8. NATIONAL INSTITUTE OF HYDROLOGY, ROORKEE

River Gauge-Discharge Modeling

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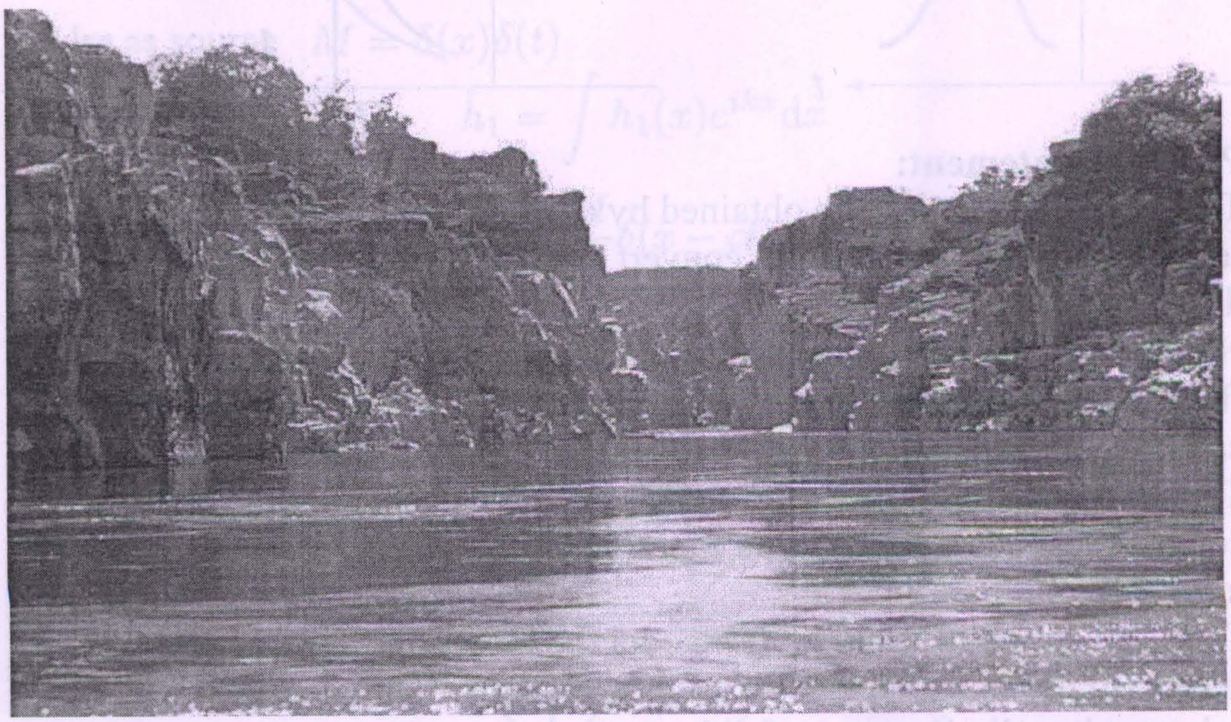
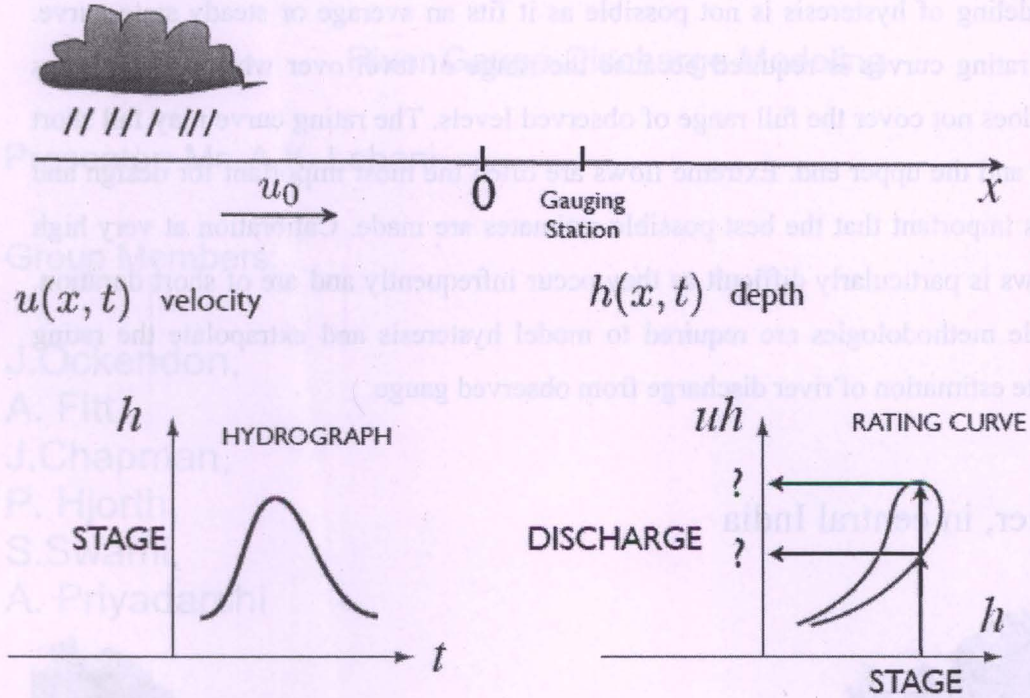
Problem: Stream flow information is important for effective and reliable planning and management of various water resources activities and the assessment, management and control of water resources can be effective if accurate and continuous information on river-flow is available. Direct measurement of discharge in a stream is not only difficult and time consuming but also expensive. Therefore, the discharge in a stream is related to the stage through a number of carefully measured discharge values. Generally a network of river gauging stations provides continuous information on river stage and sparse information of corresponding discharges. The continuous discharge data corresponding to observed gauge can be obtained by developing a stage discharge relationship and using this relationship to convert the recorded stages into corresponding discharges. This relationship is determined by correlating measurements of discharge with the corresponding observations of stage. However, under certain conditions (flatter gradients and constricted channels) the discharge for a flood on a rising stage differs from that on the falling stage. This phenomenon is called hysteresis and results in a looped stage-discharge curve for floods with different stage-discharge relations for rising and falling water stages. The functional relationship between stage and discharge is complex and can not always be captured by the traditional modeling techniques. Using the conventional curve fitting approach the modeling of hysteresis is not possible as it fits an average or steady state curve. Extrapolation of rating curves is required because the range of level over which gauging has been carried out does not cover the full range of observed levels. The rating curve may fall short at both the lower and the upper end. Extreme flows are often the most important for design and planning and it is important that the best possible estimates are made. Calibration at very high instantaneous flows is particularly difficult as they occur infrequently and are of short duration. Therefore, suitable methodologies are required to model hysteresis and extrapolate the rating curves for accurate estimation of river discharge from observed gauge.

Narmada River, in central India



the problem



Problem statement:
The discharge data can be obtained by developing a stagedischarge relaitionship and use this to convert recorded stages to corresponding discharges.
However, under certain conditions the discharge for a [rising] flood differs from that on the [falling] stage. This phenomenon is called *hysteresis*, and results in a looped stage-discharge curve...
The functional relationship between stage and discharge is complex and cannot always be captured by traditional modeling techniques.
The study group is asked to: (a) model the loop stage-discharge curve; (b) use this to develop a method to extrapolate measured values at low discharge to a full loop curve.

1-D nonlinear equations for a river
Horizontal base, constant cross section

$$\frac{\partial h}{\partial t} + \frac{\partial}{\partial x}(hu) = \text{source term} = M(x,t)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial h}{\partial x} = 0$$

Linearize about $(u,h) = (0,h_0)$

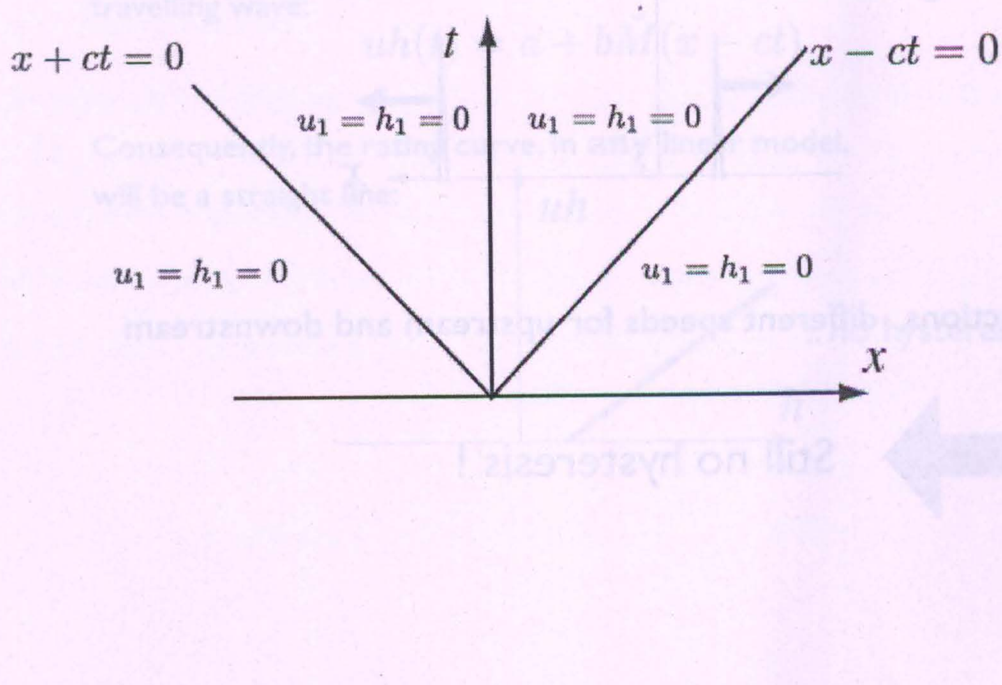
$$\frac{\partial h_1}{\partial t} + h_0\frac{\partial u_1}{\partial x} = M(x,t)$$

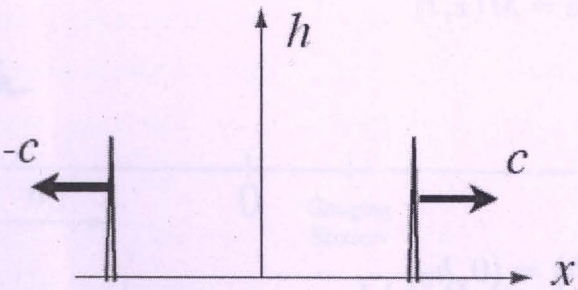
$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial h}{\partial x} = 0$$

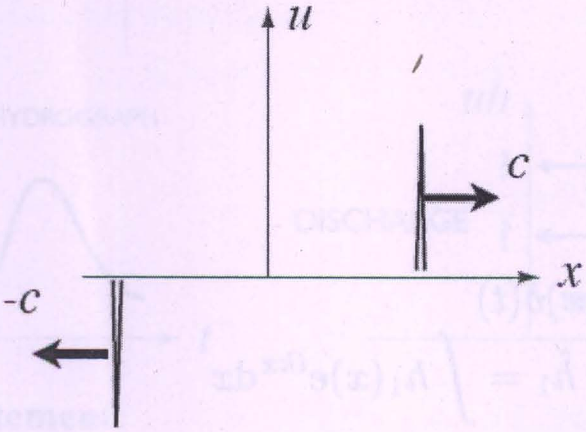
Use as source $M = \delta(x)\delta(t)$

Fourier transform: $\hat{h}_1 = \int h_1(x)e^{ikx}\mathrm{d}x$

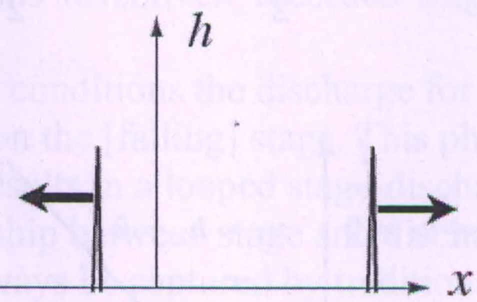
$$h_1 = \frac{M}{2}\delta(x-ct) + \frac{M}{2}\delta(x+ct)$$







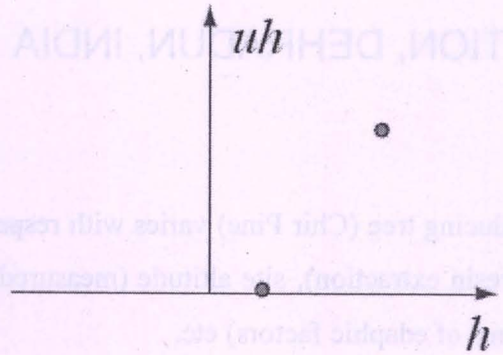
On a **flowing** river:



Still δ functions, different speeds for upstream and downstream

Still no hysteresis !

Rating curve:



No hysteresis !

General argument why this is so:

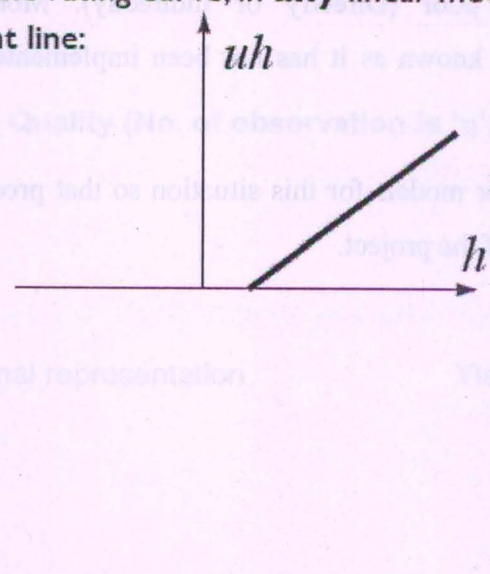
When we use a linear model, the signal h(t), seen at some fixed x value far from the source, will be a travelling wave:

$$h(t) = M(x - ct)$$

The discharge, uh(t) will be some linear combination of the same travelling wave:

$$uh(t) = a + b\tilde{M}(x - ct)$$

Consequently, the rating curve, in any linear model, will be a straight line:



:: no hysteresis !