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# **BASINS Technical Note 1**

## Creating Hydraulic Function Tables (FTABLES) for Reservoirs in BASINS

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April 2007

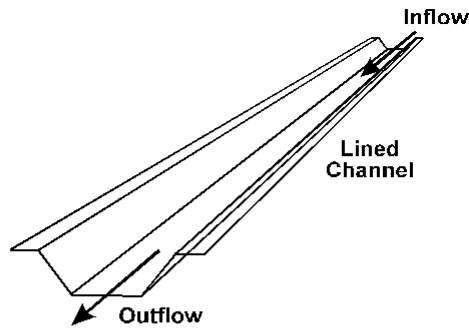
## INTRODUCTION

The HSPF model (Bicknell, et al, 2005) uses a hydraulic function table, called an FTABLE, to represent the geometric and hydraulic properties of both stream reaches and fully mixed reservoirs. When the WinHSPF module of the BASINS program constructs the HSPF User Control Input (UCI) file, it automatically derives the FTABLEs from stream attributes computed during watershed delineation. These stream attributes contain only rudimentary channel characteristics and does not adequately describe the hydraulic behavior of reservoirs. This technical memo describes a procedure that BASINS users can follow to manually create FTABLEs appropriate for reservoirs.

### The FTABLE in HSPF

The FTABLE describes the hydrology of a river reach or reservoir (RCHRES) segment by defining the functional relationship between water depth, surface area, water volume, and outflow in the segment (see Figure 1). The relationship described in the FTABLE is independent of the shape of the reach or waterbody in that waterbodies with different shapes could have the same FTABLE. That is, HSPF makes no assumptions regarding the shape of a stream channel (e.g. that the cross-section be trapezoidal or even that the shape be prismoidal). The assumption of a fixed depth, area, volume, outflow relationship rules out cases where the flow reverses direction or where one RCHRES influences another upstream of it in a time-dependent way. The routing technique falls in the class known as "storage routing" or "kinematic wave" methods. In these methods, momentum is not considered.

The user specifies the properties of a RCHRES in the FTABLE, which is a piecewise linear function table (see Example 1). It has columns for the depth, surface area, and volume, plus up to five columns for volume-dependent outflows. Each row contains values corresponding to a specified water surface elevation. The system obtains intermediate values by interpolation. Thus, the number of rows in the FTABLE depends on the size of the cross section and the desired resolution. The stage-discharge relationship, specified in FTABLE columns, defines volume-dependent outflows. If only time-dependent releases are to be used, then no discharge column is necessary. The HSPF manual (Bicknell et al, 2005) describes several ways to specify more complex outflow situations, such as time-dependent releases, seasonal rating curve variability, and combinations of volume-dependent rule curves with time-dependent release demands.



| Col   | 1     | 2            | 3      | 4        | 5        | 6        | 7        |
|-------|-------|--------------|--------|----------|----------|----------|----------|
| Row # | Depth | Surface area | Volume | F1 (vol) | F2 (vol) | F3 (vol) | F4 (vol) |
| 1     | 0     | 0            | 0      | 0        | 0        | 0        | 0        |
| 2     | 1.5   | 1            | 8      | 12       | 6        | 10       | 0        |
| 3     | 10    | 15           | 80     | 12       | 18       | 10       | 0        |
| 4     | 50    | 100          | 2500   | 12       | 36       | 20       | 20       |

RCHTAB

B) Function table used to specify geometry and hydraulic properties of a RCHRES

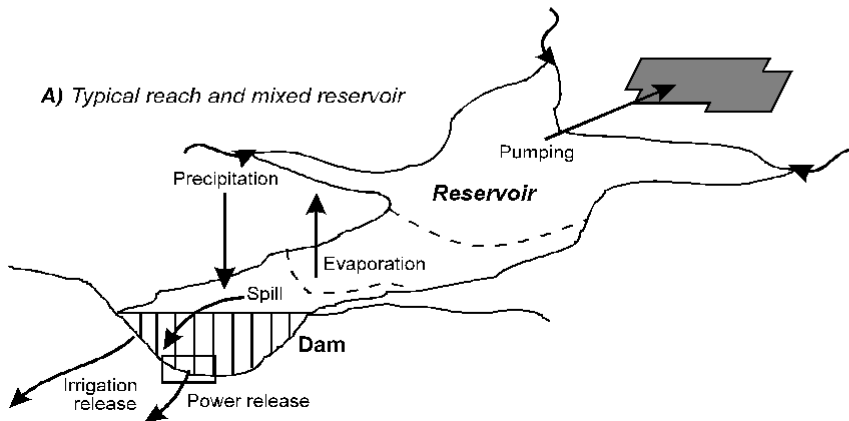


Figure 1. Typical RCHRES configurations and the method used to represent geometric and hydraulic properties

### The FTABLE in WinHSPF

WinHSPF uses a series of four simple text files in creating a new project. These files are intended to be produced using the Model Setup plug-in of BASINS 4.0, accessed through the *Models:HSPF* menu in the BASINS 4.0 GIS interface. Since these four files are text files, they may be built manually. Once a new project (UCI) has been created, these files will no longer be needed by the project. One of these files, called the Channel Geometry File, is used by WinHSPF for computing FTABLES. The Channel Geometry File has a .ptf extension.

The Model Setup plug-in for HSPF writes the Channel Geometry File using the GIS data layers specified through its interface. In that interface the user must specify fields of a GIS layer containing stream attributes including stream length, slope, mean depth, and mean width. In most cases the BASINS user will have computed those values through the process of watershed delineation. Mean width and mean depth are computed during watershed delineation as a function of upstream area. See the BASINS User's Manual for details on the Watershed Delineation tools and the use of the Model Setup plug-in.

WinHSPF automatically creates FTABLEs at the point the UCI is built using data from the Channel Geometry File. WinHSPF assumes a pre-set channel and flood plain geometry and calculates outflow using Manning's equation. The following assumptions are used in computing the channel cross-section geometry (see Figure 2):

- the channel cross-section is trapezoidal
- the channel sides have slopes of 1:1
- the channel depth is 1.25 times the mean channel depth
- the flood plain width, on each side of the reach, is equal to the mean channel width
- the depth at which the flood plain slope changes is 1.5 times the channel depth
- the default slopes of the upper and lower flood plain are 0.5:1
- the maximum depth in the FTABLE is set to 50 times the channel depth

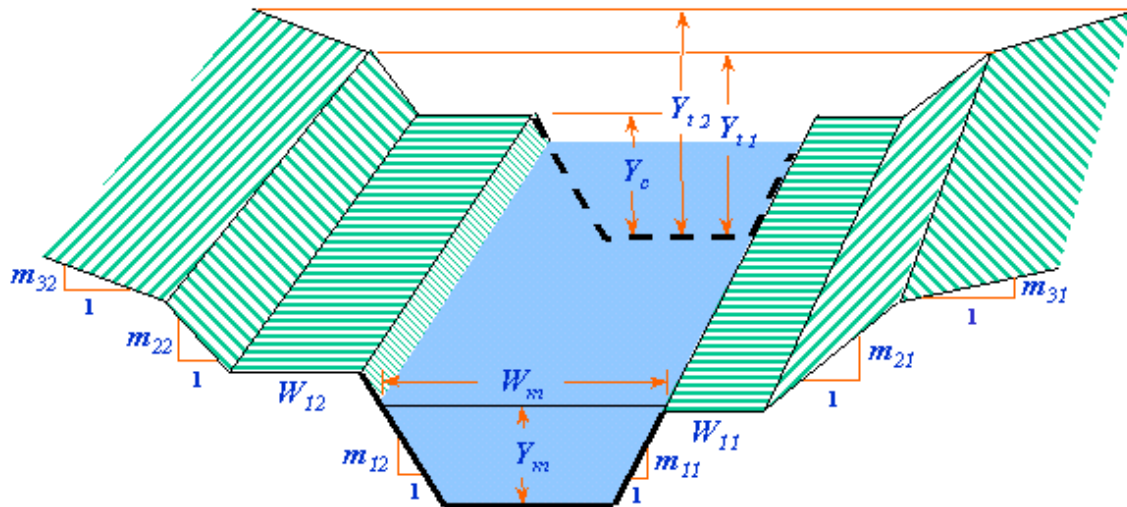


Figure 2. Assumed channel cross-section geometry used in WinHSPF

WinHSPF then uses the above cross-sectional geometry, the Manning's  $n$  and slope, and Manning's equation, to calculate outflow for different depths. The user can specify additional volume dependent outflows by adjusting the FTABLE size and increasing the number of outflows. To change the number of rows or outflow columns in the FTABLE, change the values in the NRows and NCols fields in the WinHSPF FTABLE interface (Figure 3).

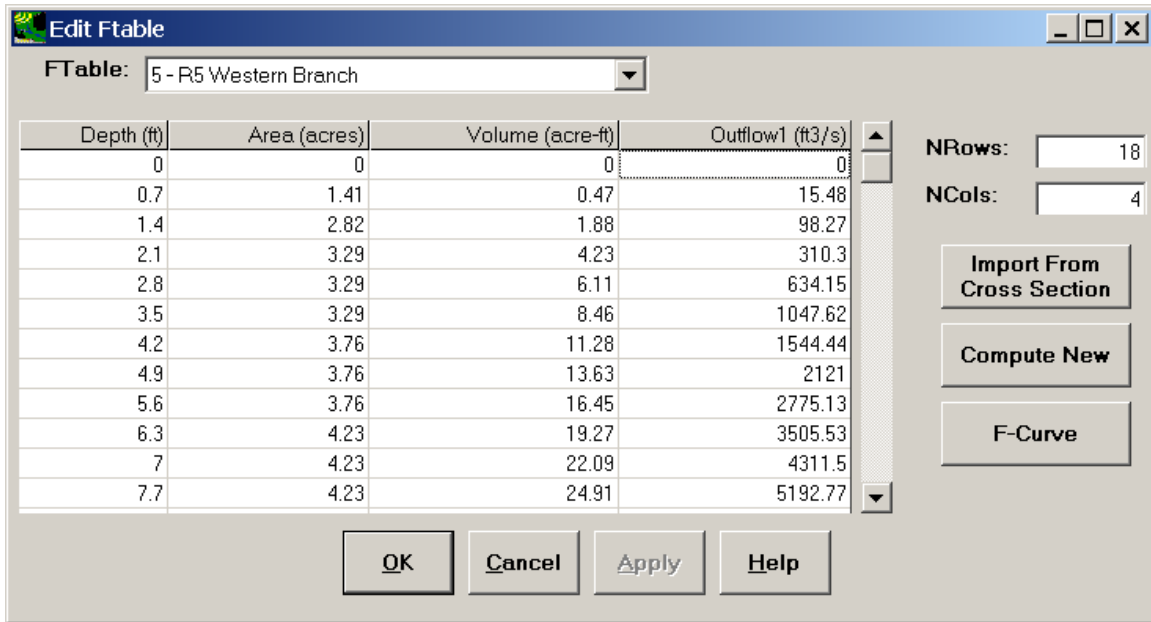


Figure 3. The WinHSPF Interface for Editing an FTABLE

The above FTABLE editing interface can be found within the Reach Editor interface in WinHSPF. The number of reach exits can be changed using the 'NExits' field in the WinHSPF Reach Editor. The 'Import From Cross Section' feature can be used to compute an FTABLE by specifying the full range of geometry measurements shown in Figure 2, enabling a user to override the WinHSPF assumptions of cross-sectional geometry. The 'Compute New' feature provides an alternative mechanism for computing the stream mean width, mean depth, and Manning's roughness coefficient based on physiographic province and drainage area (see technical note #2). See the WinHSPF User's Manual for full details on the use of the WinHSPF Reach Editor.

#### POPULATING RESERVOIR FTABLES IN WINHSPF

The combination of default data and assumptions used in BASINS/WinHSPF provide an inadequate representation of reservoir characteristics; the user instead should manipulate the FTABLE to describe the reservoir. WinHSPF allows the user to edit FTABLEs through the user interface. To edit an FTABLE in WinHSPF, select the FTABLE button from the Reach Editor window, select the reach of interest, and type values in the table.

#### Reservoir Geometry

As described above, FTABLEs describe how outflow, water volume and surface area change as a function of depth in the reach or reservoir (RCHRES) segments. For reservoir segments, the user must obtain data describing the reservoir. Data tables or graphs describing the depth-area and depth-volume relationships are generally available from the agency managing the reservoir. When depth-area and/or depth-volume data not available, a bathymetric map of the lake must be created. Bathymetric methods can be

found in texts such as Welsch, 1948. The surface area can then be calculated from planimetry; the volume of the lake at a given depth is then:

$$V_m = \int_{z=0}^{z=z_m} A_z \bullet dz$$

where  $V_m$  is the volume at depth  $z_m$  of interest,  $A_z$  is the surface area of the lake at depth  $z$ , and  $dz$  is the incremental depth (Hutchinson, 1975).

Tables of depth-area and depth-volume data can be used directly to create the first three columns of the FTABLE. The depth values may be given in terms of stage or elevation rather than depth, in which case the depth is the stage minus the elevation of the deepest point of the reservoir (parameter STCOR in HSPF section HYDR). Additionally, where depths on the depth-area and depth-volume tables do not correspond exactly, the user must interpolate on one table such that the depth, surface area, and volume data are complete for each row in the FTABLE. Graphical data must be linearized by selecting points which define linear sections of the curve, again using the same depth values on both plots. Since HSPF linearly interpolates between rows in the FTABLE, regions of the curve where the slope changes rapidly should be sampled more closely than relatively flat portions. There is an upper limit of 100 on the number of entries (rows times columns) in the FTABLE. Important elevations such as the gate invert and the spillway crest should be among those chosen. Finally, the depth (and therefore storage) for the last row should exceed the highest level ever expected, to prevent HSPF from terminating due to FTABLE exceedance.

### Reservoir Releases

The final step is to add any necessary discharge columns. Historical gage station data is available from the United States National Water Information System (NWIS) data retrieval web page at: <http://waterdata.usgs.gov/nwis/sw>. Methods for measuring stage and discharge is discussed in USGS Circular 1123: Stream-Gaging Program of the U.S. Geological Survey (Wahl, et al, 1995) at: <http://pubs.usgs.gov/circ/circ1123/index.html>.

Up to five outflows may be specified, each of which may be routed to a downstream reach (in HSPF), or may be assumed to leave the system (i.e. a diversion out of the watershed). While HSPF can model two or more reservoir outflows separately (e.g. gate and spillway) and still route them to the same downstream reach, WinHSPF currently is capable of displaying a watershed schematic showing only one exit from each reach. Three examples of UCI modifications for reservoirs follow. Example 1 shows a sample FTABLE for a reservoir. Example 2, below, describes modifications to the UCI file required to route multiple outflows (as defined in the FTABLE) to the downstream reach. Example 3 describes additional UCI file modifications required to route a specific outflow to the downstream reach while allowing other outflows to be removed from the system. The UCI file can be modified in any text editor or through the WinHSPF interface.

EXAMPLES

**Example 1:** The sample FTABLE shown in Table 1 is for a moderate-sized reservoir with two exits. The first three columns were taken from a tabular summary of the stage-area and stage-volume curves. The first discharge column is the rule curve for the gate based on the storage in the reservoir. The second is the spillway rating curve. Both exits will be routed to the same downstream reach (in the NETWORK or SCHEMATIC block in HSPF). The gate invert lies 38 ft above the lowest point in the reservoir, with a dead storage capacity of 1,148 acre-feet. There is no outflow below this elevation. The spillway crest is at 123 feet, giving a total storage capacity of 28,949 acre feet. Remember that the actual elevations of the gate invert and spillway crest are the respective depths plus the stage correction parameter STCOR.

Table 1 - Example Reservoir FTABLE

```

FTABLE      1
ROWS COLS  ***
  14      5
  DEPTH      AREA      VOLUME      GATE      SPILLWAY  ***
  (FT)      (ACRES)    (AC-FT)    (CFS)    (CFS)    ***
    0.0         0.0         0.0         0.00         0.00
    8.0         4.0         17.0        0.00         0.00
   18.0        24.0        143.0        0.00         0.00
   28.0        47.0        491.0        0.00         0.00
   38.0        86.0       1148.0        0.00         0.00
   48.0       132.0       2230.0       100.00         0.00
   58.0       182.0       3791.0       750.00         0.00
   78.0       307.0       8636.0       945.00         0.00
   98.0       504.0      16643.0     1245.00         0.00
  113.0       640.0      24020.0     1450.00         0.00
  123.0       734.0      28949.0     1650.00         0.00
  126.0       810.0      33040.0     1750.00         800.00
  129.0       891.0      37120.0     1850.00        1750.00
  132.0       977.0      41221.0     2000.00        2740.00
END FTABLE 1

```

\*\*\* Note that all lines containing three consecutive asterisks are comment lines, which are ignored by the program. They may be included anywhere in the UCI file, often to assist the user in aligning data fields. Numeric entries are generally right-justified within the field.

**Example 2:** In Table 2, the reservoir is at the base of the containing subbasin between upper and lower reaches of the river. Notice the number of exits (NEXITS) for the reservoir is set to 2. This value, which corresponds to the number of outflows from the reservoir, is specified in the WinHSPF Reach Editor. In the HYDR-PARM1 table of the UCI file, the ODFVFG(2) value for reach 3 (the reservoir) was changed from 0 to 5 to indicate that the fifth column of the reservoir FTABLE should be used to determine its second outflow. Up to three additional outflows could be identified here as necessary. With the above two minor modifications, the model will now remove flow from the reservoir as per the second outflow column in the FTABLE (FTABLE column 5) as well as the primary outflow; the total flow will be routed to the downstream reach.

Table 2 - Modifications to UCI file for Multiple Outflows

*(Original)*

```

GEN-INFO
RCHRES      Name      Nexits  Unit Systems  Printer      ***
# - #<----->>----> User T-series  Engr Metr LKFG ***
              in out
1 Lower River      1    1    1    1    34    0    0
2 Upper River      1    1    1    1    34    0    0
3 Reservoir        2    1    1    1    34    0    1
END GEN-INFO

HYDR-PARM1
RCHRES      Flags for each HYDR Section ***
# - # VC A1 A2 A3 ODFVFG for each *** ODGTFG for each FUNCT for each
              FG FG FG FG possible exit *** possible exit possible exit
1      0 1 1 1 4 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0
2      0 1 1 1 4 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0
3      0 1 1 1 4 0 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0

```

*(Modified)*

```

GEN-INFO
RCHRES      Name      Nexits  Unit Systems  Printer      ***
# - #<----->>----> User T-series  Engr Metr LKFG ***
              in out
1 Lower River      1    1    1    1    34    0    0
2 Upper River      1    1    1    1    34    0    0
3 Reservoir        2    1    1    1    34    0    1
END GEN-INFO

HYDR-PARM1
RCHRES      Flags for each HYDR Section ***
# - # VC A1 A2 A3 ODFVFG for each *** ODGTFG for each FUNCT for each
              FG FG FG FG possible exit *** possible exit possible exit
1      0 1 1 1 4 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0
2      0 1 1 1 4 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0
3      0 1 1 1 4 5 0 0 0 0 0 0 0 0 0 0 1 1 0 0 0

```



**Example 3:** To modify the link to the downstream reach, modify the MASS-LINK block in the UCI file. Table 3 shows the original block for RCHRES to RCHRES connections as well as a modified version that will connect only the first outflow to the downstream reach. The first line in the modified version is the original code commented out with three asterisks at the end of the line. The second line in the modified block indicates that the first outflow (OFLOW, member # 1) from the reservoir (RCHRES 3) should be routed to the inflow (INFLOW) time series for the lower river segment (RCHRES 1). The second flow will then exit the model upon removal from the reservoir. Additional routing options can be found in the HSPF user manual.

Table 3 - Modifications to UCI file to Route Only One Outflow Downstream

*(Original)*

```

MASS-LINK          3
<-Volume-> <-Grp> <-Member-><--Mult-->    <-Target vols> <-Grp> <-Member->   ***
<Name>          <Name> x x<-factor->      <Name>          <Name> x x   ***
RCHRES          ROFLOW                      RCHRES          INFLOW
END MASS-LINK    3

```

*(Modified)*

```

MASS-LINK          3
<-Volume-> <-Grp> <-Member-><--Mult-->    <-Target vols> <-Grp> <-Member->   ***
<Name>          <Name> x x<-factor->      <Name>          <Name> x x   ***
RCHRES          ROFLOW                      RCHRES          INFLOW          ***
RCHRES          OFLOW          1            RCHRES          INFLOW
END MASS-LINK    3

```

Note: The above example shows the changes for the MASS-LINK block. Similar changes would be required for the NETWORK block for a UCI that uses that block to connect operations.

## References:

Bicknell, B.R., J.C. Imhoff, J.L. Kittle Jr., T.H. Jobes, and A.S. Donigian, Jr. Hydrological Simulation Program - Fortran (HSPF). User's Manual for Release 12.2. U.S. EPA National Exposure Research Laboratory, Athens, GA, in cooperation with U.S. Geological Survey, Water Resources Division, Reston, VA, 2005.

Duda, P.B., J.L. Kittle, Jr., M.H. Gray, P.R. Hummel and R.A. Dusenbury. 2001. WinHSPF - An Interactive Windows Interface to HSPF: User's Manual. U.S. EPA Office of Water, Washington DC.

Hutchinson, G. Evelyn. A Treatise on Limnology. Volume I, Part1 - Geography and Physics of Lakes. New York, John Wiley & Sons, 1975.

Wahl Kenneth L., Wilbert O. Thomas, Jr., and Robert M. Hirsch., et al, 1995, Stream-Gaging Program of the U.S. Geological Survey: U.S. Geological Survey Circular 123, Reston, Virginia, 1995 (available on the internet at <http://pubs.usgs.gov/circ/circ1123/index.html>).

Welch, P.S. Limnological Methods. Philadelphia, Blakiston, 381 pp., 1948.