APPENDIX F–WATER MONITORING AND MODELING

State water managers and regulators are responsible for making daily decisions about the protection and use of Maryland's surface-water and ground-water resources. These decisions can affect the lives and livelihoods of Maryland's more than five million residents, as well as the future condition of the rivers, streams, and aquifers of the State. It is in the best interest of the State and the people of Maryland that decisions about water resources be made based on the most complete and best available monitoring.

Rivers and streams are monitored by measuring streamflow at stream gages, and aquifers are monitored by measuring ground-water levels in observation wells. Maryland is fortunate to have had excellent, long-standing, scientific data-collection programs in which these types of monitoring have been conducted. Recent evaluations, however, have shown that streamflow and ground-water level monitoring conducted by the U.S. Geological Survey (USGS) and the Maryland Geological Survey (MGS) is not as comprehensive as it needs to be and is threatened by declining State funding support. Stable long-term funding that accounts for inflation is needed to support these monitoring activities so that State water managers and regulators can continue to make informed decisions about Maryland's water resources.

A streamflow monitoring network for Maryland should include stream gages on all major rivers and streams in the State, as well as numerous smaller streams that are representative of various watershed settings throughout the State. Similarly, a ground-water level monitoring network for Maryland should include observation wells in all major aquifers and hydrogeologic settings in the State. Streamflow and ground-water level networks designed to address the disparate areas and settings of Maryland will provide a valuable snapshot of current water conditions and a basis for recognizing any long-term trends.

However, because water is a highly interconnected resource, a network that integrates streamflow and ground-water level monitoring can be even more powerful than separate networks. Streamflow and ground water are not separate water resources; they are inextricably connected because on average ground water contributes about 50% of total streamflow. Rivers and streams are fed by precipitation and ground water from aquifers, and aquifers are recharged by precipitation and sometimes streamflow. It is the complete picture of this interconnected resource that must be "visible" to State and local water managers and regulators. Decisions cannot be made about one resource without affecting the other. Just as streamflow and ground water are connected, so should streamflow and ground-water level monitoring programs be connected through integrated water monitoring. Observation wells that monitor ground-water levels can be sited to be near stream gages that monitor streamflow, thereby allowing an integrated data analysis that raises the level of scientific understanding to support sound water-resources decision-making. Another key component of integrated monitoring and analysis is a comprehensive network of precipitation gages, which will soon be addressed by the Maryland Water Monitoring Council. A comprehensive, integrated water-monitoring network that includes stream gages, observation wells, and precipitation gages is an essential tool for decision-making based on sound data and science.

The optimal streamflow and ground-water level monitoring networks described in the next two sections are presented as separate networks with separate design criteria. However, in implementing these two networks, every effort would be made to site observation wells and stream gages coincident with each other to achieve an integrated water monitoring network for Maryland.

Streamflow Monitoring Network

The State of Maryland has a need for a comprehensive network of stream gages to monitor the flow of water in its rivers and streams. Streamflow is the most available and most visible natural water resource in Maryland. It is absolutely critical to the wise utilization of the State's water resources that the amount of water flowing in its rivers and streams be known. The USGS, with funding support from many Federal, State, and local agencies, currently operates a streamflow monitoring network of 115 stream gages in Maryland.

Streamflow data are valuable to the State for many reasons. The data are used for water-supply assessments, watershed management, stream restoration, bridge design, flood warning, sediment and contaminant loadings, assessing development impacts, water-quality improvements, and support of recreational activities. Without streamflow data, it would be impossible to know how much water is potentially available from Maryland's rivers and streams for drinking-water supply, industrial and commercial use, electric power generation, preservation of ecological resources, and many other purposes.

One example of the value of streamflow data is that they provide the basis for allocation of water from rivers and streams for various and sometimes competing purposes. A river or stream can supply water for many purposes along its length, including supply for drinking water, industries, and businesses, and sufficient flow for recreational activities and to dilute sewage effluent. These uses can not be properly balanced without consistent and accurate measurement of the amount of water flowing in rivers and streams.

Another example of the value of streamflow data is flood prediction and warning. The historical record of a long-term stream gage can be used to estimate when precipitation events will cause a flood in a river or stream. In addition, when a stream gage is instrumented for near-real-time data delivery, a developing flood can be tracked via the world-wide web, providing State and other emergency-management officials with valuable lead time to prepare for evacuation of flood-prone areas, often saving human lives and avoiding significant property loss.

Due to declines in State and local funding support, the number of Maryland stream gages declined from 95 in the early 1990s to 76 in 1995. A workshop sponsored by the Maryland Water Monitoring Council in 1997 resulted in a greater understanding of the value of long-term stream gages and a commitment to develop a comprehensive network of stream gages for Maryland. The workshop led to a report (Cleaves and Doheny, 2000) that showed a need for 157 stream gages in Maryland. As a direct result of the workshop and report, the Maryland stream-gage network grew to 115 gages by late 2003 to early 2004 (Fig. F–1)**.**

The stream-gage report describes an optimal, multi-purpose, streamflow monitoring network for Maryland. The report recommends additional stream gages to: (1) Provide a core network that would include all major rivers and streams in Maryland; (2) provide a network of stream gages on streams in small watersheds in the various settings in Maryland; and (3) provide a network of stream gages to fill the remaining geographic gaps in the monitoring of streamflow in Maryland.

Unfortunately, in 2003, State funds used to support the stream-gage network began to decline. By the fall of 2004, the network will be reduced by 12 gages, 8 of which are on the Eastern Shore, an area where coverage is already relatively sparse. Further declines are likely as State and County funding sources are increasingly stressed, and as USGS matching funds also continue to decline. Maryland is in danger of relinquishing its stream-gage gains of the past 5 years. A long-term, stable source of funding for stream gages is needed to ensure that Maryland has the streamflow data it needs to properly manage its surface-water resources.

The first step in assuring a viable stream-gage network for Maryland would be to maintain the 12 stream gages that have been or are about to be lost due to insufficient State funds. However, maintaining the stream-gage network at its 2003 level is only the first step. It is equally critical to enhance the network by adding new stream gages as recommended in the stream-gage report. A current interpretation of the recommendations of the workshop report suggests that 47 new stream gages need to be added to address remaining core-network, small-watershed, and spatial-gap needs (Fig F-2)**.** Without all these additional recommended stream gages, the network will be sorely lacking in coverage in some parts of Maryland. This lack of appropriate coverage will force State water managers and regulators to make important, necessary decisions about water resources by extrapolating from stream gages in sometimes distant and disparate settings that do not accurately reflect conditions in areas impacted by those decisions.

To maintain the stream-gage network at its 2003 level, State funding is needed to retain the 12 stream gages that have been lost or are about to be lost in 2003-2004 (see map in appendix). The necessary State funding would be $75,000, to be matched by $75,000 of USGS matching funding. To enhance the stream-gage network by adding the 47 new gages recommended in the 2000 workshop report would require that State funding cover the cost of establishing these 47 new gages and 50% of the cost of the annual operation of these new gages. Under this scenario, State funds on the order of $300,000 per year would be needed to add these 47 new stream gages over a 5-year period. If funding is available from the State, it would be incumbent on the USGS and selected Counties to provide the necessary funds to match the State contributions for annual operation.

Should only some, but not all, of the above State funding be available for the 47 new gages needed, the addition of new stream gages would proceed at a slower pace as funding allows based on the following priorities. The highest-priority new gages to be added would be the core-network gages, of which there are 30. Following those new gages, the small-watershed (11) and spatial-gap (6) gages would be the next priorities. The number of new stream gages that could be added would be in direct proportion to the amount of State funding available.

Ground-Water Level Monitoring Network

A comprehensive network of observation wells is needed in Maryland to monitor ground-water levels in both the major water-supply aquifers and the shallow aquifers that supply base flow to important stream ecosystems. The Maryland observation-well network, currently funded and operated by the USGS and the MGS, is being threatened with termination by declining State funding support.

Observation wells provide the only direct measurement of the health of Maryland’s aquifers. Ground-water level data are critical to the understanding of the condition of the State’s ground-water resources, providing: (1) Insight into long-term trends due to natural or human influences; (2) a tool for drought warning and tracking; and (3) data to inform the State’s ground-water appropriation permitting process. Without ground-water level data, there would be no direct way to keep a finger on the pulse of Maryland’s ground-water resources.

One recent example of the value of ground-water level data is the use of the data as one of the major indicators of the progress of the drought of 2002. Ground-water level data indicated when the drought was approaching, when it equaled and exceeded previous droughts, and when it ended (Fig. F-3). Moreover, having ground-water level data from different geographic areas and geologic settings of Maryland assisted the State in applying water-use restrictions at different times and at different levels in different areas, thereby impacting the people and the economy of Maryland only as much as was necessary.

Another example of the value of ground-water level data is the monitoring of declining water levels in the confined Coastal Plain aquifers of Maryland (also see the previous section on the Southern Maryland pilot study in this report). Increased pumpage of ground water in southern Maryland, parts of the Eastern Shore, and other areas of the Coastal Plain, has lowered ground-water levels by about 150 feet in some locations. The existence and magnitude of these declines would not be known if there were not many years of ground-water level data available for these areas, and the State would not have a scientific basis for permitting ground-water appropriations for these aquifers.

A multi-agency workgroup sponsored by the Maryland Water Monitoring Council has completed an evaluation of the statewide Maryland observation-well network and has recommended an optimal network for monitoring the surficial aquifer and the seven major confined aquifers of Maryland. The goals of the optimal network are to: (1)

monitor the effects of climate variability, particularly drought, on the shallow ground-water resources of Maryland, and (2) monitor the effects of ground-water pumpage on the seven major confined aquifers of the Maryland Coastal Plain.

The workgroup determined that 240 observation wells are needed to adequately monitor the condition of Maryland's ground-water resources (Fig. F–4 thru F–11). 141 of the needed observation wells are already included in the Maryland network and have many years of valuable record; the remaining 99 observation wells will have to be added to the network.

Unfortunately, the elimination of State funding for the State observation-well network has left the future of the network in doubt. The optimal observation-well network that the workgroup has recommended is in jeopardy, and the ground-water level trends apparent only through decades of data will be truncated. To ensure that Maryland will continue to have a viable observation-well network for the future, a long-term, stable source of State funds is needed.

It is critical to at least maintain the monitoring of the 141 existing wells that have significant periods of record. However, without additional funding to establish, or at least begin to "phase in", the additional 99 new wells that are needed, important areas and settings of the State will not have the necessary monitoring in place to address the many critical ground-water questions and issues that Maryland will face in the future. Without these additional recommended observation wells, State water managers and regulators will be forced to base important water-resources decisions on the limited existing observation wells that may not accurately reflect conditions in the areas impacted by those decisions.

To maintain that portion of the recommended Maryland observation-well network that already exists (141 observation wells), State funding on the order of $150,000 per year is needed, to be partially matched by $100,000 in USGS funding. To implement the entire optimal 240-well network that the network workgroup has recommended would require the addition of 99 new observation wells (most by drilling) and would require additional State funds on the order of $600,000 per year over a 5-year period.

Should only some, but not all, of the above State funding be available to enhance the observation-well network, the addition of new wells could proceed at a slower pace as funding allows based on the following priorities. The highest-priority new wells to be added would be those located near major pumpage centers in the Maryland Coastal Plain, to be followed by new wells in the shallow aquifers west of the Fall Line in physiographic units without sufficient coverage to address drought conditions. The number of new observation wells that could be added would be in direct proportion to the amount of State funding available.

COASTAL PLAIN AQUIFER MODELING AND MANAGEMENT

One of the most vexing and complex water-resources issues in the State of Maryland is the declining ground-water levels in the seven major confined Coastal Plain aquifers east of the Fall Line. These seven aquifers (Chesapeake, Piney Point, Aquia, Magothy, Upper Patapsco, Lower Patapsco, and Patuxent) are heavily used for water supply; about 80 million gallons per day of ground water is being withdrawn for various uses. Ground-water levels are declining by an average of about 2 feet per year in these aquifers. If this rate of decline continues, it is clear that the water supply of Maryland's heavily populated Coastal Plain communities would be in serious jeopardy in the not too distant future.

The seven major confined aquifers comprise a complicated multi-aquifer system that extends from the Fall Line, under the Chesapeake Bay, to the Atlantic coast. Before major pumping began, ground water generally flowed from recharge areas near the Fall Line to discharge upward into the Chesapeake Bay and the Atlantic Ocean. Under current pumping conditions, however, the natural ground-water flow system has been modified so that much of the ground water in these aquifers is now flowing toward production wells in numerous major pumping centers.

Because of the variability in aquifer geometries and characteristics, and the complex interrelationships among recharge, discharge, leakage and pumpage, there is no simple way to evaluate the water-supply potential of these confined aquifers. Ground-water flow models frequently have been used by the MGS and USGS to simulate these aquifers for the purpose of estimating their water-supply potential. Partly due to resource limitations and partly due to technological considerations, these models have been restricted to individual aquifers or small subsets of aquifers, and to selected geographic areas of the Maryland Coastal Plain. In reality, all seven aquifers are closely related to each other, and they are affected by what happens in their distant outcrop areas. A more comprehensive approach that assesses all the aquifers of the Maryland Coastal Plain as a package, and that includes the entire extent of each aquifer from the Fall Line to the Atlantic coast, is needed.

The computational methods and tools needed to manage a large volume of aquifer information over a large area are now available. Ground-water flow models can be built in a Geographic Information System (GIS) context, and the models can solve the necessary complex ground-water flow equations in large numbers of grid cells much more quickly than was previously possible. In addition, a single model can now be used to simulate both regional and local aquifer conditions through the use of telescoping grids. Also, it is possible to link stream-routing models in the recharge areas to ground-water flow models in the confined portions of the aquifers. These advances now permit the undertaking of a single large ground-water flow model of the Coastal Plain aquifers of Maryland.

An important step crucial to the success of such a model is the development of an accurate model representation of the hydrogeologic framework of the aquifer system. Much more hydrogeologic information is now available since the last modeling studies in most parts of the Maryland Coastal Plain, and a much better framework can now be developed. In addition, new techniques of interpreting aquifer frameworks, such as the concept of sequence stratigraphy, have recently been developed and could be applied to improve the framework. Any comprehensive modeling effort would have to involve a compilation of an improved aquifer framework.

In addition, there are still some gaps in knowledge about the presence and water-yielding characteristics of some of the aquifers, particularly in the deeper portions of the aquifers. A comprehensive model would greatly benefit from the acquisition of this information in areas where such information does not now exist. This could be accomplished by selective drilling and aquifer testing that would provide key information to complete the aquifer framework.

Ultimately, though, as with models of all types, the quality of the results will depend on the quality of the data available to build and calibrate the model. In the case of the confined aquifers in the Maryland Coastal Plain, several critical data needs must be addressed before a more definitive and defensible model can be constructed and used to determine the potential for water supply from these aquifers. The key data that are needed for a more accurate, comprehensive ground-water flow model are those data that have the most impact on the simulation of the pumpage of ground water from the major pumping centers.

Previous modeling studies have suggested that the amount of ground water ultimately available to production wells in these aquifers is largely dependent on the amount of increased recharge and leakage that are available. Consequently, it is absolutely critical to understand the processes which govern recharge and leakage. Detailed studies of recharge and leakage processes are needed to provide the necessary data to ground-truth the models. These studies would necessarily involve the full array of field and analytical tools currently available, including the installation of new wells, long-term aquifer testing, installation of other instrumentation such as stream and rain gages, application of analytical solutions, small-scale flow models, water-quality sampling, age-dating of ground water, and other similar approaches.

With all the above information in hand, a comprehensive, multi-aquifer, ground-water flow model could be developed, calibrated, and used to test scenarios of ground-water pumpage in the seven major aquifers of the Maryland Coastal Plain. The scenarios of pumpage could be optimized to determine the spatial and temporal distribution of pumpage that produces the least amount of water-level decline. This optimization approach has not yet been attempted on a large scale in Maryland, and would provide a major enhancement over previous modeling studies.

The final step toward a comprehensive, multi-aquifer model that could be used for ground-water management purposes would be the development of a set of tools that would facilitate the incorporation of flow model results into the management decision-making process. Optimization software is available that will automatically provide modeling results in the form of management options that can be used as the basis for decision-making. In this way, the ground-water flow model can be maintained and updated every time more aquifer data are available and every time there is a change in pumpage. Current climatic conditions also can be incorporated. Such a model can be used in a dynamic, real-time fashion to simulate current aquifer conditions, enabling State officials to immediately test the impact of any proposed ground-water pumpage changes, and determine whether a ground-water appropriation should be granted.

The separate tasks mentioned above, from compiling the aquifer framework to conducting recharge and leakage studies to developing a ground-water flow model, are all part of an overall program that leads to a set of management tools that can be used to inform water-resource decisions in the Coastal Plain aquifers of Maryland. Each task can be approached separately and will yield useful information by itself. However, if all the tasks are not undertaken as part of a comprehensive program, the ultimate goal of providing a set of management tools cannot be realized. It is recommended that all of the above tasks be undertaken as integral parts of the comprehensive program outlined in the above section.

The development of a comprehensive, multi-aquifer, ground-water flow model that can be optimized and incorporated into State decision-making procedures, would be a major undertaking that would require significant resources. In fact, undertaking and accomplishing this probably would take about 7-8 years, require the fulltime efforts of 4-5 scientists, and cost on the order of $10-12,000,000. This is a large resource commitment, but the preservation of the future of the ground-water resources of the Maryland Coastal Plain is an important goal that must be pursued.

Should the resources not be available to undertake the entire set of tasks above, the following breakdown of tasks is provided so that selected tasks may be undertaken individually. The number of years shown is not necessarily sequential; some tasks would overlap in time:

Compile aquifer atlas, build preliminary flow model, and set up preliminary management tools (2 yrs)	$1,000,000
Augment aquifer data through drilling and testing (5 yrs)	$4,000,000
Conduct recharge studies (3 yrs)	$2,500,000
Conduct leakage studies (2 yrs)	$1,500,000
Reinterpret aquifer framework (2 yrs)	$ 500,000
Calibrate flow model and refine management tools (2 yrs)	$1,000,000
Implement model and tools for State use and maintain model and tools (annually in the future)	$ 500,000

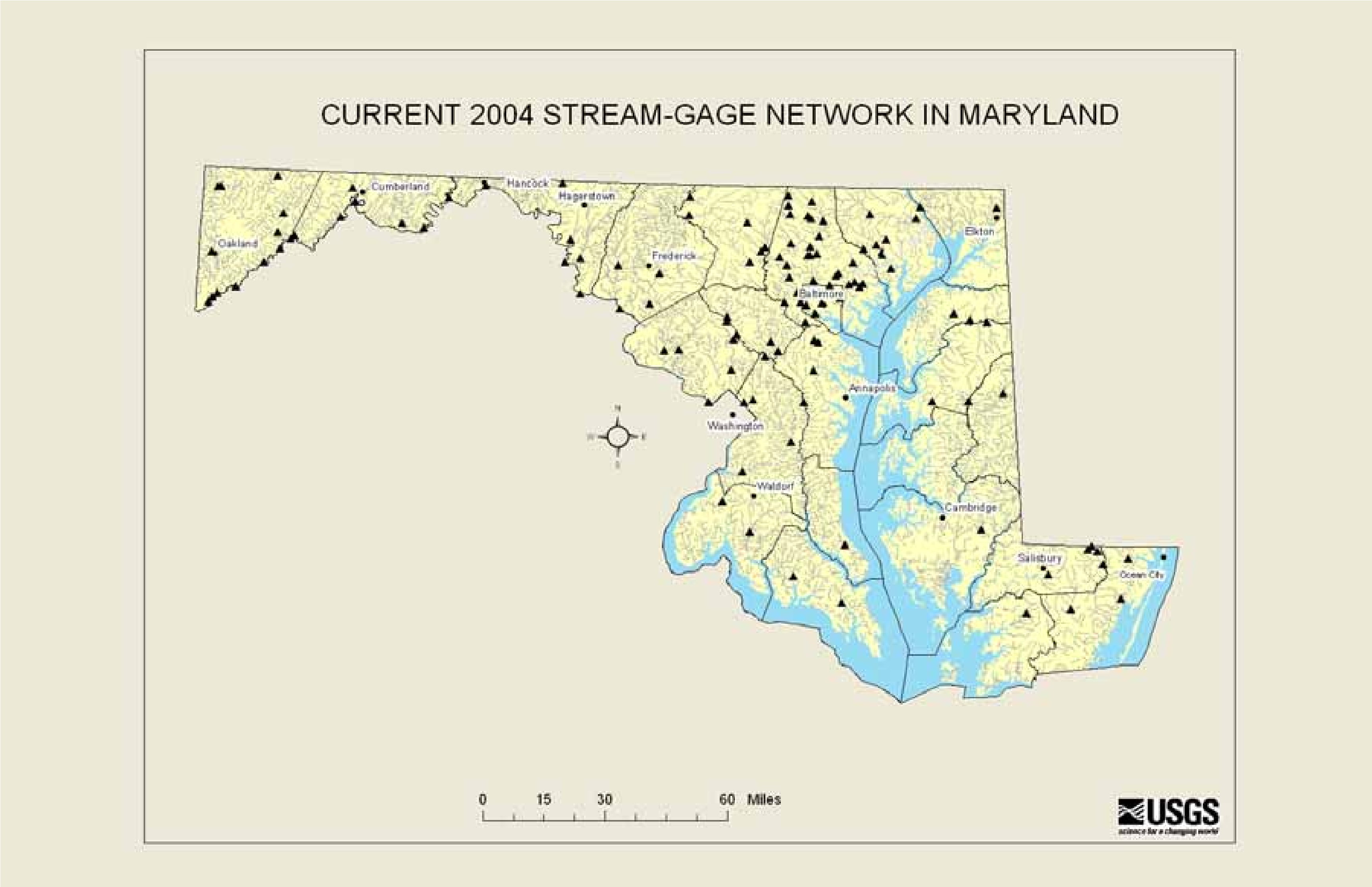

Figure F–1. Current (2004) Stream Gage Network

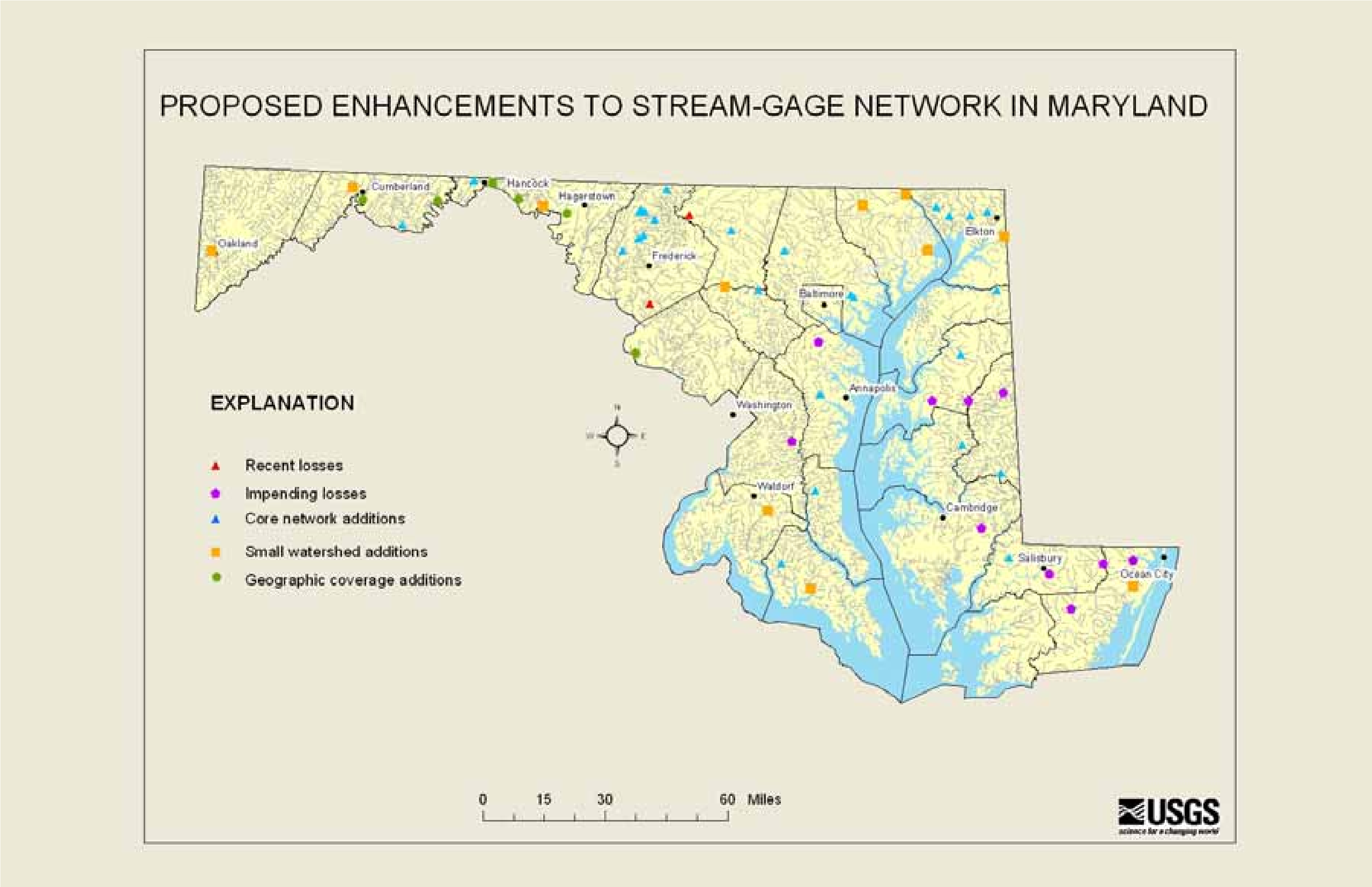

Figure F–2. Proposed Enhancements to Stream Gage Network

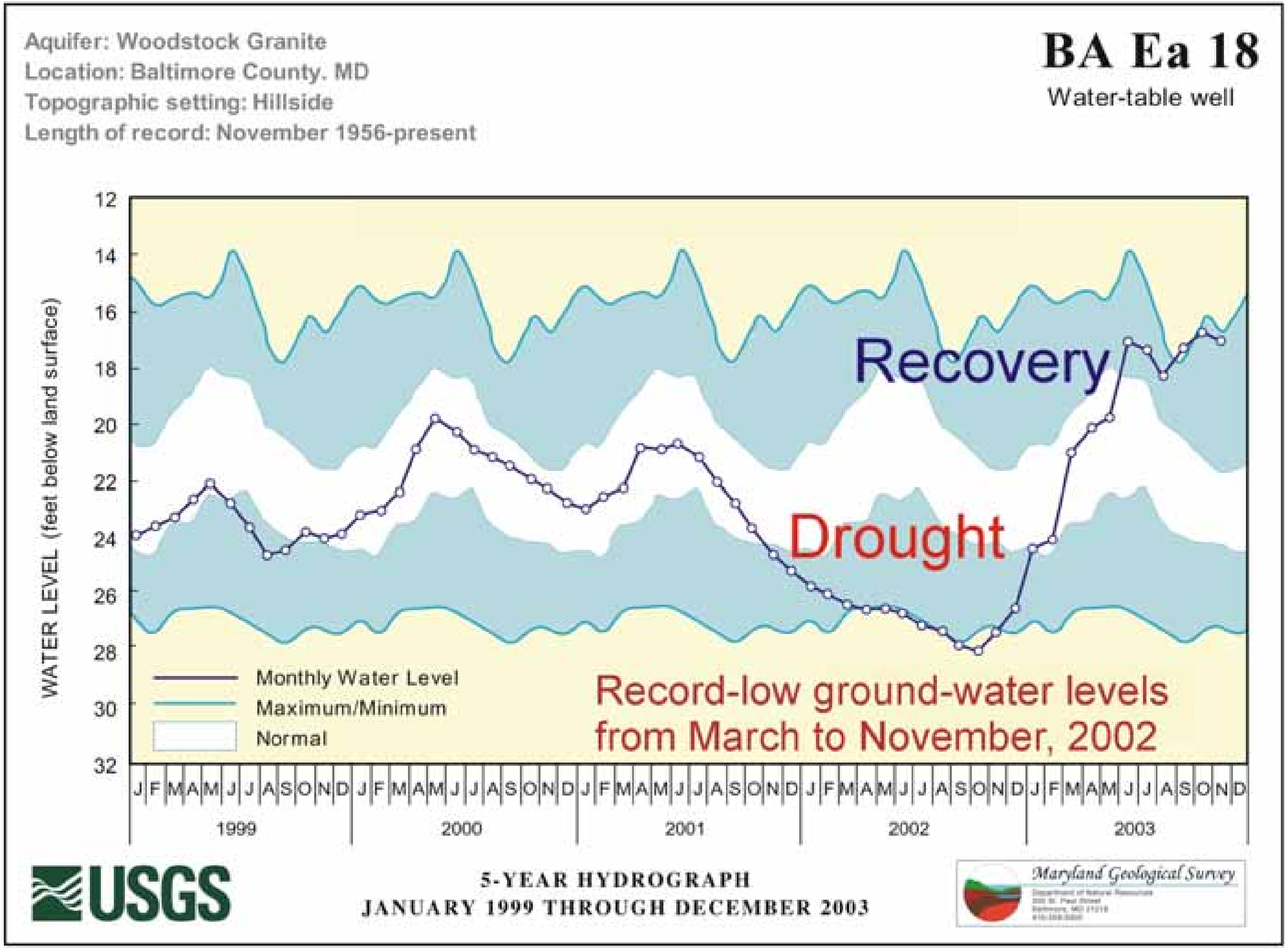

Figure F–3. Ground Water Levels in Well BA Ea 18 Show the Start and End of the Drought of 2002 in Maryland

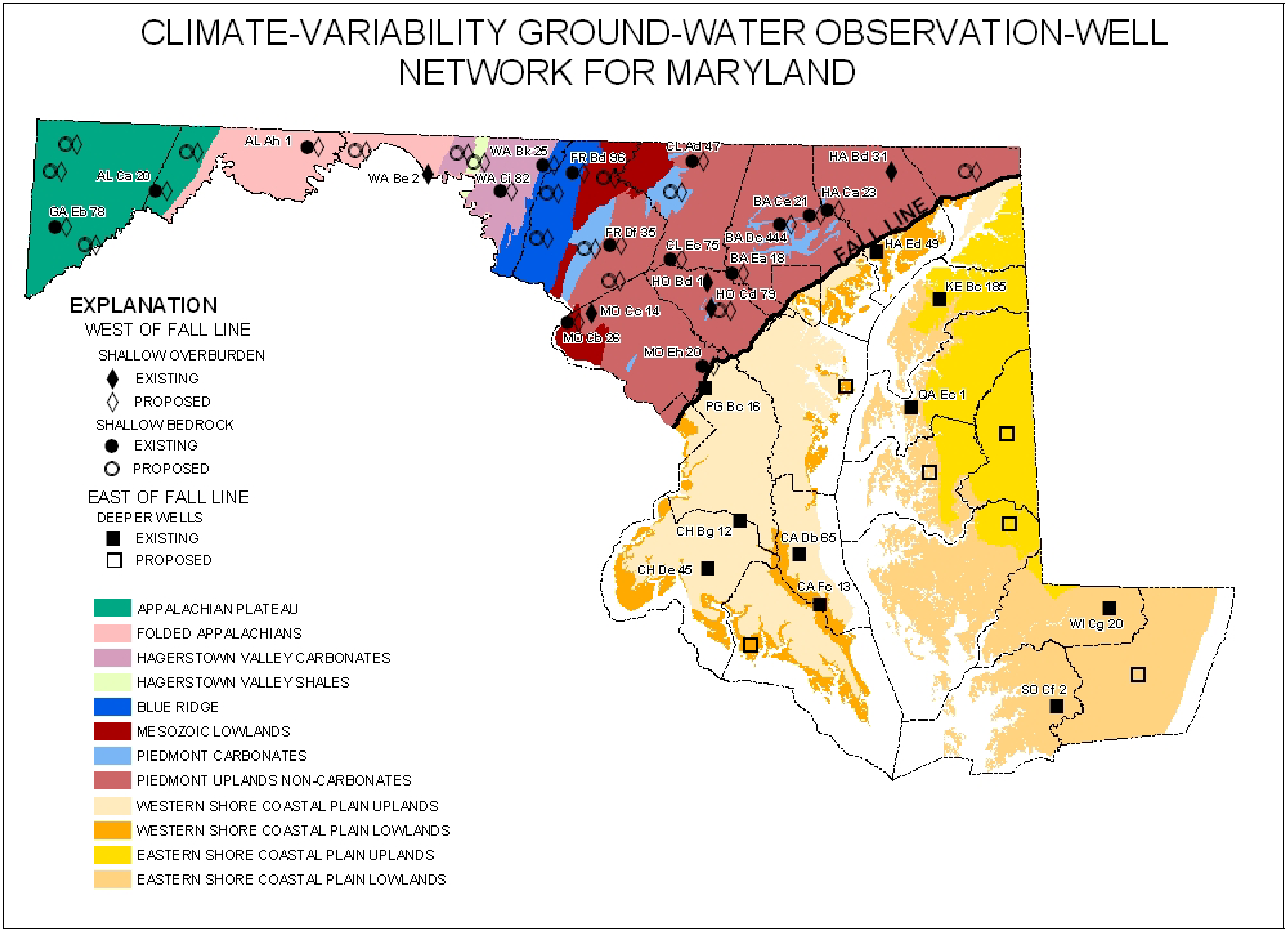

Figure F–4. Surficial Aquifer Monitoring Wells

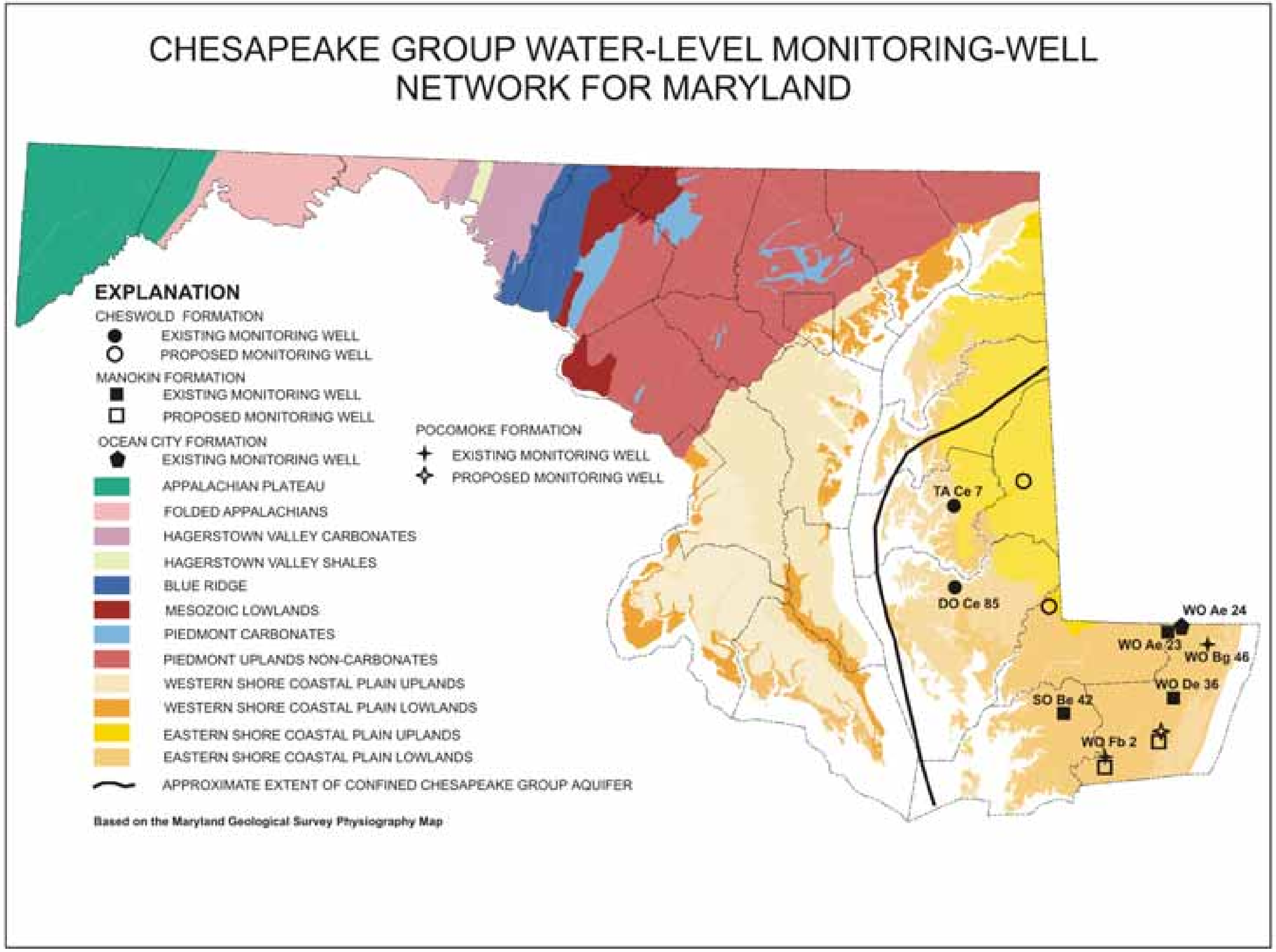

Figure F–5. Chesapeake Group Monitoring Wells

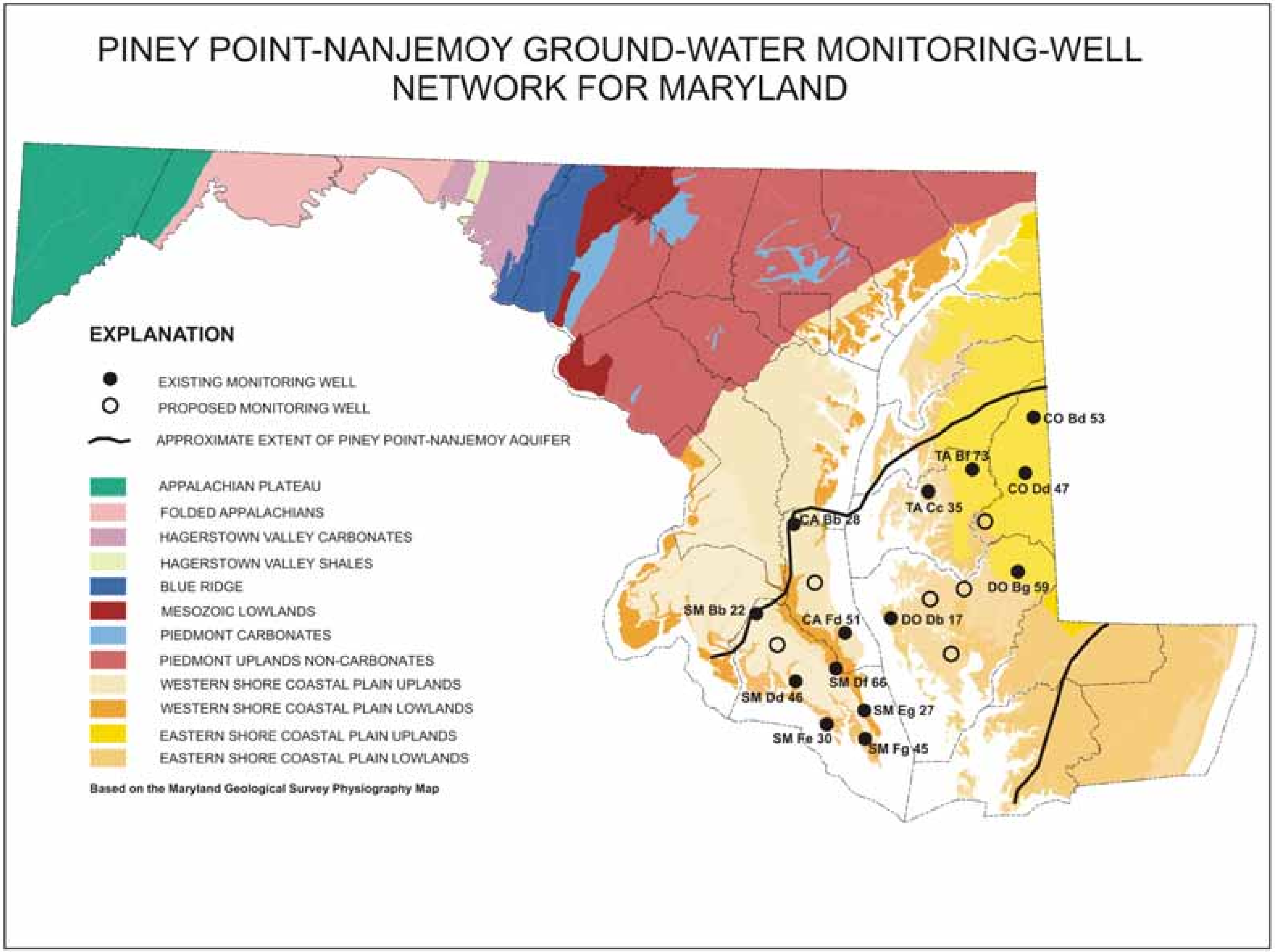

Figure F–6. Piney Point-Nanjemoy Monitoring Wells

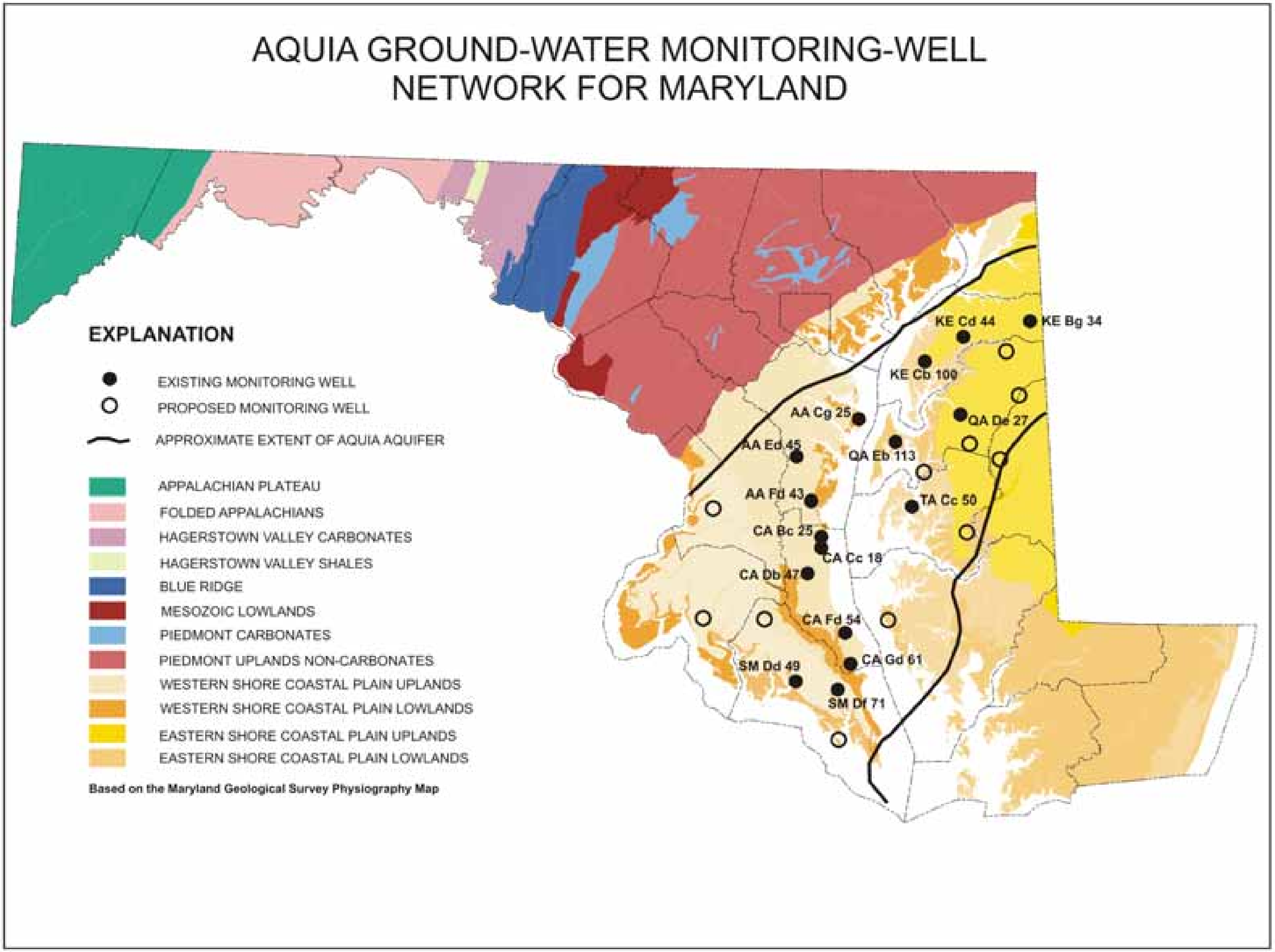

Figure F–7. Aquia Monitoring Wells

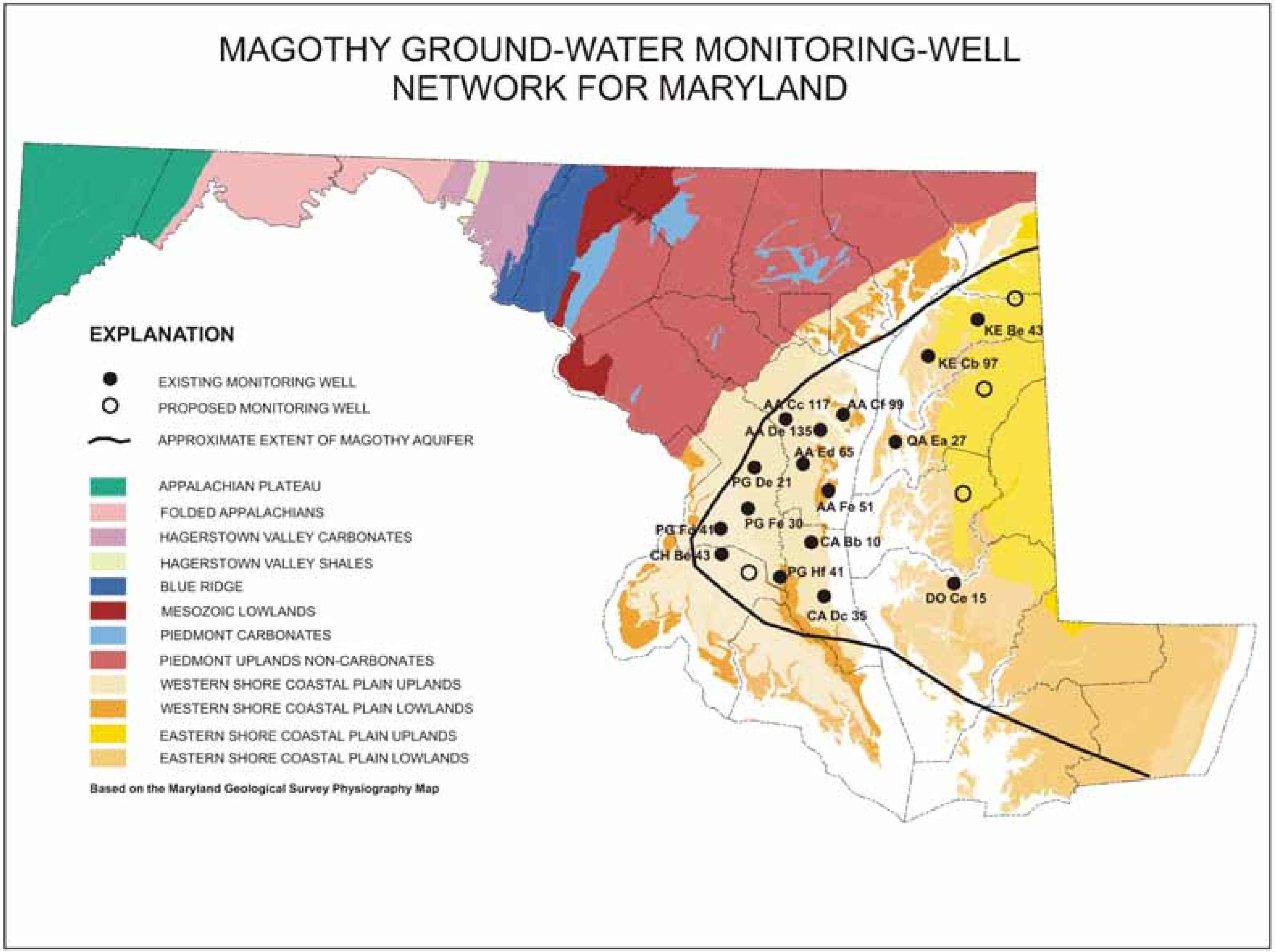

Figure F–8. Magothy Monitoring Wells

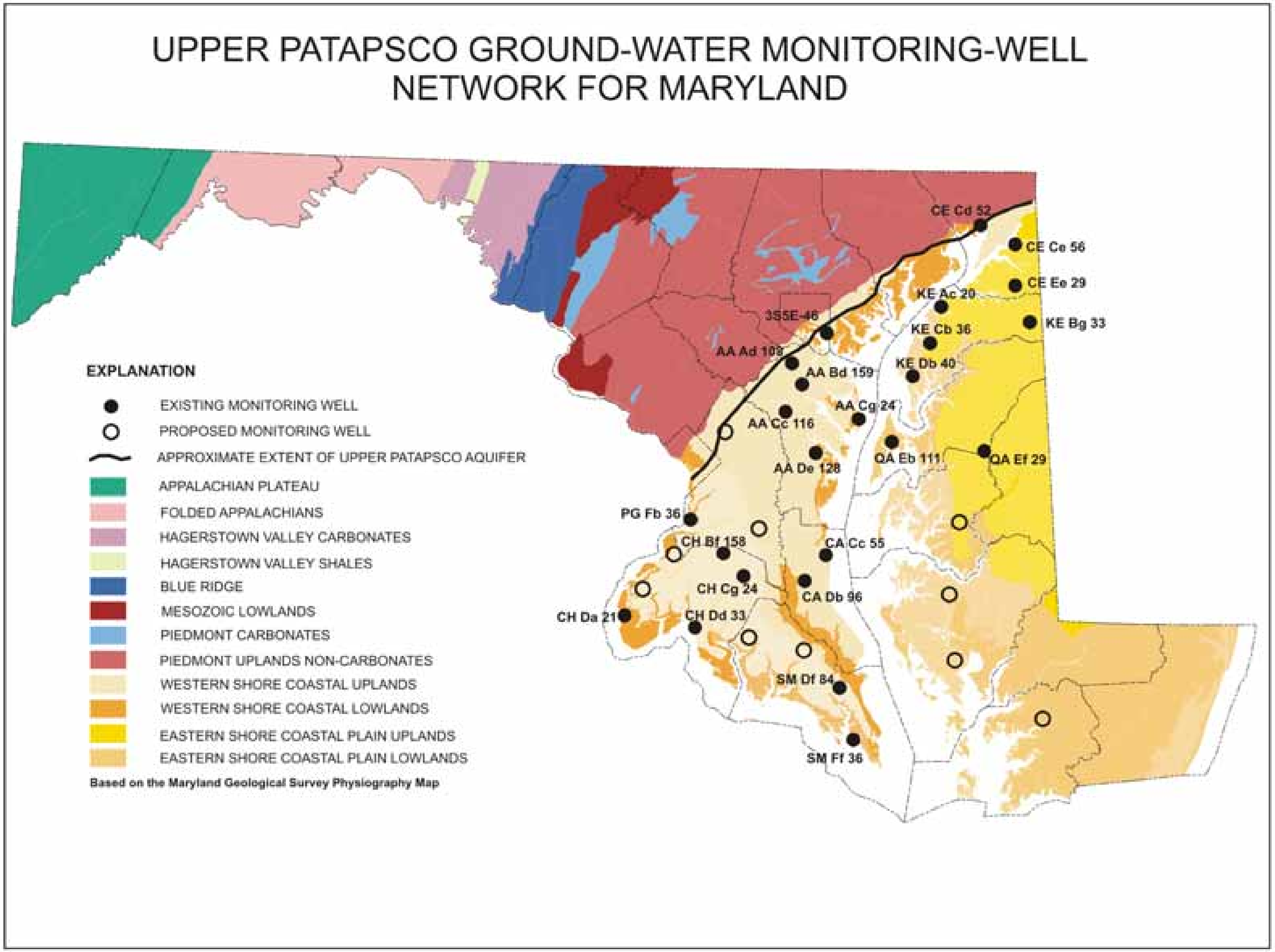

Figure F–9. Upper Patapsco Monitoring Wells

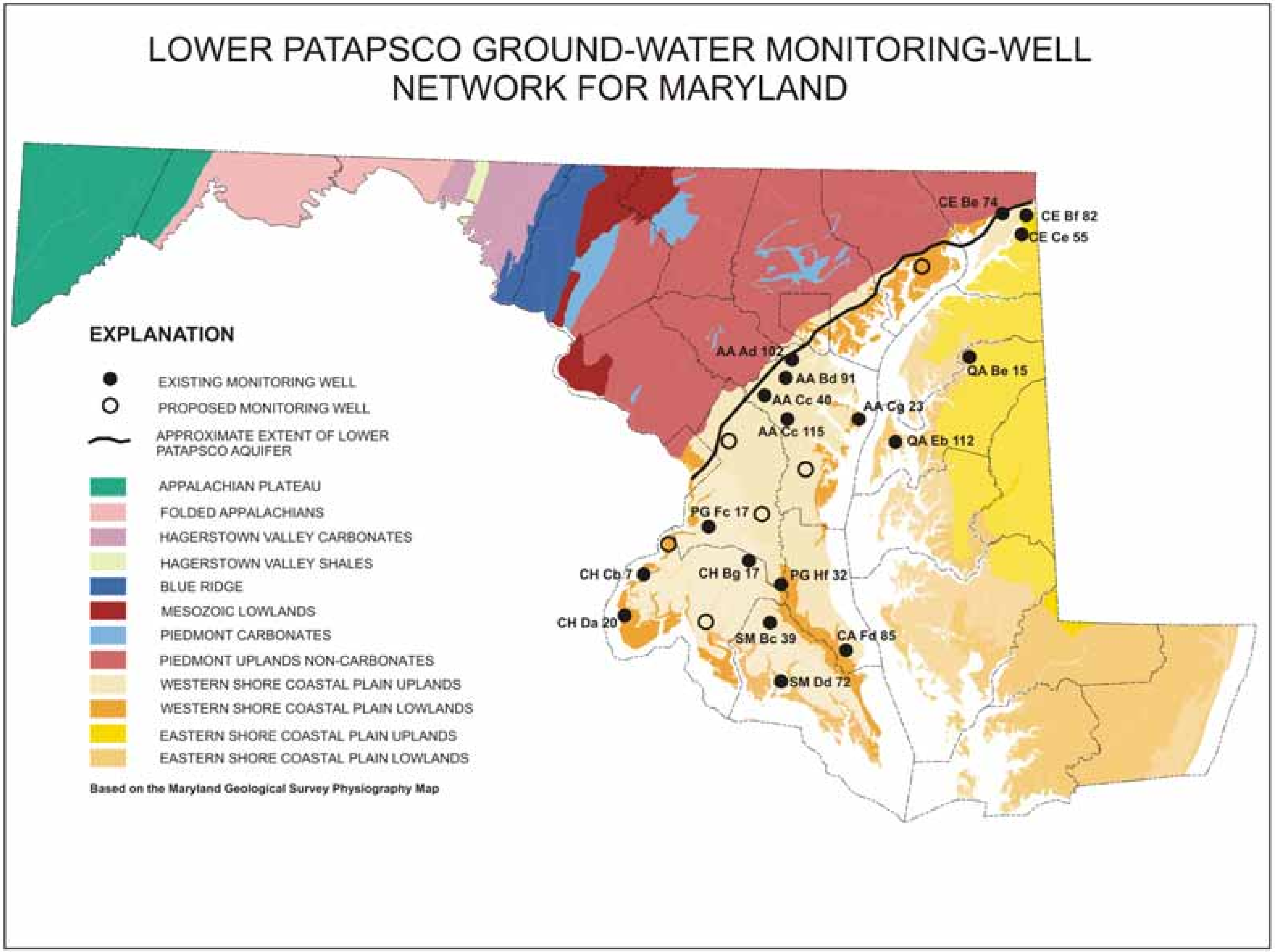

Figure F–10. Lower Patapsco Monitoring Wells

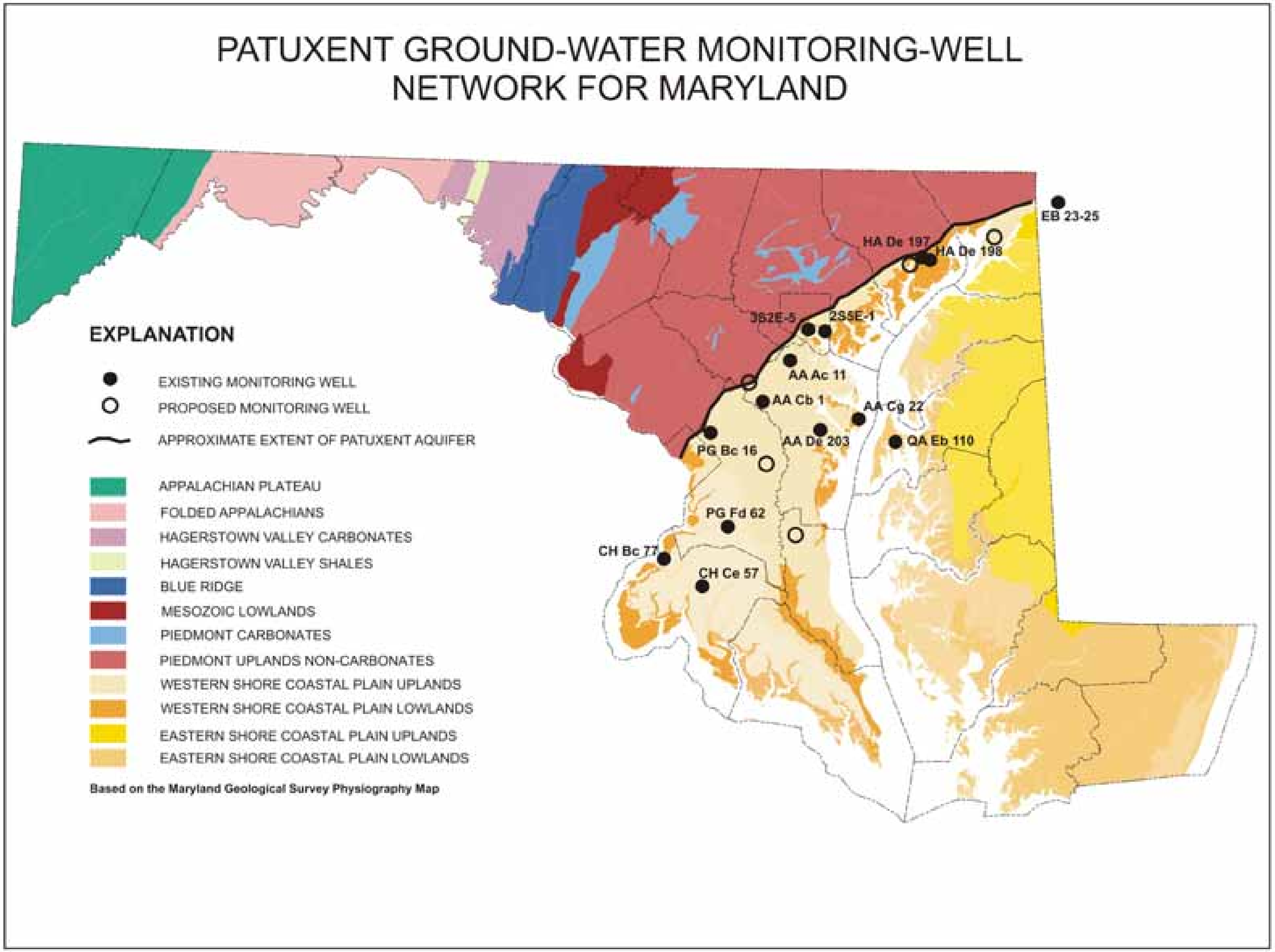

Figure F–11. Patuxent Monitoring Wells

References and Data Sources

Cleaves, E.T and Doheny, E.J., 2000, A strategy for a stream-gaging network in Maryland: Maryland Geological Survey Report of Investigations No. 71, 72 p.