Micro Irrigation Engineering

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Lecture-14
Measurement of Irrigation Water

Dear participants of this course on micro irrigation engineering, now we are starting lecture 14. I welcome you to this lecture on the measurement of irrigation water. This is a very important component when we apply irrigation water in the field. Irrespective of whatever method of irrigation we apply, we need to know the accurate quantity of water that can be supplied to the field. So, its measurement is very important.

Now, in this particular irrigation lecture, we will be dealing with the measurement of irrigation water when we supply through an open channel, measurement of irrigation water when the water is flowing through pipes. In the case of measurement of water through an open channel, it is mainly dealing with surface irrigation, but sometimes situation happens we are getting water from a long distance and then bringing it to the place where we store this water and then use it by a network of pipe through a sprinkler irrigation system or drip irrigation system. So, measurement of irrigation water in an open channel or measurement of irrigation water through closed conduit pipe are all important components when we supply irrigation water through a micro irrigation system or open channel system in surface irrigation.

Now, why irrigation water measurement is important? Why should we measure this water? We know water is the most valuable natural resource and when we apply this water in agriculture, it is the life of any living system or agriculture plant system. So, its accurate measurement will be used for a more intelligent way of applying irrigation water. Also, measurement reduces the losses which take place during the conveyance system, losses that take place in the field. So, this is very important. So, water to be distributed among the users or in the field is an important component.

Now, this water can be in rest position, which means it can be in a reservoir, it can be in a pond or it can be in any container, then we say water is in rest condition. Now say when we are interested to know the total volume of water it will be needed for the whole crops season or daily water supply system.

So, we bring water from a long distance and store it in a reservoir, store it in a pond, or we store it in some storage tank. So, in that case, water when it is brought and kept in a pond we are interested to know what is the volume or what is the capacity of the tank? What is the capacity of a particular system? Sometimes we need to know if water needs to be supplied in a given irrigation system. So, we know that how much amount of water it is available when it is at the rest or it is in motion means when water is in flowing condition. So, this flowing condition could be in an open channel, it could be in the closed conduit or a pipeline system.

Now, when water is in rest condition means it is in a stored condition, when water is in moving condition or motion, it needs to be expressed in a particular unit. So, if you say water is to be given in a volumetric unit, liter, or cubic meter or when we are giving water in hectare centimeter, hectare meter, these all are a volumetric way of expressing units of water measurement.

So, when water is in rest condition or when we are giving water in a field of 1-hectare area and then the certain depth of water is to be given then we express it in hectare centimeter or hectare metre. So, this can be expressed in a volumetric form, let us say that when we are telling hectare centimeter. So, a volume is necessary to cover an area of 1 hectare or we can say 10,000 square meter up to a depth of one centimeter.

So, when we say 1-hectare centimeter, this is equivalent to 1 lakh liters of water. Now, when we say water is in a movement condition when it is in flowing condition, so this is expressed when it is in a smaller pipeline, when it is in a small channel we expressed it in liter per second. So, a continuous flow of water amounting to 1 liter passing through a point at each second, this unit is expressed as a liter per second.

When the discharge from a canal we are measuring or discharged from a very big pipeline when we are expressing, this can be in a larger unit, and then this unit is expressed as a cubic meter per second. So, a flow of water is equivalent to a stream of 1 meter wide and 1 meter deep flowing at a velocity of 1 meter per second. So, this can be expressed as 1 cubic meter per second.

When we say water is flowing, so the water can be in an open channel or it can be pipe flow. So, hydraulics of flow through the pipe, hydraulics of flow through open channel slightly if differs. So, when we say the open channel flow, it defines a passage in which liquid flows with it is upper surface exposed to the atmosphere. So, the top surface of the flowing water is exposed to the atmosphere means it is under atmospheric pressure.

The flow is due to gravity, the flow normally in open channel flow is the inertial flow that is caused by the elevation difference or due to velocity of flow it makes the flow. So, it could be the gravitational flow is dominant and the flow conditions are greatly influenced by the slope of the channel. So, the hydraulic grade line coincides with the water surface. So, the slope of the channel, slope of the water surface; the slope of the energy line is parallel when we say the flow is uniform through an open channel.

Flow can be uniform or non-uniform that is one kind of a condition. So, when we say hydraulic grade line coincides with the water surface, this is one of the characteristics of the hydraulics of flow through the open channel. Maximum velocity occurs at a little distance below the water surface because at the top of the water surface there is some resistance due to wind. So, that resistance causes a reduction in the velocity at the top surface, but slightly below. Let us say that about 2 to 3% below the top surface, the maximum velocity is attained. And the shape of the velocity profile is dependent on the roughness of the channel means surface roughness bottom of the channel, as well as the sides of the channel, affect the velocity profile. So, it influences the slope of the velocity profile, normally it takes a parabolic shape, and then the other important characteristic is given by the Reynolds number.

Reynolds number is defined as the inertial force to the viscous force it is the ratio between the inertial forces to the viscous force. Inertial force is due to velocity or flow, and then the viscous force is due to the viscosity of the water or any liquid which is flowing through the channel. So, the Reynolds number for the laminar flow is given as you know in an open channel, it is less than 500 for turbulent flow, it is greater than 2000 or 2200. And transitional flow that is between laminar and the turbulent flow the ranging between 500 and 2000, sometime it is also expressed as 2200.

Now pipe flow, when the flow takes place through a pipe, so the pipe is a closed conduit for carrying fluids under pressure. So, flow in a pipe is termed as pipe flow when fluid completely fills the cross-section of the pipe and there is no free surface of a fluid. Here as in the case of open channel flow, we were seeing that the top surface is exposed to the atmosphere, here the free surface it is not exposed to the atmosphere. So, the hydraulic grade line not necessarily it will coincide with the water surface. Maximum velocity occurs at the center of the pipe because there is a boundary effect. So, the boundary of the pipeline causes resistance and so the boundary effect causes resistance or maximum velocity it attains at the center of the pipeline.

Velocity distribution is symmetrical about the pipe axis and flow cross-section is known and fixed. The Reynolds number in pipe flow 2000 to 2300 the flow is known as a laminar flow, turbulent flow when the flow is means Reynolds number is greater than 4000. And critical or transition flow is between 2300 and 4000, so this is the transitional flow between these.

Now we will discuss different methods of water measurement in the open channel. So, methods which are put up under measurement of flow through an open channel, they can be means one can have the volumetric measurement or velocity area method or one can use by putting measuring structures or tracer technique, dilution technique. So, volumetric measurement is a very simple thing that suppose flow it is a small flow that can be collected in a bucket of known volume at any given time. So the time it fills the bucket is known volume, then one can know what is the discharge through the open channel. So, if it is a small stream the water can be collected, that one can find out or pipeline also that discharged from the pipeline it can be calculated by simply measuring the volume of the water-filled in the container divided by the time required to fill that particular volume.

So, this can be given in a liter per second, because such measurements are can be done only when the discharge is of a small quantity.

Now area-velocity method or rate of flow passing a point in a pipe or opened channel is determined by multiplying the cross-sectional area of the flow section at right angles to the direction of flow by the average velocity of the water. So, the entire cross-section here is divided into several sub-sections and the average velocity at each section is determined by using the appropriate device, it could be a current meter or it can be a simply float. And this velocity is multiplied by the cross-section area of the subsection. So, velocity is obtained by using the current meter or by float method, and then the cross-sectional area is multiplied and then one can know the discharge.

Velocity area method, when I was telling that current meter is a device, so what we see this is a current meter, you see in this part. So, there is a rod, which we see is a rod, which is mounted and there is a cable which is suspended. So, when you are suspending it like this and then the flow which is taking place, the velocity of flow when it is coming in contact with the cups, these cups are being rotated by the flow of water. So, means the cups got a small revolving wheel that is turned by the movement of water.

It may be suspended by a cable, this is what we see that there is a cable, for measurement in a deep stream or attached to a rod in a shallow stream. And then the propeller is rotated, this is what we see these are the cups which I told that the propeller is rotated by flowing water and the speed of the propeller is directly related or linearly related with the number of revolution.

Speed is directly related to the number of revolutions, so here is velocity $V = a*N + b$ where a and b are the constant, that will depend upon the particular type of calibration parameters or the particular type of current meter and at the number of revolutions. So, the number of revolutions is basically directly related to the average velocity of the flow.

So, corresponding to the number of revolutions the velocity can be obtained, so a calibration graph is to be prepared or a table is made that is supplied by the normally manufacturer. So, from the table, one can interpolate what is the velocity of flow.

Now, once we got the velocity, this velocity is to be multiplied with the area of cross-section. So the area of cross-section which we are seeing this is a natural stream where the bed of the stream which you see it is not uniform. And so at the corner means where the depth is shallow, we take the measurement at one particular depth. So, at this particular point, we are taking the observation by using the current meter. Then we are dividing the whole width of the channel into a number of small strips.

So, what do we see here? This is one strip where measurement is being taken then another strip is this part this is your W_1 which you see this is your width, this is your W_2, then this is your W_3 and W_4 like this there will be a number of verticals. And then the center of these verticals, observations are taken means velocities are taken and we can find out the area under each smaller subsections. So, this is subsection 1, this is subsection 2, like this you know this is subsection 3. So, like this, the discharge is measured. So, each individual subsection will give delta Q_1, this delta Q_1 is nothing but the width multiplied by the depth y_1 multiplied by V_1. So, here delta Q_1 is delta A_1 multiplied by V_1 bar, V_1 bar is nothing but the mean velocity at section 1, so mean velocity at section 1 like this there will be another V_2.

So, measurements suppose we are taking at 2 places, so, these 2 places measurement that is at 0.8d and 0.2d. And here it is 0.6d, for shallow depth and when it is a deeper level, then measurements will be taken at 2 places. That is at 0.2d and 0.8d and then we will take, so V_1 bar refers to the average mean velocity. So, this gives a delta Q 1, so like this, all these delta Q's will be obtained and then we will get the discharge of the stream.

Measuring structures means quite a good number of structures that are available one of the structures is Weirs. So, what is a weir? Weir is a notch of a regular form through which an irrigation stream is made to flow, which means it passes through the notch. The stream is means made to flow, so water is passing through a notch, and then weir could be of different shape. It can be a rectangular shape, it can be shaped Cipoletti weir as the name it is given it is named after a scientist Cipoletti is an Italian scientist.

So, it is named after him it is a trapezoidal weir. And then it could be a V shape or V notch weir. So, when we are interested or from a larger stream, it may be by using a rectangular weir. If it is a medium discharge means slightly lower discharge then we use a trapezoidal weir. And V notch is used for smaller or medium stream sizes. The discharge from a rectangular weir is given by

$Q = 0.0184\ LH^{3/2}$

Where Q is the discharge in liter per second, L is the length of the crest (cm) and H is the head over the weir crest (cm).

So, the length of the crest is this, this is a crest of the weir. So, this is the length and then whatever depth of water it is flowing above the weir, this is your H, in this case, this is H. So, these rectangular weirs, it can be suppressed weir or it can be contracted weir. When I say is suppressed weir means the width of the channel and then the length of the weir crest, they are the same, this is what you see here.

Say water from with the channel it is coming we are not contracting the stream, but as such in the same width the weir plate is fixed and then water is made to flow over this and this is the depth. And when the condition is when the width of the flowing stream is large and we are allowing the weir length is smaller. In that case, what you see is that it is broad contracted, so there is an effect of contraction and that has to be taken care of while we are finding out a discharge from a rectangular contracted weir. If the contraction is from both ends, this length is reduced. So, from both ends, we are giving it by

$Q = 0.0184\ (L-0.2H)\ H^{3/2}$

That will be the contracted rectangular weir from both ends.

A triangular weir, as the name, says that it is triangular in shape. There are different angle triangular weirs. The 90 degree V notch is commonly used and this is used for the measurement of discharge of a stream of a smaller size. This is an empirical Francis formula which has been given that discharge from a 90 degree V notch is given by

$Q = 0.0138\ H^{5/2}$

So, like this these discharge, it can be obtained.

Now, an orifice is another device that is used where water is allowed to flow through a circular or rectangular opening. So, discharged from an orifice and orifice is given by

$$Q = \frac{\pi d^2}{4} \times C_d \times \sqrt{2gh}$$

h refers to the head above the center of the orifice, d is the diameter of the orifice opening, and C_d into the area of cross-section of the flow multiplied by root 2gh gives the discharge from an orifice. The orifice can be used for the open channel flow; this can be used for the pipe flow.

Flumes are another devices that are used to measure the flow from the open channel and these are giving precise discharge as compared to and it does not need the head loss as it happens in case of weirs. So, these are giving reasonably accurate discharge and even in for the partially submerged condition.

Now let us come to the flow through pipes and then how the discharge can be measured by using a device which is known as Venturimeter. Venturimeter is a device that is used to measure the rate of flow of fluid and it is normally in a pipe system it is fixed permanently. And then any venture system consists of 3 sections one is the converging section, then there is a throat section and diverging section.

Like the shape it shows, now to measure the discharge from a Venturi, it uses the principle of the Bernoulli equation that is the energy equation. It uses the principle of a law of conservation of mass that is a continuity equation. So, this is a well-known Bernoulli equation, where you are seeing that there is a pressure head, velocity head, and then elevation head. So, as per the Bernoulli principle, this pressure head plus velocity head plus elevation head is a constant.

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

But when we are considering 2 sections, one at the converging section another one in the throat section, so these sections are given as section 1 and section 2. So, accordingly, for section 1 and section 2 this P_1, V_1, and Z_1, refer to section 1. And P_2, V_2, and Z_2 refer to section 2, accordingly if we make it that when the Venturimeter is kept at the same elevation, then this equation comes in this form that we V_1 square by 2g.

This velocity head difference is equal to the pressure head difference, which can be written as the pressure head difference $h = (V_2^2 - V_1^2)/2g$, so this is the pressure head difference.

Now, this pressure head is used to finding out the discharge from the pipeline. So, here when we are using a continuity equation that is your $Q = A_1 V_1 = A_2 V_2$. So, we get the expression in terms of the V_1,

$$A_1 v_1 = A_2 v_2 \Rightarrow v_1 = \frac{A_2 v_2}{A_1}$$

$$h = \frac{v_2^{\,2}}{2g}\left[\frac{A_1^2 - A_2^2}{A_1^2}\right]$$

$$\Rightarrow v_2 = \frac{A_1}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh}$$

$$Q = A_1 v_1 = A_2 h$$

$$\Rightarrow Q = \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}\sqrt{2gh}$$

So, this discharge is to be multiplied with a coefficient of discharge. And then this coefficient of discharge for a particular Venturimeter is to be from the calibration one has to get and then apply here to for finding out a discharge.

Now, Venturimeter for measuring what is the head difference it could be Venturimeter can have a heavy liquid or a light liquid? So, depending on the specific gravity of liquid the value of the h can be appropriately changed.

$$h = x[\frac{S_h}{S_o} - 1]$$

By using the expression when there is a heavier liquid it is used for measurement when the manometric liquid is lighter than the flowing liquid that is your water. Then, in that case, the appropriate value of h is to be modified and used.

$$h = x[1 - \frac{S_h}{S_o}]$$

Where,

h = Head difference in terms of the liquid flowing in the pipe

x = Head difference in the manometer

S_h= Specific gravity of the liquid flowing in the pipe

S_o= Specific gravity of the manometric liquid

A pitot tube is another device that is used for the measurement of flow through the pipeline and the shape it says that it also uses the concept of the Bernoulli equation. So, the water when it is coming and at this particular point the velocity head is directly related with the change in the pressure head and that causes means we are measuring the pressure head at this point and pressure head at this point. These 2 places when it coming in contact that causes the rise of water level or liquid level in the pitot tube column, and that is used to find out the how much is the discharge.

Water meter gives the volumetric value and these are very commonly used for measurement of the flow-through pipeline. So, the only thing is that the pipe must flow full at all times. So, you might have seen in domestic purpose, the volume of water which is coming and accordingly the auditing or water charges are made. So, one can know that how much volume of water it has passed through and these are available in liters, 1000 liters, and cubic meters, and where there is a scale is given by counter made here. So, low-pressure pipelines flow through an open channel, open flow meters, these are all available in the market, these are commercially available.

Orifice meter, already I have explained to you, the orifice meter means the orifice plate is inserted into the pipeline. And then the appropriate discharge expression means here we will be getting the value of what is the area of cross-section? That is of the orifice and then the area of cross-section of pipe and then the change in the value in the pressure head at this point, pressure head at this point, these 2 values are used to find out h and then the Q is obtained by using the orifice meter formula.

$$Q = C_d \frac{A_0 A_1 \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}}$$

Where,

Q = Discharge from orifice (m^3 s^{-1})

A_0 = Area of the orifice (m^2)

A_1= area at section 1 (m^2)

h = Differential head (m)

C_d=Coefficient of discharge for orifice meter

g = Acceleration due to gravity (m s^{-2})

Propeller meter is another device these are commercially available for measurement of flow that is used at the ends of pipe and conduits flowing full under pressure. So, propeller meters use multiple blades made up of rubber, plastic, or metallic, so this is a propeller and then it is more or less the same as a water meter. It consists of a propeller mounted in a short section of pipe and gear to a revolution counter, which records the rate of flow and cumulative total. So, in the case of the water meter, it gives volumetric measurement, here it gives in the terms of rate of flow, or also one can know the volumetric measurement also it can be done.

So, here in this particular lecture, we have discussed the devices that are used for the measurement of irrigation water through an open channel, through a closed conduit pipeline. In all these cases, you have seen how the fundamentals of fluid mechanics that are using the energy equation, law of conservation that is a continuity equation. These 2 principles are in majority of cases it is being used, when we are using the flow measurement in open channels when we are using flow measurement in pipes and then the concept of uniform flow is also used in case of open channel flow.

Now, in the forthcoming lecture means coming lecture we will discuss irrigation efficiency. You can refer to these books which are for this particular topic to read in detail. These are some internet Google search you can have and get more details about the examples, working out the examples also you can