Use of a GIS-based Hydrogeologic Database to Estimate Groundwater Storage Volumes and Annual Recharge Volumes within the Entiat River Valley, Chelan County, Washington

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Abstract

Estimates of groundwater storage volumes and annual groundwater recharge are critical in evaluating the health of a watershed. In addition, annual groundwater recharge is the defining factor used to determine the sustainability of a groundwater resource. The use of hydrograph separation methods to estimate storage volume and recharge is limited in basins that are regulated by dams or influenced heavily by snowmelt. Other methods used to estimate groundwater volumes are either too complex to be easily applied or too general to provide convincing estimates. A geographic information system (GIS) used in conjunction with even limited hydrogeologic data can overcome these types of problems and yield reliable estimates. Such a method was applied to the Entiat River Valley in Chelan County, Washington. For the year 2002, groundwater storage volumes within the Entiat River Valley mainstem aquifer were estimated to range from 111,153 acre feet to 107,122 acre feet. The change in volume or annual groundwater recharge for 2002 was estimated to be 4,031 acre feet. Although the method was successfully applied to the Entiat River watershed, it should be noted that there are numerous factors to be considered before applying the method to other basins.

Introduction

The unregulated Entiat River is approximately 43 miles in length, flows primarily from the NW to the SE, and discharges directly to the Columbia River near the town of Entiat. The valley floor is quite narrow in width ranging from approximately 500 feet to 4,000 feet wide. The Entiat River changes in elevation from approximately 6,000 feet mean sea level at its head to approximately 700 feet mean sea level at its mouth. Late Pleistocene glaciation has significantly affected the upper 30 miles of the basin. Evidence suggests that two successive alpine glaciers occurred within the Entiat Valley, and that the younger glaciers did not advance down valley as far as the older more extensive glaciers (Long, 1951). This is reflected today in a thickening of the unconfined aquifer material within a portion of the upper half of the basin. Precipitation within the basin occurs primarily between the months of October and March with most winter precipitation occurring as snow.

The Entiat River Valley aquifer system is bounded by igneous and metamorphic bedrock. The unconfined aquifers within the Entiat River Valley are composed of glacial, colluvial, fluvial and alluvial cobbles, gravels, sands, some silts and discontinuous clays. Recharge to the unconfined aquifer is derived primarily from precipitation and potentially from irrigation return flows, but is largely dependent on surface water exchange with the Entiat River. As a result, a high degree of hydraulic connection between the Entiat River and the valley fill aquifer is recognized.

Within an alluvial system such as that described above, groundwater storage is defined as the volume of water that could be theoretically extracted if the aquifer were completely drained. Assuming that the surficial extent of the aquifer represents the lateral extent of the aquifer at depth, the groundwater storage within an unconfined aquifer can be estimated by multiplying the aquifer surface area by the saturated thickness (b) of the aquifer and the specific yield (Sy) of the aquifer materials.

Groundwater Storage Volume = (aquifer surface area)(b)(Sy)

Saturated thickness is the distance from the top of the water table to the top of the underlying bedrock aquitard. Specific yield, also referred to as the unconfined storativity, is expressed as a ratio of the volume of water that can be released to the volume of material containing that water. Therefore, specific yield is a dimensionless factor that represents the volume of water that an unconfined aquifer releases from storage per unit surface area of aquifer per unit decline in the water table. (Freeze & Cherry, 1979)

Changes in storage volumes, commonly referred to as annual recharge, is the defining factor used to determine the sustainability of a groundwater resource. This change in storage volume can be expressed as a volume flux per surface area of the aquifer due to seasonal changes in precipitation, temperature, and other factors such as withdrawals from wells. On an annual basis, most systems display steady state conditions, discharge approximately equals recharge, and the net annual change in volume is zero (Hoos, 1990). However, if groundwater extraction combined with losses due to evapotranspiration exceeds annual recharge, water level declines should be expected.

This paper describes a methodology by which to estimate groundwater storage volumes and annual recharge for a small watershed using limited but well distributed hydrogeologic data in combination with a geographic information system (GIS).

Methodology

A good distribution of hydrogeologic data throughout the basin is essential for performing the analysis and improves volume estimations. Therefore, the first task of the project was to obtain the hydrogeologic data for the basin and determine where that data existed spatially. Utilizing ArcView's ability to join and link GIS features to tabular data, 190 well locations were plotted as points and database tables were populated with information from the well logs. Specific well information captured within the database included well depth, well stratigraphy, and depth to bedrock if available. Static water levels from the well logs were not used to estimate the depth to the water table due to the high degree of temporal variation regarding the date of measurement. A well monitoring project was developed for 25 wells, and water levels throughout the basin were measured on a monthly basis for one year. Once gathered and input into the system this data provided the basis for defining aquifer depths (top of the bedrock surface) and the top of the water table. The aquifer's saturated thickness (b) could then be calculated for each monitored well location. In areas with no monitoring wells, well logs still provided information on depth to bedrock or at least a minimum depth of the unconsolidated aquifer materials. Interpreted well log stratigraphy used in conjunction with the Washington State Department of Natural Resources' (DNR's) 1:100,000 scale digital geological maps provided the basis for determining specific yield values.

The next step in the process involved delineating the discreet polygons that would define the surface area of the unconfined aquifer. Polygon delineation was based on similarities in well depths and surface elevation as well as the lateral extent of the unconsolidated aquifer material. 205 polygons were delineated using a combination of digital GIS coverages including aerial photos, DNR's 1:100,000 scale geologic maps, the U.S. Geologic Survey's 10 meter digital elevation data, and the U.S. Geologic Survey's 7.5 minute topographic quadrangles. Acreages were then calculated for all polygons using ArcView.

Aquifer depths were assigned to the aquifer polygons using the entered well log data. In those instances where depth to bedrock was unknown, a conservative depth was assigned based on the deepest well occurring within that polygon. For those polygons with no well data, estimates of the aquifer depth were based on data from adjacent polygons and/or geologic and topologic characteristics of the valley.

Once aquifer depths, acreages, and specific yield values were determined for all 205 polygons it was necessary to assign a saturated thickness value to each discreet polygon. Monthly static water levels had only been measured for 25 wells representing 25 polygons distributed spatially throughout the basin. Assuming that the water level within a single polygon was similar in adjacent polygons, a ratio of the measured water depth to the total aquifer depth was calculated for those polygons with measured water levels. These ratios were then assigned to adjacent polygons and used to calculate the monthly saturated thickness for the remaining 180 polygons. An estimate of the groundwater storage volume was then calculated for each polygon by multiplying the polygon area by the saturated thickness and by the specific yield. The change in storage volume (annual recharge) was then calculated for the basin by subtracting the lowest storage volume from the highest storage volume. This change in storage volume could also be evaluated for each individual polygon on a month by month basis by calculating the fluctuation in water levels.

Results

Using the methods described above the total aerial extent of the mainstem Entiat River Valley aquifer is 10,732 acres. During 2002 the saturated thicknesses within the unconfined valley aquifer ranged from 10 feet to 151 feet with an average aquifer depth of 52 feet. 205 aquifer polygons were delineated and ranged in size from 2 acres to as large as 3,210 acres with an average size of 52 acres. Elimination of the 3,210 acre outlier polygon which defines the uppermost headwater aquifer reduces the average polygon size to 37 acres with a maximum polygon size of 467 acres.

Groundwater storage volumes within the Entiat River Valley mainstem aquifer were estimated to range from a high in June, 2002 of 111,153 acre feet to a low in December, 2002 of 107,122 acre feet (Figure 1). The change in groundwater storage volume (June high – Dec low) or annual recharge for 2002 was estimated to be 4,031 acre feet.

A temporal comparison of monthly aquifer storage values with mean monthly streamflow and mean monthly baseflow (for those months not influenced by snowmelt) shows a strong correlation between the rise in streamflow and the rise in groundwater volumes within the Entiat Valley (Figure 1 and Figure 2).

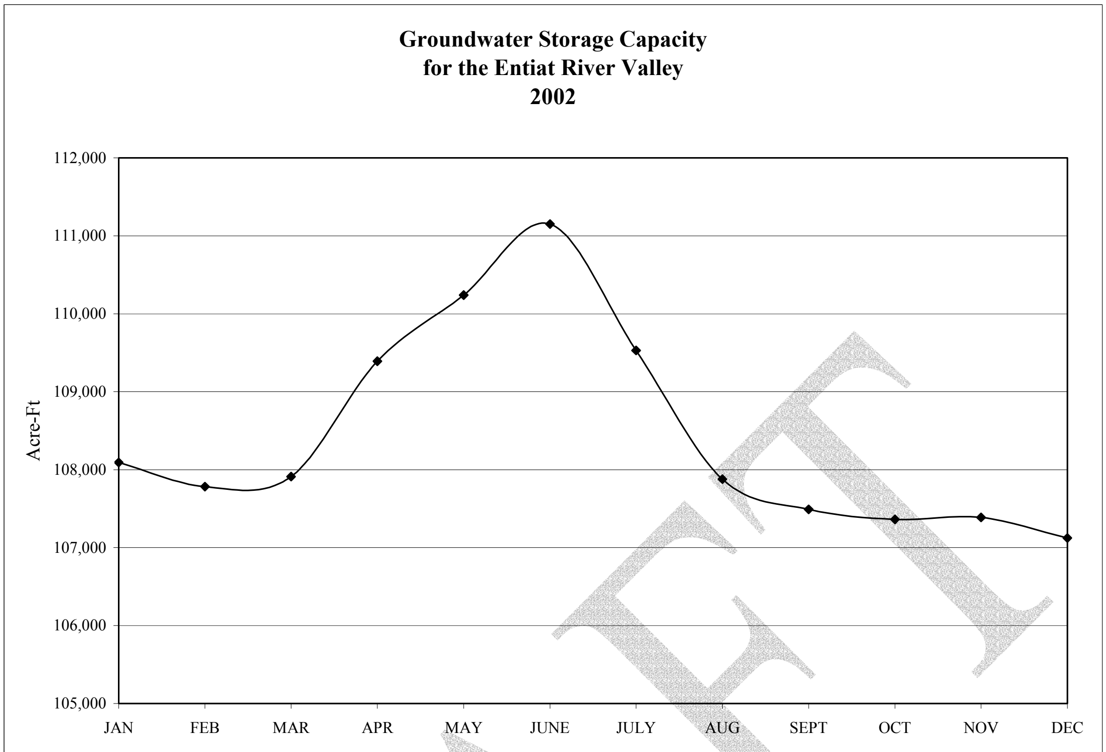

Figure 1.

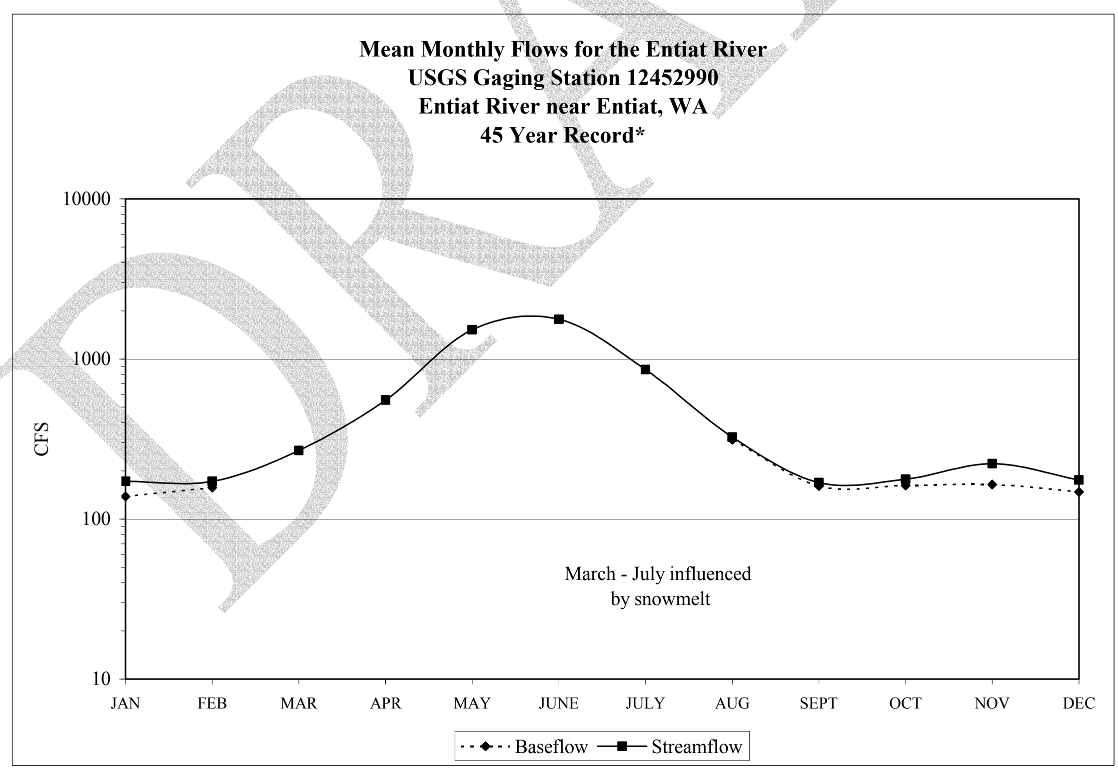

Figure 2.

*Note: Source data from the 2003 draft report on "Estimated Baseflow Characteristics Based on Historical and Synthesized Daily Mean Stream Data" by the Chelan County Conservation District.

In addition, net monthly changes in storage volumes were compared to monthly groundwater storage volumes. As expected net positive changes in storage corresponded to a rise in total storage volumes and net negative values corresponded with declines in total storage volumes (Figure 3). The sharp drop between May and June may reflect the beginning of the irrigation season.

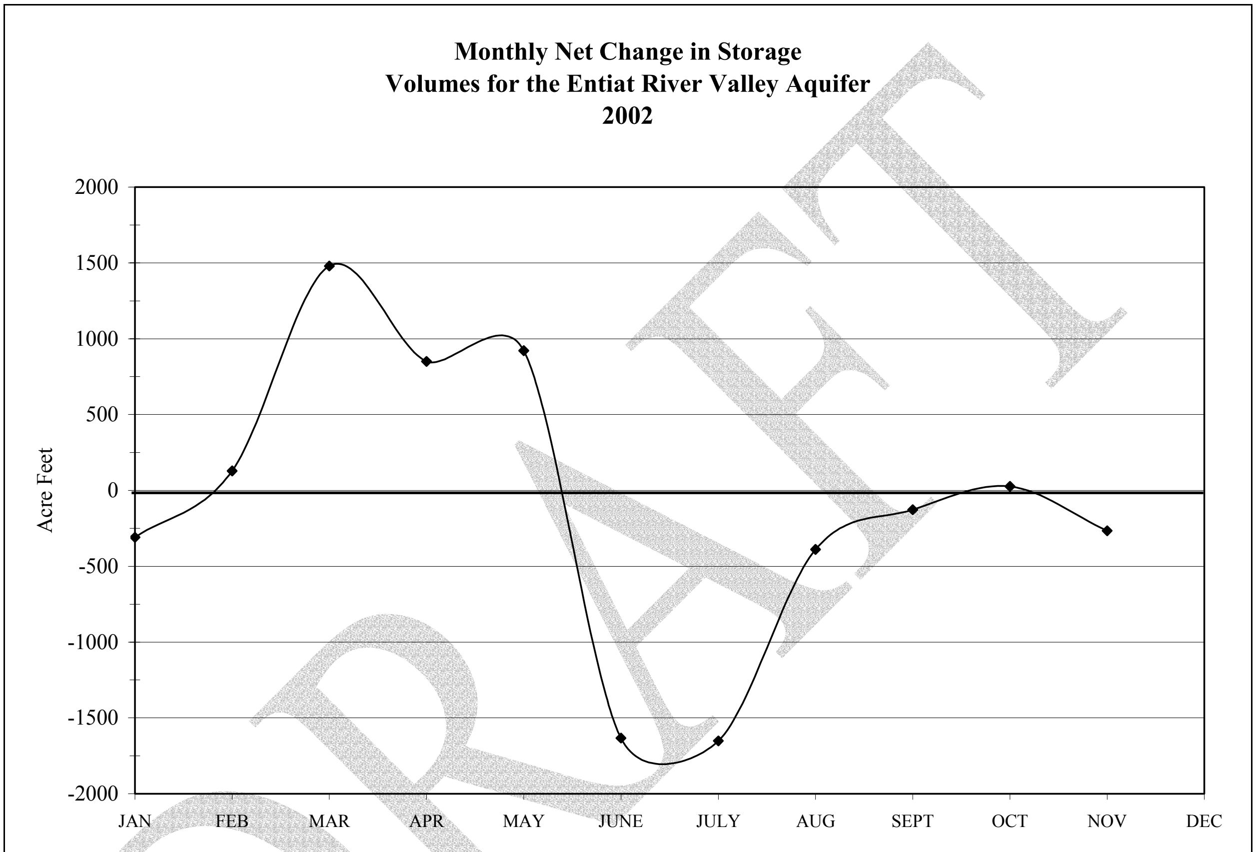

Figure 3.

Conclusions

Hydrograph separation is a method commonly used to determine the groundwater contribution (baseflow) to total stream flow within a drainage system. However, this methodology is not applicable in basins that contain highly regulated streams or that have a strong snowmelt component. Another method commonly employed to estimate groundwater storage and annual recharge in unconfined aquifer systems is to apply an average saturated thickness and average specific yield value to the entire aquifer. The method describe in this paper can be used to circumvent the temporal problems associated with hydrograph separation involving snowmelt or stream regulation and may well yield a more accurate estimate than obtained by applying average values to the entire watershed. The method was successfully applied to the Entiat River watershed. However, it should be noted that factors such as the availability of hydrogeologic data, basin size, basin geology, geologic structures, and topographic complexity can all influence the applicability of this method to other basins.

References

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