

Water Quality Management Practices

Prof. Gourav Dhar Bhowmick

Agricultural and Food Engineering Department

Indian Institute of Technology Kharagpur

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Lecture - 47

Constructed Wetlands

Hello everyone, welcome to this NPTEL online certification course on Water Quality Management Practices. My name is Gourav, Professor Gourav Dhar Bhowmick. I am from the Department of Agriculture and Food Engineering of Indian Institute of Technology Kharagpur. In this particular module we were discussing we are discussing about the advanced aerobic anaerobic wastewater treatment systems. In this particular lecture I will be focusing on the development of constructed wetland. This will be the concepts that we will be covering in this lecture the overall overview of constructed wetland systems, the classification of constructed wetland systems, surface flow, subsurface flow or the hybrid ones, the plants that we normally use in constructed wetland, its salient features and the design of a constructed wetland system.

To start with let us figure out like figured out like what is the basic difference between a natural wetland and the constructed wetland systems. In case of natural wetland systems what is happening there we have a saturated or we have a land which is saturated or submerged with water either on surface or the groundwater or saline or freshwater where selective water loving plants are majorly grown. Example are the marshes the salt marshes or the normal fresh marshes and all. So, where the or the edge of the lake or the ocean area, the delta in the river of the in the mouth of the river where like majorly the estuary areas, the low lying areas where which frequently flooded with water up to a certain height that promotes the growth of plants that are considered as the natural wetlands and all.

Oxygen which produced by the plant which diffuses towards the root and it creates an aerobic anaerobic zone and the microorganisms in this zone actually it contribute to the organic matter degradation and further nitrification and denitrification. That means, this natural wetlands are like a natural purification systems. So, the wastewater when it enters with the any impurities that is present in the water what happens because of the because

of this natural wetlands and all it has this first of all it has a soil system which acts like a natural filtration system plus its plant it also it is plant root zone it also because of the oxygen that is actually liberated with the specific type of wetland plants. So, what happened they generate a aerobic anaerobic zone in the nearby vicinity because of this aerobic plus anaerobicity that is maintained in this soil this upper layer and what is happening the micro that is the pollutant that is present in the wastewater is being consumed by this different aerobic and the anaerobic microorganisms present in this area. So, this is how in generally in the natural wetland systems how they can actually consume they can actually get rid of the waste I mean like the pollutant present in the wastewater.

So, what happened in case of constructed wetland? In case of constructed wetland it is built for this wastewater treatment specifically artificially built it is a because of it is a human made structure where we mimic the natural wetland principles ok. It normally consist of a soil gravels selective this water loving plants and the active microorganisms which actually helps us to mimic the natural wetland, but at the same times we can accelerate the process the this the treatment of the wastewater or the treatment of the pollutant that is present in the wastewater we can accelerate the process by actually manually or the literally engineered the whole system. Aerobic and anaerobic zone that is present in this constructed wetland or in short we call it CWs normally promote the symbiotic interactions between the plant as well as the different beneficial microorganisms the bacteria as I know. This see this is how a wetland looks like we have in general natural atmospheric condition you see this what is happening in the aerobic zone on the top layer and normally the root where some of this you know what is happening in this kind of wetland plants. So, the because the water the root system stays in the water law conditions.

So, it needs to breathe right it needs some oxygen. So, this oxygen is normally being supplied from the soot from this aran camel to this there is a pathway and it actually goes to the root systems and in some cases the root even breathe out some of the excess amount of oxygen from the systems. So, that is why there is a this is a very specific type of plants and they are having this specific aerobic condition prevailing around its root system. So, this aerobic condition that it prevails around its root system plus because of the shallow water depth or the soil depth the aerobicity is maintained in that region. So, this is the aerobic part then in the little bit down you will have this anaerobic systems where the microorganisms and the substrate and which will be going down and this anaerobic microorganisms plus aerobic microorganisms they both combinedly will treat the oxygen the organic matter present in the wastewater as well as the denitrification as well as the nitrogen present in the wastewater.

How it is happening if you see in this left side? So, whenever they the excess organic matter the wastewater along with this excess organic matter come into coming into the picture I mean like in this wetland. So, this they started decomposing in presence of anaerobic microorganisms in the bottom and it will liberate the methane and the oxygen and the carbon dioxide. So, because of this methane and carbon dioxide then it will liberate from the systems and it will reduce the organic matter present in the system organic matter present in the unit. At the same time the nitrogen's like suppose the nitrogen or the phosphorus organic phosphorus it also converted organic matter organic phosphorus it converted into mineral mineralized phosphorous like phosphorus in a mineralized it will just mineralize the phosphorus. So, because of that it will what will happen because of this biochemical mineralization it will stay back in the systems by this way we can trap the organic phosphorus.

Then the nitrogen, nitrogen what is happening to this ammonia rich ammonia rich wastewater and all what is happening this ammonia rich wastewater in presence of aerobic condition it converts into nitrite to nitrate because of the process of nitrification on the surface layer then this nitrate rich wastewater say it will go down further and or in and it will because of the anaerobic city that is maintained there it will lead to the denitrification process. Because of the denitrification process it converts into nitrogen. Parallely there is some advance you know the research is going on where people have find out that there is another pathway where also nitrogen can be liberated from the systems this nitrate can be converted nitrate and ammonia can be converted into dinitrogen gas. So, this process is called the anammox process ammonia oxidation and anaerobic ammonia oxidation processes and all. So, this process what is happening because of that this nitrogen dinitrogen gas is now free it is now it will simply liberate from the systems.

In some cases nitrogen nitrous oxide also stays back in the systems and that is also some little bit nuisance creating actually this NO_2 because N_2O because N_2O is it is actually greenhouse gas it has more than 280 times the capacity of a carbon of carbon dioxide to retain the heat. So, because of that it actually causing a huge amount of greenhouse gases in the system. So, anyway there are some recent studies where people are addition to this wetland systems they also introduce some amount some type of biochar or some type of this plant extracts which actually reduces has the capacity which acts as a soil amendment material and because of the because of the introduction of this new foreign particles materials and all what happened the soil started producing less amount of nitrous oxide and it will like you know make it go through the anammox process and the follow because of that there is a less chances of production of the nitrous oxide. So, anyway so, this is the this is how it works in the in this green out inland sorry in this constructed wetland systems how it works the whole system how it actually are actually

they are interdependent to each other, but at the end of the day our goal is fulfilled that the wastewater is getting completely pollutant free. Then we if we classify the constructed wetland in general based on the water level that is maintained in the constructed wetland based on that we can divided into 3 types surface flow subsurface flow and the hybrid constructed wetland.

Then based on the water flow pattern we can also further divided into 2 category basic 2 category that is the vertical flow and the off flow or the horizontal flow in some cases ok. So, what is happening in the surface flow wetland you see in the bottom in the picture 1 in the surface flow wetland the native soil. So, water is coming from one side to the another side and this water the waste this the vegetation is rooted and it emerges above the ground surface in general and it is in general this water flow primarily above the ground level, but whereas, in case of subsurface if you see this picture figure number 2 here the water level is there below the ground level ok. It is the water majorly flowing through the sand and gravel penetrating up to the bottom of the native soil or the bed. So, this is called the subsurface flow ok.

Let us discuss about the surface flow first what is surface flow how it looks like. So, in generally if you see it is called the free surface water constructed wetland as well or the surface flow constructed wetland systems. It normally holds a submerged and the floating plants in the open water areas and all ok. So, in this type of wetland systems majorly it flows in long and narrow channels safeguarding the near plug flow region which is regulated by less velocity of the flow, low water depth and availability of the deep route and the stocks in of the wetland plants and all ok. You see this figure number 2 where the inland inlet site if you see the water is coming in into certain one direction and then it goes through the system and then at the end it will go through the siphon process to the outlet systems and all where we can control the water level by siphoning or by up going up and down this outlet unit and all.

In general the physical operations majorly which are carried out in this kind of free surface water constructed wetland are the filtration, sedimentation and the UV contact from the solar radiation and all. And because of that because of the UV contact what is happening the disinfection phenomena is also happening taking place there. What are the chemical processes in the adsorption and the precipitation is also happening there and the biological process like uptake from the root zone, microbial degradation as well as the nutrient transformation to some other valuable by products or some less toxic by products can also is also possible. So, in general because of the physical operations like filtration, sedimentation and UV contact from solar radiation, chemical process like adsorption and the precipitation, biological process like uptake from the root zone by then just because of the nutrient requirement of the plant, microbial degradation to

aerobic or aerobic conversion to some byproduct and the nutrient transformation by itself. Because of all this reason the pollutant can be eliminated from the wastewater.

So, this is how the things works. So, I mean like the how we can actually clean the how we can actually reduce the pollutant load of a wastewater by introducing it to a constructed wetland systems. How the sedimentation and filtration in general the sedimentation and filtration it support the removal of the solid and the organic matter which can effectively degraded further by the biodegradable micro bulb breakdown on the bottom. Nitrogen removal is majorly governed by the factor that the amount of dissolved oxygen present because if the dissolved oxygen is available it will lead to a nitrification process, temperature of the wastewater, organic load at the inlet and as well as the seasonal variations. Why organic load is important? Because if we if you want the denitrification to occur it needs some additional carbon it needs it has some carbon demand.

So, unless until you have the CO_2 to nitrogen ratio say like you know around CO_2 to total general nitrogen ratio of around say 7 is to 1. So, unless until you have this ratio it varies in depending upon the depending over the structural requirement or but in general this is the ratio that we normally prefer. So, then only denitrification process can easily occur in the system ok. So, this is why the organic load in the inlet is also important. Nitrogen in generally takes place on the top layer of the aerobic zone by aerobic micro enzymes followed by the nitrification of nitrate at the bottom layer of the anoxic zone by numerous microorganisms thus supporting the overall nitrogen removal or ammonia removal from the system.

Some of the nitrogen removal also occurs through the uptake of the plant root this nitrate can be consumed by the micro by the plant and they also use it. This way also we can get rid of some of the nitrogen. This subsurface flow constructed wetland it also facilitated the like the phosphorus removal through physical chemical as well as the biological processes. In general the phosphorus which presents both in soluble as well as particulate form in the wastewater it undergoes a various transformation inside the within the wetland, but the major utilization happens in the microorganisms for its cellular processes and whereas, a soluble phosphate reacts with the aluminum iron oxide hydroxide etcetera and precipitate as aluminum iron or calcium phosphate. And because of that this because of this mineralization process the presence the phosphorus when it converts into calcium iron or aluminum phosphate what is happening it reserves it is it is stacks in the it is keep on stacking on the bottom of the wetland and because of that what is happening it is the whereas, the initially the phosphorus was when it is in the dilution when it is in the diluted form or when it is there in the suspended form in the wastewater which is dangerous for the follow up follow up you know if it is still present in the

wastewater it can be very dangerous.

So, that is why if it can be removed it can be removed the way of the do the way we do the mineralization it can be getting out of the system easily. This particulate phosphorus normally settles in the wetland through the sedimentation and aided by the plant structures. Periodic removal of this plant biomass and the soil is thus necessary to enhance the phosphorus removal because after a while the system will be you know literally will be having a enough amount of this mineralized phosphate and there will be no additional like you know this mineral though no additional aluminum or iron oxide or hydroxide will be present in the systems to actually consume further to continue with this reaction amount ok. So, that is why continuous removal is necessary I mean like time to time. This kind of surface flow constructed wetland it designs it includes a bed compost of soil coarse sand gravels with specific depth slope and porosity.

In general we normally do the clay lining to prevent the groundwater contaminations because there are other polyethylene linings are also there we also use sometimes the artificial this polyethylene linings and all poly lining and all, but in general in order to reduce the groundwater in order to you know control the groundwater contaminations we normally provide the clay linings. Inlet and outlet points majorly it is equipped with the water level controller piping systems and the channels for proper wastewater distribution in the system. If you see this subsurface flow constructed wetland it can also it can further be divided into 3 types. One is vertical flow see inlet is in the top and it goes down because of the force of gravity and it will go down and it will be collected in the in an outlet channel ok. So, there while the water is going down slowly it will actually if the pollutant present in the this wastewater will be consumed by the microbes that is present in this column ok.

Then next is the horizontal flow where the inlet is from one side and outlet is from other side. So, here generally the depth is I mean like the depth is shallow whereas, in case of vertical flow the depth is quite deep ok. In case of hybrid flow you can have the inlet outlet you can I mean a hybrid you can have off flow this is the last one is the off flow one where the inlet pipe is in the middle and in the bottom and the outlet is in the surface. And in this case you have to pressurize the water to go through this water flow. So, what you can do you can either have the reservoir on top further in a higher altitude because of the this additional water pressure they definitely the whenever you open the inlet pipe the wastewater will enter and it will try to escape through the it will go up and it will try to go out of the systems from the outlet channel that is present on the top of this wetland and all.

So, this is called the off flow wetland systems ok. So, there are lot of pros and cons of

this vertical flow, horizontal flow and off flow wetland system the subsurface flow constant of wetland systems. To start with let us discuss about the horizontal surface subsurface flow constant of wetland systems. In general you see this wastewater is entered from this one side it gently flows through this bed media in a horizontal manner where the vegetation is planted and to reach its reach to the outlet. When the common read like the common read this is it should be the figure 4 actually ok.

So, please try to correct it is the figure 4. So, in this common read this fragments Australia. So, normally it is a very it is famously used in this constructed wetland systems it also known as the that is why it is also known as the read bits or the read bed treatment system. To avoid the seepage and to guarantee the controlled outflow the bottom and the side of this horizontal subsurface flow constant at wetland normally are usually sealed with a liner usually made by the clay bentonite clay we can use or some cases a plastic mats can also be used ok. So, this way you can actually control the we can actually avoid the seepage losses in the system.

As the wastewater flows from inlet to the outlet through the wetland bed which is working as a filter media it passes through the aerobic zone around the root and the rhizomes of the plant and then anoxic then anaerobic when the bottom of the wetland bed ok. At the bottom of this constructed wetland it is normally anaerobic environment is prevails and because of due to the less amount of oxygen that can penetrate from the plant roots and this oxygen depleted zone organic matter decomposed in the presence of anaerobic microorganisms which can also support the denitrification process as we discussed earlier as well ok. So, what is happening in what is the benefit of these things like you know because of this anaerobic respiration it also creates a heat. You know that in the temperate regions for us in India it is we are quite lucky, but in the temperate regions it whenever there is a in the winter season say suppose there is like 3 4 months of it will completely be completely covered with snow. So, in those cases how those microbes will survive in this kind of huge wetland systems.

What happened because of this anaerobicity this anaerobic this conditions what happened this bed media it releases the heat due to this exothermic reaction of this anaerobic system anaerobic digestion systems. This additional heat it maintains the favorable temperature in the wetland bed which support the microbial activities to take place even in the cold temperature especially in the night I mean the during the winter when there is a snow outside. This temperature correlations with this microbial activities are actually making it more suitable for using it in a varied seasonal variation in the place with the varied seasonal variations and all ok. It is naturally suitable with the cold regions with the surface ice cover also anaerobic decomposition is also produces enough internal heat to the microbial activity to take place. And this plant and the litter on the

wetland surfaces it actually acts as a insulation additional insulation against this freezing temperature from the top ok.

The one problem is the oxygen limitations and the external adhesions is required oxygen release from this rhizomes in this horizontal subsurface flow concentrated wetland may not be adequate for the aerobic degradation on the top in some cases. In that case external adhesion may require to improve the oxygen transfer capacity. It is properly if you properly design this diffusers and all this external adhesion systems and all this diffuser tubing and this air blower can actually used to enhance the removal efficiency of different wastewater different wastewater pollutants and all. What is the basic major effect of this external adhesion on this BOD and the TSS removal? Majorly this external adhesion in this horizontal subsurface flow concentrated wetland is significantly improve the BOD removal compared to the non aerated ones. And higher total suspended solid removal efficiency can also you know observed in this aerated this horizontal subsurface flow concentrated wetland due to the increased protozoa growth and especially the effective in the presence of oxygen.

So, this additional this protozoa this particular type of animal. So, it further consumes the pollutant the different type of pollutant present in the wastewater and converts it into its biomass ok. It also enhances the removal efficiency of BOD obviously, the if the organic matter is removed what will happen the BOD will also remove right. The BOD means like BOD is a means by which we actually we can quantify the amount of organic matter present right.

So, if the organic matter is removed. So, BOD₅ will be reduced. The total suspended solid will be reduced total gel-dell nitrogen would be reduced drastically compared to the non aerated counterpart because gel-dell nitrogen remove means because of the aeration efficiency we are providing some aeration external means of aeration it will increase the nitrification efficiency right because the nitrification process needs the excess amount of dissolved oxygen present in the system. So, this because of that the nitrification process will increase. So, overall total gel-dell nitrogen process will also total gel-dell nitrogen removal efficiency will also increase. In case of off flow vertical surface subsurface flow concentrated wetland what is happening? The wastewater enters through the bottom of the wetland it flows to the upward direction through this filter media and it exists on the top level of the exists from the top level of the wetland.

You can see in this figure 5. In general it also known as tidal flow concentrated wetland because it works in the principle of feel react drain and rest as same as the if you remember we also discussed about the sequencing batch reactors or the SVR. There also we follow the same principle we feel it we let it rest familiar wait for some reaction to

take place we drain the water we rest the system for further aeration ok. So, that is how it is done here also you have this certain you have the reservoir present on the certain height or you pump it pump the water to like you know flow through the systems you have this inlet pipes the wastewater will try to you know like you know go through this system and then it will reach the top and the outlet you can collect the system you can collect the waste out of the system ok, the treated effluent out of the system. In this kind of a tidal flow constructed wetlands the wastewater entrance through the aeration pipes at the bed of the bottom then flows upwards till it reaches to the top level of the bed surface then we stop the pump or we stop the valve. When the surface is completely saturated we switch off the pump and the wastewater comes in contact with the microorganism which is growing in the surface of this bed media having the plant root systems after a fixed time period the wastewater is drained out of the systems the void of the filter media is now filled with air.

The same air pipe is now used for supplying the air and this additional air it actually helps the treatment system to be completed with when the complete drainage as well as this aerobic bacteria aerobic micro environment to be formed in this zone. So, this is how the this is how this kind of system works and in general if you see this the wastewater once it enters from the bottom of this filter bed it initially the wastewater is treated by the aerobic oxidation and gradually an anaerobic environment will be formed the more you go. So, due to the consumption of oxygen coupled with the oxidation of organic matter on the bottom because when it is in the like you know idle stage in the idle stage what we are doing we are supplying the aeration. So, during that time the it is all these voids are all filled up with the aerobic microorganisms and all. Then you supply the wastewater the first the aeration this aerobic microorganisms will consume the wastewater the organic matter present in the wastewater then it will go to the next stage ok.

So, in general before starting a new cycle we allow the air to fill the filter bed that develops an aerobic environment to combat the oxygen transfer limitation that occurs due to the off flow mode of operation. Clogging of the filter is the one of the major disadvantages of this kind of systems you can as you can understand ok. Therefore, you have to select we have to be very cautious about selecting the bed material and also you have to be very precise in the estimation of the appropriate hydraulic loading rate which are very crucial factor to achieve the uniform spreading of the wastewater throughout the wetland surface and for better treatment efficiency. In case of hybrid constructed wetland systems where we can have say like you know one horizontal flow then the vertical flow or the vertical flow then the horizontal flow. So, in general the single constructed wetland are capable of removing the organic matter, but may not be enough.

So, in those cases so, what is happened combining of both the systems horizontal flow as well as vertical flow actually helps the helps us to reach the goal of higher efficient efficient removal of the target pollutant. So, different combination of sequence are there in general the vertical flow horizontal flow vertical flow horizontal flow or free water surface horizontal flow multi stage vertical flow horizontal flow hybrid normally we practice. The design majorly divided into two phases like which many parallel vertical flow constructed wetland followed by two or three horizontal flow constructed wetland in succession that comes out as a one of the best practice to be followed. The less large size horizontal flow constructed wetland can also be provided in the beginning of the hybrid treatment systems to reduce the organic and the suspended solid and then the small size periodically loaded vertical flow can be provided for further removal of organic and suspended solid as well as the achieve the nitrification process. If necessary this can be followed by a third stage of horizontal flow to facilitate the denitrification process.

So, majorly in general the only difference that it occurs is like you know the type of constructed wetland is the which you are targeting your target is the organic matter removal or the nitrogen removal. If your target is to remove the you remove the ammonia from the systems the particle flow works the best way. Then if you remove the if you want to have the denitrification to have a proper facultative zone on the bottom then you can go for horizontal flow constructed wetland. So, there are like different based on the demand of your operation you can actually choose the sequence and you make your hybrid constructed wetland design in such a way ok. So, what are the criteria for selecting the plants if you see it is it should be able to withstand the large organic and nutritional loading.

It should often denser root system should be there in the rhizomes to supply the substrate for associated bacteria and the oxygenation of the region close to the root and the rhizomes. So, this is a very specific type of plant that can be allowed in a constructed wetland systems which can actually oxygenate the region close to its root by this process as I mentioned in the very beginning. Have a lot of above ground biomass for insulation during the winter season as well as a nutrient removal through the harvesting. Most noticeable characteristics of this wet of wetland is the presence of macrophytes particularly in case of free water surface constructed wetland. This which distinguishes the constructed wetland from unplanted soil filter or the aerobic lagoon the basic difference the presence of this macrophytes.

This macrophytes are like if you see this examples are given this Phragmites species, Typhus species, Scarpus species or Phalaris species, Iris species, there are Cana species, Cana indica which is also which is also species. So, all these are quite famous and they

are normally used in case of constructed wetland system this kind of macrophytes. So, what are the salient feature of wetland system? First it is a low cost and the sustainable solution of wastewater treatment in terms of construction operations as well as maintenance cost. It is applicable for the treatment of domestic wastewater, agricultural runoff, raw water runoff and in even in some cases a constant industrial effluents as well including the mining drainages and all. No energy is required for the operation of constructed wetland unless until you are applying this some additional means of aeration which is very often it is not very common.

It is a very seldom like it is not very common. It can be operated for long term without any requirement of frequent or maintenance. It treated effluent from this constructed wetland can be reused for different purposes. The preserve the groundwater and the surface water level and also it facilitate the conservation and the environmental protection to the habitat for plant, animal and the insect and it makes a nice ecosystem near in nearby in near vicinity. The accommodation volume of storage of water including the storm water it does not really also it does not release any order and contribute to the natural aesthetics to the system as well. So, overall it is a very pleasing one of the most greener greenest I mean like one of the most green treatment unit that we have in a constructed wet in we have in wastewater treatment systems.

So, let us now try to design one constructed wetland. So, it is very easy. So, just remember this equation this Kikuchi equation where we normally use for finding out the area the constructed wetland bed surface area that it requires using this $Q \ln C_i - \ln C_o$ by K of BOD.

$$A = \frac{Q(\ln C_i - \ln C_o)}{K_{BOD}}$$

So, whereas, this Q is the average flow of the wastewater in meter cube per day, C_i is the BOD 5 concentration in the influent wastewater in milligram per liter or gram per meter cube, C_o is the BOD concentration of in the in the outlet or the effluent and K_{BOD} is the rate constant in meter per day. The value of this rate constant it varies with the temperature and the type of constant of wetland and this typical values are given in this table you see the 10 degree Celsius in horizontal flow see constructed wetland this value of K_{BOD} will be 0.1 meter per day and in case of vertical flow it will be 0.13 meter per day likewise it will change. So, in general we normally use the value say this normally this it is recommended to use an average depth of 40 centimeter for calculating these values and in case 70 centimeter in case of the this is the average depth in case of vertical flow constructed wetland. The length to width ratio should be should be somewhere around in case of horizontal flow it should be 1 is to 1 length to width ratio

in case of vertical flow it should be 1 is to 1 to 2 is to 1 this ratio ok. So, let us design one constructed wetland system. So, let us design one horizontal flow constructed wetland for treatment of sewage generated from a population of 300 percent only 300 percent your local area with per capita wastewater generation is 85 liter per capita per day and the effluent shall have a BOD 5 concentration of less than or equal to 30 milligram per liter and in laboratory analysis of BOD 5 of effluent it was found to be 425 milligram per liter with 25 percent of the BOD is removed during the primary treatment itself considered the rate constant as 0.2 meter per day. So, first thing is effluent BOD concentration is 30 milligram per liter that is known to us rate constant is 0.2 meter per day that is also known to us average flow of wastewater that is 300 percent into 85 liter per capita per day. So, 300 into 85 divided by 1000 they will make it in the meter cube. So, 25.5 meter cube per day of effluent is coming out of the system ok. Out of them I mean like out of the total flow I mean out of the total BOD 25 percent of the BOD is removed already. So, that means, what is the concentration of the inlet BOD of the inlet washed water coming into the horizontal flow constructed wetland is 425 multiplied by 0.75 it is coming around somewhere 319 milligram per liter ok. So, estimating the surface area we can easily estimate it by this equation $A = \frac{Q(\ln C_i - \ln C_o)}{K_{BOD}}$ C_i is now known to us is 319 Q is 25.5 meter cube per day C_o is 30 k_{BOD} is 0.2 meter per day. If you replace this equation replace this values in this expression you will get the final surface area as 301.41 square meter.

$$\text{Surface area} = A = \frac{Q(\ln C_i - \ln C_o)}{K_{BOD}} = \frac{25.5(\ln 319 - \ln 30)}{0.2} = 301.41 \text{ m}^2$$

If you provide a depth of 0.4 meter because it is a horizontal flow. So, 0.4 meter is 40 centimeter of depth the and the length to width ratio is 2 is to 1. So, so what will be happen? So, you will have to divide you can easily find out the total the surface area is known to you ok. So, 1 into B that means, 1 is equal to 2 times the B.

So, 2 B into B that is 2 B square is equal to 301.41. So, B can be easily find out 301 by 0.41 divided by 2 root over of that even.

So, the value comes around 12.28 or say 12.3 meter. So, the length will be 2 times the width 2 times the breadth. So, that is 24.6. So, the you can easily design a horizontal flow constructed wetland with a bed of 24.6 meter length 12.3 meter wide width and 0.4 meter depth that is it you your design is complete ok. So, this is how we normally design a horizontal flow constructed wetland isn't it easy it is very easy actually ok. If you just realize it when we actually do it in real life it is actually very the equations are very easy just needs a very basic understanding of the system. So, in conclusion we understand the what is constructed wetland systems it actually kind of mimic the natural process of wetland by for treating the wastewater efficiently and sustainably. In case of natural

wetland it can be water saturated or submerged land supported by the supporting the water loving plants which will play a crucial role in the organic matter stabilization and nutrient removal.

We can have the surface flow or the subsurface flow we can further have the hybrid flow systems as well. It has a numerous advantages including the low construction and operation cost energy efficient minimal maintenance requirement and they are widely used in the treating the sanitary sewage and reducing the organic load and nitrogen and phosphorus. So, the design also we understood we can we are now capable of designing a constructed wetland by ourself. So, these are the references I would request you to go through it for having more in depth knowledge about the constructed wetland systems and all and how it performs. Thank you so much see you on the next video.