Contents

Surface Water

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Streams are important for water supply, for flood prediction and forecasting, and from a water quality perspective. In this section we will cover the processes by which precipitation excess enters streams and moves through the network and rainfall-runoff modeling.

Hyetograph is the graph of water input vs. time.

Streamflow hydrograph is a graph of stream discharge vs. time. Watershed response to the event is characterized by measuring the stream discharge (volume rate of flow).

Some of the characteristics of a hydrograph of a stream responding to an isolated event are: the flow rate increases relatively rapidly called the **hydrograph rise** to a well-defined **peak discharge** then it declines more slowly as the **hydrograph recession** brings the flow rate near its pre-event value. Streamflow is an integrated response to spatially and temporally varying input rates, and the time required for each drop to the water to travel into and through the stream network.

Water falls on the hillslopes and flows in an infinite number of paths. Then as it is channeled to the stream network, it is an accumulation of temporally and spatially varying lateral inflows from the hillslope. We can use the conservation of mass and the equation of motion to describe the flows. In the stream the flow takes the form of a floodwave moving downstream. The volume of water that appears in response to a given event is only a small fraction of the total input, because the remainder leaves as evapotranspiration and base flow.

1. Hydrograph Separation

Some of the water in the hydrograph response comes from previous events "old water". How do we associate the portion of a stream response for a certain event? One way is isotopes, but isotopes are not generally available. Usually, we only have total water inflow and total streamflow, so graphical techniques are usually used to separate streamflow into:
event flow (direct runoff, storm runoff, quick flow or storm flow) which is the direct response to an event.
base flow not associated with a specific event usually assumed to be ground-water input.

Figure 1: Dingman Figure 8-38

The volume of baseflow varies greatly depending on the method used. One must always use the same method if the goal is to compre between watersheds, but all of these methods are somewhat arbitraty. The event flow volume at any instant is calculated as:

$$q_{ef} = q - q_{bf} \tag{1}$$

where q is the total flow rate, q_{bf} is the base-flow and q_{ef} is the event-flow rate. Graphical hydrograph separation is a convenient fiction that must be invoked to analyze the streamflow response.

2. Quantitative Description of Response Hydrographs

We focus only on the portion of streamflow identified as event flow.

effective water input fraction of water input that appears as event flow.

storm duration $T_W = t_{we} - tw0$.

hydrograph rise begins at t_{p0} until qpk, time of peak flow which occurs when or soon after input ceases.

response lag time between beginning of input and beginning of rise $T_{LR} = t_{q0} - t_{w0}$.

lag to peak time between the beginning of input and the peak $T_{LP} = t_{pk} - t_{w0}$.

time of rise or time to peak duration of hydrograph rise $T_r = t - pk - t_{q0}$

base time total duration of response hydrograph $T_b = t_{qe} - t_{q0}$.

centroid or center of mass of input is the weighted average time of occurrence of the hyetograph t_{wc}.

$$t_{wc} = \frac{\sum_{i=1}^{n} W_i t_i}{\sum_{i=1}^{n} W_i} \tag{2}$$

we can do the same for the hydrograph and find the centroid of a response hydrograph t_{qc}

centroid lag time between centroids of input and response $T_{LC} = t_{qc} - t_{wc}$.

centroid lag to peak $T_{LC} = t_{pk} - t_{wc}$.

time of concentration time it takes for the water to travel from the most distant part of the watershed to the outlet $T_c = t_{qe} - t_{we}$.

equilibrium runoff if effective water input continues at a constant rate for a duration T_c the outflow rate will equal the input rate and the time at which this occurs is the **time to equilibrium** T_{eq}. This can occur in parking lots or small areas (not natural watersheds).

3. Linear-Reservoir Model of Watershed Response

Using conservation of mass where w is input rate, q is output flow, and V is storage.

$$w - q = \frac{dV}{dt} \tag{3}$$

We can assume that the outflow is proportional to the storage, and that the proportionality constant is $1/T^*$ where T^* characterizes the response of the reservoir, and it is the only parameter that we need for this model.

$$q = \frac{1}{T^*} V \tag{4}$$

This captures the most basic aspects of watershed response. If we combine these two equations:

$$w - q = T^* \frac{dq}{dt} \quad (5)$$

which for a constant w has the solution:

$$q = w + (q_0 - w)exp(-t/T^*) \quad (6)$$

where q_0 is the outflow at $t = 0$. If we assume $q_0 = 0$, then for all $t \leq t_w$

$$q = w(1 - exp(t/T^*)) \quad (7)$$

for the recession, $w = 0$, the initial discharge q_{pk} at t_{pk}, for all $t \geq t_w$

$$q = q_{pk}exp(-(t - t_{pk})/T^*) \quad (8)$$