# II.4-UNIT-HG UNIT HYDROGRAPH

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## Introduction

The unit hydrograph converts runoff volume into instantaneous discharge at a gage or flow-point (Sherman, 1932 and Linsley, Kohler, Paulhus, 1975).

The unit hydrograph is based on a given unit (depth) of runoff occurring over a given watershed (area) during a given data time interval. It produces the typical hydrograph defined at specific ordinates which this volume of runoff would characteristically generate at a flow-point. In terms flow the unit hydrograph can be defined as the outflow hydrograph in CMS which results from 1 MM of runoff from a runoff period of given duration. In terms of volume it represents 1000 M3 per KM2 since a depth of 1 MM over 1 square KM is equal to 1000 M3.

The unit hydrograph is a useful hydrologic tool because it is an effective yet simple method of distributing runoff. In technical terms it represents a linear and time invariant system. It continuously takes into consideration channel storage effects above a flow-point and the travel time or areal distribution of runoff. Unit hydrographs also have the important characteristic of proportionality. For runoff intervals of a constant length, changes in runoff volume do not alter the base length of the unit hydrograph. Ordinates are raised or lowered in proportion to the volume of runoff produced. In addition the time distribution of runoff from a given computational interval is independent of concurrent runoff (or the lack thereof) from antecedent or future intervals. Runoff distributed to ordinates from one computational interval may be added to or superposed upon distributed runoff from adjacent intervals.

Application

The unit hydrograph can be used to time distribute the runoff produced by each of the rainfall-runoff models. The unit hydrograph that is used for a given flow-point is dependent on the type of rainfall-runoff model that is used to generate runoff. For example the runoff produced by the Sacramento soil moisture accounting model is the amount of water that is entering the channel system during a given time interval. Physically, this includes the following components of runoff:

1. Surface runoff which occurs when the storage capacity of the UZFW is exceeded.

2. Impervious runoff from impermeable surfaces within the catchment if PCTIM > 0.0.

3. Direct runoff from surfaces which become impermeable when ADIMP > 0.0 and UZTWC=UZTWM.

4. Interflow and baseflow contributions which are mostly the result of additions to free water storages caused by rain + melt during previous computational intervals.

At the end of every computational time interval the sum of these components is applied to the unit hydrograph. Unit hydrograph computations are performed by subroutine EX2 which is the execution subroutine of the unit hydrograph Operation. It is important to realize that most of the water which enters interflow (UZFWC) and baseflow (LZFSC, LZFPC) storages during an interval of rain or melt does not enter the channel during that interval. Instead this water is delayed by lateral drainage rates and ultimately reaches the channel system during subsequent computational intervals, at which time it is then included in runoff applied to the unit hydrograph.

The most common and traditional unit hydrographs are those which were developed to distribute runoff from antecedent precipitation index (API) rainfall-runoff procedures. However API-type unit hydrographs are different from the type of unit hydrograph required to distribute runoff produced by Sacramento soil moisture accounting. In order to develop and apply a unit hydrograph appropriate for the Sacramento model, it is necessary to understand the components of runoff described in the previous paragraph. It is not necessary to develop an API-type unit hydrograph as a preliminary step toward developing a Sacramento model unit hydrograph. The latter can be developed on its own from scratch or the elements of existing time-delay-histograms may be converted to unit hydrograph ordinates. Under certain circumstances, an API-type unit hydrograph may be similar to the unit hydrograph needed for the Sacramento model. This occurs when a flow-point receives most of its flow from surface, impervious and direct runoff. The API-type unit hydrograph may be used with caution as a first approximation to a Sacramento model unit hydrograph under these circumstances. But these circumstances are the exception and not the rule and new unit hydrographs would have to be developed for most flow-points. The following examples and discussion should help to clarify this matter.

Figure 1 [Bookmark], Figure 2 [Bookmark] and Figure 3 [Bookmark] illustrate three examples of runoff/unit hydrograph relationships. A rain of 35.0 MM during one computational time interval (6 hours in this example) was applied to three soil moisture accounting areas. Each area had its own set of Sacramento soil moisture parameters. However the following initial conditions were common to all three areas at the beginning of the rainfall: UZTWC equaled UZTWM, UZFWC equaled 0.0, LZFSC equaled 0.0 and LZTWC equaled LZTWM. Each area produced a different amount of runoff during the rainfall interval and during subsequent intervals, all of which were rainless. In this case, runoff due to primary baseflow carried over from before the event and additions to primary baseflow resulting from the rainfall were neglected. Runoff (channel inflow) from each computational interval was then applied to a common unit hydrograph. The resulting hydrographs from all three areas are then considered to be the observed hydrograph and a unit hydrograph is derived from each by the traditional method. The resulting 'traditional' unit hydrographs are seen to differ from the unit hydrograph used with the soil moisture accounting procedure. It is evident that this difference is slight when most of the runoff is surface runoff. However when the runoff is predominantly supplemental baseflow and interflow there is a very significant difference in unit hydrographs. Thus it should be clear that API-type unit hydrographs previously developed from events which contained significant amounts of interflow and supplemental baseflow are not appropriate for use with the Sacramento soil moisture accounting model.

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## Duration and Ordinate Spacing

Unit hydrographs are always associated with a specific runoff time duration. The time duration of the unit hydrograph is determined by the computational time interval of the corresponding rainfall-runoff Operation. If the unit hydrograph for a particular flow-point does not have a time duration equal to the time interval of the rainfall-runoff Operation then the unit hydrograph must be converted so as to have the same duration. Fortunately conversion procedures are rather straightforward and durations can be either shortened or lengthened as necessary. Tabular and S-curve conversion techniques can be found in Linsley, Kohler and Paulhus (1975) when conversion is necessary.

The time duration of the unit hydrograph must be an even multiple of the time interval between ordinates. It is possible and often desirable to define a unit hydrograph with the ordinate spacing less than the runoff duration. Hydrograph shape can be more accurately defined when a greater number of ordinates are used to distribute runoff. This option is especially useful for basins which respond quickly. It allows peaks which are sharp to be more closely simulated. It also permits flows to be routed at smaller time intervals thus increasing the mathematical accuracy of the routing procedures.

Table 1 [Bookmark] is an example of a 6 hour unit hydrograph defined with ordinates spaced 6 hours apart in Example A and 3 hours apart in Example B.  Several methods (including curvilinear interpolation or simply picking values off a plot) may be used to define additional unit hydrograph ordinates.

Table 2 [Bookmark] is an example of runoff applied to the unit hydrograph from Table 1 Example B.  Beginning at midnight, runoff from eight consecutive runoff intervals (2 days) has been applied to the unit hydrograph.  Note that there is a carryover from computational intervals prior to Day 1.  Instantaneous discharge is found by summing the vertical columns which contain temporally distributed discharge values from all of the appropriate runoff intervals.  The resulting hydrograph is readily defined with ordinates spaced 3 hours apart.

Since unit hydrographs represent a unit depth of runoff over a given area the size of the drainage area can be estimated from the ordinates of the unit hydrograph.  The drainage area is estimated automatically by the parameter input routine.  The estimate is computed by assuming the ordinates are connected by straight lines thus:

$$\text{Area} = \Sigma \text{ ordinates}/(24/\text{timeint}) * 86.4$$

where timeint is the ordinate spacing in hours
86.4 is a conversion factor
area is drainage area in KM2

A warning message is printed if the computed area and the input area differ by more than 1 percent.

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## Conversion

Non-metric unit hydrographs are usually based on 1 inch of runoff. Conversion to metric is accomplished by dividing each ordinate separately by the conversion factor 897.0 which combines the factors 25.4 (MM per IN) and 35.3147 (FT3 per M3).

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## References

Linsley, R.K., Kohler, M.A. and Paulhus, J.L.H., 1975: Hydrology for Engineers, 2nd edition, McGraw Hill Book Co., New York.

Sherman, L.K., 1932: Streamflow from Rainfall by the Unit-graph Method, Engineering News Record, volume 108.

Table 1. Examples of 6 hour Unit Hydrographs

Example A: 6 hour ordinate spacing

| Ordinate Number | Ordinate (CMS) |
|---|---|
| 1 | 2.34 |
| 2 | 1.22 |
| 3 | 0.65 |
| 4 | 0.31 |
| 5 | 0.11 |

Example B: 3 hour ordinate spacing

| Ordinate Number | Ordinate (CMS) |
|---|---|
| 1 | 1.65 |
| 2 | 2.34 |
| 3 | 1.62 |
| 4 | 1.22 |
| 5 | 0.90 |
| 6 | 0.65 |
| 7 | 0.47 |
| 8 | 0.31 |
| 9 | 0.20 |
| 10 | 0.11 |
| 11 | 0.04 |

# Table 2. Runoff applied to Unit Hydrograph

| Period | Interval | Runoff | Day 1 | | | | | | | | | Day 2 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 24 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 3 |
| c/o | carryover | -- | 0.46 | 0.32 | 0.23 | 0.16 | 0.11 | 0.07 | 0.04 | 0.02 | 0.01 | 0.00 | | | | | | | | |
| 1 | 2400-0600 | 7.05 | | 11.63 | 16.50 | 11.42 | 8.60 | 6.35 | 4.58 | 3.31 | 2.19 | 1.41 | 0.78 | 0.28 | | | | | | |
| 2 | 0600-1200 | 2.04 | | | | 3.37 | 4.77 | 3.30 | 2.49 | 1.84 | 1.33 | 0.96 | 0.63 | 0.41 | 0.22 | 0.08 | | | | |
| 3 | 1200-1800 | 1.50 | | | | | | 2.48 | 3.51 | 2.43 | 1.83 | 1.35 | 0.98 | 0.71 | 0.47 | 0.30 | 0.17 | 0.06 | | |
| 4 | 1800-2400 | 1.14 | | | | | | | | 1.88 | 2.67 | 1.85 | 1.39 | 1.03 | 0.74 | 0.54 | 0.35 | 0.23 | 0.13 | 0.05 |
| 5 | 2400-0600 | 0.87 | | | | | | | | | | 1.44 | 2.04 | 1.41 | 1.06 | 0.78 | 0.57 | 0.41 | 0.27 | 0.17 |
| 6 | 0600-1200 | 0.69 | | | | | | | | | | | | 1.14 | 1.61 | 1.12 | 0.84 | 0.62 | 0.45 | 0.32 |
| 7 | 1200-1800 | 0.56 | | | | | | | | | | | | | | 0.92 | 1.31 | 0.91 | 0.68 | 0.50 |
| 8 | 1800-2400 | 0.47 | | | | | | | | | | | | | | | | 0.78 | 1.10 | 0.76 |
| Instantaneous Discharge | | (CMS) | 0.46 | 11.95 | 16.73 | 14.95 | 13.48 | 12.20 | 10.62 | 9.48 | 8.03 | 7.01 | 5.82 | 4.98 | 4.10 | 3.74 | 3.24 | 3.01 | 2.63 | -- |

Number of Ordinates = 11    Ordinate spacing = 3 hours    Area = 102.7 KM2

Ordinates = 1.65  2.34  1.62  1.22  .90  .65 .47  .31  .20  .11  .04

Figure 1. Hydrograph Produced Mainly by Surface Runoff

Runoff Breakdown: Surface=64% Interflow=15% Supplemental=21%

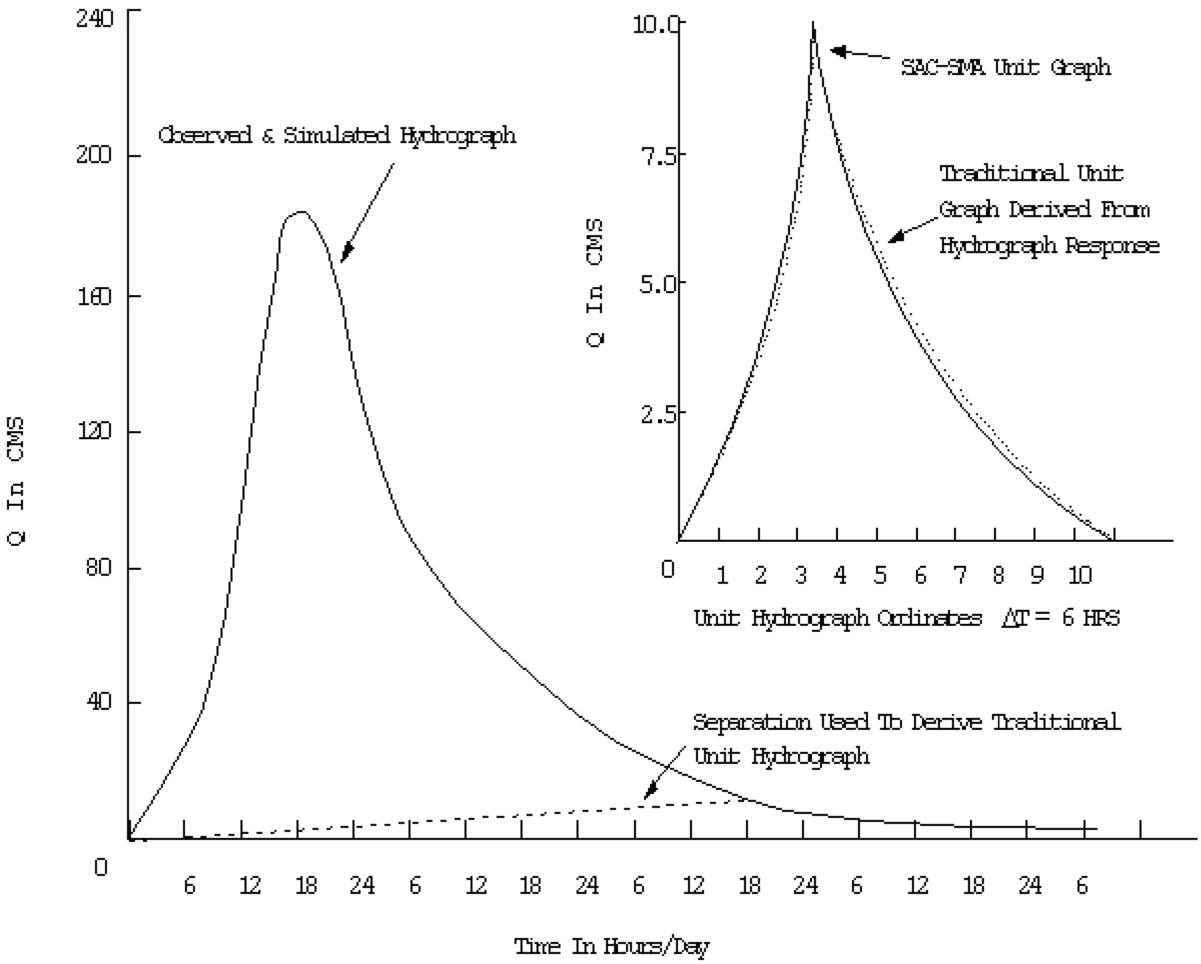


Figure 2. Hydrograph produced by mixed runoff

Runoff Breakdown: Surface=27% Interflow=33% Supplemental=40%

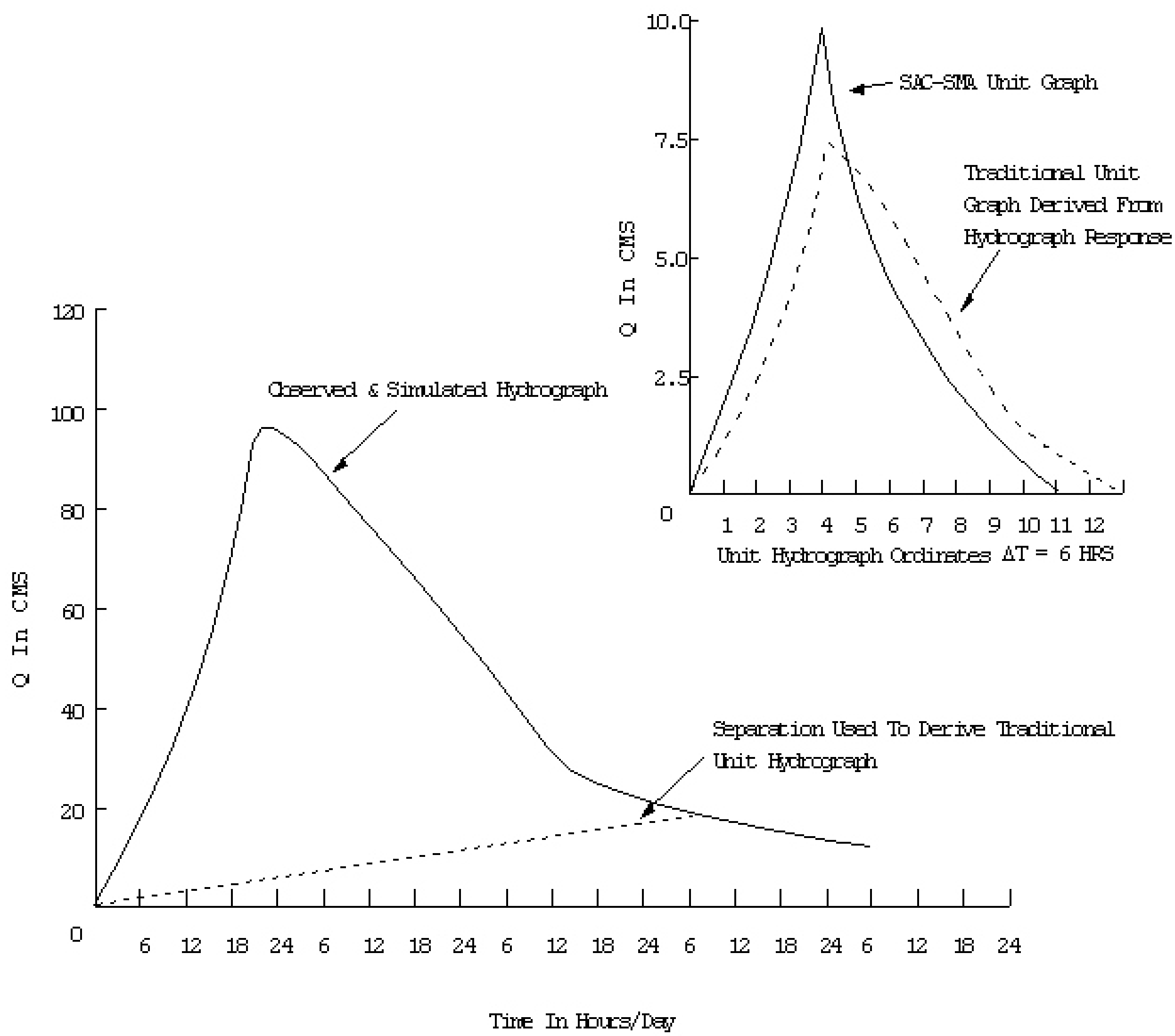
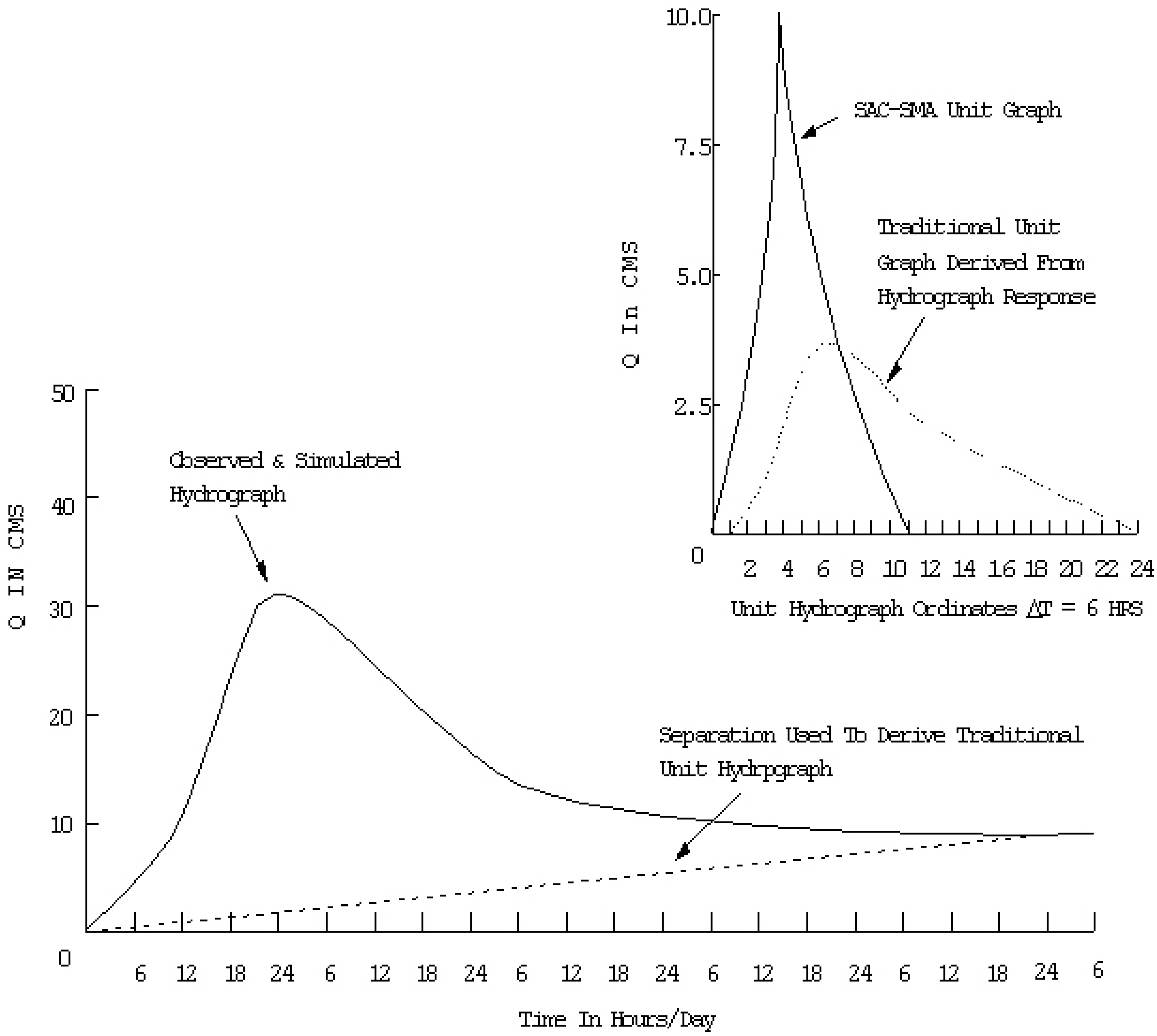


Figure 3. Hydrograph containing no surface runoff

Runoff Breakdown: Interflow=17% Supplemental=83%

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