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FIELD TESTS TO VERIFY EQUATIONS FOR PREDICTING LATERAL VELOCITY DISTRIBUTIONS IN RIVERS

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Water Resources Series
Technical Report No. 66
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The study was supervised by Ronald E. Nece, Professor of Civil Engineering, the Principal Investigator. Mr. Robert P. Vilker, Graduate Assistant in the Department of Civil Engineering, performed the field measurements of velocities and carried out the calculations. The study served as the basis for Mr. Vilker's MSCE thesis. The manuscript was typed by Ms. Jane Lybecker and Ms. Janet Steadman-Chadwick.

Dr. Robert T. Milhous, formerly of the State of Washington Department of Ecology, was instrumental in initiating the work. Mr. Rod Williams of the United States Geological Survey provided provisional flow rate data for the Renton gage.

ABSTRACT

Three models proposed by Milhous for predicting the lateral distribution of depth-averaged velocities in rivers were tested. Each model requires a different level of input data; all, however, assume that the stage-discharge relationship is known at that river station where the velocities are to be predicted. Two of the models incorporate Manning's equation for uniform flow as applied to sub-elements of the stream cross-section, and the third applies the "hydraulic geometry" concept to the sub-elements.

Field studies were carried out in the Cedar River and the Deschutes River, in Western Washington. The experimental results apply to gravel bed rivers. Some modifications in calculation procedure were suggested.

The principal application of the models is in the quantitative evaluation of reaches of rivers as fish habitats.

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LIST OF SYMBOLS

A_i	area of element i
a_i, b_i	numerical constants for the i-th element
$C_{m,c}$	constant which relates the n values of the m-th element to that of the element adjacent to the m-th element
D_{84}	particle size diameter for which 84 percent of the particle diameters are less than or equal to
d_i	depth of element i
$d_{i,c}$	depth of element i measured at the calibrated flow
k'	adjustment factor relating estimated discharge to actual discharge
$n_{e,c}$	Manning's n of the particular element adjacent to the m-th element determined at the calibrated flow
n_i	Manning's n of element i
$n_{i,c}$	Manning's n of element i as determined at the calibrated flow
$n_{m,c}$	Manning's n of the particular m-th element as determined through comparison with the n value of the adjacent element which contains a calibrated n value
P	number of elements in a cross section
Q	total actual discharge
Q'	first estimate of total discharge
q_i	discharge of element i
q_i'	first estimate of discharge of element i
r_i	hydraulic radius of element i
S	slope of the water surface at a cross section
S_c	slope of the water surface at a calibrated flow
v_i	average velocity of element i
v_i'	first estimate of the average velocity of element i
$v_{i,c}$	average velocity measured at the calibrated flow

w_i	width of element i
wp_i	wetted perimeter of element i

I. INTRODUCTION

The historically rising demand of water created by industrial and agricultural growth in the United States, particularly in the West, has reduced the diminishing supply of available water for instream use. Instream use is the water demand which requires a certain minimum discharge in the natural channel. With the recent awareness of environmental protection and conservation of natural resources, the American public has forced water resource planners and managers to consider not only traditional instream flow uses such as irrigation, hydroelectric power generation, etc., but also the needs of fish, wildlife, recreationists, and people who admire the sights of a free flowing river in water policy decisions. Researchers in the field have been called upon in a relatively short period of time to provide methodologies and appropriate data to consider fully these newly discovered instream flow needs. One need which has been in the forefront of this competition has been the fisheries flow requirement. The fish need is more often of greater economic importance than wildlife, recreation, or aesthetics. Because the utilization of water resources is viewed primarily in economic terms the instream flow case for fisheries also has to be argued on an economic basis. Although public values are changing to reflect a greater recognition of environmental and social concerns, the benefits and costs to fish are weighed on economic terms.

The realization that instream flow competition is based on economics has forced biologists to quantify the case for fish needs. In response to this pressure there has been a concerted multi-disciplined effort to develop methodologies to analyze the needs of fish. This effort has centered on two fundamental areas: determining what habitats are suitable for fish (assuming a direct connection between the presence of fish and a suitable habitat), and measuring the impacts when the habitats are altered by incremental changes in flow. To substantiate and quantify fish flow requirements, biologists use models which address the impacts of flow alteration. The models tested in the study are part of this impact assessment.

There are two different approaches in assessing changes in flow to habitat availability. One is to consider a target species and determine the limiting or critical habitat for that species. The assumption is that the target species which inhabits the shallow areas will be most sensitive to reduction in discharge. If the target species' habitat is maintained, the needs of all other aquatic life are satisfied. The other approach is an evaluation of reaches in the stream assuming these will be representative of the fish habitat throughout. This differs from the critical habitat approach because it involves evaluating conditions fish seem to consider optimum rather than conditions fish need to survive.

The approach to which the hydraulic models investigated in this report apply is the "habitat worth model," which is based on the assumption that the suitability of a river reach as a fish habitat is related to the velocity, depth, and temperature of the water as well as to the bed material. The model involves weighting each stream characteristic in relationship to the optimum condition, assigning each parameter an index as to its compatibility with an optimum condition. Clearly, what is meant by optimum and how the optimum condition relates to a species' needs have to be well defined. The usefulness of the model hinges on answering these questions. Work has been done with certain species of fish, particularly anadramous species

(Stalnaker and Arnette, 1976; Waters, 1976), defining what type of stream conditions are preferred, not those defining a habitat needed for survival. Habitat worth curves can be developed for a particular species; typically, these curves rank depths, velocities, and water temperatures most suitable to the species at different life stages. As depth, velocity, temperature, and bed material change, the corresponding probable change in fish population can be assessed through use of the curves. By incorporating in the model the amount of total surface area of a reach and its weighted overall suitability, a fishery manager can quantify in terms of square miles of habitat the potential effects of instream flow decisions. The habitat worth model gives biologists a valuable tool in assessing benefits and costs to fish on economic terms.

The importance of velocity and depth on fish populations has been documented (e.g., Stalnaker and Arnette, 1976). A general conclusion is that velocity and depth are the most important variables for habitat suitability for fish. This reasoning coupled with the relative ease and accuracy obtainable in measuring velocities and depths make these two variables the most closely studied and most heavily weighted at the time this report is prepared. The fit of the hydraulic simulation models studied here into the habitat worth model is illustrated in Figure 1.

Because the problem area of determining fish requirements and interpreting impacts involves a wide range of expertise, it was imperative for a coordinating group to be formed for this effort. This group is the Cooperative Instream Flow Service Group, formed in 1976 under the sponsorship of the U.S. Fish and Wildlife Service. The habitat worth model is a result of the Group's recent efforts in developing workable methodologies.

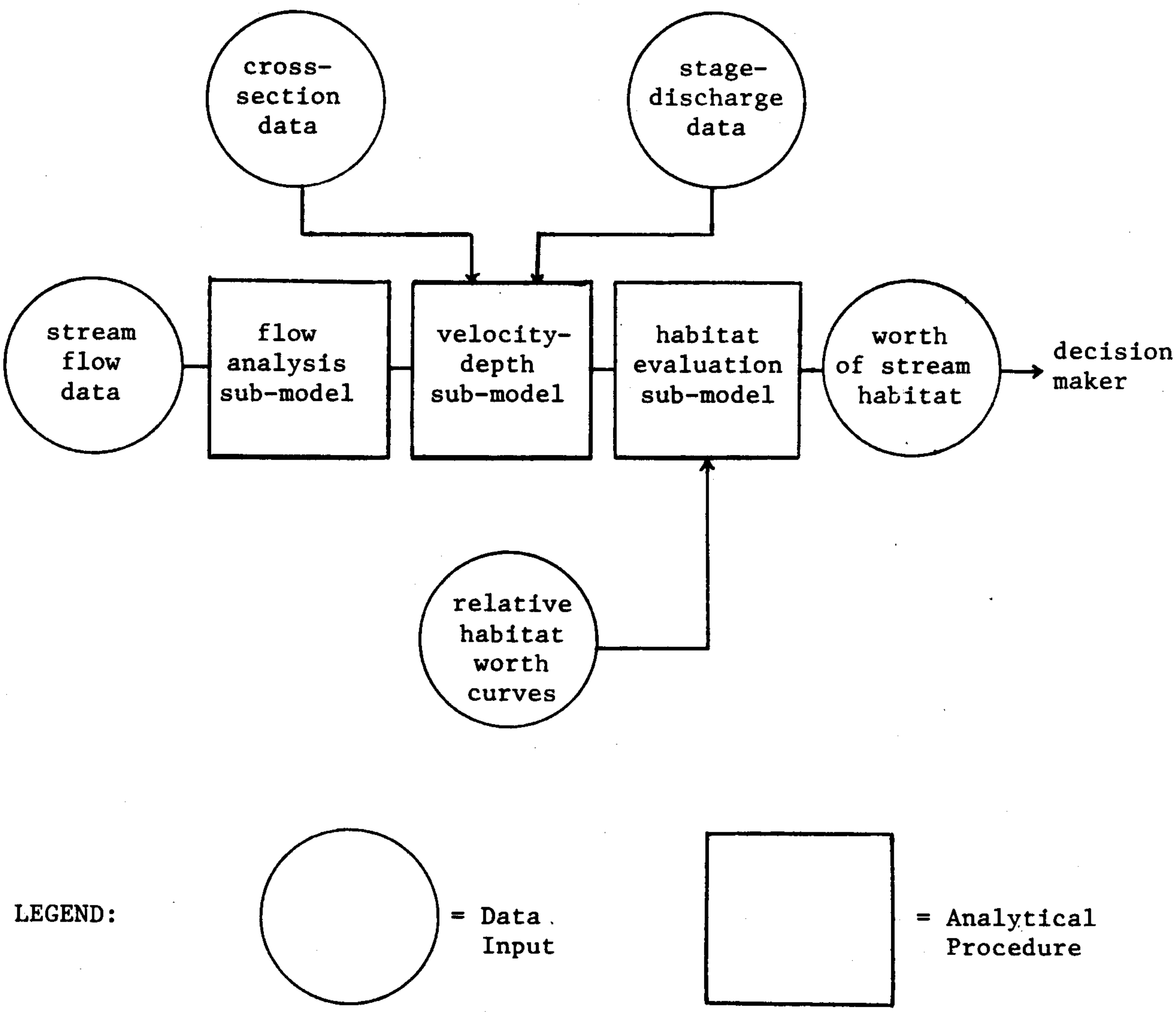


Figure 1. Information Flow Diagram for Habitat Worth Model

The hydraulic simulation models, first discussed by Milhous (1977), are being promoted by the Instream Flow Group in the form of computer program IFG4 (Main, 1978). The program is designed to provide velocity and depth input into a computer version of the habitat worth model. This report details an investigation of three different hydraulic models. The evaluation of the models is necessary so that their degree of validity can be documented prior to wider use.

The specific purpose of the present study was to conduct necessary field studies in order to evaluate and/or verify three hydraulic simulation models which have been proposed (Milhous, 1977). The objective of each of the three models is to provide with reliability but at minimum cost the lateral distribution of depth-averaged velocities across a stream of known cross-sectional shape for a given discharge. Not specifically included as a part of each model is the assumption that the stage-discharge relationship is known or can be determined independently of the model used to obtain the velocity distribution. This report considers the velocity distribution question only; the stage-discharge relationship is treated as a known. Limits have been suggested (Bovee and Milhous, 1978) for applying different procedures for obtaining (extending) the stage-discharge relationships to be used with the models investigated here.

A secondary objective of this research is to make available to proponents of these and other methods field data such that comparisons can be made among models.

It is emphasized that the present study neither evaluates the habitat worth model nor evaluates how well each of the hydraulic models serves as a sub-model to the habitat worth model. The emphasis is on the velocity distributions obtained by application of traditional one-dimensional equations to segmented cross-sections of natural streams. It also is pointed out that the results obtained are not "universal," but apply to gravel-bed rivers.

II. THREE VELOCITY DISTRIBUTION MODELS

General Approach

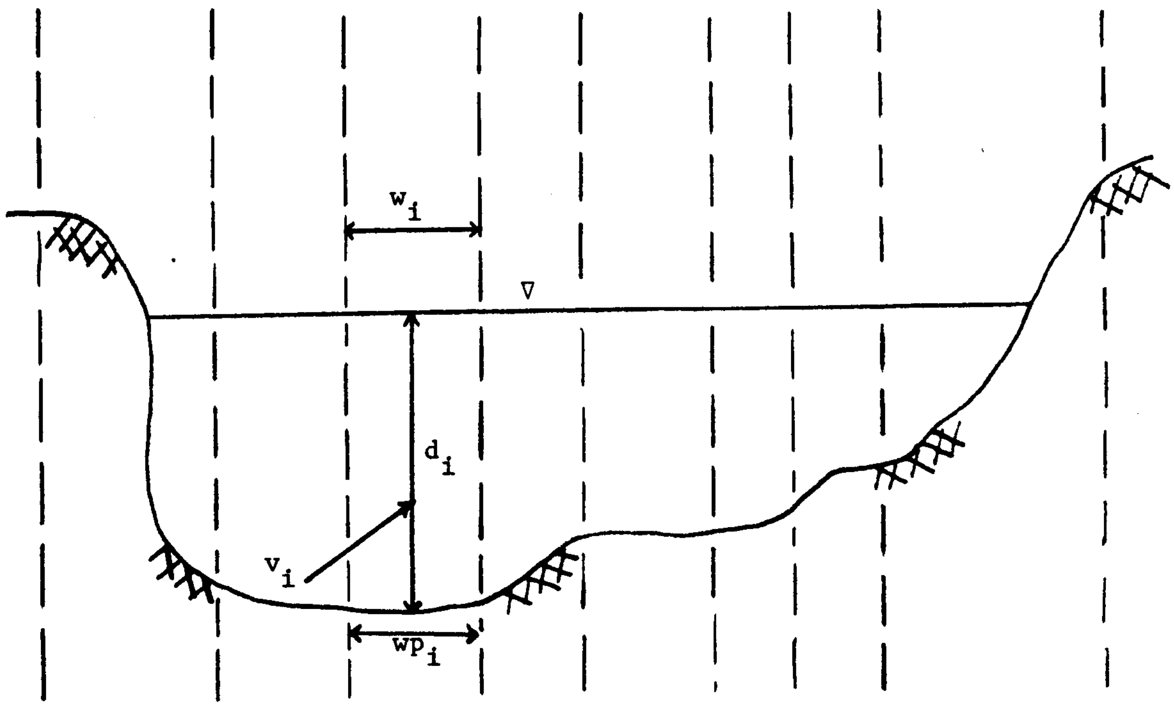
The objective of each of the three models is to provide the lateral distribution of depth-averaged velocities across a stream of known cross-section geometry for a given discharge. The total cross-section is divided into a number of sub-elements, each with its own depth and average velocity. In application of the results to the habitat worth model, the relative worth of each sub-section can then be calculated. It is stressed again that the stage-discharge relationship is assumed known; therefore, each model can perform only as well as the stage-discharge relationship is defined at a particular site. Some field work which the potential user of the models may at first glance believe is being avoided may be required to establish an accurate stage-discharge rating curve.

The three models consider the gross cross-section to be comprised of a series of channel sub-elements, or sections, each with its own depth and average velocity. The approach is illustrated in the definition sketch on the following page. The cross section is divided into p segments with the i-th segment having a width w_i, depth d_i, wetted perimeter wp_i, area A_i, and average velocity v_i. The total flow, Q, is the summation of all flows through the respective segments.

$$q_i = A_i v_i = A_i w_i d_i$$

$$Q = \sum_{i=1}^{p} q_i$$

The notation used in the following descriptions of the models is summarized in the List of Symbols



The following description of each model closely follows the discussion by Milhous (1977). All models assume that the bed form and cross section geometries remain unchanged with time.

If the velocity distribution so described can be measured for each flow of interest, the data can be used directly and no analytical procedure is needed to estimate the velocity distribution. In most cases the resources available to do the necessary field work at a site in any particular instream flow study are limited, and therefore estimates must be made of the velocity distributions of discharges for which velocity distribution data are not available. The models address this problem in the following sequence: Model 1 considers the case of no velocity measurements, Model 2 considers the case of one set of velocity measurements, and Model 3 considers the case where more then one set of velocity measurements is available.

Model 1: The Case of No Velocity Measurements

Model 1 involves applying Manning's equation to compute a flow estimate in each channel segment, summing the computed segmented flows, comparing this summation to the actual discharge and adjusting the original flow estimate accordingly. Input data required are the shape of the cross section, a known flow rate, the stage of the river (i.e., water surface elevation), and estimates of Manning's "n" (Manning's "n" is an index of channel roughness). No set of velocity measurements is needed for calibration.

The theoretical basis of the model is the assumption that Manning's equation can be applied to segments of transects. Manning's equation is applicable to uniform flow (parallel streamlines) conditions. The application of the model involves four assumptions in order to be consistent with hydraulic principles: 1) the slope of the water surface is the same for all the channel segments; 2) there is no slope of water surface normal to the direction of flow; 3) Manning's equation is valid (i.e., uniform flow is present); 4) each segment or element is rectangular.

Each segment (i.e., element or subelement) carries an actual flow q_i, with area A_i, width w_i, wetted perimeter wp_i, depth d_i, hydraulic radius r_i, and Manning's "n_i."

The estimated discharge q_i' in each element is calculated using Manning's equation:

$$q_i' = \frac{1.49}{n_i} A_i r_i^{2/3} S^{1/2}$$

where $A_i = d_i w_i$

$$r_i = \frac{A_i}{wp_i}$$

but $wp_i = w_i$

therefore $r_i = \frac{d_i w_i}{w_i} = d_i$

and $q_i' = \frac{1.49}{n_i} d_i^{5/3} w_i S^{1/2}$

The sum of the estimated discharges yields the total estimated discharge:

$$Q' = \sum_{i=1}^{p} q_i' = 1.49 S^{1/2} \sum_{i=1}^{p} \frac{d_i^{5/3} w_i}{n_i}$$

This estimate will differ from the actual discharge Q for the total cross section. This difference can be accounted for and used to adjust each element's discharge value by defining the factor k':

$$k' = \frac{Q}{Q'} = \frac{Q}{1.49 S^{1/2} \sum_{i=1}^{p} \frac{d_i^{5/3} w_i}{n_i}}$$

Now, consider the adjusted flow in a particular m-th element, assuming that the adjustment factor k' applies equally to every element flow estimate as it does to the total flow estimate:

$$q_m = k' q_m' = \frac{Q(1.49 S^{1/2} d_m^{5/3} w_m)/n_m}{1.49 S^{1/2} \sum_{i=1}^{p} \frac{d_i^{5/3} w_i}{n_i}}$$

The average velocity in the m-th element directly follows:

$$v_m = \frac{q_m}{d_m w_m} = \frac{Q d_m^{5/3}/n_m}{\sum_{i=1}^{p} \frac{d_i^{2/3} w_i}{n_i}}$$

The mathematics are simple. The usefulness of Model 1 hinges upon how well the user carries out the exercise of estimating Manning's "n" values, or relative values of "n," across the entire width of the stream. This point is the crux of Model 1, and is discussed in more detail in Chapter IV.

Model 2: The Case of One Set of Velocity Measurements

The computational approach is similar to that of Model 1. Model 2 in effect involves the calibration of Manning's "n" for each element by using one set of velocity measurements although the actual evaluation of "n" values is not utilized in the model because the "n" values are assumed to be independent of discharge. In addition to one set of velocity measurements, the input data required are the shape of the cross section, the total discharge, and the stage.

From the one set of measurements the calibrated "n" can be calculated for each segment:

$$n_{i,c} = \frac{1.49 d_{i,c}^{5/3} S_c^{1/2}}{v_{i,c}}$$

where $n_{i,c}$ = calculated value of n_i

$v_{i,c}$ = measured velocity

$d_{i,c}$ = depth of element

S_c = slope at the measured discharge

Using this calibrated "n" the velocity at a different discharge (i.e., stage) is calculated under the assumption that "n" remains constant:

$$v_i' = \frac{1.49 d_i^{2/3} S^{1/2}}{1.49 d_{i,c}^{2/3} S_c^{1/2}} v_{i,c}$$

$$v_i' = \left(\frac{d_i}{d_{i,c}}\right)^{2/3} \left(\frac{S}{S_c}\right)^{1/2} v_{i,c}$$

Summing the flows for the individual elements and adjusting the total estimate to agree with the actual discharge:

$$k' = \frac{Q}{Q} = \frac{Q}{\sum_{i=1}^{p} v_i' d_i w_i} = \frac{Q}{\sum_{i=1}^{p} \left(\frac{d_i}{d_{i,c}}\right)^{2/3} \left(\frac{S}{S_c}\right)^{1/2} v_{i,c} d_i w_i}$$

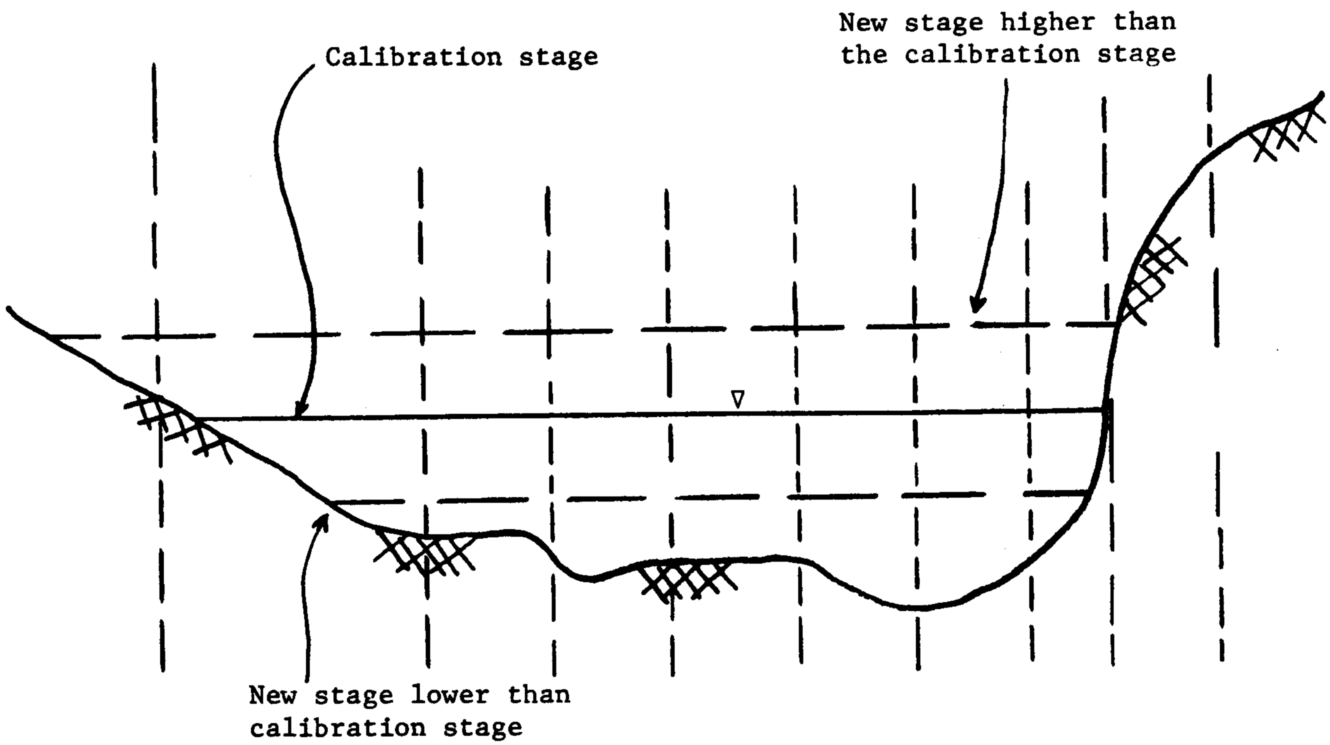
Consider the velocity in the m-th channel as:

$$v_m = k' v_m'$$

$$v_m = \frac{Q}{\sum_{i=1}^{p} \left(\frac{d_i}{d_{i,c}}\right)^{2/3} \left(\frac{S}{S_c}\right)^{1/2} v_{i,c} d_i w_i} \left(\frac{d_m}{d_{m,c}}\right)^{2/3} \left(\frac{S}{S_c}\right)^{1/2} v_{m,c}$$

$$v_m = \frac{Q \left(\frac{d_m}{d_{m,c}}\right)^{2/3} v_{m,c}}{\sum_{i=1}^{p} \left(\frac{d_i}{d_{i,c}}\right)^{2/3} d_i w_i v_{i,c}}$$

This equation is applicable when the calibrated flow is higher than the flow of interest because all elements have calibrated "n" values. However, if the flow of interest is greater than the calibrated flow there may be elements without a calibrated "n." These two situations are shown in the sketch below.



If the flow of interest lies outside the bounds of calibration a modification to the above equation is made. For the elements with no calibrated "n," an estimate of the segment's "n" is made relative to the adjacent segment's "n." The relationship is:

$$n_{m,c} = C_{m,c} n_{e,c}$$

Where $n_{m,c}$ = roughness of added m-th segment

$n_{e,c}$ = roughness of adjacent calibrated channel segment

$C_{m,c}$ = constant relating n_m to n_e.

With a quasi-calibrated "n" value based on the adjacent "n" the added segment can be treated the same way as the other elements in the flow summations.

Model 3: The Case of More Than One Set of Velocity Measurements

Model 3, unlike Models 1 and 2, is based on empirical relationships in which changes in depth and velocity are expressed as power functions of discharge. The approach is not based on uniform flow equations, but rather is based on the "hydraulic geometry" concept (Leopold and Mattock, 1953). Illustrations of the mutual adjustment of channel form and discharge were given by a series of empirical equations in which changes in width, mean depth and average velocity were expressed as power functions of discharge either as they varied with discharge at particular stations on a stream or, at a constant flow, in the downstream direction. The three basic hydraulic geometry relations can be expressed in the form:

$$v = aQ^b$$

$$w = kQ^m$$

$$d = cQ^f$$

where w = surface width

d = average depth

v = average velocity

Q = total discharge

a, b, c, f, k, and m are constants.

This empirical approach can be thought of as describing a river system developing in such a way as to maintain an equilibrium between the channel and the water and sediment it transports. Park (1977) provides good documentation in the form of a bibliography as to the concept's application.

Model 3 assumes that the average velocity in each element is related to the total discharge in the same way as is the average cross sectional velocity, i.e., $v_i' = a_i Q^{b_i}$. To compute the constants a_i and b_i at least two sets of velocity measurements and their discharges are needed.

With a_i and b_i defined, the horizontal distribution of depth-averaged velocities at any other flow can be computed. Consider the elements at a known flow Q for which the estimate of the average velocity in every element is:

$$v_i' = a_i Q^{b_i}.$$

The discharge follows:

$$q_i' = v_i' w_i d_i$$

The flows are summed and compared to the actual total flow in a way similar to the procedure in Models 1 and 2. The adjustment factor, k', is defined:

$$k' = \frac{Q}{\sum_{i=1}^{p} v_i' w_i d_i}$$

and the estimated velocity is calculated

$$v_i = k' v_i'$$

III. FIELD PROCEDURES

Site Descriptions

Considerations in selecting the rivers for the study were: proximity to Seattle, Washington, so that it would be possible for a two-man field party to travel to the site and take the requisite data in less than a full day, particularly during the academic year, so dependence on weekend days only was avoided; sufficient flow variability during the year so that a range of discharges necessary to test the models could be anticipated; shallow enough so that the streams could be waded at enough stages. Attention was focused on the Cedar River and the Deschutes River.

The particular sites were selected to meet the following more specific criteria:

1. Because of the great dependence of Models 1 and 2 on uniform flow conditions, the transects were located in relatively straight reaches free of obstructions so as to best approximate uniform flow.
2. Proximity to bridges, roadways, or parks to allow easy access.
3. Free of deep sections which would prevent wading.
4. Proximity to fish spawning reaches.

The fourth criterion was not absolutely necessary; however, the models do apply to evaluating fish habitats so the criterion was considered.

Three sites were located on the Cedar River: Renton, Cedar Grove, and Cedar Grove Upstream (refer to Summary Table I). The Cedar River drains the western slope of the Cascade Mountains and empties into Lake Washington at the lake's most southern point, approximately 15 miles south of Seattle.

This gravel bed river with a relatively small suspended sediment load has a mean annual flow of 700 cfs with a maximum monthly average of 1280 cfs in February and a minimum monthly average of 190 cfs in August as measured at the U.S. Geological Survey gaging station in Renton. The sites are located downstream of Chester Morse Lake which supplies water to the City of Seattle. The City regulates the discharge from Chester Morse Lake to maintain minimum flows. The Cedar River supports one of the largest artificial sockeye salmon runs in the contiguous United States.

The Renton site is located in downtown Renton, Washington approximately 250 feet upstream of U.S. Geological Survey stream gaging station 12119000, "Cedar River at Renton, WA." The gaging station location is at latitude 47° 28' 58" N, longitude 122° 12' 08" W, and approximate elevation 23 feet MSL. The cross-section, as shown in Figure 2, is quite regular. The site is near the upper end of a straight reach that was originally excavated as an artificial channel for the river. The stream bed is covered with rounded gravel in the 1-6 inch range.

The Cedar Grove and Cedar Grove Upstream sites are located approximately 10 miles upstream of the Renton site and 2-1/2 miles downstream from the town of Maple Valley, at latitude 47° 26' 28" N., longitude 122° 03' 45" W, and elevation 227. No major tributaries enter the Cedar River between the Cedar Grove and the Renton sites. The two Cedar Grove sites are 300 feet apart. The original site was found to be too close to a downstream control at lower flows to approximate uniform flow conditions; therefore, the Cedar Grove Upstream site was established during the low summertime flow period. Both Cedar Grove sites have deep sections near the left banks (looking downstream) with depths becoming shallower toward midchannel and the right bank (see

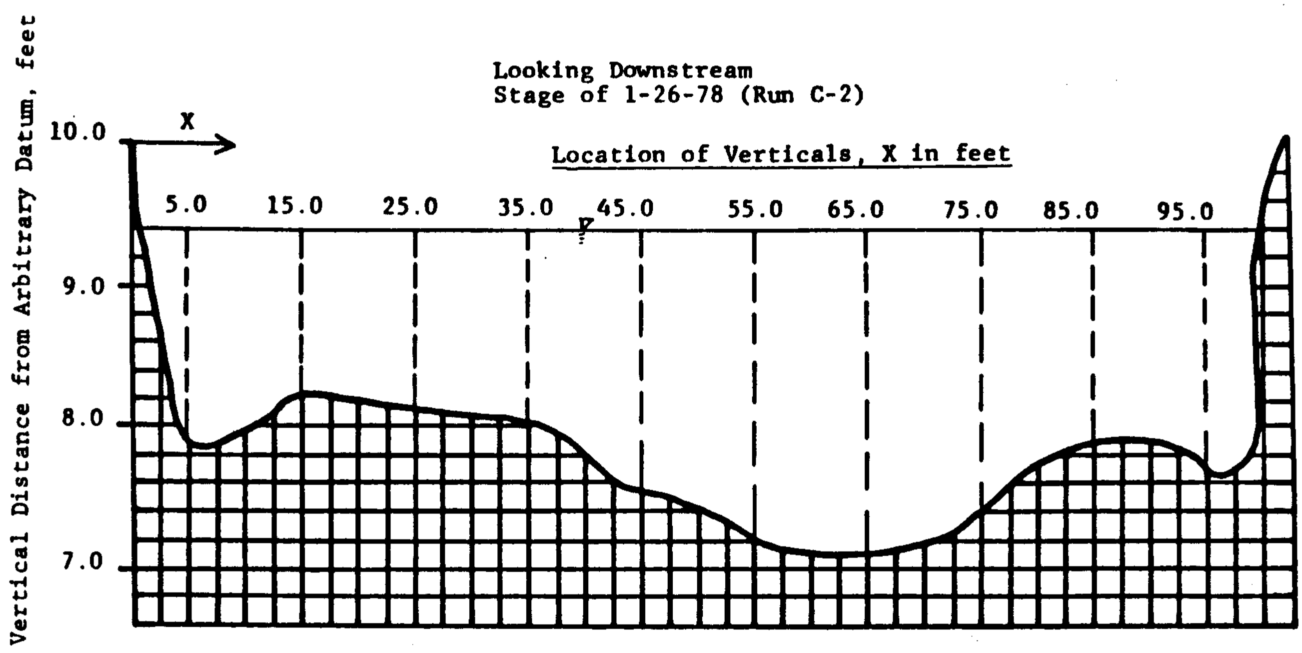


Figure 2. Cedar River Renton Site "C", Transect

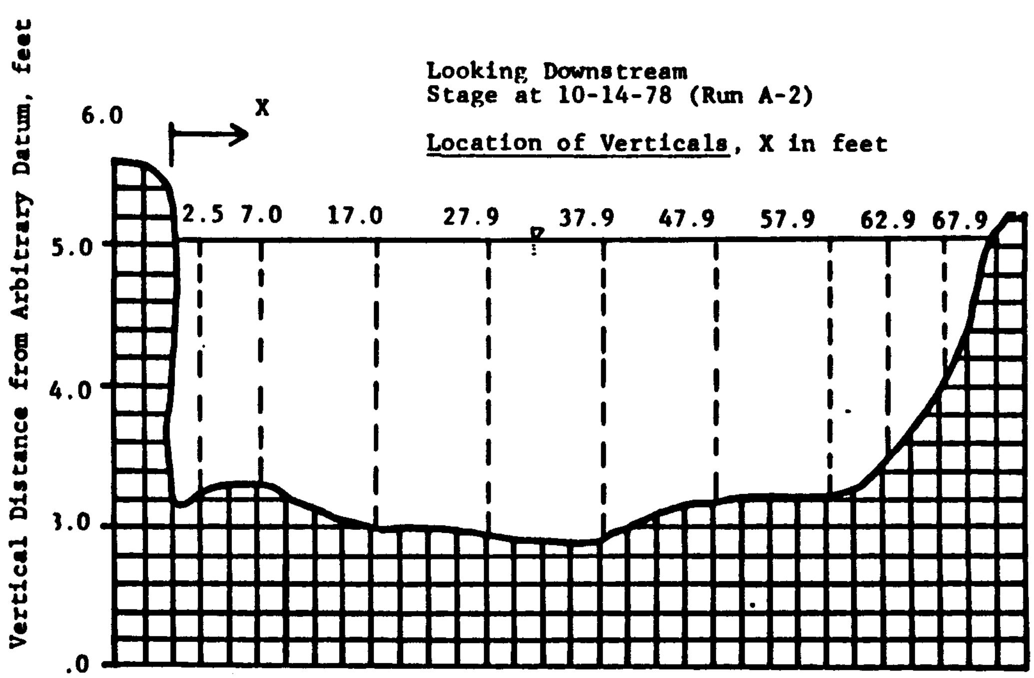


Figure 3. Cedar River Cedar Grove Site "A", Transect

Figures 3 and 4). This deepening of the left bank sections was formed by a flood control levee of riprap construction. This levee created a much steeper left bank composed of rock sizes much larger than those on the channel bottom. The channel geometry remained constant for all Cedar River sites throughout the study period. Large sockeye salmon populations were present in the spawning season (late autumn) at all three sites.

The Deschutes River also drains the Western slope of the Cascade Mountains; the river flows into Puget Sound at Olympia, roughly 40 air miles south of Seattle. The site "D" on the Deschutes is located just downstream of a public park owned by the Weyerhaeuser Corporation, at approximately river mile 20.6, at latitude 46° 52' 58" N, longitude 122° 45' 00" W, at elevation 300 (approximate). The U.S. Geological Survey operated a stream gaging station roughly 4 miles upstream of site "D" for 13 years. The following flow values were based on this 13 year record. The mean annual flow is 265 cfs with the maximum monthly flow of 540 cfs in January and the minimum monthly of 55 cfs in August. Although few fish were observed at the site fishermen were seen at the park. Bed material consists of rocks 1 to 10 inches in diameter with the river transporting a small suspended sediment load. The cross-section is nearly regular in shape (see Figure 5) and remained constant over the study period. Although the reach containing the site was essentially straight it was also rather short, and the high velocity filament of the flow was crossing, at a slight angle, from left to right at the measurement site.

Table 1 lists pertinent data for the four field sites.

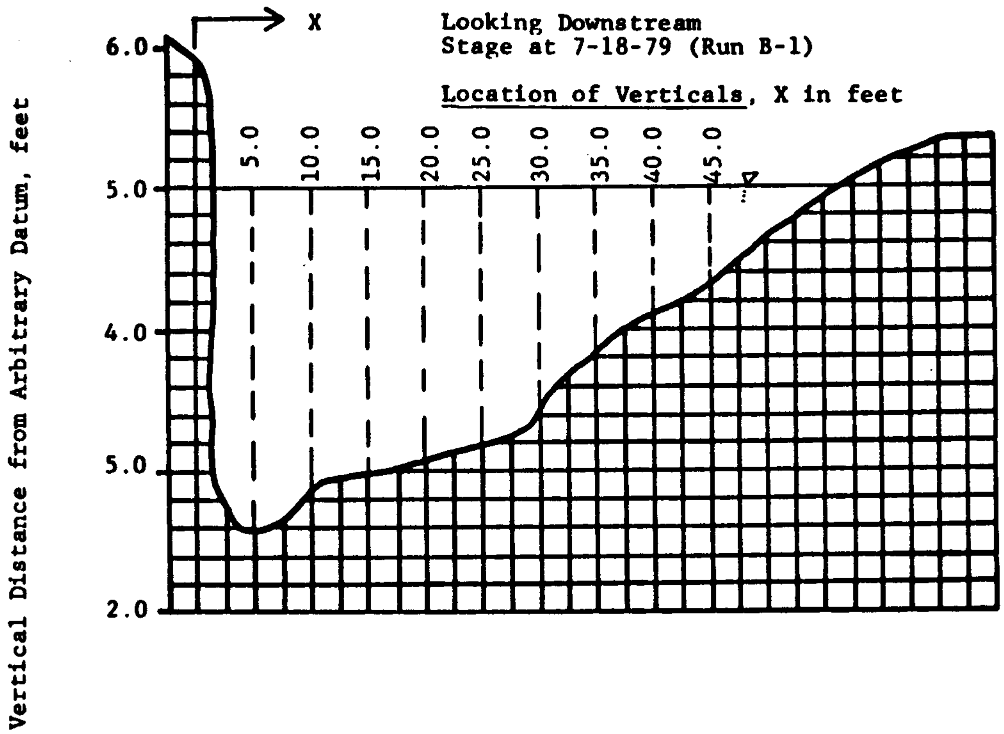


Figure 4. Cedar River Cedar Grove Upstream Site "B", Transect

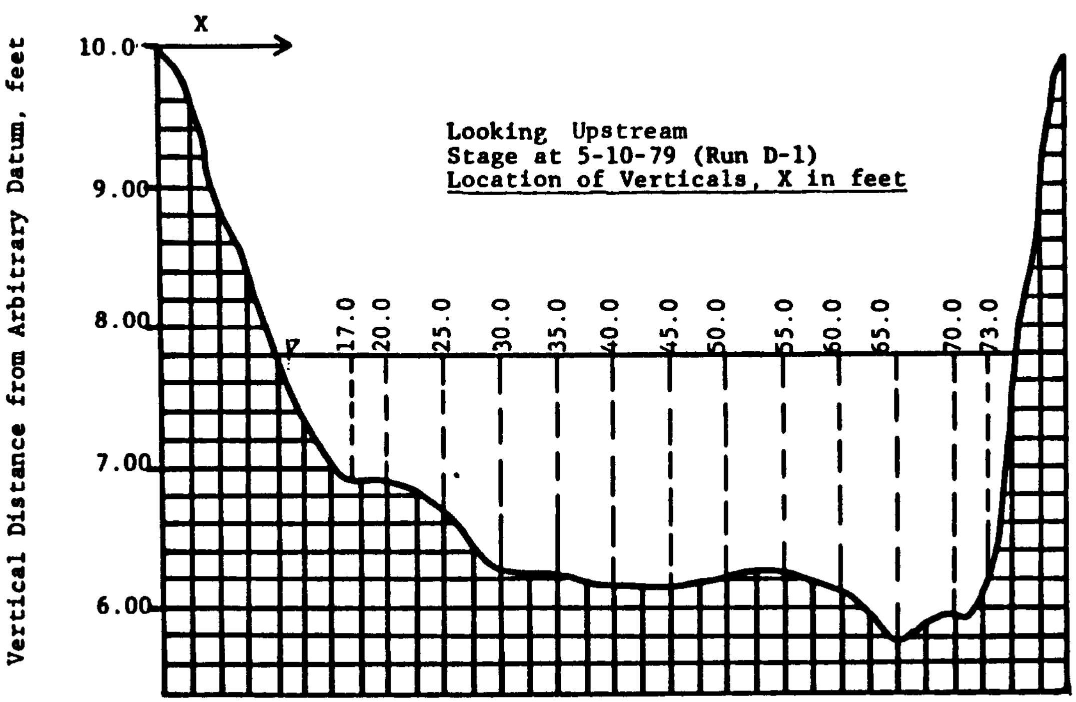


Figure 5. Deschutes River Site "D", Transect

Field Procedures

The transects were established using standard surveying techniques. A reference station was established on one bank, and all horizontal distances were measured from the reference station. The verticals (i.e., points along the transects where velocity measurements were taken) were spaced at 5 and 10-foot intervals. On the ungaged Deschutes River, the verticals (velocity measurement stations) also were located to meet USGS stream gaging criteria (Corbett, 1945). The rating curve at the gaging station at Renton was not well defined at lower stages so extra verticals were added to more accurately determine the flow. Each vertical served as the midpoint of a rectangle with a depth measured at the vertical and width being the distance between the evenly spaced verticals. These rectangles formed the channel segments used in the models. The layout of verticals can be seen in Figures 2-5. Velocity data collected at each vertical are presented in Table 2.

For each set of data the water surface width was measured and water edges located with respect to the reference station. Depths were measured at each velocity station. Slope data listed in Table 1 were obtained by leveling, measuring the slopes of the water surface along a number of longitudinal lines at each site.

Velocity profiles were defined as fully as possible at each vertical. Typical velocity profiles are shown in Figure 6. The velocity measurements were taken using a conventional Price-type (Gurley) current meter mounted on a graduated staff, headset, and stop watch using sixty-second time intervals. A direct readout electromagnetic current meter was found to be too sensitive to turbulent eddies in the gravel bed rivers to be of use. A

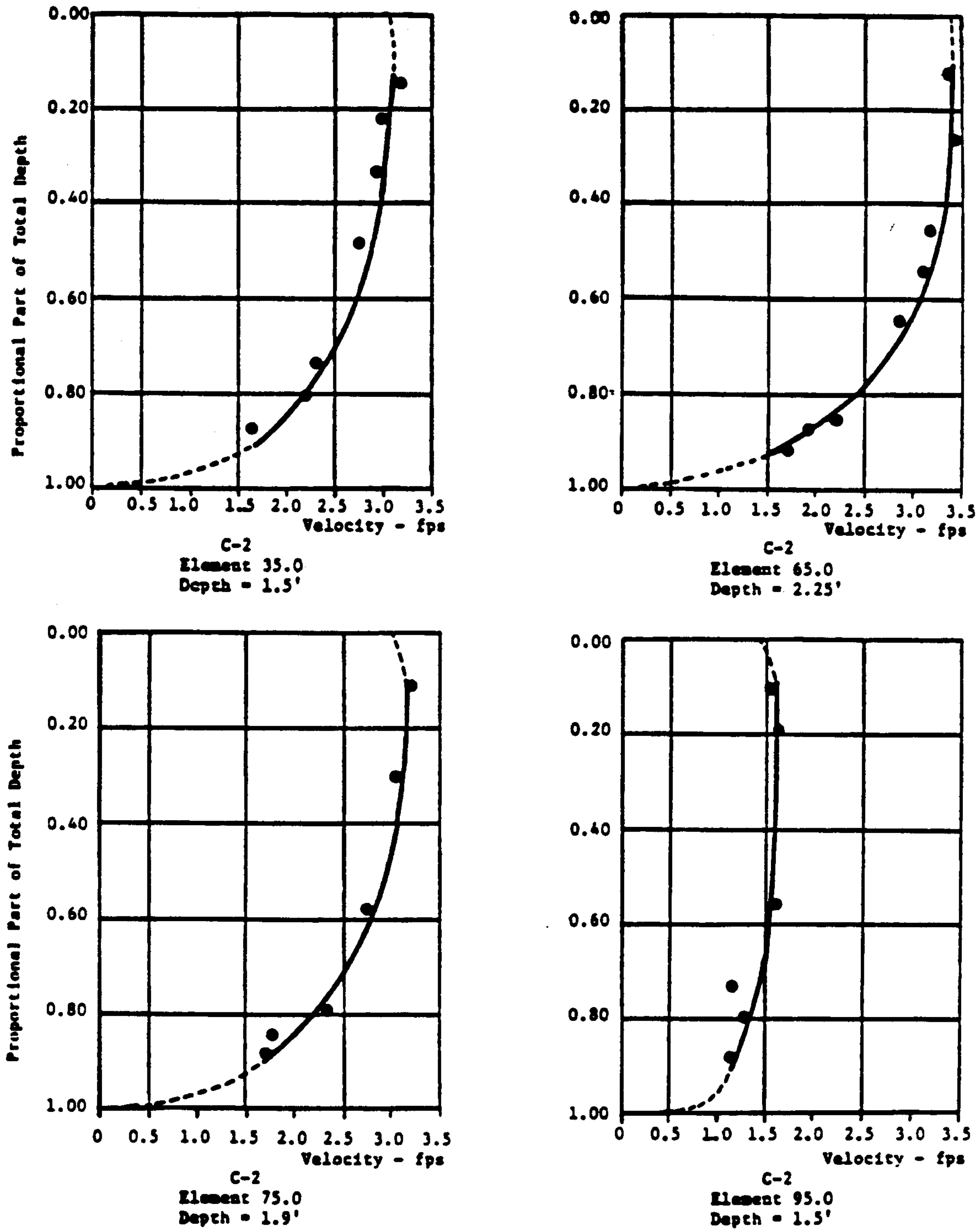


Figure 6. Sample Velocity Profiles

higher concentration of measurements was taken near the bottom where velocities change rapidly with depth. The practical limits of measurement were 0.2 feet off the bottom and 0.2 feet below the water surface due to the meter limitations (size). The meter calibration was checked in the instrument rating facility at the U.S. Army Corps of Engineers North Pacific Division Hydraulic Laboratory, Bonneville, Oregon. The meter was tested at a submergence of 0.2 feet; this calibration was then applied to the near-surface current readings in the data reduction process. At greater depths of submergence, the original meter calibration applied.

The estimate of the roughness coefficient necessary for Model 1 is based on particle sizes of the bed material. The procedure used to sample particles was a crude modification of the Wolman method (Limerinos, 1970), in which a grid is established and samples are taken at grid intersections. The following technique was used at the Cedar River sites in determining D_{84}, the minimum particle diameter which 84 percent of the minimum particle diameters are smaller than or equal to. Each transect was divided into thirds. Based on visual inspection, each one-third of the bottom width was felt to contain progressively larger gravel sizes, going toward the deeper side of the river. Within each one-third, three longitudinal sampling lines were established 8 to 10 feet apart on the transect. Each sampling consisted of taking a sample stone at 2-foot intervals on each line progressing upstream from the transect. Ten samples were collected on each line. At Renton there was a total of 120 samples with the calculated D_{84} for each one-third of the stream bed width based on the 40 samples collected in that area. The D_{84} used in Model 1 (see Table 3) for each vertical is the D_{84} of the particular one-third of the transect in which the vertical is located.

Diameters were measured in the field to only the nearest 1/4-inch. The same approach was used at the Cedar Grove sites. For the Deschutes River a D_{84} estimate was made from photographs taken of the bed at the transect at low flows when the bed was visible. A scale was included in each photo enabling a determination of the horizontal diameters of each particle to be made. The horizontal diameters were correlated with the vertical diameter by using the vertical versus horizontal relative dimensions measured at the Cedar River sites. As discussed in Chapter IV, the vertical diameter is of most interest in relative roughness determinations.

The difficulty in determining water surface slopes deserves further note. A theodolite and level rod were used to establish water surface elevations at discrete distances upstream and downstream of the transect. Attempts in measuring the slopes were made throughout the year with best results coming in the summer. The reasons for this are: the lower velocities in the summer provided a calmer surface making it easier to measure elevations, and the researchers were more experienced later in the project at taking measurements. It is recommended in taking slope measurements to always measure elevations at the mid point of the channel to avoid elevation differences associated with secondary flows, i.e., cross-stream velocities.

Data Reducation

The velocity measurements at each vertical were plotted and a best fit curve was drawn by eye to approximate the velocity profile. The velocity for each channel segment, or element, is the depth-averaged velocity obtained from the plotted profile.

The elements were assumed to be rectangular, to be consistent with the model descriptions. This assumption is acceptable in all but the near-bank elements where the depth at the vertical produces a calculated area that is too large if the assumption of a rectangular element is maintained. The arbitrary choice was made to calculate the area of the near-bank element as two-third's of the area defined by the enclosing rectangle.

The contants a_i and b_i in Model 3 were computed for each element by plotting depth and velocity versus total discharge for each set of velocity measurements on log-log paper and fitting a line of best fit to the data by the method of least squares. Figures 7 and 8 show the log-log plots for two elements at Renton (site C), defining the power relationships between depth and discharge and velocity and discharge. Figure 7 is the plot for near-bank Element 5.0 (showing the greatest deviations), while Figure 8 shows the plot of Element 65.0 which is typical of mid-channel elements that are more consistent. Least-squares fitting was used as a consistent method of plotting straight lines on log-log paper.

All calculations used in processing the data were performed on a programmable hand calculator.

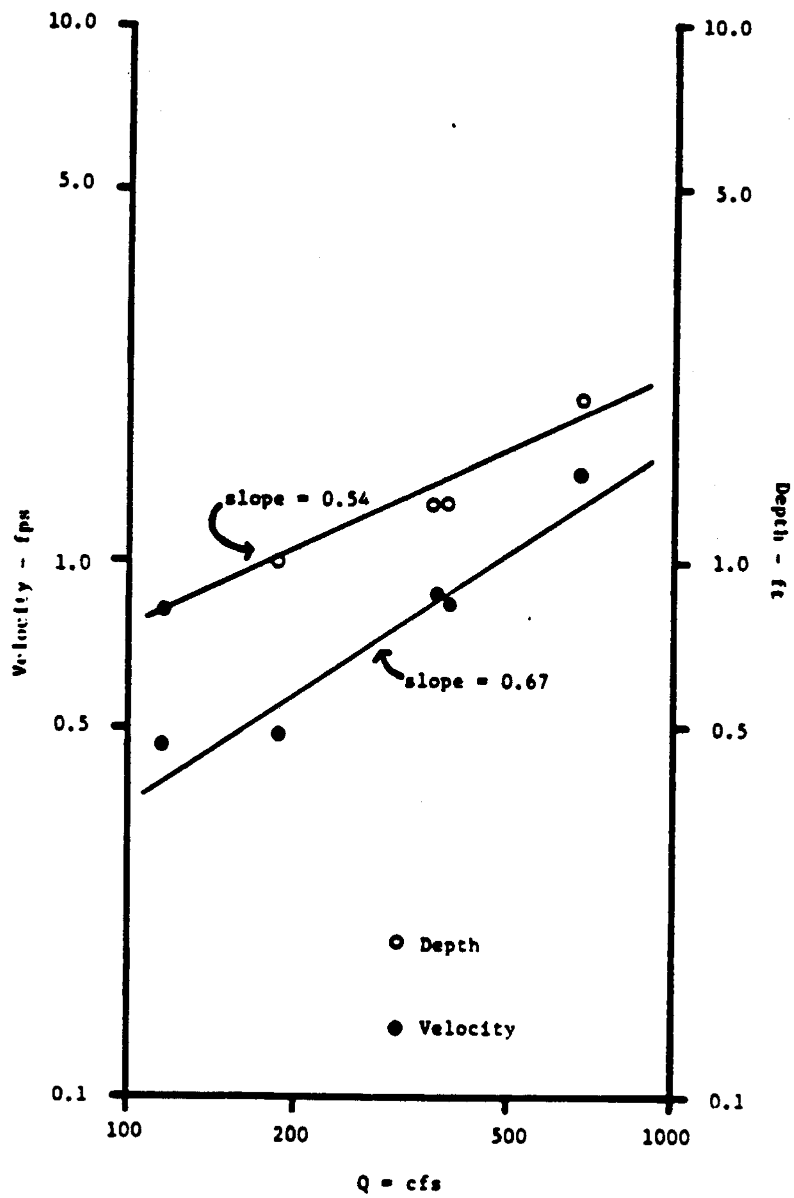


Figure 7. Discharge vs. Velocity and Depth, Element 5.0, Renton

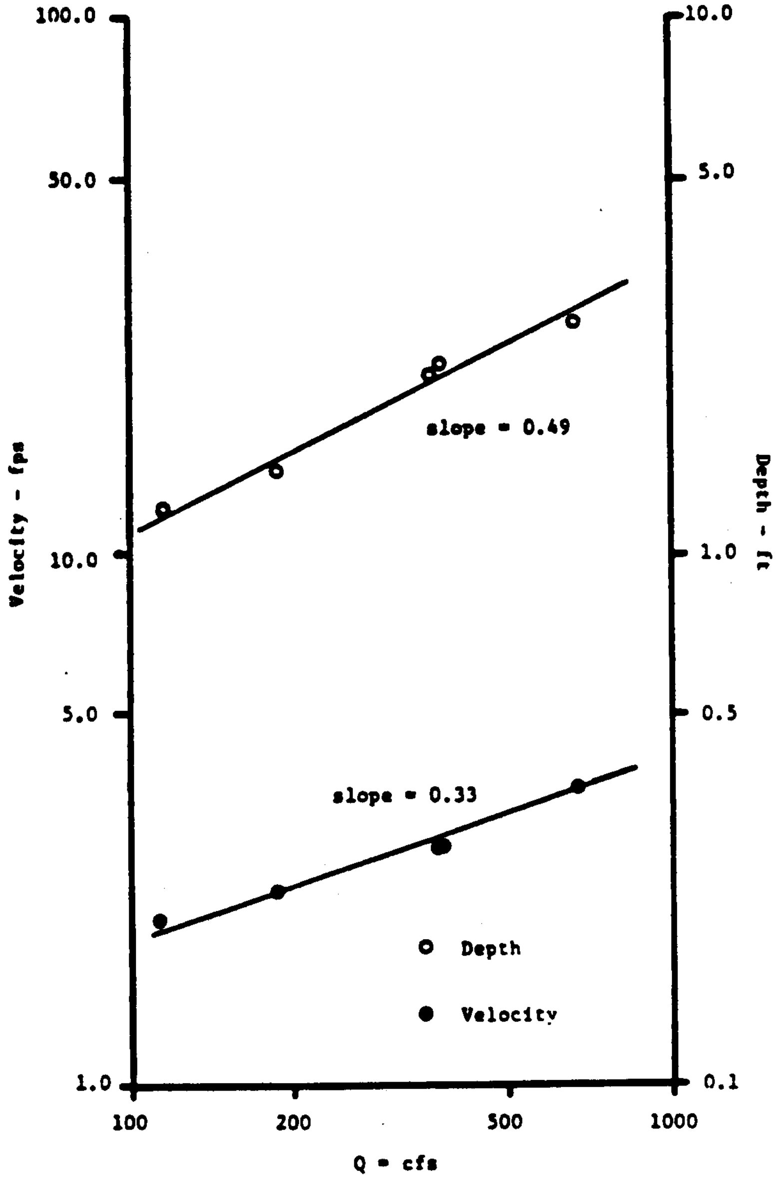


Figure 8. Discharge vs. Velocity and Depth, Element 65.0, Renton

IV. RESULTS

Model 1: Results and Discussion

As stated previously, the usefulness of Model 1 depends upon appropriate approximations of Manning's "n" values across the width of the stream. As will be shown below, relative values of "n" over the stream width are of more concern than absolute values. Confident estimates of "n" usually require considerable experience. Tables of computed "n" values for various channel conditions are readily available. Barnes (1976) published photographs and descriptions of fifty streams with their associated "n" values. These references, however, apply to calculations using one-dimensional equations applied to the entire cross-section, using A-R, and average velocity v for the stream. This report applies to reaches of river where "uniform" flow is assumed, and thus specifically does not address the influence of riffles and pools which were excluded from the test areas. The study sites were located in straight channels, free of vegetation and of nearly regular shape. In many streams particle size is the major influence on flow resistance. This is particularly the case at the Cedar River and Deschutes River field sites where the bed material is of intermediate to large diameter gravel (1" to 10"). Therefore, it was assumed that the grain roughness was more significant than any of the other flow resistance components in the test reaches.

In order to minimize dependence upon subjective evaluations of "n", the "n" values were predicted by the rather common approach of extrapolating results for fully turbulent (rough pipe behavior) flow in pipes to open channels. The relation (e.g., Rouse, 1946) linking the Darcy-Weisbach friction factor f to the Manning equation is

$$\frac{1}{\sqrt{f}} = \frac{1.49}{\sqrt{8g}} \frac{R^{1/6}}{n}$$

where g is the gravitational acceleration. For rough pipe flow (i.e., f independent of Reynolds number and dependent on relative roughness only) the Kármán-Prandtl equation is

$$\frac{1}{\sqrt{f}} = 2.0 \log_{10} \frac{r_o}{k} + 1.74$$

where r_o is the pipe radius and k is the equivalent Kikmadse sand grain size. Converting to the hydraulic radius, where $R = r_o/2$, and using foot-second units,

$$\frac{n}{R^{1/6}} = \frac{0.0926}{2.0 \log_{10}(R/k) + 2.34} .$$

This form of relationship, which allows changes in "n" with depth, was used in the present study. Bray (1979) and Limerinos (1970) have used a similar approach. The characteristic roughness dimension, or particle size, used was D_{84}. The size is based on the smallest of the three mutually perpendicular diameters which define a particular geometry. Limerinos rationalized the choice of the diameter by arguing that the minimum diameter is most effective in producing resistance to flow because bed particles usually orient themselves so that the minor axis is normal to the flow. The 84th percentile was chosen to represent a size whose logarithm is one standard deviation greater than the mean if the particles are lognormally distributed. Although in this study only rough sampling procedures were followed and no cumulative frequency-distribution curves were drawn, a size larger than the mean was needed with the argument for the D_{84} being documented. Limerinos (1970) and others have stated "that a single flow-resistance parameter involving bed particle size should use a size larger than the D_{50}." Because the influence of the larger particles extends over a relatively greater volume of channel with many of the smaller particles being located in the turbulence field created by the larger areas a relative large characteristic particle diameter was used.

Limerinos (1970), using stream-average values determined from studies in gravel-bed streams, proposed the following relationship, based on the 84-percentile size of minimum diameter of streambed particles:

$$\frac{n}{R^{1/6}} = \frac{0.0926}{2.0 \log_{10}(d/D_{84}) + 0.76} \quad .$$

In the present study, due to an inadvertent substitution of R for r_o in the resistance equation, the "n" values for the individual channel segments were calculated from

$$\frac{n}{R^{1/6}} = \frac{0.0926}{2.0 \log (d/D_{84}) + 1.74} \quad .$$

Manning "n" values calculated according to the above are lower than those given by Limerinos' empirical equation and higher than those given by the direct conversion of the Kármán-Prandtl equation. Comparison of the distribution of relative "n" values over the stream width for representative tests tabulated in this report indicated that the Limerinos equation and that used here produce essentially the same relative distributions.

Results of the Model 1 tests are given in Table 3. Table 3 lists for each site and flow the D_{84} as approximated by procedures described in Chapter III, "n_i," and the calculated velocity V_m, using Model 1. This velocity is compared to the actual velocity measured, v_{ave}, to give a percentage error, $\frac{Vave-Vm}{Vave}$ x 100. (A negative sign in the error fraction indicates that the actual velocity is lower than that predicted by the model.) These latter results are tabulated for all elements in Table 6. The error analysis (Table 6) is split to present the total results and those excluding the near-bank elements. As can be expected, the near-bank elements contribute substantially to the largest errors. These elements are most difficult for which to estimate roughness because particle size is not the principal component; rather, bed form, vegetation, and small obstructions can play major roles in the overall resistance. Also, the rectangular element assumption is not completely valid for these segments. Although an attempt was made to refine this assumption by considering only 2/3 of the area defined by the element's enclosing rectangle, it is clear that Model 1 and the characteristic particle size "n" estimate lose their effectiveness in this region.

Comparison of the average n values listed in Table 1 and the n_i values listed in Table 3 for the respective field tests indicates some large differences. Also, the v_m velocities listed in Table 3 for the individual segments do not agree with values which would be calculated by direct application of the Manning equation to the corresponding n_i values, using the slope values from Table 1. An obvious and perhaps not surprising conclusion is that the model will tolerate a lot of imprecision in the input. The "n" values in Table 1 are based on the measured total discharge, the measured total cross-section geometry, and on the measured water surface slope. This latter was treated as a constant over the range of flows measured in the field. Further, the field measurements indicated that at no site was the surface slope truly uniform; consequently, the slope values indicated are based on leveling measurements over reaches which were too short (250 feet, maximum) and hence cannot be considered accurate. However, in the equation used to predict the velocity v_m in the m-th segment,

$$v_m = \frac{Q\, d_m^{5/3}/n_m}{\sum_{i=1}^{p} \frac{d_i^{2/3}\, w_i}{n_i}}$$

the slope term vanishes from the equation. Therefore, neither an accurate measurement of slope nor determination of "n" is really necessary in order to use the model. As noted, the equations based on relative roughness all produce essentially the same relative distribution of "n" values, and these latter calculations are all independent of the slope so long as hydraulically rough flow is assumed. The ratio R/n^6 represents a ratio of two lengths similar to the relative roughness k/r_o, or in terms of the present notation, d/D_{84}, and the result is that "n" is relatively insensitive to changes in D_{84} for a given depth d.

In summary, a pragmatic advantage of Model 1 is that so long as it is applied in reaches where flows are nearly uniform and devoid of significant cross-currents, reasonable results can be expected, except close to the banks, with a relative minimum of detailed information.

Model 2: Results and Discussion

Model 2, which uses one set of velocity measurements avoids the problem of estimating "n" which is encountered in Model 1. However, the assumption of uniform flows over the range of discharges is still necessary. As stated previously, relative roughness is affected by many variables, one of which is stage. Clearly the extra work involved in collecting one set of velocity measurements warrants the expectation of better accuracy with Model 2 than with Model 1. However, definite limitations exist in extrapolating the results of Model 2 at the calibrated flow to a different flow of interest.

The results of the application of Model 2 to the field data are presented in Table 4. The slopes at the Cedar Grove sites were measured at a low flow (100 cfs), the slope at Renton was measured at 375 cfs, and the slope at the Deschutes River was measured at 210 cfs (see Table 1 for slope values). No slope measurements were made at other flows. The slope terms are not necessarily considered to remain constant in the model but do cancel out of the equations (i.e., the term $(S/S_c)^{1/2}$ appears in both the numerator and denominator).

A major concern in the use of Model 2 is how Manning's "n" will change with the flow. The model does not explicitly address this issue of changing "n." Rather it is assumed that "n" remains constant over variations in depth and discharge and it is hoped that the "n" value computed for the calibration flow is closely approximated at the other flows of interest. As pointed out in the discussion of Model 1, "n" can change with flow and thus can increase errors in velocity predictions; Model 1 allows this variation to be incorporated, but Model 2 does not.

Table 4 is set up so that any set of measurements can act as either the calibrated run or the predicted run in comparison with other runs at a particular site. For example, at Renton there are five sets of measurements but two of the sets, C-1 and C-2, were considered to be too close in flow and in velocity measurements to be considered as separate sets. Therefore, with the four distinct sets there can be six combinations where one set can be the calibration and the other the predicted. The error analysis summary (Table 7) was generated using these six combinations. If the combinations are reversed, that is if C-5 is used as the calibrated run to predict velocities at C-2, the errors of prediction are almost the same but of opposite sign if C-2 is calibtated to predict C-5. Tables 4d through 4g illustrate this point. All of the possible permutations of run combinations are not listed in Table 4.

The ratio of the calibrated flow to the predicted flow can be defined as the "flow difference factor." It is emphasized that the calibrated and predicted flows occur at different depths. For example, the combination in Table 4f is of a calibrated flow of 662.8 cfs and a predicted flow of 186.5 cfs; the flow difference factor in this case is 3.55. It follows that as the difference factor approaches 1.0, the error in predicting velocities should decrease. It would appear intuitive that as the flow at which a lateral velocity distribution is being predicted nears the calibrated flow, errors should be reduced. This result was not clear in the field results. Tables 41 and 4m have difference factors of 4.01 and 0.19, respectively; errors are not much different from those in Table 4n where the difference factor is 1.30. Generally the results of this study do not support a clear anticipated correlation between the proximity of predicted to calibrated flows and velocity prediction errors. However, the point remains a major consideration in the application of Model 2. The flow selected to calibrate the model should be centered within the range of anticipated flows where lateral velocity distribution estimates are to be made.

Bovee and Milhous (1978) recommend that the flow difference factor to be in the range 0.4-2.5 for application of Model 2. The model in this report was applied to run combinations whose factor substantially exceeded this recommended range. The extreme difference at the Deschutes River is illustrated in Table 4m. The factor is 0.19, with velocity prediction errors all within 20% excluding the near-bank elements. The extreme difference between flows at Renton is presented in Table 4k. The flow difference factor is 5.77 with errors generally within 20%.

Model 3: Results and Discussion

Park (1977) presented a compilation of exponents data for the hydraulic geometry concept for 139 at-a-station sites. This approach is relevant to Model 3, as the variation of velocity over time (i.e., with discharge) at a station is the point of concern. Park's summary of distribution characteristics of hydraulic geometry exponents for at-a-site stations, with theoretical values from Leopold and Langbein (1962) is reproduced below. These values apply for the average velocity and mean depth of the entire cross-section.

	Velocity Exponent b	Width Exponent m	Depth Exponent f
Range	0.07-0.71	0.00-0.59	0.06-0.73
Model Class	0.4 -0.5	0.0 -0.1	0.3 -0.4
Theoretical	0.35	0.23	0.42

The range of velocity exponents "b" above can be compared with the results for individual segments presented in Table 5. The assumption implicit in Model 3 is that each channel element, or segment, develops the equilibrium postulated in the hydraulic geometry concept. This assumption appears to be more applicable to the mid-channel segments where the majority of flow passes. The results of Table 5 indicate that Model 3 may not perform as well at the fringe elements and that the tendency to develop the hydraulic geometry equilibrium may not apply to near-bank elements. The values of exponents "b" of the near-bank elements in Table 5 are far less consistent than the "b" exponents for the mid-channel elements. Figures 7 and 8 also show this. Figure 7 is a log-log plot of velocity and depth versus total discharge of a near-bank element at the Renton site. Figure 8 is a similar plot at a mid-channel element at the same site. Clearly, the line of best fit is better related to the plotted points in the middle element than in the near-bank element. The exponent "b" at the mid-channel element is 0.33, which is close to the Leopold and Lanbein value of 0.35.

Figures 7 and 8 also show the relationship between depth of the particular element and the total discharge. The exponent "f" which relates depth to discharge according to the hydraulic geometry concept is the slope of the lines of best fit in the figures. If Manning's equation is assumed applicable and both Manning's and the water slope are approximately constant over range of discharge of interest, then it follows:

$$V \alpha \, d^{2/3}$$

$$A \alpha \, d, \quad Q = vA$$

$$Q \alpha \, d^{5/3}$$

$$d \alpha \, Q^{0.6}$$

$$f = 0.6$$

The corresponding values of "f" in Figures 7 and 8 are 0.54 and 0.49, respectively.

The only other results noted by the authors and which treat the application of Model 3 to natural channels is a study performed on a large prairie (alluvial) river (Bovee, et al., 1977). That study concluded that the model could predict velocities with less than 10% error, 90% of the time. Results of the present study do not show as much promise, as can be seen in the error analysis compilation in Table 8. However, this may be due in part to how the error analysis was generated.

It seems reasonable that better results from the model would result if more than two sets of measurements were used to define the constants a_i, b_i. Renton was the only site at which enough measurements were made to properly analyze Model 3. Tables 5a, 5e, 5i and 5m use three sets of measurements to define the constants; the other calculations only use two sets. Again, all different combinations were used to generate the error analysis in Table 8. It also seems reasonable that Model 3 would perform better if the calibration sets of measurements bounded the flow range of interest rather than requiring extrapolation of the line of best fit to predict velocities at a larger or smaller flow.

The questions of model performance versus number of sets of measurements used to define a_i, and b_i, and performance versus whether extrapolation or interpolation is used were not explicitly addressed in the error analysis. However, inspection of the appropriate results does not indicate a marked increase of model accuracy when using three sets of measurements instead of two, or interpolating rather than extrapolating to predict the velocities at the flow of interest. It was felt that too few measurements were made to warrant a more precise breakdown of errors. However, these two issues of model performance may help explain the difference in results reported here and those of Bovee, et al. (1977).

V. CONCLUSIONS

This report has presented a study concerning the validity of application to gravel bed rivers of three models which have been proposed for predicting the lateral distribution of depth-averaged velocities in natural streams. The field data are somewhat limited, so results must still be considered as exploratory. Following the same sequence as in the prior chapters, each of the three models will be considered in turn. Final comments apply to the general application of the models.

Model 1 predicted 29% of the velocities with an error of less than 5% and 45% with an error of less than 10%. When the near-bank elements were excluded the model predicted 34% of the velocities with an error of less than 5%. In the study the near-bank elements contained most of the large errors in each model.

Although Model 1 does not require a set of velocity measurements, field work is required to obtain a cross-section data and a discharge-stage relationship, and a site inspection may be necessary. The key to Model 1 is the estimate of the roughness distribution across the full stream width. The approach used to estimate "n" requires little extra field work since the bed sampling can be done at the time the cross section is surveyed. Model 1 may become more useful if a stream gage is located near the reach of interest thereby eliminating the need for establishing the stage-discharge relationship since often extensive field work is required to define the rating curve at a site.

Model 2 incorporates a trade-off of spending extra effort collecting one set of velocity measurements versus trying to estimate flow resistance. If a potential user of these models is experienced at estimating flow resistance, i.e., Manning's "n" distributions, Model 1 may be more cost effective. Model 2 does appear to give better results than Model 1 (see Tables 6 and 7); it predicted 36% of the velocities with an error of less than 5% and 44% with an error of less than 10%. When the near-bank elements were excluded the model predicted 44% of the velocities with an error of less than 5%. There are limitations to application of Model 2 and close consideration must be given to selecting the calibrated flow and over what range of flows this calibration will be expected to apply. Based on results of this study on gravel bed streams the flow difference factor can vary from 0.25-4.0 and Model 2 can still be expected to predict 90% of the velocities with less than 20% error for the flow of interest.

Again, Model 2 requires an amount of initial input which could involve substantial field effort. Obtaining the velocity measurements, cross-section data, and the stage-discharge relationships may involve considerable field effort.

Model 3 predicted 33% of the velocities with an error of less than 5%, and 56% with an error of less than 10%. When the near-bank elements were excluded the model predicted 39% of the velocities with an error of less than 5%. Model 3 does not depend upon using uniform flow equations and assumptions, so conceivably it may be applicable when flow conditions change seriously with stage and flow conditions could become considerably non-uniform, and Models 1 and 2 would not apply. This point bears further investigation.

With reference to the error analysis of each model it was felt that not enough data were taken to warrant a more rigorous statistical analysis. Percentages quoted apply to the particular field data; they may not be general. In examining the applicability of these models, it is important to consider how they are to be used and what results they are expected to provide. The expectation is that each model will predict the lateral distribution of depth-averaged velocities over a range of flows with the results to be used in a not-so-accurate empirical model (habitat worth model). The reliability of these velocity and depth data is strongly dependent on the amount of time and effort expended in obtaining them. The user has to determine exactly the objectives and requirements of his particular study, and the resources available, before a recommendation can be made on model selection.

Within the limited scope of this study the errors involved in predicting velocities in the near-bank segments are of little importance; because so little of the total flow passes through the near-bank segments, the overall performance of each model is not greatly affected. However, in the context of a stream's overall suitability for fish the planform surface area represented by near-bank elements may constitute a substantial part of the total spawning surface area regardless of the small amount of flow passing through the elements. More accurate velocity predictions can be made in near-bank elements if the spacing of the verticals is reduced near shore. Horizontal velocities can change rapidly near shore. If a near-bank element incorporates a large lateral variation in velocity across its width, it is difficult to predict the average velocity of the element based on one vertical established in the middle of the element. By spacing the verticals closer together near the shores the average velocities of each vertical are closer in magnitude to the average velocity of the element it defines and can be predicted with less error.

The following conclusions can be reached from the results of the investigation:

Within the scope of the objectives of this thesis the following conclusions are most important and relevant:

1. Based on work performed on gravel bed rivers the application of Manning's equation to elements which compose a transect is reasonable. This is, of course, not a new finding.

2. The hydraulic geometry concept applies to elements of transects in the same fashion as it applies to the entire transect.

3. Because of the dependence of each model on knowing the discharge at the stage for which the velocity distribution is needed, an accurate stage-discharge relationship is of paramount importance. This requirement may involve considerable field work which may not make the models as economically attractive.

4. The relative roughness approach employed in Model 1 is an adequate procedure for obtaining the lateral distribution of Manning's "n" over the width of the stream. The procedure accommodates possible changes in the distribution of relative "n" values with stage changes when used in Model 1. It would be possible to affect a small refinement in Model 2 by incorporating the ratio $n_{m,c} : n_i$ in the predictive equation for v_m, thereby releasing the constraint of assumed n = constant with changes in depth.

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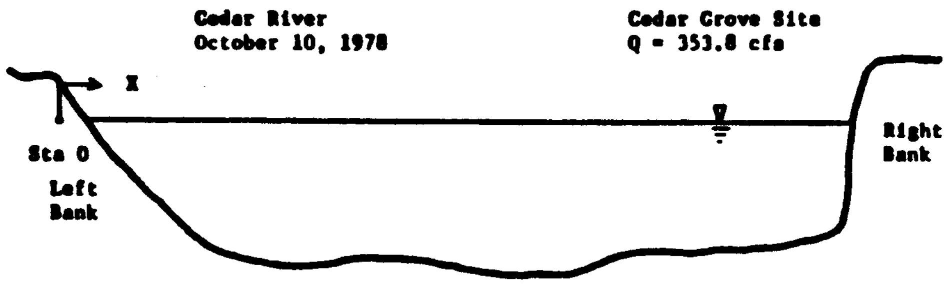
Table 1: Summary Table of Site Characteristics

	CEDAR RIVER										DESCHUTES RIVER		
	Cedar Grove Site			Cedar Grove Upstream Site		Renton Site					Park Site		
Date Run Number	10-10-78 A-1	10-14-78 A-2	7-13-79 A-3	7-18-79 B-1	9-13-79 B-2	10-19-78 C-1	10-26-78 C-2	12-15-78 C-3	7-18-79 C-4	9-13-79 C-5	5-10-79 D-1	7-12-79 D-2	7-26-79 D-3
Area (ft^2)	144	141	112	80	104	155	159	205	74	105	89	44	42
Wetted Perimeter (ft)	79	78	76	58	68	105	105	109	98	102	69	63	62
Hydraulic Radius (ft)	1.83	1.81	1.47	1.38	1.53	1.48	1.51	1.88	0.76	1.03	1.30	0.70	0.67
Slope	.00075	.00075	.00075	.00068	.00068	.00074	.00074	.00074	.00074	.00074	.0025	.0025	.0025
Flow (cfs)	353.8	337.9	190.5	81.5	170.5	366.8	375.2	662.8	114.8	186.5	211.9	52.8	40.7
Manning's n	0.025	0.025	0.031	0.047	0.031	0.022	0.023	0.019	0.022	0.023	0.037	0.049	0.058

Table 2: Field Data Continued

2a: Run A - 1

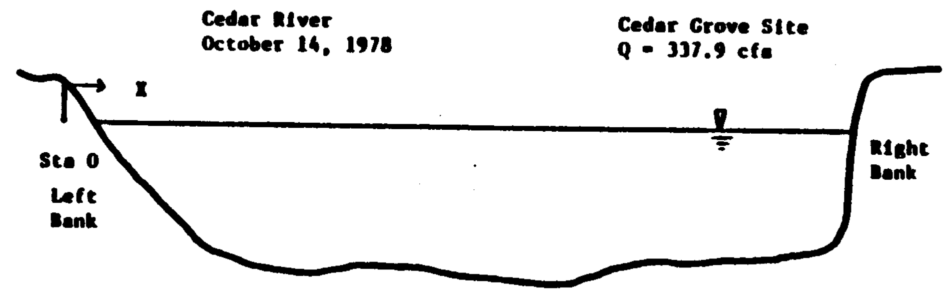


X (ft)	Water Depth (ft)	VELOCITY - fps Distance Above Bottom - ft 0.4	0.5	0.8	1.0	1.2	1.5	1.6	1.75	1.9	2.0
73.1	water edge										
68.1	1.2		0.80		0.98						
58.1	1.9		0.98		1.16			2.55			
48.1	2.0		2.05		2.52		3.01		3.09*		
38.1	2.2	1.34		2.45		2.94		3.27			3.38*
28.1	2.2	2.19		3.01		3.16		3.74			4.01*
17.9	2.2	2.34		2.78		3.27		3.42		3.42*	
7.9	1.9	2.15		2.59		2.78		2.90			
2.9	1.9	1.75		2.05		2.12		2.19			
0	water edge										

* adjusted value to compensate for near surface effects on current meter reading

Table 2: Field Data Continued

2b: Run A-2



X (ft)	Water Depth (ft)	VELOCITY - fps / Distance Above Bottom - ft: 0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.1
73.7	water edge																
68.7	1.2	0.98	1.12	1.45	1.52			1.70	1.60*								
63.7	1.6		1.23	1.33			1.97			2.23		2.23*					
58.7	1.9		1.08	1.48		2.05	2.15			2.45			2.41	2.63*			
48.7	2.0	1.70	1.79	1.94		2.30	2.59			2.71		2.75	2.94		3.09*		
38.7	2.1	1.52	1.70	1.79	2.20	2.49	2.75		3.05	3.12		3.16	3.31		3.27	3.46	
28.7	2.3	1.60	1.87	2.05			2.82				3.20		3.60			3.56	3.74*
17.9	2.1	1.27	1.75	2.05			2.71			3.12			3.27			3.64*	
7.9	1.8	1.52	1.82	2.22			2.63			2.84			2.82*				
2.5	1.8	1.23	1.37	1.60			1.97			2.05			2.38*				
0	water edge																

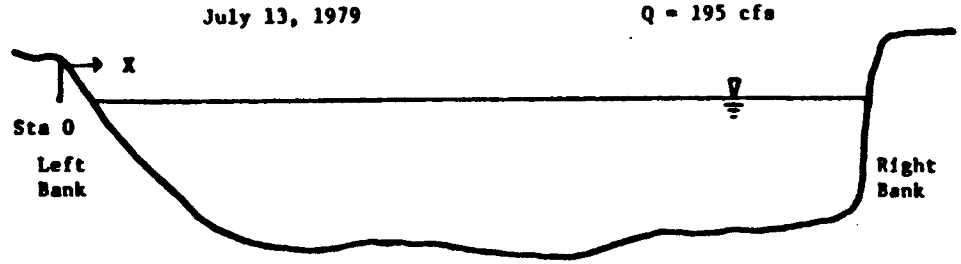
* adjusted value to compensate for near surface effects on current meter reading

Table 2: Field Data Continued

2c: Run A - 3

Cedar River
July 13, 1979

Cedar Grove Site
Q = 195 cfs

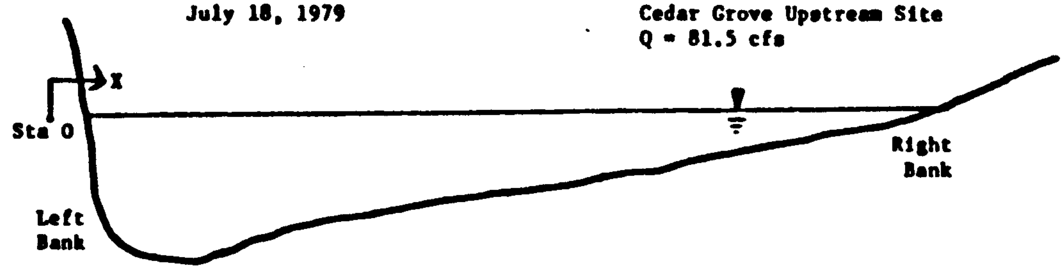


X (ft)	Water Depth (ft)	VELOCITY - fps Distance From Bottom - ft 0.2	0.3	0.35	0.4	0.5	0.6	0.65	0.7	0.75	0.8	1.0	1.15	1.2	1.25	1.3	1.4	1.45	1.5	1.6	1.75
72.2	water edge																				
67.9	0.65	0.90	1.05		1.13	1.09*															
62.9	1.25	0.82	0.75		1.05		1.41				1.67	1.67*									
57.9	1.45	0.57	0.79		1.05		1.13				1.48			1.75*							
52.9**	1.60		0.94					1.56							1.82						
47.9	1.70		0.67		0.94	1.13					1.45		1.67							1.83*	
42.9**	1.78			1.45					1.52									1.67			
37.9	1.85		1.08		1.27	1.33					1.71			2.12						2.20	
32.9**	1.85				1.71					2.01									2.45		
27.9	1.95	1.01	1.19		1.45						2.08			2.41						2.55	2.55*
22.9**	1.85				1.71					2.30									2.67		
17.9	1.80	1.19	1.60	1.64							2.01			2.45						2.55*	
12.9**	1.75			1.48					1.87								2.37				
10.4**	1.60		1.33				1.71									2.12					
7.9	1.58	1.15	1.30		1.52		1.87					2.16				2.20					
2.5	1.40		0.50		0.79	0.90					1.15	1.27		1.37*							
0	water edge																				

* adjusted value to compensate for near surface effects on current meter reading
** vertical used for stream gauging only

Table 2: Field Data Continued

2d: Run B - 1

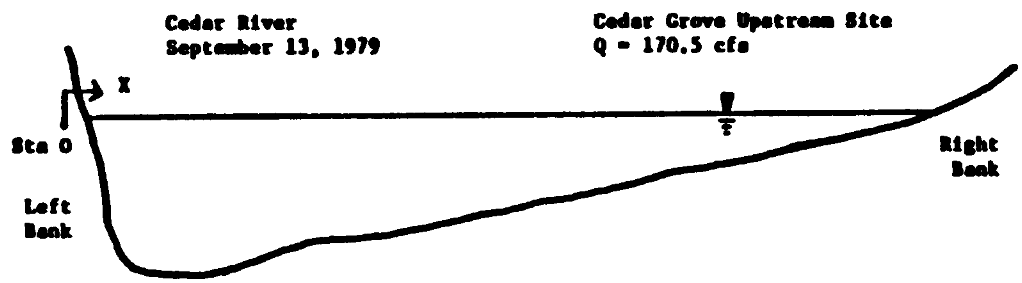


X (ft)	Water Depth (ft)	VELOCITY - fps Distance Above Bottom - ft 0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.3	1.4	1.6	1.7	1.8	2.0
0.6	water edge															
5.0	2.40		0.87	0.87		0.90			1.13			1.15			1.30	1.27
10.0	2.02	0.77	0.80	0.87		0.98			1.20			1.27			1.41*	
15.0	1.98	0.60	0.73	0.90		1.20			1.30			1.48		1.56		
20.0	1.90	0.77	0.87	0.90		1.15			1.37		1.52		1.56			
25.0	1.70	0.47	0.83	1.01		1.06			1.20	1.37		1.37				
30.0	1.48			0.73	0.83	0.80		1.15	1.15	1.27						
35.0	1.18	0.43	0.64	0.73		0.79		1.06	1.09*							
39.5	0.90	0.43	0.53	0.69		0.94	0.98*									
45.0	0.50	0.47	0.57*													
55.2	water edge															

* adjusted value to compensate for near surface effects on current meter readings

Table 2: Field Data Continued

2e: Run B-2

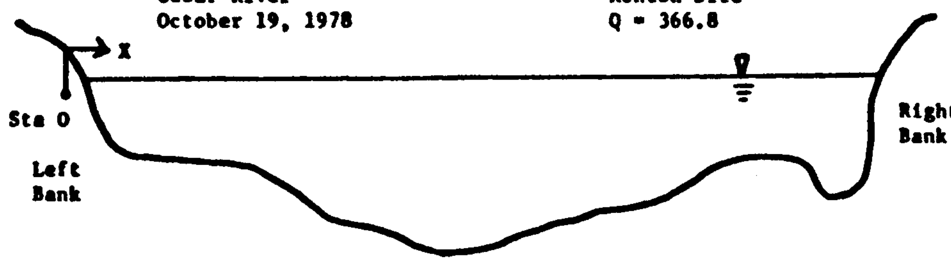


X (ft)	Water Depth (ft)	VELOCITY - fps / Distance Above Bottom - ft: 0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
0	water edge																
5.0	2.90	1.09		1.30		1.41					1.67			1.94			2.05
10.0	2.62		1.27			1.56		1.79			1.94		2.26			2.30	
15.0	2.42		1.30			1.71		1.90			2.26		2.26			2.49*	
20.0	2.40	1.09		1.56				1.90			2.01		2.30			2.23*	
25.0	2.25		1.13			1.41		1.64			2.05		2.15		2.19		
30.0	1.90			1.09		1.56		1.71			1.94	2.19	2.05				
35.0	1.60		1.09	1.16		1.34		1.56		1.64		1.71*					
39.7	1.15	0.83	1.01	1.16		1.45		1.67	1.60*								
45.0	0.92		1.09	1.20	1.13	1.16	1.20*										
50.0	0.81		0.25	0.44		0.83*											
55.0	0.37	0.25															
62.3	water edge																

* adjusted to compensate for near surface effects on current meter readings

Table 2: Field Data Continued

2f: Run C - 1

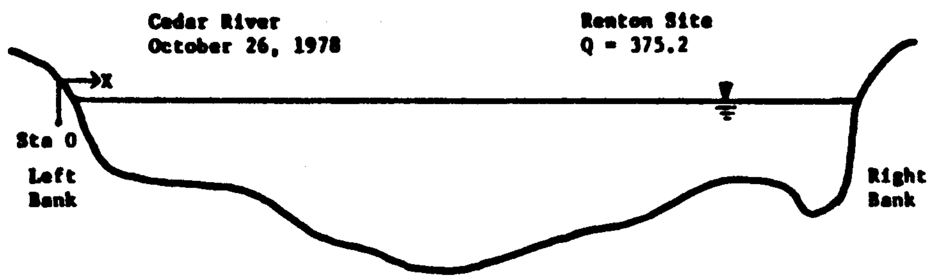


X (ft)	Water Depth (ft)	VELOCITY - fps / Distance Above Bottom - ft: 0.2	0.3	0.4	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.0
0.6	water edge																
5.0	1.55	0.45	0.55	0.82		0.97		1.05		1.15							
15.0	1.10	1.08	1.33	1.41	1.77	1.87	1.94*										
25.0	1.25	1.64	1.62	2.08		2.37		2.34									
35.0	1.50	1.87	2.04	2.30		2.71		3.01	2.97	2.92							
45.0	1.75	1.60	2.08	2.45		2.97				3.27		3.30					
55.0	2.05	1.77	2.22	2.12		2.90				3.23			3.53		3.64*		
65.0	2.15	1.63	1.97	2.15		2.97				3.05			3.38			3.53	3.75
75.0	1.90	1.71	2.04	2.30		2.63				2.94			2.97	3.09*			
85.0	1.45	1.93	2.08	2.42		2.71				2.86	2.94*						
95.0	1.55	0.77	1.08	1.38		1.38				1.79	1.82						
99.7	water edge																

* adjusted value to compensate for near surface effects on current meter readings

Table 2: Field Data Continued

2g: Run C - 2

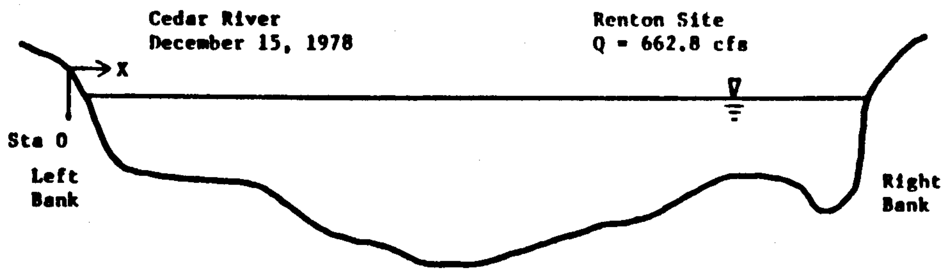


X (ft)	Water Depth (ft)	VELOCITY - fps											
		Distance Above Bottom - ft											
		0.2	0.3	0.4	0.6	0.8	0.9	1.0	1.2	1.3	1.6	1.8	2.0
0.6	water edge												
5.0	1.60	0.60	0.77	0.86		0.90		1.05	0.96	0.94			
15.0	1.15	1.15	1.27	1.41	1.64	1.82	1.97*						
25.0	1.30	1.52	1.82	2.08		2.34		2.38					
35.0	1.50	1.71	2.22	2.38		2.75		2.97	3.12	3.24*			
45.0	1.80	1.71	2.12	2.49		2.90			3.30		3.50*		
55.0	2.10	1.75	2.01	2.26		3.01			3.16		3.38	3.34	
65.0	2.25	1.71	2.14	2.34		2.83		3.05	3.12		3.38		3.34
75.0	1.90	1.71	1.79	2.19		2.75			3.01		3.16		
85.0	1.50	1.90	2.15	2.26		2.67			2.85	2.90*			
95.0	1.50	1.20	1.34	1.14		1.52			1.54	1.52*			
99.7	water edge												

* adjusted value to compensate for near surface effects on current meter readings

Table 2: Field Data Continued

2h: Run C - 3

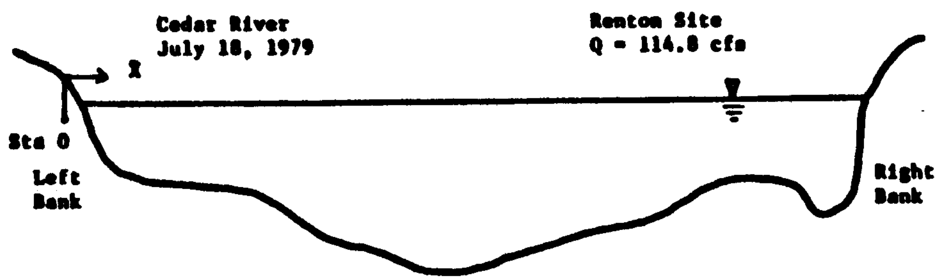


X (ft)	Water Depth (ft)	VELOCITY - fps													
		Distance Above Bottom - ft													
		0.2	0.3	0.4	0.8	1.2	1.4	1.5	1.6	1.7	1.8	2.0	2.1	2.2	2.3
0	water edge														
5.0	2.02	0.98	1.08	1.12	1.45	1.67			1.78	1.78					
15.0	1.7	1.16	1.30	1.48	1.78	1.97		2.38*							
25.0	1.8	2.38	2.78	2.78	3.38	3.67	3.74								
35.0	2.05	2.11	2.52	2.82	3.42	3.84			4.09		4,40				
45.0	2.4	2.26	2.90	2.96	3.42	4.10			4.68			4.40	4.46		
55.0	2.55	1.96	2.82	2.96	3.50	4.10			4.24			4.16		4.24	
65.0	2.7	2.02	2.60	2.74	3.50	3.64			4.16			4.32			4.24
75.0	2.2	2.30	2.38	2.82	3.42	3.74			4.10		4.10				
85.0	2.0	2.01	2.52	2.75	3.64	3.98			3.98	3.85					
95.0	2.1	1.34	1.56	1.71	2.30	2.70			3.12		3.20				
100.0	water edge														

* adjusted value to compensate for near surface effects on current meter readings

Table 2: Field Data Continued

2i: Run C - 4

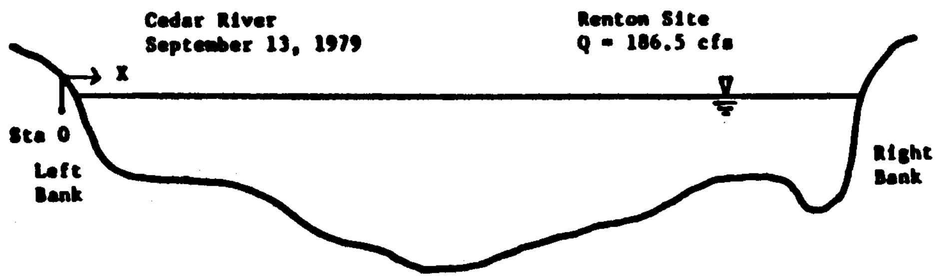


X (ft)	Water Depth (ft)	VELOCITY - fps Distance Above Bottom - ft 0.2	0.25	0.3	0.35	0.4	0.5	0.6	0.75	0.8	0.85	0.9	0.95	1.0
2.0	water edge													
5.0	0.82	0.40		0.43		0.47	0.53	0.60*						
10.0**	0.65	0.50				0.57*								
15.0	0.50	0.79		1.13										
20.0**	0.35	1.41*												
25.0	0.38	1.30*												
30.0**	0.52	1.13		1.48*										
35.0	0.60	1.34		1.67										
40.0**	0.60	1.41				1.60*								
45.0	0.78	1.23		1.71		1.94		2.12*						
50.0**	0.95	1.30				1.94			2.12*					
55.0	1.10	1.52		1.87		2.05		2.30		2.49		2.55*		
60.0**	1.18		1.52				1.94						2.34	
65.0	1.20	1.67		1.79		2.05		2.26		2.41				2.45*
70.0**	1.10	1.41				2.20					2.41			
75.0	0.98	1.20		1.45		1.71		2.14		2.26*				
80.0**	0.80	1.37			1.67			2.01*						
85.0	0.75	1.06		1.27		1.56	1.87							
90.0**	0.70	1.13		1.45			1.56*							
95.0	0.65	0.94		1.08		1.23								
98.0	water edge													

* adjusted value to compensate for near surface effects on current meter readings
** vertical used for stream gauging only

Table 2: Field Data Continued

2j: Run C - 5

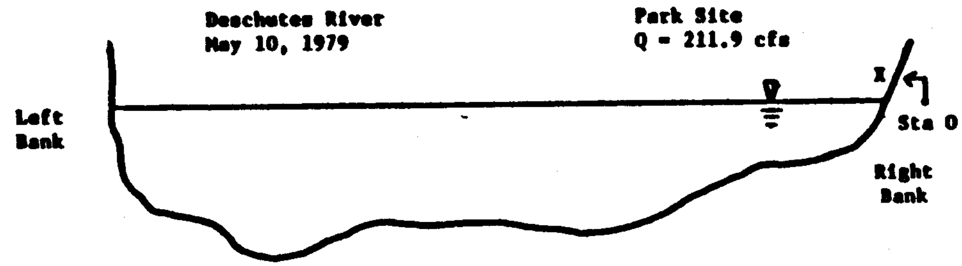


X (ft)	Water Depth (ft)	VELOCITY - fps Distance Above Bottom - ft 0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2
1.4	water edge										
5.0	1.00	0.57	0.60	0.57		0.50	0.50				
10.0**	0.94	0.80		1.09				1.37*			
15.0	0.77	0.73	0.98	1.16	1.20						
20.0**	0.63	1.41	1.30	1.79*							
25.0	0.58	1.52	1.67	1.64*							
30.0**	0.75	1.41	1.64		1.87						
35.0	0.88	1.41	1.79	2.01		2.19	2.19*				
40.0**	0.87	1.30		2.08			2.23*				
45.0	1.04	1.67	2.05	2.26		2.63		2.63*			
50.0**	1.24	1.56			2.41				2.78*		
55.0	1.38	1.75	1.90	2.15		2.45		2.67		2.78*	
60.0**	1.50		1.87			2.41					2.82
65.0	1.43	1.64	2.01	2.08		2.30		2.78			2.97*
70.0**	1.42		1.87			2.59					2.82*
75.0	1.28	1.37	1.79	2.05		2.38		2.63	2.59		
80.0**	1.08	1.41		1.90		2.30		2.38			
85.0	1.00	1.52	1.94	2.08		2.41		2.23*			
90.0**	0.93	1.52		1.87			2.26*				
95.0	0.71	1.71	1.87		1.87*						
99.1	water edge										

* adjusted value to compensate for near surface effects on current meter readings
** vertical used for stream gauging only

Table 2: Field Data Continued

2k: Run D - 1

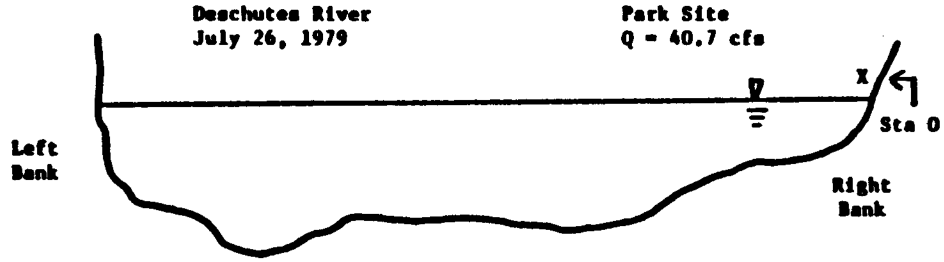


X (ft)	Water Depth (ft)	VELOCITY - fps Distance Above Bottom - ft 0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
10.3	water edge																
17.0	0.80	0.80	1.19		1.64	1.64*											
20.0	0.90	0.94	1.27	1.64		1.79	1.83*										
25.0	1.10	1.45	1.75	1.86		2.15		2.15	2.15*								
30.0	1.35	1.19	1.37	1.64		1.90		2.19		2.23							
35.0	1.50	1.60	1.82	2.16		2.45		2.53			2.74						
40.0	1.60	1.52	1.94	2.16		2.38		2.54			2.90	2.82					
45.0	1.60	1.71	2.23	2.49		2.67		2.97			3.13		3.13*				
50.0	1.60	2.01	2.20	2.49		2.71		2.94			3.28		3.50*				
55.0	1.60	1.82	2.05	2.45		2.84		3.09			3.42	3.38					
60.0	1.80	1.52	1.86	2.55		2.84		3.13			3.31			3.38			
65.0	2.02	1.56	2.12	2.30		2.59		2.75			3.31				3.42		3.60*
70.0	2.00	0.94	1.15	1.37		1.75		1.79			1.79					1.86	
73.0	1.45		1.08	1.27		1.37		1.37			1.37*						
75.8	water edge																

* adjusted value to compensate for near surface effects on current meter readings

Table 2: Field Data Continued

21: Run D - 2

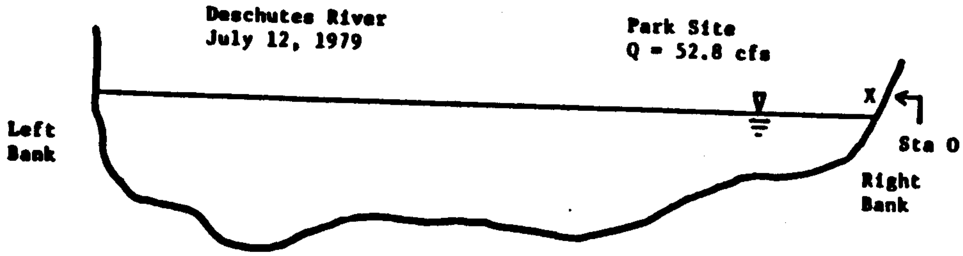


X (ft)	Water Depth (ft)	VELOCITY - fps Distance Above Bottom - ft 0.2	0.25	0.3	0.35	0.4	0.5	0.55	0.6	0.7	0.75	0.8	0.9	1.0	1.1	1.15
15.9	water edge															
17.0	0.17															
20.0	0.19															
25.0	0.34	0.53*														
30.0	0.66			0.57		0.60	0.73*									
32.5**	0.72	0.69			0.77			0.87*								
35.0	0.76	0.50		0.57		0.80	0.83		0.87*							
37.5**	0.85				0.77											
40.0	0.90	0.40		0.77		0.77	0.73		0.77	0.83*						
45.0	0.87	0.73		0.87		0.94	1.01		1.05	1.05*						
47.5**	0.95	0.50				0.83					1.13*					
50.0	0.94	0.83		0.98		1.13			1.30	1.34		1.34*				
52.5**	0.95	0.90				1.08					1.23*					
55.0	0.88	1.05		1.15		1.23	1.30		1.27	1.37*						
57.5**	0.95	0.80				1.15					1.41*					
60.0	1.00	0.87		1.08		1.20	1.30		1.48			1.48*				
62.5**	1.08	0.90				1.05						1.30				
65.0	1.32	0.64		0.83		0.83			0.98			1.23		1.20		1.27*
67.5**	1.35		0.64					0.77							1.01	
70.0	1.28	0.60		0.69		0.77			0.80				0.80		0.87*	
73.0	0.87			0.53		0.60	0.69		0.64	0.73*						
75.3	water edge															

* adjusted value to compensate for near surface effects on current meter readings
** vertical used for stream gauging only

Table 2: Field Data Continued

2m: Run D - 3



X (ft)	Water Depth (ft)	VELOCITY - fps, Distance Above Bottom - ft: 0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
15.5	water edge											
17.0	0.15											
20.0	0.18											
25.0	0.45	0.40	0.60*									
30.0	0.75		0.79	0.79	0.90	0.94*						
35.0	0.90	0.53	0.77	0.90		1.01	1.09*					
40.0	0.98	0.79	0.94	1.01		1.15	1.15	1.23*				
45.0	1.02	0.76	1.13	1.19		1.34	1.34	1.45*				
47.5**	1.02	0.73			1.34	1.26		1.37*				
50.0	1.08	0.94	1.15	1.27		1.54	1.56	1.52				
52.5**	1.02	0.97		1.26				1.45*				
55.0	1.02	1.00	1.05	1.26		1.37	1.48	1.48*				
57.5**	1.05	0.94		1.26				1.63				
60.0	1.10	0.79	1.37	1.48		1.63		1.71	1.71*			
62.5**	1.15	1.08			1.27				1.52*			
65.0	1.40	0.73	0.84	0.98		1.19		1.37		1.45		1.52*
67.5**	1.40		0.77			0.87					1.05	
70.0	1.35	0.57	0.70	0.73				0.80	0.83		0.83*	
73.0	0.98	0.40	0.43	0.47		0.57		0.57*				
75.3	water edge											

* adjusted value to compensate for near surface effects on current meter readings
** vertical used for stream gauging only

Table 3: Model 1 Results

3a.

CEDAR GROVE SITE

Run: A-1; Q = 353.8 cfs; S_o = .00075

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.2	2.25	.0286	10.0	19.34	1.87	1.62	-15.4
2	1.9	2.25	.0275	10.0	43.26	2.65	2.13	-24.4
3	2.0	2.25	.0300	10.0	43.19	2.51	2.41	-4.2
4	2.2	3.25	.0297	10.0	51.14	2.70	2.53	-6.7
5	2.2	3.25	.0297	10.1	51.65	2.70	3.13	+13.7
6	2.2	3.25	.0297	10.1	51.65	2.70	2.93	+7.9
7	1.9	3.25	.0301	8.0	31.42	2.62	2.48	+2.4
8	1.9	3.25	.0301	5.0	13.03	2.39	1.92	-24.5

Q' = 304.68
k = 1.161

3b.

Run: A-2; Q = 337.9 cfs; S_o = .0075

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.2	2.25	.0286	7.5	14.50	1.86	1.36	-36.8
1a	1.6	2.25	.0279	5.0	16.01	2.31	1.73	-33.5
2	1.9	2.25	.0275	7.5	32.44	2.62	2.10	-24.8
3	2.0	3.25	.0300	10.0	43.19	2.48	2.47	0.0
4	2.1	3.25	.0299	10.0	41.01	2.25	2.70	+16.7
5	2.3	3.25	.0296	10.4	57.47	2.26	2.87	+21.3
6	2.1	3.25	.0299	10.4	48.89	2.57	2.74	+6.2
7	1.8	3.25	.0303	7.7	27.63	2.30	2.42	+5.0
8	1.8	3.25	.0303	5.2	12.44	2.29	1.82	-25.8

Q' = 293.58
k = 1.151

3c.

Run: A-3; Q = 190.5 cfs; S_o = .00075

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.65	2.25	.0306	6.	2.95	0.90	0.94	+4.3
1a	1.25	2.25	.0284	5.0	10.42	1.50	1.34	-11.9
2	1.45	2.25	.0281	7.5	20.23	1.68	1.30	-29.2
3	1.70	3.25	.0304	10.0	32.51	1.72	1.37	-25.6
4	1.85	3.25	.0302	10.0	37.68	1.84	1.72	-7.0
5	1.95	3.25	.0300	10.0	41.41	1.91	2.01	+5.0
6	1.80	3.25	.0303	10.6	38.03	1.80	2.07	+13.0
7	1.58	3.25	.0306	7.1	20.30	1.63	1.82	+10.4
8	1.40	3.25	.0310	5.2	8.00	1.49	0.99	-50.5

Q' = 211.53
k = 0.901

Table 3: Model 1 Results Continued

3d.

CEDAR GROVE UPSTREAM SITE

Run: B-1; Q = 81.5 cfs; S_o = .00068

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	2.40	2.25	.0272	7.5	46.10	1.37	1.06	-29.3
2	2.02	2.25	.0274	5.0	22.89	1.22	1.13	-8.0
3	1.98	2.25	.0275	5.0	22.14	1.20	1.20	0.0
4	1.90	3.25	.0301	5.0	18.82	1.06	1.23	+13.8
5	1.70	3.25	.0304	5.0	15.48	0.98	1.09	+10.1
6	1.48	3.25	.0308	5.0	12.13	0.88	0.95	+7.4
7	1.18	3.25	.0316	4.8	7.70	0.73	0.83	+12.1
8	0.90	3.25	.0328	5.0	4.96	0.59	0.71	+16.9
9	0.50	3.25	.0364	7.7	1.74	0.36	0.48	+25.0

Q' = 151.96
k = 0.536

3e.

Run: B-2; Q = 170.5 cfs; S_o = .00068

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	2.90	2.25	.0269	7.5	63.91	2.16	1.71	-26.2
2	2.62	2.25	.0270	5.0	35.84	2.01	1.92	-4.7
3	2.42	2.25	.0272	5.0	31.16	1.89	1.94	+2.6
4	2.40	3.25	.0296	5.0	28.24	1.73	1.93	+10.4
5	2.25	3.25	.0297	5.0	25.28	1.65	1.79	+7.8
6	1.90	3.25	.0301	5.0	18.82	1.45	1.67	+13.2
7	1.60	3.25	.0306	4.8	13.34	1.27	1.37	+7.3
8	1.15	3.25	.0317	5.0	7.74	0.99	1.28	+22.7
9	0.92	3.25	.0327	5.2	5.38	0.83	1.07	+22.4
10	0.81	3.25	.0333	4.9	2.68	0.74	0.51	-45.1

Q' = 232.39
k = 0.734

Table 3: Model 1 Results Continued

3f.

RENTON SITE

Run: C-1; Q = 366.8 cfs; S_o = .00074

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.55	1.50	.0254	9.4	20.76	2.37	0.87	-172.4
2	1.10	1.50	.0260	10.0	18.27	1.84	1.52	-21.1
3	1.25	1.50	.0258	10.0	22.79	2.02	2.00	-1.0
4	1.50	1.75	.0264	10.0	30.18	2.23	2.46	+9.4
5	1.75	1.75	.0261	10.0	39.47	2.50	2.75	+9.1
6	2.05	1.75	.0259	10.0	51.78	2.80	2.88	+2.8
7	2.15	1.75	.0259	10.0	56.06	2.89	2.86	-1.1
8	1.90	2.00	.0268	10.0	44.09	2.57	2.49	-3.2
9	1.45	2.00	.0273	10.0	27.58	2.11	2.51	+15.9
10	1.55	2.00	.0272	9.7	20.01	2.21	1.49	-48.3

Q' = 330.99
k = 1.108

3g.

Run: C-2; Q = 375.2 cfs; S_o = .00074

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.60	1.50	.0254	9.4	21.89	2.38	0.84	-183.3
2	1.15	1.50	.0259	10.0	19.76	1.87	1.51	-23.8
3	1.30	1.50	.0257	10.0	24.42	2.05	2.03	-1.0
4	1.50	1.75	.0264	10.0	30.18	2.19	2.55	+14.1
5	1.80	1.75	.0261	10.0	41.37	2.50	2.81	+11.0
6	2.10	1.75	.0259	10.0	53.91	2.80	2.85	+1.8
7	2.25	1.75	.0258	10.0	60.71	2.94	2.82	-4.3
8	1.90	2.00	.0268	10.0	44.09	2.53	2.59	+2.3
9	1.50	2.00	.0272	10.0	29.29	2.13	2.43	+12.4
10	1.50	2.00	.0272	9.7	18.94	2.13	1.37	-55.2

Q' = 344.56
k = 1.089

Table 3: Model 1 Results Continued

3h.

RENTON SITE

Run: C-3; Q = 662.8 cfs; S_o = .00074

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	2.02	1.50	.0251	10.0	43.19	3.21	1.48	-116.9
2	1.70	1.50	.0253	10.0	48.15	2.83	1.73	-63.6
3	1.80	1.50	.0252	10.0	53.18	2.95	3.20	+7.8
4	2.05	1.75	.0259	10.0	64.26	3.13	3.40	+7.9
5	2.40	1.75	.0257	10.0	85.23	3.51	3.77	+3.7
6	2.55	1.75	.0257	10.0	93.19	3.65	3.73	+2.1
7	2.70	1.75	.0256	10.0	102.90	3.81	3.69	-3.3
8	2.20	2.00	.0266	10.0	70.39	3.20	3.42	+6.4
9	2.00	2.00	.0267	10.0	59.83	2.99	3.44	+13.1
10	2.10	2.00	.0267	10.0	43.26	2.49	2.45	-1.6

Q' = 533.90
k = 1.241

3i.

Run: C-4; Q = 114.8 cfs; S_o = .00074

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.82	1.50	.0266	8.0	5.84	1.65	0.46	-258.5
2	0.50	1.50	.0281	10.0	4.54	1.12	0.92	-21.7
3	0.38	1.50	.0292	10.0	2.77	0.90	1.30	+30.8
4	0.60	1.75	.0287	10.0	6.03	1.24	1.42	+12.7
5	0.78	1.75	.0279	10.0	9.60	1.52	1.70	+10.6
6	1.10	1.75	.0270	10.0	17.60	1.98	2.05	+3.4
7	1.20	1.75	.0268	10.0	20.50	2.11	2.04	-3.4
8	0.98	2.00	.0282	10.0	13.90	1.75	1.75	0.0
9	0.75	2.00	.0291	10.0	8.62	1.42	1.40	-1.4
10	0.65	2.00	.0296	8.0	3.56	1.27	1.04	-22.1

3j.

Run: C-5; Q = 186.5 cfs; S_o = .00074

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.00	1.50	.0262	8.6	8.87	1.95	0.48	-307.1
2	0.77	1.50	.0268	10.0	9.78	1.60	1.01	-58.4
3	0.58	1.50	.0276	10.0	5.92	1.29	1.46	+11.6
4	0.88	1.75	.0275	10.0	11.91	1.68	1.79	+6.2
5	1.04	1.75	.0271	10.0	15.97	1.94	2.18	+11.0
6	1.38	1.75	.0265	10.0	26.16	2.35	2.35	0.0
7	1.43	1.75	.0265	10.0	27.77	2.41	2.32	-3.9
8	1.28	2.00	.0276	10.0	22.16	2.19	2.15	-1.9
9	1.00	2.00	.0282	10.0	14.37	1.82	1.96	+7.1
10	0.71	2.00	.0292	9.1	4.76	1.39	1.69	+17.8

Q' = 147.67
k = 1.263

Table 3: Model 1 Results Continued

3k.

DESCHUTES RIVER

Run: D-1; Q = 211.9 cfs; S_o = .0025

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.80	4.0	.0358	5.0	4.78	1.39	1.28	-8.6
2	0.90	4.0	.0351	5.0	8.90	1.53	1.50	-2.0
3	1.10	4.0	.0340	5.0	12.84	1.80	1.86	+3.2
4	1.35	4.0	.0330	5.0	18.62	2.13	1.86	-14.5
5	1.50	4.0	.0326	5.0	22.46	2.31	2.32	0.0
6	1.60	4.0	.0324	5.0	25.17	2.43	2.38	-2.1
7	1.60	4.0	.0324	5.0	25.17	.2.43	2.65	+8.3
8	1.60	4.5	.0335	5.0	24.34	2.35	2.84	+17.3
9	1.60	4.5	.0335	5.0	24.34	2.35	2.78	+15.5
10	1.80	4.5	.0330	5.0	30.07	2.58	2.72	+5.2
11	2.02	4.5	.0326	5.0	36.89	2.82	2.92	+3.4
12	2.00	4.5	.0326	4.0	29.03	2.81	1.63	-72.4
13	1.45	4.5	.0339	4.3	11.70	2.18	1.24	-75.8

Q' = 274.31
k = 0.773

3l.

Run: D-2; Q = 52.8 cfs; S_0 = .0025

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.15	4.0	.0647	2.8	0.09	0.15	—	—
2	0.18	4.0	.0579	4.0	0.30	0.19	—	—
3	0.45	4.0	.0406	5.0	2.42	0.49	0.45	-8.9
4	0.75	4.0	.0362	5.0	6.37	0.77	0.76	-1.3
5	0.90	4.0	.0351	5.0	8.90	0.90	0.86	-4.7
6	0.98	4.0	.0346	5.0	10.41	0.96	0.99	+3.0
7	1.02	4.0	.0344	5.0	11.19	0.99	1.17	+15.4
8	1.08	4.5	.0354	5.0	11.96	1.00	1.29	+22.5
9	1.02	4.5	.0357	5.0	10.78	0.96	1.20	+20.0
10	1.10	4.5	.0353	5.0	12.37	1.02	1.44	+29.2
11	1.40	4.5	.0341	5.0	19.14	1.24	1.19	-4.2
12	1.35	4.5	.0342	4.0	14.37	1.21	0.72	-68.1
13	0.98	4.5	.0359	4.1	8.23	1.39	0.48	-189.6

Q' = 116.53
k = 0.453

3m.

Run: D-3; Q = 40.7 cfs; S_o = .0025

Element	d_i ft	D_{84} in	n_i	w_i ft	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.17	4.0	.0598	2.6	0.11	0.16	—	—
2	0.19	4.0	.0562	4.0	0.33	0.19	—	—
3	0.34	4.0	.0441	5.0	1.40	0.36	0.50	+28.0
4	0.66	4.0	.0371	5.0	5.02	0.67	0.53	-26.7
5	0.76	4.0	.0361	5.0	6.53	0.75	0.69	-8.7
6	0.90	4.0	.0351	5.0	8.90	0.86	0.70	-22.9
7	0.87	4.0	.0353	5.0	8.37	0.84	0.87	+3.5
8	0.94	4.5	.0362	5.0	9.28	0.86	1.07	+19.6
9	0.88	4.5	.0366	5.0	8.22	0.82	1.16	+29.3
10	1.00	4.5	.0358	5.0	10.41	0.91	1.17	+22.2
11	1.32	4.5	.0343	5.0	17.25	1.14	1.00	-14.0
12	1.28	4.5	.0345	4.0	13.04	1.11	0.75	-48.0
13	0.87	4.5	.0367	4.0	4.29	0.81	0.56	-44.6

Q' = 93.15
k = 0.437

Table 4: Model 2 Results

4a.

CEDAR GROVE SITE

Calibration Run: A-3; Q = 190.5 cfs
Predict: A-1; Q = 353.8 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.65	1.2	1.50	10.0	0.94	16.92	1.92	1.62	-18.5
2	1.45	1.9	1.20	10.0	1.30	29.58	2.13	2.13	0.0
3	1.70	2.0	1.11	10.0	1.37	30.54	2.08	2.41	+13.7
4	1.85	2.2	1.12	10.0	1.72	42.47	2.64	2.53	-4.4
5	1.95	2.2	1.08	10.1	2.01	48.40	2.97	3.13	+5.1
6	1.80	2.2	1.14	10.1	2.07	52.58	3.23	2.93	-10.2
7	1.58	1.9	1.13	8.0	1.82	31.09	2.79	2.48	-12.5
8	1.40	1.9	1.23	5.0	0.99	7.61	1.64	1.92	+14.6

Q' = 259.19
k = 1.365

4b.

Calibration Run: A-2; Q = 337.9 cfs
Predict: A-3; Q = 190.5 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.2	0.65	0.66	6.8	1.36	3.97	0.70	0.94	+25.5
1a	1.6	1.25	0.85	5.0	1.73	9.17	1.14	1.34	+14.9
2	1.9	1.45	0.84	7.5	2.10	19.07	1.36	1.30	-4.6
3	2.0	1.70	0.90	10.0	2.47	37.68	1.72	1.37	-25.5
4	2.1	1.85	0.92	10.0	2.70	45.90	1.92	1.72	-11.6
5	2.3	1.95	0.90	10.0	2.87	50.50	2.01	2.01	0.0
6	2.1	1.80	0.90	10.6	2.74	47.05	1.91	2.07	+7.7
7	1.8	1.58	0.92	7.1	2.42	24.89	1.72	1.82	+5.5
8	1.8	1.40	0.85	5.2	1.82	7.47	1.19	0.99	-20.2

Q' = 245.70
k = 0.775

4c.

CEDAR GROVE UPSTREAM

Calibration Run: B-1; Q = 81.5 cfs
Predict: B-2; Q = 170.5 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	2.40	2.90	1.13	7.5	1.06	26.16	1.68	1.71	+1.8
2	2.02	2.62	1.19	5.0	1.13	17.61	1.88	1.92	+2.1
3	1.98	2.42	1.14	5.0	1.20	16.60	1.92	1.94	+1.0
4	1.90	2.40	1.17	5.0	1.23	17.25	2.01	1.93	-4.2
5	1.70	2.25	1.21	5.0	1.09	14.78	1.84	1.79	-2.8
6	1.48	1.90	1.18	5.0	0.95	10.66	1.57	1.67	+6.0
7	1.18	1.60	1.23	4.8	0.83	7.81	1.42	1.37	-3.7
8	0.90	1.15	1.18	5.0	0.71	4.81	1.17	1.28	+8.6
9	0.50	0.92	1.50	5.2	0.48	3.45	1.01	1.07	+5.6
10	—	0.81	—	4.9	—	2.68*	1.42	0.51	-178.0

Q' = 121.81
k = 1.400

* value obtained using Model 1

Table 4: Model 2 Results Continued

4d.

RENTON SITE

Calibration Run: C-2; Q = 375.2 cfs
Predict: C-5; Q = 186.5 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.60	1.00	0.73	8.6	0.84	3.52	0.70	0.48	-45.8
2	1.15	0.77	0.77	10.0	1.51	8.90	1.33	1.01	-31.7
3	1.30	0.58	0.58	10.0	2.03	6.87	1.36	1.46	+6.9
4	1.50	0.88	0.70	10.0	2.55	15.73	2.05	1.79	-14.5
5	1.80	1.04	0.69	10.0	2.81	20.27	2.24	2.18	-2.8
6	2.10	1.38	0.76	10.0	2.85	29.73	2.47	2.35	-5.1
7	2.25	1.43	0.74	10.0	2.82	29.81	2.39	2.32	-3.0
8	1.90	1.28	0.77	10.0	2.59	25.48	2.29	2.15	-6.5
9	1.50	1.00	0.76	10.0	2.43	18.54	2.12	1.96	-8.2
10	1.50	0.71	0.61	9.1	1.37	3.59	0.96	1.69	+43.2
						Q' = 162.44			
						k = 1.148			

4e.

Calibration Run: C-5; Q = 186.5 cfs
Predict: C-2; Q = 375.2 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.00	1.60	1.37	9.4	0.48	6.59	0.61	0.84	+27.4
2	0.77	1.15	1.31	10.0	1.01	15.18	1.23	1.51	+18.5
3	0.58	1.30	1.71	10.0	1.46	32.51	2.32	2.03	-14.3
4	0.88	1.50	1.43	10.0	1.79	38.31	2.32	2.55	+9.0
5	1.04	1.80	1.44	10.0	2.18	56.57	2.92	2.81	-3.9
6	1.38	2.10	1.32	10.0	2.35	65.29	2.88	2.85	-1.1
7	1.43	2.25	1.35	10.0	2.32	70.62	2.92	2.82	-3.6
8	1.28	1.90	1.30	10.0	2.15	53.16	2.59	2.59	0.0
9	1.00	1.50	1.31	10.0	1.96	38.53	2.36	2.43	+2.9
10	0.71	1.50	1.65	9.7	1.69	26.99	2.58	1.37	-88.3
						Q' = 404.38			
						k = 0.928			

Table 4: Model 2 Results Continued

4f.

RENTON SITE

Calibration Run: C-3; Q = 662.8 cfs
Predict: C-5; Q = 186.5 cfs

Element	1 $d_{i,c}$ ft	2 d_i ft	3 $[d_i/d_{i,c}]^{2/3}$	4 w_i ft	5 $v_{i,c}$ fps	2x3x4x5 q'_m cfs	v_m fps	v_{ave} fps	% error
1	2.02	1.00	0.63	8.6	1.48	5.35	0.93	0.48	-93.8
2	1.70	0.77	0.58	10.0	1.73	7.73	1.00	1.01	+1.0
3	1.80	0.58	0.47	10.0	3.20	8.72	1.51	1.46	-3.4
4	2.05	0.88	0.57	10.0	3.40	17.05	1.94	1.79	-8.4
5	2.40	1.04	0.57	10.0	3.77	22.35	2.14	2.18	+1.8
6	2.55	1.38	0.66	10.0	3.73	33.97	2.46	2.35	-4.7
7	2.70	1.43	0.65	10.0	3.69	34.30	2.40	2.32	-3.5
8	2.20	1.28	0.70	10.0	3.42	30.64	2.39	2.15	-11.2
9	2.00	1.00	0.63	10.0	3.44	21.67	2.16	1.96	-10.2
10	2.10	0.71	0.49	9.1	2.45	5.17	1.20	1.69	+29.0
						Q' = 186.95			
						k = 1.000			

4g.

Calibration Run: C-5; Q = 186.5 cfs
Predict: C-3; Q = 662.8 cfs

Element	1 $d_{i,c}$ ft	2 d_i ft	3 $[d_i/d_{i,c}]^{2/3}$	4 w_i ft	5 $v_{i,c}$ fps	2x3x4x5 q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.00	2.02	1.60	10.0	0.48	10.34	0.83	1.48	+43.9
2	0.77	1.70	1.70	10.0	1.01	29.11	1.84	1.73	-6.4
3	0.58	1.80	2.13	10.0	1.46	55.92	3.34	3.20	-4.4
4	0.88	2.05	1.76	10.0	1.79	64.49	3.38	3.40	+0.6
5	1.04	2.40	1.75	10.0	2.18	91.37	4.09	3.77	-8.5
6	1.38	2.55	1.51	10.0	2.35	90.24	3.80	3.73	-1.9
7	1.43	2.70	1.53	10.0	2.32	95.70	3.81	3.69	-3.3
8	1.28	2.20	1.43	10.0	2.15	67.87	3.32	3.42	+2.9
9	1.00	2.00	1.59	10.0	1.96	62.22	3.36	3.44	+2.3
10	0.71	2.10	2.06	10.0	1.69	47.29	3.63	2.45	-48.2
						Q' = 616.68			
						k = 1.075			

Table 4: Model 2 Results Continued

4h.

RENTON SITE

Calibration Run: C-4; Q = 114.8 cfs
Predict: C-1; Q = 366.8 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.82	1.55	1.53	9.4	0.46	6.83	0.68	0.87	+21.8
2	0.50	1.10	1.69	10.0	0.92	17.12	1.50	1.52	+1.3
3	0.38	1.25	2.21	10.0	1.30	35.94	2.77	2.00	-38.5
4	0.60	1.50	1.84	10.0	1.42	39.24	2.52	2.46	-2.4
5	0.78	1.75	1.71	10.0	1.70	50.99	2.81	2.75	-2.2
6	1.10	2.05	1.51	10.0	2.05	63.64	2.99	2.88	-3.8
7	1.20	2.15	1.48	10.0	2.04	64.70	2.90	2.86	-1.4
8	0.98	1.90	1.55	10.0	1.75	51.70	2.63	2.49	-5.6
9	0.75	1.45	1.55	10.0	1.40	31.50	2.09	2.51	+16.7
10	0.65	1.55	1.78	9.7	1.04	18.61	1.79	1.49	-20.1

Q' = 380.28
k = 0.965

4i.

Calibration Run: C-2; Q = 375.2 cfs
Predict: C-3; Q = 662.8 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.60	2.02	1.17	10.0	0.84	13.23	1.18	1.48	+20.3
2	1.15	1.70	1.30	10.0	1.51	33.31	2.35	1.73	-35.8
3	1.30	1.80	1.24	10.0	2.03	45.39	3.03	3.20	+5.3
4	1.50	2.05	1.23	10.0	2.55	64.38	3.76	3.40	-10.6
5	1.80	2.40	1.21	10.0	2.81	81.70	4.08	3.77	-8.2
6	2.10	2.55	1.14	10.0	2.85	82.72	3.89	3.73	-4.3
7	2.25	2.70	1.13	10.0	2.82	85.98	3.81	3.69	-3.3
8	1.90	2.20	1.10	10.0	2.59	62.83	3.42	3.42	0.0
9	1.50	2.00	1.21	10.0	2.43	58.88	3.53	3.44	-2.6
10	1.50	2.10	1.25	10.0	1.37	24.08	2.06	2.45	+15.9

Q' = 552.53
k = 1.200

Table 4: Model 2 Results Continued

4j.

KENTON SITE

Calibration Run: C-2; Q = 375.2 cfs
Predict: C-4; Q = 114.8 cfs

Element	1 $d_{i,c}$ ft	2 d_i ft	3 $[d_i/d_{i,c}]^{2/3}$	4 w_i ft	5 $v_{i,c}$ fps	2x3x4x5 q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.60	0.82	0.64	8.0	0.84	2.35	0.59	0.46	-28.3
2	1.15	0.50	0.57	10.0	1.51	4.33	0.96	0.92	-4.4
3	1.30	0.38	0.44	10.0	2.03	3.40	0.99	1.30	+23.9
4	1.50	0.60	0.54	10.0	2.55	8.31	1.53	1.42	-7.8
5	1.80	0.78	0.57	10.0	2.81	12.55	1.77	1.70	-4.1
6	2.10	1.10	0.65	10.0	2.85	20.37	2.04	2.05	0.0
7	2.25	1.20	0.66	10.0	2.82	22.25	2.05	2.04	0.0
8	1.90	0.98	0.64	10.0	2.59	16.32	1.84	1.75	-5.1
9	1.50	0.75	0.63	10.0	2.43	11.48	1.69	1.40	-20.7
10	1.50	0.65	0.57	8.0	1.37	2.71	0.86	1.04	+17.3

Q' = 104.05
k = 1.103

4k.

Calibration Run: C-3; Q = 662.8 cfs
Predict: C-4; Q = 114.8 cfs

Element	1 $d_{i,c}$ ft	2 d_i ft	3 $[d_i/d_{i,c}]^{2/3}$	4 w_i ft	5 $v_{i,c}$ fps	2x3x4x5 q'_m cfs	v_m fps	v_{ave} fps	% error
1	2.02	0.82	0.55	8.0	1.48	3.56	0.78	0.46	-69.6
2	1.70	0.50	0.44	10.0	1.73	3.83	0.73	0.92	+20.7
3	1.80	0.38	0.35	10.0	3.20	4.31	1.08	1.30	+16.9
4	2.05	0.60	0.44	10.0	3.40	8.99	1.42	1.42	0.0
5	2.40	0.78	0.47	10.0	3.77	13.90	1.69	1.70	+0.6
6	2.55	1.10	0.57	10.0	3.73	23.42	2.03	2.05	+1.0
7	2.70	1.20	0.58	10.0	3.69	25.79	2.04	2.04	0.0
8	2.20	0.98	0.58	10.0	3.42	19.55	2.05	1.75	-17.1
9	2.00	0.75	0.52	10.0	3.44	13.42	1.70	1.40	-21.4
10	2.10	0.65	0.46	8.0	2.45	3.89	1.06	1.04	-1.9

Q' = 120.70
k = 0.954

Table 4: Model 2 Results Continued

4l.

DESCHUTES RIVER

Calibration Run: D-1; Q = 211.9 cfs
Predict: D-2; Q = 52.8 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.80	0.15	0.33	—	1.28	—	—	—	—
2	0.90	0.18	0.34	—	1.50	—	—	—	—
3	1.10	0.45	0.55	7.5	1.86	2.31	0.59	0.45	-31.1
4	1.35	0.75	0.68	5.0	1.86	4.71	0.73	0.76	+4.0
5	1.50	0.90	0.71	5.0	2.32	7.43	0.95	0.86	-10.5
6	1.60	0.98	0.72	5.0	2.38	8.41	0.98	0.99	+1.0
7	1.60	1.02	0.74	5.0	2.65	10.01	1.13	1.17	+3.4
8	1.60	1.08	0.77	5.0	2.84	11.80	1.26	1.29	+2.3
9	1.60	1.02	0.74	5.0	2.78	10.50	1.19	1.20	+0.8
10	1.80	1.10	0.72	5.0	2.72	10.77	1.13	1.44	+21.5
11	2.02	1.40	0.78	5.0	2.92	16.01	1.32	1.19	-10.9
12	2.00	1.35	0.77	4.0	1.63	6.77	0.72	0.72	0.0
13	1.45	0.98	0.77	4.1	1.24	2.55	0.55	0.48	-14.6

Q' = 91.27
k = 0.579

4m.

Calibration Run: D-3; Q = 40.7 cfs
Predict: D-1; Q = 211.9 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.17	0.80	2.81	5.0	—	4.78*	3.26	1.28	-154.7
2	0.19	0.90	2.82	5.0	—	8.90*	3.60	1.50	-140.0
3	0.34	1.10	2.19	5.0	0.50	4.01	1.99	1.86	-7.0
4	0.66	1.35	1.61	5.0	0.53	5.76	1.55	1.86	+16.7
5	0.76	1.50	1.57	5.0	0.69	8.14	1.98	2.32	+14.7
6	0.90	1.60	1.47	5.0	0.70	8.22	1.87	2.38	+21.4
7	0.87	1.60	1.50	5.0	0.87	10.45	2.38	2.65	+10.2
8	0.94	1.60	1.43	5.0	1.07	12.20	2.78	2.84	+2.1
9	0.88	1.60	1.49	5.0	1.16	13.47	3.07	2.78	-10.4
10	1.00	1.80	1.48	5.0	1.17	15.58	3.15	2.72	-15.8
11	1.32	2.02	1.33	5.0	1.00	13.41	2.42	2.92	+17.1
12	1.28	2.00	1.35	4.0	0.75	8.08	1.84	1.63	-12.9
13	0.87	1.45	1.41	4.3	0.56	3.31	1.45	1.24	-16.9

Q' = 116.31
k = 1.822

* values obtained using Model 1

4n.

Calibration Run: D-2; Q = 52.8 cfs
Predict: D-3; Q = 40.7 cfs

	1	2	3	4	5	2x3x4x5			
Element	$d_{i,c}$ ft	d_i ft	$[d_i/d_{i,c}]^{2/3}$	w_i ft	$v_{i,c}$ fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.15	0.17	1.09	—	—	—	—	—	—
2	0.18	0.19	1.04	—	—	—	—	—	—
3	0.45	0.34	0.83	7.5	0.45	0.63	0.34	0.50	+32.0
4	0.75	0.66	0.92	5.0	0.76	2.30	0.64	0.53	-20.7
5	0.90	0.76	0.89	5.0	0.86	2.92	0.71	0.69	-2.9
6	0.98	0.90	0.94	5.0	0.99	4.21	0.87	0.70	-24.3
7	1.02	0.87	0.90	5.0	1.17	4.58	0.98	0.87	-12.6
8	1.08	0.94	0.91	5.0	1.29	5.53	1.09	1.07	-1.9
9	1.02	0.88	0.91	5.0	1.20	4.79	1.01	1.16	+12.9
10	1.10	1.00	0.94	5.0	1.44	6.76	1.25	1.17	-6.8
11	1.40	1.32	0.96	5.0	1.19	7.55	1.06	1.00	-6.0
12	1.35	1.28	0.97	4.0	0.72	3.56	0.64	0.75	+14.7
13	0.98	0.87	0.92	4.0	0.48	1.03	0.41	0.56	+26.8

Q' = 43.86
k = 0.928

Table 5: Model 3 Results

5a: C-5, C-2, C-3 predict C-4

Element	VELOCITY - fps C-5 Q=186.5	C-2 Q=375.2	C-3 Q=662.8	a_i	b_i	C-4; Q = 114.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.48	0.84	1.48	.005	.885	0.33	1.44	0.35	0.46	+23.9
2	1.01	1.51	1.73	.110	.430	0.85	4.25	0.89	0.92	+3.3
3	1.46	2.03	3.20	.057	.613	1.04	3.95	1.09	1.30	+16.2
4	1.79	2.55	3.40	.127	.506	1.40	8.40	1.47	1.42	-3.5
5	2.18	2.81	3.77	.228	.429	1.74	13.57	1.83	1.70	-7.7
6	2.35	2.85	3.73	.349	.361	1.93	21.23	2.03	2.05	+1.0
7	2.32	2.82	3.69	.342	.363	1.91	22.92	2.01	2.04	+1.5
8	2.15	2.59	3.42	.317	.362	1.77	17.35	1.86	1.75	-14.7
9	1.96	2.43	3.44	.192	.439	1.54	11.55	1.62	1.40	-15.7
10	1.69	1.37	2.45	.363	.271	1.31	4.54	1.38	1.04	-32.7

Q' = 109.20
k = 1.051

5b: C-5, C-2 predict C-4

Element	VELOCITY - fps C-5 Q=186.5	C-2 Q=375.2	a_i	b_i	C-4; Q = 114.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.48	0.84	0.007	0.801	0.31	1.36	0.30	0.46	+34.8
2	1.01	1.51	0.050	0.575	0.76	3.80	0.74	0.92	+19.6
3	1.46	2.03	0.124	0.472	1.16	4.41	1.14	1.30	+12.3
4	1.79	2.55	0.127	0.506	1.40	8.40	1.37	1.42	+3.5
5	2.18	2.81	0.327	0.363	1.83	14.27	1.79	1.70	-5.3
6	2.35	2.85	0.555	0.276	2.06	22.66	2.02	2.05	+1.5
7	2.32	2.82	0.539	0.279	2.02	24.24	1.98	2.04	+2.9
8	2.15	2.59	0.534	0.266	1.89	18.52	1.85	1.75	-5.7
9	1.96	2.43	0.393	0.308	1.69	12.68	1.66	1.40	-18.6
10	1.69	1.37	8.124	-.300	1.96	6.79	1.92	1.04	-84.6

Q' = 117.13
k = 0.980

5c: C-2, C-3 predict C-4

Element	VELOCITY - fps C-2 Q=375.2	C-3 Q=662.8	a_i	b_i	C-4; Q = 114.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.84	1.48	0.002	0.995	0.22	0.96	0.28	0.46	+39.1
2	1.51	1.73	0.366	0.239	1.14	5.70	1.43	0.92	-55.4
3	2.03	3.20	0.018	0.800	0.80	3.04	1.00	1.30	+23.1
4	2.55	3.40	0.127	0.506	1.40	8.40	1.75	1.42	-23.2
5	2.81	3.77	0.132	0.517	1.53	11.93	1.92	1.70	-12.9
6	2.85	3.73	0.173	0.473	1.63	17.93	2.04	2.05	0.0
7	2.82	3.69	0.171	0.473	1.61	19.32	2.02	2.04	+1.0
8	2.59	3.42	0.143	0.489	1.45	14.21	1.82	1.75	-4.0
9	2.43	3.44	0.065	0.611	1.18	8.85	1.48	1.40	-5.7
10	1.37	2.45	0.003	1.022	0.38	1.32	0.48	1.04	+53.9

Q' = 91.66
k = 1.253

Table 5: Model 3 Results Continued

5d: C-5, C-3 predict C-4

Element	VELOCITY - fps C-5 Q=186.5	VELOCITY - fps C-3 Q=662.8	a_i	b_i	C-4; Q = 114.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.48	1.48	0.005	0.888	0.34	1.49	0.35	0.46	+23.9
2	1.01	1.73	0.110	0.424	0.82	4.10	0.84	0.92	+8.7
3	1.46	3.20	0.057	0.619	1.07	4.07	1.10	1.30	+15.4
4	1.79	3.40	0.127	0.506	1.40	8.40	1.44	1.42	-1.4
5	2.18	3.77	0.228	0.432	1.77	13.81	1.82	1.70	-7.1
6	2.35	3.73	0.350	0.364	1.97	21.67	2.03	2.05	+1.0
7	2.32	3.69	0.342	0.366	1.94	23.28	2.00	2.04	+2.0
8	2.15	3.42	0.317	0.366	1.80	17.64	1.85	1.75	-5.7
9	1.96	3.44	0.193	0.444	1.59	11.93	1.64	1.40	-17.1
10	1.69	2.45	0.366	0.293	1.47	5.10	1.51	1.04	-45.2

Q' = 111.49
k = 1.030

5e: C-4, C-2, C-3 predict C-5

Element	VELOCITY - fps C-4 Q=114.8	VELOCITY - fps C-2 Q=375.2	VELOCITY - fps C-3 Q=662.8	a_i	b_i	C-5; Q = 186.5 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	0.84	1.48	.021	.643	0.61	3.50	0.66	0.48	-33.3
2	0.92	1.51	1.73	.072	.629	1.93	14.86	2.08	1.01	-105.9
3	1.30	2.03	3.20	.121	.430	1.15	6.67	1.24	1.46	+15.1
4	1.42	2.55	3.40	.134	.497	1.80	15.84	1.94	1.79	-8.6
5	1.70	2.81	3.77	.200	.450	2.10	21.84	2.26	2.18	-3.7
6	2.05	2.85	3.73	.418	.332	2.37	32.71	2.55	2.35	-8.5
7	2.04	2.82	3.69	.423	.328	2.35	33.61	2.52	2.32	-8.6
8	1.75	2.59	3.42	.293	.374	2.07	26.50	2.23	2.15	-3.7
9	1.40	2.43	3.44	.126	.506	1.78	17.80	1.92	1.96	+2.0
10	1.04	1.37	2.45	.116	.450	1.22	5.25	1.31	1.69	+16.6

Q' = 173.33
k = 1.076

5f: C-4, C-3 predict C-5

Element	VELOCITY - fps C-4 Q=114.8	VELOCITY - fps C-3 Q=662.8	a_i	b_i	C-5; Q = 186.5 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	1.48	0.020	0.667	0.64	3.67	0.67	0.48	-39.6
2	0.92	1.73	0.167	0.360	1.10	8.47	1.15	1.01	-13.9
3	1.30	3.20	0.114	0.514	1.67	9.69	1.75	1.46	-19.9
4	1.42	3.40	0.134	0.498	1.81	15.93	1.89	1.79	-5.6
5	1.70	3.77	0.197	0.454	2.12	22.05	2.22	2.18	-1.8
6	2.05	3.73	0.406	0.341	2.42	33.40	2.53	2.35	-7.7
7	2.04	3.69	0.411	0.338	2.40	34.32	2.51	2.32	-7.8
8	1.75	3.42	0.286	0.382	2.11	27.01	2.21	2.15	-2.8
9	1.40	3.44	0.123	0.513	1.80	18.00	1.88	1.96	+4.1
10	1.04	2.45	0.102	0.489	1.32	5.69	1.38	1.69	+18.3

Q' = 178.23
k = 1.046

Table 5: Model 3 Results Continued

5g: C-4, C-1 predict C-5

Element	VELOCITY - fps C-4 Q=114.8	C-1 Q=366.8	a_i	b_i	C-5; Q = 186.5 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	0.87	0.034	0.549	0.60	3.44	0.64	0.48	-54.2
2	0.92	1.52	0.118	0.432	1.13	8.70	1.21	1.01	-19.8
3	1.30	2.00	0.224	0.371	1.56	9.05	1.67	1.46	-14.4
4	1.42	2.46	0.151	0.473	1.79	15.75	1.92	1.79	-7.3
5	1.70	2.75	0.239	0.414	2.08	21.63	2.23	2.18	-2.3
6	2.05	2.88	0.512	0.293	2.36	32.57	2.53	2.35	-7.7
7	2.04	2.86	0.513	0.291	2.35	33.61	2.52	2.32	-8.6
8	1.75	2.49	0.415	0.304	2.03	25.98	2.18	2.15	-1.4
9	1.40	2.51	0.129	0.503	1.79	17.90	1.92	1.96	+2.0
10	1.04	1.49	0.240	0.310	1.21	5.21	1.30	1.69	+23.1

Q' = 173.84
k = 1.073

5h: C-2, C-3 predict C-5

Element	VELOCITY - fps C-2 Q=375.2	C-3 Q=662.8	a_i	b_i	C-5; Q = 186.5 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.84	1.48	0.002	0.995	0.36	2.06	0.43	0.48	+10.4
2	1.51	1.73	0.366	0.239	1.28	9.86	1.55	1.01	-53.5
3	2.03	3.20	0.018	0.800	1.18	6.84	1.42	1.46	+2.7
4	2.55	3.40	0.127	0.506	1.80	15.84	2.17	1.79	-21.2
5	2.81	3.77	0.132	0.517	1.97	20.49	2.38	2.18	-9.2
6	2.85	3.73	0.173	0.473	2.05	28.29	2.47	2.35	-5.1
7	2.82	3.69	0.171	0.473	2.03	29.03	2.45	2.32	-5.6
8	2.59	3.42	0.143	0.489	1.84	23.55	2.22	2.15	-3.3
9	2.43	3.44	0.065	0.611	1.59	15.90	1.92	1.96	+2.0
10	1.37	2.45	0.003	1.022	0.63	2.71	0.76	1.69	+55.6

Q' = 154.57
k = 1.207

5i: C-4, C-5, C-3 predict C-2

Element	VELOCITY - fps C-4 Q=114.8	C-5 Q=186.5	C-3 Q=662.8	a_i	b_i	C-2; Q = 375.2 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	0.48	1.48	.014	.711	0.94	9.43	0.91	0.84	-8.3
2	0.92	1.01	1.73	.151	.373	1.38	15.87	1.33	1.51	+11.9
3	1.30	1.46	3.20	.097	.535	2.31	30.03	2.22	2.03	-9.4
4	1.42	1.79	3.40	.132	.500	2.55	38.25	2.83	2.55	-11.0
5	1.70	2.18	3.77	.204	.450	2.93	52.74	2.82	2.81	0.0
6	2.05	2.35	3.73	.392	.346	3.05	64.05	2.94	2.85	-3.2
7	2.04	2.32	3.69	.393	.344	3.02	67.95	2.91	2.82	-3.2
8	1.75	2.15	3.42	.293	.379	2.77	52.63	2.67	2.59	-3.1
9	1.40	1.96	3.44	.137	.499	2.63	39.45	2.53	2.43	-4.1
10	1.04	1.69	2.45	.138	.449	1.98	19.21	1.91	1.37	+39.4

Q' = 389.61
k = 0.963

Table 5: Model 3 Results Continued

5j: C-3, C-3 predict C-1

Element	VELOCITY - fps C-4 Q=114.8	C-3 Q=662.8	a_i	b_i	C-1; Q = 366.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	1.48	0.020	0.667	1.00	9.71	0.97	0.87	-11.5
2	0.92	1.73	0.167	0.360	1.40	15.40	1.36	1.52	+10.5
3	1.30	3.20	0.114	0.514	2.36	29.50	2.29	2.00	-14.5
4	1.42	3.40	0.134	0.498	2.53	37.95	2.46	2.46	0.0
5	1.70	3.77	0.197	0.454	2.88	50.40	2.80	2.75	-1.8
6	2.05	3.73	0.406	0.341	3.05	62.53	2.96	2.88	-2.8
7	2.04	3.69	0.411	0.338	3.02	64.93	2.94	2.86	-2.8
8	1.75	3.42	0.286	0.382	2.73	51.87	2.65	2.48	-6.0
9	1.40	3.44	0.123	0.513	2.54	36.83	2.47	2.51	+1.6
10	1.04	2.45	0.102	0.489	1.83	18.34	1.78	1.49	-19.5
					Q' = 377.46				
					k = 0.972				

5k: C-5, C-3 predict C-2

Element	VELOCITY - fps C-5 Q=186.5	C-3 Q=662.8	a_i	b_i	C-2; Q = 375.2 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.48	1.48	0.005	0.888	0.89	8.92	0.86	0.84	-2.4
2	1.01	1.73	0.110	0.424	1.36	15.64	1.31	1.51	+13.3
3	1.46	3.20	0.057	0.619	2.25	29.25	2.16	2.03	-6.4
4	1.79	3.40	0.127	0.506	2.55	38.25	2.45	2.55	+3.9
5	2.18	3.77	0.228	0.432	2.95	53.10	2.84	2.81	-1.1
6	2.35	3.73	0.350	0.364	3.03	63.63	2.91	2.85	-2.1
7	2.32	3.69	0.342	0.366	3.00	67.50	2.89	2.82	-2.5
8	2.15	3.42	0.317	0.366	2.78	52.82	2.67	2.59	-3.1
9	1.96	3.44	0.193	0.444	2.67	40.05	2.57	2.43	-5.8
10	1.69	2.45	0.366	0.293	2.07	20.70	2.05	1.37	-49.9
					Q' = 389.86				
					k = 0.962				

5l: C-4, C-5 predict C-2

Element	VELOCITY - fps C-4 Q=114.8	C-5 Q=186.5	a_i	b_i	C-2; Q = 375.2 fps v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	0.48	0.303	0.088	0.51	5.11	0.49	0.84	+41.7
2	0.92	1.01	0.370	0.192	1.15	13.23	1.10	1.51	+27.2
3	1.30	1.46	0.418	0.239	1.72	22.36	1.64	2.03	+19.2
4	1.42	1.79	0.148	0.477	2.50	37.50	2.39	2.55	+6.3
5	1.70	2.18	0.150	0.513	3.14	56.52	3.00	2.81	-6.8
6	2.05	2.35	0.540	0.282	2.87	60.27	2.74	2.85	+3.2
7	2.04	2.32	0.580	0.265	2.79	62.78	2.66	2.82	+5.7
8	1.75	2.15	0.234	0.424	2.89	54.91	2.76	2.59	-6.6
9	1.40	1.96	0.052	0.693	3.16	47.40	3.02	2.43	-24.3
10	1.04	1.69	0.009	1.001	3.38	32.79	3.23	1.37	-135.8
					Q' = 392.87				
					k = 0.955				

Table 5: Model 3 Results Continued

5m: C-4, C-5, C-2 predict C-3

Element	VELOCITY - (fps) C-4 Q=114.8	C-5 Q=186.2	C-2 Q=375.2	a_i	b_i	C-3; Q = 662.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	0.48	0.84	0.035	0.529	1.08	14.54	1.24	1.48	+16.2
2	0.92	1.01	1.51	0.115	0.429	1.87	31.79	2.15	1.73	-24.3
3	1.30	1.46	2.03	0.206	0.383	2.48	44.64	2.85	3.20	+10.9
4	1.42	1.79	2.55	0.135	0.495	3.37	69.09	3.87	3.40	-13.8
5	1.70	2.18	2.81	0.236	0.420	3.61	86.64	4.14	3.77	-9.8
6	2.05	2.35	2.85	0.549	0.278	3.34	85.17	3.83	3.73	-2.7
7	2.04	2.32	2.82	0.520	0.282	3.24	87.48	3.72	3.69	-0.8
8	1.75	2.15	2.59	0.379	0.327	3.16	69.52	3.63	3.42	-6.1
9	1.40	1.96	2.43	0.169	0.455	3.24	64.80	3.72	3.44	-8.1
10	1.04	1.69	1.37	0.476	0.195	1.69	23.66	1.94	2.45	+20.8

Q' = 577.33
k = 1.148

5n: C-5, C-2 predict C-3

Element	VELOCITY - fps C-5 Q=186.5	C-2 Q=375.2	a_i	b_i	C-3; Q = 662.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.48	0.84	0.007	0.801	1.32	17.78	1.54	1.48	-4.1
2	1.01	1.51	0.050	0.575	2.10	35.70	2.45	1.73	-41.6
3	1.46	2.03	0.124	0.472	2.65	47.70	3.09	3.20	+3.4
4	1.79	2.55	0.127	0.506	3.40	69.70	3.96	3.50	-16.5
5	2.18	2.81	0.327	0.363	3.46	83.04	4.03	3.77	-6.9
6	2.35	2.85	0.555	0.276	3.34	85.17	3.89	3.73	-4.3
7	2.32	2.82	0.539	0.279	3.31	89.37	3.86	3.69	-4.6
8	2.15	2.59	0.534	0.266	3.01	66.22	3.51	3.42	-2.6
9	1.96	2.43	0.393	0.308	2.89	57.80	3.37	3.44	+2.0
10	1.69	1.37	8.124	0.300	1.15	16.10	1.34	2.45	+45.3

Q' = 568.58
k = 1.166

5o: C-4, C-2 predict C-3

Element	VELOCITY - fps C-4 Q=114.8	C-2 Q=375.2	a_i	b_i	C-3; Q = 662.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	0.84	0.041	0.509	1.12	15.08	1.29	1.48	+12.2
2	0.92	1.51	0.127	0.418	1.92	32.64	2.21	1.73	-27.8
3	1.30	2.03	0.218	0.376	2.51	45.18	2.89	3.20	+9.7
4	1.42	2.55	0.136	0.494	3.38	69.29	3.89	3.40	-14.4
5	1.70	2.81	0.227	0.424	3.58	85.92	4.12	3.77	-9.3
6	2.05	2.85	0.548	0.278	3.34	85.17	3.84	3.73	-3.0
7	2.04	2.82	0.558	0.273	3.29	88.83	3.78	3.69	-2.4
8	1.75	2.59	0.364	0.331	3.13	68.86	3.60	3.42	-5.3
9	1.40	2.43	0.154	0.466	3.17	63.40	3.65	3.44	+6.1
10	1.04	1.37	0.345	0.233	1.56	21.84	1.79	2.45	+26.9

Q' = 576.21
k = 1.150

Table 5: Model 3 Results Continued

5p: C-4, C-5 predict C-3

Element	VELOCITY - fps C-4 Q=114.8	VELOCITY - fps C-5 Q=186.5	a_i	b_i	C-3; Q = 662.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	0.46	0.48	0.303	0.088	0.54	7.23	0.54	1.48	+63.5
2	0.92	1.01	0.370	0.192	1.29	21.90	1.28	1.73	+26.0
3	1.30	1.46	0.418	0.239	1.97	35.54	1.97	3.20	+38.5
4	1.42	1.79	0.148	0.477	3.28	67.24	3.27	3.40	+3.8
5	1.70	2.18	0.150	0.513	4.20	100.85	4.19	3.77	-11.1
6	2.05	2.35	0.540	0.282	3.37	86.01	3.36	3.73	+9.9
7	2.04	2.32	0.580	0.265	3.24	87.59	3.23	3.69	+12.5
8	1.75	2.15	0.234	0.424	3.68	80.89	3.67	3.42	-7.3
9	1.40	1.96	0.052	0.693	4.39	87.89	4.38	3.44	-27.3
10	1.04	1.69	0.009	1.001	6.00	84.06	5.99	2.45	-144.5

Q' = 659.20
k = 0.997

5q: D-1, D-3 predict D-2

Element	VELOCITY - fps D-1 Q=211.9	VELOCITY - fps D-3 Q=40.7	a_i	b_i	D-2; Q = 52.8 cfs v'_m fps	q'_m cfs	v_m fps	v_{ave} fps	% error
1	1.28	—	—	—	—	—	—	—	—
2	1.50	—	—	—	—	—	—	—	—
3	1.86	0.50	0.026	0.796	0.62	0.93	0.63	0.45	-40.0
4	1.86	0.53	0.032	0.761	0.65	2.44	0.66	0.76	+13.2
5	2.32	0.69	0.045	0.735	0.84	3.78	0.85	0.86	+1.2
6	2.38	0.70	0.045	0.742	0.85	4.17	0.86	0.99	+13.1
7	2.65	0.87	0.071	0.675	1.04	5.30	1.06	1.17	+9.4
8	2.84	1.07	0.119	0.592	1.24	6.70	1.26	1.29	+2.3
9	2.78	1.17	0.163	0.530	1.33	6.78	1.35	1.20	-12.5
10	2.72	1.17	0.176	0.511	1.34	7.37	1.36	1.44	+5.6
11	2.92	1.00	0.090	0.650	1.18	8.26	1.20	1.19	-0.8
12	1.63	0.75	0.131	0.471	0.84	4.54	0.85	0.72	-18.1
13	1.24	0.56	0.094	0.482	0.63	1.69	0.64	0.48	-33.3

Q' = 51.96
k = 1.016

Table 6: Error Analysis for Model 1

Number and percent of predicted velocities within error intervals when compared to measured velocities.

$$\text{Percent error} = \frac{V_{MEAS} - V_{PRE}}{V_{MEAS}} \times 100$$

Percent Error	Number of Predicted Velocities in Error Interval	Percent of Predicted Velocities in Error Interval
50 <	13	10
45–50	3	2
40–45	1	1
35–40	1	1
30–35	1	1
25–30	6	5
20–25	8	6
15–20	1	1
− 10–15	3	2
↑ 5–10	6	5
0– 5	18	14
0– 5	20	15
↓ 5–10	14	11
+ 10–15	16	12
15–20	9	7
20–25	6	5
25–30	3	2
30–35	1	1

Similar breakdown of errors as above but excludes near-bank elements

Percent Error	Number of Predicted Velocities in Error Interval	Percent of Predicted Velocities in Error Interval
50 <	4	4
45–50	1	1
40–45	0	0
35–40	0	0
30–35	1	1
25–30	3	3
20–25	6	6
15–20	0	0
− 10–15	3	3
↑ 5–10	4	4
0– 5	17	16
0– 5	19	18
↓ 5–10	14	13
10–15	16	15
+ 15–20	8	8
20–25	5	5
25–30	2	2
30–35	1	1

Table 7: Error Analysis for Model 2

Number and percent of predicted velocities within error intervals when compared to measured velocities.

$$\text{Percent error} = \frac{V_{MEAS} - V_{PRE}}{V_{MEAS}} \times 100$$

	Percent Error	Number of Predicted Velocities in Error Interval	Percent of Predicted Velocities in Error Interval
	50 <	2	2
	45–50	1	1
	40–45	0	0
	35–40	2	2
	30–35	2	2
	25–30	2	2
	20–25	6	5
−	15–20	4	3
	10–15	13	11
	5–10	11	9
	0– 5	22	18
	0– 5	22	18
	5–10	8	7
	10–15	7	7
+	15–20	6	5
	20–25	6	5
	25–30	3	3
	30–35	1	1
	35–40	0	0
	40–45	1	1

Similar breakdown of errors as above but excludes near-bank elements.

	Percent Error	Number of Predicted Velocities in Error Interval	Percent of Predicted Velocities in Error Interval
	35–40	2	2
	30–35	1	1
	25–30	1	1
	20–25	4	4
−	15–20	2	2
	10–15	12	12
	5–10	11	11
	0– 5	21	22
	0– 5	21	22
	5–10	8	8
	10–15	6	6
+	15–20	4	4
	20–25	4	4

Table 8: Error Analysis for Model 3

Number and percent of predicted velocities within error intervals when compared to measured velocities.

$$\text{Percent error} = \frac{V_{MEAS} - V_{PRE}}{V_{MEAS}} \times 100$$

Percent Error	Number of Predicted Velocities in Error Interval	Percent of Predicted Velocities in Error Interval
50 <	7	4
45-50	2	1
40-45	1	1
35-40	3	2
30-35	3	2
25-30	2	1
20-25	4	2
− 15-20	8	5
10-15	11	6
5-10	33	19
0- 5	31	18
0- 5	25	15
5-10	7	4
10-15	10	6
+ 15-20	8	5
20-25	5	3
25-30	3	2
30-35	1	1
35-40	2	1
40-45	1	1
45-50	1	1
50 <	3	2

Similar breakdown of error as above but excludes near-bank elements.

Percent Error	Number of Predicted Velocities in Error Interval	Percent of Predicted Velocities in Error Interval
50 <	3	2
45-50	0	0
40-45	1	1
35-40	0	0
30-35	0	0
25-30	2	1
20-25	4	3
− 15-20	7	5
10-15	10	7
5-10	32	23
0- 5	29	21
0- 5	25	18
5-10	7	5
10-15	8	6
+ 15-20	5	4
20-25	1	1
25-30	2	1
30-35	0	0
35-40	1	1