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FLOW AND VELOCITY MEASUREMENTS USING VORTEX SHEDDING AND MAGNETIC FLOW METERS, JONES HOLE NATIONAL FISH HATCHERY

by

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Flow and Velocity Measurements Using Vortex Shedding and Magnetic Flow Meters, Jones Hole National Fish Hatchery

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Abstract

The water supply for the Jones Hole National Fish Hatchery near Vernal, Utah is collected from shallow groundwater in perforated pipes. This flow is then directed to the hatchery through supply pipes by gravity. The hatchery is being evaluated for expansion, since the water is free from "whirling disease", a parasitic malady that is devastating native trout populations throughout the West. The problem can be spread by stocking trout that have been infected in the hatchery. In order to determine if the available flow from the groundwater source is adequate for the planned expansion at Jones Hole, the flow needed to be measured at various points throughout the underground pipe network. The paper will discuss the measurement methods considered, describe the installations, and the measurements made with the chosen method of vortex shedding meters. Additional calibration data were collected at selected sites in the hatchery with an insertion magnetic flow probe. These measurements are also described.

Figure 1 - Location, Jones Hole National Fish Hatchery (NFH), Utah

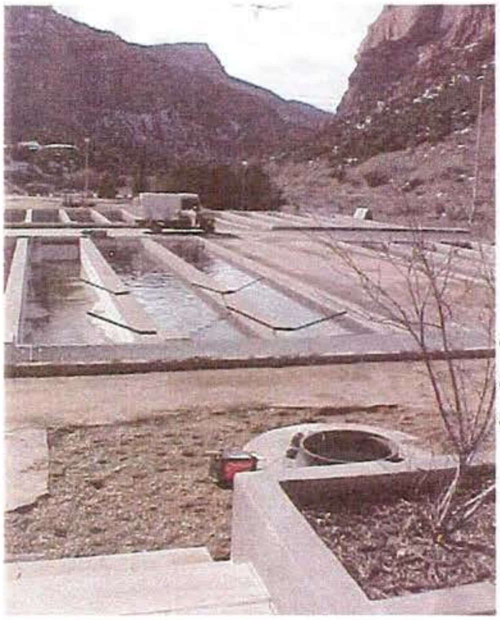

Figure 2 - Photograph looking down the canyon, over raceways A and B, (note flow measurement access manhole in the foreground)

Introduction

The purpose of the flow measurement system at Jones Hole National Fish Hatchery (JHNFH) near Vernal, Utah, (Figure 1) is to determine how much water is being collected and reused in each part of the system, and estimate the amount of water that is not being used. With this information, expansion of the hatchery can be evaluated to determine how many extra raceways could be added, and where to locate them. Adequate water of reasonable quality needs to be available for fish rearing. The Jones Hole NFH is preferred for expanded fish production instead of a new hatchery, since the spring fed (groundwater) source of water provides resistance to whirling disease, a common problem in trout populations in recent times. Nitrogen supersaturation in the groundwater is a problem at the Jones Hole NFH. However, reaeration towers and oxygen injection methods should minimize this problem. Measurement of water quality parameters (as well as quantity) at key locations would facilitate operational decisions to facilitate use and reuse of water for fish rearing.

Description of the Fish Hatchery Flow System

The hatchery is about a kilometer long and 100 meters wide, It runs parallel to Jones Hole Creek and takes advantage of the natural drop in elevation to supply the water. Features of the hydraulic system include;

(1) the Jones Hole Creek bypass structure (a rectangular concrete lined channel to carry Jones Hole Creek flows around the hatchery),
(2) a shallow underground spring-water perforated-pipe collector system,
(3) diversion structures to direct flow from the collector pipe to the hatchery,
(4) control structures to direct flow through "first-use" pipes to the raceways and hatchery building, and to return excess flow to the collector pipe,
(5) the hatchery building, and raceways (where the fish are raised),

(6) interconnecting pipelines to deliver "first-use" water, and "re-use" water to and from the raceways , and
(7) drains to send "used" water to the clarifier pond, where solids settle out before the flow returns to Jones Hole Creek.

There is also an abandoned USGS gaging station downstream from the hatchery on the creek. Figure 2 is a photo looking down the canyon from the hatchery building at about the center of JHNFH.

Water from the springs is collected throughout the hatchery and diverted from the collector pipes to the first-use supply pipelines at the diversion structures. After the water is diverted from the collector pipelines at four diversion structures, it is distributed to the various raceways and the hatchery building with control structures. In order to track the flow at various locations, the water delivered is measured in the "first-use" and "reuse" pipelines. Several flow measurement methods were considered to evaluate the flow distribution and availability at JHNFH.

- Weirs in control structures - not enough approach, low head, and poor flow conditions
- Propeller meters - to difficult to install, maintain, expensive
- Acoustic flow meters - expensive, high maintenance, difficult to install on concrete pipes
- In-line magnetic meters - difficult to install, expensive
- Vortex shedding meters (the method chosen);
  - Wet installation, saddle on pipe with one 50mm (2 inch) hole with standard National Pipe Thread (NPT) connection
  - No moving parts, waterproof, rugged, easily removed for cleaning if needed
  - Large flow range 0.10-5.0 m/s (0.3-15 fps), accurate, digital output
  - Relatively inexpensive
  - Can be used on all types of pipe, including concrete

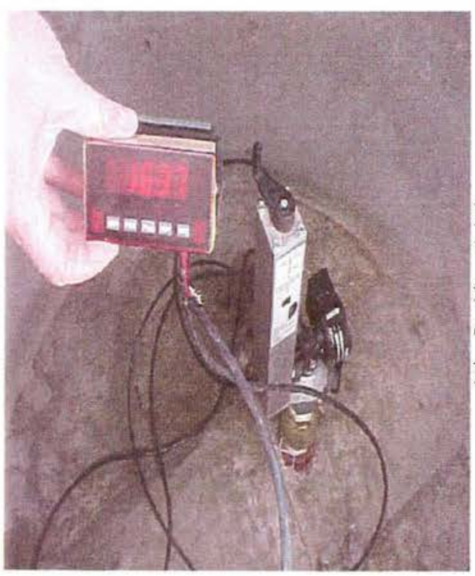

Figure 3 - Model 3100 Fluidyne Vortex Flowmeter installed in the manhole shown in Figure 2 with a digital-LED readout (flow in gallons per minute).

Figure 4 - Vortex shedding meter in flow demonstration model

The pipes leaving each control structure were accessed by excavating with a backhoe and installing a concrete manhole to gain access to the pipe. The meter was installed by drilling a hole in the pipe and attaching a pipe saddle with an NPT connection to accommodate the meter. The actual meter location should not be submerged since the meter connections are water resistant but not waterproof. However, if the meter is above the water surface in a manhole, it functions well. Each meter has twenty feet of cable for connection to a digital readout to be located at or near ground level. The meters each have a ball valve and retraction/insertion crank for easy installation and removal without de-watering the pipeline.

There were a total of 16 meters installed throughout the system. The locations were selected to provide ten to thirty pipe diameters downstream from the control structure (where possible), the best location to avoid local traffic around the hatchery was also considered.

Each unit included a flowmeter with pipe saddle, pre-wired for a 4-20 ma output (to accommodate future remote monitoring) and an LED remote readout unit. The meter shown in Figure 4 has a readout on the meter instead of a remote readout. The meters can also track cumulative water deliveries in the selected volume units. At Jones Hole thousands of gallons are tracked.

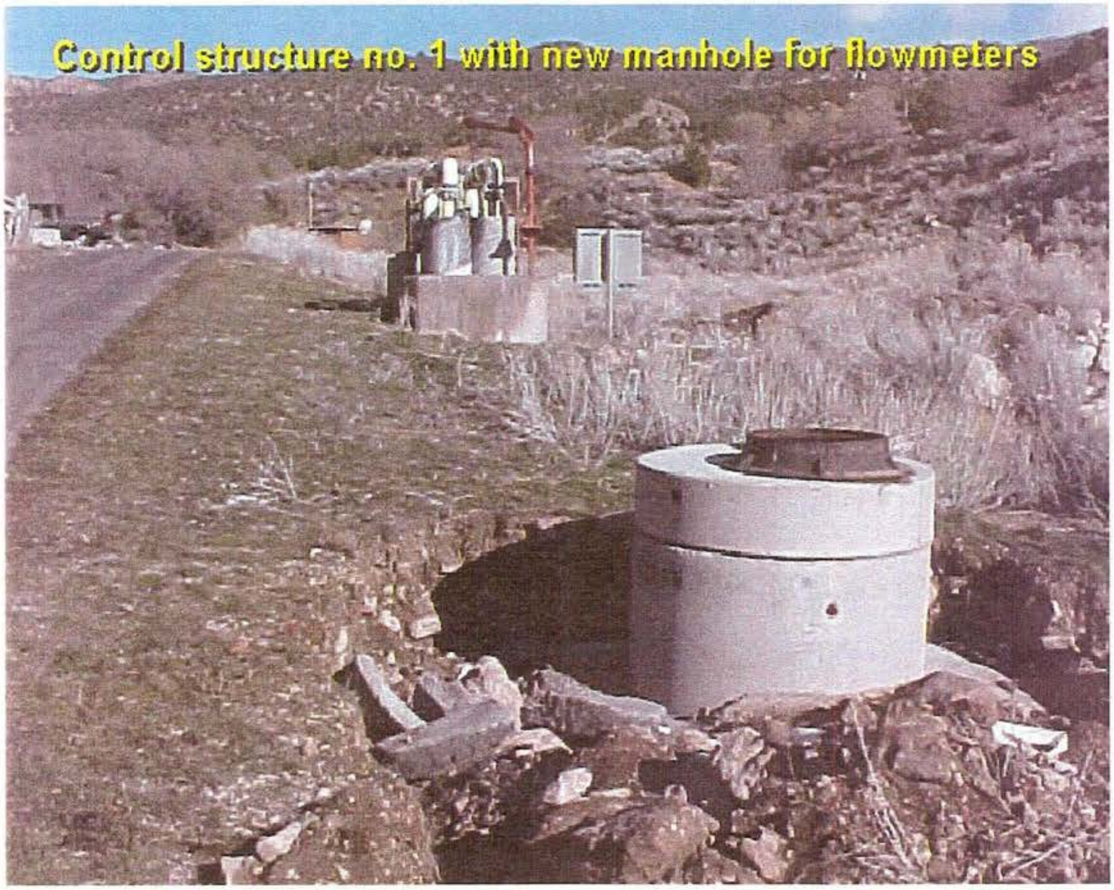

Figure 5 - New flow measurement manhole in the foreground and control structure number one in background.

At Jones Hole the total cost of mounting apparatus and instruments was approximately $2,000 per meter. The labor to install the manholes, and the cost of the concrete manholes was in addition to the meter costs. The flowmeters can be battery operated with 12 Vdc or powered by a dc converter if 110 Vac power if available.

Vortex Shedding Principal

Rouse discusses the formation of vortex pairs behind a bluff body in irrotational flow in "Elementary Mechanics of Fluids." This phenomena is sometimes termed the von Kármán vortex trail. The relationship of the fluid velocity (v_o) to the period of oscillation (T) is related to the diameter and shape of the body and the Reynolds number (R_e) of the flow. Therefore, for a given body form, the dimensionless combination of the period of oscillation, the fluid velocity, and a linear measure (L) of the body may be expressed as:

$$\frac{Tv_o}{L} = \phi(R_e)$$

In the case of a cylinder it was found that $\frac{Tv_o}{D} \cong 5$, for values of R_e between 2 x 10^2 and 2 x 10^5.

The vortex trails can be observed in air flowing past a flag pole (see Figure 6). As the wind velocity increases, more ripples form on the flag. The vortex meter uses a stable rod shape (a trapezoid) to shed vortices. The period of oscillation is measured with a piezoresistive pressure sensor to detect force fluctuations in the rod.

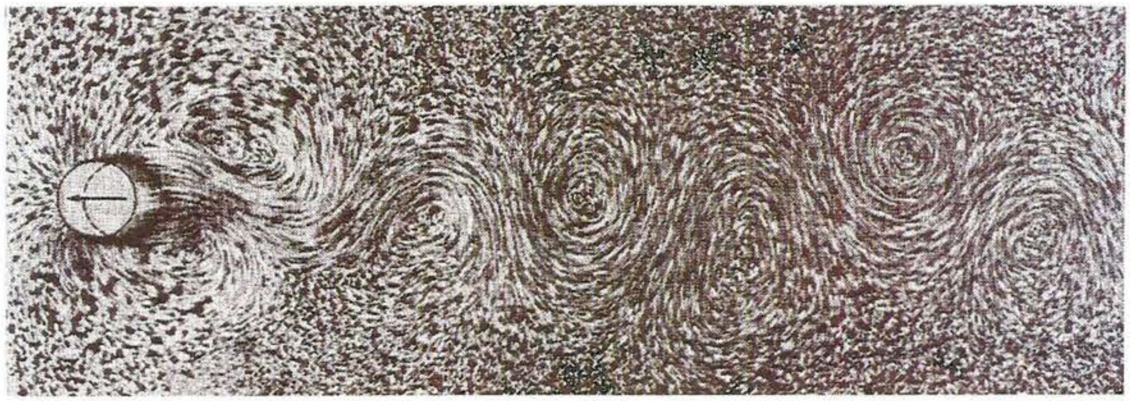

Figure 6 - Vortex trail in the wake of a moving cylinder.

Vortex Meter Performance

Accurate flow measurement with a vortex meter requires that the pipe diameter and meter insertion distance be designated for each installation. Of the 16 meters installed at Jones Hole, 12 performed well after the initial set up. In the remaining 4 locations, the meters failed to give an indication of flowrate. An investigation into the nonfunctional measurement locations revealed several problems. At two of the control structures, the slope of the pipes returning excess flow to the collection pipe was steeper than anticipated and the pipes were not flowing full. This left the associated vortex meters (located near the top of the pipe) out of contact with the water. At another location the meter was installed at what was later determined to be a local high spot in the pipe. Although flow in the pipe was pressurized, accumulation of air in the crown at this point left the meter in the dry. An air-relief vent was used to remedy the problem at this location. The final problem occurred in a manhole where the water table was higher than the buried pipe being metered. This resulted in the entire meter assembly being submerged. The meter connections are not designed for continuous submergence and thus failed. This problem was resolved by installing a waterproof stand pipe around the meter connection and sealing it at the base.

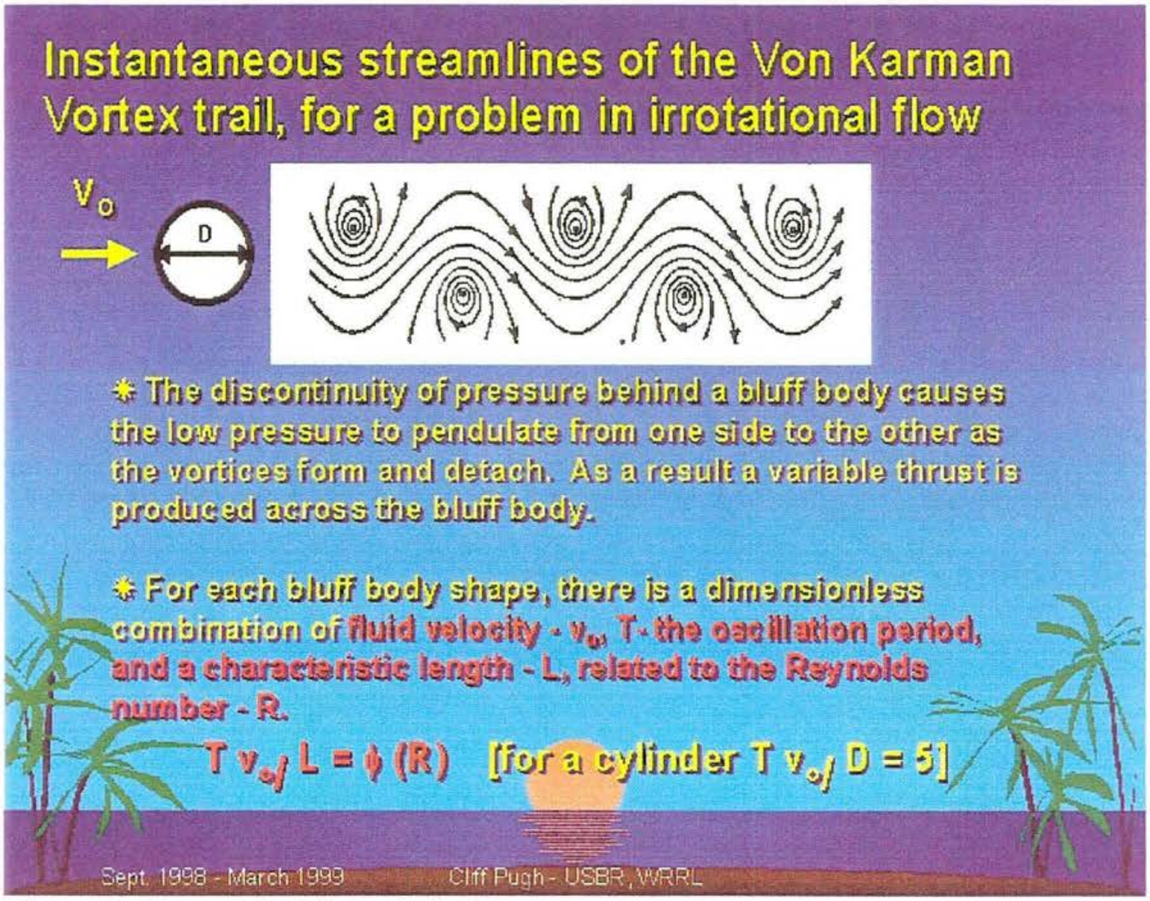

Figure 7 - Vortex Shedding principal.

Velocity Measurements with Magnetic Flow Probe

Diagnosis of the vortex meter problems was aided by use of an insertion magnetic flow probe. This probe, manufactured by Marsh-McBirney, Inc. was used with their Model 2000 Flo-Mate portable flowmeter (Figure 8). The insertion probe can be used to measure flow velocities in pipes flowing full or partially full. The probe is inserted through the wall of the pipe using an O-ring adapter attached to a 50 mm (2 inch) NPT connection on the pipe. The adapter holds the probe in place while allowing the insertion depth to be varied. This type of connection provides a water-tight seal for applications where the pipe is pressurized, while providing the flexibility necessary to measure velocities along a diametric path through the pipe.

At each of the four sites where the vortex meters were not providing discharge readings, the vortex meters were removed, and the magnetic flow probe was used to assess the flow conditions in the pipe. The general procedure was to insert the probe to the invert of the pipe and take a velocity measurement. The probe was then raised 30.5 mm (0.1 ft) and another velocity measurement was taken. This process was repeated until the probe reached the top of the pipe or lost contact with the water. In this manner a vertical velocity profile was developed for each location. This data was used to estimate the discharge as well as to determine the approximate

Figure 8 - Marsh-McBirney insertion magnetic probe with Model 2000 Flo-Mate portable flowmeter.

location of the free surface for the partially-full pipe cases. Figures 9 and 10 depict the measured profiles for a full and partially-full condition, respectively. The velocities shown in Figures 9 and 10 are adjusted upwards slightly based on a laboratory calibration of the insertion magnetic probe which determined that the output velocities from the probe were consistently under-reported by 0.037 m/sec (0.12 ft/sec).

Aside from confirming which pipes were flowing full, the velocity profiles provided other important information. The full-pipe profile (Figure 9) confirmed that the flow was fully-developed and essentially symmetric about the pipe axis. This is an important requirement in order for a single-point velocity-measurement instrument such as a vortex meter to be able to accurately compute the discharge. Conversely, the partially-full profile (Figure 10) confirmed that, in addition to the vortex meter not contacting the water surface, the meter had been installed too close to an undershot control gate located approximately 3 m (10 ft) upstream. Without a sufficient approach distance for the flow profile to develop, the effect of the gate caused higher flow velocities to be skewed toward the invert rather than the water surface.

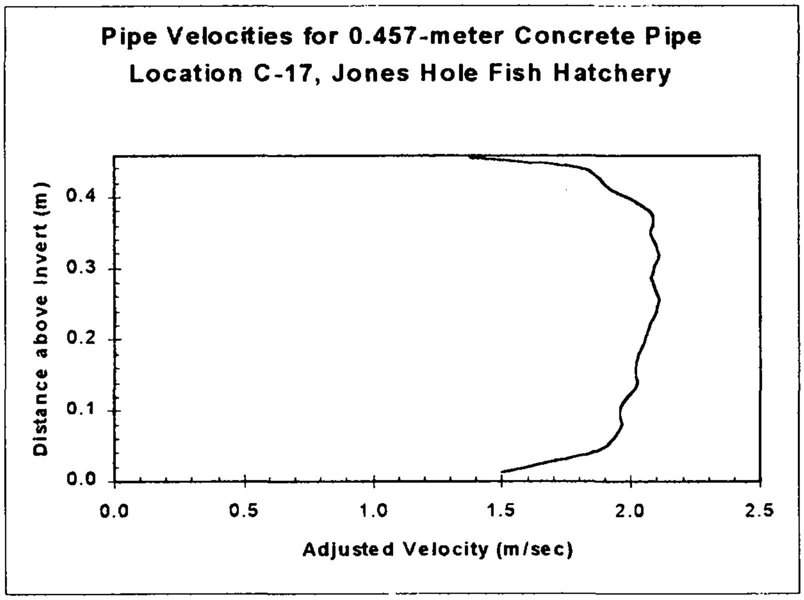

Figure 9 - Velocity profile for a full-pipe condition.

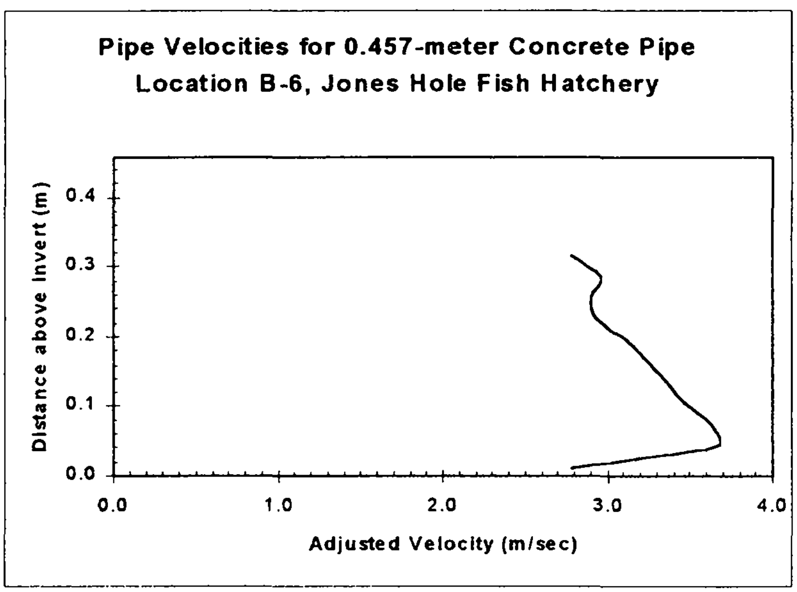

Figure 10 - Veloctiy profile for partially-full condition.

Conclusions

Vortex shedding meters are a viable alternative for measurement of discharge and volume in full pipe flow. They have several advantages over other technologies, including;

- Wet installation, saddle on pipe with one 50mm (2 inch) hole with standard National Pipe Thread (NPT) connection
- No moving parts, waterproof, rugged, easily removed for cleaning if needed
- Large flow range 0.10-5.0 m/s (0.3-15 fps), accurate, digital output
- Relatively inexpensive
- Can be used on all types of pipe, including concrete

Insertion magnetic flow meters are a versatile method for flow profiling in a full or partially full pipes to determine what the flow profile looks like. Magnetic insertion probes can be used in places where propeller type meters, or Pitot tubes would not fit. At Jones Hole, measurements were made at locations where the pipe was full and partially full. Velocities ranged from 1 m/s to 5 m/s.

References

Rouse, Hunter, "Elementary Mechanics of Fluids," 1946, pp. 239-241, John Wiley & Sons, Inc., New York, New York.