NOSE VELOCITIES IN PHYSICAL HABITAT SIMULATION

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ABSTRACT

The physical habitat of many species of aquatic animals is partially related to the velocity and depths in a stream. The Physical Habitat Simulation System (PHABSIM) is often used to simulate the physical habitat as a function of the discharge in the stream. In most applications of PHABSIM the mean column velocity is considered to be the appropriate velocity to use in the simulation. But in some situations, the calculations for velocity should be made at the expected location of a fish in the water column. The point velocity at the location of the fish (nose velocity) can be calculated using the power law or the universal logarithmic velocity distribution law. The mean column velocity will result in calculated habitat areas available in mountain streams during spring runoff with a snow-melt hydrograph less than half of the habitat calculated using the nose velocities. When the theoretical velocity distributions are used and when the nose depth is in the order of the roughness elements the nose velocities may need to be adjusted because velocity shelters are not adequately accounted for in the nose velocity and habitat calculations. Adjusting the habitat simulations to consider some of the nose locations are behind roughness elements where the nose velocities are less than the theoretical nose velocities increased the physical habitat calculated for the higher streamflows by 20 percent or more.

Keywords: point velocities, nose velocities, velocity simulation, habitat simulation, aquatic habitat.

INTRODUCTION

The physical habitat of many species of aquatic animals is partially related to the velocity and depths in a stream. The Physical Habitat Simulation System (PHABSIM) is often used to calculate physical habitat as a function of the discharge in the stream (Milhous et al, 1988). In most applications of PHABSIM the mean column velocity is used as the appropriate velocity. But in some situations, the calculations should be made at the expected location of a fish. Examples are 1) the spawning life stage of salmon and trout which spawn on the bottom of a stream, 2) behind cobbles because fish locate areas of low velocity as feeding and nesting habitat, and 3) over the top of cobbles because that is where attached invertebrate food is most plentiful.

In an analysis of the physical habitat for trout in the Upper Animas Basin in southwestern Colorado it was shown that 1) characteristics of the substrate limit the winter habitat which, in turn, limits the population; and 2) high stream flows during spring runoff significantly limit the habitat available during spring (Milhous, 1998). The analysis also showed that substrate characteristics are important; presumably because large substrate provides velocity shelters. This paper considers concepts of nose velocity simulation as an element of physical habitat simulation. Nose velocities are the point velocities at the location of fish or other aquatic animals. The importance of velocity shelters is in reducing the velocity at the location of the fish (i.e., reducing the nose velocity).

The next section discusses equations for calculating noses velocities with a following section on the application of the equations to a physical habitat model of a reach of lower Cataract Creek in central Montana.

NOSE VELOCITIES

THEORY

The power law of velocity distribution (Schlichting, 1968) is:

$$v = u^* C [(y u_*/\nu)^{**}m]$$

where v is the velocity at a distance y from the wall (stream bed in an open channel), u_* is the shear velocity, n is the kinematic viscosity and C is a constant. Integrating over the depth of flow, D, gives the mean velocity, V_m. Then dividing the nose velocity, V_n, at the nose depth (measured from the stream bed), D_n, by the mean velocity gives the equation for the calculation of the nose velocity from the mean velocity:

$$V_n = V_m [(m+1) (D_n/D)^{**}m]$$

According Schlichting the value of m is approximately 1/7 but is shown by Schlichting to be a function of the Reynolds number for smooth pipes, and of the ratio of hydraulic radius to roughness height for rough pipes. The equation for rough pipes is:

$$m = 0.30 (R/ks)^{**}\text{-}0.144$$

where R is the hydraulic radius and ks is the roughness height.

An equation take from the literature (source unknown) and included in the habitat simulation programs to calculate the value of m is:

$$m = 7.75\ n\ (D\ ^{**}\ \text{-}0.167)$$

where n is the Manning's roughness coefficient. Using the Strickler equation for roughness the above equation can be transformed to:

$$m = 0.31\ (D/ks)\ ^{**}\ \text{-}0.167$$

The universal velocity distribution law for turbulent open channels (Schlichting, 1968) can also be transformed to an equation relating the mean velocity to the velocity at a point in the vertical. The equation is:

$$V_n = V_m \{\log(33.2\ D_n/ks)/\log(12.12\ D/ks)\}$$

For streams the characteristic roughness height is often taken as the size of the bed material at which 65 percent of the particles are smaller (the D65 size).

An empirical equation can be used for the nose calculations based on the power law equation. This equation is:

$$V_n = V_m \{ a (D_n/D)^{**}b\}$$

where a and b are obtained by regression analysis. The equation for m can also be calculated from an empirical equation of the form:

$$m = a (D/D65) ^{**} b$$

TEST OF THE EQUATIONS

Empirical coefficients were determined for a data set from the Salmon River in New York State. The D65 size was 9.1 cm and with a nose depth of 9.1 cm.

The relation between nose velocity and mean velocity based on the power relation was found from regression analysis to be:

$$V_n = V_m [1.318 (D_n/D)^{**}0.338]$$

The relation for the coefficient m was also determined. The equation is:

$$m = 0.175 (D/D65) ^{**} -0.0918$$

These equations were used with the same set of data to calculate the nose velocities and then to calculate the error. The error term used is the difference between simulated and measured note velocity divided by the measured nose velocity. A summary of the absolute value of the errors from the various equations is give in Table 1. The empirical fit of a power equation and the logarithmic distribution have the lowest errors.

Table 1. Errors resulting from the use of various equations to calculate the nose velocity. Nosed Depth is 9.1 cm and D65 size of bed material is 9.1 cm. Data from Altmar Bridge section on the Salmon River, New York.

Error	percent in the interval			
(percent)		Power Law		Logarithmic
	empirical	m variable	1/7th	
0 - 10	25.0	25.0	25.0	28.3
10 - 20	18.3	18.3	18.3	15.0
20 - 30	15.0	6.7	5.0	13.3
30 - 40	13.3	8.4	11.7	8.3
40 - 50	8.3	13.3	11.7	6.7
50 - 60	1.7	0.0	0.0	5.0
60 - 70	3.3	5.0	5.0	3.3
70 - 80	5.0	1.7	1.7	3.3
80 - 90	3.3	5.0	5.0	0.0
90 - 100	0.0	0.0	0.0	1.7

100 - 150	1.7	10.1	10.0	8.3
150 - 200	1.7	1.7	1.7	3.3
>200	3.3	5.0	5.0	3.3
<30	58.3	50.0	48.3	56.6
>70	15.0	23.5	23.4	19.9

The error in the logarithmic distribution versus the measured nose velocity is shown in Figure 1. About 15 percent of the nose velocities have over 100 percent error which is important in habitat simulation (see following section). The causes of the large errors in predicted versus measured velocities are of two general classes - those caused by the measurement techniques and those caused by the actual situation not being consistent with the theory.

The techniques used to collect the nose velocity data was for one crew to measure the mean column velocities and a second crew to measure the nose velocities; the result is that measured nose velocity is not necessarily in the same water column as the measured mean column velocity. In many situations, this would not be of concern but when the nose depth is the same order as the size of the bed material, the result is scatter in predicted versus measured nose velocity.

The measurement technique does not cause the four nose velocities shown in Figure 1 with over 150% error where the measured nose velocity is much lower than the calculated nose velocity. These low velocities are probably caused by cobbles, rock, and depressions in and on the stream bed. These "hiding spots" are not considered in the theory; consequently, these are not simulated by the equations. The data suggests from fifteen and twenty percent of the locations in the Altmar Reach of the Salmon River are hiding locations with low velocities (the percentage with errors larger than 70%).

APPLICATION TO LOWER CATARACT CREEK, MONTANA

The physical habitat for adult rainbow trout in lower Cataract Creek in Montana was simulated using PHABSIM. The results are presented in Figure 2. The mean velocities in cells across the stream were used as were two approaches to the calculation of the habitat considering the nose velocities. The range in typical annual maximum discharges at a nearby peak flow gage is from 5 to 11 cubic meters/second (cms). This means that the spring habitat simulated using PHABSIM is significantly influenced by the use of nose velocities in the simulation.

In the simulation of the nose velocities the nose depth was 9.1 cm and the D65 of the substrate was 15.2 cm. The size of the substrate was determined using the Wolman procedure (Wolman 1954). The roughness heights were also determined by surveying. A common assumption is that the Wolman procedure gives a representation of the roughness heights. The two procedures are compared in Figure 3.

The nose velocities in the curve on Figure 2 labeled 'Nose Vel' were determined using the universal logarithmic velocity distribution law. The discussion on hiding spaces associated with boulders in the previous section suggests the roughness heights should be used to adjust downward the nose velocities when the roughness height is larger than the nose depth. This was done and the curve in Figure 2 labeled 'Nose Vel (adj)'.

The logic used to adjust the velocities is that when the roughness height is less than or equal to the nose depth the calculated nose velocity is used. When the nose depth is less than one half the roughness height the nose velocity used in the habitat calculations is one fourth the nose velocity calculated using the logarithmic velocity distribution law. For roughness heights between these limits a linear interpolation was used. The lower limit of 0.25 V_n was based on an examination of the Salmon River data.

CONCLUSIONS AND DISCUSSION

The conclusions are 1) that nose (point) velocities simulations are an important component of physical habitat simulation for mountain streams with a spring runoff hydrographs, and 2) the nose velocities may be calculated with the theoretical velocity distribution equations but the results will be enhanced by being adjusted to account for possible velocity shelters behind roughness elements.

The conclusions about the importance of nose velocities in high flow habitat simulation results form the observation on Figure 2 that the physical habitat is more than doubled by including nose velocities.

The conclusions about the use of theoretical velocity distribution equations was based on the smaller change in the habitat caused by the adjustment of the nose velocities. The error data in Table 1 and on Figure 1 shows that most of the calculated nose velocities will be acceptable (less than 30% error) and that errors in the remainder are probably reduced by considering the ratio of the nose depth and the roughness height to adjust the nose velocities.

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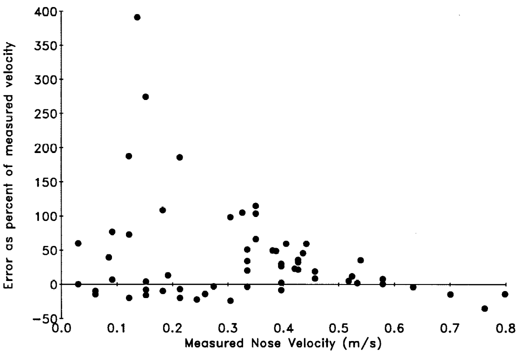

Figure 1.
The relation between measured nose (point) velocity and the error in the nose velocity calculated as percent of the measured velocity. The nose velocities were calculated using the logarithmic equation.

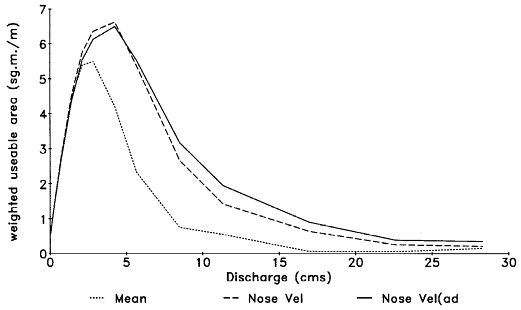

Figure 2.
The physical habitat versus streamflow functions for Adult Rainbow Trout in lower Cataract Creek, near Basin Montana.

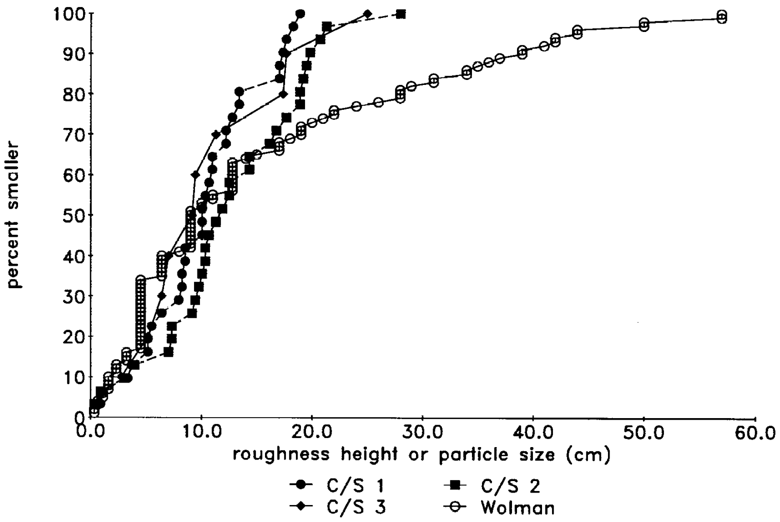

Figure 3. Roughness heights for three cross sections and the particle size of the stream bed measured using the Wolman procedure. Lower Cataract Creek near Basin, Montana.