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Open Channel Flow in Aquaculture

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Open channel flow of water has been used in aquaculture production for many years. Distribution canals, raceways and drainage ditches are some examples. Since the beginning of civilization man has been interested in flow in open channels. Attempts to record the levels on the Nile River date back to 3500 B.C. In 52 A.D. Sextus Julius Frontinus as Water Commissioner of Rome attempted to determine the quantity of water delivered to each user by measuring the cross-sectional area of each discharge spout. The technology available today is much more accurate but, for the most part, is an adaptation of these earlier concepts.

The flow of water in open channels can be an effective and efficient way to move water for aquaculture. Often, the large flow rates needed in aquaculture require large, costly piping systems. Open channels offer an alternative for movement of large flows over long distance if the land slope is appropriate and water losses to evaporation and percolation are acceptable. Open channels should be designed and maintained to handle the needed flow. This fact sheet will discuss the design of open channels and measurement of flow in open channels.

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Methods of determining flow in open channels

By definition, an open channel flow is flow in any channel in which the liquid flows with a free surface. There are several ways to determine flow in open channels. Some are discussed below.

Time gravimetric

With this method the entire stream flow is collected in some type of container for a measured length of time. The flow rate is calculated by dividing the volume of water collected by the time to collect it. This is the "bucket and stop watch" technique. Most practical considerations limit the use of this method to low flow rates. In aquaculture uses, if the container is large enough, i.e., a pond of known volume, the technique may have practical application.

Dilution

With this procedure the flow rate is measured by determining how much the flowing stream dilutes an added tracer solution, usually a radioactive material or fluorescent dye. The dilution technique uses theoretical formulas to indicate stream flow and does not alter the flow. A disadvantage of this method is that it requires costly equipment that is not very rugged in field use.

Velocity area

In this method, the flow rate is calculated measuring the cross-sectional area of the channel and multiplying that area by the mean flow velocity across the area.

Hydraulic structure

In this method some type of hydraulic structure is placed in the stream. The purpose of the hydraulic structure is to produce a relationship between the liquid level (head) and the flow rate of the stream. These structures are normally either weirs or flumes as shown in Figure 1. Restrictions caused by weirs or flumes will alter the flow of the stream.

Slope-hydraulic radius

In this method the slope of the water surface, the cross-sectional area and the wetted perimeter over a length of uniform section of the channel are used to measure flow using a resistance equation such as Manning's Formula.

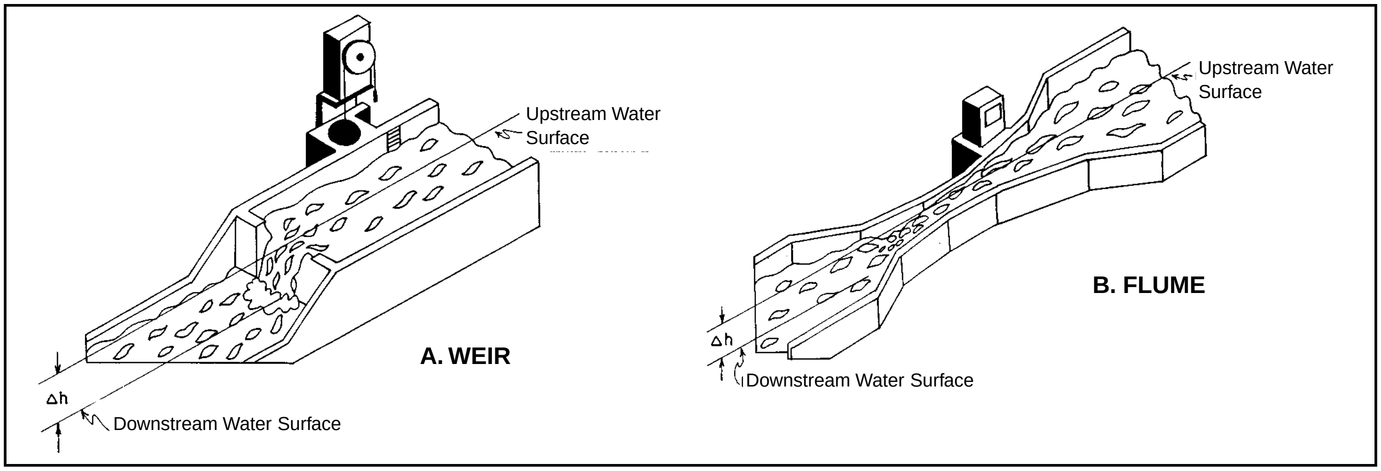


Figure 1. Hydraulic structures are either weirs or flumes.

The wetted perimeter is the length of wetted surface of the cross-sectional area and is an indicator of the efficiency of the channel shape and therefore the resistance to flow. The Manning Formula requires a knowledge of the cross-section of the channel, the slope of the channel, the water depth and a roughness factor dependent on the channel surface.

Practical flow measurement in aquaculture

It should be understood that the study of open channel flow is complex. Flow is seldom uniform, the roughness of the channel may vary, turbulence is almost always present, and the cross-sectional area may not be constant. Most flow measurements are estimations at best, and empirical methods (methods developed by real world experiences) are very common.

Because of the length of this publication and the practicality to aquaculture, more in-depth discussion will be presented only for the velocity-area and the slope-hydraulic radius methods.

How to use the velocity-area method

The velocity-area method is a procedure that is simple and practical for channels of the size normally used in aquaculture. The basic relationship is:

$Q = VA$, Where

Q = Flow in cubic feet per minute

V = Velocity in feet per minute

A = Cross-sectional area in feet^2

This is the basic equation of all flow. Therefore, to evaluate a channel to determine the amount of water flowing we need to measure the cross-sectional area (A) and the average velocity (V) across the cross-sectional area.

Area (A) is determined by measuring the width (W) (Figure 2) and taking measurements of the depth at equal distances across W and averaging them. Then W X D will give the cross-sectional area.

Measuring the velocity is the difficult part of this procedure since the velocity varies widely across the cross-section. There at least 8 procedures used to determine the mean velocity. The most common are the two-point method and the six-tenths-depth method. The two-point method is used where the water depth is more than 2 feet. Here the velocity is measured at .2 and .8 of the depth and averaged. Accuracy of this method is high. The six-tenths-depth method measures velocity at .6 the depth from the surface. The accuracy is not as good as the two-point method, but adequate in shallow channels. With both methods a current meter is required. Velocity measurements are recorded at equal intervals across the channel and averaged. The equation $Q = AV$ is then applied to determine the flow (Q). Accuracies of ± 20 percent should result if care is taken with measurements.

Devices used to measure velocity in open channels are known as current meters. A number of different types of current meters are available. Morris and Wiggert (1972) reviewed these devices. The more common are Doppler Ultrasonic meters, Turbine meters, rotating element meters, electro-magnetic probe meters and Eddyshedding Vortex meters. Improvements in electronics have enhanced the accuracy of these meters.

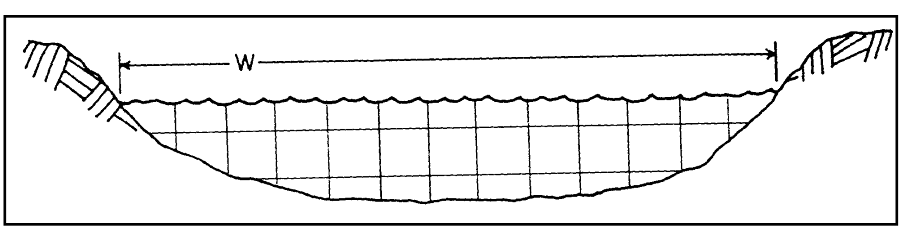


Figure 2. Typical cross-section of any open channel.

How to use the slope hydraulic radius method

The Manning Equation in its various forms is the most used empirical method for estimating the flow in open channels. This equation can also be used to design open channels. The Manning Equation can be written as follows:

$$Q = A \times V = \frac{1.49\, R^{\frac{2}{3}} \times S^{\frac{1}{2}} \times A}{n}$$

Q = Flow in cubic feet per second

R = Hydraulic Radius = A / P in ft.

A = Cross-sectional area of the channel in $ft.^2$

P = Wetted perimeter of the channel in ft.

S = Slope of the channel - dimensionless

n = The roughness coefficient - dimensionless

If Q is desired in gal / min, the equation becomes

$$Q = 669\, \frac{R^{\frac{2}{3}} \times S^{\frac{1}{2}} \times A}{n}$$

For the Manning formula to be applied the channel should be nearly uniform in slope, cross-section and roughness, and free of outside water sources, turns and rapids. The straight section should be at least 200 feet long (longer if possible).

It can be seen that the average velocity and flow vary inversely with the roughness of the channel (n). Therefore, the higher the n value the lower the flow, all other factors being equal. Table 1 gives n values for several channel types. R is defined as the hydraulic radius, the cross-sectional area divided by the wetted perimeter. This is dependent on the slope and depth of water flowing. Table 2 provides geometric elements for channels of 4 cross-sectional slopes. The most common shape for earthen open channels is the trapezoid. This shape allows for varying side slopes which can minimize erosion. Table 3 shows permissible side slopes depending on soil types. This information is useful when designing an open channel.

The slope of the channel (S) is a measure of the channel bottom elevation difference at the ends of the uniform section divided by the length of the section.

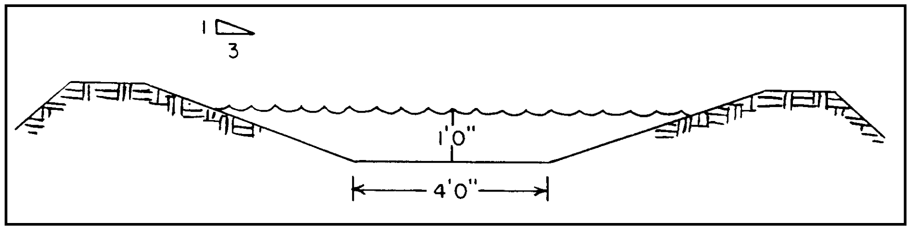


Figure 3. Measuring water flow in an open ditch.

As an example, suppose we want to know how much water is flowing in an open ditch with the following trapezoidal cross-sectional shape (Figure 3).

The ditch bottom is known to drop 1 foot in 400 feet of nearly straight uniform cross-section. The channel is vegetated and not well kept.

n = (Table 1) is estimated as .030

$$S = \frac{\text{elevation difference}}{\text{section length}} = \frac{1}{400} = .0025$$

From Table 3

$$A = (b + zh)\, h = [4 + 3\,(1)\,]\; 1 = 7$$

$$R = \frac{(b + zh)\, h}{b + 2h\sqrt{1 + z^2}} = \frac{[4 + 3\,(1)]\; 1}{4 + 2\,(1)\sqrt{1 + (3)^2}} = \frac{7}{= 10.32} = .68$$

$$Q = 669\, \frac{(R)^{\frac{2}{3}} \times S^{\frac{1}{2}} \times A}{n}$$

$$Q = \frac{669\, (.68)^{\frac{2}{3}} \times (.0025)^{\frac{1}{2}} \times 7}{.030} = \frac{669\, (.77)\, (.05)\, (7)}{.030}$$

Q = 6,010 gal / min.

This seems to be a large amount of water flowing. Is the velocity too high for the sandy loam soil? Table 4 shows that the maximum allowable mean velocity to minimize erosion = 160 ft / min. The average velocity in our example channel is:

$$Q = 6{,}010 \text{ gal / min} = 803 \text{ ft}^3\text{ / min } (7.48 \text{ gal} = 1 \text{ ft}^3)$$

$$V = \frac{Q}{A} = \frac{803}{7} = 115 \text{ ft / min}$$

Therefore, the velocity will not cause excessive erosion.

From the discussion and the example it should be evident that in the design of an open channel that is to be nearly straight and uniform, the Manning Equation can be very useful. By considering various cross-sectional shapes and depths of flow with known slopes, needed flow rates for aquacultural applications can be planned. Remember, the calculated values are only as good as the input values. Variances in the shape, slope and straightness will cause the procedure to be less accurate and less useful.

Table 1. Channel condition and values of the roughness coefficient n.	
Channel Condition	**Value of n**
Exceptionally smooth, straight surfaces; enameled or glazed coating; glass; lucite; brass	0.009
Good wood, metal, or concrete surfaces with some curvature, very small projections, slight moss or algae growth or gravel deposition; shot concrete surfaced with troweled mortar	0.014
Rough brick; medium quality cut stone surface; wood with algae or moss growth; rough concrete; riveted steel	0.015
Well-built earth channels covered with thick, uniform silt deposits; metal flumes with excessive curvature, large projections, accumulated debris	0.018
Smooth, well-packed earth; rough stone walls; channels excavated in solid, soft rock; little curving channels in solid loess, gravel or clay, with silt deposits, free from growth, in average condition; deteriorating, uneven metal flume with curvatures and debris; very large canals in good condition	0.020
Small, manmade earth channels in well-kept condition; straight natural streams with rather clean, uniform bottom without pools and flow barriers, cavings and scours of the banks	0.025
Ditches; below average manmade channels with scattered cobbles in bed	0.028
Well-maintained large floodway; unkept artificial channels with scours, slides, considerable aquatic growth; natural stream with good alignment and fairly constant cross-section	0.030
Permanent alluvial rivers with moderate changes in cross-section, average stage; slightly curing intermittent streams in very good condition	0.033
Small, deteriorated artificial channels, half choked with aquatic growth, winding river with clean bed, but with pools and shallows	0.035
Irregularly curving permanent alluvial stream with smooth bed; straight, natural channels with uneven bottom, sand bars, dunes, few rocks and underwater ditches; lower section of mountainous streams with well-developed channel with sediment deposits; intermittent streams in good condition; rather deteriorated artificial channels, with moss and reeds, rocks, scours and slides.	0.040
Artificial earth channels partially obstructed with debris, roots, and weeds; irregularly meandering rivers with partly grown-in or rocky bed; developed flood plains with high grass and bushes.	0.067

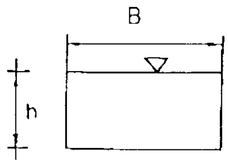
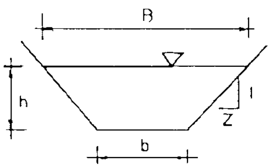
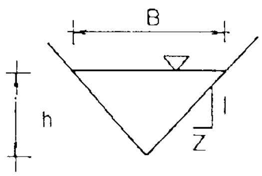
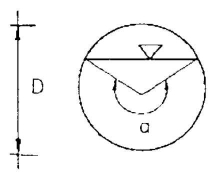
Table 2. Channel section geometry and associated parameters.			
Section	Area A	Wetted perimeter P_w	Hydraulic radius $R = \frac{A}{P_w}$
	$B \times h$	$B + 2h$	$\frac{Bh}{B + 2h}$
	$(b + zh)h$	$b + 2h\sqrt{(1+z^2)}$	$\frac{(b + zh)\,h}{b + 2h\sqrt{1+z^2}}$
	zh^2	$2h\sqrt{1 + z^2}$	$\frac{zh}{2\sqrt{1 + z^2}}$
	$\frac{(\alpha - \sin\alpha)D^2}{8}$	$0.5\,\alpha D$	$0.25\left(\frac{1-\sin\,\alpha}{\alpha}\right)D$

Table 3. Allowable side slopes (run over rise) for trapezoidal channels in various soils.

Type of Soil	Z/1
Light sand, wet clay	3:1
Wet sand	2.5:1
Loose earth, loose sandy loam	2:1
Ordinary earth, soft clay, sandy loam, gravelly loam or loam	1.5:1
Ordinary gravel	1.25:1
Stiff earth or clay, soft moorum	1:1
Tough hard pan, alluvial soil, firm gravel, hard compact earth, hard moorum	0.5:1
Soft rock	0.25:1

Table 4. Allowable mean velocities to protect against erosion or scour in channels for various soils and materials.

Description	V in m/sec	V in ft/min
Soft clay or very fine clay	0.2	40
Very fine or very light pure sand	0.3	60
Very light loose sand or silt	0.4	80
Coarse sand or light sandy soil	0.5	100
Average sandy soil and good loam	0.7	140
Sandy loam	0.8	160
Average loam or alluvial soil	0.9	180
Firm loam, clay loam	1.0	200
Firm gravel or clay	1.1	220
Stiff clay soil; ordinary gravel soil, or clay and gravel	1.4	280
Grass	1.2	240
Coarse gravel, cobbles, shale	1.8	360
Conglomerates, cemented gravel, soft slate, tough hardpan, soft sedimentary rock	1.8-2.5	360-500
Soft rock	1.4-2.5	280-500
Hard rock	3.0-4.6	600-920
Very hard rock or cement concreted (1:2:4 minimum)	4.6-7.6	920-1,520

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