools like geographic information system, data – we may have to get from remote sensing, and then very complicated numerical methods like finite element method or finite different techniques – we have to utilize to see whether the flooding possibilities and other things. So, in urban flooding, major issues are loss of life, economic loss, disturbance to the transportation, and the telecommunication systems.

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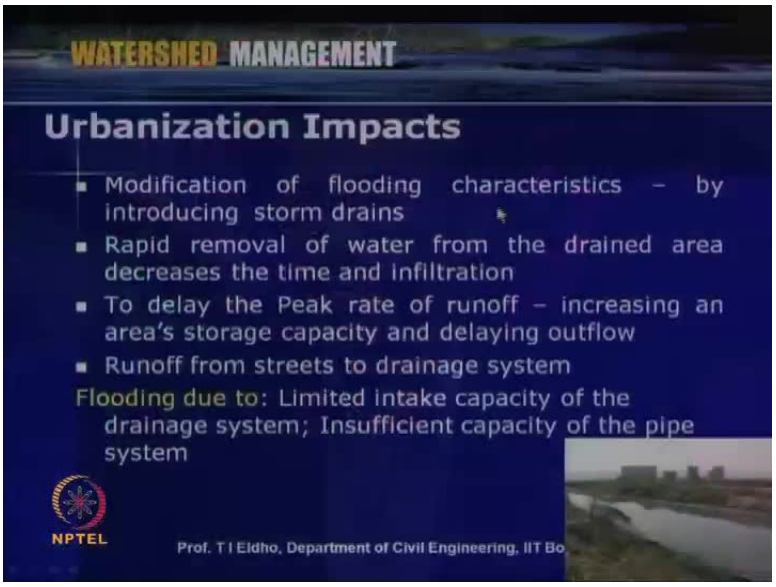

Also, the urbanization impacts – there can be modification of flooding characteristics – will be modified by introducing the storm drains in many of the urban areas. Rapid removal of water from the drained area takes place as we discussed, since the time and infiltration decreases. To delay the peak rate of runoff – increasing the area's storage capacity and delaying outflow. So, we can have the possibility of detention pond, so that all these problems can be reduced. Runoff from streets to drainage system takes place directly instead of through the drainage systems. Flooding takes place since limited intake capacity of the drainage system; if it is pipe system, insufficient capacity of the piped drainage systems.

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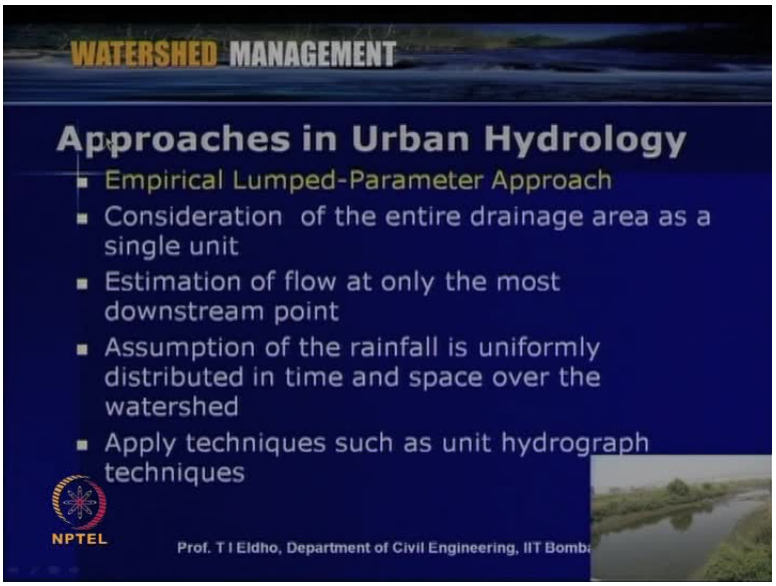

To deal with the urban flooding problems, in urban hydrology, generally two types of approaches are used. First one is empirical lumped parameter approach. In the empirical lumped parameter approach, we consider the entire drainage area's single unit. Then, we estimate the flow only at the most downstream point or the outlet of the watershed. Then, we assume the rainfall is uniformly distributed in time and space over the entire watershed. Then, we can have techniques like unit hydrograph; instantaneous unit hydrograph techniques. Then, we can see that how the system is behaving.

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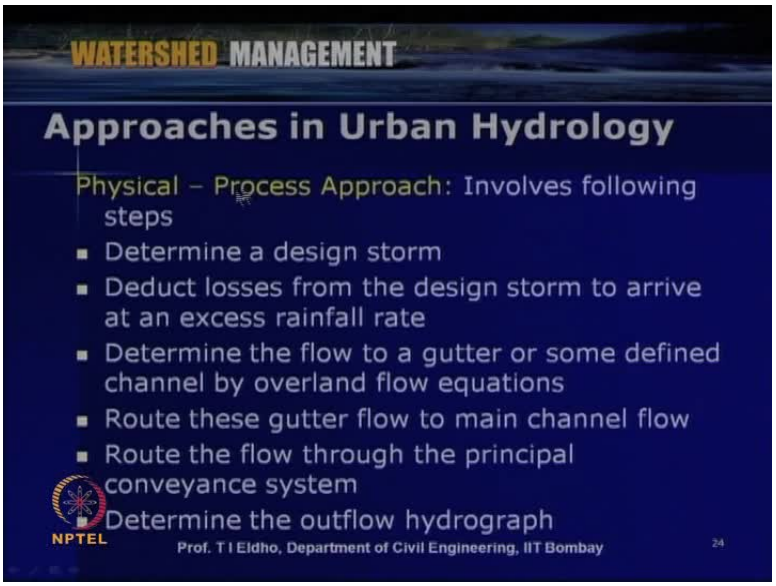

Other approach is called a physical process approach. In the physical process approach, we have to go for appropriate design of this stormwater system; we deduct losses from the design storm to arrive at an excess rainfall rate – how much is the excess rainfall taking place. Then, we can determine the flow to gutter or the drainage systems. Then, we can route through this gutter to the main channel. Then, we can route the flow through the principal conveyance systems. Finally, we can determine the outflow hydrograph. So, accordingly, depending upon the outflow hydrograph and the outlet of the watershed, we can go for design or we can go for the management of the system, which we consider. Now, what we are discussing is about the stormwater management and urban flooding related problems. When we deal with the various measures to delay, we cannot completely control the storm runoff, or we cannot totally deal with the entire systems.

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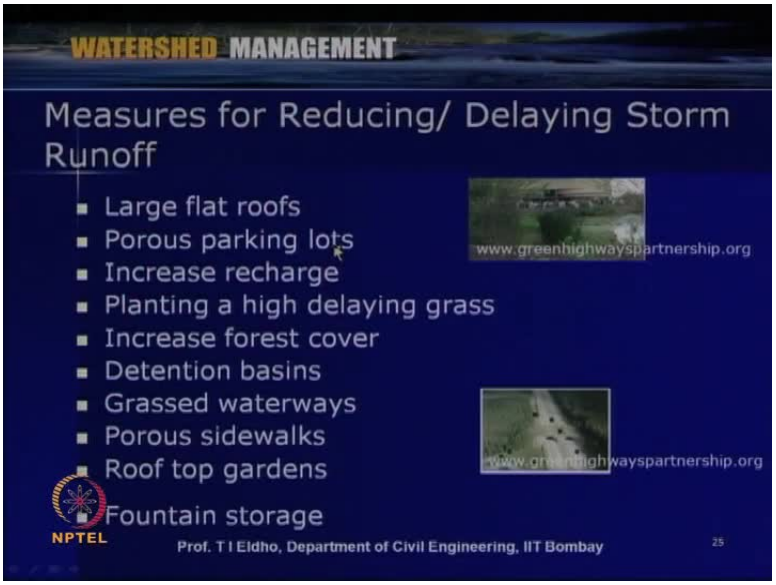

Generally, we can reduce or delay these storm runoff, so that number of measures are available like some of the measures, which we can utilize include – large flat roofs, porous parking lots, increase recharge, planting a high delaying grass, increase forest cover, detention basins, grassed waterways, porous sidewalks, roof top gardens, fountain storage, etcetera. In all these, what we are trying is, we are trying to delay the movement of the stormwater; we are trying to infiltrate down some of the portion of the storm runoff; we are trying to delay the movement of the runoff, so that the time to peak will be

increased and the peak also will be reduced as far as these urban storm runoff is concerned.

Before closing this lecture, let us look into a case study related to the stormwater drainage for an urban area.

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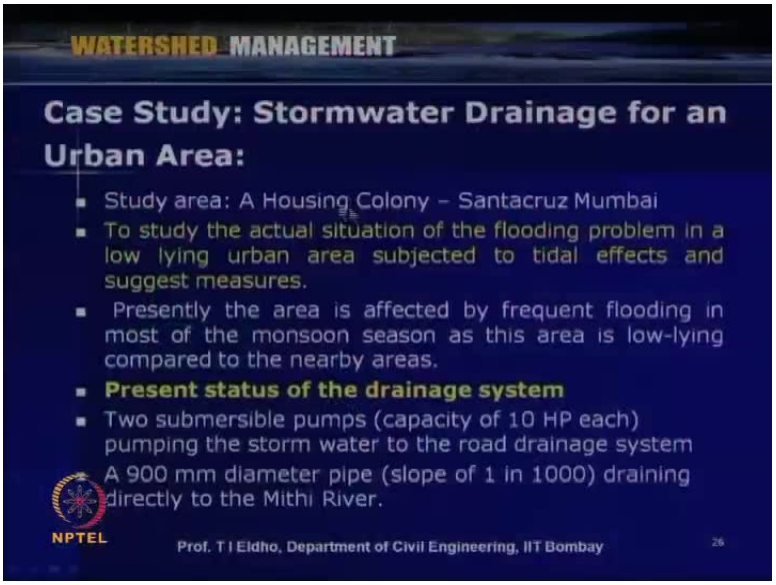

The study area is a housing colony in Santa Cruz Mumbai. Here the aim is to study the actual situation of the flooding problem in a low lying urban area subjected to tidal effects and suggest measures. Presently, the area is affected with frequent flooding – this study, was carried out in 2006; there were heavy flooding in 2005 itself. Present status of the drainage system; two submersible pumps, which pumps this stormwater to outside drainage system; then, there is a 900 mm diameter pipe draining directly to a nearby river called the Mithi river.

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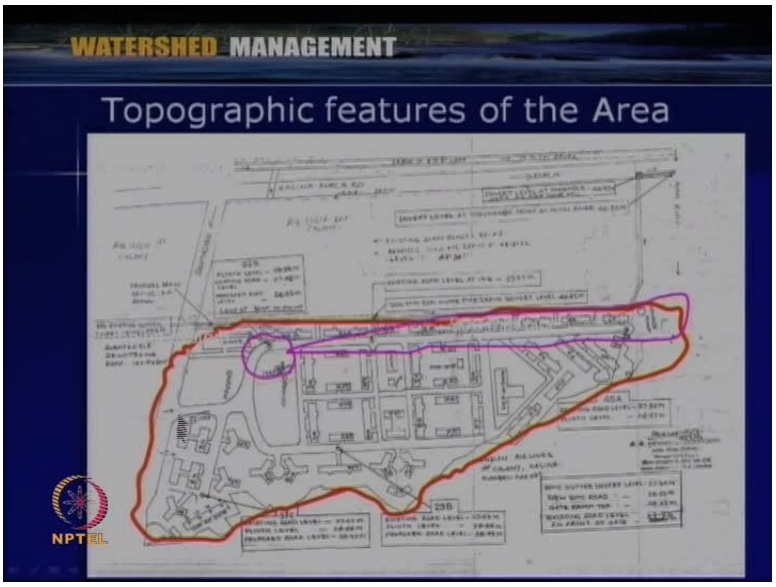

This is the area; you can see that here for this entire area, there is a major drainage system going to the Mithi river here, which will be join to the Arabian sea. Here the existing system was – there was a drainage system, which is joining here and then there was a 900 mm pipe, which is taking all these stormwater from the area. However, due to the heavy rainfall conditions, for example, in 2005 July 26, this entire area was flooded for few days, and then the housing colony came to us to see the remedial measures.

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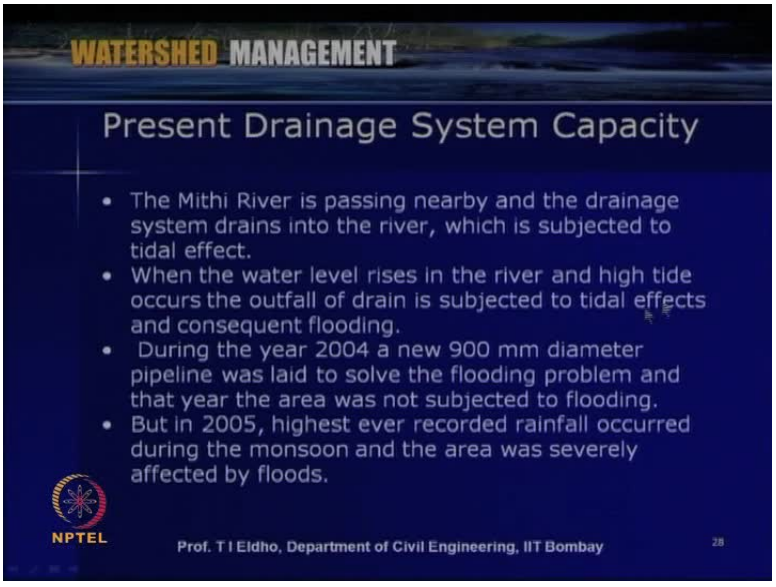

Here the two issues are there: one is the main flow taking place within the area and then also the tidal rise, what is happening within this river system. Then, that will be the back flow coming to the area. When the water level rises in the river and high tide occurs, the outfall of drain is subjected to tidal effects and consequent flooding. During the year 2004, a new 900 mm diameter pipeline was been constructed, but in 2005 as I mentioned, again there was flooding.

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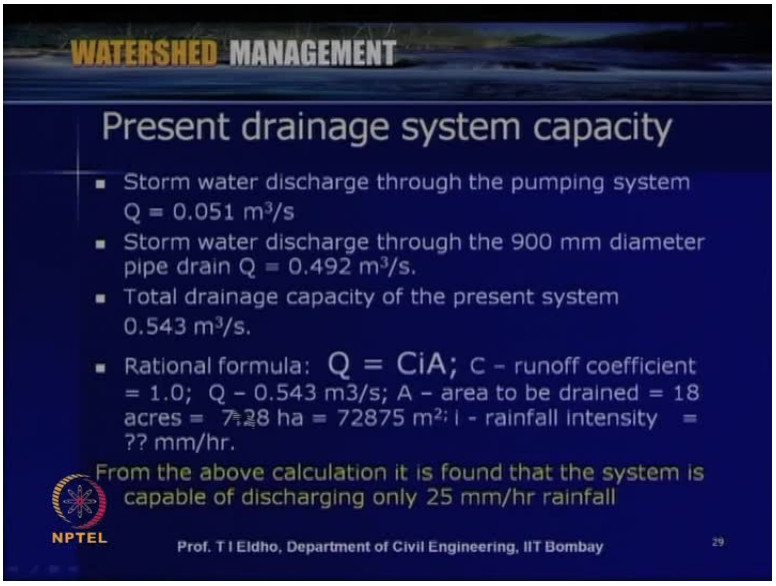

Here we analyze the system hydrologically and then hydraulically also, our analysis showed that the storm water discharge through the pumping is about 0.051 meter cube per second. The storm water discharge through the 900 mm diameter pipe was 0.492 meter cube per second. Total drainage capacity is 0.543 meter cube per second. We used here a rational formula, Q is equal to CiA and runoff coefficient has been considered as 1. Accordingly, we found that this drainage system is effectively useful only up to a rainfall of 25 mm per hour.

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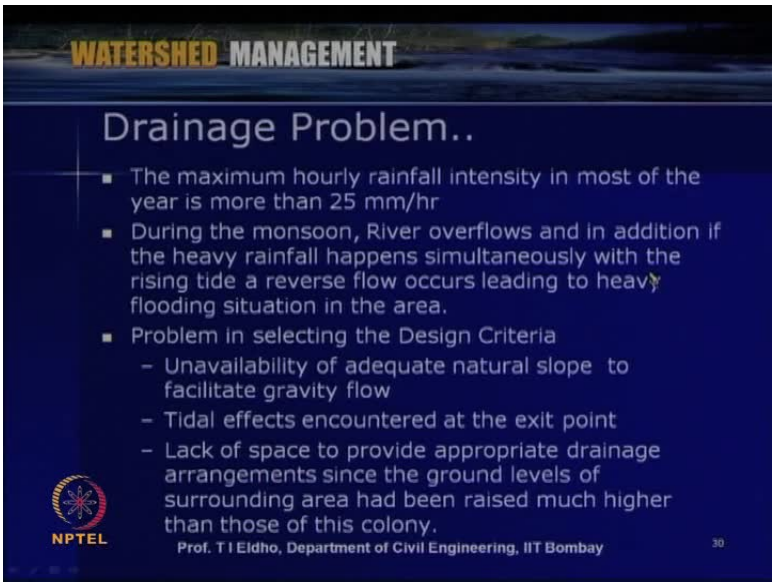

However, many times the rainfall exceeds; many years the rainfall exceeds – it can be 50 mm per hour. During the monsoon, as I mentioned, river overflows and in addition the heavy rainfall happens, simultaneously, the reverse flow occurs. That is the main issue here. The problem in selecting the design criteria like unavailability of adequate natural slope to facilitate gravity flow, tidal effects encountered at the exit point, lack of space to provide appropriate drainage systems. So, these were some of the problems in this area.

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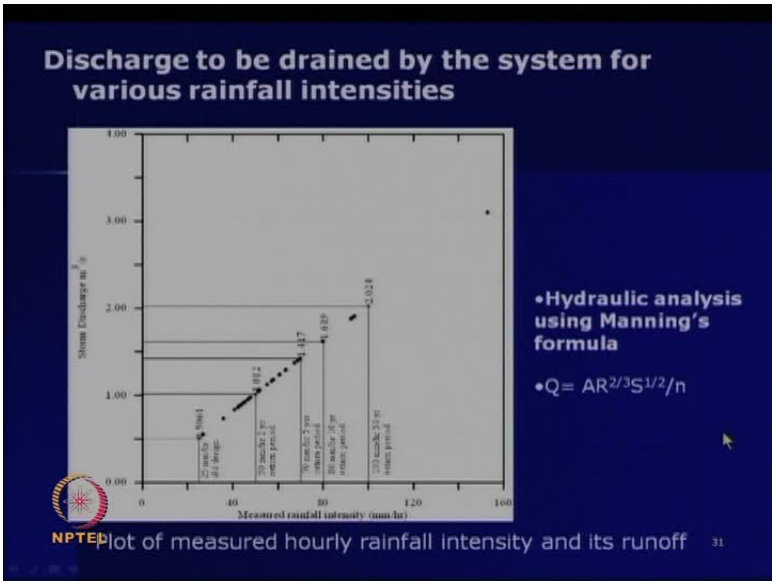

Then, we analyze hydrologically and hydraulically various rainfall conditions like 25 mm per hour, 50 mm per hour, 100 mm per hour – like 2 year retain period, 5 year retain period, 10 year retain periods – like that up to 50 years retain period like 100 mm per hour. This shows the measured rainfall intensity and this shows the stormwater discharge. Then, we did the hydraulic analysis using the Manning's equations: Q is equal to A into R to the power 2 by 3 S to the power 1 by 2 by n; where, n is the Manning's reference coefficient, A is the drainage sectional area, R is hydraulic radius: A by p; p is the weighted perimeter, S is a slope. There we use this hydraulic analysis to suit, for example, at least a 50 mm per hour; if the rainfall intensity takes place how we can effectively design?

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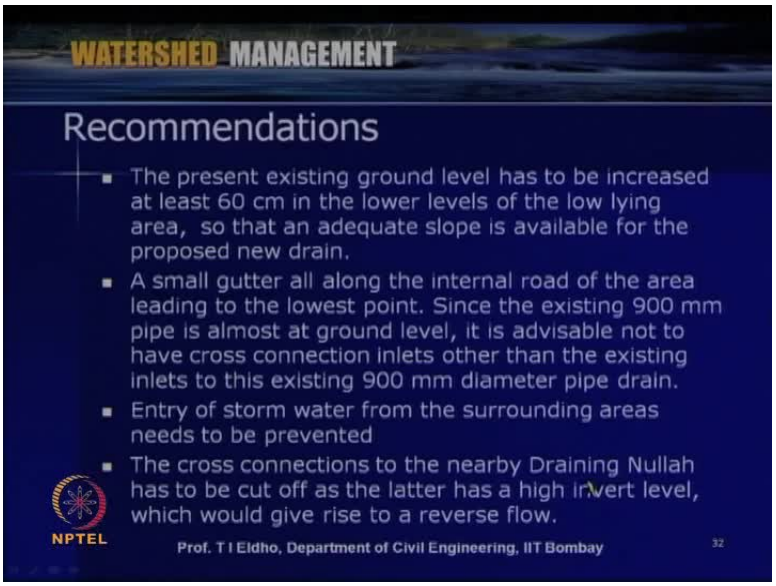

What we identify through the study is – the present existing ground level has to be increased at least 60 centimeter in the lower levels of the low lying area, so that adequate slope is available. Then, a small gutter all along the internal road of the area leading to the lowest point should be given. Since the existing 900 mm pipe is almost at ground level, it is advisable not to have cross connection to this. Then, entry of stormwater from the surrounding areas needs to be prevented. Then, the cross connections to the nearby Draining Nullah has to be cutoff. So, these were some of the recommendations as far as this study area is concerned.

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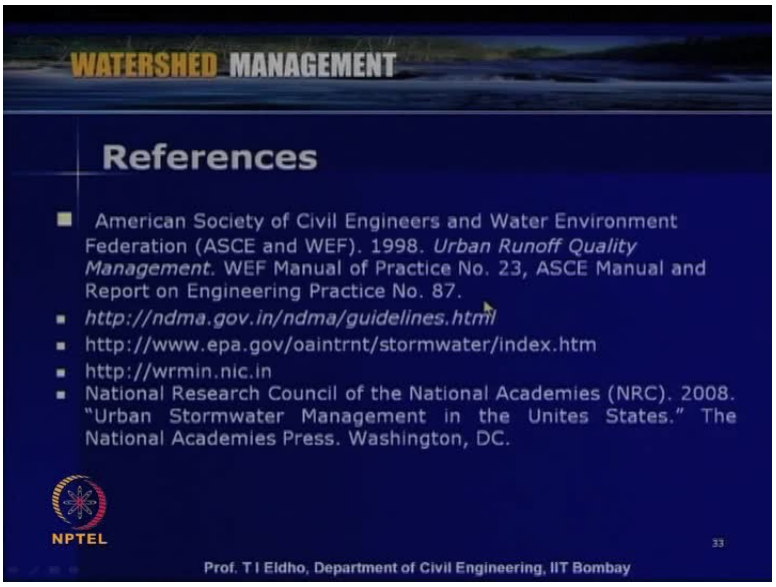

We did the hydrological analysis, hydraulic analysis, and then we came up with certain recommendations to reduce the urban flooding problem in this area due to the stormwater.

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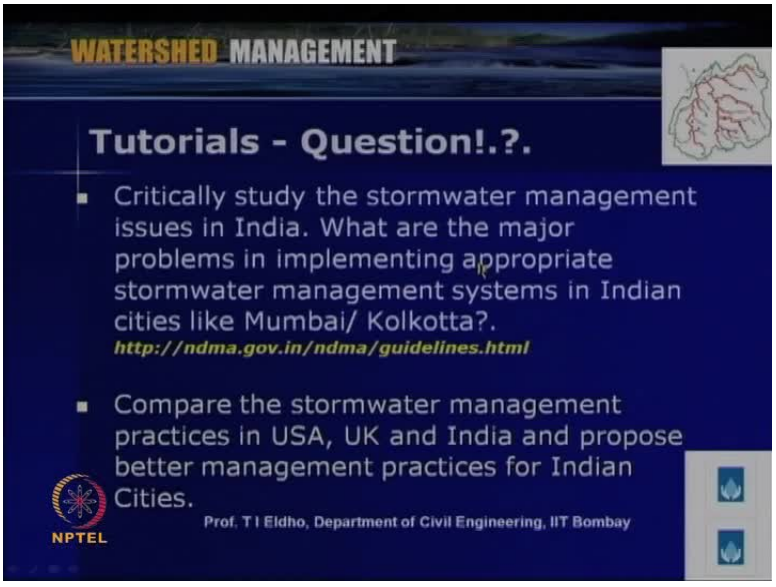

Before closing some of the questions like tutorial questions, critically study the stormwater management issues in India. What are the major problems in implementing appropriate stormwater management systems in Indian cities like Mumbai and Kolkata?

Then, you can compare with the systems in USA or UK, and then come up with better proposal for stormwater management for Indian cities.

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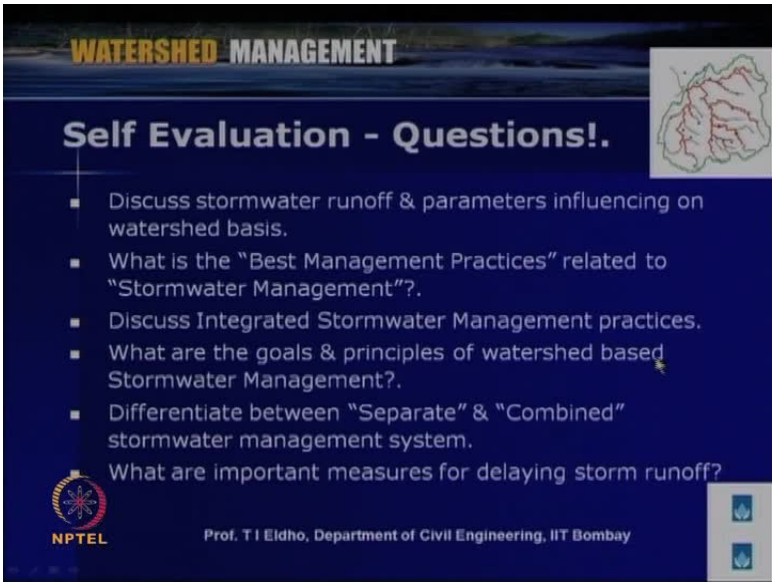

Some few self-evaluation questions: Discuss stormwater runoff and parameters influencing on watershed basis. What is the best management practices related to stormwater management? Discuss the integrated stormwater management practices. What are the goals and principles of watershed based stormwater management? Differentiate between separate and combined stormwater management systems. What are the important measures for delaying stormwater storm runoff?

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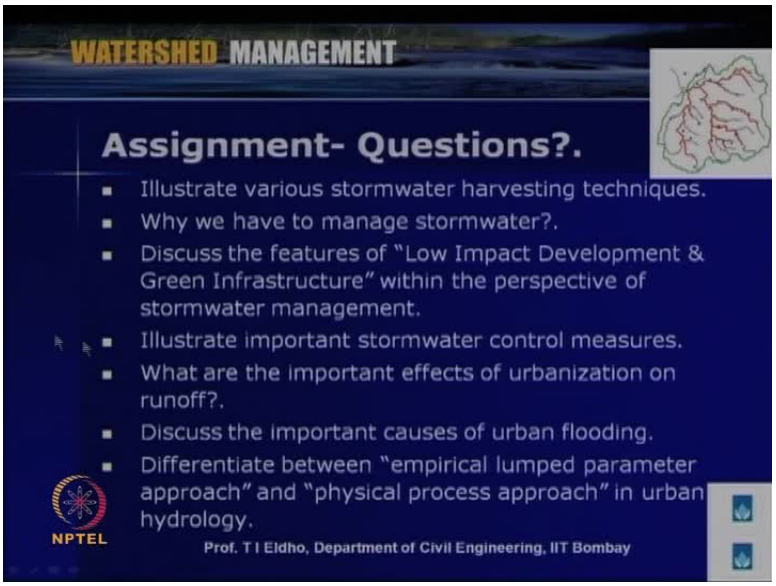

Few assignment questions: Illustrate various stormwater harvesting techniques. Why we have to manage stormwater? Discuss the features of Low Impact Development and Green Infrastructure within the perspective of stormwater management. Illustrate important stormwater control measures. What are the important effects of urbanization on runoff? Discuss the important causes of urban flooding. Differentiate between empirical lumped parameter approach and physical process approach in urban hydrology. All these questions you can answer by going through today's lecture.

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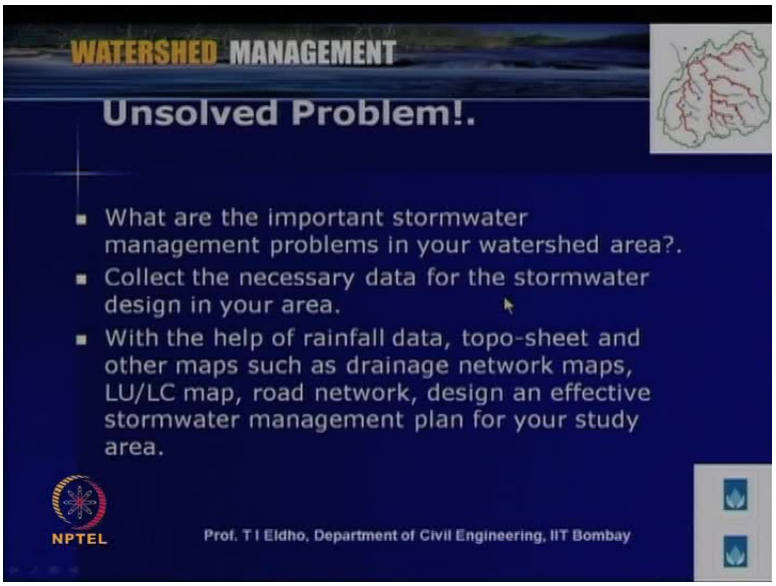

Before closing down one unsolved problem: What are the important stormwater management problems in your watershed area? Collect the necessary data for the stormwater design in your area. With the help of rainfall data, topo-sheet and other maps such as drainage network maps, land use or land cover map, road network, design an effective stormwater management plan for your study area.

As presented the case study, for your study area, you can come up with a typical design to deal with the stormwater management issues. Today, what we discussed is stormwater management. In the next lecture, we will be discussing about the drainage design and related issues as far as the stormwater system is concerned.

Thank you.