ANNUAL AND SEASONAL WATER BUDGETS FOR THE MONOCACY/CATOCTIN DRAINAGE AREA
- Final Report

By

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Executive Summary

The Potomac River basin comprises a 14,670 square mile drainage area which includes the city of Washington, DC, and some of the most rapidly growing counties in our nation. The recent period of drought in the region, from 1999 through 2002, focused public attention on water supply issues and the potential vulnerability of developing areas to future water shortages. Basin residents rely upon both ground water and surface water resources, with ground water being a major source of water supply for the majority of people living outside of the major urban centers. Many people living in the upper portion of the basin, upstream of the Washington, DC metropolitan area, obtain their water from wells drawing from aquifers in the fractured bedrock formations in the Piedmont, Blue Ridge, and Appalachian Valley and Ridge physiographic provinces. A large number of residents of the lower portion of the basin rely on water from a system of confined aquifers in the sand and gravel formations underlying the Coastal Plains province. In Washington, DC and surrounding areas, the primary source of water supply is the Potomac River itself.

The upper portion of the Potomac basin poses a challenge for water availability assessment for two reasons. First, ground water and surface water resources are closely interconnected. Ground water contained in the fractured bedrock aquifers of the upper basin continually discharges to the network of streams in the basin's watersheds and eventually flows into the Potomac River. Thus, ground water in the upper portion of the basin provides water for human consumption via both withdrawals from wells and withdrawals from surface waters, and also provides stream flow necessary to sustain the ecological health of our streams and rivers. Second, potential water supply problems are seasonal in nature. Concern about water availability is generally restricted to the summer and early autumn months, when both water levels in wells and ground water discharge to streams, i.e. stream baseflow, typically fall to their lowest levels of the year.

Groundwater availability is extremely difficult to characterize on a regional scale, and water management agencies often rely on a watershed water budget approach, which provides a relatively simple accounting of the quantity of water entering and leaving a system of interest in a given time frame. Water budgets are particularly useful for assessments of watersheds underlain by fractured bedrock aquifers, where, because of the interconnection between ground water and surface water, stream flow data can be used to help estimate important water budget components. However, water budget analyses use a variety of simplifying assumptions which may limit their accuracy and usefulness in particular cases.

The objective of this study is to assess the quantity of water available in the fractured bedrock aquifers underlying a pilot study area in the upper portion of the Potomac River basin, within the framework of the watershed water budget approach. The water budget analyses in this report rely on estimates of the quantities of ground water discharging to basin streams to obtain estimates of ground water recharge. The resulting estimates of water availability pertain to the quantity of water available in the interconnected stream network/aquifer system under conditions resulting in nonzero stream baseflow. The estimates in this study do not provide an assessment of the quantity of ground water remaining in a sub-basin aquifer in situations where ground water has dropped to a level resulting in zero stream flow.

In particular, the goal of this study is to evaluate and compare the predictions of two different water budget methodologies and to provide water supply planners with estimates, at the sub-basin scale, of water availability. The pilot study area includes the adjoining watersheds of the Monocacy River and Catoctin Creek, and drains a 1115 square mile area of Adams County, Pennsylvania and Frederick, Carroll, and Montgomery Counties, Maryland. Communities in the Monocacy/Catoctin drainage area, including Frederick, MD and Gettysburg, PA, are rapidly attracting new residents who commute daily to the Washington, DC metropolitan area.

Two different analyses are applied to the Monocacy/Catoctin drainage area to help assess water availability, the first based on an annual water budget and the second on a seasonal water budget. Both water budget analyses rely primarily on stream flow data from gaged sub-basins within or near the study area. The first analysis provides estimates of annual recharge to sub-basin aquifers throughout the study area. Estimates of annual recharge are believed to be reasonably reliable, and are sometimes used by water resource managers as a rough indication of the annual quantity of water available in a basin for both human consumptive use and maintenance of adequate stream baseflow to sustain the ecological health of basin streams. The second analysis, only carried out for a limited number of sub-basins within the study area, investigates the importance of seasonal effects and storage on water availability estimates. In this seasonal water budget approach, a simple measure of water availability is defined, as the volume of water stored in the upper portion of the sub-basin aquifer at the beginning of summer plus the volume provided by summer recharge.

Annual Water Budget Results

In the annual water budget analysis, ground water recharge was estimated from estimates of annual ground water discharge, i.e., annual stream baseflow, for 34 sub-basins where stream flow data was available. Annual baseflow statistics were extrapolated to ungaged portions of the study area using multiple linear regression techniques. The explanatory variables considered in the study were drainage area and percent of sub-basin in each of four hydrogeomorphic regions represented in the study area, Piedmont Crystalline (PCR), Mesozoic Lowlands (ML), Blue Ridge (BR), and Piedmont Carbonate (PCA). The annual water budget analysis used the simplifying assumptions that there is no change in storage from the beginning of one year to the beginning of the next and that water withdrawals are negligible. The main results of this analysis are the following:

- The set of parameters used to describe the geology/hydrogeology of the study area sub-basins were all significant predictors, at the 90% confidence level, of stream baseflow for the 10-year and the 20-year drought.

- Annual recharge rates for an average year for the PCR, ML, BR, and PCA hydrogeomorphic regions were estimated to be 8.5, 5.3, 12.2, and 14 inches, respectively, or equivalently, 630, 390, 910, and 1000 gpd/ac (gallons per day per acre).

- Annual recharge rates for a dry year (20-year drought) for the PCR, ML, BR, and PCA hydrogeomorphic regions were estimated to be 5.2, 2.4, 6.8, 14 inches, respectively, or equivalently, 390, 180, 510, and 1000 gpd/ac. Based on these estimates, the recharge rate for the Mesozoic Lowlands, underlain primarily by shale and sandstone formations, is less than half of that found in other regions. Results for PCA are subject to considerable uncertainty because of the more limited extent of this HGMR in the study area.

- Uncertainties for the dry year annual recharge estimates are on the order of roughly ± 50%.

Seasonal Water Budget Results

In the seasonal water budget analysis, sub-basin precipitation, stream baseflow, aquifer recharge, total evapotranspiration, and other water budget components were computed for every quarter in the time period, 1960 through 2002, for four sub-basins in the study area: Catoctin Creek, the upper Monocacy basin (above gage at Bridgeport, MD), Big Pipe Creek and Bennett Creek. Seasonal estimates were also made of ground water withdrawals throughout the time period of the study. The seasonal water budget includes seasonal changes in ground water storage, computed using information from ground water recession analyses. A summary of methods and results appears below:

- Baseflow recession coefficients were computed for the four sub-basins of interest. The recession coefficient is an estimate of the amount of time it takes, during periods of no precipitation, for stream baseflow to fall to 10% of its initial value. Median and mean values were found to range from approximately 30 to 90 days for the four sub-basins, indicating fairly poor storage properties for the upper portion of the fractured bedrock aquifers, especially in the upper Monocacy and Catoctin Creek sub-basins.

- "Beginning-of-quarter storage", that is, the volume of water stored in a sub-basin aquifer above the zero stream discharge level, was computed using baseflow recession indices, estimates of "beginning-of-quarter stream baseflow", and the standard assumption of log linear baseflow recession. The match between beginning-of-quarter storage and mean water levels from available well data, plotted over time, was found to be quite good, indicating that the storage estimates are reasonably reliable.

- A measure of the quantity of water available in the summertime, V_{Q3}, was defined as the sum of beginning-of-summer aquifer storage (above the zero stream discharge level) and summer recharge. The seasonal water budget was used to compute this quantity for each of the 42 summers (i.e. July, August, September) in the time period of interest, and frequency analyses were done to predict summer water availability in average years and in dry years.

- Summer water availability for an average year for the Catoctin, upper Monocacy, Big Pipe, and Bennett sub-basins were estimated to be 0.7, 0.4, 1.5, 1.4 inches per quarter, respectively, or equivalently, 210, 120, 460, and 420 gpd/ac.

- Summer water availability for a dry year (20-year drought) for the Catoctin, upper Monocacy, Big Pipe, and Bennett sub-basins was estimated to be 0.2, 0.1, 0.5, 0.5 inches per quarter, respectively, or equivalently, 60, 30, 150, and 160 gpd/ac.

- Summer water availability predictions for dry years for the Catoctin and upper Monocacy sub-basins are much lower than the corresponding annual recharge rates, and are on the order of only twice the rate of current ground water withdrawals in those sub-basins, estimated to be 24 and 15 gpd/ac, respectively (estimated primarily from 2001 data).

Conclusions

The results of this study provide two different estimates of the quantity of water available in the stream network/aquifer systems of sub-basins in the Monocacy/Catoctin Creek drainage areas, under conditions of non-zero stream flow. Water supply planners must apportion available quantities in a manner that meets both the consumptive use needs of human society and the requirements to maintain stream baseflow at levels adequate to sustain the ecological health of our streams. Provided that seasonal water budget components can be reliably computed, they should give more accurate predictions of summer water availability than analyses based on annual averages, since they include the effects of seasonality and aquifer storage. The approach to computing seasonal water budget components developed in this study, based on a baseflow recession analysis using “beginning-of-quarter” baseflow estimates, appears to give reasonably reliable results when compared with available well data. It is not surprising that the seasonal water budget analysis predicts considerably lower summertime water availability than annual recharge estimates, since water supply problems in the region typically occur only in summer and early fall. The seasonal water budget’s extremely low predictions for dry-year summer water availability for the Catoctin and upper Monocacy sub-basins appear in part to be the result of these aquifers’ poor ability to store recharge, as indicated by their low recession indices. For this type of sub-basin, it appears that the annual recharge estimates, which include the significant recharge which occurs in fall and winter, can mask the presence of potential water supply problems in the summer months. It should be noted that the Catoctin and upper Monocacy sub-basins, which primarily represent the BR and ML hydrogeomorphic regions, respectively, have both experienced significant water availability problems during times of drought.

In this study, a simple approach was developed to estimate seasonal water availability in sub-basins with closely interconnected stream network/fractured bedrock aquifer systems. In the four gaged sub-basins considered, the seasonal water availability estimates appeared to give important information concerning summertime availability which was not provided by the more commonly used annual recharge estimates. In order to extend this seasonal water budget approach to other areas in the upper Potomac River basin, it will be necessary to extrapolate results from gaged sub-basins to sub-basins where no stream flow data is available. As a first step, statistical regression analyses must be conducted to see whether the quantities used in summer availability predictions, that is, recession indices, beginning-of-summer baseflow, and summer recharge, can be estimated for ungaged sub-basins. Results from the regression analyses for annual baseflow characteristics carried out in this study indicate that hydrogeomorphic regions may be useful predictors of sub-basin flow characteristics.

Estimates of water availability made in this report, in both the annual and the seasonal analyses, were computed from stream flow data collected at USGS stream gage stations. Daily flow values from continuous record gage stations provide the most useful data, allowing the computation of baseflow recession indices and more accurate estimates of annual and seasonal baseflow. However, at this time only a handful of these stations are still in operation in the study area. Continuation of stream gage data collection programs is crucial for developing a better understanding of water availability in the Potomac River basin.