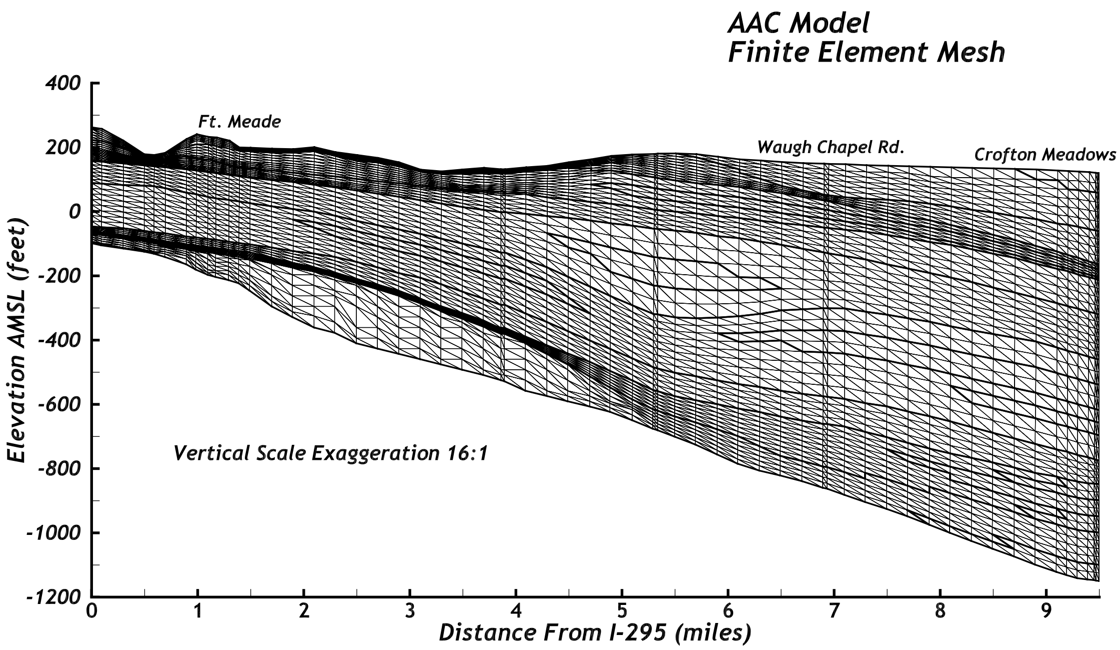
A Hydrogeologic Analysis of Fly-Ash Contamination of Regional Aquifers in the Gambrills-Waugh Chapel Area, Anne Arundel County, Maryland



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Summary

Beginning in 1995 fly ash from coal-fired power plants was placed in excavated portions of the Waugh Chapel Pit and Turner Pit, Anne Arundel County, as reported to the Maryland Department of the Environment (MDE) by the Maryland Power Plant Research Program (PPRP) (Erbe et al., 2007). Furthermore, beginning in 1999 groundwater quality data collected from monitoring wells in the Magothy aquifer down gradient of the Turner Pit revealed elevated concentrations of sulfate and heavy metals (Erbe et al., 2007, p. 32).

The hydrogeologic analysis reported below addresses whether the MDE has correctly asserted that for the confined aquifers underlying the Waugh Chapel Road/Crofton Meadows area "*There is little or no risk from surficial contamination"* from fly-ash leachate in the overlying Magothy aquifer, as stated in their Feb. 23, 2010 e-mail (Macy Nelson, personal communication, Sept. 23, 2010). The hydrogeologic analysis presented below, however, contradicts the MDE assertion. Based on a review of the subsurface geology and hydrology of Anne Arundel County, there appears to be in fact significant risk of groundwater contaminants, from fly-ash disposal fill at the Turner Pit and Waugh Chapel Pit, for entering regional aquifers of the underlying Patapsco Formation. New hydrologic calculations indicate that contaminants from fly-ash fill will enter the Upper Patapsco aquifer about 15 years after leaching began in the pits. Fly-ash contaminants are predicted to enter the Lower Patapsco aquifer later, about 50 years after leaching began. Assuming fly-ash leachate was first generated in 1995, the calculations indicate the arrival of contaminants by about 2010 in the Upper Patapsco aquifer and by about 2045 in the Lower Patapsco aquifer.

The hydrogeologic assessment presented below is based on numerous geologic and hydrologic data published in professional journal publications, on reports by the Maryland Geological Survey, and on borehole-geophysical data correlations completed by an expert in stratigraphy. The conclusions are further supported by mathematical results, based on computer-based modeling of groundwater flow across the Gambrills-Waugh Chapel area of Anne Arundel County (AAC). Supporting geologic observations and the hydrologic analysis are presented below.

Hydrogeologic Framework

A thick wedge of fluvial and marine deltaic-type unconsolidated sediments (gravel, sand, silt, and clay) forms Maryland's coastal plain, and the geology and hydrology of these sediments are well documented in voluminous publications, many dating back to the excellent works of Harry Hansen and Fred Mack in the 1970's, and others. The coastal plain hydrogeology literature is thoroughly reviewed and summarized for Maryland by Hansen (1971), Vroblesky and Fleck (1991), Andreasen and others (1999, 2007a, 2007b), Calis and Drummond (2008), and for adjacent areas of Delaware (Benson, 2006), New Jersey (Sugarman and others, 2005), and Virginia (McFarland and Bruce, 2006). In the subsurface of AAC, the study area is underlain by four major sand/gravel aquifer units of Upper Cretaceous age that dip towards the southeast: the Magothy aquifer, the Upper Patapsco aquifer, the Lower Patapsco aquifer, and the basal Patuxent aquifer. Aquitards of clay-siltfine sand are mapped between the aquifers, but boundaries are mostly gradational, not sharp, and in some areas nonexistent. For example, MGS authors report that in some areas of AAC, Magothy sands may rest directly on Upper Patapsco sands. These formations exhibit classic deltaic facies patterns--sediments of the same geologic age may grade laterally from clay to sand to gravel, often over short distances of 10's to 100's feet.

To constrain the geologic framework in the study area, a Tufts University geology colleague, Professor Anne F. Gardulski, constructed a northwest to southeast profile across AAC (Fig. 1), along the general direction of groundwater flow and structural dip, as mapped by the MGS. Her stratigraphic reconstruction is based on MGS published electrical resistivity and natural gamma geophysical logs from exploration boreholes and production wells, and made available to us in digital format (Andreasen, 2010, personal communication).

Hydrogeologic Model

To provide constraints on subsurface hydrology, such as the rates of groundwater flow and patterns of cross-formational flow, it is standard practice in hydrogeology and civil engineering to build mathematical models and construct flow nets displaying groundwater flow patterns (Bear, 1972; Pinder and Celia, 2006). Using the geological reconstruction of A.F. Gardulski, I have constructed a vertical profile of the hydrogeology with a finite element grid (Fig. 2). The vertical scale exaggeration of this profile is 16:1 to display geological details.

Figure 2 displays three hydrostratigraphic units, which are color coded according to their hydraulic properties: aquitard (green), mixed (brown), and aquifer (yellow). The profile extends from the Ft. Meade area in the northwest to the Crofton Meadows area in the southeast, a lateral distance of about 9.5 miles. Along this transect, the sediment wedge thickens from about 300 ft to 1,400 ft down dip.

The base of the model represents the bottom of the Patuxent Formation, and assumed to be impermeable, resting on top of much less permeable and old metamorphic rocks. The top of the model is represented by the water table (pore pressure~atmospheric), which is a subdued replica of the land-surface topography and gently sloping towards the Chesapeake Bay. The left boundary of the model is a hydraulic divide, but groundwater seeps into the deeper sand aquifers from areas to the west where the Patuxent Formation eventually crop out northwest of I-95. The right-side outflow boundary is assigned to the well field at Crofton Meadows, where groundwater discharges over screened intervals in the Patuxent and Lower Patapsco aquifers. Groundwater discharge is also assigned to the Upper Patapsco and Magothy aquifers, as these units are pumped down-dip from the study area.

Based on the geology and range of hydrologic data reported for these formations (hydrostratigraphic units), the following model parameters were assigned for the hydraulic conductivity K and effective porosity n:

Aquifer Beds (yellow):	*K*=10,000 m/yr ~ 33,000 ft/yr,	*n*=25%
Mixed Beds (brown):	*K*=100 m/yr ~ 330 ft/yr,	*n*=15%
Aquitard Beds (green):	*K*=0.1 m/yr ~ 0.33 ft/yr,	*n*=10%

Most sedimentary formations are internally bedded at various scales, and this bedding fabric creates directional permeability and hydraulic anisotropy (Freeze and Cherry, 1979). Furthermore, permeability naturally increases with spatial scale due to heterogeneity and natural joints/fractures, and therefore laboratory permeability measurements for aquitards rarely accurate represent the effective permeability at the formation scale (Garven, 1995). For the interbedded Upper Cretaceous sediments of the AAC coastal plain, the anisotropy ratio KAR (*K*-parallel : *K*-perpendicular) has been assigned as KAR= 10:1, so that the vertical hydraulic conductivity is much reduced compared to the lateral, bedding-parallel direction.

Hydrogeologic Calculations

Subsurface hydrologic calculations were made with the finite element groundwater flow modeling software *cpflowGL*, which is extensively documented by Raffensperger and Garven (1995) and Raffensperger (1996), and subsequently used in many PhD theses and peer-reviewed articles by Garven and his graduate students and other professional colleagues over the past 15+ years. Given appropriate hydrogeologic data and geometry, *cpflowGL* predicts the groundwater flow patterns, temperature field, and salinity along a vertical profile, for either steady or transient flow, assuming fully-saturated media. For this study, only steady flow is considered and temperature/salinity gradients are not considered.

Figure 3 shows the fluid flow patterns predicted for the hydrogeologic profile, rendered as fluid flowlines (blue) of the groundwater. The map here clearly shows how groundwater from the surficial Magothy aquifer crosses into the deeper confined Patapsco and Patuxent aquifers below. The closer the flowlines are together the higher the flow rate predicted. Figures 4a and 4b display the horizontal and vertical components of the groundwater seepage velocity, contoured in units of feet per year. Figure 5 and Figures 6a and 6b display computed results from *cpflowGL,* zoomed into the area of fly-ash pit fill, to show more detail in this region.

Conclusion

<u>Downward</u> groundwater velocities of 5 to 10 feet per year are computed for the subsurface in the study area, for both the Magothy and underlying confining beds. From the hydrogeologic model, the predicted travel time for aqueous contaminants in the unconfined Magothy aquifer to reach the underlying Upper Patapsco aquifer is approximately 15 years, since the placement of fly ash in shallow quarry pits. Contaminants will enter the Lower Patapsco aquifer in about 50 years. Assuming fly-ash leachate was first generated in 1995, the groundwater velocities indicate the arrival of contaminants by about 2010 in the Upper Patapsco aquifer and by about 2045 in the Lower Patapsco aquifer.

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