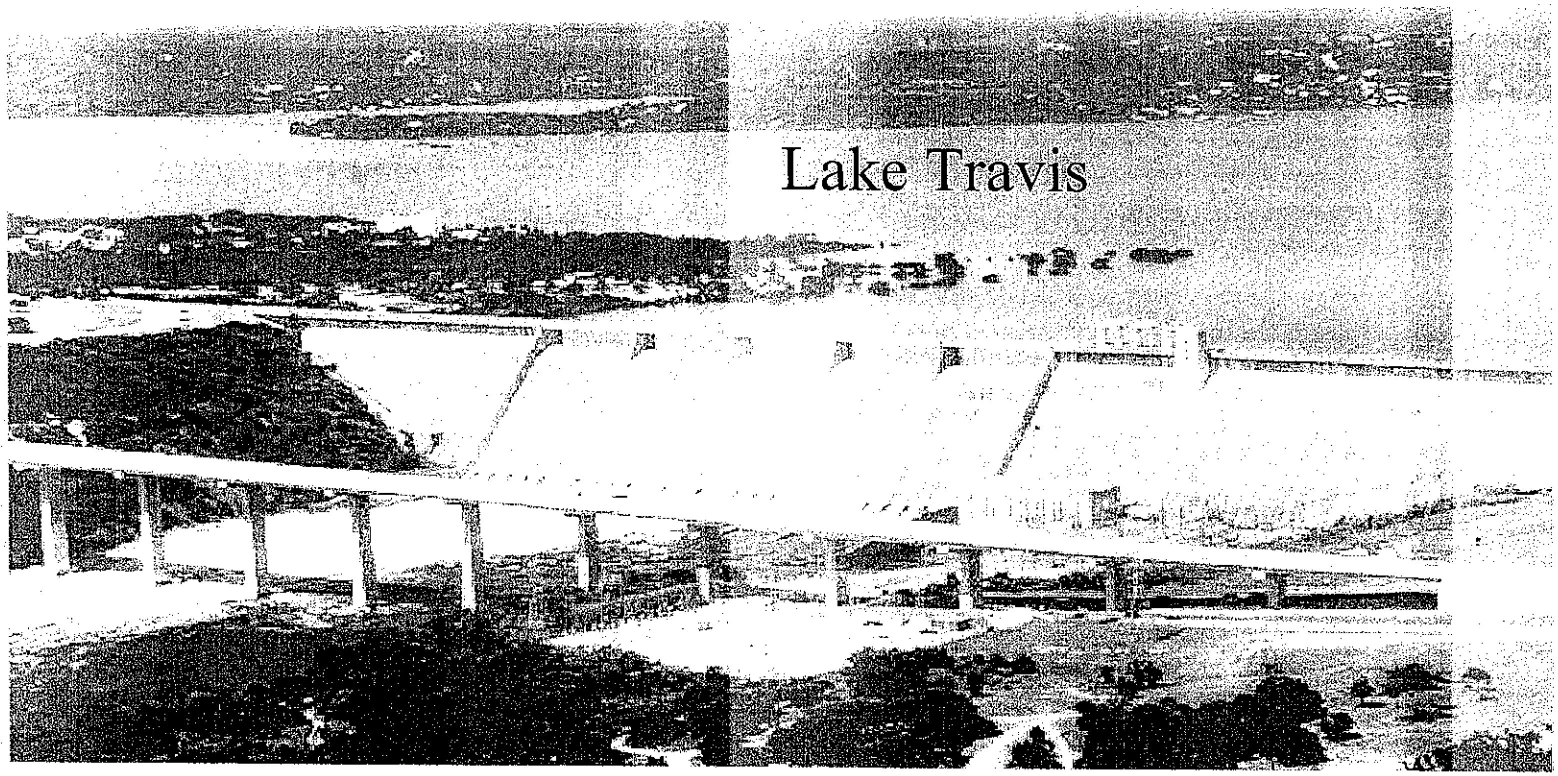
HAND OUT 14: Flood reservoir routing (Chapter 5 of our syllabus). Source: Adapted from classes from Prof. Bedient of Rice University.

Review of Flood Reservoir Routing

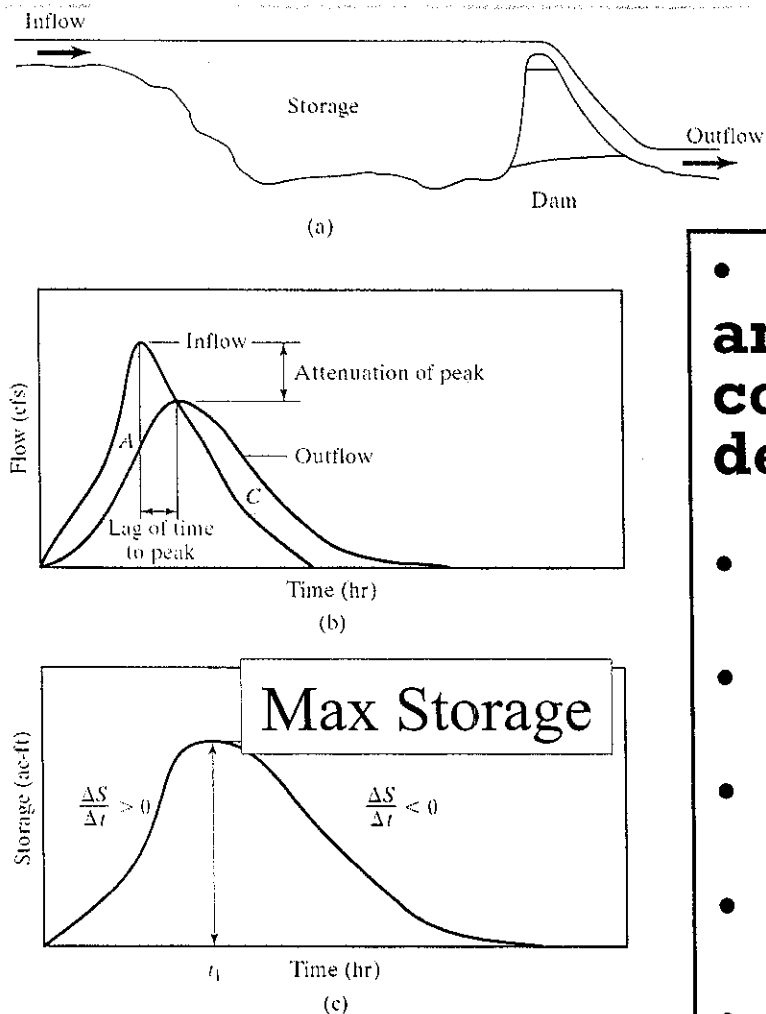
Modified from classes by Philip B. Bedient
Rice University

Mansfield Dam, Austin, Texas



Mansfield Dam, Hill Country of Texas

Reservoir Routing



- **Reservoir acts storing water, and releasing it through the control structure with a certain delay**
- **Inflow hydrograph**
- **Outflow hydrograph**
- **Storage - Discharge Rel'n**
- **Outflow peaks are reduced**
- **Outflow timing is delayed**

Inflow and Outflow

$$I - Q = \frac{dS}{dt}$$

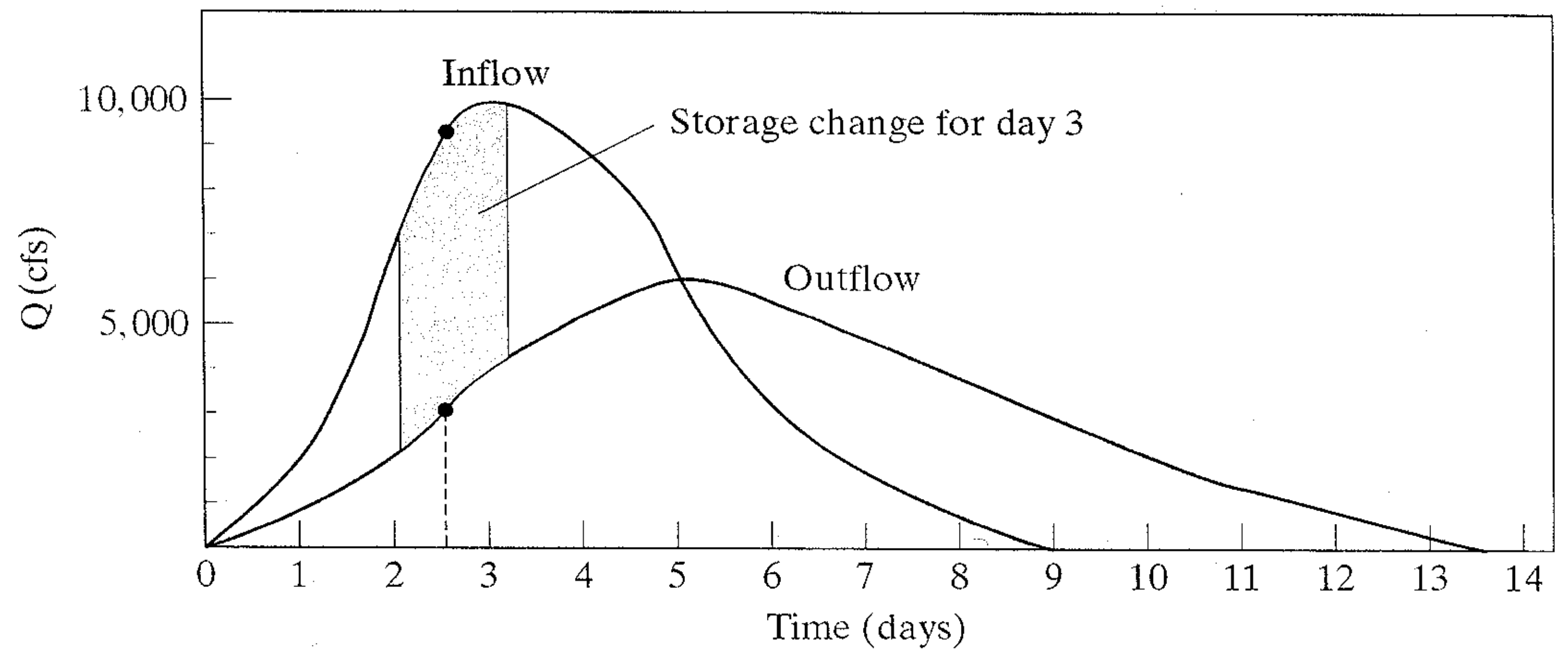


Figure E4.1(a)

Inflow and Outflow

= change in storage / time

$$(I_2+I_3)/2-(Q_2+Q_3)/2=\frac{S_3-S_2}{dt}$$

Re Repeat for each day

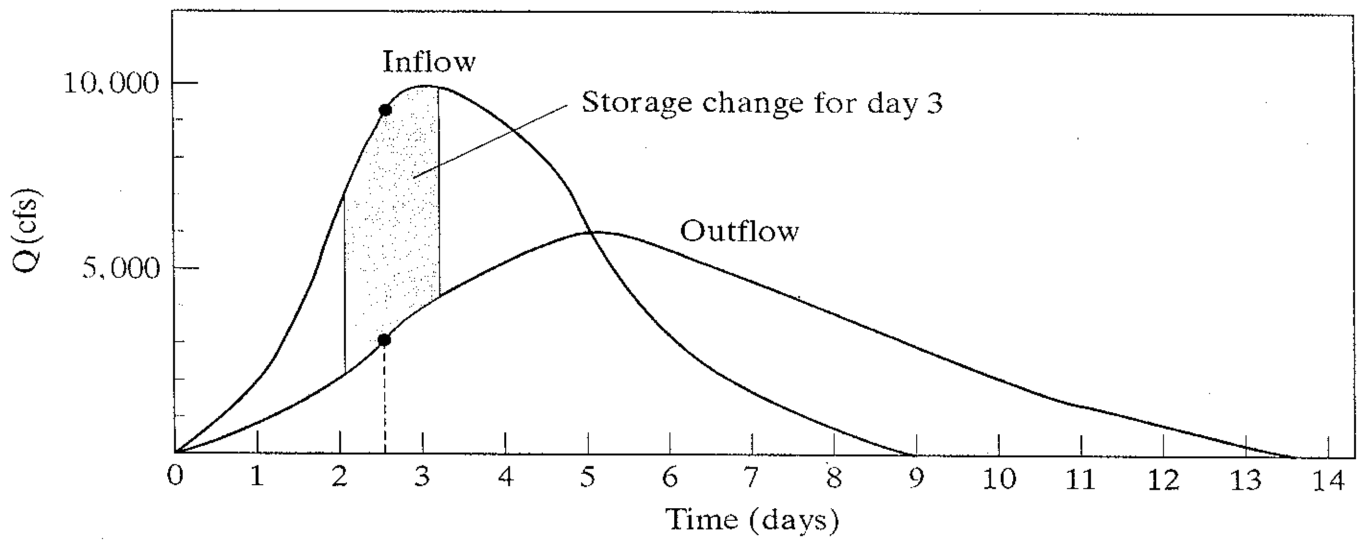


Figure E4.1(a)

Determining Storage

- Evaluate surface area at several different depths
- Use available topographic maps or GIS based DEM sources
- Outflows can be computed as function of depth for either pipes, orifices, or weirs

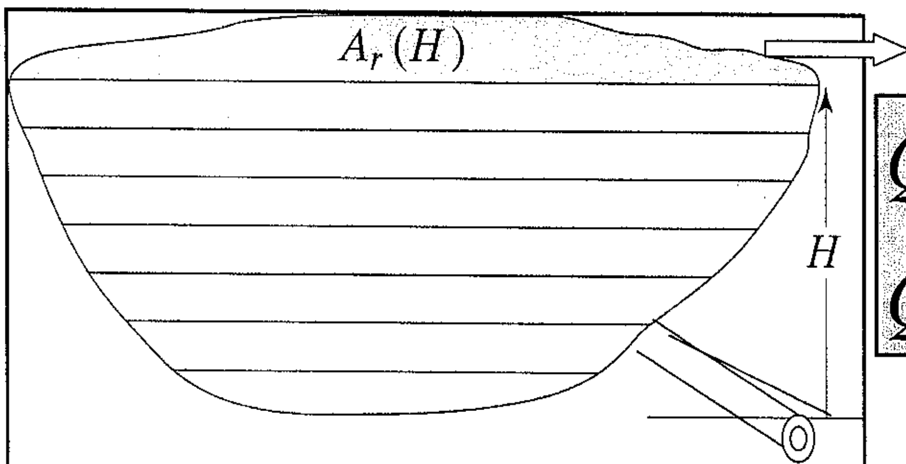


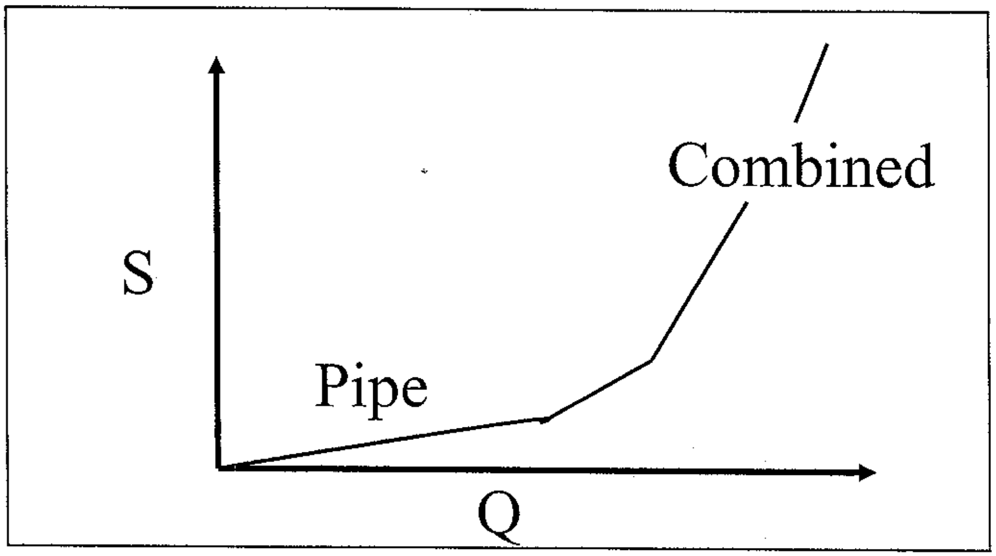
Figure E4.2(b)

$$Q = CA\sqrt{2gH} \text{ for orifice flow}$$

$$Q = CLH^{3/2} \text{ for weir flow}$$

Typical Storage -Outflow

- Plot of Storage in acre-ft vs. Outflow in cfs
- Storage is largely a function of topography
- Outflows can be computed as function of elevation for either pipes or weirs



Reservoir Routing

$$I_1 + I_2 + \left(\frac{2S_1}{dt} - Q_1\right) = \left(\frac{2S_2}{dt} + Q_2\right)$$

1. LHS of Eqn is known
2. Know S as fcn of Q
3. Solve Eqn for RHS
4. Solve for Q_2 from S_2

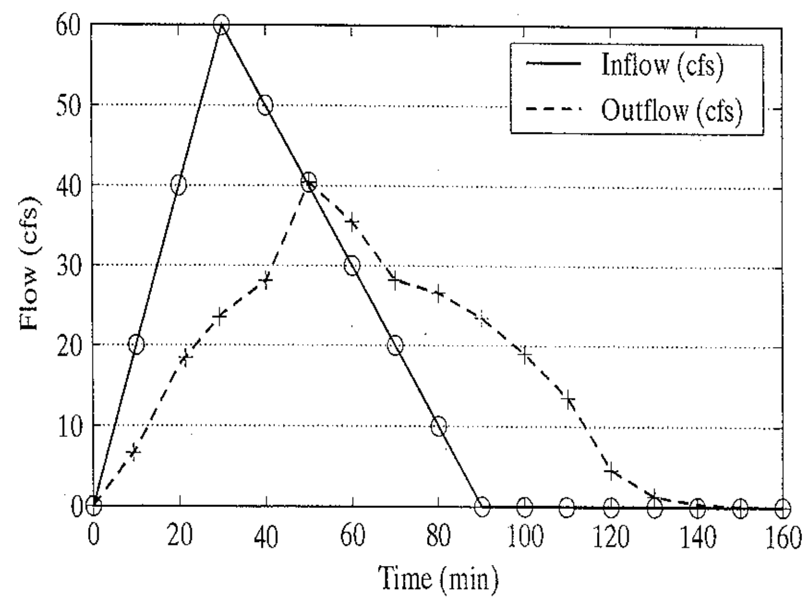
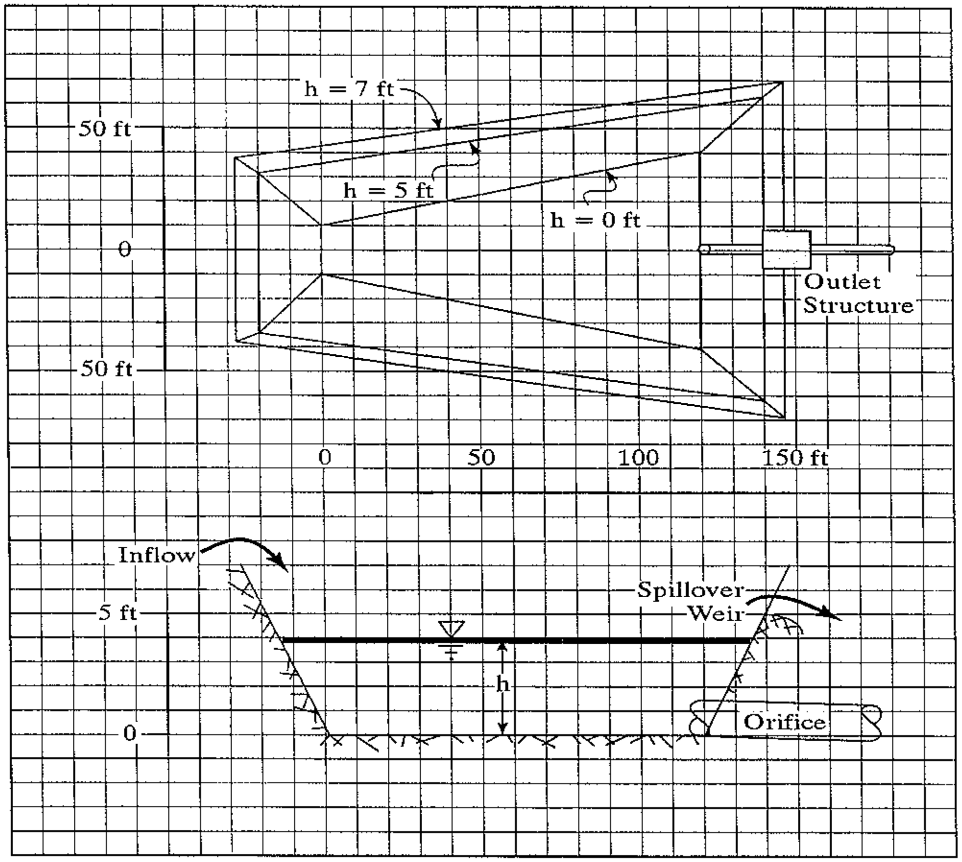


Figure E4.5(a)

Hydrographs.

Repeat each time step

Example Pond Routing



Note that outlet consists of weir and orifice.

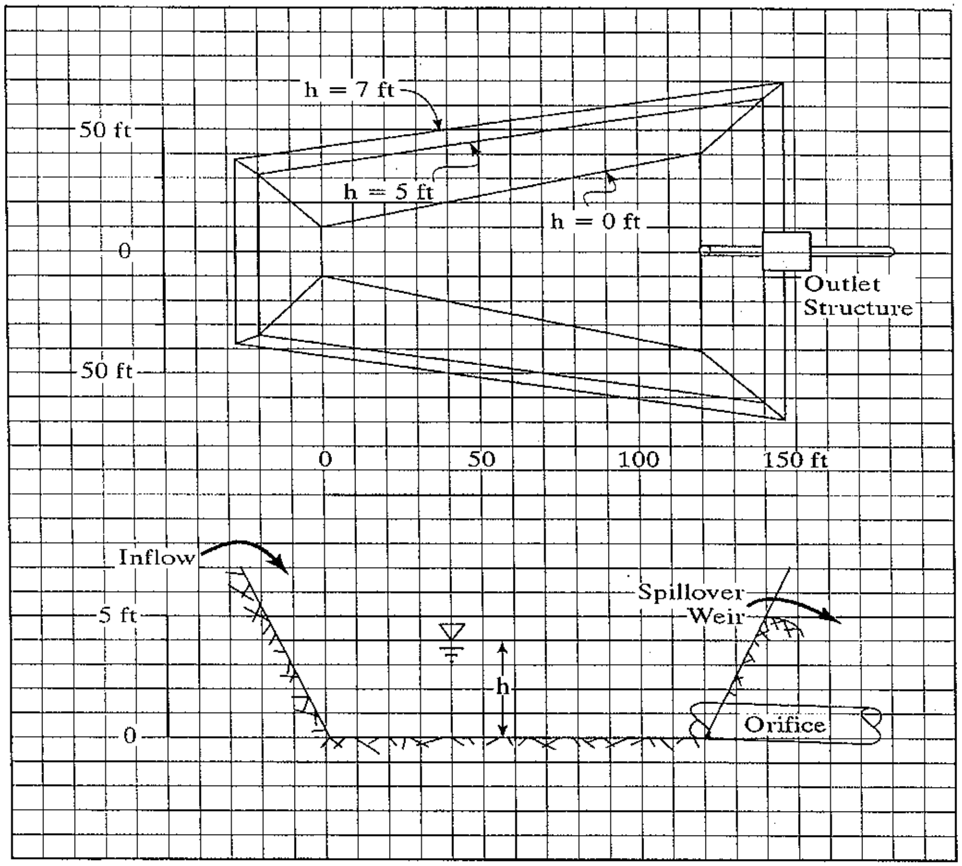
Weir crest at h = 5.0 ft

Orifice at h = 0 ft

Area (6000 to 17,416 ft^2)

Volume ranges from 6772 to 84006 ft^3

Example Pond Routing



- **Develop Q (orifice) vs h**
- **Develop Q (weir) vs h**
- **Develop A and Vol vs h**
- **Storage - Indication**
- **$2S/dt + Q$ *vs* Q where Q is sum of weir and orifice flow rates.**

Storage Indication

$$I_1 + I_2 + \left(\frac{2S_1}{dt} - Q_1 \right) = \left(\frac{2S_2}{dt} + Q_2 \right)$$

1. **LHS of Eqn is known at initial t**
2. **Know S as fcn of Q from outlet**
3. **Solve Eqn for -- $(2S_2/dt + Q_2)$**
4. **Solve for Q_2 from S_2**

Storage Indication Curve

- **Relates Q and storage indication, $(2S / dt + Q)$**
- **Developed from topography and outlet data**
- **Pipe flow + weir flow combine to produce Q (out)**

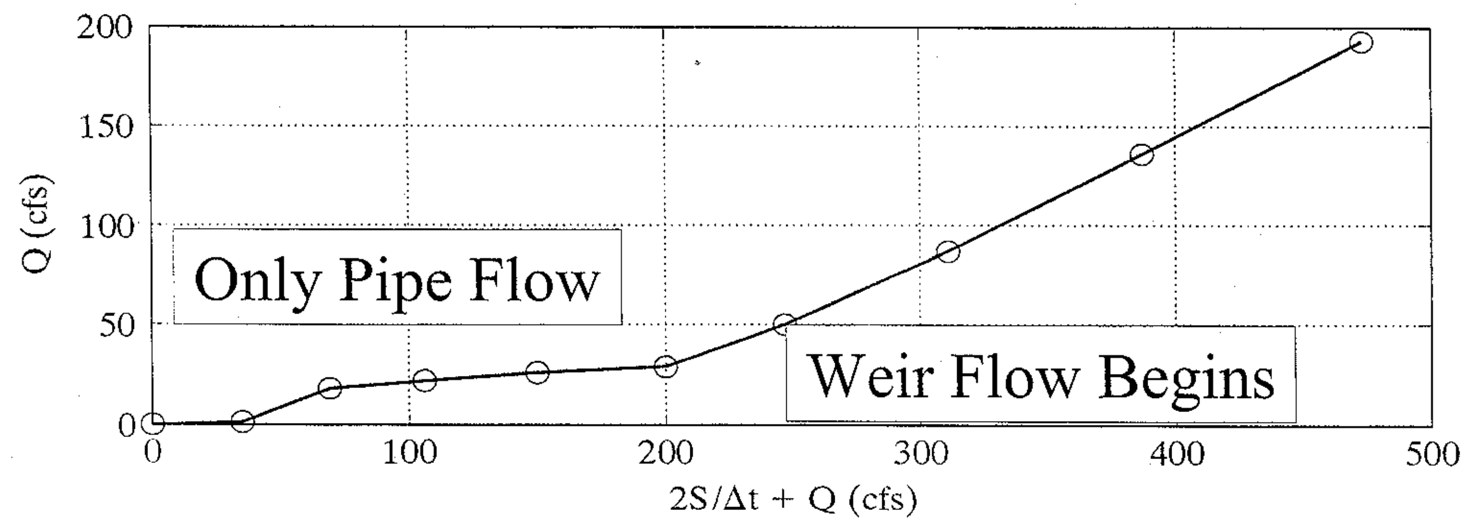


Figure E4.5(c)

Storage indication curve.

Storage Indication Inputs

height h - ft	Area 10^2 ft	Cum Vol 10^3 ft	Q total cfs	$2S/dt + Q_n$ cfs
0	6	0	0	0
1	7.5	6.8	13	35
2	9.2	15.1	18	69
3	11.0	25.3	22	106
4	13.0	37.4	26	150
5	15.1	51.5	29	200
7	17.4	84.0	159	473

Storage Indication Results

Time	I_n	$I_n + I_{n+1}$	$2S/dt - Q_n$	$(2S/dt + Q)_{n+1}$	Q_{n+1}
0	0	0	0	0	0
10	20	20	0	20	7.2
20	40	60	5.6	65.6	17.6
30	60	100	30.4	130.4	24.0
40	50	110	82.4	192.4	28.1
50	40	90	136.3	226.3	40.4
60	30	70	145.5	215.5	35.5

And so on ….

S-I Routing Results

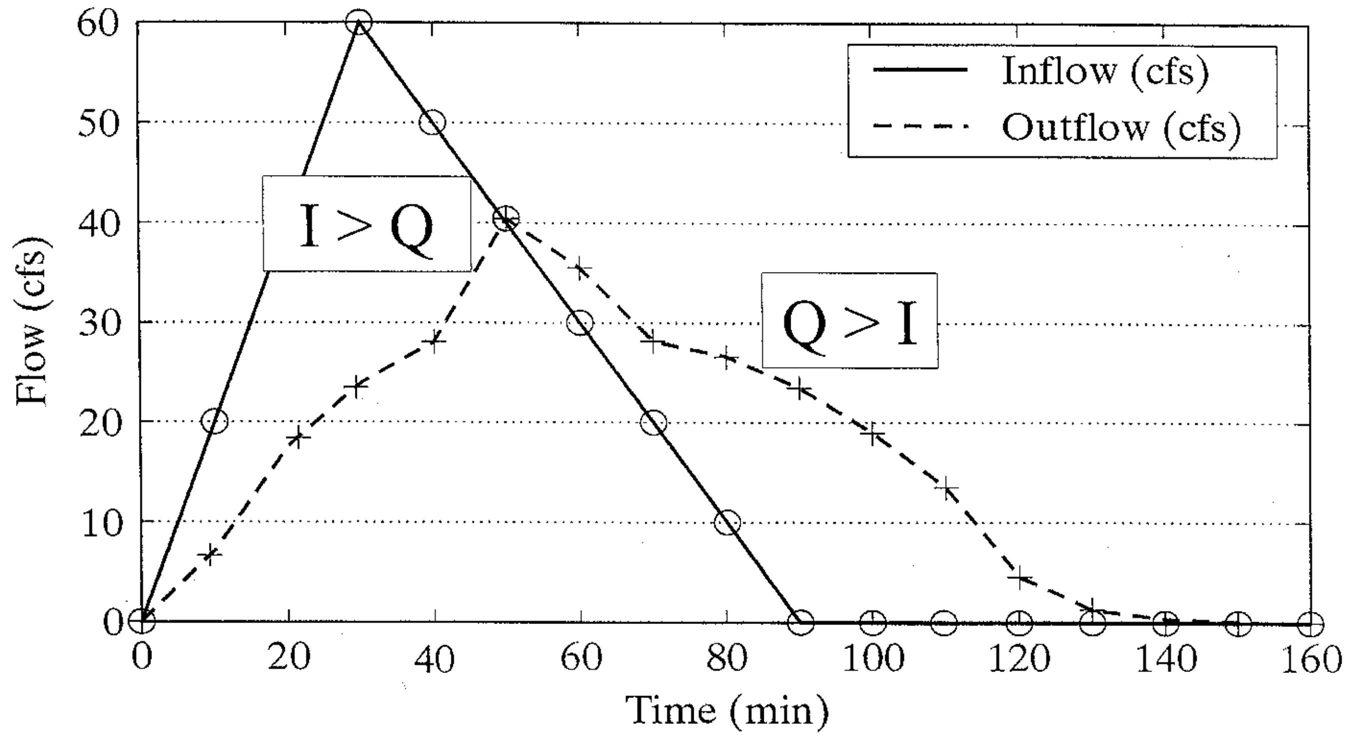


Figure E4.5(a)

Hydrographs.

S-I Routing Results

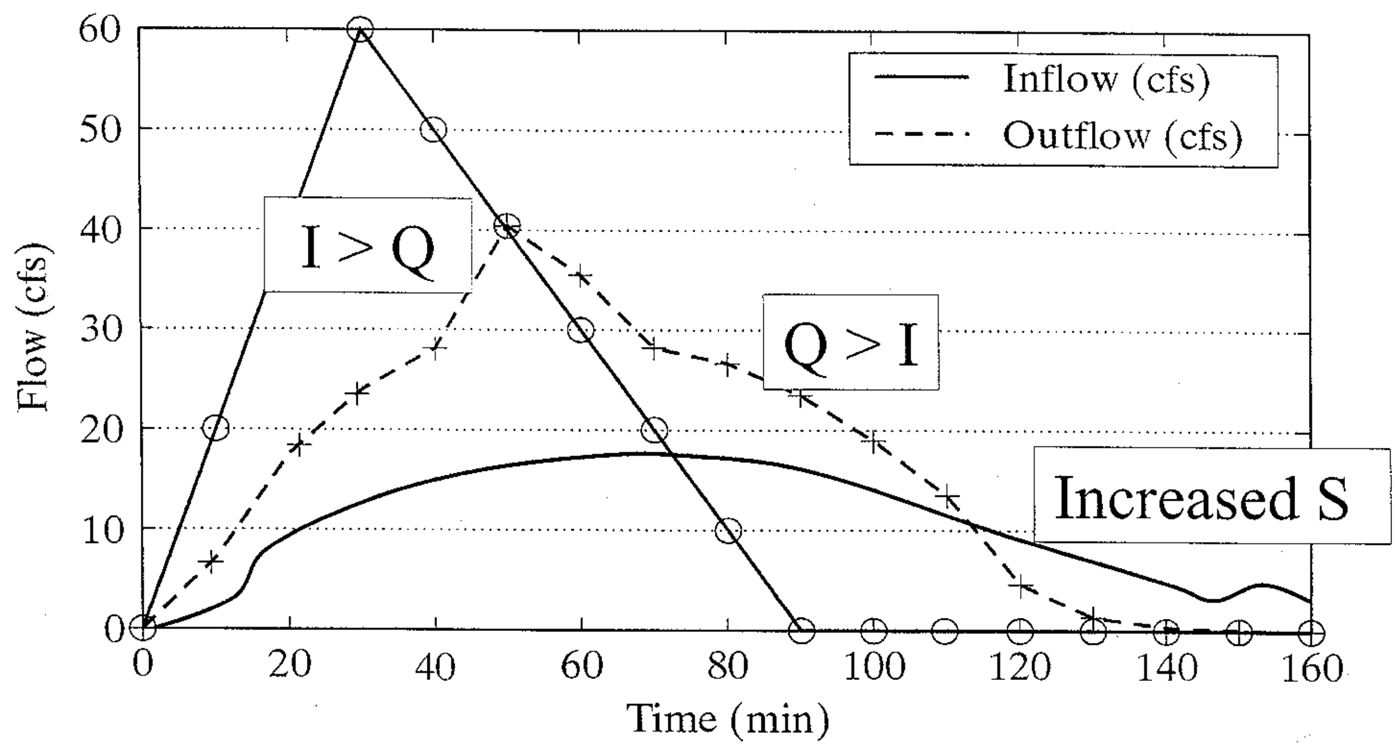
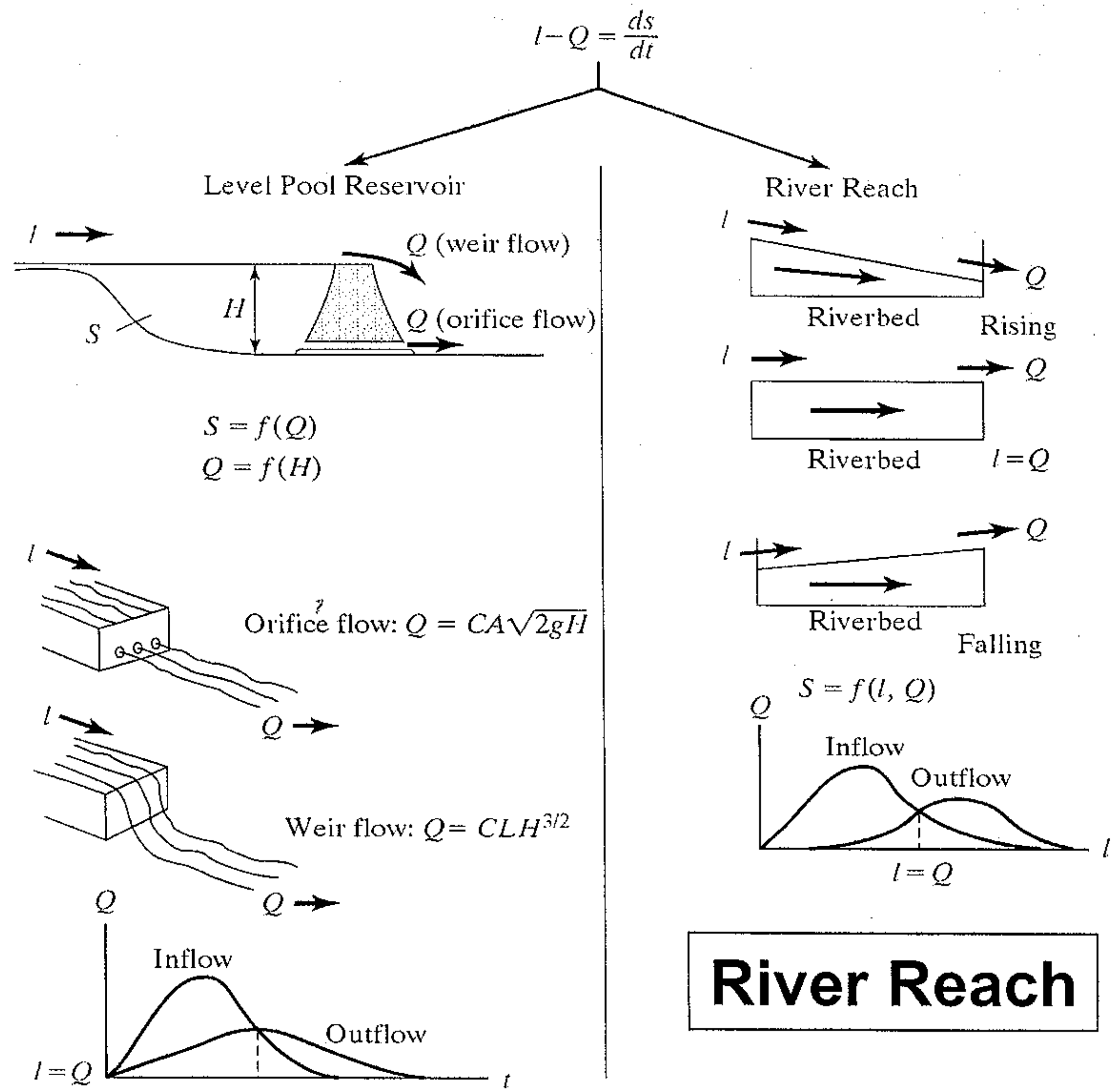


Figure E4.5(a)

Hydrographs.

Comparisons: River vs. Reservoir Routing



Level pool reservoir

River Reach

HAND OUT 15: Types of backwater (Chapters 5 and 6 of our syllabus).
Source: Mays, L. (2006). *"Water resources engineering."* John Wiley and Sons.

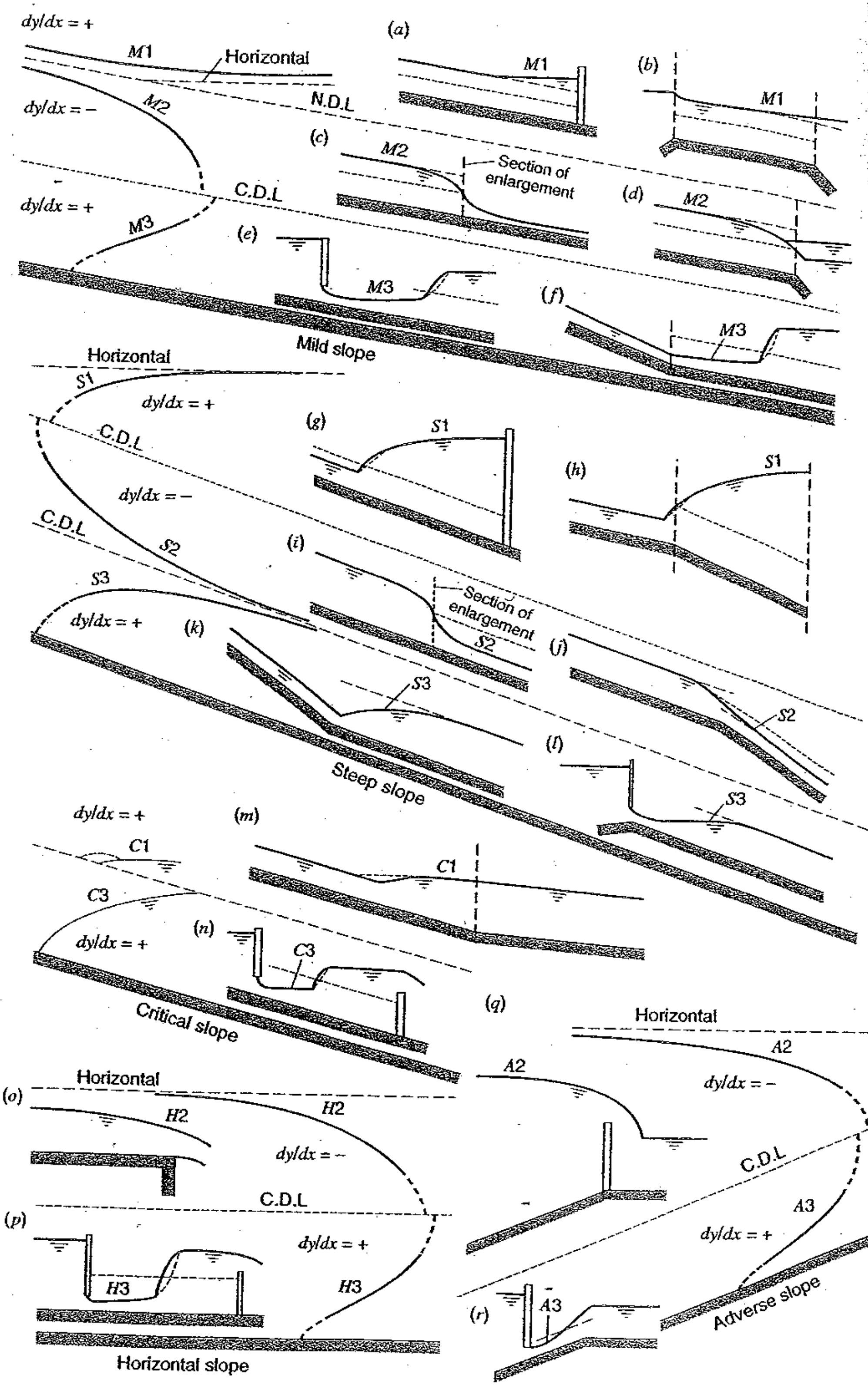


Figure 5.3.3 Flow profiles (from Chow (1959)).

HAND OUT 16: Numerical solution for backwater curves (Chapters 5 and 6 of our syllabus). Source: pages from Chow, V. T. (1959). *"Open-channel hydraulics."* Mc-Graw Hill.

BACKWATER CURVES

Gradually-varied flows

Differential equation:

$$\frac{dH}{dx} = -S_f \quad (1)$$

where: $H = \frac{U^2}{2g} + z + y$ (2)

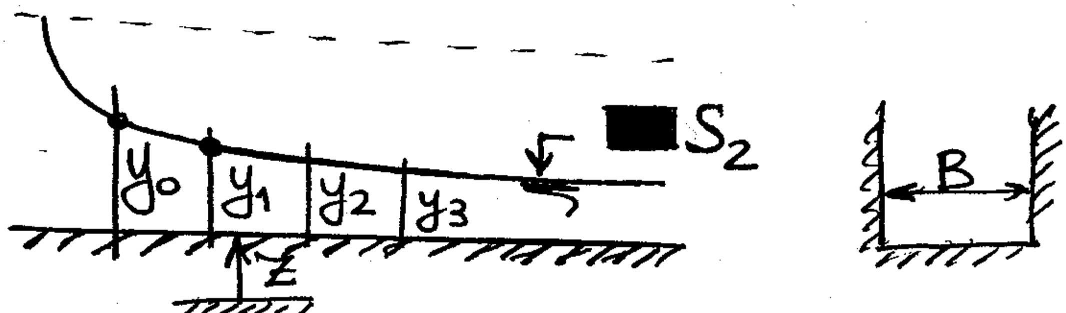
and: $S_f = C_f \frac{U^2}{gy}$ (3)

We can discretize (1) using any of the methods we saw for $\frac{du}{dt} = -Ku$. Notice that the two equations look very similar. We can use a forward, backward, or a centered scheme. Using a centered scheme:

$$\frac{H_{j+1} - H_j}{\Delta x} = -\frac{1}{2}\left(S_{fj} + S_{fj+1}\right) \quad (4)$$

H is a function of y. S_f is also a function of y. Recall that in backwater curves our objective is to compute the variation of y with distance. The computation starts at one of the [redacted] boundaries of the cur ve and proceeds to the other boundary. (2)

Example:



The problem with (4) is that, since $H = H(y)$ and $S_f(y)$, y is at both sides of the equal sign.

<u>First method</u>: We can circumvent this problem by <u>fixing y</u>. Say $y_0 = 10$ m; let's fix $y_1 = 9.9$ m, $y_2 = 9.8$ m, etc. If we know y, and the channel has a rectangular cross section, we can compute the area as: $A_0 = By_0$, $A_1 = By_1$, $A_2 = By_2$, etc. Further, if the discharge per unit width, q_w, is known, we can compute: $U_0 = \frac{q_w}{y_0}$, $U_1 = \frac{q_w}{y_1}$, $U_2 = \frac{q_w}{y_2}$, etc.

If C_f is given, we can compute H_0, H_1, H_2, etc., and S_{f0}, S_{f1}, S_{f2}, etc.

For the first two cross sections:

$$\frac{H_1 - H_0}{\Delta x} = -\frac{1}{2}\left(S_{f_0} + S_{f_1}\right) \quad (5)$$

From (5), we know everything except Δx. So we can compute Δx from (5). This means that we compute the distance at which $y_1 = 9.9$ m occurs from $y_0 = 10$ m. This method is called <u>explicit</u>, because we can compute Δx from known values:

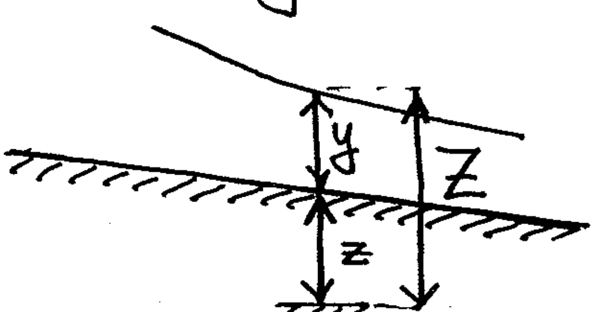
$$\Delta x = \frac{(H_0 - H_1)\,2}{(S_{f_0} + S_{f_1})} \quad (6)$$

We repeat the procedure between H_1 and H_2, H_2 and H_3, etc. In this way, we build the curve.

<u>Second method</u>: Equation (4) is also used. Let's denote Z the elevation of the water surface from the datum:

$$Z = z + y$$

$$H = Z + \frac{U^2}{2g} \quad (7)$$



From (4):

$$H_{j+1} = H_j - \frac{1}{2}\left(S_{fj} + S_{fj+1}\right)\Delta x \quad (8)$$

This method is best suited for natural channels. This method is based on trial and error procedure (iterative). Thus, it is called implicit method. Procedure:

1) We guess a value of Z [redacted] $_1$ (recall eqn. (5)) Since we know z_1, we can obtain y_1. Having y_1, we compute A_1, U_1, S_{f1} and H_1^1. All these values at 0 are known because it is the initial condition. But this value of Z_1 corresponds to a given Δx that we specify. Thus, all these values give us another value of H_1^2. If H_1^2 is different from H_1^1, we need to vary our guess of [redacted] Z_1. The iteration continues until

$$\left|\frac{H_1^{m+1} - H_1^m}{H_1^{m+1}}\right| < \text{tol.}$$

Then, we need to move to another pair of cross sections and repeat the procedure.