Lecture 25—Flood routing

We spent some time last week chatting about flood frequency, and estimating flood peak. One of the things we'd most like to know about, though, is something about the *dynamics* of a flood wave as it passes through a watershed. This is especially important in large river systems because it can help predict flood peaks—this might help with things like knowing how high you have to sandbag, or enable reservoir managers to know how much to draw down reservoirs.

In fact, flood control dams are a great place to start. Here in Ohio most of our dams are for water supply—a mill needs water either for some industrial process or to generate power. But in California and other arid environments, most dams are put up for flood control. These dams are designed simply to hold onto water for a little while, and release it slowly. This results in a hydrograph with a lower peak, but the same area as the undammed watershed {figure}. An aside—there *are* flood-control dams in the world that actually alter the area under the hydrograph. In Oman, a basically desert country, crops are grown only on the north coast (Al Baitnah), a region separated from the arid interior by a range of mountains. Overproduction has resulted in salinization of a number of important wells in the Al Batinah region, and loss of cropland. Rain, when it falls, falls heavily in the mountains, and flash floods run down *wadis* to the sea, so that water is lost for irrigation. However, a number of flood control dams have been placed on these wadis, but not with an eye to reducing the hydrograph peak—instead in intent is to cause some of the water to soak into the ground and recharge the failing wells (and yes, it's working).

Basically, a flood control dam is a lot like the *linear reservoir* we talked about earlier. Water is held in storage for some time (controlled by the dam manager) before being released. This results in a quick and easy equation for dams:

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

Take a look {example problem}.

The process of predicting the attenuation of a flood wave as it travels downstream, or through a control structure, is called *flood* *routing*. There's two different ways people attempt to do it—one uses our basic hydrologic continuity equation $\left(I - O = \frac{dS}{dt}\right)$ to balance inflow, storage, and outflow, and then governs the relationship between outflow and storage through some form of storage-discharge relationship. This is called *hydrologic routing*. The *other* method uses the continuity equation for open channel flow $(Q = VA)$ and a statement about the conservation of momentum for unsteady flow. This is called *hydraulic routing*. Hydraulic routing is generally more complex than hydrologic routing, and is often solved using finite difference or finite element rather than explicitly.

For natural rivers the attenuation process is more complex than for dams. Take, for example, the 1993 Upper Mississippi floods. We know that great portions of the Upper Mississippi valley were flooded, yet by the time the flood reached New Orleans, it wasn't anything like as bad as in Iowa. Why is that? It's because of storage within the river system itself. When flow is rising, there's a parcel of storage within the reach between inflow and outflow because of the lag between inflow increase and outflow increase. This is called *wedge storage*. The elevated reach of water during the flood is called *prism storage*, and finally as the flow falls, there's wedge storage while the outflow is greater than the inflow. So, if you had a routing method that allows for wedge storage, you could predict the flow at points downstream, and see how the flood wave attenuates.

Several such methods exist. Two we're going to talk about (because they show up in papers a lot) are the Muskingum method and the Runge-Kutta methods.

Muskingum

The Muskingum method uses the basic hydrologic continuity equation we've used before, and a storage term that depends both on the inflow and outflow:

$$S = K[xI + (1 - x)Q]$$

where x is a weighting factor between 0 and 0.5 that says something about how inflow and outflow vary within a given reach, and K is the travel time of the flood wave.

For the case of a linear reservoir like we talked about, S depends only on outflow, so x=0 and S=KQ. In a perfectly smooth channel, x=0.5 and S=0.5K(I+Q), which results in simple translation of the wave. Typical streams have values of x=0.2 to 0.3.

The routing procedure itself uses the finite difference form of the storage-discharge relationship:

$$S_2 - S_1 = K\left[x(I_2 - I_1) + (1-x)(Q_2 - Q_1)\right]$$

which can be rearranged to produce the outflow equation:

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$$

where

$$C_0 = \frac{-Kx + 0.5\Delta t}{D}$$

$$C_1 = \frac{Kx + 0.5\Delta t}{D}$$

$$C_2 = \frac{K - Kx - 0.5\Delta t}{D}$$

$$D = K - Kx + 0.5\Delta t$$

Note that K and Δt must have the same units, and that $2Kx < \Delta t \leq K$ for numerical accuracy, and that $C_0+C_1+C_2=0$. The routing procedure is accomplished successively, with Q_2 becoming Q_1 of the successive calculation. {example}.