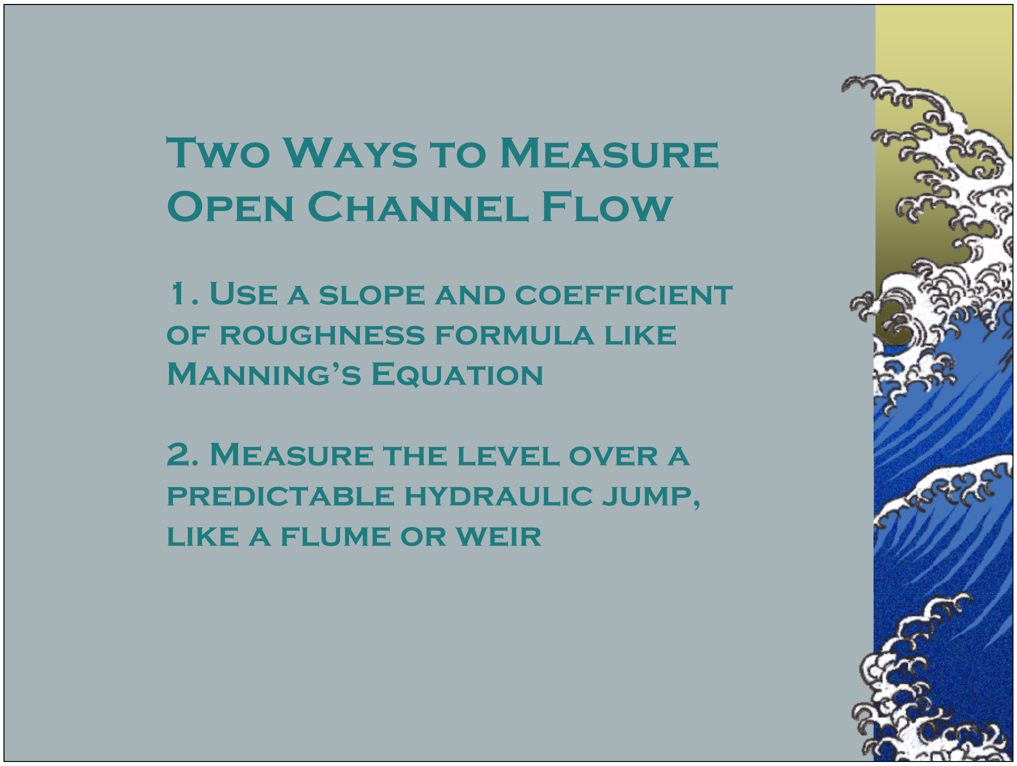
I'm Walt Boyes, and if you are like most automation professionals, you don't do flow measurement design daily or even weekly. So some of the basics may be new to you…especially in the area of open channel flow.

The picture you see is of a “Nilometer.” It is one of many devices built since 3000 BC to measure the height (and calculate the flow) of the Nile river in Egypt. It is very likely the first flowmeter, and it measures open channel flow.

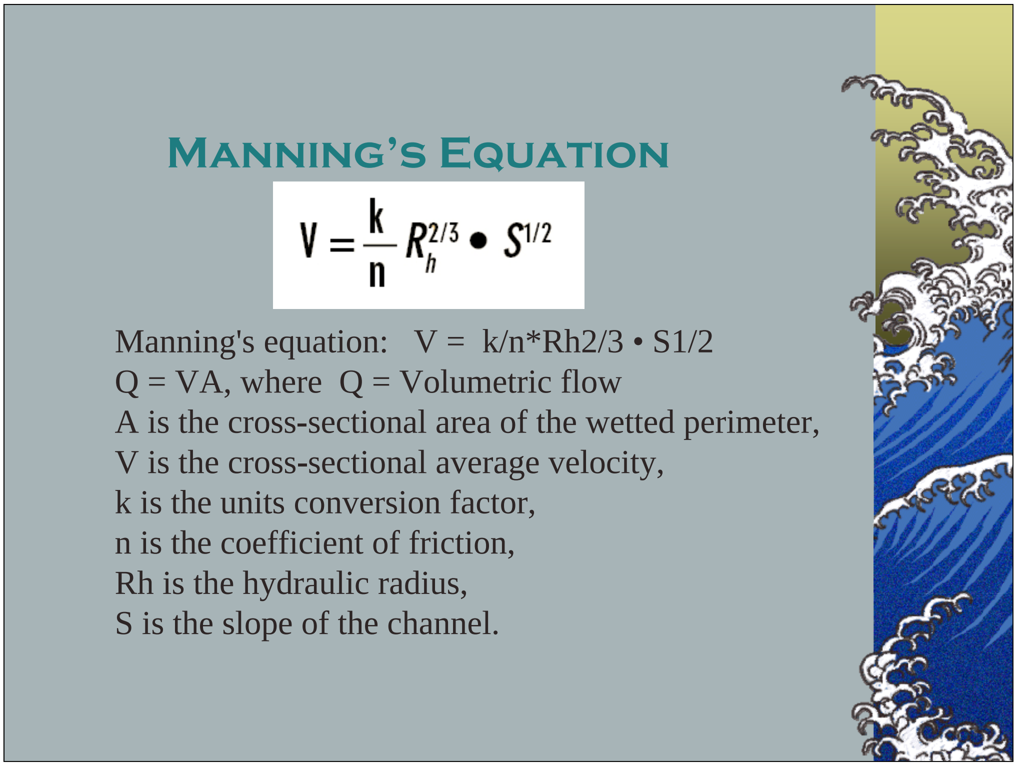
For the next few minutes, we are going to look at the theory and practice of open channel flow, and by the end of our time together, you will be able to “Flow Like an Egyptian.”



There are two basic ways to measure flow in an open channel or conduit.

The first is to use one of the formulas like Manning's Equation, which have been developed for open channel flow in ditches, rivers, and canals. You must calculate a wetted perimeter, and know the slope of the conduit, and guess at the roughness of the bottom of the conduit, or pipe.

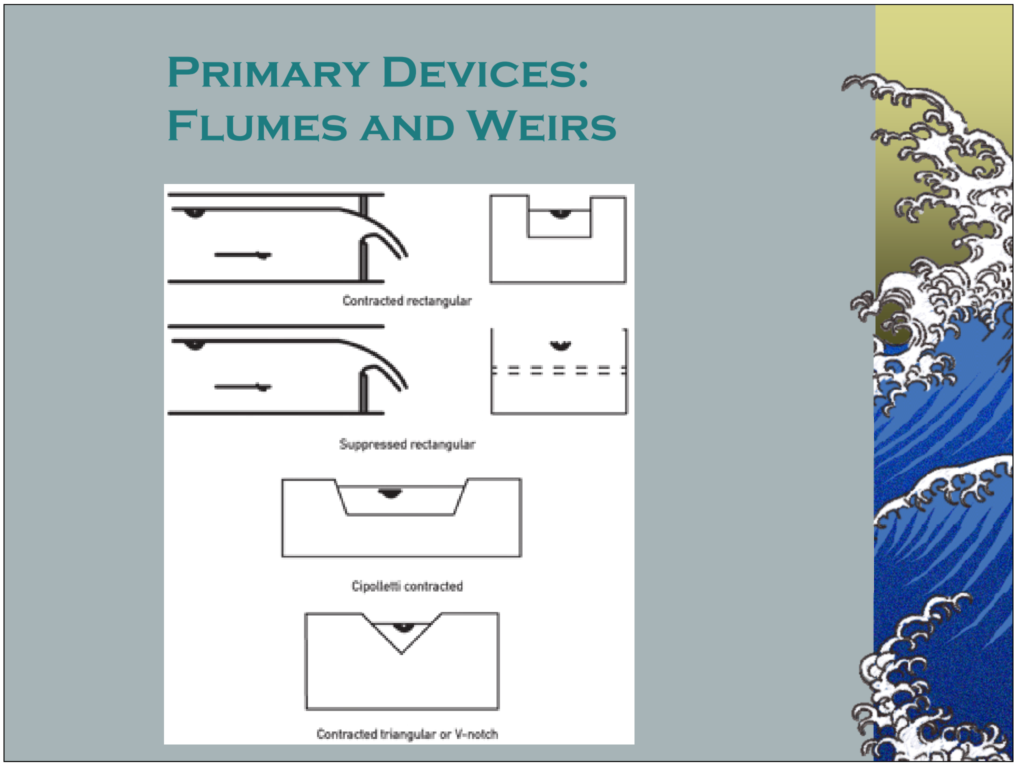
The second method is to measure the height of the flowing stream at a known distance behind (upstream) of a predictable hydraulic jump, such as a flume or weir.



In 1889, Irish engineer Robert Manning produced an equation for calculating flow in open conduits from the level in the channel.

Manning's equation works best in man-made conduits because the hydraulic radius, slope and coefficient of friction can be better known or estimated. It will work in any open channel, but the error expands as these terms are less well known. Manning's equation, and its successors, are often used for calculating the flow in sewers and in man-made irrigation channels.

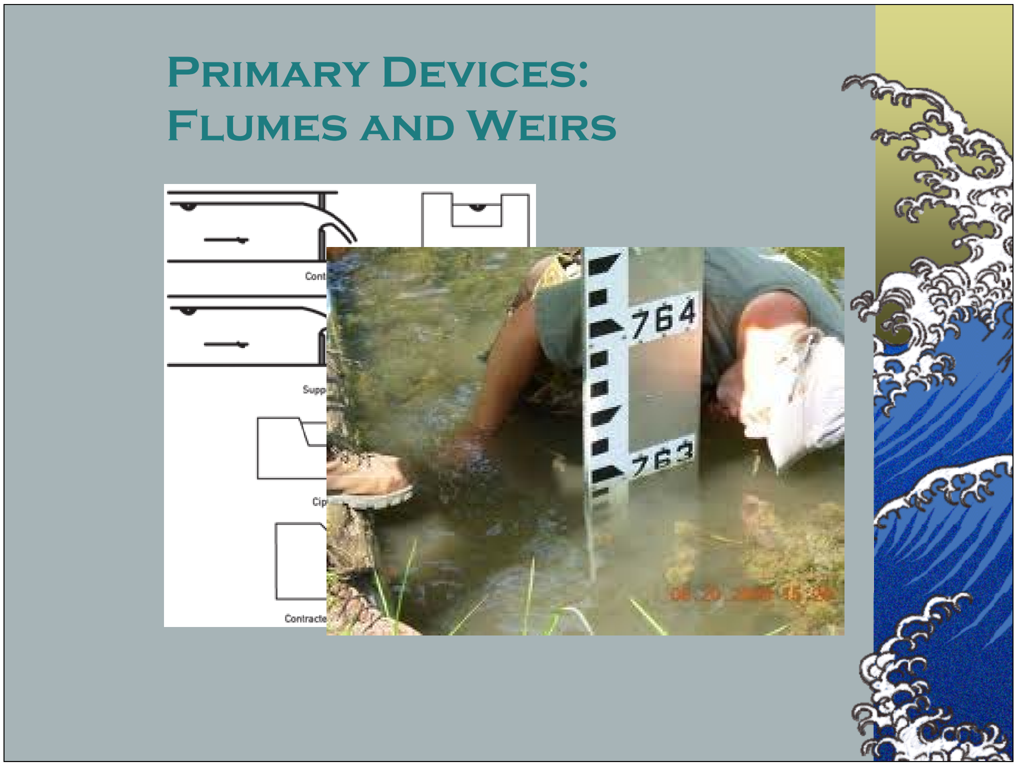
Although tables of Manning's "n" are common, it is nearly impossible to accurately calculate "n," so it is almost always an educated guess, based on the engineer's experience and expertise. A small change in "n" can result in a large change in "V" and thus a large change in "Q."



For real accuracy, the use of a primary device is required. These are restrictive devices placed in the flow stream that raise the height of the water behind the restriction to a predictable level based on volumetric flow. Typically, these devices are flumes and weirs. Weirs have been known for centuries, and were used as primitive spillways from small earthen dams. Measurement weirs come in several configurations: v-notch, rectangular and trapezoidal, among others. The U. S. Department of the Interior’s Bureau of Reclamation publishes an online version of its comprehensive "Water Measurement Manual" which details all the various types of weirs and flumes, and how to install them and maintain them.

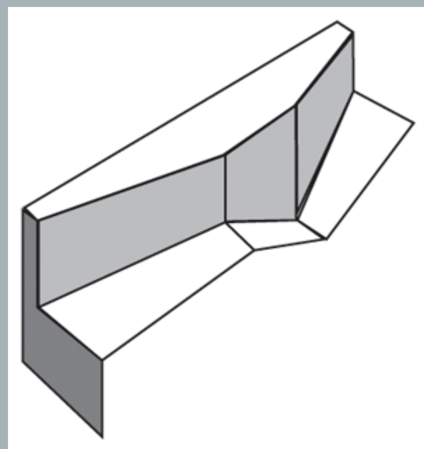
In a v-notch weir, all the water flows through the weir, and the level is measured at a known point behind (upstream) of the weir. This level forms the "H" in our formula.

Sometimes, if very high accuracy is required at the lowest flow rates, a compound weir can be used. This is often a rectangular weir with a sharp v-notch forming the bottom of the weir. Thus, the rectangular weir equation can be used for high flows, and once the flow reduces to below the zero point of the rectangular weir, the v-notch equation is used. Many open channel flow transmitters have the ability to switch equations like this.



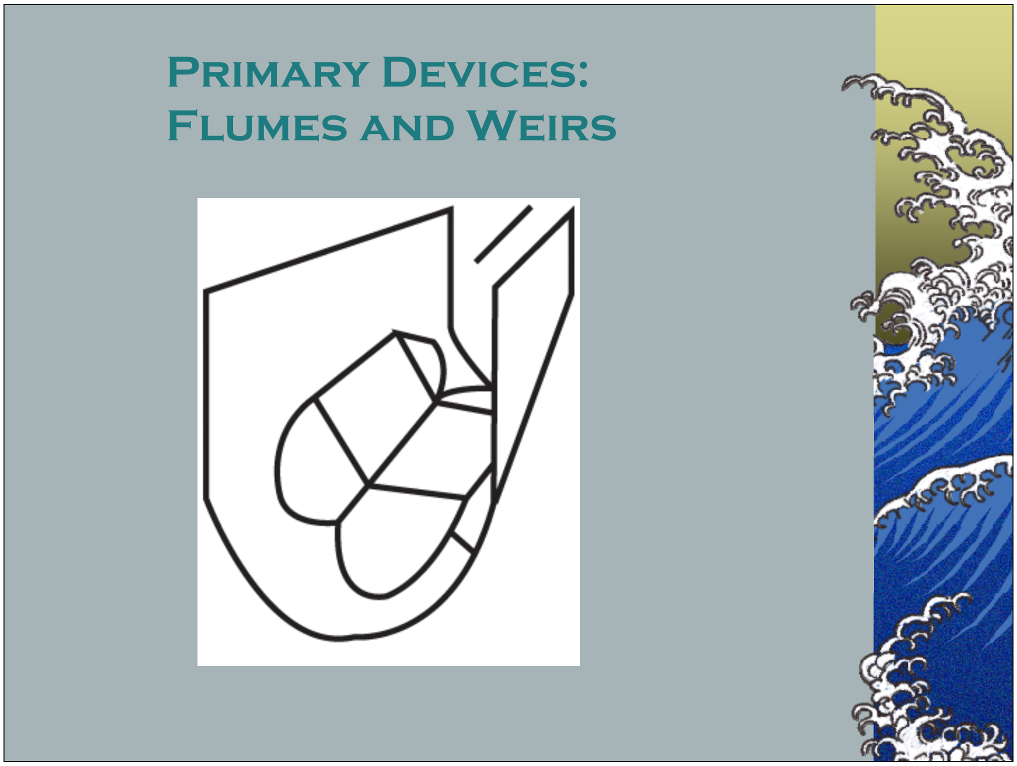
Note that I said flow transmitter not flow meter. That's because the primary device is itself the flow meter. All the transmitter does is to automate the staff gauge. As with the Nilometer, a primary device can measure flow using the calibrated Mark 1 eyeball. What the various types of flow transmitters do is to make it unnecessary for somebody to stand there and eyeball the primary device.

Primary Devices: Flumes and Weirs



Flumes have a constriction in the flow, and a "hydraulic jump" that causes the head height to be linear and repeatable. There are dozens of kinds of flumes. In modern times, the most common are the Parshall and the Palmer-Bowlus flumes.

Parshall flumes are commonly used for flow measurement at the inlet and outlet to wastewater treatment plants and surface water intakes for treatment plants and power plants. Typically, a Parshall flume is supplied as a fiberglas "liner" that is installed and then cemented in place. In this picture, the flume is cutaway so you can clearly see the hydraulic jump.



Palmer-Bowlus flumes were originally developed for measurement in sewers and other open conduits with relatively low flow. There is no constriction, as with a Parshall flume, but there is a complex hydraulic jump that forms the point where the height is directly proportional to flow rate, the "H" in our equation.

Primary Devices: Flumes and Weirs

$Q=KH^n$ Where Q is volumetric flow
K is a units coefficient
H is the measured height over the flume or weir
n is the specific coefficient of the type of flume or weir.

For example here's the calculation for a 90 degree v-notch weir:

$Q_{cfs} = 2.49H_{ft}^{2.48}$; so if H=2.23 ft, Q=69.5 CFS

Here's the equation for flumes and weirs. Note how critical the measurement of H, liquid level, is. There are many tables of coefficients and examples of how to calculate flow. Flow transmitters all have equations built into them.

Making Flumes and Weirs Work

1. Install as close to level inlet to outlet and side to side as possible.
2. Beware of bowing in in fiberglass flume inserts.
3. Make sure weirs are installed exactly vertical.
4. Use the correct level sensor
5. Install level sensor correctly

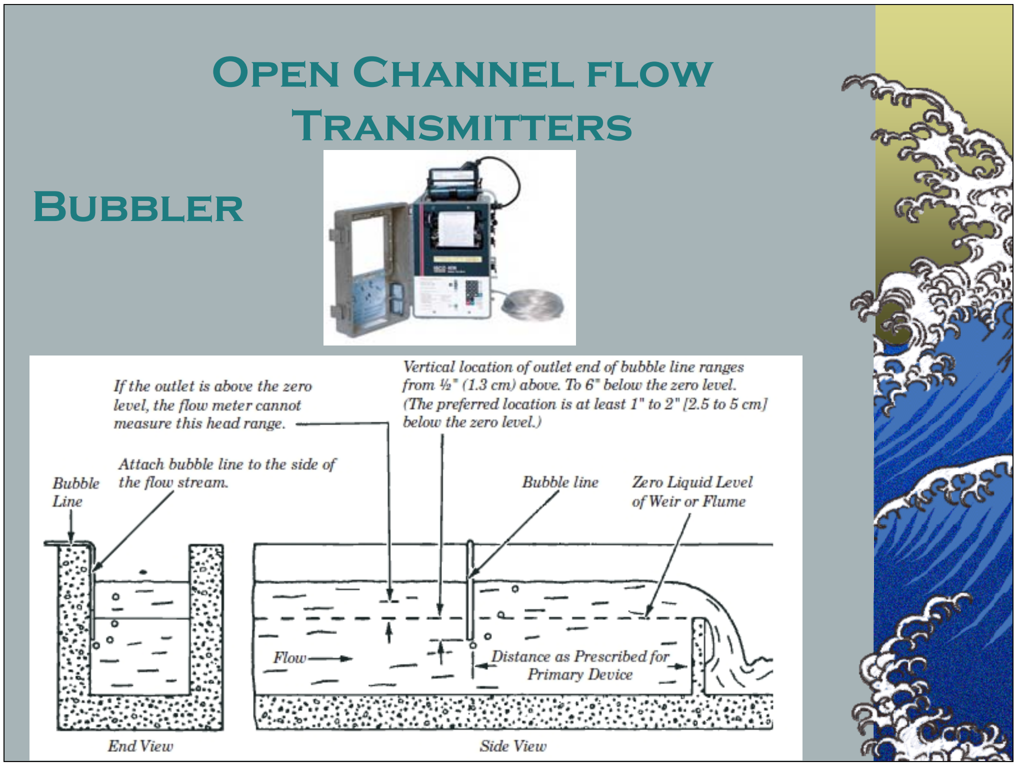
For a flume or weir to be accurate, it must be installed properly. Most error problems with open channel flow measurements are traceable to the accuracy of the flume or weir, not the level measurement or the flow transmitter.

All flumes and weirs must be installed as close to perfectly level inlet-to-outlet as possible, and side-to-side, too. Fiberglass flumes often "bow in" when concrete is poured behind them, and this produces unexpected inaccuracies, which may not be able to be calibrated out, except by in-situ flow testing and the use of a strapping table in the flow transmitter.

All flumes and weirs have what is called the "submergence point" where the level goes above the measurement range of the device. Flow may continue to be moving in either direction during submergence, but the measurement is meaningless during that condition.

Open Channel flow Transmitters

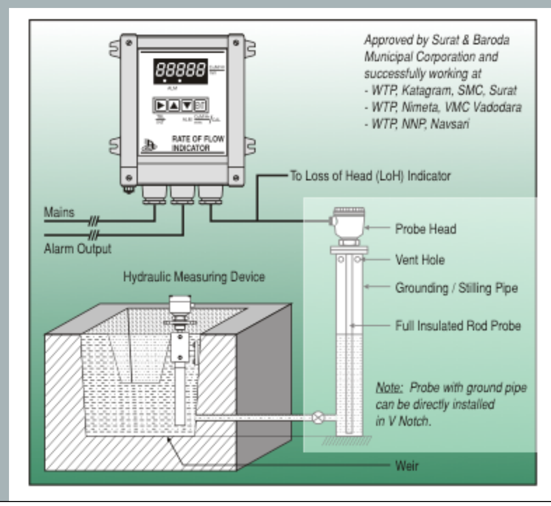
- Bubbler
- Capacitance
- Float and Tape
- Ultrasonic
- Radar
- Staff gauge
- Area-Velocity
- DataGator



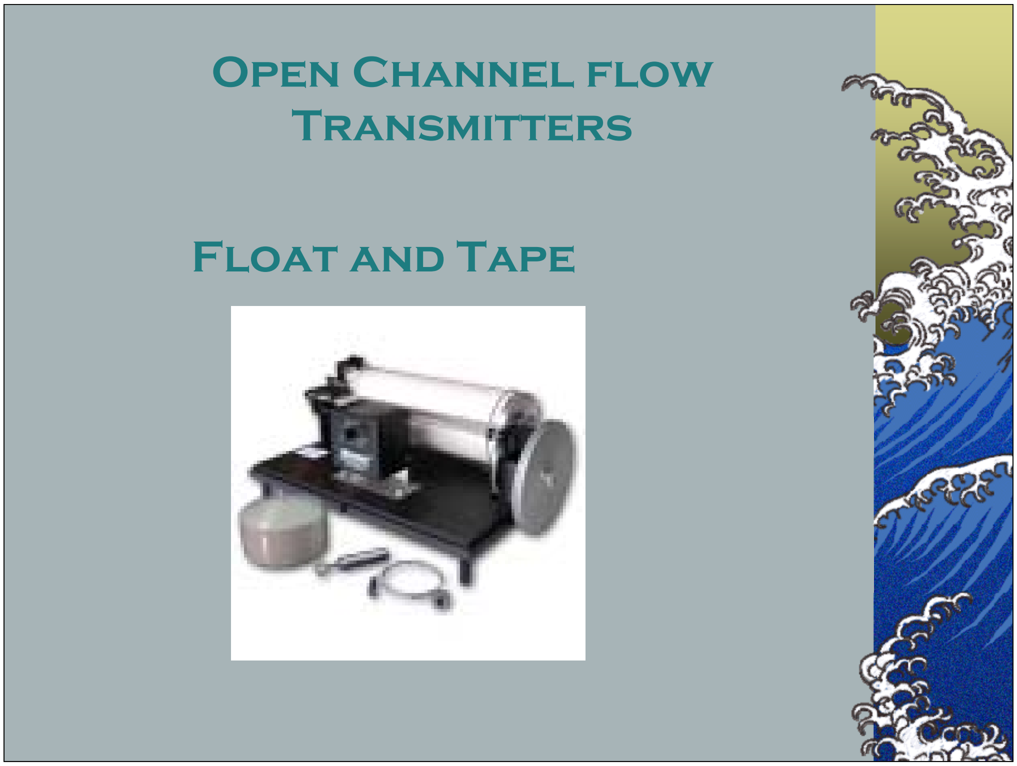
A small compressor pumps air into a reservoir. This air is released slowly by a needle valve into a bubble line, a length of small diameter flexible tubing. The other end of this tube is submerged in the flow stream. Inside the flow transmitter, the bubble line also connects to one side of a differential pressure transducer. As air is released slowly into the bubble line by the needle valve, pressure builds inside the line to force the air out of the line into the flow stream. When there is enough pressure to counteract the hydrostatic pressure of the flow stream, a bubble is forced from the end of the line. The amount of pressure required to force the bubble from the end of the line is directly dependent on the hydrostatic pressure of the flow stream over the end of the bubble line. The pressure transducer inside the flow meter senses this pressure and converts it into an electrical signal that the flow transmitter converts into level. From the measured level detected by the bubbler the flow meter then calculates flow rate and total flow.

Open Channel flow Transmitters

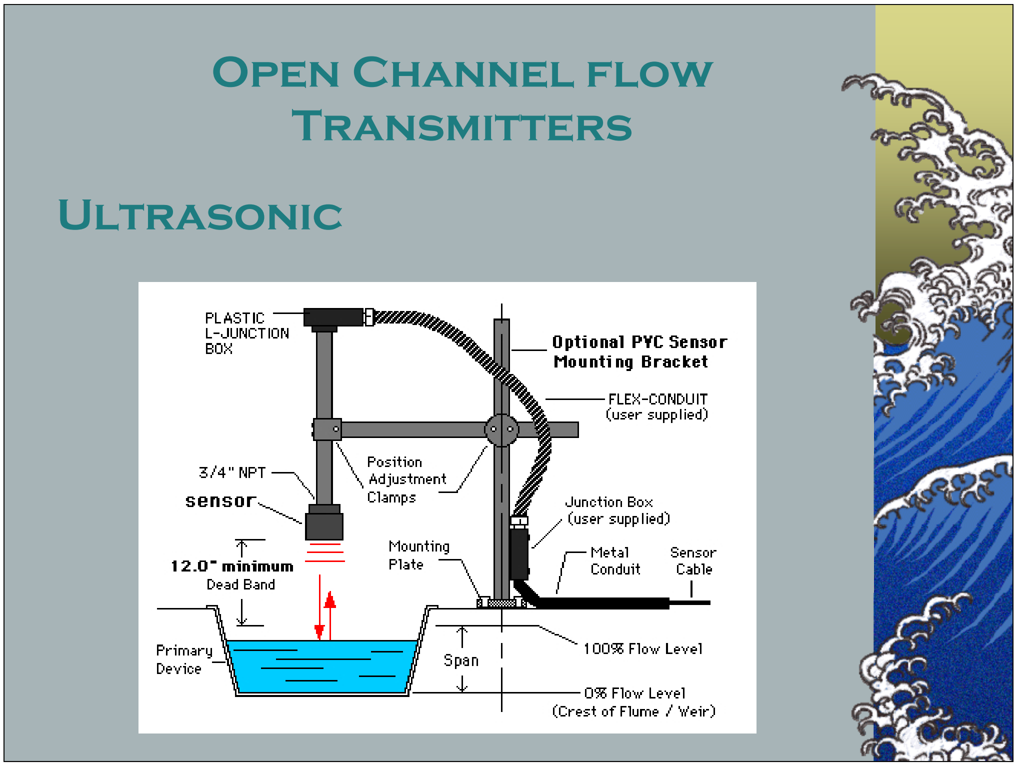
Capacitance



You can still find capacitance or RF Admittance Flow Transmitters for open channel flow, like this one. The capacitance or admittance changes with the level on the sensor, and the level signal is then converted to flow. These sensors have lots of issues, especially with grease or foam in wastewater or irrigation, but they work very well in small flumes and weirs.



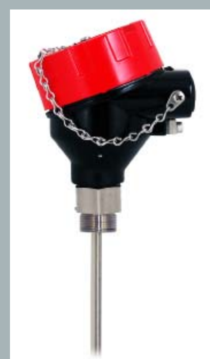
Originally a purely mechanical measurement, with a windup chart recorder, float and tape flowmeters are still in use all over the world, mostly for stream gauging for organizations like USGS. The movement of the float drives a cam operated pen across the chart. Simple, effective, accurate, and doesn’t require power. The operator winds the chart motor every week or so, when he comes to change the chart.



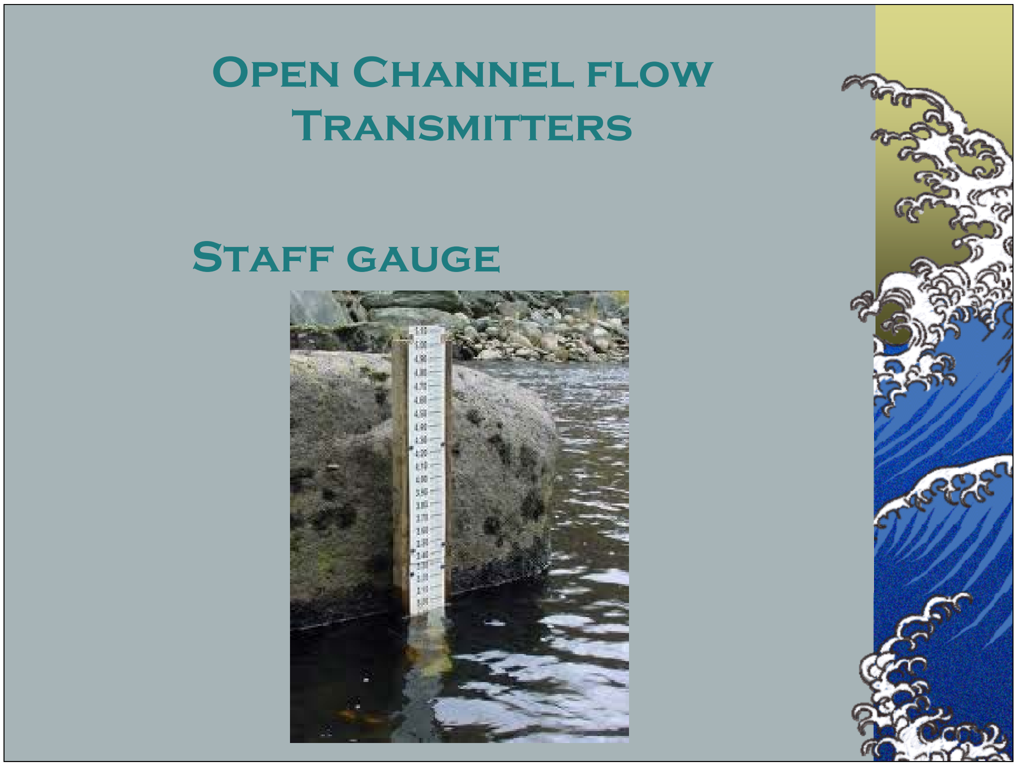
Ultrasonic open channel flowmeters have become the workhorse of the industry. They are non-contacting, and they are very accurate if installed correctly. Note that the picture shows that it isn't just a matter of sticking a sensor over a flume or weir. For example, the plastic condolet and the flex conduit are there not to make the mounting easy but to damp ringing of the sensor. Think of the sensor as a drum that is struck every n times a second. It beats, then listens for the echo. The time difference between the time the drumbeat left the sensor and the time the return signal arrives gives the distance to the liquid height. The key to good applications is to mount the sensor so that it is absolutely vertical, and far enough away from the channel wall so it doesn't get a signal back from the hard surface. Such signals sometimes overpower the circuitry in the flow transmitter. Wind, foam, steam and other off-gases interfere, sometimes terminally, with ultrasonic open channel flowmeters.

Open Channel flow Transmitters

Radar



Both guided wave and downlooking radar transmitters have been used for open channel flow where wind or other interference makes it impossible to use ultrasonic flow sensors.



Just like its ancient predecessor, the Nilometer, the staff gauge is a ruler stuck in the flow with its end point at the arbitrary zero flow point. It is read by the calibrated MK I Eyeball.

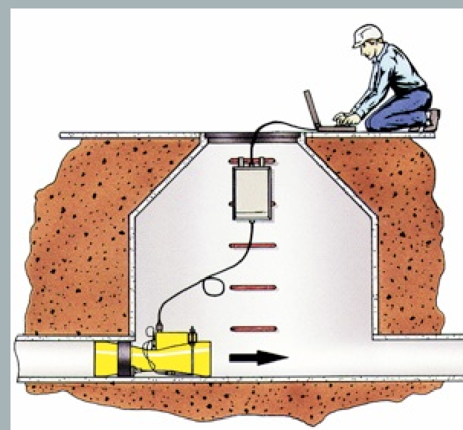
Open Channel flow Transmitters

Area-Velocity

Area-velocity flow meters are based on the theory that there is a point in the flow in an open conduit where the measured flow is equal to the average flow rate in the fluid. These flow meters are usually used for sewer flow and sewer capacity and surcharge studies, since the velocity sensor is designed to be bidirectional. Sensors that have been used include differential pressure, ultrasonic and radar for the top level, and ultrasonic (doppler type) and electromagnetic for the velocity. Proponents of this theory say that Q=VA works with this methodology. However, a cautionary tale. Quite a few years ago, a consulting engineer doing a flow study for a large city in New Jersey found data from one A-V flowmeter that indicated that Manhattan had been underwater up to the top of the Empire State Building.

Open Channel flow Transmitters

DataGator



Area-velocity flow meters being problematic, a flow meter was designed with a special purpose (and highly calibratable) primary device for measuring sewer flows and surcharges. It was called the DataGator, and is still available from Renaissance Instruments. It won an R&D100 award the year it was introduced. It is the only third-party calibratable flow meter for use in sewers. There are four categories of flow that the DataGator works in. For free flow, it works like a standard flume. In submerged flow, it operates using its proprietary flume design. In full pipe flow at transition (from submerged to pressurized) it works like a calibrated venturi tube. And the venturi measurement continues when the pipe is full and the measurement is fully bidirectional.

If you've followed me so far, you get a gold star…and Continuing Education Units!