

# **EPA BASINS Technical Note 1**

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

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## INTRODUCTION

The HSPF model (Bicknell, et al, 1996) 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 NPSM module of the BASINS program constructs the NPSM project (.PRJ) file, it automatically derives the FTABLEs from data contained in the reach file (RF1) companion file. Unfortunately, the RF1 data table contains 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, 1996) 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.

## The FTABLE in NPSM

The NPSM automatically creates FTABLEs, using data from the EPA RF1 data table, by assuming a pre-set channel and flood plain geometry and by calculating outflow using Manning's equation. The NPSM extracts the following four values from the BASINS RF1 data table:

- Pdepth - mean channel depth;
- Pwidth - mean channel width;
- Pmann - Manning's n; and
- Pslope - longitudinal slope of the channel.

The NPSM derives the channel cross-section geometry using the Pdepth and Pwidth values along with the following assumptions (see Figure 3):

- the channel cross-section is trapezoidal
- the channel sides have slopes of 1:1
- the channel depth is 1.5 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 100 times the depth of the flood plain slope break

The NPSM then uses the above cross-sectional geometry, the Manning's n and slope from the RF1 table, 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, click on the "Adjust Table Size" button and change the values for "Number of rows" and/or "Number of outflows." Also, change the number of exits in the "Add/Remove Reaches" screen in the reach editor. See also Section 10.4 in the BASINS User's Manual for examples and figures.

The NPSM also allows the user to create FTABLEs manually as one would in HSPF, with the added benefit of being in a Windows interface. For reservoirs, the combination of default data and assumptions used by the NPSM provide an inadequate representation; the user instead should manually input a customized FTABLE to describe the reservoir. Edit the FTABLEs in NPSM by selecting the FTABLE button from the Reach Editor window, select the reach of interest, and type values in the table.

## POPULATING RESERVOIR FTABLES IN NPSM

### Reservoir Geometry

Figure 1 shows a conceptual free-flowing reach and a multi-purpose reservoir. FTABLEs describe how water volume and surface area change as a function of depth in the reach or reservoir (RCHRES) segments. 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:

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

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 the program from crashing.

### 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 Data Retrieval web page (NWIS-W) at: <http://waterdata.usgs.gov/nwis-w/US/>. 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://water.usgs.gov/pubs/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, NPSM currently is capable of simulating only one outflow. All other

outflows defined in the FTABLE are ignored in the NPSM. To work around this, the user can modify the outflow column to include the sum of all outflows. Alternatively, and for more complex flow routing scenarios, the user must modify the HSPF User's Control Input (or UCI) file and run HSPF in dos mode. 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, which can be modified in any text editor, is created upon running the NPSM; NPSM creates the file and then runs the HSPF v. 11 in dos mode using the UCI file as input. NPSM puts the UCI file in the modelout/<proj\_name> sub-directory. The dos version of NPSM (i.e. XNPSM11x.exe) is found in the directory: \BASINS\models\Npsm\.

## EXAMPLES

**Example 1:** The sample FTABLE shown in Table 1 (for HSPF) and in Figure 2 (for NPSM) 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 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 Conemaugh Reservoir is at the base of the Conemaugh basin between upper and lower reaches of the Conemaugh River (from the BASINS tutorial data set). Notice the number of exits (NEXITS) for the Conemaugh Reservoir is set to 2. This value, which corresponds to the number of outflows in the Conemaugh Reservoir outflow, is specified in the NPSM Reach Editor. In the HYDR-PARM1 block, the ODFVFG(2) value for reach 3 (Conemaugh Reservoir) was changed (in the text editor) from 0 to 5 to indicate that the fifth column of the Conemaugh 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  Engl Metr  LKFG***
              in  out
1      Lower Conemaugh      1      1      1      1      34      0      0
2      Upper Conemaugh      1      1      1      1      34      0      0
3      Conemaugh Reservoir    2      1      1      1      34      0      1
END GEN-INFO
HYDR-PARM1
RCHRES      Flags for 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      1  0  0  0  0
2              0  1  1  1      4  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      1  1  0  0  0

```

(Modified)

```

GEN-INFO
RCHRES      Name      Nexits  Unit Systems  Printer      ***
# - #              user t-series  Engl Metr  LKFG***
              in  out
1      Lower Conemaugh      1      1      1      1      34      0      0
2      Upper Conemaugh      1      1      1      1      34      0      0
3      Conemaugh Reservoir    2      1      1      1      34      0      1
END GEN-INFO
HYDR-PARM1
RCHRES      Flags for 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      1  0  0  0  0
2              0  1  1  1      4  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      1  1  0  0  0

```

Note: Any modification to the UCI file should be performed once all NPSM input parameters are set. Modifying the NPSM PRJ file and running the project in NPSM will overwrite the existing UCI file.

**Example 3:** To modify the link to the downstream reach, modify the NETWORK block in the UCI file. Table 3 shows the original block for RCHRES 3 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 Conemaugh Reservoir (RCHRES 3) should be routed to the inflow (INFLOW) time series for the Lower Conemaugh (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)*

```
NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>    #          <Name> # #<-factor->strg <Name>    #    #          <Name> # #    ***
***** INPUT TO RCHRES # 003 *****
RCHRES    3 ROFLOW                                RCHRES    1      INFLOW
```

*(Modified)*

```
NETWORK
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>    #          <Name> # #<-factor->strg <Name>    #    #          <Name> # #    ***
***** INPUT TO RCHRES # 003 *****
RCHRES    3 ROFLOW                                RCHRES    1      INFLOW      ***
RCHRES    3 OFLOW      1                          RCHRES    1      INFLOW
```



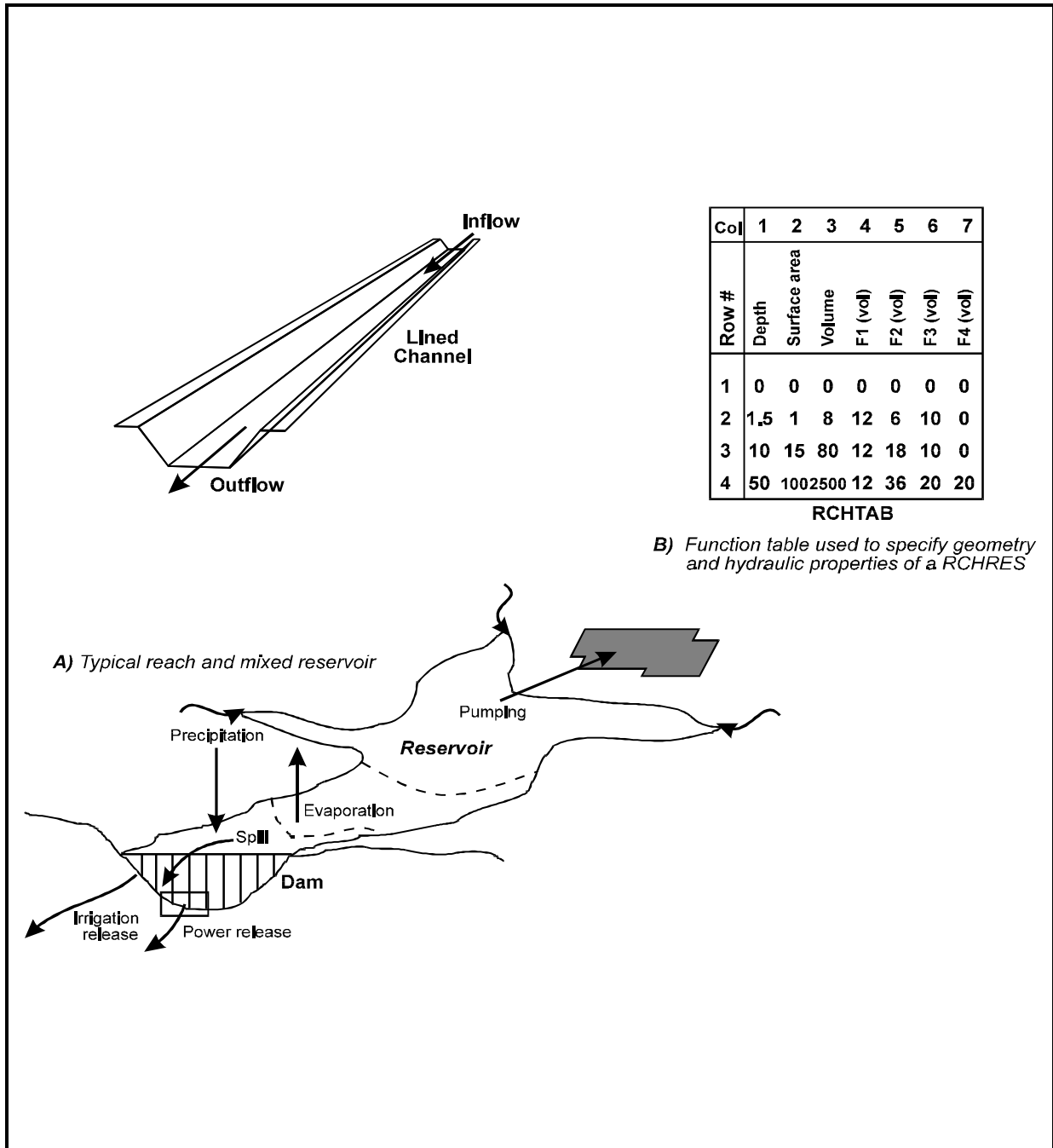


Figure 1. Typical RCHRES configurations and the method used to represent geometric and hydraulic properties

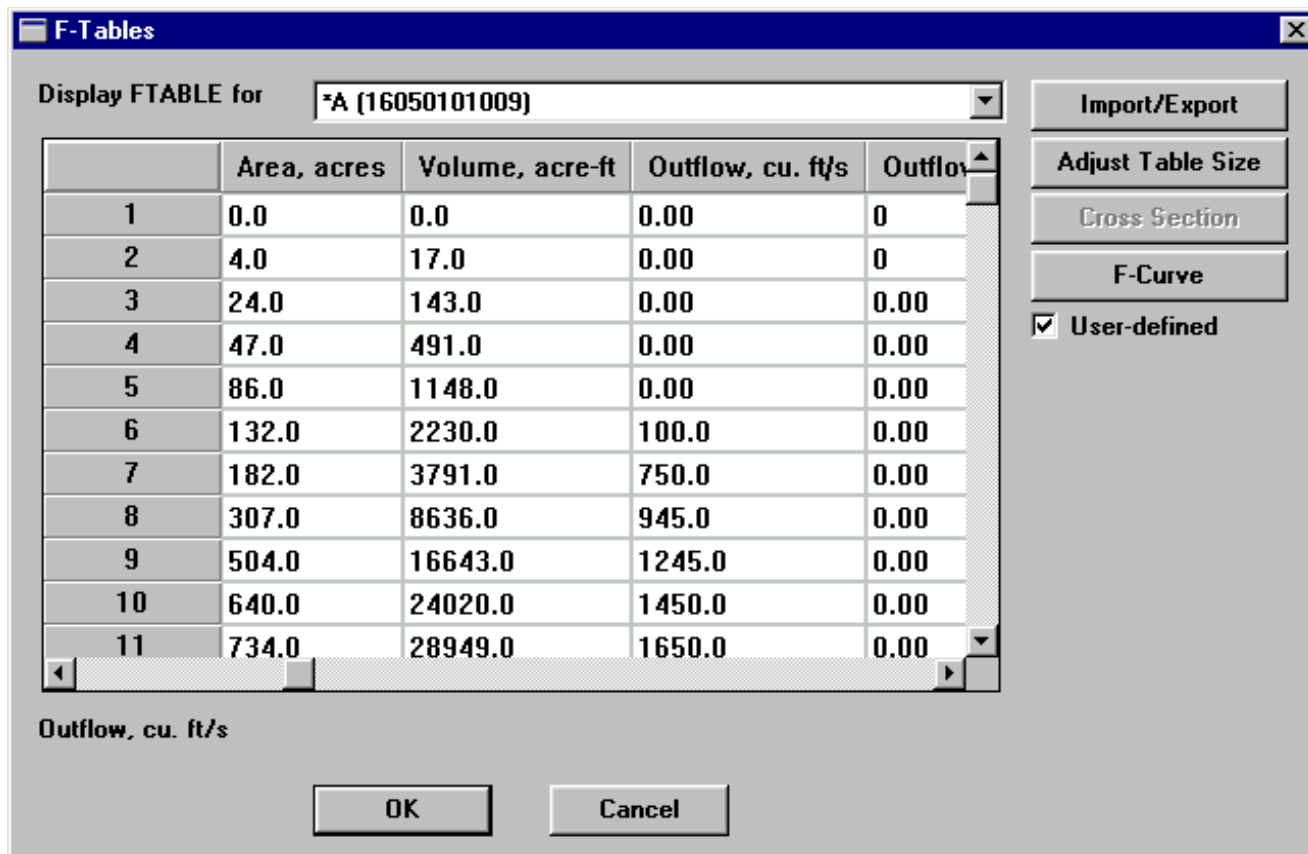


Figure 2. FTABLE in NPSM for Example Reservoir

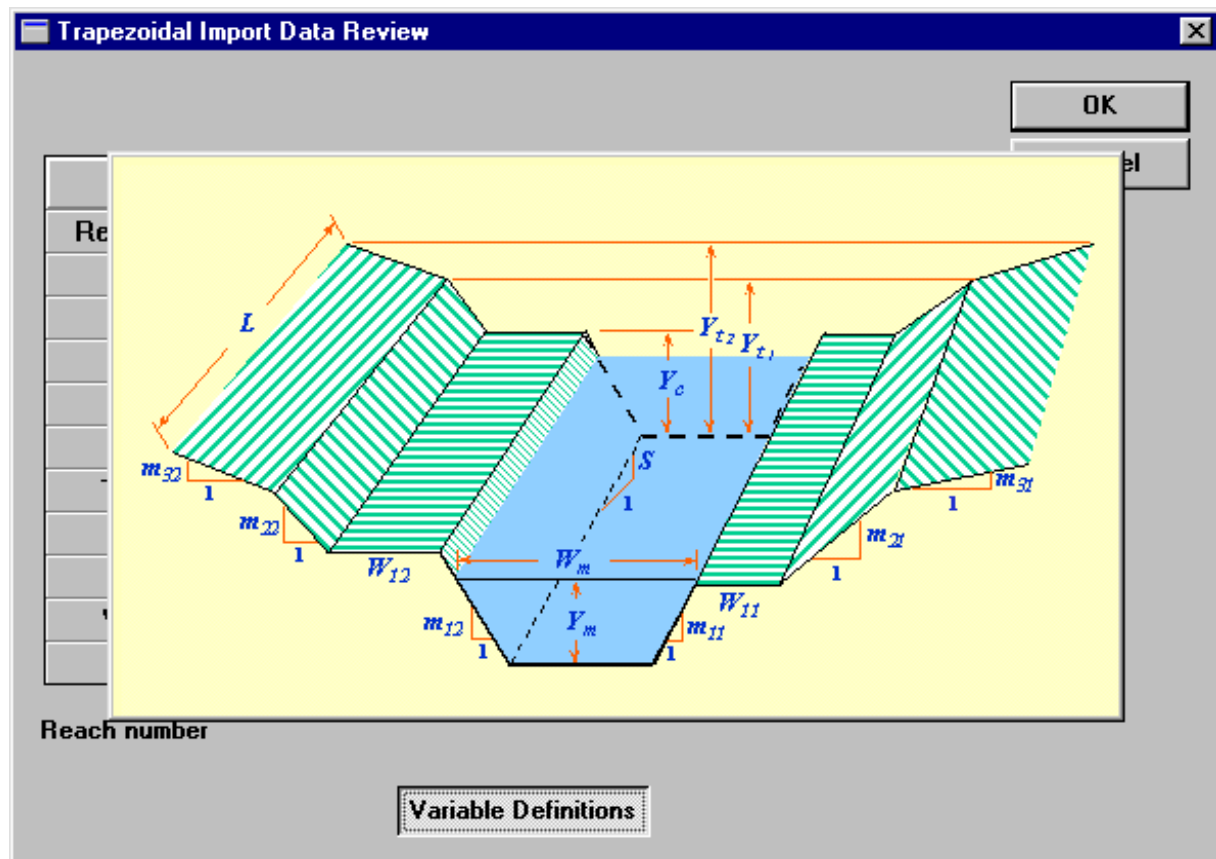


Figure 3. Assumed channel cross-section geometry used in the NPSM

## References:

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

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://water.usgs.gov/pubs/circ1123/index.html>).

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