THE GREAT MARYLAND WATER THEFT HYPOTHESIS

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Prologue

In 1868, a famous American paleontologist, Edward Drinker Cope, reconstructed the skeleton of a large, marine reptile--a long-extinct plesiosaur named *Elasmosaurus platyurus.* He was very proud of his discovery. He showed it off at the Academy of Natural Sciences in Philadelphia and published a detailed scientific paper on the animal. Cope's reconstruction showed it to have a long sinuous tail like a lizard. When one of his contemporaries--we're not certain whether it was O. C. Marsh of Yale University's Peabody Museum or Joseph Leidy of Harvard University--visited the museum to view the skeleton, he noticed that Cope had made a grievous error when he assembled the bones of the plesiosaur. He had placed the head of the specimen at the wrong end of the skeleton--on the end of the plesiosaur's **tail**.

This story seems to me to be an ideal metaphor for the natural sciences. One scientist assembles fragmentary observations into a comprehensive picture that reflects his or her experience. Later, another scientist comes along and, perhaps with the assistance of additional facts, creates a new picture of the phenomenon. An error is made and then corrected. Science progresses and our knowledge of the world is increased. *Scientia non habet inimicum nisp ignorantem.*

Introduction

The website of the Northumberland Association for Progressive Stewardship, www.napsva.org/va_dry_wells.html, presents an article entitled *Wells in Virginia Go Dry as Maryland Withdraws Water.* The article was written by geologist Lynton Land and had appeared previously in the *Northumberland Echo*. In this article Dr. Land asserts that large groundwater withdraws in southern Maryland are drawing water from Virginia and have caused roughly five dozen artesian wells on the Northern Neck to "go dry."

In 2009 for a course on groundwater sponsored by the Rappahannock Institute for Lifelong Learning, I taught a lesson entitled "Is Maryland Stealing Our Groundwater" http://groundwatervirginia.org/files/Chapter_3_Maryland.pdf. In this course, I presented evidence that the groundwater of Virginia was only minimally influenced by withdrawals in Maryland. And I suggested that blaming Maryland for water level declines in Virginia was bad public policy as well as bad science and would only divert our attention from the actual cause of groundwater depletion--aquifer overdraft right here in Virginia.

Recently, Dr. Land has expressed objections to my analysis and has argued that his original view, which I am calling "The Great Maryland Water Theft Hypothesis," is correct. In response to Dr. Land's criticism, I have undertaken a re-examination of the facts of the hypothesis. Let me say straightaway that honest debate on scientific matters is good. Science progresses by renewed examination of its tenets and correction of any errors. But we must keep in mind that bad science leads to bad public policy. If we intend to initiate actions that avoid serious economic and social harm resulting from the depletion of the groundwater supply of the Virginia Coastal Plain, then we must make certain that we have diagnosed the problem correctly. We can't be out chasing down red herrings.

Summary of the Great Maryland Water Theft Hypothesis

Approximately five dozen wells located on the Northern Neck, Virginia have "gone dry" as a result of a decline of the artesian water levels caused by large groundwater withdrawals in southern Maryland. These groundwater withdrawals have created a deep cone of depression (Figure 1), causing groundwater to flow north-eastward from the Northern Neck toward the vicinity of Lexington Park, Maryland. (source) *To quote the original report,* "Withdrawal in Maryland is obviously responsible for localization of these failed wells."

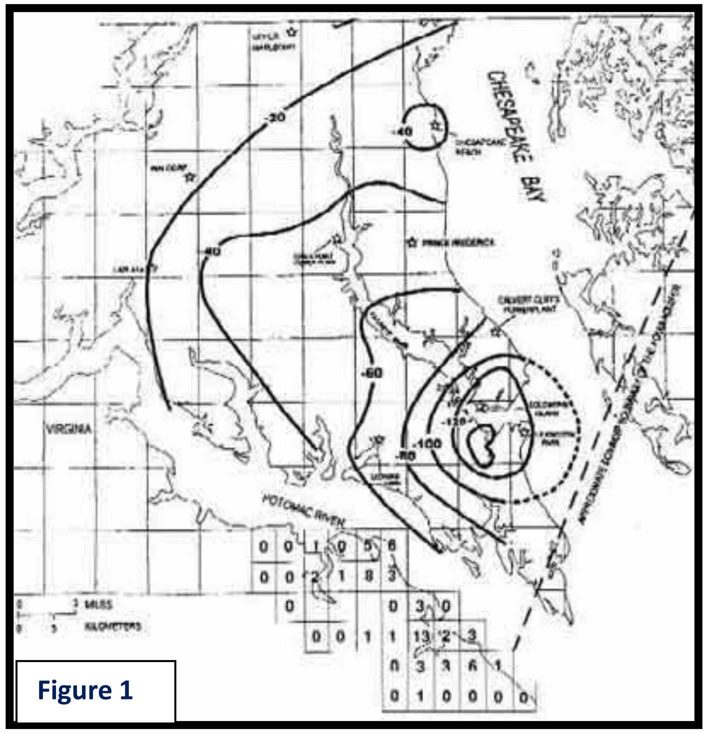


Figure 1

Critique

The soundness of the Great Maryland Water Theft Hypothesis rests on several questionable assumptions.

1. The aquifer from which the "dry" wells initally pumped groundwater is the same aquifer (and same hydraulic system) in which the cone of derpression illustrated in Figure 1 has formed.
2. The cone of depression extends into the Northern Neck of Virginia and encompasses the sites of the "dry" wells.
3. The hydraulic gradient in the direction of groundwater flow is great enough to facilitate substantial groundwater discharge.

Assumption One

The original account of the hypothesis* alleged that artesian wells on the Northern Neck have "gone dry" because water levels in the wells "dropped below the capability of the pumps." ". . . [T]here can be no doubt," the account continued, "that withdrawals in southern Maryland are responsible." This assertion is based on the the assumption that there is a direct link between the decline of water levels on the Northern Neck and the cone of depression in southern Maryland, illustrated on the contour map of Figure 1. Stating this another way, the assertion can be true only if there is a **hydraulic connection** between the aquifer in Virginia (from which the wells pumped groundwater) and the aquifer in southern Maryland (in which groundwater withdrawals created the cone of depression depicted in Figure 1). It is not too much of a stretch to argue that this connection could exist only if the wells in Virginia and the wells in southern Maryland tapped the **same** aquifer.

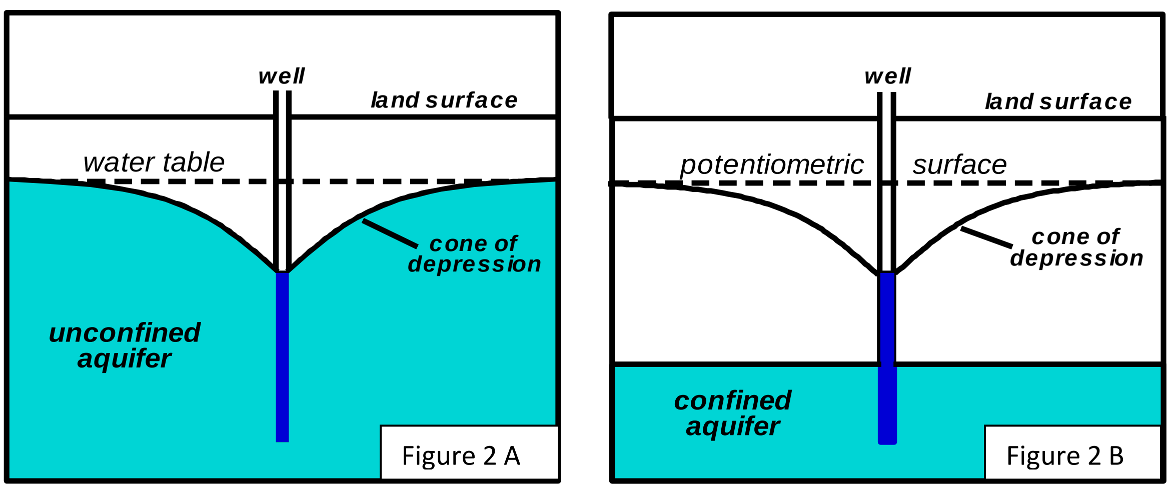
* FOOTNOTE. *A hypothesis is a tentative explanation of facts or observations.*

Although the original account of the Great Maryland Water Theft Hypothesis never mentioned the Aquia aquifer, the diagram (see Figure 1) that accompanied it is based on an Open-File Report of the USGS entitled *Potentiometric Surface of the Aquia Aquifer in Southern Maryland, September 2002*. This map is crucial to the hypothesis because it illustrates a large cone of depression, a sort of groundwater sump into which Virginia's groundwater is draining. To quote the original account,

> *[W]ater levels deepen toward a large center of usage near Lexington Park and Solomons Island, defining a "cone of depression." Water is flowing in all directions toward the center of that cone, where withdrawals are greatest and where water levels are deepest (depressed). The water level at the center of that cone is more than 140 feet below sea level. Water levels drop more than 100 feet between the Virginia shoreline and the center of withdrawal. Water is flowing "downhill" from Virginia into Maryland.*

Any narrow, rectangular-shaped region "between the Virginia shoreline and the center of withdrawal" is pictured as a kind of giant sluice or millrace in which water is flowing from high hydraulic head (Northern Neck) to low (southern Maryland).

A cone of depreesion is created when groundwater is withdrawn from an aquifer. In an unconfined (water table) aquifer, this is an actual depression of the water level (see Figure 2 A). In a confined (artesian) aquifer, the cone of depression is not a water surface; it is a depression in the potentiometric surface* resulting from a reduction in the pressure head surrounding the



pumped well(s) (see Figure 2 B). (The water level in an artesian well is a measure of the hydrostatic pressure in the aquifer.) Although its not entirely clear from the original account, the advocate of the Great Maryland Water Theft Hypothesis may be confusing the two types. However, the USGS map clearly displays the geometry of the potentiometric (pressure) surface (see APPENDIX A) of the Aquia artesian aqufer--and the Aquia aquifer alone. What **is** clear is that the original account of the hypothesis refers to artesian wells. "Water levels in artesian wells

* FOOTNOTE: *An imaginary surface representing the total head of groundwater in a confined aquifer, defined by the level to which water will rise in artesian wells.*

have declined steadily since wells were first drilled in the early 1900's." Presumably, then, it is artesian wells that have "gone dry."

Several important conclusions follow from the facts above. First, the dry wells of the Northern Neck are alleged to have pumped groundwater from a confined (artesian) aquifer--not from the unconfined surficial aquifer. Second, if this condition is correct, then the confined aquifer had to be the same aquifer in which the Maryland cone of depression has formed, namely the Aquia aquifer. In other words, there had to be a substantial hydraulic connection between the groundwater withdrawals in Maryland and the water level declines in Virginia. In an artesian groundwater system, each confined aquifer has a unique hydrostatic pressure regime, separate from that of other confined aquifers of the system (see APPENDIX A). If the "dry" wells of the Northern Neck did not tap groundwater from the Aquia aquifer, then groundwater withdrawals from Aquia aquifer in Maryland would have had little or no influence on them and would not be responsible for their failure.

The Aquia aquifer underlies both southern Maryland and the Northern Neck of Virginia. It serves as a major source of groundwater in southern Maryland, but because it thins markedly in eastern Northumberland County, Virginia, its use as a source of groundwater is limited east of

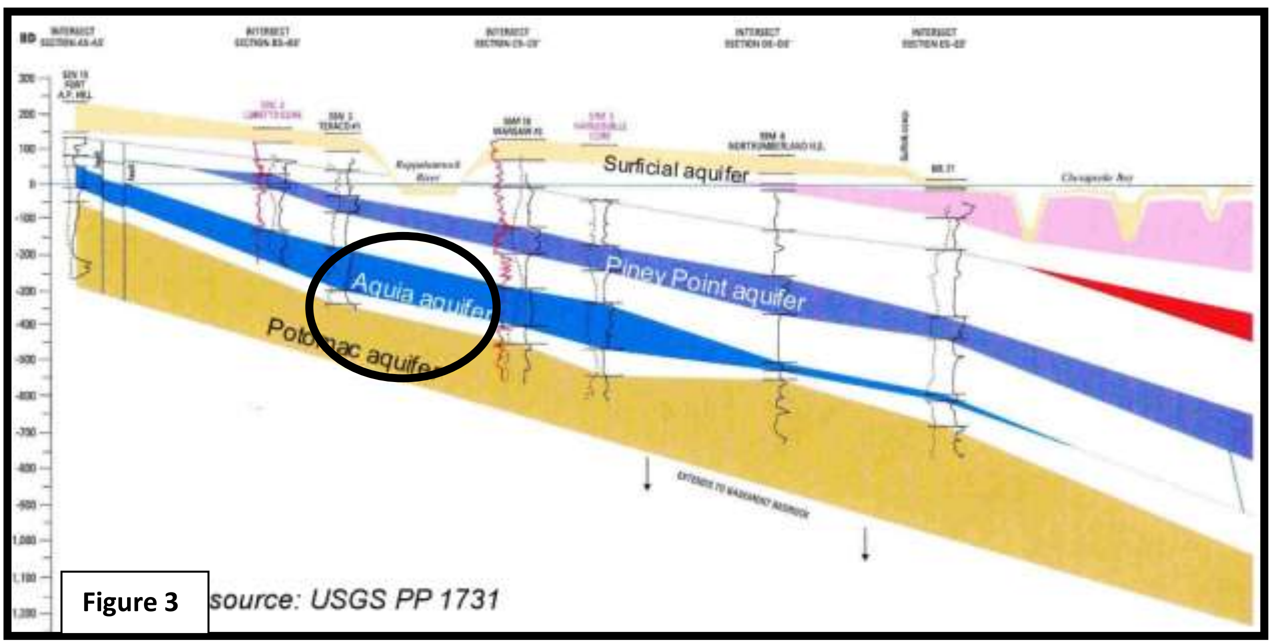


Figure 3 source: USGS PP 1731

Northumberland High School (Claraville) (see Figure 3). As the hydrogeologic cross-section in Figure 3 illustrates, the Aquia aquifer dips eastward at about 10-12 feet per mile. According to USGS Professional Paper 1731, the top of the aquifer lies at an altitude of -350 feet to - 450 feet msl in the region from Nomini Bay to Yeocomico Bay (where most of the dry wells are situtated). At Lexington Park, Maryland the top of the Aquia aquifer occurs roughly 400 feet below sea level (see also Figure 6).

In order to have reached the Aquia aquifer, the wells of the Northern Neck had to be at least 350 feet deep. The original account of the Great Maryland Water Theft Hypothesis refers to the **drilling** of "small diameter pipe" wells. If in fact these wells were drilled and not driven, then they could have reached depths of several hundred feet and have drawn water from the Aquia aquifer. But if some or all of the wells were driven pipe wells, then for technical reasons they were restricted to depths not exceeding 50 feet or so. In this case they could not have reached the Aquia aquifer.

Additionally, the initial static water level in the Northern Neck wells must have been no deeper than 20 or 25 feet. In the original account of the hypothesis, the wells were described as being "drilled many years ago, to depths of several hundred feet, using small diameter pipe. 'Suction pumps' were installed, which are only capable of drawing water up from depths of about 30 feet" (Actually, according to the principles of hydraulics, the practical vertical lift of a suction pump is approximately 7 meters, or (roughly 25 feet.). If this is true, then the initial water levels in the wells could not have been deeper than about 20 feet below the land surface. This constraint eliminates all wells in the Aquia aquifer in which their pumps (that is, the well heads) were placed higher than about 50 feet above sea level.

USGS SIR 2009-5039 (*Heywood, C.E., and Pope, J.P., 2009, Simulation of groundwater flow in the Coastal Plain aquifer system of Virginia: U.S. Geological Survey Scientific Investigations Report 2009–5039, 115 p.)* presents contour maps of "predevelopment" water levels for several aquifers of the Virginia Coastal Plain. In the region of the dry wells (between Nomini Bay and Yeocomico Bay), computer simulations place the predevelopment level of the Aquia aquifer at 30 to 35 feet above sea level. If this interpretation is accurate, then water levels in the affected wells that were sited on the uplands of the Northern Neck (higher than an altitude of 50-55 feet above sea level) could **not** have tapped groundwater from the Aquia aquifer, but must have drawn water from a shallow aquifer, perhaps the unconfined surficial aquifer. That is to say, they must have drawn groundwater from an aquifer that had little or no hydraulic connection with the Aquia aquifer. For more information on this topic, refer to APPENDIX B.

Assumption Two

If the Virginia wells "went dry" because their water levels were lowered by the groundwater withdrawals that created the Maryland cone of depression illustrated in Figure 1, then the wells must have been sited within the outer boundary of the cone of depression That is, they must have been sited within the zone of influence of the withdrawal wells. Figure 1, however, does not explicitly illustrate an extension of the cone of depression into Virginia. The contour lines of the potentiometric surface terminate at the Potomac River. Direct evidence of the level of potentiometric surfaces on the Northern Neck is sparse because the region has only a few groundwater monitoring wells.

Given the paucity of groundwater monitoring wells, the most trustworthy evidence comes from computer simulations of groundwater flow conducted by the USGS (SIR 2009-5039) The map in Figure 4 is taken from Figure 27b of the USGS report and illustrates simulated 2003 water levels in the Aquia aquifer. The Maryland cone of depression is clearly (if not precisely) shown at top-center of the map. In Virginia the geometry of the contour lines demonstrates a potentiometric surface that slopes southeastward across the Northern Neck and Middle Peninsula and eastward in the lower Tidewater region. Although there is not enough field evidence to define precisely the perimeter of the Maryland cone of depression, it is apparent from the map in Figure 4 that it does not extend very far into the Northern Neck. To state this another way, if the locations of the "dry" wells of the Northern Neck were actually within the Aquia cone of depression, they were sited only just within the zone of influence, at the feather edge of the cone.

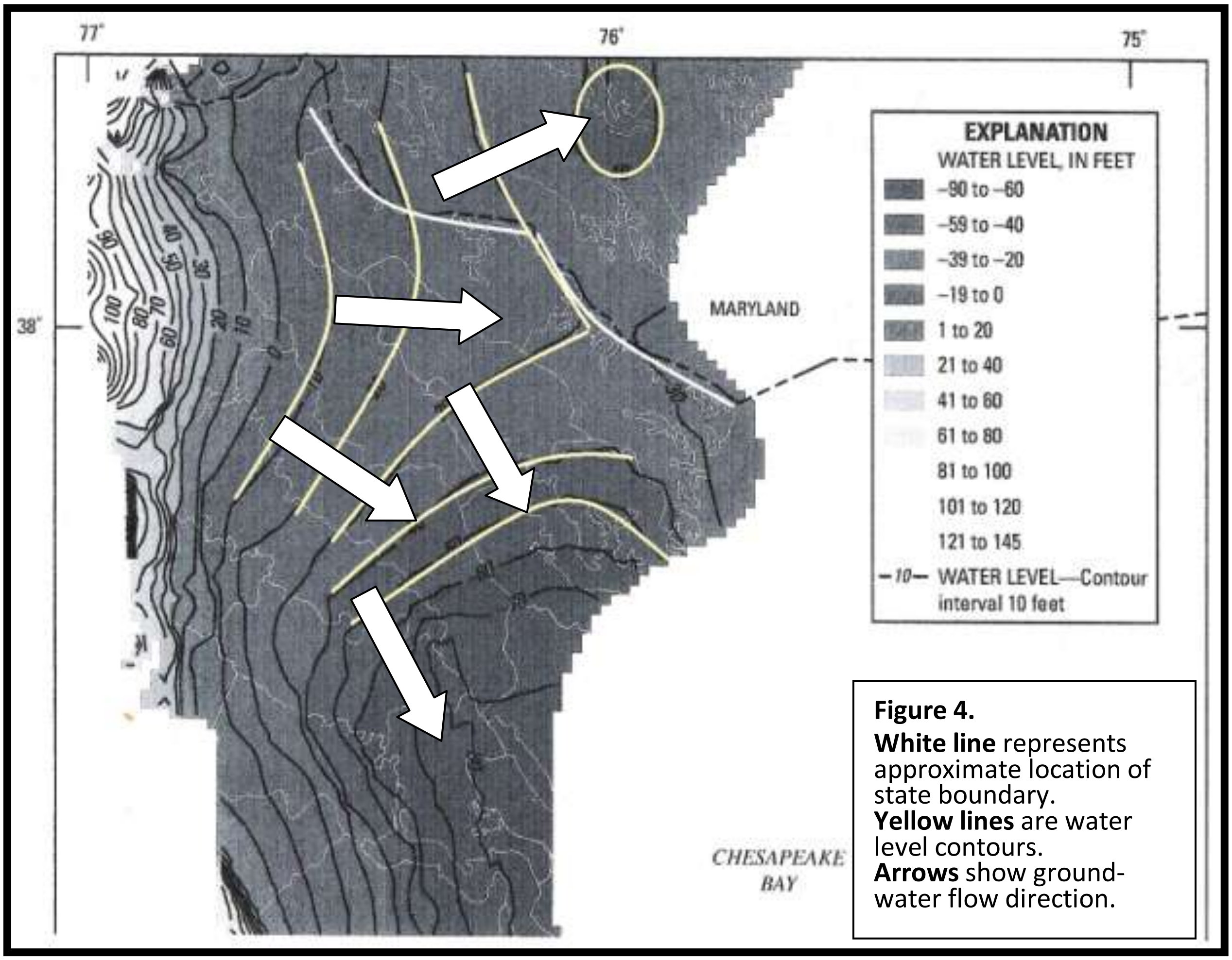


Figure 4.
White line represents approximate location of state boundary.
Yellow lines are water level contours.
Arrows show ground-water flow direction.

In this case, then, a groundwater flow divide in the Aquia aquifer runs down the Northern Neck from northwest to southeast and separates the flow regime south of the divide (Virginia) from that north of the divide (Maryland).

The diagram in Figure 5 is an idealized flow net of the potentiometric surface of the Aquia aquifer in the Northern Neck-Southern Maryland region. It illustrates that the cone of depression in Maryland represents a local (but rather significant) hydrologic feature in the Atlantic Coastal Plain groundwater flow system (see also the maps of USGS SIR 2009-5039). In southern Maryland, equipotential lines (water level contour lines) curve around the center of groundwater withdrawals near Lexington Park, and groundwater flows through the Aquia aquifer toward the center of the cone of depression. But south of the Potomac River, the equipotential lines follow a broad bend toward the south and southwest. Here, groundwater flow direction is eastward, toward the Chesapeake Bay and Atlantic Ocean. Between these two zones, in the region of the Potomac River, exists a zone of flow divergence.

A comparison of Figure 5 and Figure 1 demonstrates that the assertion that "Water is flowing 'downhill' from Virginia into Maryland" is more problematical and the hydrologic picture more complex than the original account of the hypothesis portrays. In fact, the evidence supports the interpretation that the Aquia flow system on the Northern Neck has little or no hydraulic connection with the Aquia flow system in southern Maryland. While this conclusion does not refute the claim that declining water levels caused the Northern Neck wells to "go dry." it does cast serious doubt on any claim that large groundwater withdrawals in Maryland currently have a damaging influence on the groundwater supply of Virginia.

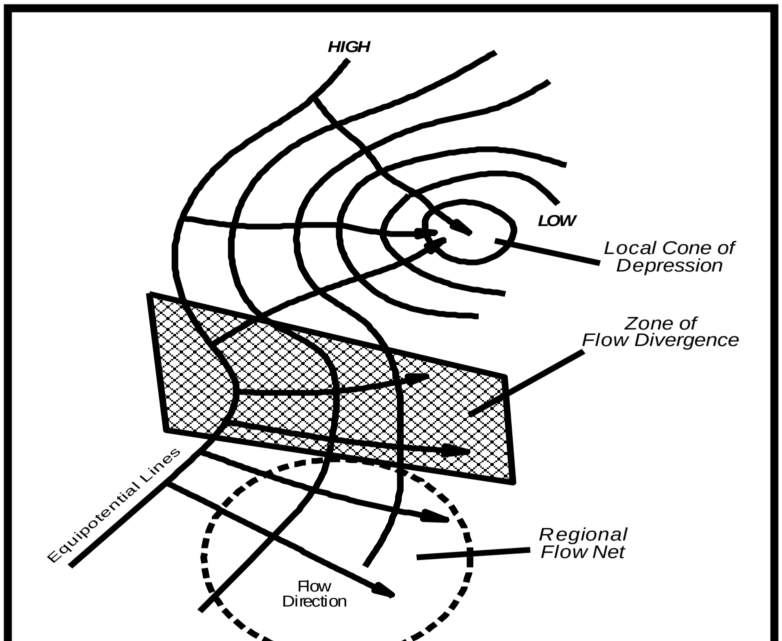


Figure 5

Assumption Three

A key assertion of the Great Maryland Water Theft Hypothesis is that "Water is flowing 'downhill' from Virginia into Maryland." What remains unanswered, however, is: **How much** groundwater is flowing from Virginia into southern Maryland? Is it a lot? Does the quantity of flow threaten the groundwater supply of the Northern Neck? Unfortunately, the rather breathless tone of the original account suggests that the groundwater withdrawals from the Aquia aquifer of Maryland is a great danger to the Virginia groundwater supply. Instead, the hydrogeologic evidence indicates that very little groundwater flows through the Aquia aquifer between the Northern Neck and southern Maryland.

The discussion of the previous assumptions demonstrates that if, as the Great Maryland Water Theft Hypothesis implies, the Northern Neck of Virginia is situated within the Aquia cone of depression, it can occupy a location only very near the periphery of the cone, barely within the zone of influence surrounding the center of groundwater withdrawals in southern Maryland. The geometry of a cone of depression is such that the highest values of hydraulic gradient (i.e., slope of the potnetiometric surface) occur in the near vicinity of the center of pumping, whereas the lowest hydraulic gradients are present near the outer boundary of the zone of influence. This fact is crucial because it bears on the volume of groundwater that flows through an artesian aquifer in the direction of the hydraulic gradient. Darcy's law ($Q = K\ A\ dh/dl$) states that the volume of groundwater flow (Q) through an aquifer is directly proportional to the hydraulic gradient (dh/dl). Thus, nearby the outer boundary of the cone of depression, where the hydraulic gradient is very low, volumetric groundwater flow is also small.

Figure 6 is an idealized hydrogeologic cross-section along an azimuth between Montross, Virginia (southwest) and Lexington Park, Maryland (northwest). It illustrates several important features of the hydologic system of the region. First, the Aquia aquifer dips (i.e., descends in altitude) toward the northeast from Montross to Lexington Park. (Technically, this is apparent not true dip. True dip of the layer is more easterly, toward the Atlantic coastline.) The potentiometric surface of the Aquia aquifer also slopes toward the northeast. On the Northern Neck near Montross (left-hand side of diagram), the hydraulic gradient in the direction of Maryland is very low, ranging from zero to approzimately 0.0005, or roughly an average of 3 feet per mile. Near Lexington Park the hydraulic gradient increases to approximately 6 feet per mile.

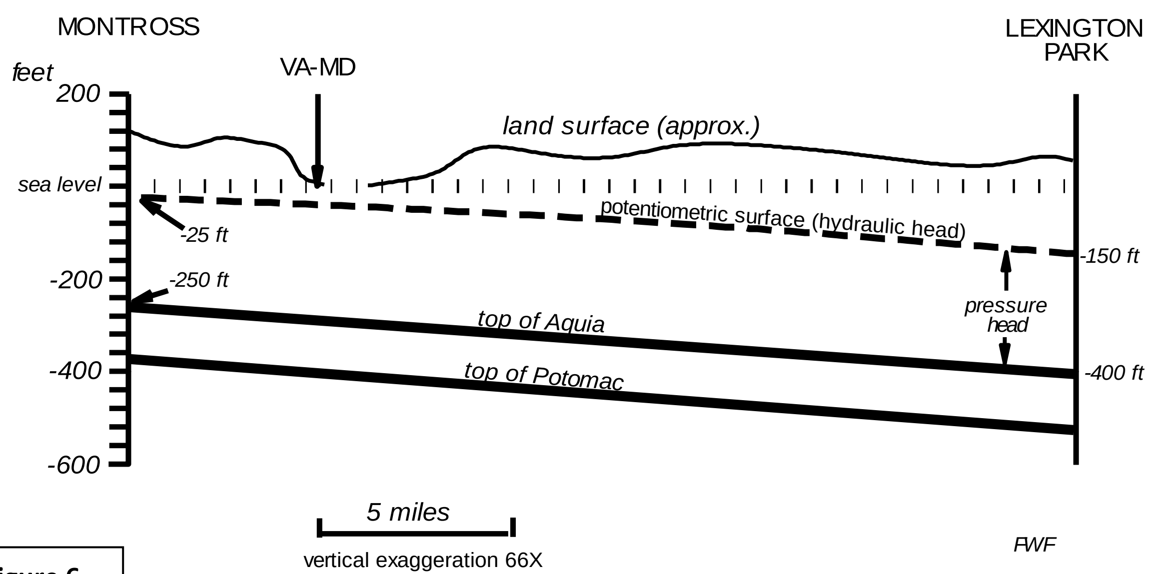


Figure 6

The application of Darcy's law to the groundwater flow system in the Northern Neck-Southern Maryland region demonstrates that large groundwater withdrawals from the Aquia aquifer near Lexington Park, Maryland are not "draining" large volumes of groundwater from Virginia. To the contrary, the computer simulations presented in USGS SIR 2009-5039 prove that most of the groundwater flow on the Northern Neck and Middle Peninsula is toward the southeast and away from the Virginia-Maryland state boundary.

Conclusion

A rigorous examination of the hydrogeologic evidence demonstrates that large groundwater withdrawals in southern Maryland, while hardly harmless to the groundwater supply of southern Maryland, have had minimal influence on the groundwater supply of the Virginia Northern Neck. On the contrary, as the computer simulations of groundwater flow in the Virginia Coastal Plain (USGS SIR 2009-5039) demonstrate, the decline of artesian water levels across the Northern Neck and elsewhere in the Tidewater is largely the result of steady and long term groundwater withdrawals within artesian aquifer system of Virginia. If the groundwater supply is to be conserved for further generations of Virginias, then the rate of groundwater withdrawal must be slowed and reversed. In the future; only a sustainable water supply that relies on extensive water recycling and reuse can prevent calamity.

APPENDIX A

In the section *Assumption One*, I stated that groundwater withdrawals from the Aquia aquifer in Maryland have lowered artesian water levels in the Northern Neck wells **only if** there exists a hydraulic connection existed between the two. If the failed wells of the Northern Neck had initially pumped water from an aquifer shallower than the Aquia aquifer, then there is little likelihood that their failure resulted from groundwater withdrawals from the Aquia aquifer in Maryland.

The water level (hydraulic head) in an artesian well is a pressure head, representing the amount of pressure in the aquifer tapped by the well. (The hydraulic head in numerous wells defines an imaginary pressure surface termed the potentiometric surface.) The groundwater of artesian aquifers is under a pressure greater than atmospheric because of the weight of rock and pore water overlying the aquifer. The decline of water level in the artesian well is the consequence of a reduction of aquifer pressure. The most common cause of pressure reduction is groundwater withdrawal from the aquifer. In Figure 7 the decline of the hydraulic head in Well

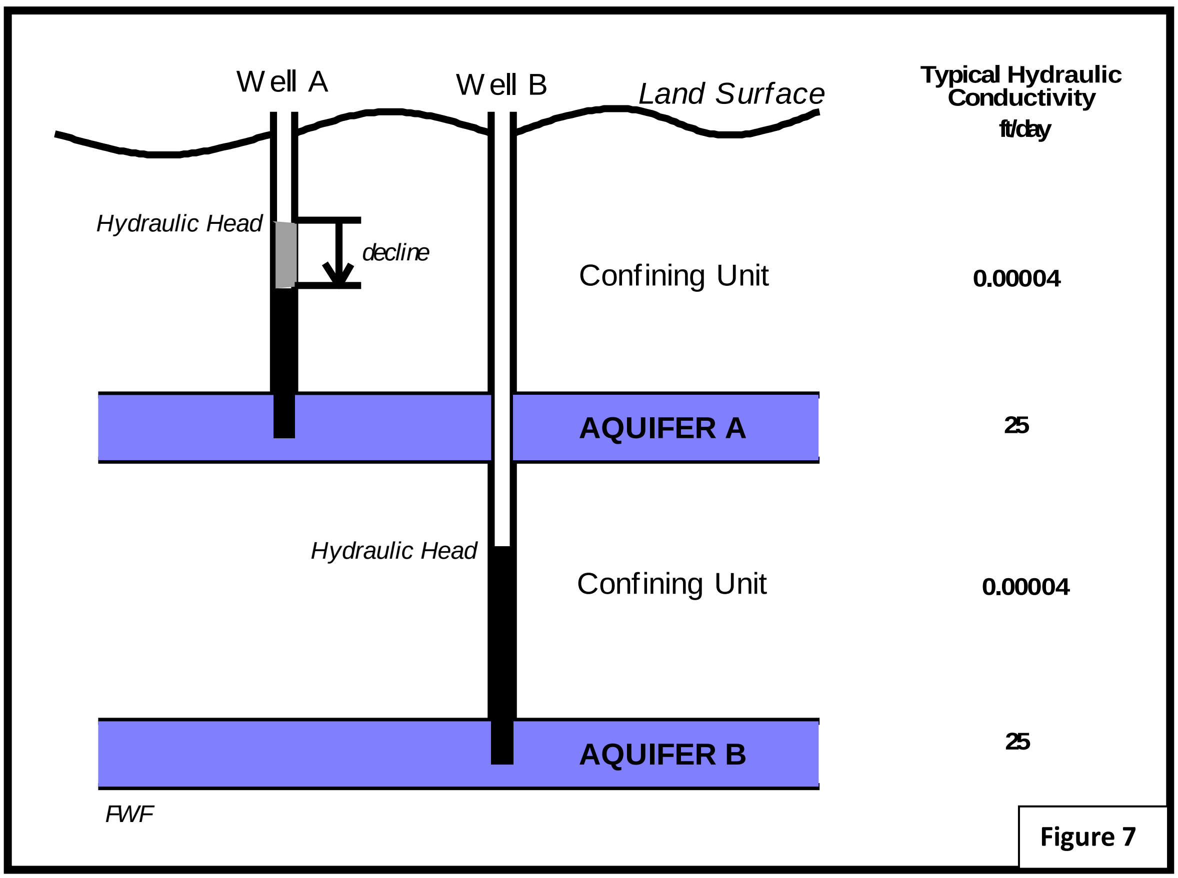


Figure 7

A is the result of a reduction of hydrostatic pressure in Aquifer A. Changes in pressure in Aquifer B have little or no significant effect on the water level in Well A because of the presence of an intervening confining unit, which has a very low value of hydraulic conductivity. The low permeability confining unit precludes any substantial hydraulic connection between Aquifer A and Aquifer B and, therefore, any effect of pressure changes in Aquifer B on the hydraulic head in Well A. Moreover, the greater the thickness of intervening confining units, the less the influence of any hydraulic connection.

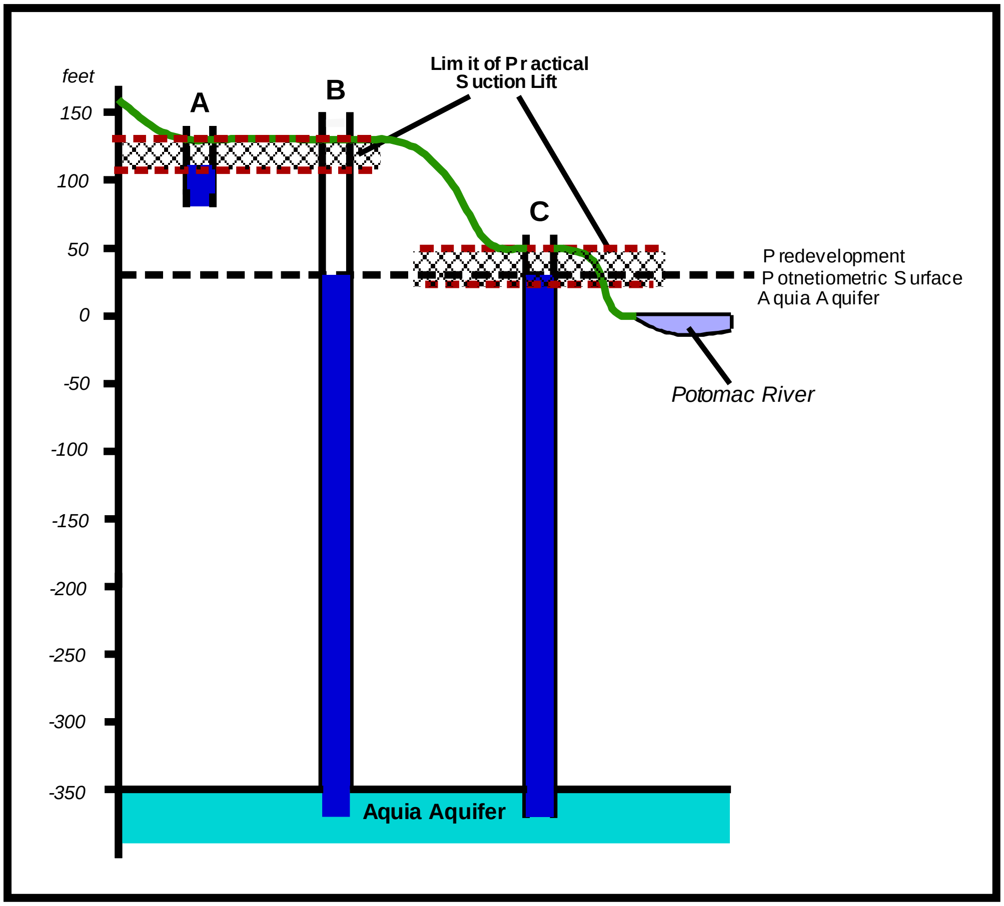
APPENDIX B

As the discussion in APPENDIX A points out, the hypothesis that large groundwater withdrawals in southern Maryland have dried up wells in the Virginia Northern Neck rests on the assumption that a hydraulic connection existed between the aquifer in which the Maryland cone of depression has formed and the aquifer that the Virginia wells tapped for groundwater. Let's examine some requirements for establishing such a hydraulic connection.

First, under *Assumption One* I demonstrated that a hydraulic connection existed only if the wells had been drilled to depths of at least 350 feet into the Aquia aquifer. Shallower well such as pipe-driven wells are incapable of reaching those depths. If any of the failed wells were less than 350 feet deep, then other causes for their failure must be sought. In Figure 8, well A is not deep enough to reach the Aquia aquifer, thus any decline of its water level cannot be caused by pressure changes (or groundwater withdrawals) in the Aquia aquifer. Well B is deep enough to withdraw groundwater from the Aquia aquifer, but for reasons described below, it could not operate successfully with a suction pump.

Second, the initial water levels in the wells that "went dry" could not have been deeper than about 20 feet below the land surface. This constraint eliminates all wells in the Aquia aquifer in which their pumps (that is, the well heads) were placed at altitudes higher than about 50 feet above sea level. In Figure 8, at the site of well C, the predevelopment potentiometric surface of the Aquia aquifer had an altitude of roughly 35 feet above sea level (USGS SIR 2009-5039). Only suction-pump wells where the pump was set between sea level and an altitude of approximately 50 feet msl (within the limit of practical vertical lift) would be able to withdraw groundwater from the Aquia aquifer. Suction-pump wells higher than an altitude of 50 feet (for example well B), even if they were deep enough to tap the Aquia aquifer, would have been failures right from the time of construction.

In the case of well A, a suction pump would be able to operate successfully only if the well tapped an aquifer much higher than the Aquia aquifer, such as the water-table (i.e., surficial) aquifer. Any decline in the water level of well A could not be influenced by conditions in the Aquia aquifer, but must result from changes in the water table or potentiometric surface of the shallow aquifer. These facts demonstrate rather conclusively that any suction-pump well sited on the Northern Neck above altitude 50 feet msl could not have "gone dry" as a result of groundwater withdrawals from the Aquia aquifer in Maryland. (The original account of the Great Maryland Water Theft Hypothesis made no mention of the altitudes of the wells or pumps.)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