APPENDIX D–MONOCACY RIVER WATERSHED–PILOT STUDY

General Characteristics and Approach

The Monocacy Watershed drains an area of approximately 969 square miles. This drainage area includes significant portions of Frederick County, Maryland; Carroll County, Maryland; and Adams County, Pennsylvania. It also includes a small portion of Montgomery County, Maryland; a very small portion of Washington County, Maryland; and Franklin County, Pennsylvania. Four hydrogeology regions[1] occur in the watershed. A vicinity map is shown as Figure D-1.

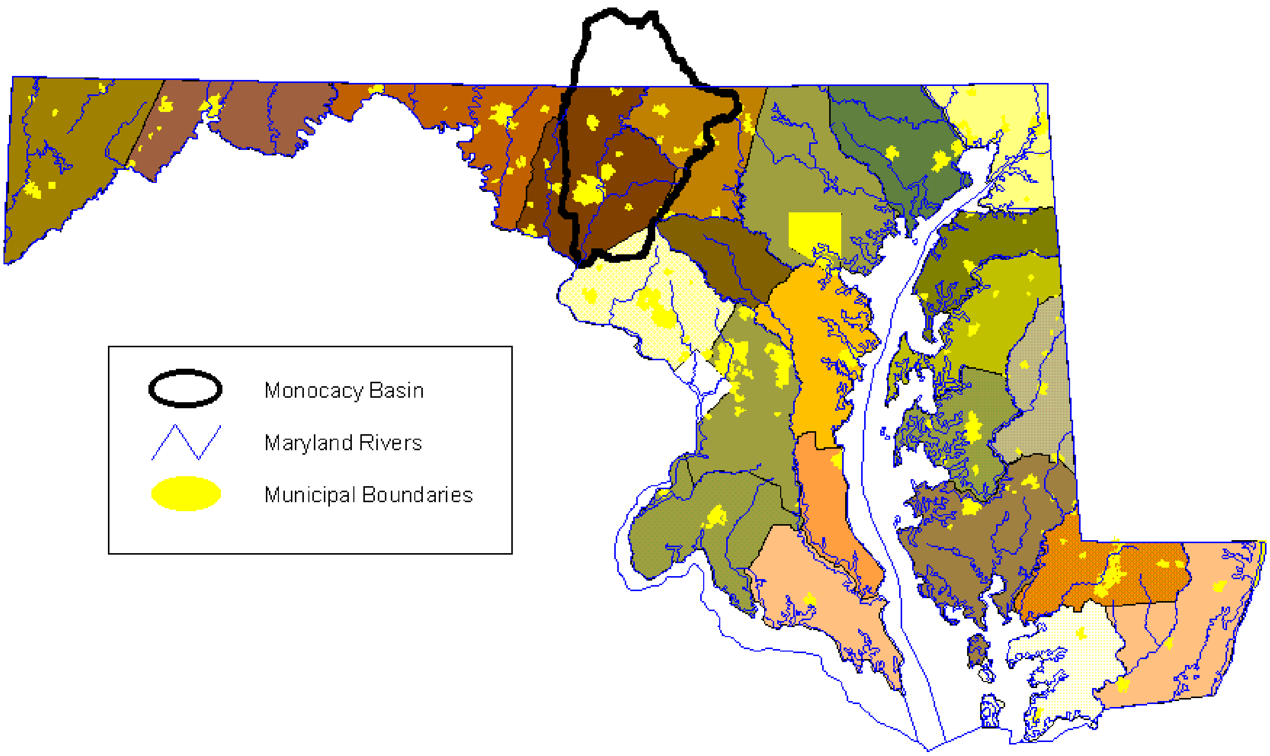

Figure D-1 Monocacy Vicinity Map

The population of Frederick County and Carroll County, which include most of the Maryland portion of the Monocacy Basin, have grown from by 125% in the period from 1970 to 2000[2]. The population in the Maryland portion of the Monocacy basin is projected to grow by 57% between 2000 and 2030[3]. This continued population increase has raised questions concerning the availability of water to support the anticipated growth.

[1] Piedmont Crystalline, Mesozoic Triassic, Blue Ridge and Piedmont Carbonates.
[2] Based on numbers taken from *Population of Counties by Decennial Census: 1900 to 1990* Compiled and edited by Richard L. Forstall, Population Division, US Bureau of the Census, Washington, DC 20233 and *Census 2000 Summary File 1 (SF 1) 100 Percent Data*, U.S. Census Bureau
[3] *ROUND 6.3 COOPERATIVE FORECASTING: Employment, Population and Household Forecasts to 2030 by Traffic Analysis Zone*, Department of Human Services, Planning and Public Safety, Metropolitan Washington Council of Governments, 2003

Because of the relatively low yields of the fractured rock aquifers that cover most of this basin, and other problems associated with the karst aquifer that covers the remainder of the basin, the use of ground water as a water supply is less desirable as a water supply then it would be where sand and gravel aquifers are available. Surface water and ground water are appropriated in roughly equal quantities within the basin. Both surface and ground water must be evaluated in order to assess the adequacy of water resource in the Monocacy watershed.

For this analysis, the Watershed was divided into fifteen subwatersheds as shown in Figure D–2. In Maryland, these watersheds are aggregations of the Twelve Digit Watersheds. For the Pennsylvania portion of the Watershed, the sub-basins are based on a small watershed GIS layer for Pennsylvania, but were sometimes modified in order to match Maryland watershed boundaries.

Ground water was evaluated based on a water balance approach. Reliably available ground water was estimated based on a set of baseflow separation analyses performed by ICBRB[4] for each hydrogeologic region[5]. Specifically, gages representing each region were analyzed using computer program HYSEP[6] in order to determine baseflow per unit area in each hydrogeologic rock type. These values were then multiplied by the area of each rock type in each sub-area and combined to yield the baseflow in each sub-watershed for an average year. This analysis was repeated using baseflows representing a 10-year drought and a 20-year drought. These baseflows, which represent the recharge rate for ground water, were used to compute water balance assessments for the 15 sub-watersheds.

For surface water, a simulation was created using surface water measurements from 1947 through 2003. This was used to estimate the number of days for each region where sufficient surface water would not be available to meet permitted surface water use under current and future conditions. Both ground and surface water estimates are intended for the gross analysis of watersheds and are not necessarily applicable to any particular permit.

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[4] Personal communications with Deborah Tipton of ICPRB, 24 March 2004

[5] As in a GIS layer entitled, *Hydrogeomorphic Regions of the Chesapeake Bay Watershed*, J. W. Brakebill and S. K. Kelley, USGS Open File Report Number 00-424, USGS, 2000. This GIS layer groups different rock types based on water bearing characteristics.

[6] *HYSEP: A COMPUTER PROGRAM FOR STREAMFLOW HYDROGRAPH SEPARATION AND ANALYSIS*, Ronald A. Sloto and Michèle Y. Crouse, U.S Geological Survey, Water-Resources Investigations Report 96-4040, 1996.

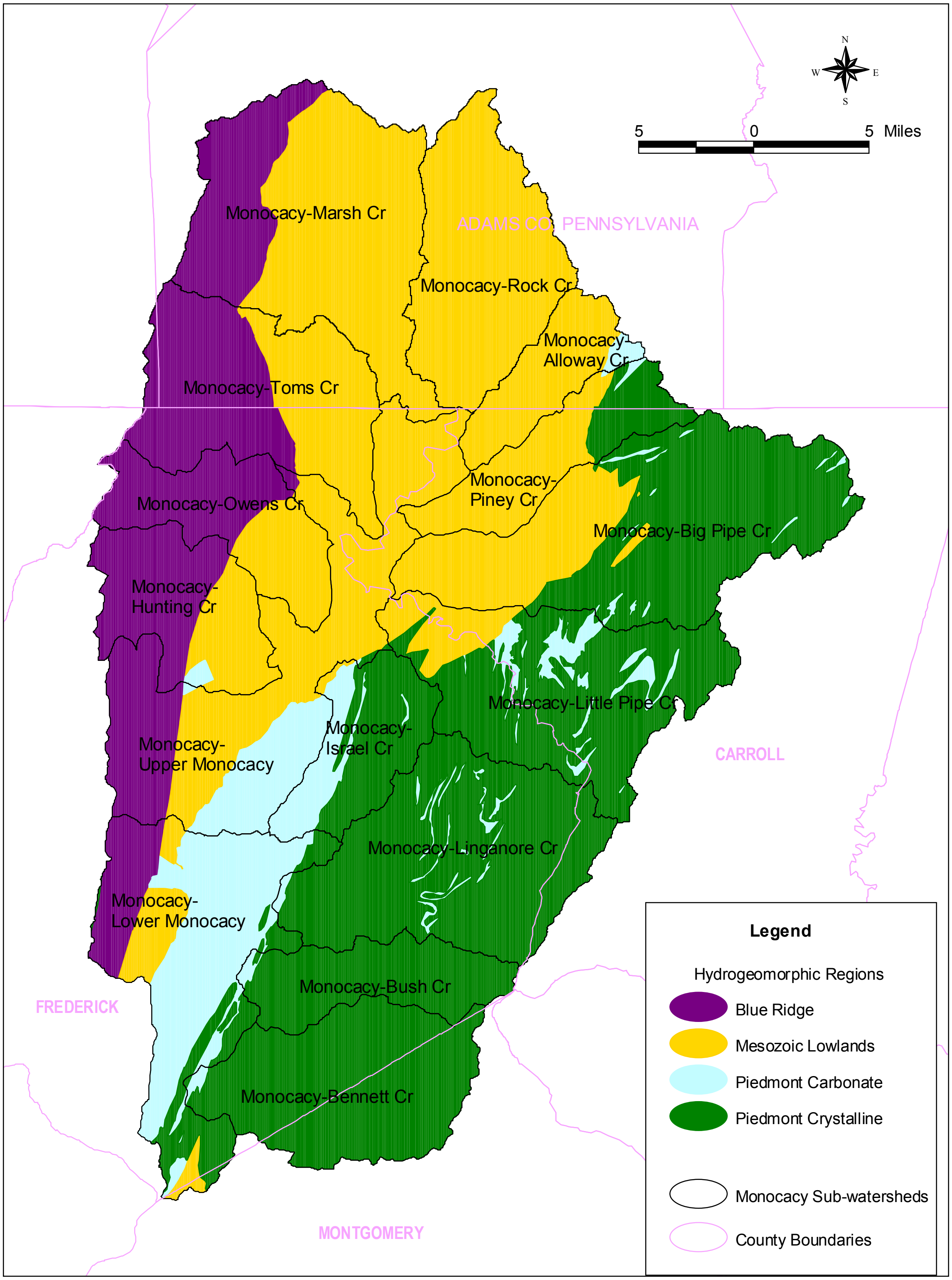

Figure D–2. The Fifteen Sub-Watersheds in the Monocacy Watershed Pilot Study. The sub-watersheds are aggregations of the DNR twelve-digit watersheds in Maryland, created for the express purpose of analyzing water supply and demand for this pilot study. The naming convention is used to avoid confusion with sub-watershed names recognized in other recognized watershed divisions. Hydrogeomorphic classifications are adopted from USGS GIS Coverage previously cited in footnote 5.

Demand Analysis

The current water demand by use class in the Maryland portion of the Monocacy drainage area in the year 2000 was determined first. For all uses except self supplied single-family domestic use (that is, houses with their own wells), this was based on a Geographic Information System (GIS) analysis of water appropriation permit data. Self supplied single family domestic use was determined by a comparison of census data within the watershed to information on households served by public water systems within each of the fifteen sub-watersheds. Current and projected population within each sub-watershed was determined based on 2003 Metropolitan Washington Council of Governments Traffic Analysis Zone (TAZ) data and GIS files[7].

USGS provided a yearly breakdown of water use by type and county in Maryland for the period from 1985 thru 2001[8]. This was analyzed for correlation with population, first for the state as a whole and then for Frederick, Carroll and Montgomery Counties[9]. As a result of this analysis, regression equations were generated relating demand to population. These equations were used to compute projected demand within the Maryland portion of the fifteen sub-watersheds. Because municipal and industrial discharges were being explicitly represented in our analysis of the Maryland portion of the Basin, Maryland demand is the total demand and is not based on consumptive use.

A significant assumption of these projections is that, when a demand is projected into the future, the current percentage split between ground and surface water for that demand is assumed to continue. This should be improved to better reflect the intended split in water demand. Another improvement would be to incorporate information from water and sewer planning to improve the projection of what portion of the projected population growth will be on public water and sewer as opposed to individual well and septic.

For Pennsylvania, discharge data was not available to MDE and most water appropriations do not require a permit. Therefore, consumptive use estimates generated for 2000, 2020 and 2030 by the

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[7] *ROUND 6.3 COOPERATIVE FORECASTING: Employment, Population and Household Forecasts to 2030 by Traffic Analysis Zone*, Department of Human Services, Planning and Public Safety, Metropolitan Washington Council of Governments, 2003

[8] Personal communications with Judith C Wheeler of USGS, 13 February 2004. Data has previously been published as *MD Water Withdrawal* reports. Data was provided as 17 excel spreadsheet covering the years 1985 thru 2001.

[9] The negligible area of Washington County was treated as an extension of Frederick County.

Interstate Commission on the Potomac River Basin (ICPRB)[10] were distributed to each sub-watershed using year 2000 census data. For Pennsylvania, the 1995 percentage split between surface and ground water within Pennsylvania portion of the Monocacy Basin[11] was assumed to carry forward into the future.

Three tables that show current and future demand for each sub-basin follow. These are Table D-1, which tabulates total demand, Table D-2, which tabulates ground water demand, and Table D-3, which tabulates surface water demand:

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[10] ICPRB Report No. 00 - 5, *Water Supply Demands and Resource Analysis in the Potomac River Basin* by Roland C. Steiner, Erik R. Hagen and Jan Ducnuigeen, Interstate Commission on the Potomac River Basin, November 2000.
[11] Ibid page G-10

Table D-1 Total Demand for Water by Sub-basin in mgd

Total Ground Water and Surface Water Demand in mgd									
	MD Demand[12]			PA Demand			Total Demand		
Sub-basin	2000	2020	2030	2000	2020	2030	2000	2020	2030
Monocacy-Alloway Cr	0.11	0.17	0.17	0.25	0.29	0.30	0.36	0.46	0.48
Monocacy-Bennett Cr	13.20[13]	13.54	13.89	-	-	-	13.20	13.54	13.89
Monocacy-Big Pipe Cr	2.45	3.55	3.73	-	-	-	2.45	3.55	3.73
Monocacy-Bush Cr	1.40	1.87	2.33	-	-	-	1.40	1.87	2.33
Monocacy-Hunting Cr	1.04	1.45	1.70	-	-	-	1.04	1.45	1.70
Monocacy-Israel Cr	1.55	1.79	1.97	-	-	-	1.55	1.79	1.97
Monocacy-Linganore Cr	4.64	5.44	5.95	-	-	-	4.64	5.44	5.95
Monocacy-Little Pipe Cr	5.01	5.56	5.70	-	-	-	5.01	5.56	5.70
Monocacy-Lower Monocacy	7.17	11.60	12.66	-	-	-	7.17	11.60	12.66
Monocacy-Marsh Cr	0.00	0.01	0.01	0.54	0.63	0.65	0.54	0.63	0.66
Monocacy-Owens Cr	0.68	0.93	1.07	-	-	-	0.68	0.93	1.07
Monocacy-Piney Cr	1.07	1.30	1.34	0.17	0.20	0.21	1.24	1.50	1.55
Monocacy-Rock Cr	0.00	0.00	0.00	0.93	1.07	1.12	0.93	1.07	1.12
Monocacy-Toms Cr	0.54	0.73	0.84	0.32	0.36	0.38	0.86	1.09	1.22
Monocacy-Upper Monocacy	4.95	6.13	6.65	0.00	0.00	0.00	4.95	6.13	6.65
Total	43.81	54.07	58.03	2.21	2.56	2.66	46.02	56.63	60.69

[12] Demand is based on the existing appropriations (and self supplied domestic use) within each sub-watershed. Demand does not consider transfers that currently exist and are expected to continue of water from the Potomac River.

[13] 12 mgd of the demand from the Monocacy–Bennett Cr sub-watershed occurs as an appropriation for Lilypons Water Garden, Inc. Almost all of the water appropriated for Lilypons Water Garden is returned downstream of the point of appropriation and the 12mgd is an estimate long term average. The nature of the inlet works in such that their appropriation will be reduced in times of low flow.

Table D-2 Ground Water Demand by Basin in mgd

Total Ground Water Demand in mgd									
	MD Demand[14]			PA Demand			Total Demand		
Sub-basin	2000	2020	2030	2000	2020	2030	2000	2020	2030
Monocacy-Alloway Cr	0.11	0.17	0.17	0.20	0.23	0.24	0.31	0.39	0.41
Monocacy-Bennett Cr	1.15	1.49	1.84	-	-	-	1.15	1.49	1.84
Monocacy-Big Pipe Cr	2.42	3.52	3.70	-	-	-	2.42	3.52	3.70
Monocacy-Bush Cr	1.37	1.81	2.25	-	-	-	1.37	1.81	2.25
Monocacy-Hunting Cr	1.00	1.41	1.65	-	-	-	1.00	1.41	1.65
Monocacy-Israel Cr	1.46	1.69	1.86	-	-	-	1.46	1.69	1.86
Monocacy-Linganore Cr	0.73	1.04	1.21	-	-	-	0.73	1.04	1.21
Monocacy-Little Pipe Cr	4.85	5.27	5.34	-	-	-	4.85	5.27	5.34
Monocacy-Lower Monocacy	3.99	5.41	5.75	-	-	-	3.99	5.41	5.75
Monocacy-Marsh Cr	0.00	0.00	0.01	0.42	0.49	0.51	0.43	0.50	0.52
Monocacy-Owens Cr	0.67	0.92	1.06	-	-	-	0.67	0.92	1.06
Monocacy-Piney Cr	1.06	1.30	1.33	0.14	0.16	0.16	1.20	1.45	1.50
Monocacy-Rock Cr	0.00	0.00	0.00	0.73	0.84	0.88	0.73	0.84	0.88
Monocacy-Toms Cr	0.42	0.56	0.64	0.25	0.29	0.30	0.66	0.84	0.94
Monocacy-Upper Monocacy	4.10	4.81	5.14	0.00	0.00	0.00	4.10	4.82	5.14
Total	23.33	29.39	31.96	1.73	2.00	2.09	25.07	31.40	34.05

[14] Demand is based on the existing appropriations (and self supplied domestic use) within each sub-watershed. Demand does not consider transfers that currently exist and are expected to continue of water from the Potomac River.

Table D-3 Surface Water Demand by Sub-basin in mgd

Total Surface Water Demand in mgd									
	Maryland Demand[15]			PA Demand			Total Demand		
Sub-basin	2000	2020	2030	2000	2020	2030	2000	2020	2030
Monocacy–Alloway Cr	–	–	–	0.05	0.06	0.07	0.05	0.06	0.07
Monocacy–Bennett Cr	12.05[16]	12.05	12.05	–	–	–	12.05	12.05	12.05
Monocacy–Big Pipe Cr	0.03	0.03	0.03	–	–	–	0.03	0.03	0.03
Monocacy–Bush Cr	0.03	0.06	0.08	–	–	–	0.03	0.06	0.08
Monocacy–Hunting Cr	0.04	0.04	0.04	–	–	–	0.04	0.04	0.04
Monocacy–Israel Cr	0.09	0.10	0.11	–	–	–	0.09	0.10	0.11
Monocacy–Linganore Cr	3.90	4.40	4.74	–	–	–	3.90	4.40	4.74
Monocacy–Little Pipe Cr	0.15	0.29	0.36	–	–	–	0.15	0.29	0.36
Monocacy–Lower Monocacy	3.18	6.19	6.91	–	–	–	3.18	6.19	6.91
Monocacy–Marsh Cr	–	0.00	0.00	0.12	0.14	0.14	0.12	0.14	0.14
Monocacy–Owens Cr	0.01	0.01	0.01	–	–	–	0.01	0.01	0.01
Monocacy–Piney Cr	0.01	0.01	0.01	0.04	0.04	0.05	0.05	0.05	0.05
Monocacy–Rock Cr	–	0.00	0.00	0.20	0.23	0.24	0.20	0.23	0.24
Monocacy–Toms Cr	0.12	0.17	0.20	0.07	0.08	0.08	0.19	0.25	0.28
Monocacy–Upper Monocacy	0.86	1.31	1.51	0.00	0.00	0.00	0.86	1.31	1.51
Total	20.47	24.68	26.07	0.48	0.55	0.57	20.95	25.23	26.65

[15] Demand is based on the existing appropriations (and self supplied domestic use) within each sub-watershed. Demand does not consider transfers that currently exist and are expected to continue of water from the Potomac River.

[16] 12 mgd of the demand from the Monocacy–Bennett Cr sub-watershed occurs as an appropriation for Lilypons Water Garden, Inc. Almost all of the water appropriated for Lilypons Water Garden is returned downstream of the point of appropriation and the 12mgd is an estimate long term average. The nature of the inlet works in such that their appropriation will be reduced in times of low flow.

More research is needed to better determine what portion of appropriated water is used consumptively. For example, homes on individual well and septic are assumed to return 80% of the water they take from their well to the surficial aquifer.

Ground Water Availability

Ground water within the watershed comes from a shallow aquifer that is recharged by precipitation and discharges to stream baseflow. The reliable yield of this aquifer is the drought-year recharge less the quantity needed to sustain minimum streamflow.

The approach taken in this analysis was to estimate the recharge to the 15 regions from a set of baseflow separation analyses performed by ICBRB[17] for each hydrogeologic region[18]. Specifically, gages representing each region were analyzed using computer program HYSEP[19] in order to determine baseflow per unit area in each hydrogeologic rock type. These values were then multiplied by the area of each rock type in each sub-area and combined to yield the baseflow in each sub-watershed for an average year. This analysis was repeated using baseflows representing a 10-year drought and a 20-year drought. These baseflows represent the recharge rate for ground water.

For the ground water model, the quantity of water needed to maintain minimum streamflow was determined in a manner similar to the method used to estimate baseflow. Estimates of the 7-day, 10-year low flow (7Q10) for stream gages representing each hydrogeologic region were taken from RI 35[20]. These initial estimates of recharge for each hydrogeologic region were then calibrated so that the sum of the 7Q10s from the areas above the stream gage at Jug Bridge[21] would reproduce the 7Q10 computed by Carpenter for the Monocacy River at Jug Bridge. The computed amounts were used to reduce the available appropriation in each sub-basin. Similar computations were done for the 7Q20.

Ground water use in each basin was estimated as described in the Demand Analysis section, above. For the Maryland portion of each watershed, additional recharge from septic fields was estimated from the same data that was used to estimate the demand for individual self supplied water users. This additional recharge was added to the available water in each sub-watershed. The ground water available for each sub-watershed was therefore:

[Available] = [Precipitation Recharge] + [Septic Recharge] - [Demand] - [Instream needs (7Q10)]

When the computed balance is greater than or equal to zero, there is sufficient ground water available to meet all needs. If the computed balance is less than zero, on the other hand, there is not sufficient water to meet all needs and demand must be reduced.

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[17] Personal communications with Deborah Tipton of ICPRB, 24 March 2004.
[18] Taken from a GIS layer entitled, *Hydrogeomorphic Regions of the Chesapeake Bay Watershed*, J. W. Brakebill and S. K. Kelley, USGS Open File Report Number 00-424, USGS, 2000. This GIS layer groups different rock types based on water bearing characteristics.
[19] *HYSEP: A COMPUTER PROGRAM FOR STREAMFLOW HYDROGRAPH SEPARATION AND ANALYSIS*, Ronald A. Sloto and Michèle Y. Crouse, U.S Geological Survey, Water-Resources Investigations Report 96-4040, 1996.
[20] *Report of Investigations No. 35, Characteristics of Streamflow in Maryland*, by David H. Carpenter, USGS, 1983.
[21] 01643000 Monocacy River at Jug Bridge Near Frederick, MD

A spreadsheet model of ground water availability and demands, including instream demands, was created. A sample of the computations performed is provided in Table D-4. By comparing the current and projected ground water demand to the reliably available water, it was determined that, using the annual average demand and on the scale of the sub-watersheds analyzed for this assessment, ground water should be available to meet projected needs thru 2030 during the 20 year drought. This, however, does not provide a complete picture of ground water availability. As ICPRB has noted[22] "[T]he method used is less well suited to indicate whether the water resources will be adequate for short-term or extreme climatological conditions outside the norm and to evaluate the system's response to localized changes in water withdrawals and discharges."

Due to the heterogeneous nature of the fractured rock aquifers and the karst aquifers that provide ground water for this basin, having water available in a sub-basin does not guarantee that it will be available at a particular well. Where well yield will allow the desired use, other factors may prevent that amount of water from being withdrawn. Taneytown, in the northeast part of the Maryland portion of the Monocacy basin, provides two examples of these problems.

Taneytown cannot make full use of one of their wells because full use has been shown to have an unreasonable impact on other users of the aquifer. This impact on other users was wholly unexpected and only became apparent after the well was in use[23]. Water quality problems have required that Taneytown reduce their use of another well.

Ground water usage and recharge also varies with time, from season to season for instance. This variation is reflected in the rise and fall of ground water levels as more or less ground water is stored in the aquifer. This seasonal variation in recharge and storage can cause a well to go dry or have much reduced yield during times of drought. Accordingly, additional work defining seasonal variations in recharge and demand should be done in order to determine if seasonal shortages of ground water will develop even though the basin remains in balance on an annual average basis.

Recognizing that it is not feasible to incorporate all local issues in a regional ground water assessment in fractured rock and karst aquifers, it would still be desirable to evaluate ground water use and availability on a finer scale then was possible in the limited time available to the committee. Better information on Pennsylvania water use would also be desirable.

Another need is for an evaluation of the 7Q10 as an appropriate reserve flow for water resources management. Full allocation of ground water other then the reserve flow would allow this minimum flow to occur throughout the year. Also, research must be done on ground water recharge and discharge to determine the adequacy of estimated recharge rates used, the streamflow

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[22] Deborah Tipton, email to Matt Pajerowski of 05/03/04 10:57AM

[23] Later investigation revealed that this impact also occurred during a 72 hour pumping test. Pumping test requirements have since expanded to require a water supply inventory extending 3000 feet from the pumping well in consolidated sedimentary rock so that future impacts of this type should be caught during the pumping test.

reduction that can be expected, and the relationship of well yields in fractured rock to changes in storage.

Table D-4 Ground Water Available for 2030

MDE Sub-basin	Drainage Area	Recharge	Ground Water Demand	Internal[24] Instream Reserve Flow	Recharge from Septic	Available Ground Water
		20-year Drought	Yr 2030	7Q10	Yr 2030	
	sq miles	mgd	mgd	mgd	mgd	mgd
Monocacy-Alloway Cr	24.55	3.49	0.41	0.23	0.10	2.95
Monocacy-Bennett Cr	65.91	16.85	1.84	5.99	0.90	9.91
Monocacy-Big Pipe Cr	107.77	23.54	3.70	6.81	1.59	14.61
Monocacy-Bush Cr	32.93	8.36	2.25	2.99	1.03	4.15
Monocacy-Hunting Cr	41.71	7.70	1.65	0.45	0.22	5.81
Monocacy-Israel Cr	33.13	7.13	1.86	2.96	0.40	2.71
Monocacy-Linganore Cr	89.04	22.34	1.21	8.10	0.36	13.38
Monocacy-Little Pipe Cr	83.32	18.89	5.34	6.58	0.32	7.30
Monocacy-Lower Monocacy	83.18	14.12	5.75	5.63	2.04	4.78
Monocacy-Marsh Cr	99.35	16.18	0.52	0.60	0.00	15.07
Monocacy-Owens Cr	39.61	7.23	1.06	0.35	0.39	6.22
Monocacy-Piney Cr	34.36	6.10	1.50	1.08	0.59	4.11
Monocacy-Rock Cr	63.49	9.06	0.88	0.21	0.00	7.97
Monocacy-Toms Cr	69.62	12.56	0.94	0.59	0.09	11.12
Monocacy-Upper Monocacy	101.44	15.80	5.14	2.12	1.24	9.78

[24] "Internal" to the sub-watershed, computed without regard to upstream needs. For example, the 7Q10 at the bottom of the Monocacy-Upper Monocacy is about 19 mgd, but 17 mgd of this need originates in and is provided by sub-watersheds upstream of the Monocacy-Upper Monocacy, leaving 2 mgd to be met from recharge within the Monocacy-Upper Monocacy.

Surface Water Availability

Streamflows vary from day to day and from season to season. Appropriations from streams and rivers are required to leave a minimum amount of water in the stream (the flowby) to meet minimum biologic needs of the stream. The smallest formally calculated flowby that Maryland would consider for a new surface water appropriation would be the 7 day, 10 year low flow (7Q10). Absent a reservoir, even a stream with no appropriations in its watershed will not have adequate water to provide its minimum required flow (the 7Q10) all of the time.

Most new appropriations require flowby calculated by the Maryland Most Common Flow Method. If the minimum adequate flow to maintain a stream is taken as the flow calculated using the Maryland Most Common Flow Method[25], flow of a stream with no appropriations and no reservoirs would be inadequate, on average, 15% of the time.

Thus appropriators from streams without reservoirs or other storage will not be able meet their need from the stream all of the time, regardless of other use of the resource. Provision for storage and other sources are fundamental to appropriation from surface water. Two important questions are: To what extent will growth in the region increase the number of days that flow will be inadequate to meet all needs and what can be done to provide for days in which no appropriation can be made? Three related surface water models were evaluated as possible tools to answer these questions.

Surface Water Modeling Approach and Limitations

Originally, the intent was to develop a single surface water model that would represent all sub-basins of the Monocacy. As the modeling effort progressed, however, it became necessary to use three different but closely related models to represent the different sub-basins. These three models are described more fully later in this document. More detail and review is needed to make these models a useful tool for watershed evaluation.

The Maryland Department of Environment, Source Protection and Appropriation Division, commonly uses areally proportioned stream-gage data to determine flowbys and occasionally uses streamflow simulations to determine safe yield and water availability. Such simulations typically use one or two nearby streamgages areally proportioned to represent naturally available water at a point. Spreadsheets are normally adequate for such modeling. The size and complexity of these models outgrew the spreadsheet approach and it is recommended that any future attempt to develop a model of this complexity consider the use of a simulation package such as OASIS(tm).

These models are intended for gross watershed evaluation, and many shortcuts and simplifications were used than would be desirable in an engineering model intended for application to a particular problem. For instance, no attempt was made to model the operation of Lake Linganore, except as noted in the discussion of additions to flow and in the discussion of the Calibrated Balanced Model. In addition, a single annual average value of water appropriation, derived from pumpage reports for the year 2000, was used. The use of monthly and, where available, daily appropriation values

[25] Various internal MDE documents from 1986 to 2004

would improve confidence in the models, especially when calibrating the Calibrated Balanced Model to reproduce the problems experienced during the drought of 2002. Improved data on actual appropriations and discharges in Pennsylvania would also be beneficial. Finally, inconsistencies between how municipal discharges were projected and how water appropriations were projected need to be resolved.

A more detailed model, which could be used as a management tool to maximize the yield of Lake Linganore and Fishing Creek Reservoir, would require a greater commitment of time and resources then was available for this committee.

In developing the models that represent the Monocacy Basin, the stream gages listed in Table D-5 were used. This Table also lists a short name for each gage that will be used for reference in the remainder of the Appendix.

Table D-5 Stream Gages Used in Surface Water Models

Streamgage	Available Record	Area (square miles) and Short Name	
Monocacy River at Bridgeport, MD	1942 – 2003	173	Bridgeport
Piney Creek near Taneytown, MD	1990 – 2003	31.3	Piney Cr
Big Pipe Creek at Bruceville, MD	1947 – 2003	102	Big Pipe Cr
Hunting Creek at Jimtown, MD	1950 – 1992	7.29	Hunting Cr
Monocacy River at Jug Bridge, near Frederick, MD	1929 – 2003	817	Jug Bridge
Linganore Creek near Frederick, MD	1932, 1934–1982	82.3	Linganore Cr
Bennett Creek at Park Mills, MD	1948 – 1958, 1966 – 2003	62.8	Bennett Cr

Using correlation and regression, synthetic gage records running from October 1, 1947 through September 30, 2003 were created for each of the four gages that did not naturally include the complete period.

Additions to Natural Flows

The following values were added to the flow series generated above:

- Estimates of Municipal and Industrial Discharges for years 2000, 2020 and 2030 Discharge information for 2000 and 2020 was provided by Jeff Rein and Michael Richardson. Discharges for 2030 were estimated by straight-line extrapolation of the 2000 and 2020 values. In the Monocacy-Bennett Cr sub-basin, an additional 12 mgd was added to the discharges to reflect the flow through use of Lilypons Water Garden, Inc.

- The safe yield of the two reservoirs managed for water supply (Fishing Creek Reservoir and Lake Linganore).

- Transfers from out-of-basin by the New Design Water Treatment Plant, under two different scenarios:

  1. To consider the state of the sub-basin as a whole, the correct value to add is only that portion of the transfer that supplies consumptive use since the non-consumptive transfer of water from out-of-basin is already captured by municipal discharge estimates.

  2. To consider the users who are actually hooked to the pipeline, the correct value to add is the amount of water that actually transferred, since it would not necessarily matter to a user such as the City of Frederick that they can't withdraw from the Monocacy if they can meet their needs from the New Design pipeline.

- Recharge from septic systems for people on individual well and septic. This is estimated to be 80% of the ground water withdrawn by people on individual well and septic. Because the model works with total appropriations, (since use of ground water from the surficial aquifer must ultimately reduced baseflow) ground water discharges must be added back into the model.

- Where applicable, excess water from upstream watersheds is also added to the available water in a sub-watershed.

Subtractions from Natural Flow

The following values were subtracted from the flow series generated above:

- Demand for water as previously computed. Note that both surface and ground water appropriations were subtracted from the available water since an appropriation of ground water from a surficial aquifer must eventually reduce streamflow to some degree.

- Instream reserve flow—The 7Q10 was subtracted from the available flow for each Basin as this is flow is need to preserve stream life and is not available for appropriation.

- Out-of-basin diversions—One of the alternatives examined was the diversion of 10 mgd of to a power plant in the Catoctin basin.

Three Surface Water Models

As might be expected for from the above discussions, the available surface water in each watershed is:

[Available] = [Internally Generated Flows] + [Additions to flow] - [Subtractions from flow]

Where zero or greater, it indicates that adequate flow is available to meet all needs in the watershed. Where less than zero, it indicates that insufficient flow is available to meet all needs. All of the models report the number of days that flow was not sufficient to meet all demands in 2002, in 1966, and for the period from October 1, 1947 thru September 30, 2003.

The first model created was the Balanced Model. In the Balanced Model, generated flows in upstream sub-watersheds were adjusted to match the flows at the Jug Bridge streamgage. After examining the flow adjustments needed to make this work, it was determined this model was unsuitable for the upstream sub-watersheds. Accordingly, this model was only evaluated for the Monocacy-Upper Monocacy and Monocacy-Lower Monocacy sub-watersheds. Results from this model were used to represent the Monocacy-Upper Monocacy sub-watershed.

The second model created was the Calibrated Balanced Model. Although the Balanced Model correctly shows inadequate flows occurred during the drought of 2002, it overestimated the number of days when flow was inadequate. It was desired to reproduce, at least approximately, the number of days and the length of runs of days when flow was inadequate. Further, since the Jug Bridge streamgage is affected by upstream appropriations, some adjustment should be made to the raw gage data when it is used for the purposes of flow generation.

According to Consent Order CO-02-01-WS (State of Maryland Department of Environment v. City of Frederick), a flow of 50 cfs at the Jug Bridge streamgage corresponds to the flow at the City's intake at which they must restrict their appropriation from the Monocacy. Therefore, a computation point was added to the model that attempted to reproduce the flow at the Jug Bridge gage. Flows at this point (hereafter Jug Bridge Computed[26]) were compared were compared to actual flow reported from the Jug Bridge streamgage. The version of the Jug Bridge gage used for flow generation (in some sub-watersheds) and model balance adjustments was then altered in attempt to match the problems of 2002.

When the gage used for flow balancing was adjusted by adding 2 cfs, computed flow at Jug Bridge reproduced the problems that actually occurred at the Jug Bridge streamgage in 2002. This calibration also came close to reproducing the runs of flow less then 50 cfs experienced during 1966 drought. Accordingly, this calibration was adopted and the Calibrated Balanced Model was used to represent the Monocacy-Lower Monocacy.

The final model created was the Unbalanced Model, which was used for all of the remaining watersheds. This model was the simplest, using the generated flow for each watershed with the additions to and subtractions from flow as previously noted but without other adjustments.

Surface Water Results

For all sub-sheds except Monocacy-Lower Monocacy (MLM), it was only necessary to consider three Alternatives—Conditions in 2000, 2020 and 2030. The results from these alternatives were tabulated to show the number of days that there would be insufficient water available to meet all demands for the average demand in 2000. These results were tabulated in for the complete period of simulation (POS) from 1947 thru 2003 and for a repeat of the droughts 1966 and 2002. Similar tabulations were made for the year 2020 demand and year 2030 demand.

[26] In computing flows at Jug Bridge Computed, flows from the Linganore Creek sub-watershed during the year 2000 were taken as the higher of the flow generated by streamgage regression and the minimum flowby of Lake Linganore

In general, the number of days when flow will be inadequate to meet all needs will increase in the future. An exception occurs in the Monocacy–Little Pipe Cr sub-watershed, where the discharge from the sewage treatment plant serving the City of Westminster transfers water appropriated in the watershed of Liberty Reservoir into the Monocacy-Little Pipe Cr sub-watershed. Computations also show discharges in the Monocacy–Piney Creek and Monocacy–Hunting Cr subwatersheds are increasing more then appropriations in the future, but there are believed to be an artifact of different procedures and assumptions being used to project municipal discharges then were used to project demand. This inconsistency is another problem that will have to be addressed if a more detailed surface water model is to be developed. Better, more detailed information on municipal and industrial discharges is needed.

The Monocacy-Lower Monocacy was evaluated for four different scenarios for years 2000, 2020 and 2030 for 12 sets of results. These scenarios are:

1. Do Nothing—No action is taken to provide storage or alternate water supplies while growth continues.

2. Pipeline Watershed—Watershed Conditions where 26 mgd is available via interbasin transfer to the Monocacy-Lower Monocacy sub-basin. For this alternative, only the consumptive portion of the 26 mgd is represented.

3. Pipeline Users—User Conditions where 26 mgd is available via interbasin transfer to the Monocacy-Lower Monocacy sub-basin. For this alternative, all 26 mgd is represented.

4. Power Plant—Watershed Conditions with the 26 mgd division into the Basin but a 10 mgd division is made out of the Basin for a power plant. For this alternative, only the consumptive portion of the 26 mgd is represented. Note that this analysis is approximate and only reflects gross conditions in the Basin and does not replace the more detailed analysis that will be required if the proposed power plant proceeds.

Under the Do Nothing alternative, the number of days when flow is inadequate in the MLM sub-watershed will increase in the future. Under the Pipeline Watershed scenario, there will be fewer days when flow is inadequate in the sub-watershed then there are now, but the assumptions underlying this do not include the likelihood that operations of water treatment plant will optimize their use of the Monocacy.

The Pipeline Users alternative pointed out an interesting result. Because total demand in the MLM sub-watershed is less than the peak 26 mgd that the pipeline could supply, if transfers can be made from the Potomac, this alternative solves the problems of users connected to the pipeline. The total demand of the Monocacy–Linganore Cr sub-watershed and the MLM sub-watershed is less than 26 mgd. However, no attempt was made to assess cumulative impacts on the Potomac or to assess what limitations might be placed on Potomac withdrawal. Depending on the limitations placed, detailed watershed modeling would be of great use in planning an operator strategy to maximize the yield of the two water supply reservoirs.

The Power Plant alternative increased the number of days when flow in the MLM sub-watershed was inadequate. This result indicates that, even when wastewater is used for a thermoelectric supply, there can be a significant lose of available water in a watershed.

Conclusions

The Monocacy Pilot Study was conducted as a demonstration project to provide an example of some of the methods that might be used to evaluate water supply and demand across the state. In the course of this study, several issues arose that point to a need for additional information and resources to perform an adequate assessment and to extend this analysis to other areas of the State. In order to remedy these issues, the following areas of "need" have been identified:

- More research is needed to better determine what portion of appropriated water is consumptively used. For example, homes on individual wells and septic systems are assumed to return 80% of the water they take from their wells to the surficial aquifer as recharge. There is a need to refine this estimate.

- Water and sewer planning information should be incorporated into the projection of water use to better reflect the future split between surface and ground water and between growth of public water systems and growth on individual well and septic systems.

- When allocating ground water resources, the adequacy of the 7Q10 as an appropriate reserve flow needs to be evaluated. Full allocation of ground water would allow this minimum flow to occur throughout the year.

- More research needs to be done on ground water recharge and discharge to determine the adequacy of the estimated recharge rates used, the streamflow reduction that can be expected from ground water appropriations and the relationship of well yields in fractured rock wells to changes in ground water in storage.

- More detailed information concerning surface water discharges is needed to properly evaluate available surface water.

- A more detailed surface water model is needed as a management tool to properly evaluate the effect of appropriations on the Monocacy.