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SCS WATER SURFACE PROFILE MODEL - WSP2

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Abstract

The Soil Conservation Service (SCS) has revised its mainframe water surface profile model WSP2 and is distributing it as a microcomputer program. WSP2 is used by SCS and others in flood plain management studies and project planning. The model uses the standard step method for computing one-dimensional steady flow profiles for channel and flood plain cross sections and computes backwater at bridges and culverts.

Unique features of WSP2 are described with respect to input data, calculation procedures, user manual, error checking, and output. The use of WSP2 with other SCS hydrologic software is described.

Introduction

The SCS water surface profile model WSP2 was originally developed in the early 1970's. The SCS has historically been involved in flood control projects in small watersheds where a model of this kind was needed. Based on comments of users, the original program was enhanced, numerous error messages and data checks were added, and additional output was made available. It was also converted to operate on microcomputers with IBM or MS-DOS systems. In this paper, various features of the revised WSP2 are described with respect to improved usability and technical documentation.

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The basic energy balance equation for computing profiles used in WSP2 is:

$$z_2 + d_2 + \alpha_2 V^2 / 2g = z_1 + d_1 + \alpha_1 V^2/2g + \text{Energy Losses}$$

Where: z = elevation or datum of channel bottom
d = depth of water at the cross section
V = average velocity at the cross section
g = gravitational acceleration
α = velocity head correction factor
Subscript 1 refers to the downstream cross section and subscript 2 refers to the upstream cross section.
Energy Losses = sum of friction loss, expansion, and contraction losses.

Determination of Friction Loss

The computation of friction loss between cross sections is handled differently in the various water surface profile models. The friction loss in WSP2 is determined by solving the Manning equation for the friction loss using the conveyance at the upstream cross section. In equation form,

$$Sf = (Q / Kd)^2$$

where, Sf = friction slope,
Q = discharge at the upstream cross section, and
Kd = conveyance at the upstream cross section.

$$hf = (Sf) (L)$$

where, hf = head loss due to friction, and
L = distance between cross sections.

The solution of the energy balance equation is a trial-and-error procedure continuing until the upstream and downstream energy balance to within the tolerance of 0.1 foot. Users are recommended to select cross section locations such that the cross section represents the reach to the next downstream cross section. Also recommended is that the Manning roughness coefficient used for the cross section should represent the reach to the next downstream cross section.

One test of the computation of friction loss using various techniques is to compute profiles using different distance steps for reach lengths. The reasoning is that for short distance steps, the profile will be more accurate because the change in water depth and energy grade line will small between cross sections. WSP2 was run with a rectangular section 200 feet wide

with Manning "n" of 0.04, a slope of 0.001 ft/ft, and a discharge of 1200 cfs. Two starting conditions were selected; critical depth and a fixed backwater depth of 4.0 feet. Profiles were computed for a length of 2000 feet. The results of various distance increments are tabulated below.

Depth of Flow at End of Reach (2000 ft.)

Critical Depth start		Fixed Depth start	
Distance Increment (ft)	Depth at upstream end of reach (ft)	Distance Increment (ft)	Depth at upstream end of reach (ft)
50	2.7	50	3.0
100	2.7	100	3.0
200	2.7	200	3.0
500	2.6	500	3.1
1000	2.5	1000	3.1

Depths at intermediate points along the channel were as close as those shown in the table. The results show stability with respect to distance increment. More testing and research are needed on the impact of distance increment on the upstream water depth estimates with changing cross section shape and roughness.

Valley Cross Sections

The shape of each valley cross section can be defined by up to 48 horizontal and vertical coordinates. A cross section can be divided into as many as six segments. A segment represents a part of the cross section with a unique Manning roughness coefficient. Figure 1 shows this feature as applied to a cross section with two channels.

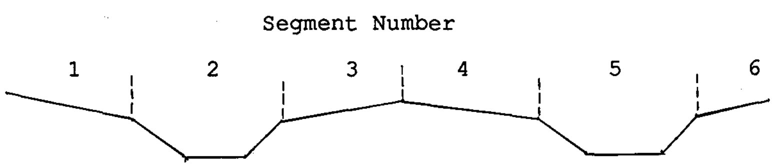

Figure 1. Representation of cross section with two channels

Each segment may be assigned a single Manning "n" or the Manning "n" for any or all segments may vary with hydraulic radius or elevation.

Cross section rating tables may be saved on disk in a format compatible with input to the SCS TR-20 hydrology program (SCS, 1983). These tables may be used in TR-20 for flood routing through valley reaches.

WSP2 may be used to compute water surface profiles for encroached valley cross sections to simulate levees or floodway. Encroachment is the loss of flow area in the overbank portion of the cross section. The user need only input the encroachment distances for each cross section where this type of analysis is desired.

WSP2 is capable of computing flow profiles for subcritical and critical flow. In natural channels and flood plains, most flow conditions are of these types.

Bridges, Culverts, and Road Cross Sections

At any one road cross section, WSP2 can compute head losses through one bridge opening and up to four culvert openings with different configurations. If there is no bridge opening at a road cross section, up to five culvert openings with different configurations can be analyzed. Each of the culvert openings may have an unlimited number of identical barrels. Although one bridge opening along with several culvert openings can be defined for one road cross section, the user should be aware of certain limitations. A single head water elevation is computed which will allow the total discharge to pass through the bridge, culverts, and over the road.

The Federal Highway Administration (FHWA) Hydraulics of Bridge Waterways procedure (BPR method) is one option used to compute bridge head loss (FHWA, 1970). This procedure is based on the energy balance equation applied from the downstream cross section through the bridge opening to the upstream cross section. Data needed for application of this procedure includes physical dimensions (top of road elevations, bridge, piers, and channel under the bridge) and descriptive information (type of abutments, type of piers, and orientation of the bridge with the direction of flow).

A contracted opening procedure is the other option used to compute bridge head loss. This procedure is based upon the ratio of approach area (flow area of the upstream cross section) to bridge opening area and an estimated contraction coefficient (SCS, 1992).

Head losses at culverts are computed using procedures in the FHWA culvert design programs HY-1, HY-2, and HY-3 programs (FHWA, 1969). Circular, pipe arch, and box

culverts may be analyzed. Culvert data needed include diameter, height, length, inlet and outlet invert elevations, top of road profile, and a culvert code which represents the shape, material, inlet type, and roughness condition. The solution of head loss through culverts involves inlet control, outlet control, and a profile through the culvert.

If all flow cannot be carried by the bridge or culverts, flow over the road is computed from a standard weir equation. The weir coefficient is selected by the user. If the tailwater is high enough the weir flow is reduced according to a relationship of downstream to upstream flow depths (a submergence relationship).

Profiles of Tributaries

The user has flexibility in application of WSP2 to any branching stream network (islands or flow diversions are not analyzed). Profiles are computed first for the main stream then profiles for tributaries are started from profile elevations at selected cross sections on the main stream.

Documentation

It is important for engineers who use complicated software to understand how computations are done in order to be able to check questionable results. Bridge and culvert output includes sufficient information to verify the head loss by hand calculation. The equations used for bridge head loss are described in the TR-61 manual and the culvert charts are in various references (SCS, 1972). A sample standard output for a bridge cross section is shown in Figure 2. Sample standard output for a valley cross section is shown in Figure 3.

The program checks input data for errors and has descriptive error messages for program operation problems. These are listed along with possible corrective actions in the TR-61 manual. WSP2 is a public domain program and is available from the National Technical Information Service (NTIS).

The program reads input from a data file prepared by the user. To assist with this file preparation, a menu driven data input program was developed which uses a popular spreadsheet software package.

Summary

WSP2 has been written and adapted to meet the needs of Soil Conservation Service engineers for a model to

compute water surface profiles. The microcomputer program is a practical tool for analyzing watershed hydrology and hydraulics when used in conjunction with other SCS software.

ROAD SECTION CANLST

HW FT	CFS	HL FT	TW FT	STARTING CSM	BRIDGE CFS	BRIDGE AREA SQ FT	CULVERT CFS	CULVERT AREA SQ FT	WEIR CFS
759.90	0.0	0.00	759.90	0.00	0.0	0.0	0.0	0.0	0.0
761.77	228.0	.02	761.75	3.00	215.0	126.5	12.9	15.8	.0
763.38	455.9	.04	763.34	6.00	418.7	244.0	37.3	34.2	.0
765.17	835.9	.08	765.09	11.00	763.0	384.3	72.9	52.7	.0
766.95	1671.8	.18	766.77	22.00	1485.7	532.0	186.1	65.7	.0
770.89	4407.4	.72	770.17	58.00	4066.8	887.7	340.6	67.2	.0
773.56	7978.9	.54	773.02	105.00	4995.8	1066.2	284.6	67.2	2698.4
779.02	17477.5	.34	778.68	230.00	3783.9	1066.2	230.7	67.2	13462.9

Figure 2. Sample output for bridge cross section.

RATING TABLE FOR SECTION 30 DA= 76.1 SQ MI EXP COEF= .30 CONT COEF= .10

ELEV FT	AREA SQ FT	Q CFS	------ACRES FLOODED------- FLOODPLAIN DAMAGE	CHANNEL	TOTAL	CRIT ELEV FT	FRICTION SLOPE FT/FT	FLOW TOP WIDTH FT
750.1	0.0	0.0						
756.1	193.1	240.2	.00	.22	.22	752.2	.00043	47.2
757.8	281.9	480.5	.00	.26	.26	752.9	.00061	55.9
759.7	400.4	880.8	.00	.30	.30	753.8	.00080	66.4
762.9	637.2	1761.7	.00	.39	.39	755.4	.00095	86.0
768.0	1215.5	4644.5	.21	.46	.76	758.9	.00111	165.9
771.6	2390.0	8408.1	1.25	.46	1.86	761.9	.00088	405.2
777.7	5363.2	18417.7	1.74	.46	2.46	767.8	.00048	535.4

Figure 3. Sample output for valley cross section.

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