APPENDIX C

STORAGE INDICATION METHOD OF ROUTING

The following flood routing procedure has been developed for the purpose of utilizing storage to derive inflow-outflow hydrograph relationships. Refer to the National Engineering Handbook, Sec. 4, Hydrology, Chapter 17 for more details.

A sample problem of a dam to design the principal and emergency spillway is used for the purpose of illustration.

Stage-Storage Table - Figure C-1

This table is obtained from topography of the damsite. The damsite must be topographically surveyed to include storage to the top of the dam.

Stage-Storage Curve - Figure C-2

Figure C-2 is the Stage (Elevation) vs. Storage Curve. This curve is obtained by plotting Col. 1 vs. Col. 7 on Figure C-1.

Data Sheet for Principal Spillway Hydrograph

Inflow Hydrograph - Figure C-3

The Inflow Hydrograph is plotted from data developed from previously described procedures. (See Chapter 6)

Typical Section - Figure C-4

The Typical Section shown on Figure C-4 shows the berms (if any), side slopes, estimated top elevation of embankment, top width, crest elevation of the principal spillway, and the assumed pipe size and length. The crest elevation of the principal spillway is determined by the purpose of the dam. The crest of the principal spillway may be set to provide a minimum depth of water or a minimum volume of permanent storage in the reservoir. After some experience, an estimate of the pipe size and length becomes less difficult. The actual flood routing determines the minimum acceptable elevation of the emergency spillway. If this elevation does not provide sufficient flow depth and freeboard to the assumed top of the dam, adjustments must be made in the pipe size, emergency spillway capacity, the top elevation of the dam if topography permits, or a cominbation of these.

Stage Discharge Data Sheet - Figure C-5

This data sheet as used shows four flow conditions; weir flow, pipe flow, orifice flow at the crest of the riser, and orifice flow at the entrance to the barrel.

Data for the riser and hydraulic design are taken from the North Dakota supplement to the Engineering Field Manual and from Kings Handbook.

Data for this table should go beyond the actual limitations so that when the Stage Discharge Curve (Figure C-6) is plotted, the controlling flow is indicated where the lines intersect.

Stage Discharge Curve - Figure C-6

From Fig. C-5, plot Col. 1 and Col. 8, for weir flow, plot Col. 1 and Col. 11, for pipe flow, and plot of Col. 1, Col. 3, and Col. 5 for orifice flow. Where the lines intersect is the change from weir flow to orifice flow to pipe flow.

Storage Indication Data Sheet Figure C-7

The Storage Indication Data Sheet is used to change the net flood storage in acre-feet to cfs, so that storage, inflow, and outflow are compatible (cfs) for the selected time interval ($\Delta\tau$ = 0.5 hrs.). The selected time interval should adequately represent the hydrograph. An explanation of each column is as follows:

Col. 1 is the elevation column. The first elevation is the elevation at the crest of the principal spillway. Sufficient elevations are to be taken between the crest of the principal spillway and the crest of the emergency spillway to give adequate coverage of the available storage. An elevation above the crest of the emergency spillway is taken for an extension of the curve.

Col. 2 is the net storage in acre-feet at each selected elevation in Col. 1. To obtain the net storage, the storage below the crest of the principal spillway is subtracted from the storage for each succeeding elevation. In this example the storage at Elevation 87.0 is 412 acre-feet. Thus, 412 acre-feet then becomes zero (0) storage and 412 acre-feet must be subtracted from the storage for each succeeding elevation to obtain the net storage. All storage below Elevation 87.0 is considered dead storage and is not used in the routing procedure.

Col. 3 is the conversion of Col. 2 from acre-feet to cfs for the selected time interval ($\Delta\tau$). In this example, $\Delta\tau$ = 0.5 hours is selected and the conversion factor is 24.2. (Table 5) The conversion factor is multiplied by each item in Col. 2 to convert to cfs. The conversion factor is explained in Table 5 of Figure C-7.

Col. 4, Outflow in cfs, is obtained by reading the outflows from the Stage Discharge Curve (Figure C-6) opposite the appropriate elevation in Col. 1 (Figure C-7).

Col. 5 is Col. 4 divided by 2.

Col. 6 is a total of Col. 3 and Col. 5 to arrive at $\frac{S}{\Delta\tau} + \frac{0}{2}$ as demanded by the routing equation.

Storage Indication Curve - Figure C-8

Plot Col. 6 and Col. 4, Figure C-7. A small circle should be made on the curve at the $\frac{S}{\Delta\tau} + \frac{0}{2}$ data opposite Elevation 91.0 which is the estimated emergency spillway elevation. A dashed line beyond this point is desirable because during the routing procedure any readings beyond the circle indicates emergency spillway flow.

Routing Data Sheet - Figure C-9

Col. 1 indicates the time interval that was previously selected when making up the Storage Indication Data Sheet (0.5 hrs., Figure C-7). This time increment must always be the same throughout the routing procedure once selected.

Col. 2 is the average inflow (I_{av}) for the time interval of Col. 1. The values for this column are obtained from the Inflow Hydrograph (Figure C-3). This is the average inflow (I_{av}) as shown in the general equation.

Col. 4 is the associated outflow from the routing equation. The value is read from the storage indication curve, Fig. C-8

The general equation in one form is

$$I_{av} + \left(\frac{S_1}{\Delta\tau} - \frac{0_1}{2}\right) \quad \left(\frac{S_2}{\Delta\tau} + \frac{0_2}{2}\right)$$

The equation is satisfied for each time interval. Since $\left(\frac{S_1}{\Delta\tau} - \frac{0_1}{2}\right)$ equals the storage factor at beginning of time interval, by adding I_{av} (average inflow) we obtain the storage factor at the end of the time interval $\left(\frac{S_2}{\Delta\tau} + \frac{0_2}{2}\right)$, if we disregard outflow. We must however, take into consideration outflow. For each $\left(\frac{S_2}{\Delta\tau} + \frac{0_2}{2}\right)$ there is associated outflow. This associated outflow is subtracted from $\left(\frac{S_2}{\Delta\tau} + \frac{0_2}{2}\right)$ to give the initial storage $\left(\frac{S_1}{\Delta\tau} - \frac{0_1}{2}\right)$ for the next time interval.

In the example the equation for the first time increment is satisfied thus:

$$I_{av} + \left(\frac{S_1}{\Delta\tau} - \frac{0_1}{2}\right) \quad \left(\frac{S_2}{\Delta\tau} + \frac{0_2}{2}\right)$$

$$50 + 0 = \left(\frac{S_2}{\Delta\tau} + \frac{O_2}{2}\right)$$

From Fig. C-8, outflow = 2 cfs when $\left(\frac{S_2}{\Delta\tau} + \frac{O_2}{2}\right) = 50$

The routing is carried past the point of maximum outflow. The routing can be carried out further depending on the individual desires.

The assumptions for the pipe size and net storage requirements are checked as follows:

From Col. 4 (Figure C-9) select the largest $\frac{S_2}{\Delta\tau} + \frac{O_2}{2}$. In this example, 6334 is the largest. Opposite this number in Col. 5 the maximum outflow is 143.

$$\left(\frac{S_2}{\Delta\tau} + \frac{O_2}{2}\right) = \frac{S_2}{\Delta\tau} + \frac{143}{2} = 6334$$

$$\frac{S_2}{\Delta\tau} = 6262$$

Convert $\frac{S_2}{\Delta\tau}$ to acre-feet as shown in Table 5, Figure C-7.

Dividing 6262 by 24.2 (for $\Delta\tau$ of 0.5 hrs.) is 258.8 acre feet of net storage used. To obtain the elevation for 258.8 acre feet, add the 412 acre feet, which was originally subtracted as dead storage for 670.8 acre feet. From the Stage Storage Curve (Figure C-2) for 670.8 acre feet, read elevation 94.5. This is 3.5 feet higher than the 91.0 elevation (E.S.) which was originally selected. If there is a large difference in elevation between the selected elevation and the routed elevation, you may wish to increase the pipe size or raise the elevation of the emergency spillway. It may be necessary to do both.

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Formerly ND-178)

U.S. Department of Agriculture
Soil Conservation Service

STORAGE CAPACITIES OF DAM SITE

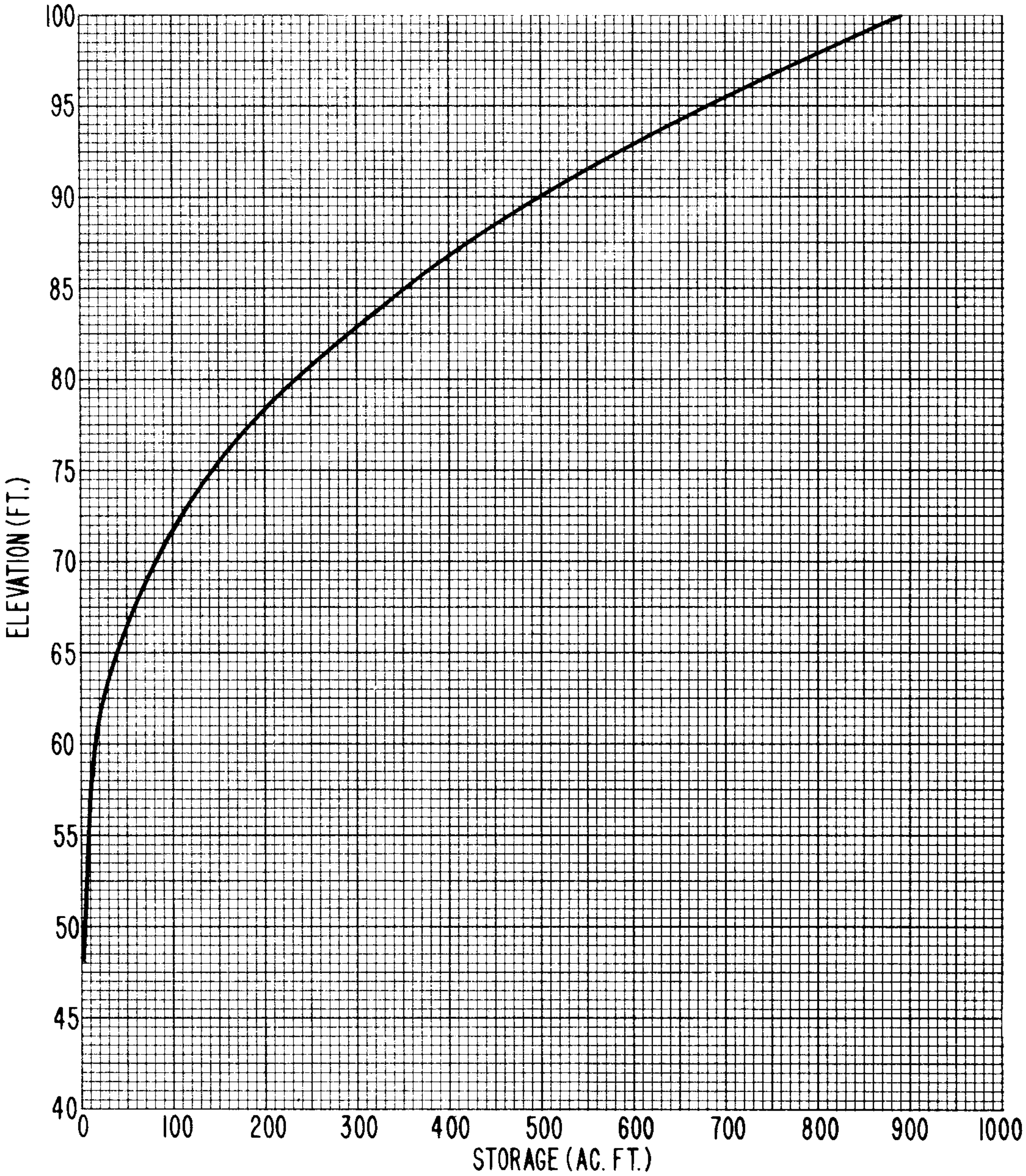
Site No. or Name Fish Dam **Watershed or County** Williams

Calculations By C. A. C. **Date** 4/26/68

Checked by: R. D. S. **Date**

1	2	3	4	5	6	7
Elev.	Area, Sq. In.	Acres	Sum of Acres 2	Contour Interval	Acre Feet Product Columns 4x5	Accumulative Acre Feet
48.10	0.00	0.00				0.00
			0.150	1.90	0.29	
50.00	1.30	0.30				0.29
			1.475	10.00	14.75	
60.00	11.50	2.65				15.04
			6.475	10.00	64.75	
70.00	44.80	10.30				79.79
			15.705	10.00	157.05	
80.00	91.80	21.11				236.84
			25.815	10.00	258.15	
90.00	132.70	30.52				494.99
			39.520	10.00	395.20	
100.00	210.95	48.52				890.19

FIGURE C-1



FISH DAM
STAGE-STORAGE CURVE

FIGURE C-2

FISH DAM

Inflow Hydrograph 4% Chance (25 yr.)

T_c = 2.0

CN = 71

D.A. = 6.4 Sq. Mi.

q_x = 120 cfs/Sq. Mi./In.

Rainfall = 3.46 4% Chance (25 yr.)

Runoff = 1.03"

q = 120 cfs/Sq. Mi./In. x 6.4 Sq. Mi. x 1.03" = 791 cfs

$T_p = \frac{484}{120} = 4.03$ hrs.

$T_b = 2.67 \times 4.03 = 10.76$

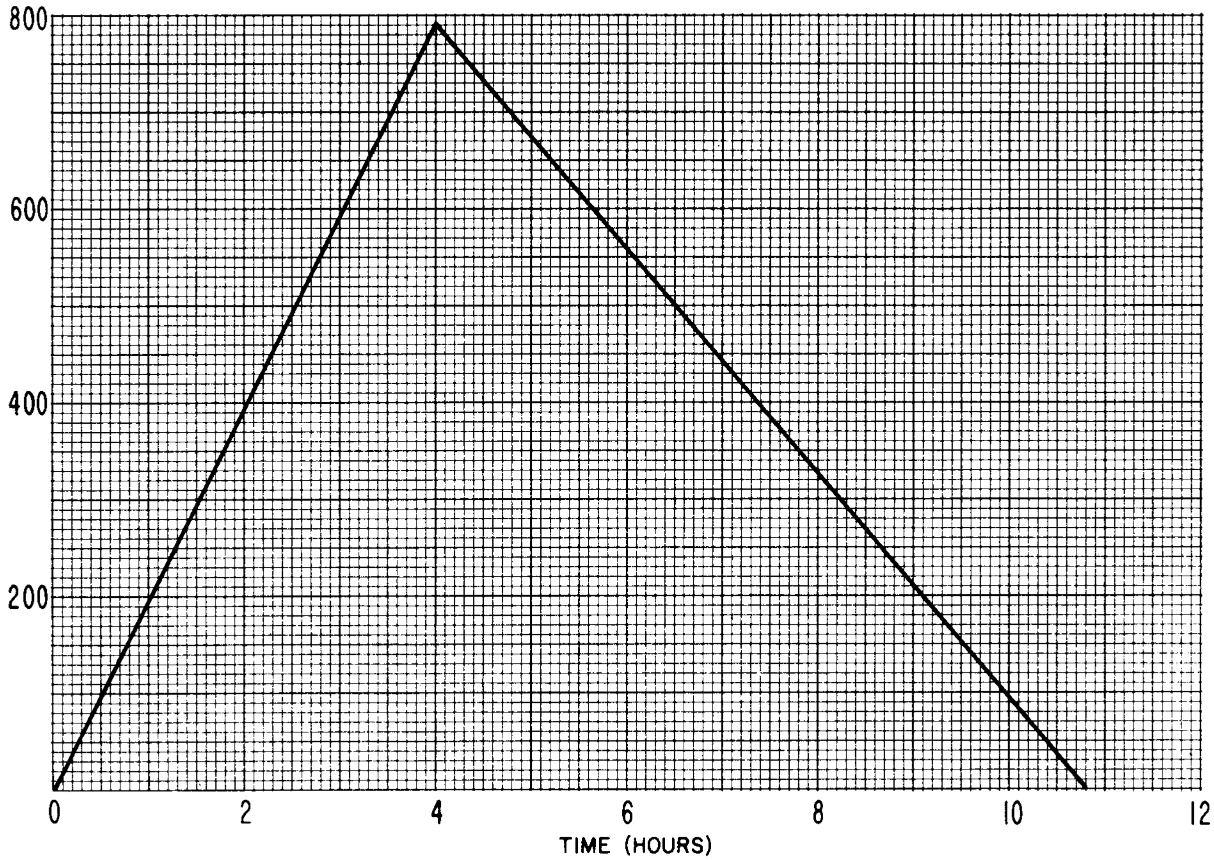
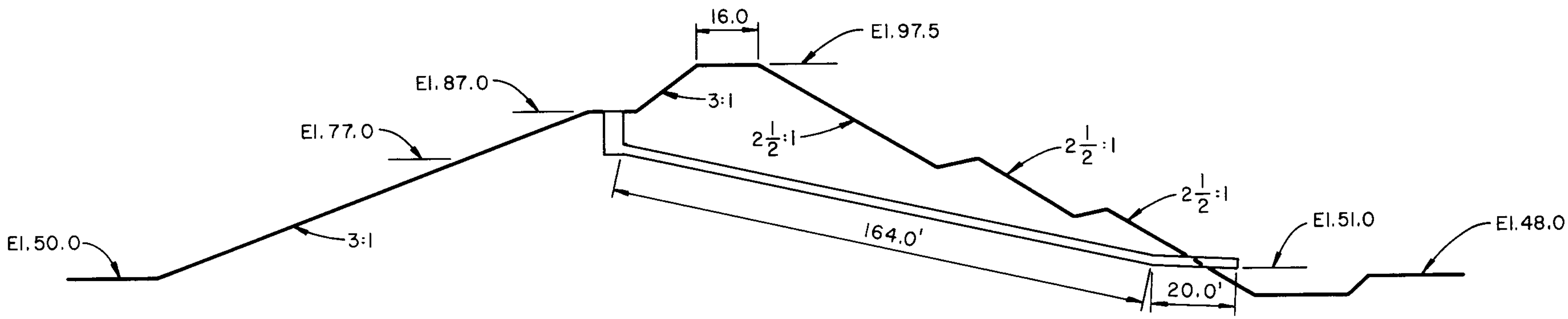


FIGURE C–3

Note: In this example, a triangular hydrograph is used for simplification. Design hydrographs can be obtained from Chapter 6.



TYPICAL CROSS SECTION OF DAM
(NOT TO SCALE)

FISH DAM

FIGURE C-4

State		Project	
North Dakota		Fish Dam	
By	Date	Checked By	Date
R.D.S.	6-3-68	C.R.J.	6-5-68

Subject

FINAL DESIGN

Outflow Tables 48" X 36" CMP Drop Inlet

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11	Col. 12
Elv.	H_{or}	q_{or}	H_{op}	q_{op}	H_w	H_w 3/2	q_w*	H_p	H_p 1/2	q_p	q_t
87.0	0		8.5	0	0	0	0.0	34.5	5.87	129.76	0
88.0	1		9.5	127.8	1.0	1.0	41.82	35.5	5.95	131.53	41.82
89.0	2		10.5	134.3	2.0	2.828	118.27	36.5	6.04	133.52	118.27
90.0	3	125.5	11.5	140.5	3.0	5.196	217.30	37.5	6.12	135.29	125.50
91.0	4	145.2	12.5	146.5	4.0	8.000	334.60	38.5	6.20	137.06	137.06
92.0	5	162.3	13.5	152.3	5.0	11.180	467.50	39.5	6.28	138.83	138.83
93.0	6	177.8	14.5		6.0	14.700	614.80	40.5	6.36	140.60	140.60
94.0	7	192.1	15.5		7.0	18.520		41.5	6.44	142.36	142.36
95.0	8	205.3	16.5		8.0	22.630		42.5	6.51	143.91	143.91
96.0	9	217.8	17.5		9.0	27.000		43.5	6.59	145.68	145.68
97.0	10				10.0	31.620		44.5	6.67	147.45	147.45
98.0	11							45.5	6.74	149.00	149.00
99.0	12							46.5	6.81	150.54	150.54
99.5								47.0	6.856	151.56	151.56
100.0	13							47.5	6.89	152.31	152.31

Elv. ℄ Outlet = 52.5
Elv. Base Riser = 77.0
L. = 190' A_B = 7.07 = Area of barrel

Four conditions to check: Orifice Flow at Inlet to Riser, Orifice Flow Inlet of Pipe, Weir Flow and Pipe Flow.

*No reduction in weir length due to headwall has been made in this example. See note on Fig. 3S.3 in the "North Dakota Supplement to the Engineering Field Manual."

FIGURE C-5

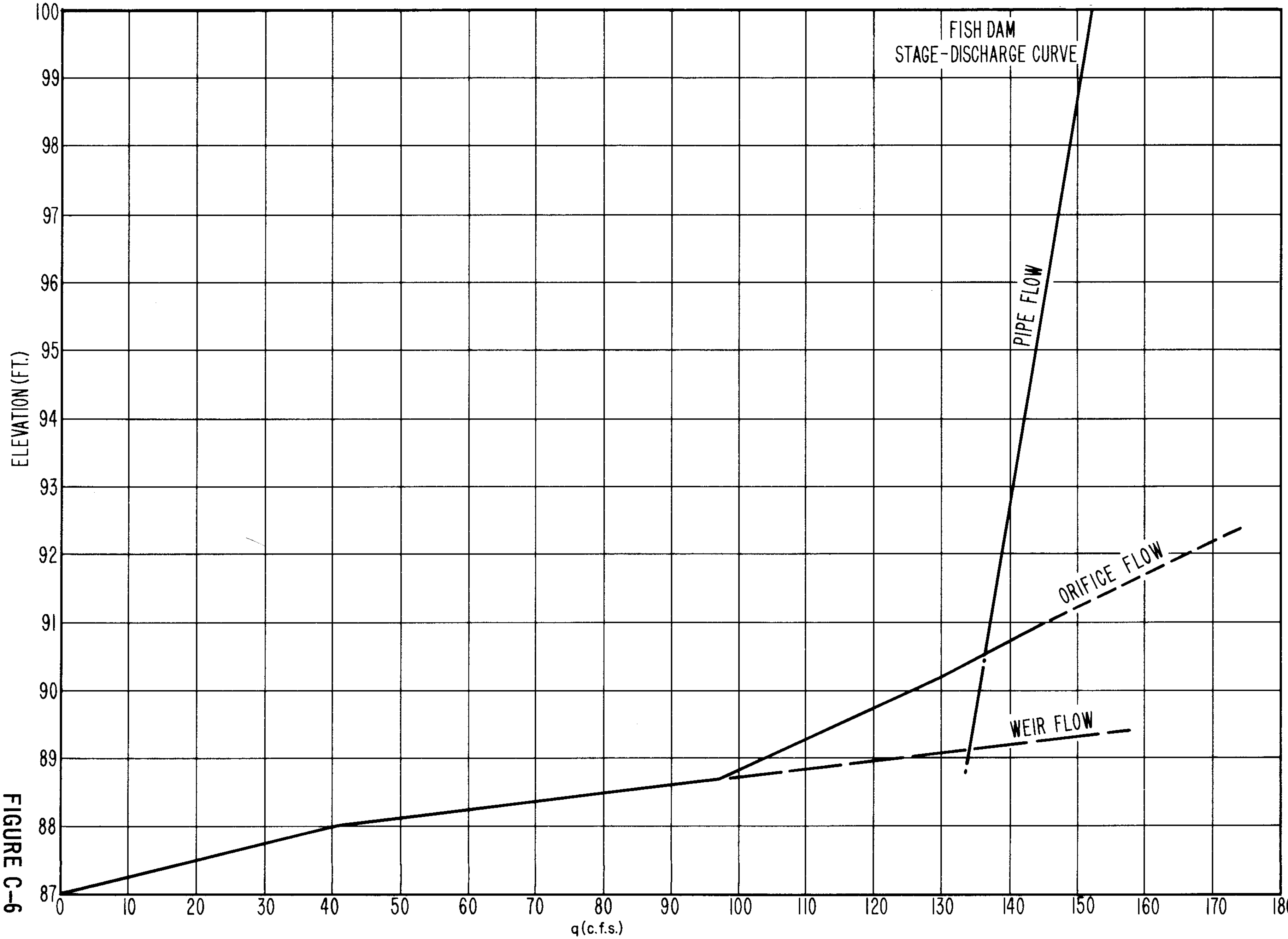

FISH DAM
STAGE-DISCHARGE CURVE
PIPE FLOW
ORIFICE FLOW
WEIR FLOW
ELEVATION (FT.)
q (c.f.s.)
100
99
98
97
96
95
94
93
92
91
90
89
88
87
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180

FIGURE C-6

Figure C-7

State North Dakota		Project Fish Dam	
By R.D.S.	Date 6-3-68	Checked By C.R.J.	Date 6-5-68
Subject FINAL DESIGN			

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6
Elv.	St.	S/Δt	0	0/2	S/Δt + 0/2
87.0	0	0	0	0	0
88.0	28.0	678.00	41.82	20.91	699
89.0	63.0	1524.00	102.30	51.15	1575
90.0	82.99	2008.00	125.50	62.75	2071
91.0	128.00	3098.00	137.06	68.53	3167
92.0	158.00	3824.00	138.83	69.42	3893
93.0	198.00	4792.00	140.60	70.30	4862
94.0	238.00	5760.00	142.36	71.18	5831
95.0	278.00	6728.00	143.91	71.96	6800
96.0	313.00	7575.00	145.66	72.84	7648
97.0	353.00		147.45	73.73	
98.0	393.00		149.00	74.50	
99.0	438.00		150.54	75.27	
100.0	478.00		152.31	76.16	

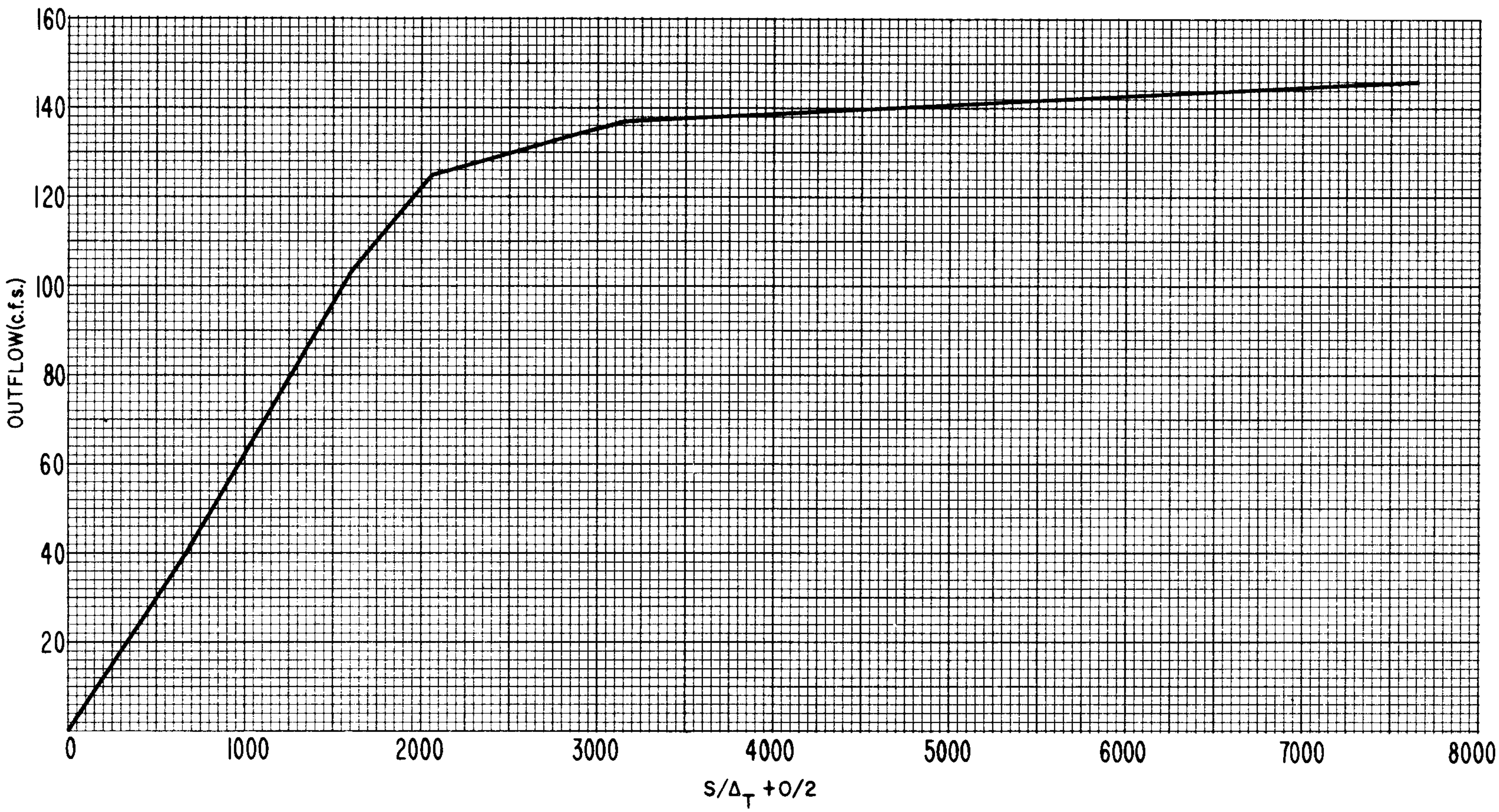
Δt = 0.5 hrs. Factor = 24.2

Table 5

For Converting Acre-Feet to cfs for Various Time Increments

Δt (hrs.)	Conversion Factor	$\frac{43560 \text{ cubic feet}}{3600 \text{ seconds}} = 12.1$ cfs hr/ac ft
24	0.504	
12	1.008	$\frac{12.1}{\Delta t}$ = conversion factor
6	2.017	
4	3.025	
3	4.033	conversion factor times column 2
2	6.050	(above) = Column 3 (cfs)
1	12.100	
0.5	24.200	
0.25	48.400	

Storage Indication Curve
Δ_T = 0.5 hrs.
Principal Spillway



FISH DAM

FIGURE C-8

FLOOD ROUTING
BY
STORAGE INDICATION METHOD

Hydrograph Principal Spillway
Δt 0.5

State North Dakota		Project Fish Dam		
By	Date	Checked By	Date	Job No.

Time (Hrs.)	Inflow (Ave.)	$\frac{S_1}{\Delta t} - \frac{O_1}{2}$	$\frac{S_2}{\Delta t} + \frac{O_2}{2}$	Out-flow	Time (Hrs.)	Inflow (Ave.)	$\frac{S_1}{\Delta t} - \frac{O_1}{2}$	$\frac{S_2}{\Delta t} + \frac{O_2}{2}$	Out-flow
0				0					
	50	0							
0.5			50	2					
	145	48				S/Δt	+ 0/2 =	6334	
1.0			193	10					
	240	183							
1.5			423	24		S/Δt	= 6334	- 143/2	
	340	399							
2.0			739	42					
	435	697				S/Δt	= 6262		
2.5			1132	70					
	530	1062							
3.0			1592	103		S	= 258.8		
	630	1489							
3.5			2119	126					
	725	1993				S	= 412	+ 258.8	
4.0			2718	132		S	= 670.8		
	760	2586				@	El 94.5		
4.5			3346	137					
	700	3209							
5.0			3909	139					
	645	3770							
5.5			4415	140					
	585	4275							
6.0			4860	141					
	525	4719							
6.5			5244	142					
	470	5102							
7.0			5572	142					
	410	5430							
7.5			5840	142					
	355	5698							
8.0			6053	143					
	295	5910							
8.5			6205	143					
	235	6062							
9.0			6297	143					
	180	6154							
9.5			6334	143					
	120	6191							
10.0			6311	143					
	60	6168							
10.5			6228	143					
	0	6085							
11.0			6085	143					

FIGURE C-9