
 **EPA BASINS Technical Note 2**

Two Automated Methods for Creating Hydraulic Function Tables (FTABLES)

Technical Note 2

Two Automated Methods for Creating Hydraulic Function Tables (FTABLES)

By Keara Moore, with assistance from Yusuf Mohamoud
May 8, 2007

INTRODUCTION

The HSPF model (Bicknell, et al, 1996) uses a hydraulic function table, called an FTABLE, to represent the geometric and hydraulic properties of water bodies, including both stream reaches and fully mixed reservoirs. The accuracy of the FTABLE is particularly important for the model's simulation of flow velocity and sediment transport. For HSPF projects originated through BASINS, FTABLEs are initially created by WinHSPF as part of the project's *.uci* file. WinHSPF constructs FTABLEs based on reach information included in the input files from BASINS along with a set of standard assumptions about channel geometry and hydraulics. As described in this technical memo, the WinHSPF interface now provides a tool to facilitate creation of a new FTABLE that is based on alternative inputs and geometric assumptions and may lead to improved accuracy. Additionally, a hydraulic calibration procedure has been introduced as an option to evaluate and improve FTABLE accuracy.

The FTABLE in HSPF

An FTABLE is a piecewise linear function table – a table used to document, in discrete numerical form, a functional relationship between two or more variables. In HSPF, the FTABLE describes the hydraulics of a river reach or reservoir (RCHRES) segment by defining the functional relationship between water depth, surface area, volume, and outflow in the segment (see Figure 1). The relationship described in the FTABLE is independent of the shape of the water body; water bodies with different shapes could have identical FTABLEs. In other words, in order to apply the functional relationship described in the FTABLE, it is not necessary for HSPF to have any assumptions regarding the shape of a stream channel. In projects with multiple reaches, each will have its own FTABLE.

The FTABLE has columns for depth, surface area, volume, and outflow with each row containing values corresponding to a specified water depth (Figure 1). The system obtains intermediate values by interpolation. The number of rows in the FTABLE depends on the range of depth to be covered and the desired resolution. The FTABLEs described in this document contain only a single outflow column, although there can be up to five columns for outflow. Consult the HSPF manual (Bicknell et al, 1996) for information on ways to use these extra columns to specify more complex outflow situations such as time-dependent releases. For information on developing FTABLEs for reservoirs see Technical Note 1, <http://www.epa.gov/waterscience/BASINS/tecnote1.pdf>.

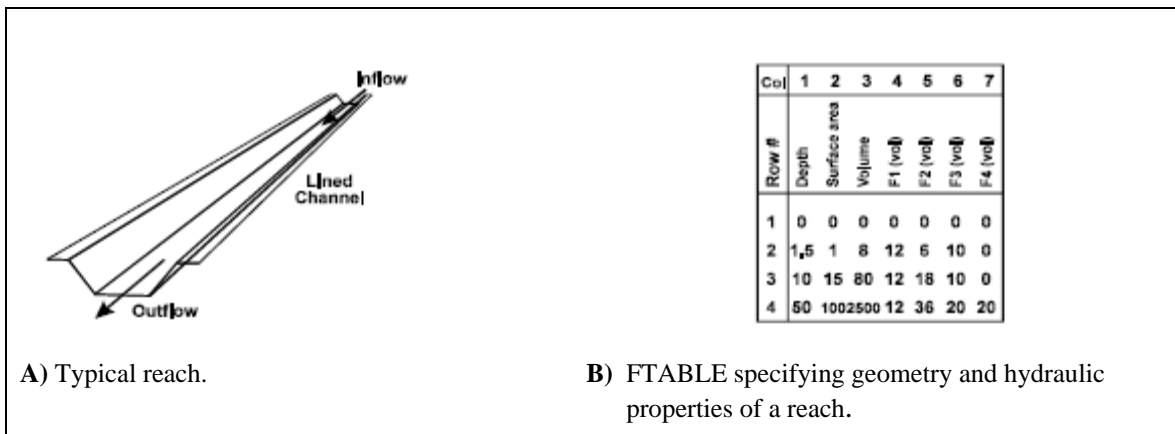


Figure 1. Typical reach configuration and the FTABLE method used to represent geometric and hydraulic properties.

FTABLE DEVELOPMENT USING WinHSPF

WinHSPF (2.3.8), the version associated with BASINS 4.0, offers two options for automatic FTABLE development: the Standard Method, used as the default when the initial FTABLE is created, and the Alternative Method, which is new to this WinHSPF version and uses different estimations of hydraulic geometry properties. It is also possible for users to create FTABLEs manually in WinHSPF, but this option will not be discussed in the current technical memo. Both automatic methods follow a similar process:

- 1) Estimate primary hydraulic geometry parameters (mean flow depth, mean flow width, Manning’s n, and longitudinal slope of the channel) based on available data about the reach;
- 2) Derive the channel cross-section using the mean flow depth and width along with a pre-defined channel and flood plain geometry;
- 3) At a variety of depth intervals, estimate surface area and volume based on the channel cross-section and estimate outflow using Manning’s equation; and
- 4) Format the results as an FTABLE that is compatible to the UCI format.

As described below, the methods differ in the assumptions and algorithms used at each step of the process. Figure 2 demonstrates an example of how FTABLES created by these different methods can differ for the same reach. Once the automatic FTABLE has been created, it can be manually edited by the user or refined through hydraulic calibration. Accuracy of the FTABLE is particularly important for accuracy in modeling flow velocity and sediment transport; it has less effect on results for discharge.

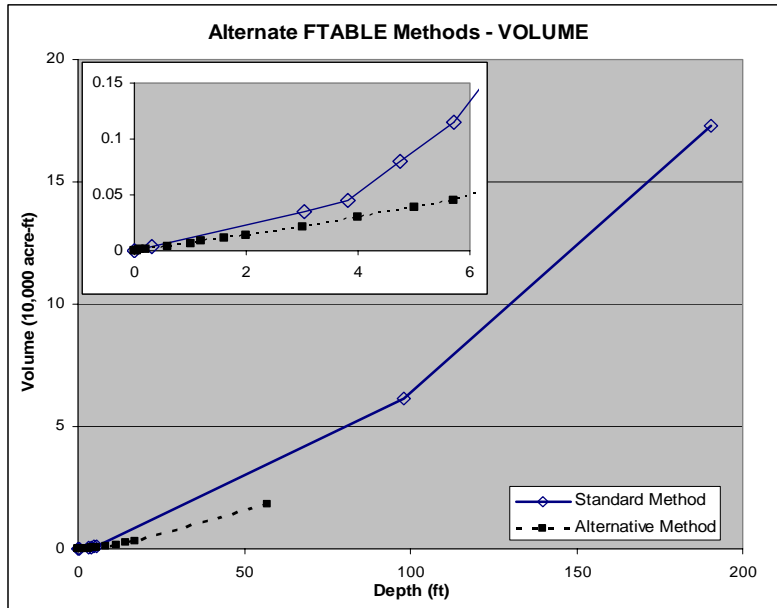
Standard Method FTABLE

Depth (ft)	Area (acres)	Volume (acre-ft)	Outflow (ft ³ /s)
0	111.85	0	0
0.31	112.76	34.25	11.36
3.05	120.96	355.04	524.40
3.81	123.24	448.14	760.07
4.77	370.86	798.89	970.59
5.72	376.56	1155.08	1774.37
98.17	929.19	61516.11	704771
190.63	1481.82	172970.4	2864918

Alternative Method FTABLE

Depth (ft)	Area (acres)	Volume (acre-ft)	Outflow (ft ³ /s)
0	0	0	0
0.02	65.93	1.32	0.11
0.06	66.11	3.96	0.7
0.1	66.29	6.61	1.63
0.2	66.74	13.26	5.19
0.6	68.53	40.31	32.43
1	70.33	68.09	76.11
1.2	71.22	82.24	103.24
1.6	73.02	111.09	167.1
2	74.81	140.65	242.95
3	79.29	217.71	480.87
4	83.78	299.24	783.17
5	88.26	385.26	1146.63
5.71	91.43	448.78	1439.6
8.56	246.15	930.42	3537.62
11.41	258.94	1651.06	7727.39
14.27	271.74	2408.2	13178.74
17.12	284.53	3201.86	19804.82
57.07	463.65	18146.3	228802.6

a) FTABLES created for the same reach using the Standard Method and the Alternative Method (Ridge & Valley physiographic province).



b) Depth vs. Volume from FTABLES created for the same watershed using both automatic methods. Inset zooms to the bankfull depth.

Figure 2. Comparison of FTABLES created for the same reach using the Standard Method and the Alternative Method.

A. Standard Method

When an HSPF watershed model is originated through BASINS, WinHSPF by default automatically creates FTABLEs using the Standard Method. For the first step, WinHSPF extracts the primary geometric parameters – mean flow depth, mean flow width, and longitudinal slope of the channel – from the BASINS stream GIS layer, defined by the user when initiating HSPF from BASINS. The roughness coefficient, Manning’s n , is set to a default value of 0.05.

WinHSPF then derives the channel cross-section by assuming a compound trapezoidal geometry that has one channel section with a side slope of 1:1 and two floodplain sections, each with side slopes of 0.5:1 (see Figure 3). Additional geometric parameters are estimated based on the mean flow depth and width using assumptions presented in Table 1. All of these estimated geometric parameters can be adjusted by the user to refine the model’s operation, as described below.

The Standard Method FTABLE consists of area-volume-flow relationships at 8 depths, including the zero, mean, bankfull, and maximum floodplain depths. Surface area and volume are calculated based on the estimated channel geometry; outflow is calculated using Manning’s equation. The standard equations used in these calculations are provided for reference in Appendix A.

How to Edit Inputs to Standard Method FTABLEs

Standard Method FTABLEs are created automatically for projects originated in BASINS. WinHSPF provides an interface (see Figure 4) so users can adjust the default input parameters in order to generate updated FTABLEs, as follows:

- Select the reach to be edited and access its FTABLE. (Go to Reach Editor screen and click “FTables” button.)
- Click “Import from Cross Section” button.
- Open project’s trapezoidal (.ptf) file. (In its project folder in BASINS/modelout/.)
- Edit the channel geometry and hydraulic parameters as needed; save file.
- Click “OK” and a new FTABLE will be generated. Click “Apply” on the FTABLE screen so that the new FTABLE will be included in the next HSPF run.

B. Alternative Method

A new tool available in WinHSPF facilitates replacement of the default Standard Method FTABLE with one developed using the Alternative Method. This Method was designed for reaches in the Mid-Atlantic Region with drainage areas greater than 3 square miles and less than 400 square miles (Mohamoud and Parmar, 2006). The Alternative Method can be applied in areas outside the Mid-Atlantic Region, but its suitability for such areas has not been fully evaluated.

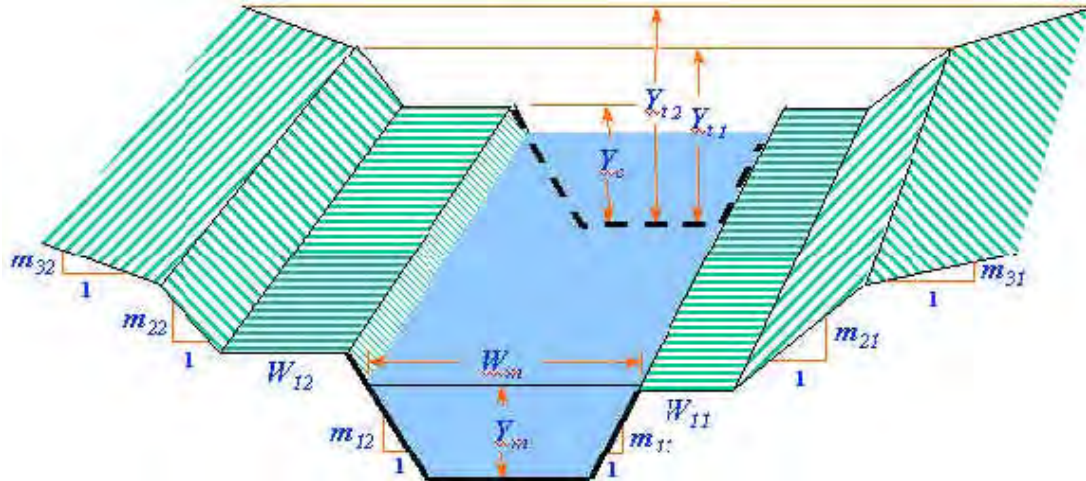


Figure 3. Channel cross-section geometry assumed by WinHSPF in creation of FTABLE using the Standard Method. For the Alternative Method, the channel geometry is the same except there is a single floodplain section instead of two, and the slope represented by “m” is the reciprocal of the slope in this figure.

		Standard Method	Alternative Method
Source of Primary Parameters			
Mean flow depth	Y_m	Reach dataset	Regional regression ^a
Mean flow width	W_m	Reach dataset	Regional regression ^a
Manning’s n	n	0.05	Regional regression ^a
Longitudinal slope	S	Reach dataset	Reach dataset
Channel Geometry Assumptions			
Channel side Slope ^b	$m_{11,12}$	1.0	0.67
Floodplain side Slope ^b	$m_{21,22}$ $m_{31,32}$	0.5	0.67
Floodplain width	$W_{11,12}$	W_m	W_m
Bankfull depth	Y_c	$1.25 \cdot Y_m$	$5 \cdot Y_m$
Max floodplain depth	Y_{t2}	$33.33 \cdot Y_{t1}$ (= $62.5 \cdot Y_m$)	$10 \cdot Y_c$ (= $50 \cdot Y_m$)
Floodplain split depth	Y_{t1}	$1.5 \cdot Y_c$	n/a – floodplain is not split

^a Mohamoud and Parmar (2006)

^b These values represent “m” as depicted in Figure 3. This is the same as the value entered as “m” in the Standard Method but is the reciprocal of the value entered as “m” in the Alternative Method. See figure in Appendix A, section 1D for graphic representation of Alternative “m.”

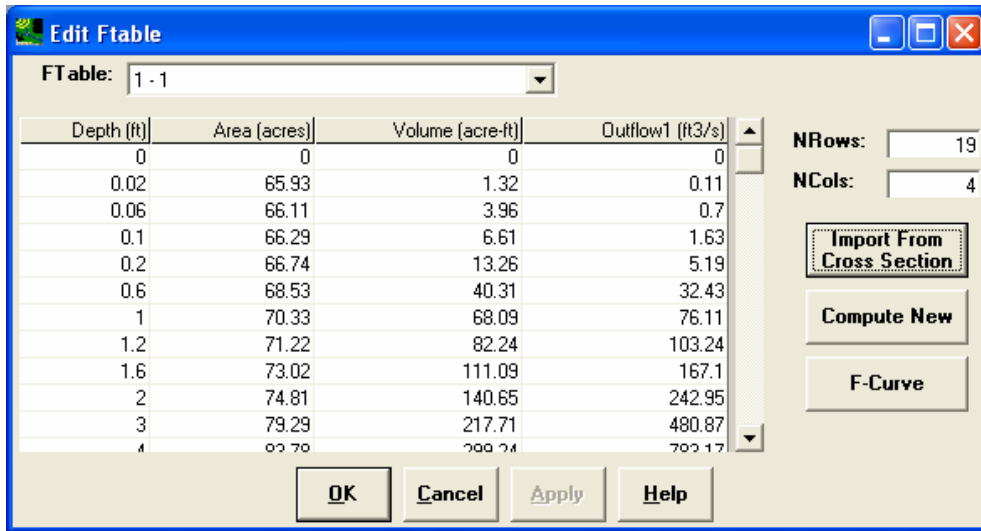
Table 1. Sources and assumptions used in estimating FTABLE parameters with the Standard Method or the Alternative Method.

The HSPF model's hydraulic representation depends on the accuracy of the FTABLE which, in turn, depends on the accuracy of the hydraulic geometry data. The primary hydraulic geometry parameters selected by automatic FTABLE development methods are generally inaccurate but provide functional initial inputs when measured data are not available. The Alternative Method was developed to enhance HSPF's channel hydraulic representation and principally differs from the Standard Method in how it estimates these initial hydraulic geometry parameters. Rather than extracting the initial hydraulic geometry parameters from the reach file, the Alternative Method is based on a set of regional regression equations developed by Mohamoud and Parmar (2006), presented in Appendix A. These equations use power functions to relate a reach's mean flow width and depth to its mean annual streamflow, which is in turn related to the reach's measured drainage area. After estimating these primary geometric parameters, the tool calculates the roughness coefficient by applying Manning's equation using those estimated values. This difference in estimating Manning's roughness coefficient is particularly important. In the Standard Method, Manning's n is set at the same default value for all reaches while in the Alternative Method, each reach has a Manning's n that is tied to its individually measured properties.

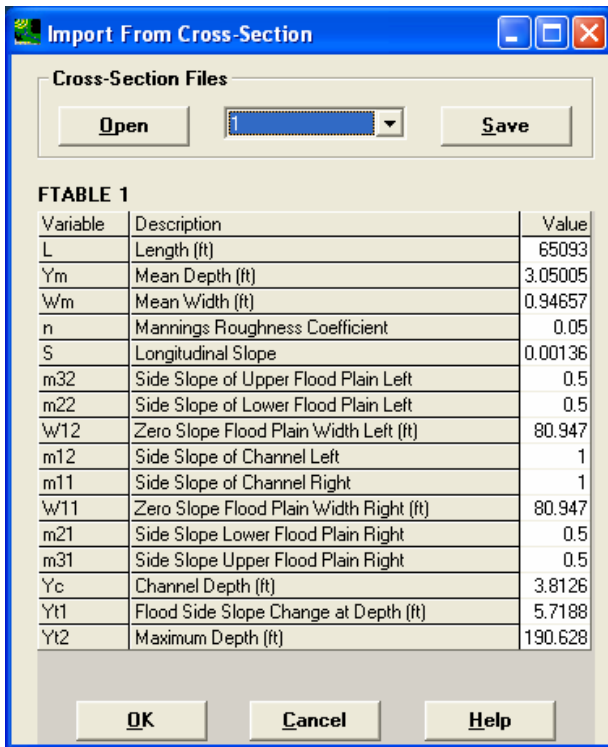
The power functions used in the Alternative Method were developed by regression of observed data from streams in physiographic provinces assumed to have similar landscape characteristics. The provinces represented by these regional regression equations are the Appalachian Plateau, the Ridge and Valley, and the Piedmont provinces of the Mid-Atlantic Region of the United States. These equations, based on localized data, are specific to the areas for which they were developed. They can be applied in other areas with similar topographies, but the uncertainty this extrapolation may lead to has not been quantified.

As with the Standard Method, once the primary hydraulic geometry parameters are set, the Alternative Method derives the channel cross-section by assuming a compound trapezoidal geometry (Figure 3). The default assumptions about the channel and floodplain geometry, however, are somewhat different than in the Standard Method. Both the channel section and the single floodplain section have side slopes of 1.5:1 with additional geometric assumptions as presented in Table 1. The difference in geometric assumptions leads to maximum depths in the Alternative Method that are much lower than in the Standard Method. In some situations such as reservoirs, these depths may not be sufficient and would need to be manually edited. It should also be noted that the parameters entered as "side slopes" in the Alternative Method do not represent the same parameters as in the Standard Method and as represented in Figure 3. The parameters represented in the Alternative Method as the "side slope" are actually the reciprocals of the "side slope" parameters in the Standard Method.

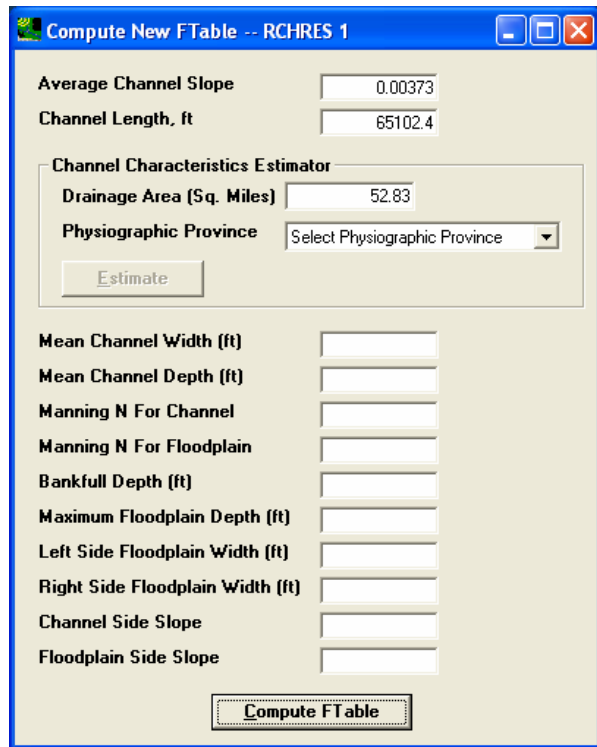
The Alternative Method also includes the option for channel and floodplain sections to have different Manning's n values. Additionally, FTABLEs created by the Alternative Method are of a higher resolution than those created in the Standard Method, with area-volume-flow relationships calculated at smaller depth intervals. Channel surface area,



a) "Edit Ftable" screen; accessed from Reach Editor by clicking "FTables." Click "Import from Cross-Section" to reach screen in (b) or "Compute New" to reach screen in (c).



b) Screen used to import and edit hydraulic geometry parameters for Standard Method FTABLE



c) Screen used to estimate and edit hydraulic geometry parameters for Alternative Method FTABLE

Figure 4. Reach Editor screens used to import and edit FTABLES.

volume, and outflow are calculated for at least twice as many depths as in the Standard Method, still including the zero, mean, bankfull, and maximum floodplain depths.

How to Create and Edit Alternative Method FTABLEs

When a project is originated in BASINS, it will initially be set up with a Standard Method FTABLE. New FTABLEs can be created through the WinHSPF interface (Figure 4a), as follows:

- Select the reach to be edited and access its FTABLE. (Go to Reach Editor screen and click “FTables” button.)
- Click “Compute New” button. The “Compute New FTABLE” window opens with the average channel slope, channel length, and drainage area populated for the current reach (Figure 4c).
- Select Physiographic Province
 - Appalachian Plateau (ruggedly hilly area, mountainous in part and containing dissected plateaus and broad ridges)
 - Blue Ridge & Ridge and Valley (long linear ridges and intervening valleys)
 - Piedmont (low rolling hills and low mountains)
- Click “Estimate” and the table will be populated with hydraulic geometry parameters calculated using the regional regression power functions and the pre-defined geometric assumptions. Edit as appropriate.
- Click “Compute FTABLE” to generate a new FTABLE. Click “Apply” on the FTABLEs screen so that the new FTABLE will be included in the next HSPF run.
- Updated FTABLEs can be created by repeating these steps to edit the geometric parameters after they have been estimated by the tool and before the FTABLE is computed.

HYDRAULIC CALIBRATION

The HSPF model requires that calibration and validation procedures both be applied before running simulations. The model has well-established calibration procedures, beginning with hydrological calibration and followed by sediment calibration and then water quality calibration. In the past, hydraulic calibration was not an integral part of traditional HSPF calibration, in part due to lack of observed hydraulic parameter data and to uncertainties associated with the model’s hydraulic representation – particularly the accuracy of its FTABLE. Along with enhancing the FTABLE, the developers of the Alternative Method have introduced a hydraulic calibration procedure to the overall process.

As described in Mohamoud (2007), comparison of observed and simulated flow velocities is proposed as the new hydraulic calibration procedure. This proposal is based on developing a relationship between an observed hydraulic variable and bed shear stress. Bed shear stress controls the deposition, scour, and transport of silt and clay fractions and so its accurate prediction is critical to instream sediment simulation. HSPF’s calculation

to determine bed shear stress includes the hydraulic radius as an input parameter, and the hydraulic radius is also related to flow velocity through Manning's equation. By eliminating hydraulic radius from both equations, then, flow velocity can be related directly to bed shear stress. Comparison of observed and simulated flow velocities can therefore be used as a measure of the model's accuracy in handling bed shear stress.

A. Hydraulic Calibration Data

Hydraulic calibration can only be performed on reaches that have observed hydraulic parameter data. When available, these data can be downloaded from a USGS gaging station(s) through BASINS 4.0. To download data for parameters DISCHARG, VELOCITY, WIDTH, and XSECT:

- Open the "Data Download" tool under the File menu.
- Select "USGS Streamflow Measurements" and click "Next."
- Click in the "Measurement Site Number" box to bring up list of gaging stations with available data. Select stations from which to download data.
- Specify WDM file in which to include these data and click "Next."

These data can be also be obtained through the USGS Surface-Water Data website at <http://waterdata.usgs.gov/nwis/sw>. After reaching the appropriate page for the gaging station of interest, hydraulic parameter data when available are included in "Available data for this site" under the category "Surface water: Field Measurements." As well as identifying parameters measured, this data source includes information about the dates of data collection.

B. Performing Hydraulic Calibration

Hydraulic calibration should be performed after hydrological calibration and prior to sediment calibration. In WinHSPF, use the Output Manager to specify that the hydraulic parameters (e.g., AVVEL, TWID, and AVSECT) should be included in the model's output. After running the model, WDMUtil or GenScn can be used to compare the observed velocity measurements with the simulated results. If agreement is good, the modeled hydraulic parameters can be accepted and the user can move on to sediment calibration. In cases where the observed and simulated flow velocities differ substantially, the modeler should adjust the hydraulic parameters, such as mean flow width and depth, slope, and roughness coefficients, and generate new FTABLEs to use in rerunning the model. Manning's n values for natural channels may vary from 0.02 for clean and straight reaches to 0.2 for very weedy reaches. For more information about the selection of n values, users may refer to Chow (1959).

REFERENCES

Bicknell, B. R., J. C. Imhoff, J.L. Kittle, and A. S. Donigian, 1996. Hydrological Simulation Program - FORTRAN: User's Manual for Release 11. US EPA.

Chow, V.T., 1959. Open Channel Hydraulics, McGraw-Hill, New York, NY.

Mohamoud, Y. M. and R. S. Parmar, 2006. Estimating Streamflow and Associated Hydraulic Geometry, the Mid-Atlantic Region, USA. Journal of the American Water Resources Association (JAWRA) 42(3):755:768.

Mohamoud, Y.M. 2007. Enhancing HSPF Channel Hydraulic Representation (in press). Journal of the American Water Resources Association (JAWRA).

APPENDIX A – Equations

This Appendix identifies the equations and assumptions used by the automated tools in WinHSPF to populate FTABLEs. An FTABLE is a piecewise linear function table with columns for depth, surface area, volume, and outflow; each row contains values corresponding to a specified water depth. To create this table, both tools discussed in this technical note start by defining values for an initial set of geometric and hydraulic parameters. The tools then calculate surface area, volume, and discharge at various depths using these predefined values along with basic trapezoidal geometry and Manning’s equation for flow.

1. Calculating in-channel FTABLE values

A) Initial Geometric Parameters (sources and default values):

	<u>Standard Method</u>	<u>Alternative Method</u>
Y_m = Mean flow depth	Reach dataset	Regional regression *
W_m = Mean flow width	Reach dataset	Regional regression *
L = Length of reach	Reach dataset	Reach dataset
S = Longitudinal slope	Reach dataset	Reach dataset
m_c = Side slope of channel **	1.0	1.5
n = Manning’s roughness coefficient	0.05	Regional regression *

* Mohamoud and Parmar (2006). Described further in Section 3 below.

** These values represent “m” as depicted in Section 1D. This is the same as the value entered as “m” in the Alternative Method but is the reciprocal of the value entered as “m” in the Standard Method. See Figure 3 for graphic representation of Standard “m.”

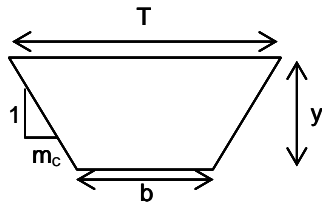
B) Equations for FTABLE parameters:

$SA = L \cdot T$	<i>Where:</i>	$SA =$ Surface Area
$Vol = L \cdot A$		$L =$ Length of reach
$Q = V \cdot A$		$T =$ Width of water surface
		$Vol =$ Volume
		$A =$ Cross-sectional area
		$Q =$ Discharge
		$V =$ Velocity

C) Manning’s Equation:

$V = \frac{c}{n} \cdot \left(\frac{A}{P}\right)^{2/3} \cdot S^{1/2}$	<i>Where:</i>	$V =$ Velocity
		$c =$ Empirical constant; <i>1 for metric, 1.486 for English</i>
		$n =$ Manning’s roughness coefficient
		$A =$ Cross-sectional area
		$P =$ Wetted perimeter
		$S =$ Longitudinal slope

D) *Basic Trapezoidal Geometry:*



$$T = b + 2 m_c y$$

$$A = \left(\frac{T + b}{2} \right) \cdot y$$

$$= by + m_c y^2$$

$$P = b + 2y \cdot \sqrt{m_c^2 + 1}$$

$$b = W_m - 2m_c Y_m$$

because at $y = Y_m$, $T = W_m$

E) *Final Calculations:*

Combining the above equations leads to the following calculations for estimating FTABLE values at in-channel depths. These equations require input of only the initially determined parameters and the depth at which the values are estimated. These equations do not account for unit conversion to acres and acre-feet, as required for SA and Vol to be compatible with FTABLEs.

$$SA = L \cdot (b + 2m_c y)$$

$$Vol = L \cdot (by + m_c y^2)$$

$$Q = \frac{c}{n} \cdot (by + m_c y^2)^{5/3} \cdot (b + 2y \cdot \sqrt{m_c^2 + 1})^{-2/3} \cdot S^{1/2}$$

Where: $b = (W_m - 2m_c Y_m)$

2. Calculating floodplain FTABLE values

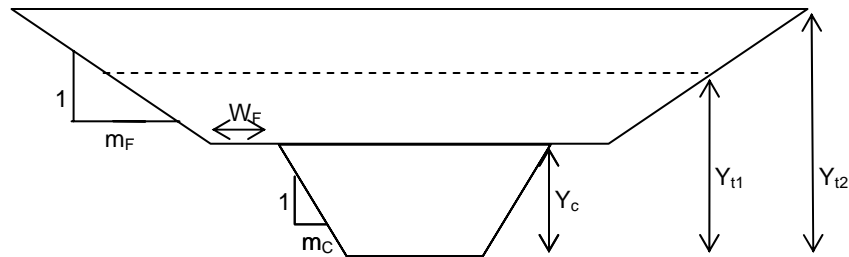
The floodplain FTABLE values are calculated based on the same initial assumptions, equations, and geometry as the in-channel values, but several additional parameters need to be accounted for, as described below.

A) Initial Geometric Parameters (default values):

	<u>Standard Method</u>	<u>Alternative Method</u>
Y_c = Bankfull depth	$1.25 \cdot Y_m$	$5 \cdot Y_m$
Y_{t1} = Floodplain split depth	$1.5 \cdot Y_c$	n/a – floodplain is not split
Y_{t2} = Max floodplain depth	$33.33 \cdot Y_{t1}$ (= $62.5 \cdot Y_m$)	$10 \cdot Y_c$ (= $50 \cdot Y_m$)
W_F = Floodplain width	W_m	W_m
m_F = Floodplain side slope*	2.0	1.5

* These values represent “m” as depicted in Section 2B. This is the same as the value entered as “m” in the Alternative Method but is the reciprocal of the value entered as “m” in the Standard Method. See Figure 3 for graphic representation of Standard “m.”

B) Basic Trapezoidal Geometry:



3. Alternative Method for estimating hydraulic geometry parameters

The Alternative Method calculates initial hydraulic geometry parameters using power equations derived from regression of observed regional data. More information about these equations, presented below, can be found in Mohamoud and Parmar (2006) and Mohamoud (2007). Note that these values are in metric units, so unit conversion in the automated tool is required to obtain results.

<u>Model</u>		<u>Appalachian Plateau</u>	<u>Ridge & Valley</u>	<u>Piedmont</u>
$Q = x DA^y$ (m^3/s)	x	0.043	0.038	0.015
	y	0.850	0.830	0.989
$A = u Q^d$ (m^2)	u	3.26	2.53	3.53
	d	0.67	0.89	0.65
$W_m = a Q^b$ (m)	a	10.21	9.41	11.95
	b	0.48	0.48	0.47
$Y_m = c Q^f$ (m)	c	0.29	0.30	0.28
	f	0.24	2.25	0.22
$V = k Q^m$ (m/s)	k	0.37	0.36	0.35
	m	0.25	0.17	0.25

Manning's
coefficient**

$$n = \frac{0.77(uQ^d)(cQ^f)^{2/3}(S^{1/2})}{xDA^y}$$

* DA = Drainage Area (km^2)

** Uses Manning's equation assuming a parabolic channel shape with a hydraulic radius equal to $0.67 \cdot Y_m$.