NATIONAL ENGINEERING HANDBOOK

SECTION 4

HYDROLOGY

CHAPTER 13. STAGE-INUNDATION RELATIONSHIPS

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The economist requires data or curves showing the relation between the area inundated and (1) stage, (2) discharge, (3) flood volume, or (4) frequency. The hydrologist generally provides information on these relations, using data obtained in field surveys by both survey engineers and economists. The party leader chooses one of the above relations according to the problem at hand. The hydrologist, therefore, should learn the specific needs of the economist before determining area-inundated relations.

Stage Versus Area Inundated Methods

Simple cases

This method relates the flooded acres in a stream reach to the stage at either end (or middle) of the reach, usually the downstream end, except when the concordant flow method is used (see Chapter 2). As given to the economist, the stage-inundation relation shows the number of acres flooded at depths selected by the economist.

The simplest case occurs when one cross section is used to represent conditions in a reach. Table 13-1 shows a typical computation of a stage versus total-area-inundated relation for this case.

The acres inundated at selected depths of flooding are computed as shown in table 13-2. Figure 13-1a shows the results as generally given to the economist. Note that the curves of acres flooded at given depth increments can also be obtained directly from the "total acres" curve by use of an engineer's scale.

Complex cases

The computation of this relation becomes more laborious when more than one cross section per reach is used, the labor increasing about in proportion to the number of cross sections to be averaged. The computation also becomes complex if a variable length of reach is used, but this procedure is seldom followed for determining acres flooded. The number of acres flooded at various depths is sometimes obtained by planimetering the areas between flow lines plotted on a map of the floodplain.

Table 13-1. Sample computation of stage versus area inundated, for a simple case using one representative cross section in the reach.

Stage	Cross section top width	Width minus channel width	Inundated area in reach	Remarks
Feet	Feet	Feet	Acres	
4	24	0	0	Bankfull stage
6	92	68	13.5	
8	367	343	68.2	
10	608	584	116.0	
12	786	762	151.2	
14	872	848	168.2	

Column 4 is computed using Column 3 and the valley length of the reach. In this case the reach is 8640 feet long. To get acres, the formula is:

$$\frac{8640}{43560} \text{ (Col. 3)} = 0.1984 \text{ (Col. 3)} = \text{(Col. 4)}$$

Slide rule computations.

Table 13-2. Sample computation of stage versus area inundated at selected depths of flooding.

Stage (Feet)	Total area inundated (Acres)	Acres inundated at given depths 0-2 (Feet)	2-4 (Feet)	4-6 (Feet)	Over 6 1/ (Feet)
4	0	0	0	0	0
6	13.5	13.5	0	0	0
8	68.2	54.7	13.5	0	0
10	116.0	47.8	54.7	13.5	0
12	151.2	35.2	47.8	54.7	13.5
14	168.2	17.0	35.2	47.8	68.2

Values in columns 3, 4, 5, and 6 can also be obtained graphically. See figure 13-1a, and text.

1/ Values in last column are those of Column 2 shifted downward three lines.

When two cross sections per reach are used, and the drainage areas at the sections are not significantly different in size, the sections may be averaged as shown in table 13-3. Determination of acres flooded for given depth increments follows the procedure of table 13-2. When the two cross sections have significantly different sizes of drainage areas, the sections may be averaged as shown in table 13-4, with the procedure of table 13-2 used to get flooding by depth increments. In this case, the inundated acreage has been related to the foot of the reach. The footnote on table 13-3 tells how the acreage may be related to the middle of the reach for that method. The method given in table 13-4 is probably at its best when acreage is related to the foot of the reach, as shown.

In table 13-4, column 3, the corresponding discharges at the upstream cross section have been proportioned using the ratio of the bankfull discharges. This method is applicable when the channels are not excessively eroded or silted. The method of taking the same discharge in csm is sometimes used, but this method ignores the fact that the upstream bankfull discharge in csm is normally greater (for natural channels in noncohesive materials and in an equilibrium condition or nearly so) than the downstream bankfull discharge in csm. In these cases the exact discharges that should be used are those of the same

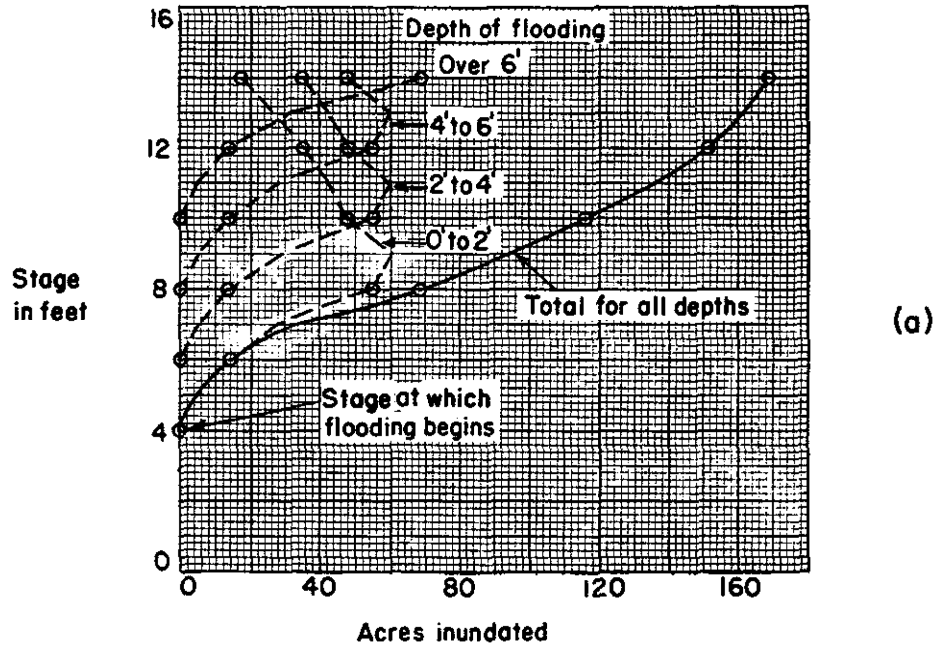

Figure 13-1(a) Area flooded at given depth of flooding increments.

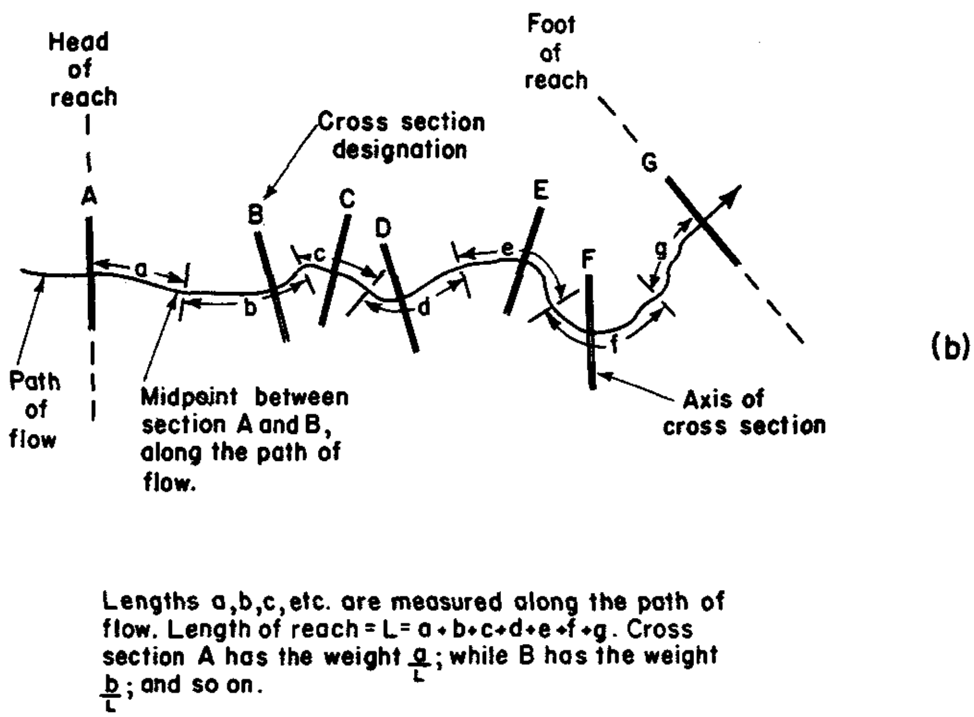

Figure 13-1(b) Flood damage reach showing weighting of area between cross sections.

Table 13-3. Sample computation of stage versus area inundated with two cross sections in the reach (head and foot) and drainage areas not significantly different.

Foot of reach		Head of reach		Areas related to foot of reach 1/			
Cross section 1		Cross section 2					
Stage	Top width	Stage	Top width	Stage	Average top width	Average top width minus channel width	Inundated area in reach 2/
(Feet)	(Feet)	(Feet)	(Feet)	(Feet)	(Feet)	(Feet)	(Feet)
10 3/	41	7 3/	30	10 3/	35.5	0	0
12	168	9	125	12	146.5	111.0	10.7
14	646	11	478	14	562.0	526.5	51.0
16	1070	13	786	16	928.0	892.5	86.5

1/ If related to middle of reach, the stages (col. 5) are 8.5, 10.5, 12.5, and 14.5.

2/ Length of valley in reach is 4230 feet, and

$$\frac{4230}{43560} \text{ (col. 7)} = \text{(col. 8)}$$

3/ Bankfull stage.

Table 13-4. Sample computation of stage versus area inundated with two cross sections in the reach (head and foot), and drainage areas at the sections vary significantly.

Cross section A Foot of reach (D.A.=36.0 sq.mi.)			Cross section B Head of reach (D.A.=24.0 sq.mi.)			Areas related to stages at foot of reach (Cross section A)	
Stage (Feet)	Discharge (cfs)	Top width (Feet)	Discharge (cfs)	Top width (Feet)	Average top width (Feet)	Average top width minus channel width (Feet)	Inundated area in reach (Acres)
10	720 1/	41	680 1/	32	36.5	0	0
12	1510	168	1430 2/	141	154.5	118.0	11.1
14	3060	646	2890 2/	362	504.0	467.5	43.7
16	5030	1070	4750 2/	858	964.0	927.5	87.0

1/ Bankfull discharge.

2/ Proportioned by the bankfull discharge ratio 680/720. For example,

$$\frac{680}{720}(1510) = 1430 \text{ cfs}$$

Length of reach 4080 feet.

frequency. For example, the top width for the 2-year frequency discharge at the upper section is averaged with the top width for the 2-year frequency discharge at the lower section, and so on. When this frequency method is not used and the channel sections vary widely, much accuracy in the averaging should not be expected.

With more than two cross sections, a system of weighting must be used. Figure 13-1b shows a typical reach with seven cross sections on it. The weight for section A is a/L, for section B it is b/L, and so on. Table 13-5 shows a computation using three cross sections. The method of table 13-2 is used to complete the work.

Planimetering method

This procedure can be used either to develop a stage vs. area-inundated relation or to check such a relation developed by other methods.

1. Locate the limits of a selected large recent flood at each cross section on aerial photographs (4-inch to the mile preferred).

2. Using a stereoscope, outline the flood plain for this flood.

3. Lay out and match the photographs, and make a tracing of the floodplain outline. Show the cross section locations and details of land use.

4. Planimeter the area flooded in each reach.

5. Compute the area flooded by using the water surface width at each cross section, for each reach, and multiplying by:

$$\frac{\text{reach length in feet}}{43560}$$

6. Compare the planimetered area with the computed area.

$$C_f = \frac{\text{planimetered area}}{\text{computed area}}$$

7. Compute the area for various other floods, using widths as in Step 5, and assuming the flood plain outline increases and decreases parallel to the outline of the selected recent large flood. Use the correction factor of Step 6, if required.

Table 13-5. Sample computation of stage versus area inundated with three cross sections in the reach and drainage areas at the sections not significantly different.

Cross section 1		Cross section 2		Cross section 3		Related to cross section 1		
Weight = 0.22		Weight = 0.47		Weight = 0.31		Weighted top width	Weighted top width minus channel width	Inundated area in reach
Stage (Feet)	Top width (Feet)	Stage (Feet)	Top width (Feet)	Stage (Feet)	Top width (Feet)	(Feet)	(Feet)	(Acres)
8 1/	42	10 1/	44	7 1/	32	39.8 2/	0	0
10	154	12	250	9	140	194.8	155.0	30.7
12	702	14	540	11	603	595.2	555.4	109.9
14	1100	16	832	13	948	926.9	887.1	175.5

1/ Bankfull stage. Widths at this stage are channel widths.

2/ 39.8 = 0.22 (42) + 0.47 (44) + 0.31 (32). The weights are in proportion to total reach length as shown on figure 13-1b.

Length of reach = 8620 ft.

8. Plot area flooded versus stage at the selected cross section.

9. Determine areas flooded at required depth increments (table 13-2).

Other methods involving planimetering are sometimes useful. For example, flood lines for each of several floods may be used to define inundated areas on aerial photos, which are planimetered and related to stage or runoff or frequency. Generally, lack of data on the location of the flood lines of historic floods limits the application of this and similar methods.

Flood Peak or Volume Versus Area Inundated Method

This method is generally used with alluvial fan floods, although it can also be used instead of the stage methods described above.

1. Make field interviews (the economist usually does this) to determine the areas flooded, for as many floods as possible.

2. Determine actual or estimated flood peak or volume for each flood, using a cross section or gage upstream from the fan as a reference point.

3. Plot the flooded area, in acres, versus the flood peak or volume for each flood, using arithmetic paper. Draw the relation between area and peak or volume.

Once the relation is determined, the effects of upstream projects can be computed in terms of runoff. A reduced runoff means a reduced area flooded. When a channel system within the fan is proposed for reducing flooding, hydrographs are prepared at the upstream section or gage and routed downstream.

Frequency Versus Area Inundated Method

This method is sometimes used instead of the methods described above. It is applicable to both stream reaches and alluvial fans.

1. Determine the area flooded for all known floods by field interview. The earliest known flood determines the length of record, y.

2. Array the "area flooded" values in order of size, the largest first.

3. Refer to Chapter 18 to get frequency plotting positions and tabulate these next to the array for convenience in plotting.

4. Arrange arithmetic graph paper with convenient scales for "area flooded" on the vertical axis and plotting positions on the horizontal axis.

5. Plot the "area flooded" values versus their plotting positions. The point for zero area is determined by field studies.

6. Draw the frequency versus area curve. The area under the curve divided by y gives the average area flooded.

A major objection to this method is that the dollar damage per acre may vary greatly from flood to flood. In such cases, it is more accurate to use a damage-frequency curve.