The Stage-Discharge Rating

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Washington, D.C.
June 6-7, 2006

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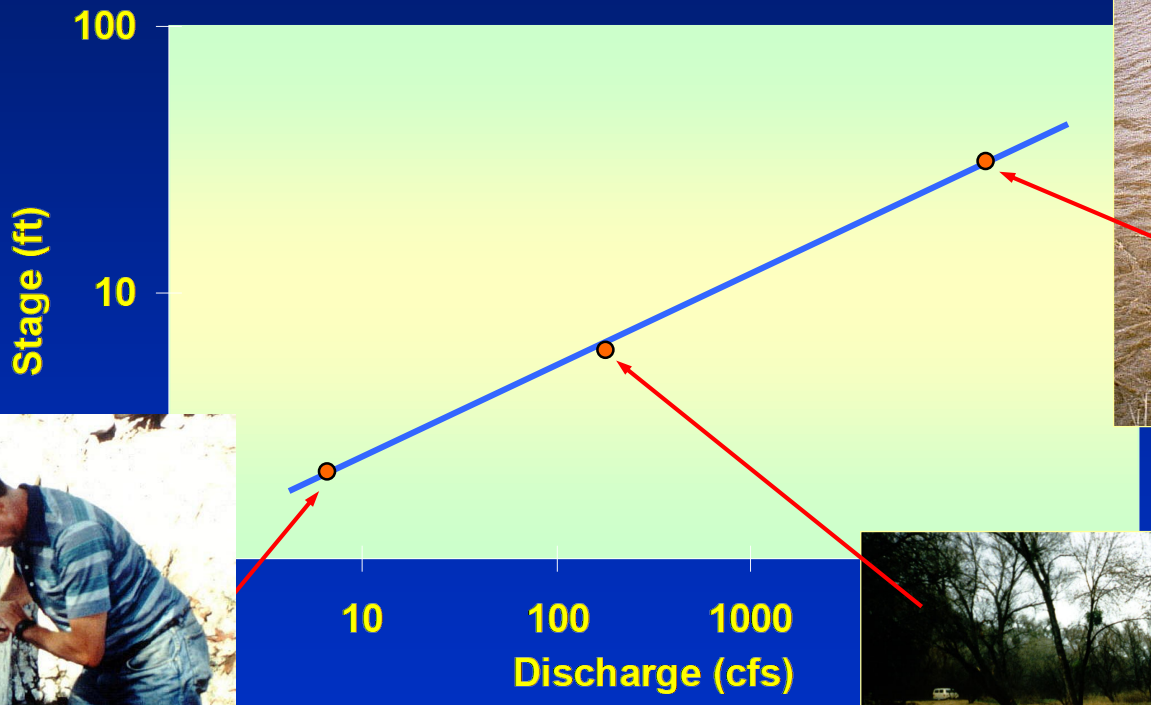
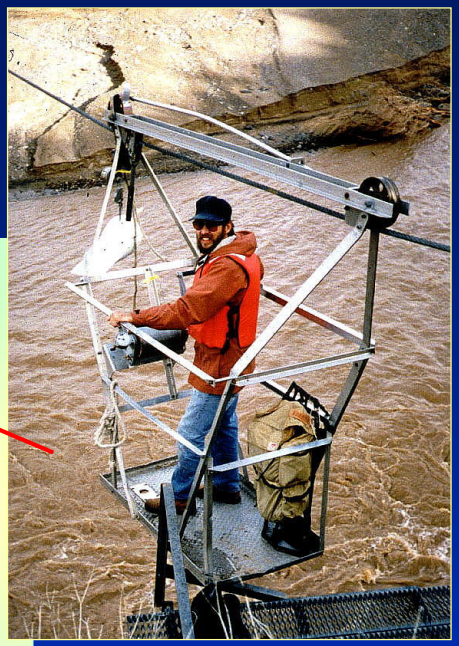
Ratings developed by making discharge measurements





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A straight line on rectilinear paper is of the form:

$$y = mx + b$$

where: m = slope of line

and: b is the y intercept

Logarithmic Coordinate System

- Many hydraulic relations are linear in log form
- Examples include:
  - Discharge equations for weirs
  - Open-channel flow equations, with simplifying assumptions
- This means SEGMENTS of ratings may be linear in log space

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Stage-Discharge Relations for Artificial Controls

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Equations commonly used to relate water discharge to hydraulic head (h)

RECTANGULAR WEIR

$$Q = C\,B\,h^{1.5}$$

where:

C = a discharge coefficient

B = top width of weir or length of weir crest normal to flow

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Equations commonly used to relate water discharge to hydraulic head (h)

V-NOTCH WEIR (90 degrees)

$$Q = 2.5\ h^{2.5}$$

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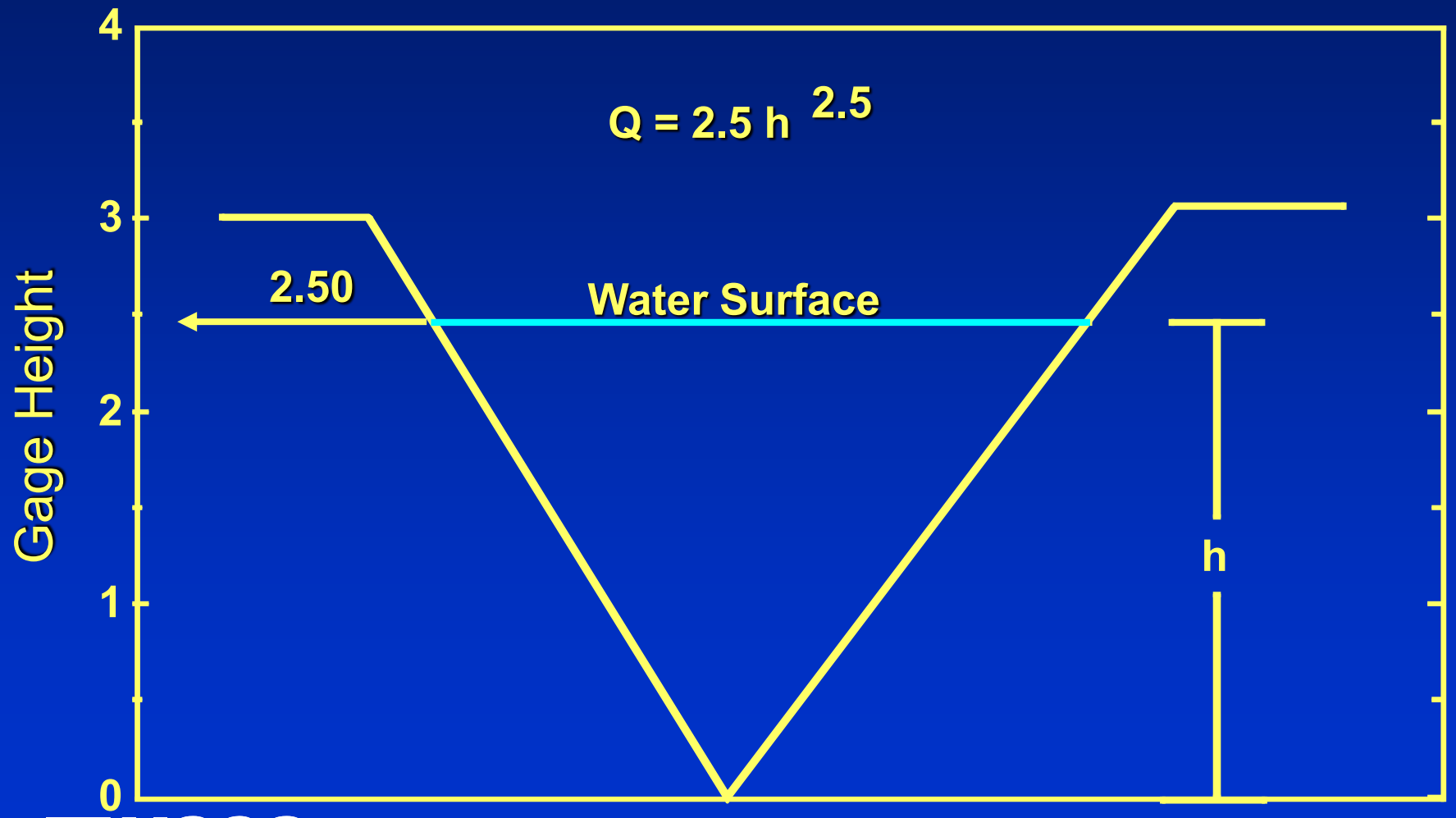
Relation between water discharge (Q) and Head (h) for a v-notch weir (pzf at gage height = 0.0)



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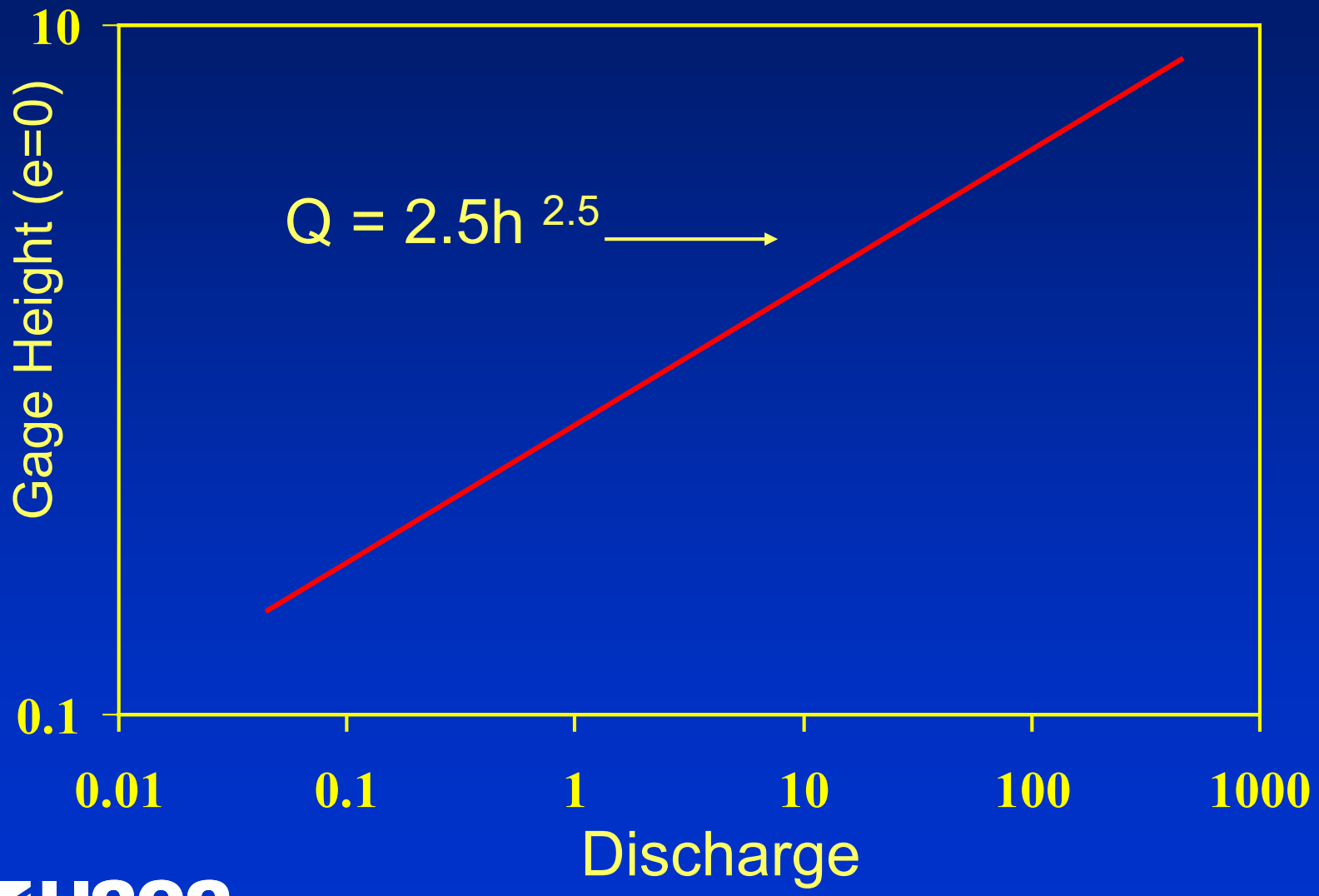
RATING CURVE FOR A V-NOTCH WEIR
(PZF at GH = 0.0, therefore h = ght)



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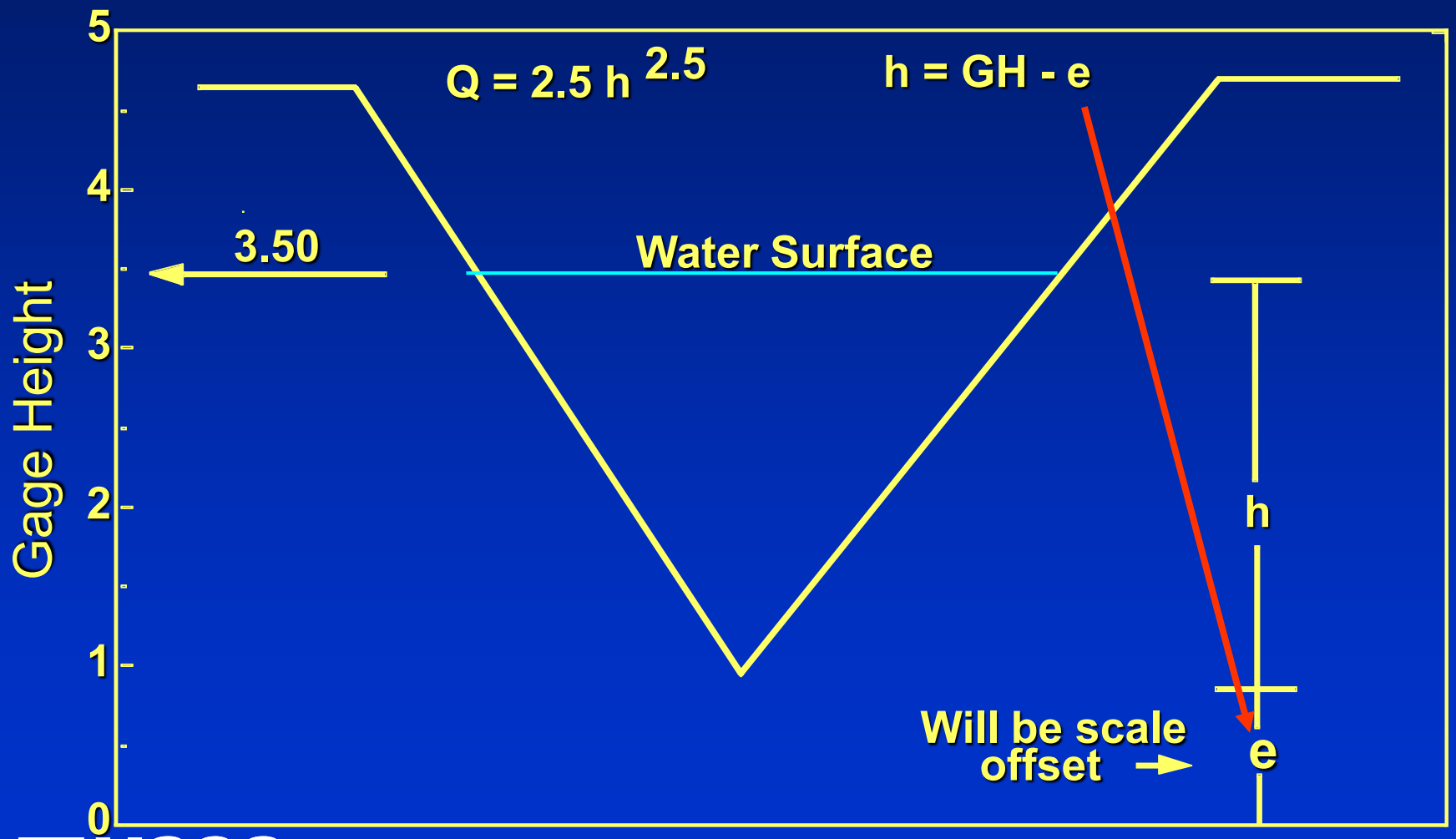
Relation between water discharge (Q) and head (h) for a v-notch weir (pzf at gage height = 1.0)



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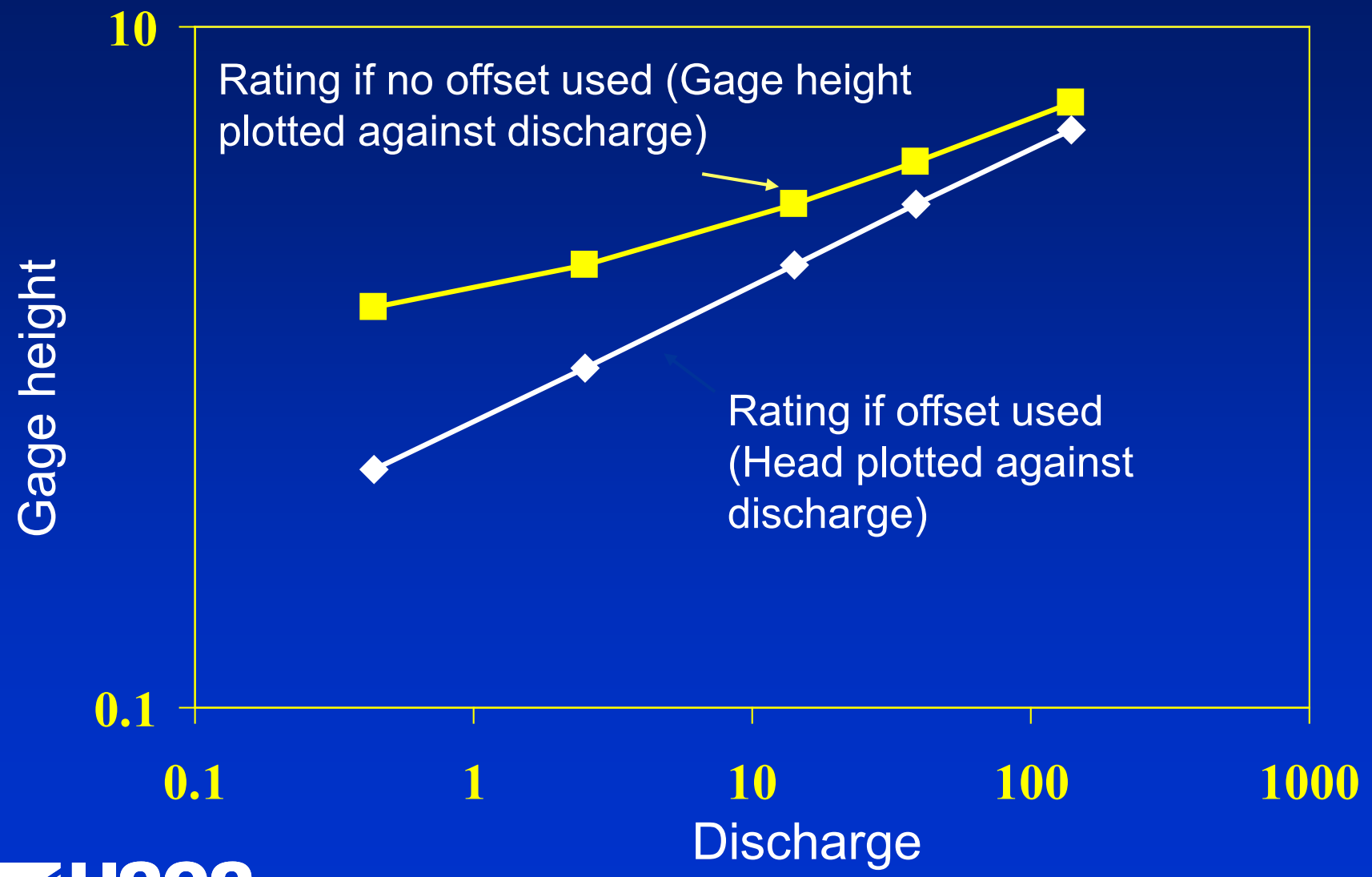
Rating for a V-notch weir when PZF = 1.0 ft.



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Example of relation between PZF and gage height

Head = GH - PZF

or about 0.37 (2.55 - 2.18)

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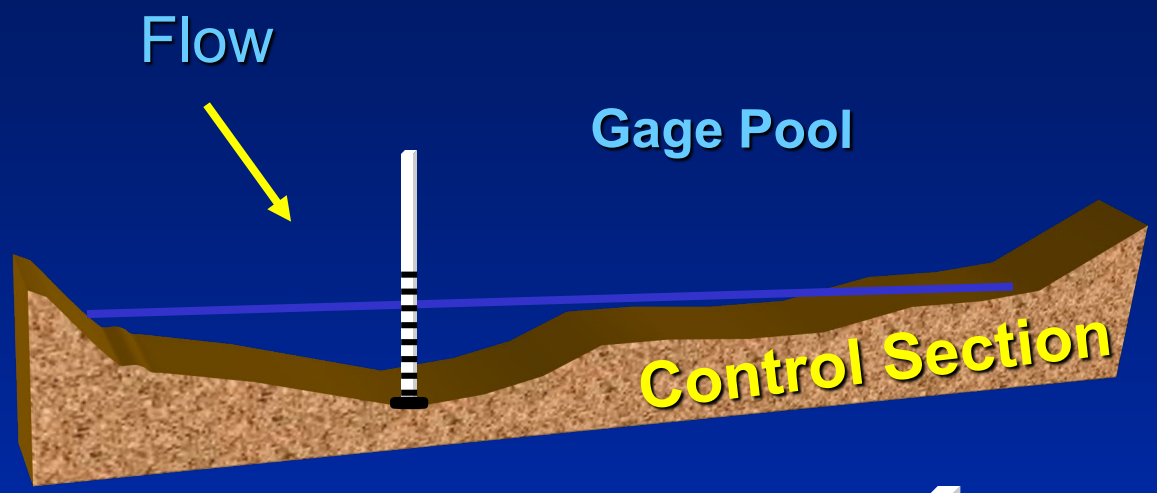
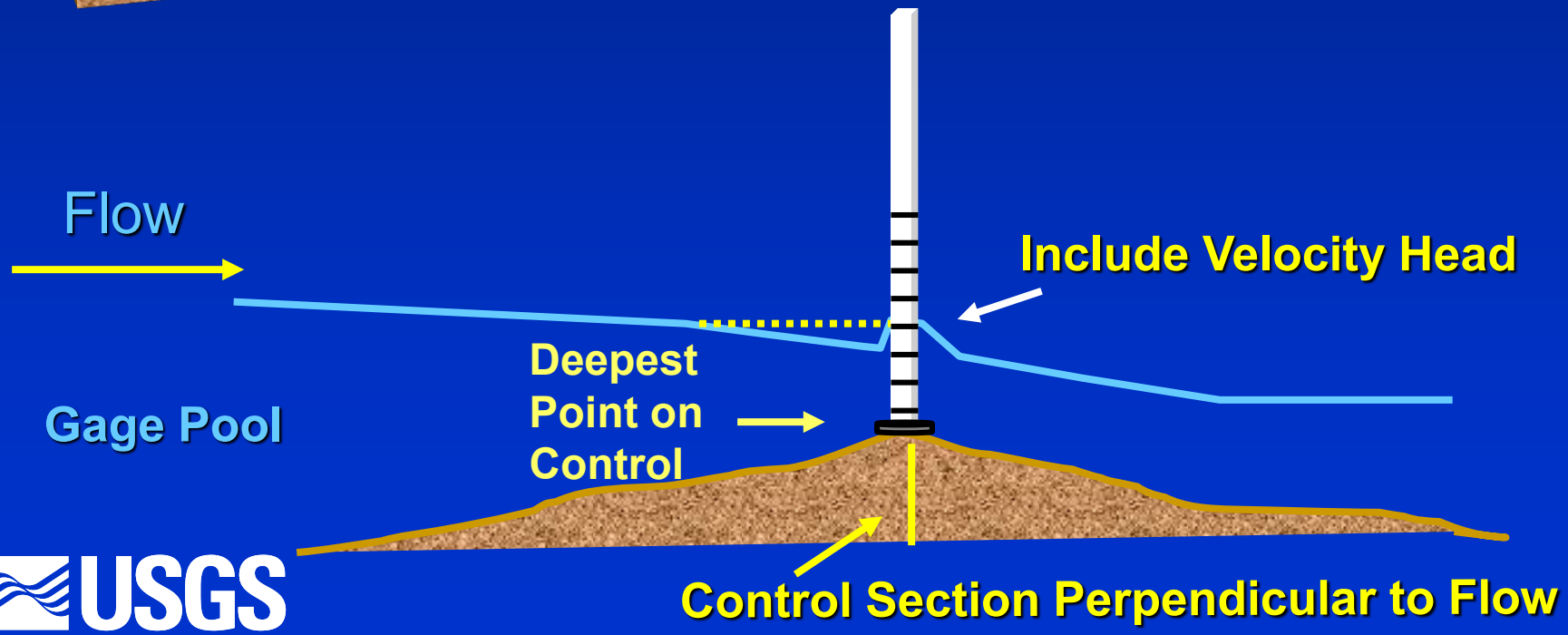
Measuring Point of Zero Flow





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Stage-Discharge Relations for Natural Controls

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Section Controls

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Section Controls

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Common equations used to relate water discharge to channel conditions

Section Control

$$Q = a(GH-e)^b$$

where:
a = coefficient
b = slope of the relations
(b is almost always greater than 2)

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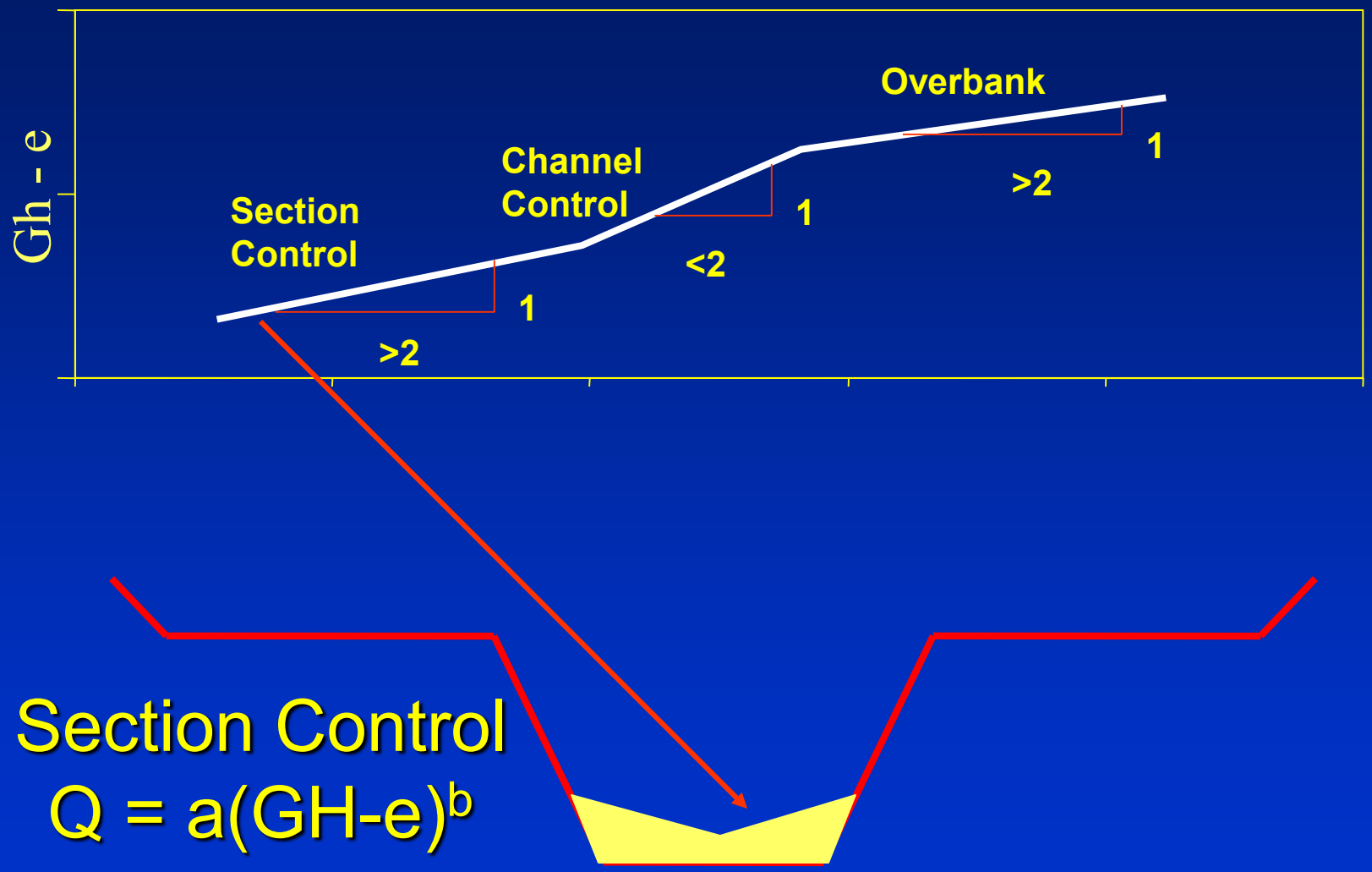
Rating curve shapes



Section Control

$Q = a(GH-e)^b$

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Channel Controls

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Common equations used to relate water discharge to channel conditions

Channel Control

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Where:

A = cross section area

R = hydraulic radius (area/wetted perimeter)

S = energy slope

n = Manning's "n" (roughness coefficient)

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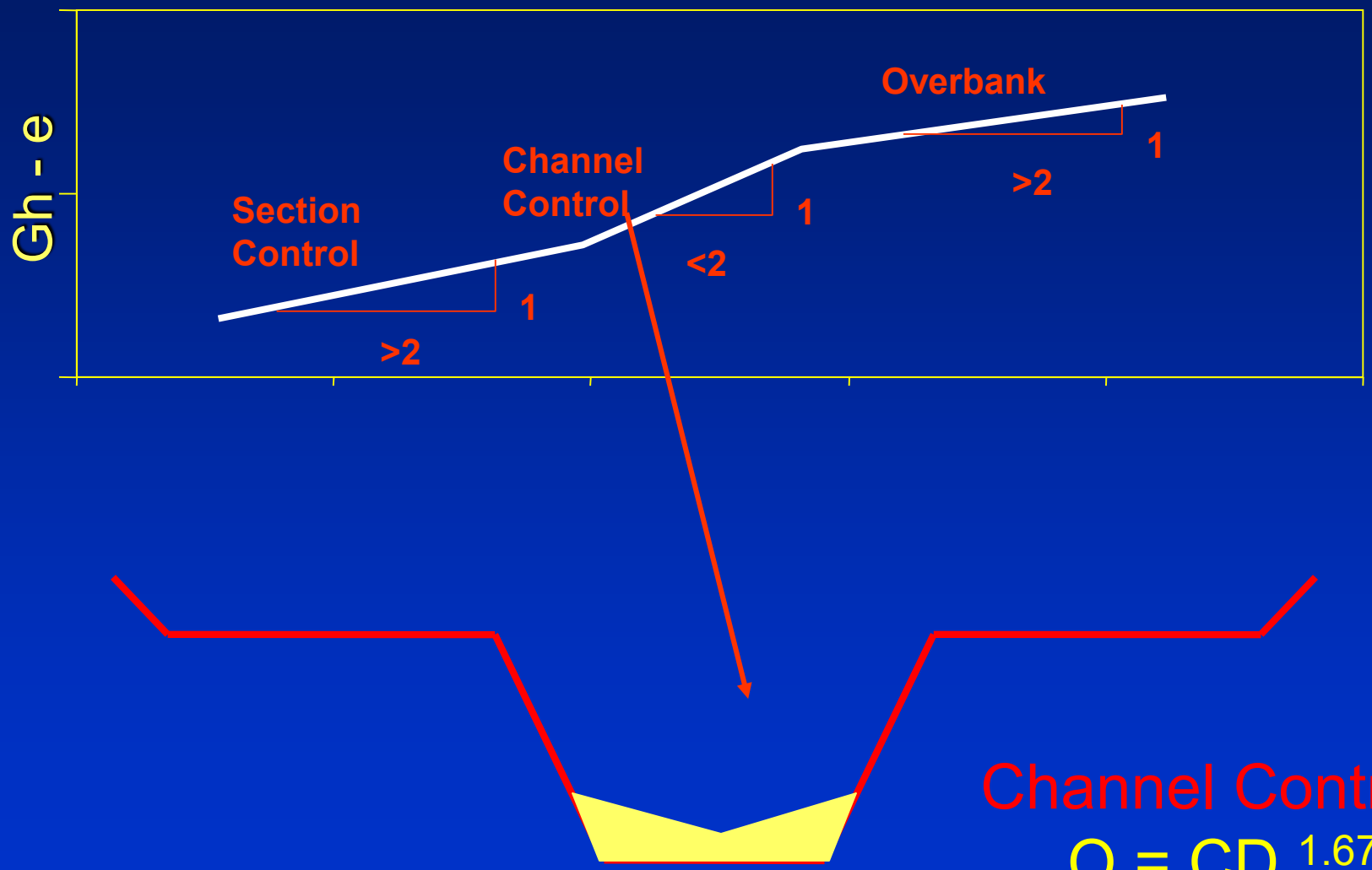
Rating curve shapes



Channel Control

$Q = CD^{1.67}$

(Manning's Eq.)

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Different Controls, Same Site

Section control

Channel control or partial channel control

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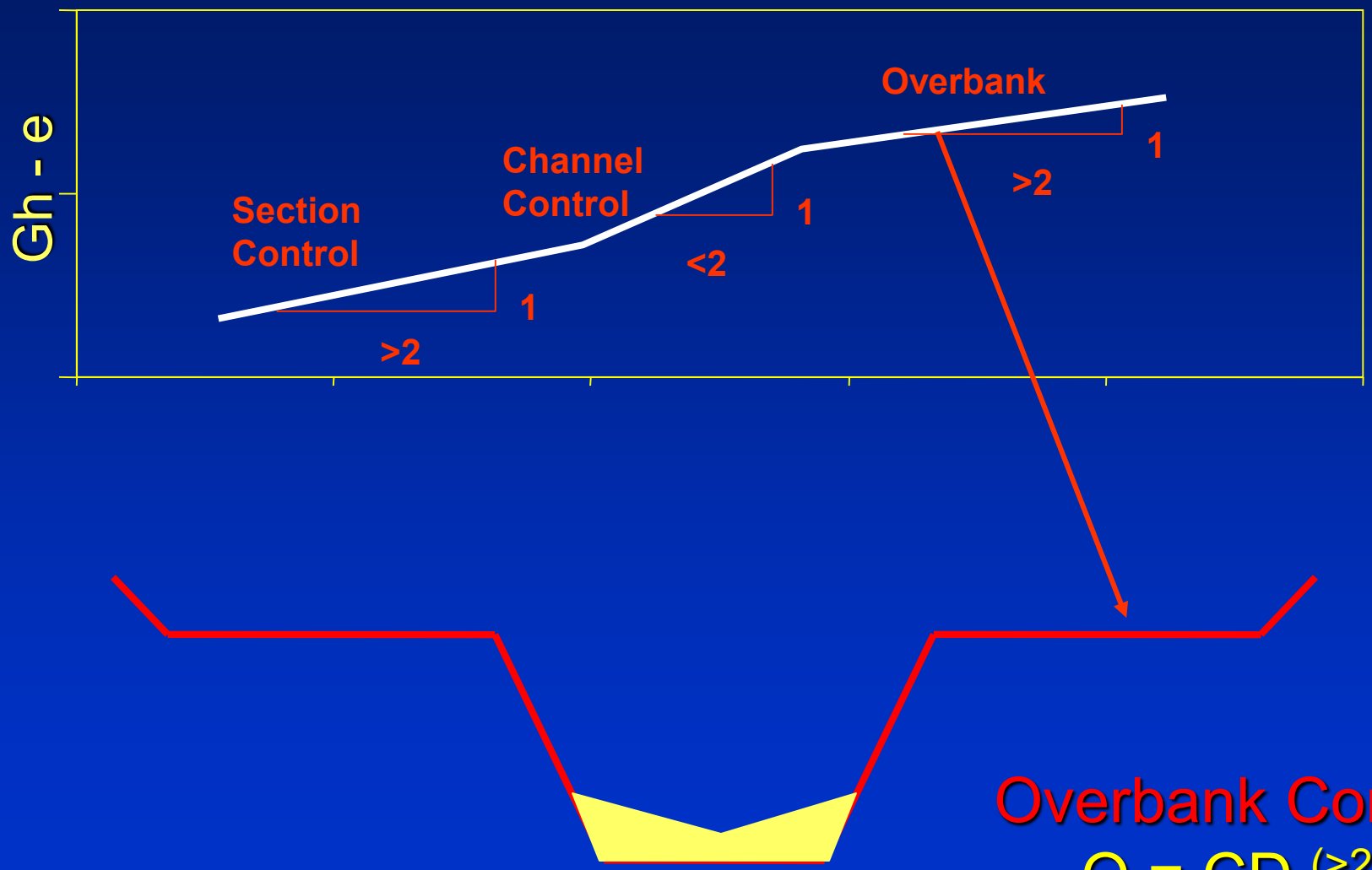
Rating curve shapes



Overbank Control

$Q = CD^{(>2)}$

(Manning's Eq.)

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Open-Channel Flow:

- Types of Flow
- States of Flow
- Regimes of Flow

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Open-Channel Flow:

- **Types of Flow**
- States of Flow
- Regimes of Flow
- Basic equations

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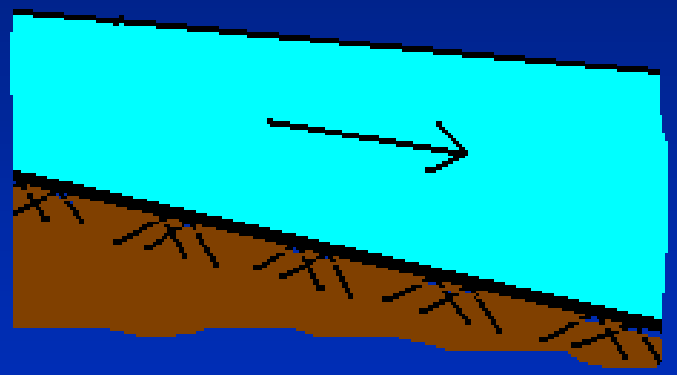
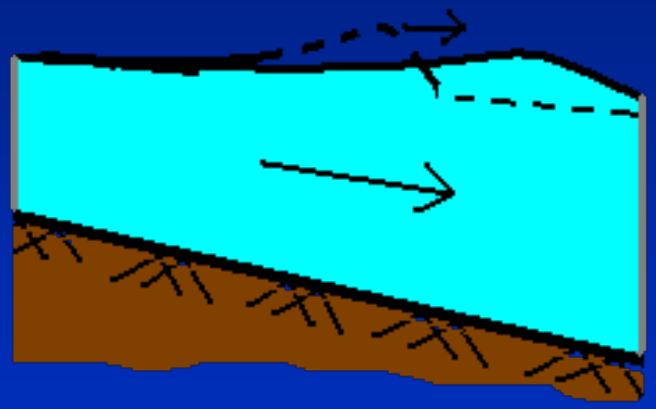
Temporal flow classifications

Steady



Depth and velocity are constant with time

Unsteady



Depth and velocity change with time

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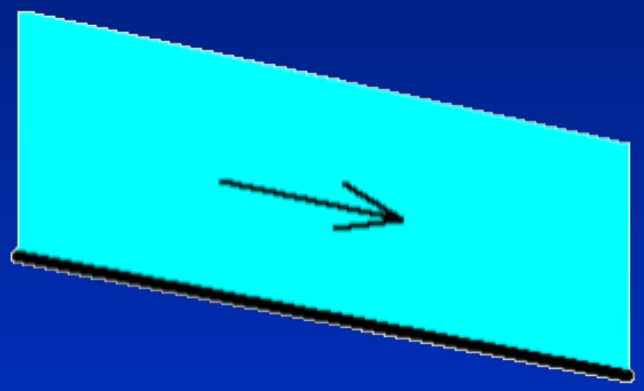
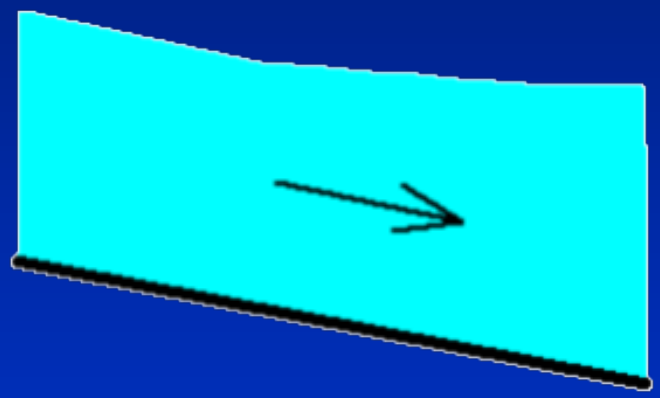
Spatial flow classifications

Uniform



Constant depth and velocity along the channel length

Varied



Changing depth and velocity along the channel length

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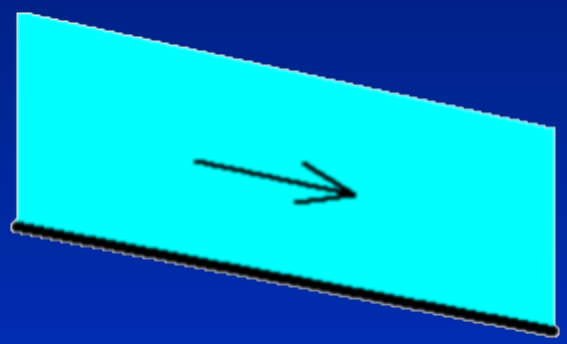
Spatial flow classifications

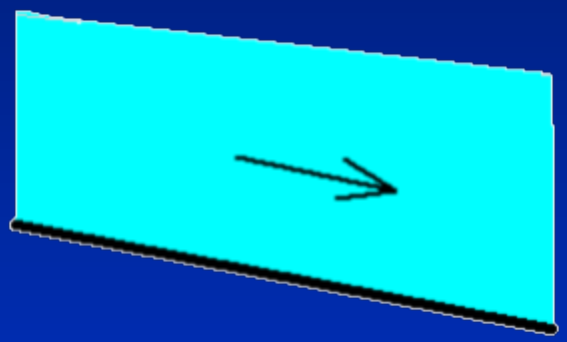
Uniform



water-surface slope = channel

Slope $S_w = S_o$

Gradually Varied



water-surface slope = friction

Slope $S_w = S_f$

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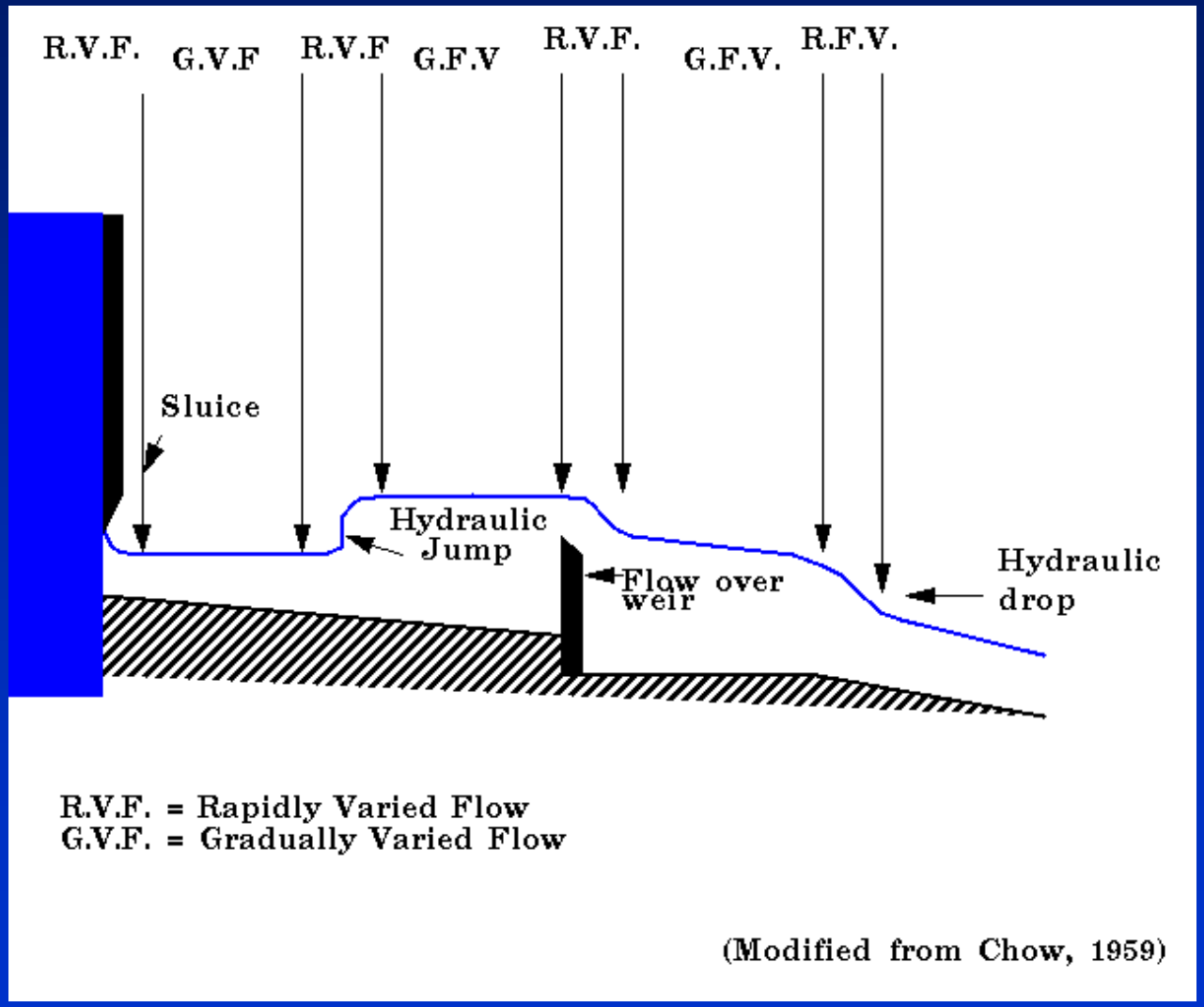
Gradually Varied Flow



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Flow-Classification Summary:

A. Steady flow
   1. Uniform flow
   2. Varied flow
      a) Gradually varied flow
      b) Rapidly varied flow

B. Unsteady flow
   1. Unsteady uniform flow (rare)
   2. Unsteady flow (i.e., unsteady varied flow)
      a) Gradually varied unsteady flow
      b) Rapidly varied unsteady flow

From Chow, 1959

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Open-Channel Flow:

- Types of Flow
- **States of Flow**
- Regimes of Flow

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State of Flow:

- State of flow governed by effects of viscosity and gravity relative to the inertial forces of the flow

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States of Flow:

- Viscosity vs. inertia: Reynold's Number

$$\mathbf{R} = VL/\nu$$

where V = velocity of flow
L = hydraulic radius
ν = kinematic viscosity of water

- Laminar flow: $\mathbf{R} \leq 500$
- Turbulent flow: $\mathbf{R} \geq 2000$

- Laminar flow rare in open channels

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States of Flow:

- Gravity vs. inertia: **Froude Number**

$$\mathbf{F} = V/(gL)^{1/2}$$

where V = velocity of flow
L = hydraulic radius (depth)
g = acceleration of gravity

- **F** = 1: $V = (gD)^{1/2}$ → Critical flow → Equilibrium
- **F** < 1: $V < (gD)^{1/2}$ → Sub-critical flow → Gravity dominates
- **F** > 1: $V > (gD)^{1/2}$ → Super-critical flow → Inertia dominates

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States of Flow:

- Critical velocity $(gD)^{1/2}$ known as the "*wave celerity*"
  - velocity of a gravity wave generated by a local disturbance in shallow water
- Ability of a gravity wave to propagate upstream is a criterion for identifying sub-critical or super-critical flow
- Flow in most channels is controlled by gravity → Sub-critical

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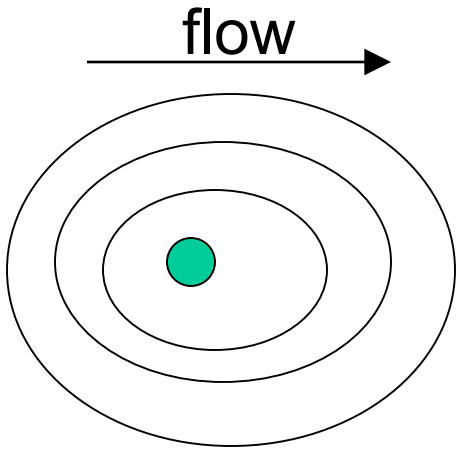
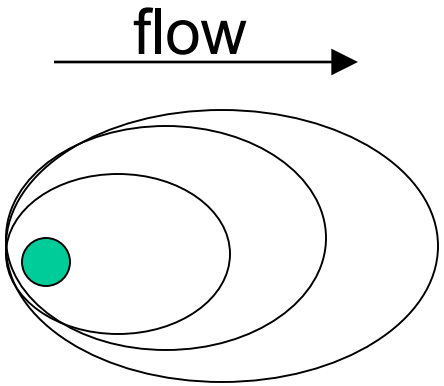
States of Flow



Sub-critical (tranquil) flow

$F < 1.0$



Supercritical (rapid) flow

$F > 1.0$

$F = 1.0$

critical flow

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Open-Channel Flow:

- Types of Flow
- States of Flow
- **Regimes of Flow**
- Basic equations

USGS

Regimes of Flow:

- Combined effect of viscosity and gravity → **4 regimes of flow**

1) Sub-critical – laminar: $F < 1$; $R \leq 500$

2) Super-critical – laminar: $F > 1$; $R \leq 500$

3) Sub-critical – turbulent: $F < 1$; $R \geq 2000$

4) Super-critical – turbulent: $F > 1$; $R \geq 2000$

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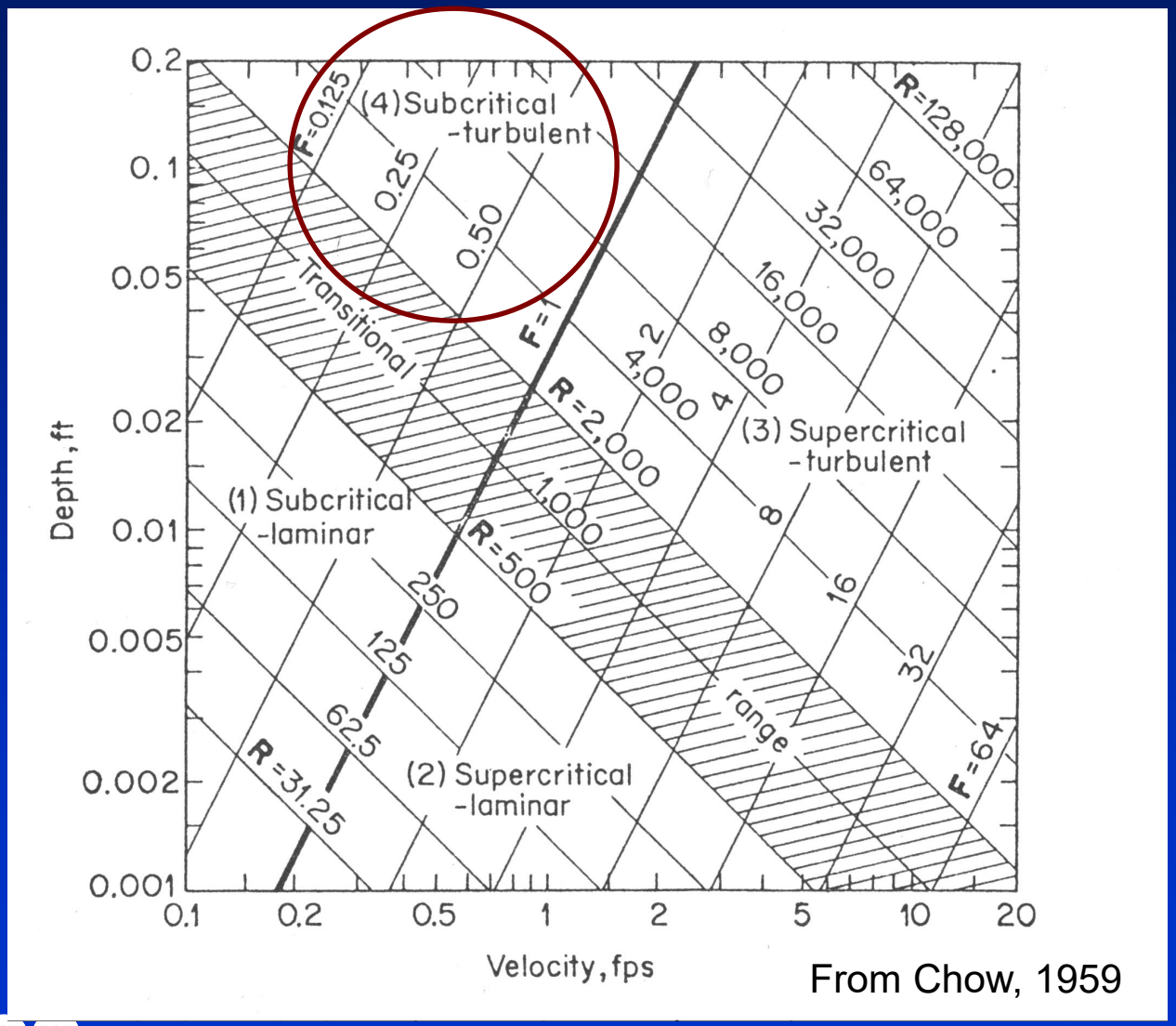
Regimes of Flow:



From Chow, 1959

Upstream Natural Control

Upstream view

Downstream view

Upstream control
- Flow past gage is supercritical

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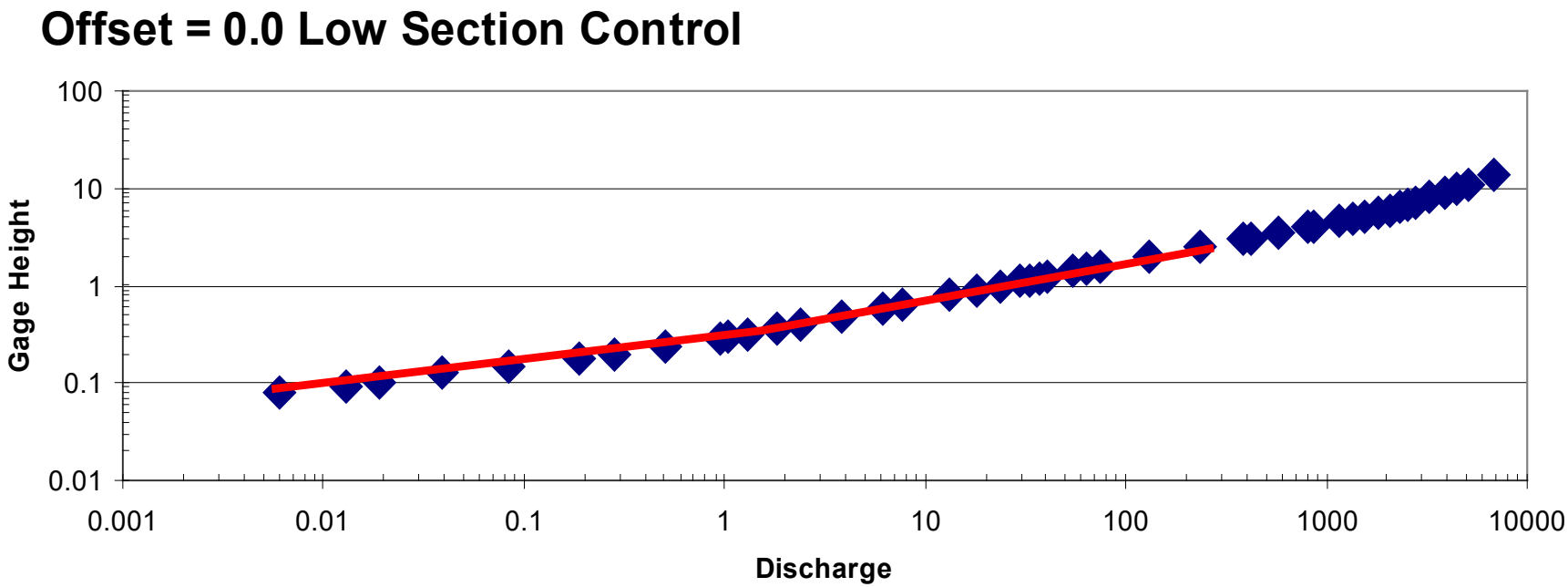
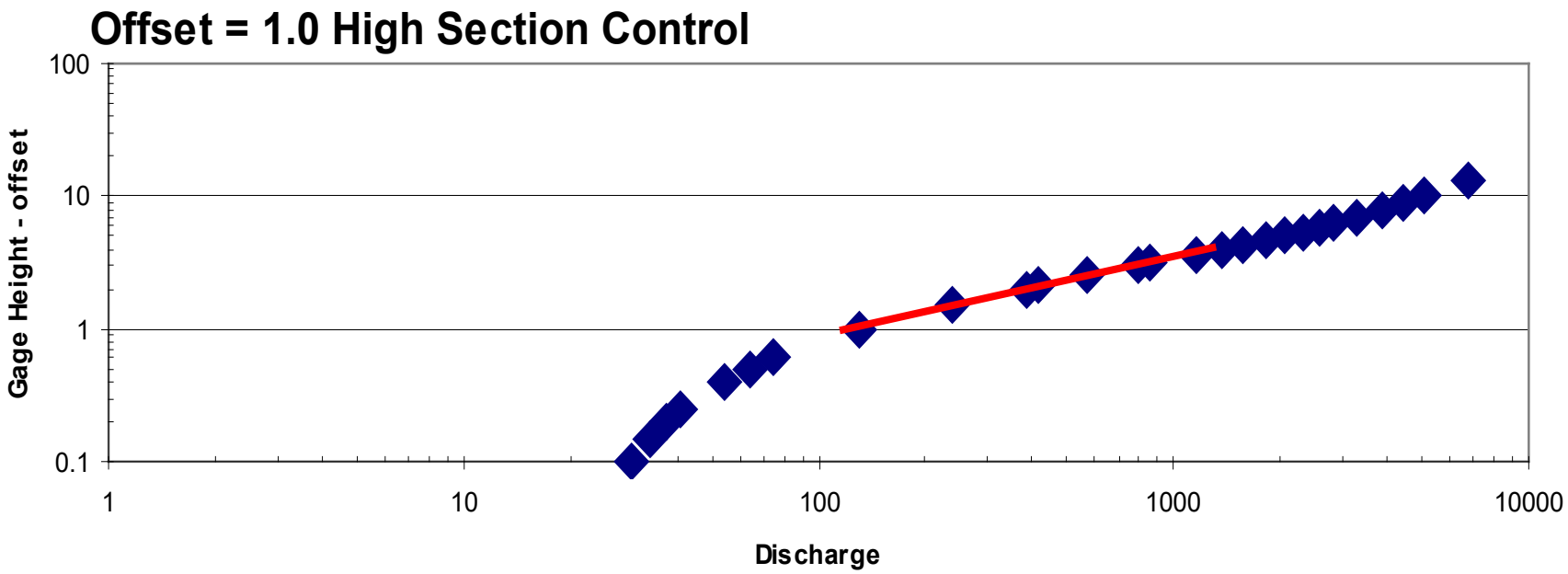
Rating and controls, San Francisquito Cr.

PZF = 0.07



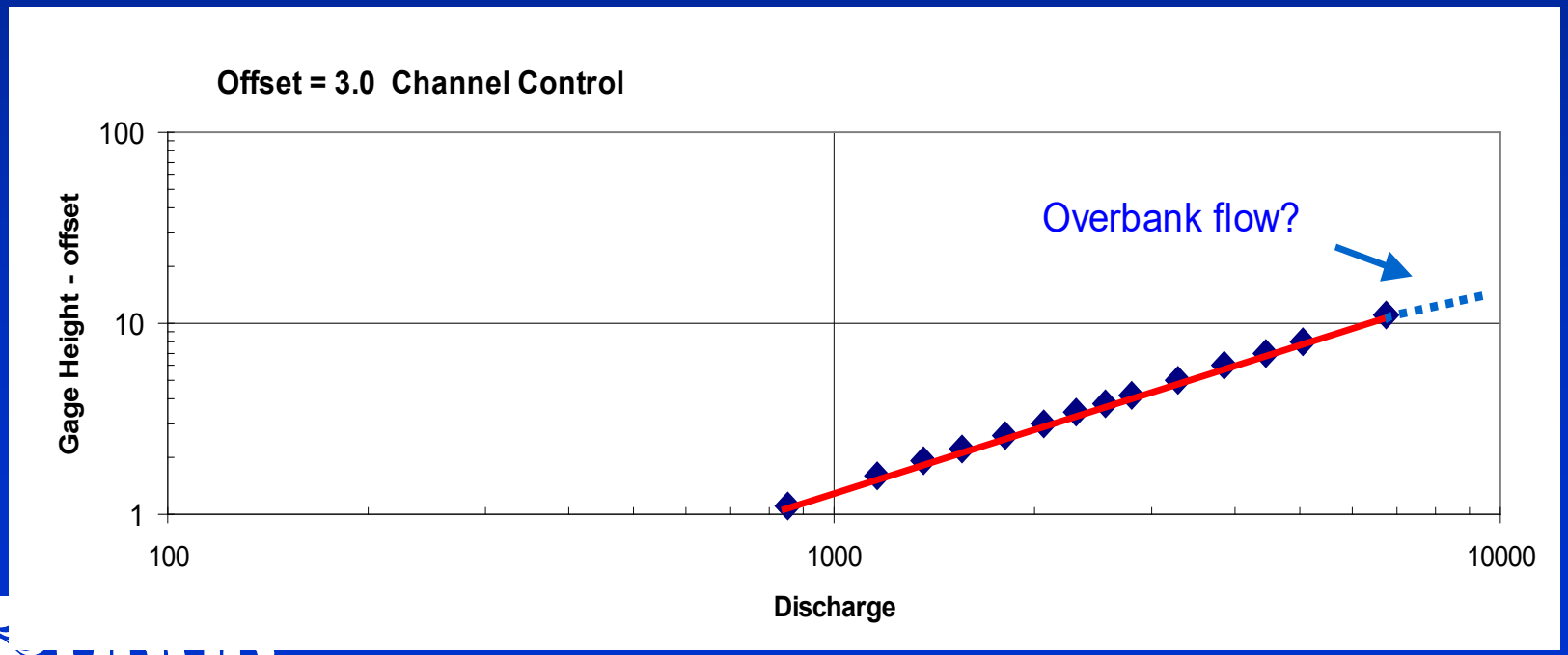
Rating and controls, San Francisquito Cr. (cont.)

Measurement at moderate flow
G.H. = 5.4

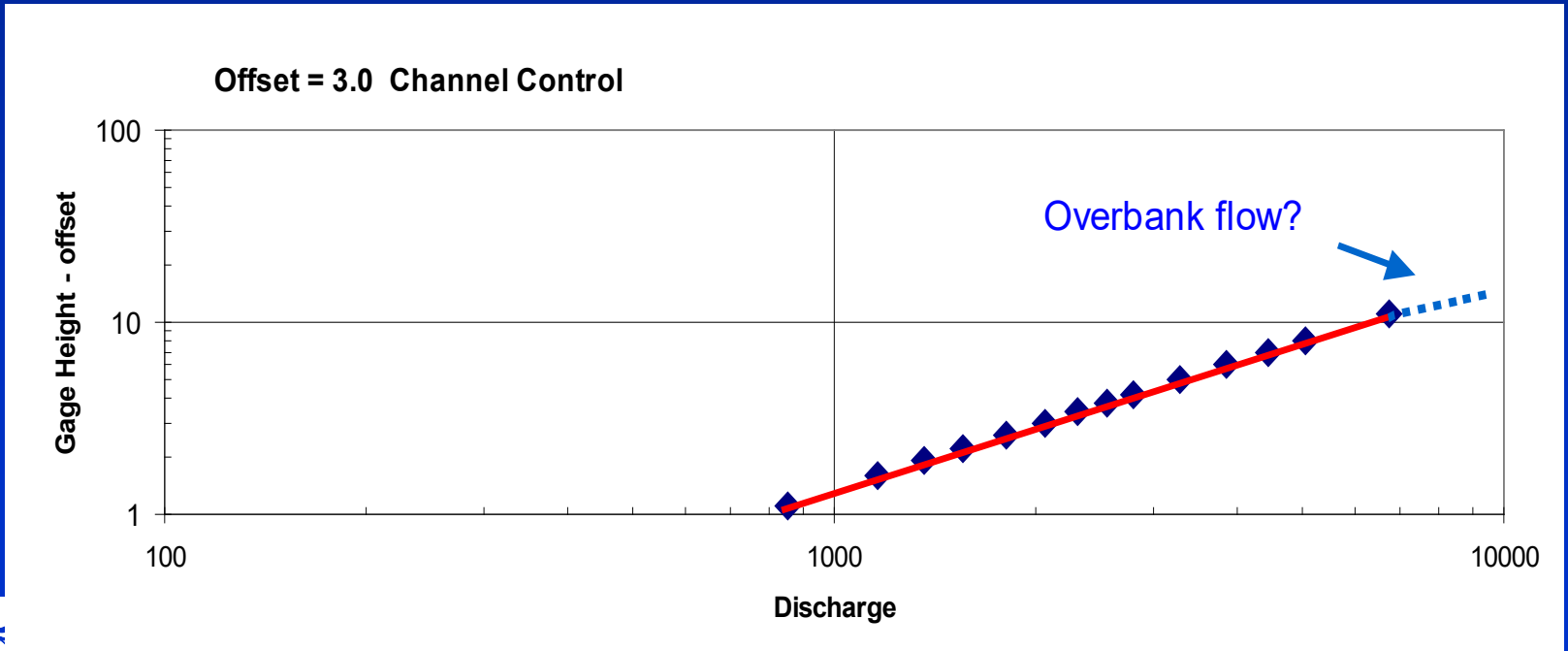


Rating and Controls, San Francisquito Cr. (cont.)

Channel Control beginning to dominate at this stage (6.25 feet)



Rating and controls, San Francisquito Cr. (cont.)



Shifting Controls

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Shifting Control

The non-cohesive streambed in this photo is subject to scour and fill, as well as changing vegetation conditions.

Unstable channel

Shifts

- Shift is a “temporary rating”
- Generally used for a <u>temporary</u> change in the control
  - Case 1: Assumes control will move back to the rating
  - Case 2: Control changes so frequently, shifts applied to avoid always making a new rating

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Shift Corrections

- Change the shape and/or position of the rating curve
- Creates a “temporary rating”
- By time
  - Simple
- By stage
  - Variable shift or V-shift diagrams
  - A better reflection of what actually happens in stream
- Combination of both

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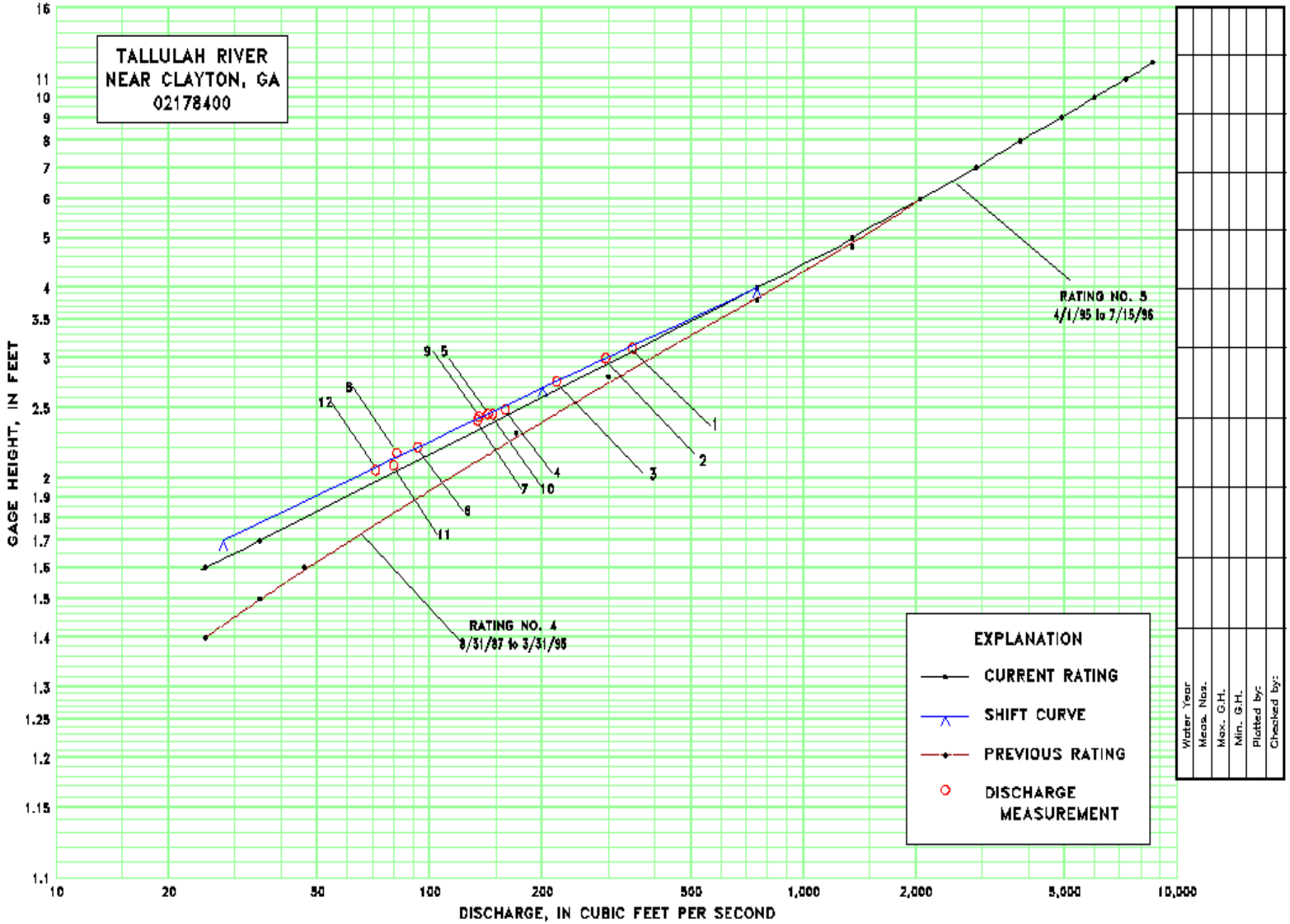
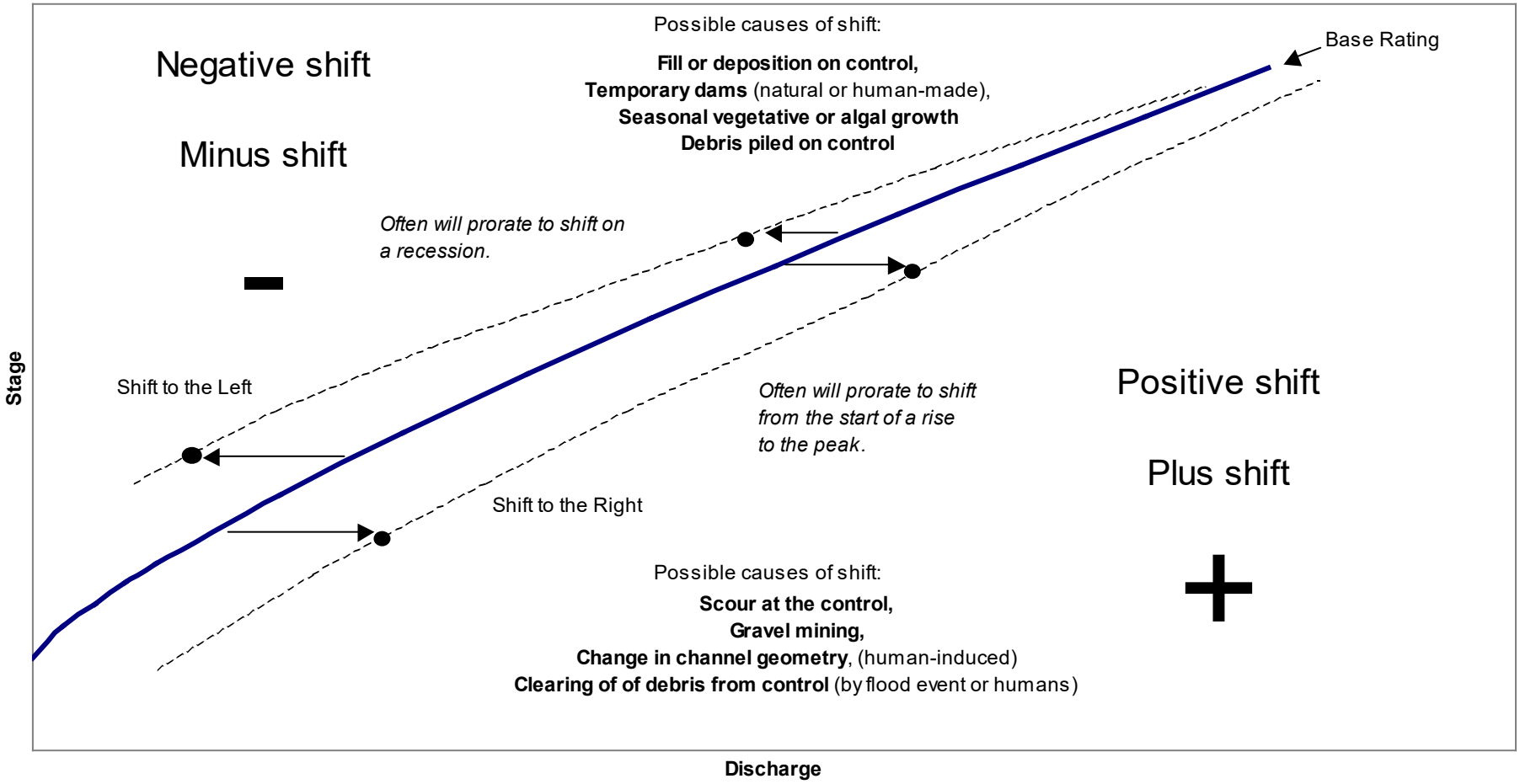
UNITED STATES DEPARTMENT OF THE INTERIOR -- GEOLOGICAL SURVEY (WATER RESOURCES DIVISION)



Rating Curve Shifts



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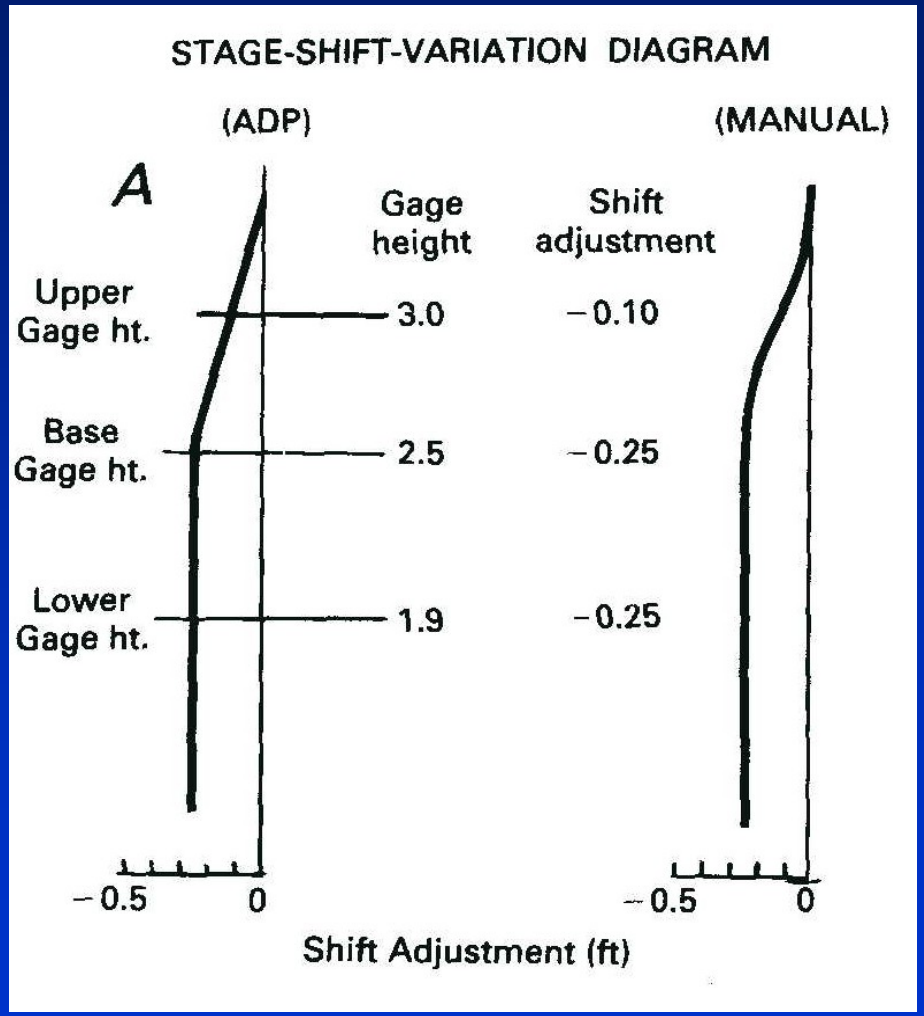
Shift Curve Shapes and Ratings



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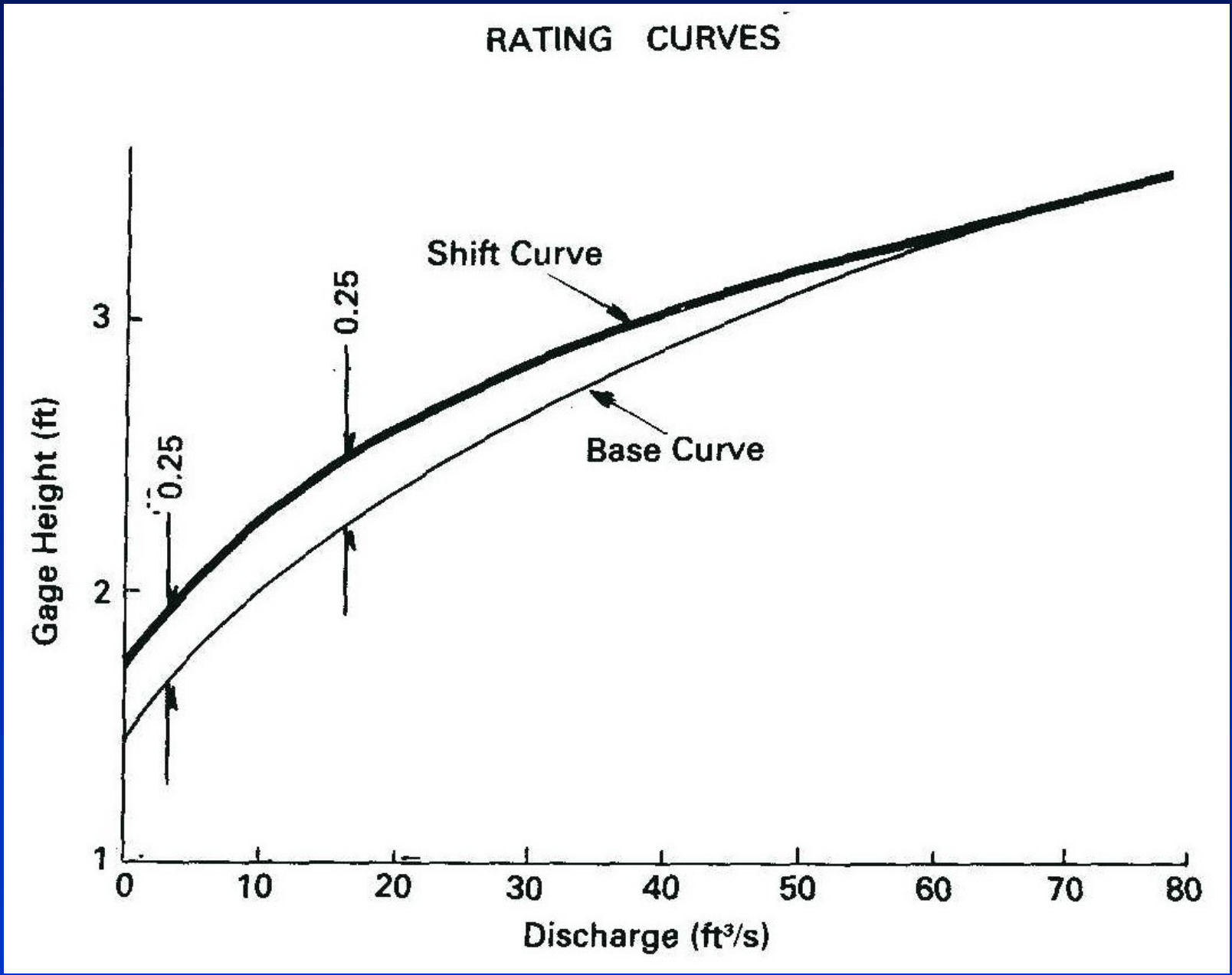
RATING CURVES
Shift Curve
Base Curve
0.25
0.25
Gage Height (ft)
1
2
3
0
10
20
30
40
50
60
70
80
Discharge (ft³/s)

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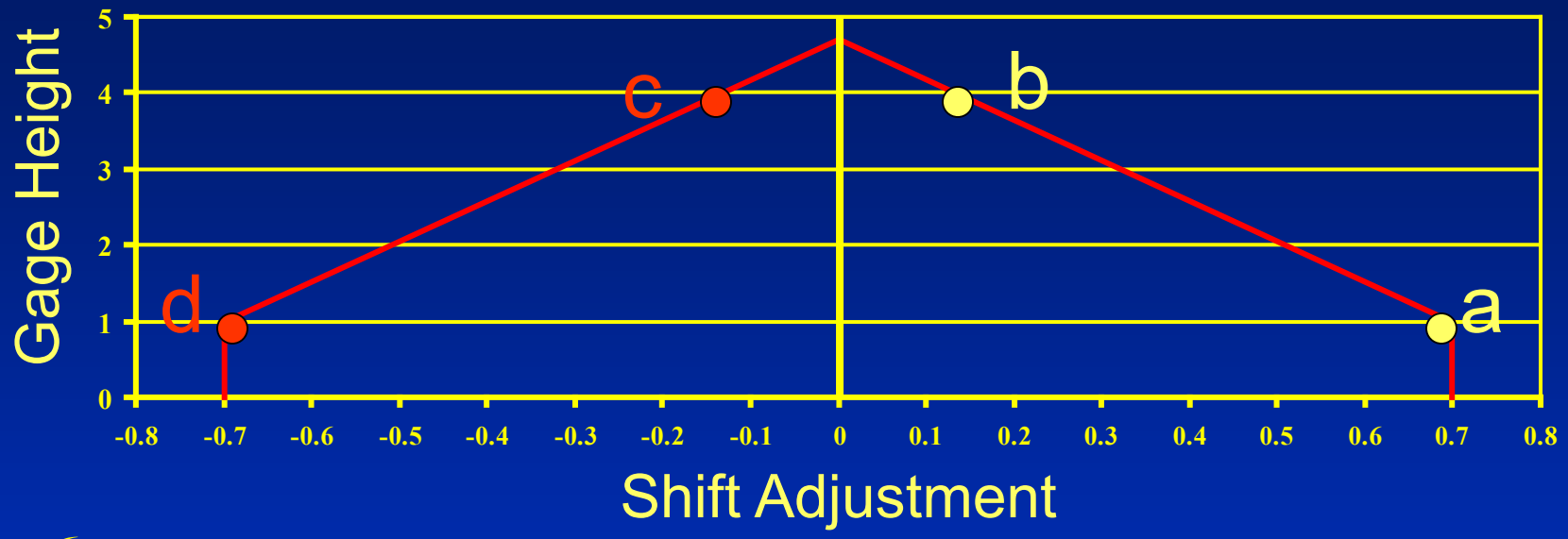
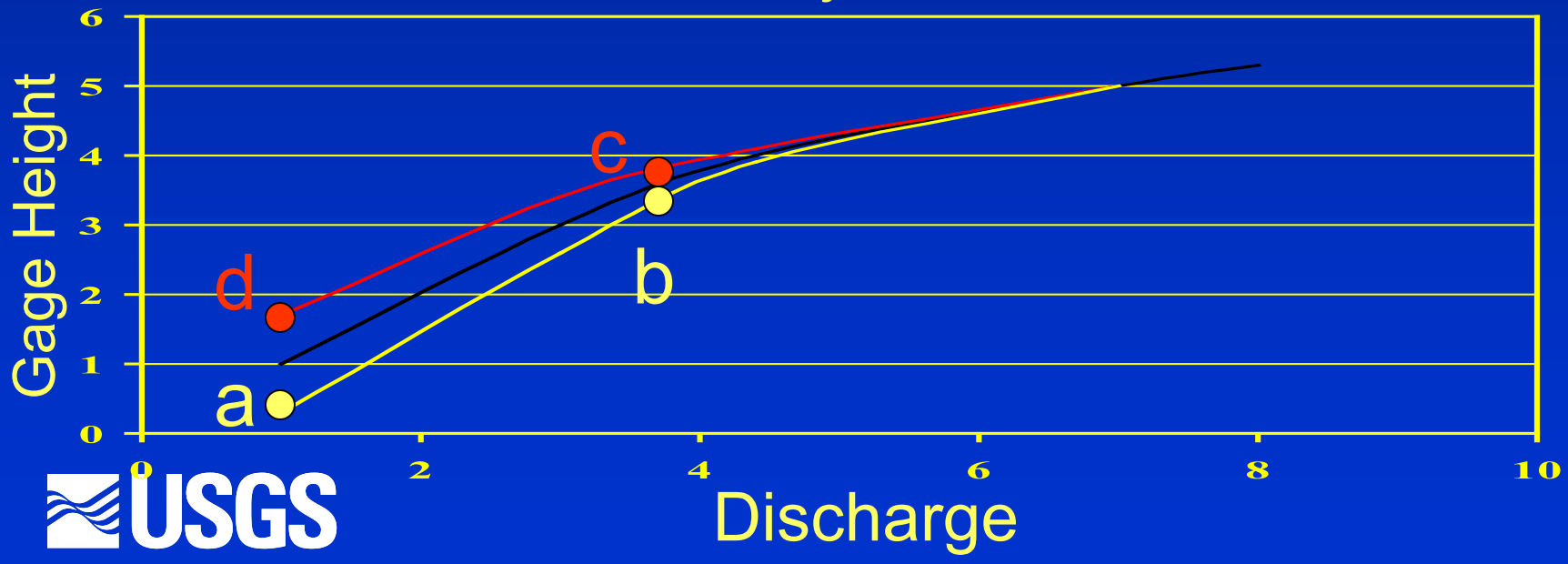
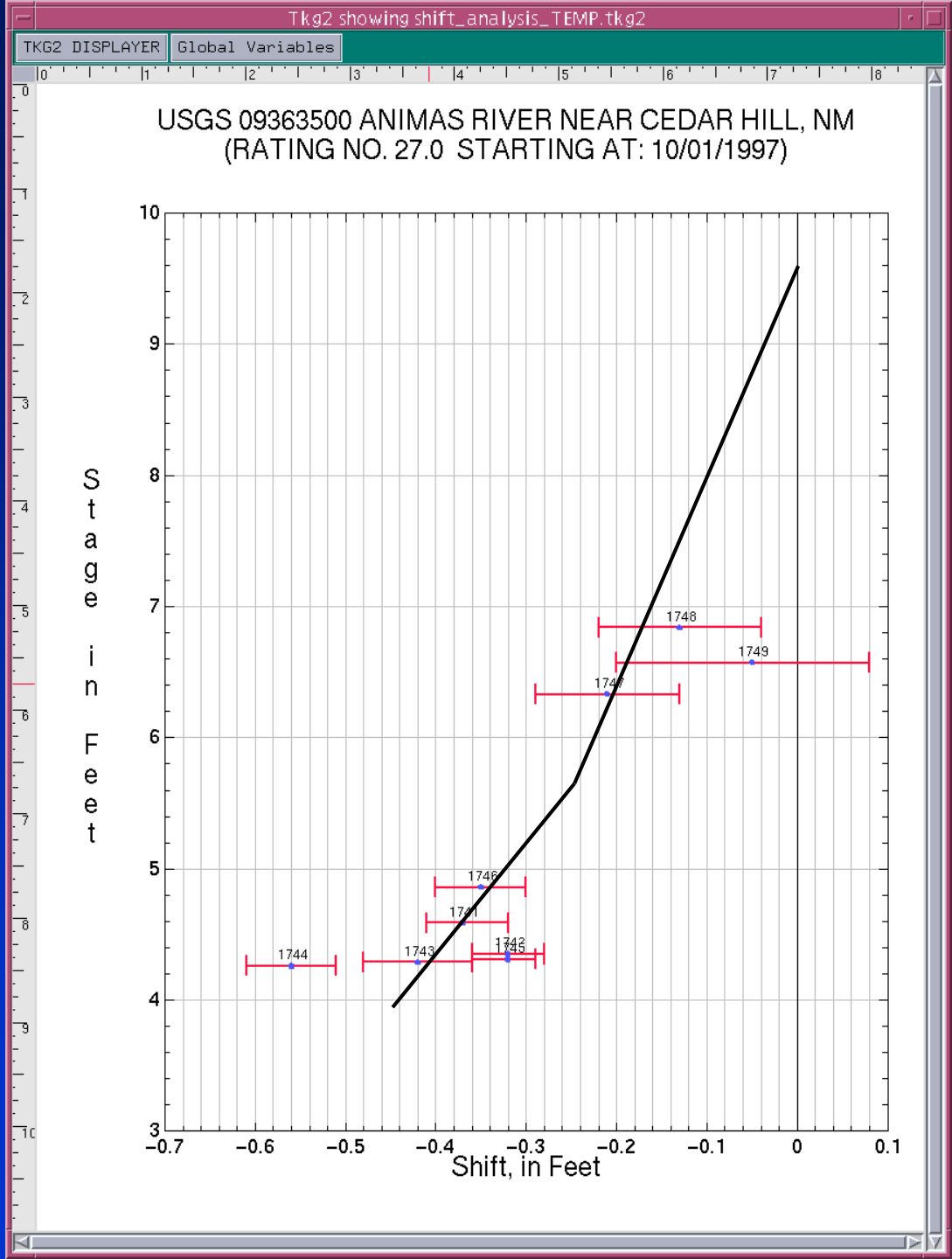
ADAPS uses up to 3-point "V-diagrams" to document shifts to ratings



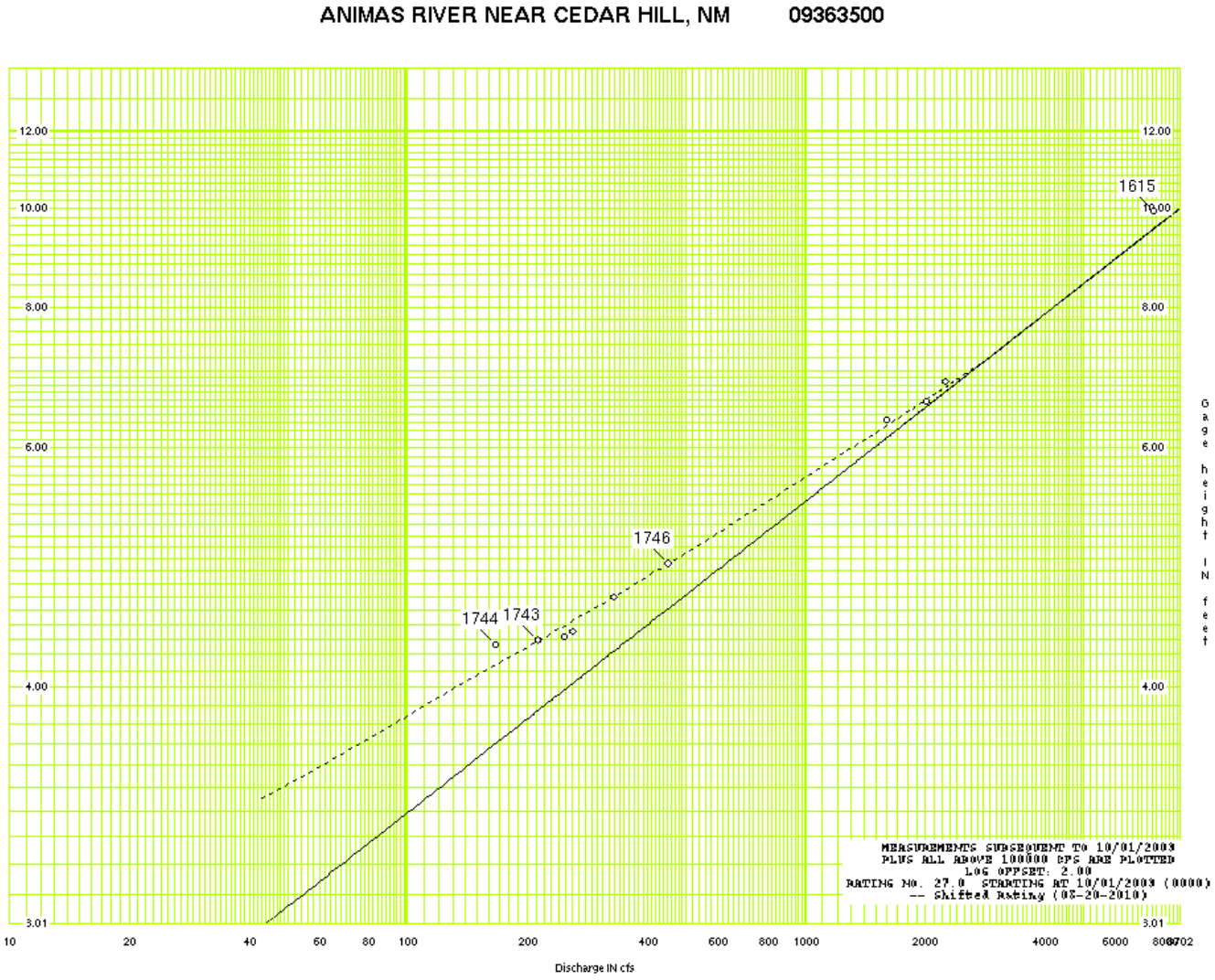



Tkg2 showing shift_analysis_TEMP.tkg2
TKG2 DISPLAYER
Global Variables
USGS 09363500 ANIMAS RIVER NEAR CEDAR HILL, NM
(RATING NO. 27.0 STARTING AT: 10/01/1997)
Stage in Feet
Shift, in Feet
1748
1749
1747
1746
1741
1742
1745
1743
1744
10
9
8
7
6
5
4
3
−0.7
−0.6
−0.5
−0.4
−0.3
−0.2
−0.1
0
0.1

USGS

Tkg2 showing cedar-shifted.tkg2

FILE | EDIT | PLOT | DATA | ANNOTATION | Global Settings | SCREEN SHOTS | HELP



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How many shifts do you see?

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