Plate 6: Piezometric Surface of the Cameron Valley Sand Member of the Potomac Formation, and Other Aspects of Urban Hydrology—Expanded Explanation City of Alexandria, VA and Vicinity

By Tony Fleming, March 2008

Introduction

The piece of terrain known as the City of Alexandria has been the site of major river systems at least sporadically since the early Cretaceous, about 144 m.a. Virtually the entire geologic record above the bedrock is the product of fluvial deposition and erosion. The most conspicuous element in the modern landscape —and arguably the most dramatic—is the Potomac River, along with its major tributaries, Four Mile Run and Cameron Run. These three drainages ultimately control the hydrology of the city in ways large and small. The most obvious is in sheer volume: the amount of water flowing past, and out of, the city in these three streams every day accounts for a majority of the total water resource available. All of the surface water that originates in the city drains into one of these three streams, via a series of tributary ravines and a network of storm sewers. During large storms, these watersheds receive overland runoff and a particularly large amount of direct urban storm-water runoff, which transforms the smaller tributaries from placid ravines into raging torrents.

On the other hand, a smaller but steadier volume of water flows unseen beneath the landscape as ground water, driven by the large elevation differential between the highlands that make up the western two thirds of the city and the valleys of the major drainages. Most of the city occupies a major piezometric high—in essence, it acts as a regional ground-water recharge area—and the eventual discharge of the ground water that originates there sustains the base flows of all of the streams, ravines, and major wetlands in the city. Ground water is transmitted through geologic units at several different horizons, but none is more prolific than the Cameron Valley sand member, which makes up the lower 100-200+ feet of the Potomac Formation beneath nearly the entire city. Also known as the "lower aquifer" of the Potomac Formation (e.g., Froelich, 1985; Johnston, 1964; Mack, 1966; Johnston and Larson, 1977; Wilson and Fleck, 1990), this mass of predominantly sandy sediment is one of the largest and most productive aquifer systems in the region. In addition to its historical role as a source of water to numerous domestic and high-capacity wells, the discharge from this aquifer system also is crucially important to the water budgets of most of the streams and ravines in the city, as well as to a number of sites of environmental and ecological interest. In this report, the Cameron Valley sand is referred to as an "aquifer system", because it is composed of many individual sand bodies that each act as an aquifer, and which are locally separated, though not entirely isolated hydraulically, from one another by less permeable units, chiefly silt and clay.

Plate 6 depicts the piezometric surface of the Cameron Valley sand, which represents the level to which ground water will rise in a well open to the aquifer system, and from which the direction of ground-water flow and its relationship to streams can be inferred. The map shows the locations of numerous seeps, springs, seepage swamps, and other places where ground water is discharging to the surface and/or interacting with surface water. Several other aspects of urban hydrology are also illustrated, among them the outfalls of filled ravines and the locations of historical wells that supplied water for a variety of purposes.

Previous Studies

Because it is the pre-eminent aquifer of the inner Coastal Plain, the lower part of the Potomac Formation has been the subject of a number of hydrogeologic studies in the greater DC area, many aimed at evaluating the water supply potential at specific sites (e.g., Andreasen and Mack, 1998; Mack, 1962; USACE, 1993). Several studies of a more regional nature, however, all by the US Geological Survey (USGS), encompassed parts of northern Virginia, including Alexandria, and contain data that were incorporated into the present study. In his treatise on the water resources of the District, Johnston (1964) compiled records for hundreds of old water wells, of which 150 are in the map area and are thus included in the water-well database that accompanies plate 1. These records comprise a series of data tables (Johnston, 1961) composed of a variety of useful hydrogeological information, such as the depth, aquifer, and water level of each well. During the course of its Fairfax County mapping initiative during the 1970's, the USGS generated a wide range of information about the Potomac Formation. Froelich (1985) compiled much of this information into a format designed to aid in the interpretation of the regional hydrogeology of the formation. Among the many USGS open-file studies compiled by Froelich (1985), a survey of historical water levels in the lower aquifer by Johnston and Larson (1977) is of particular value, because it compares water levels from two different times (many of which were obtained from now-abandoned wells) and evaluates them in terms of the impacts of changes in high-capacity pumpage, including that by wells in Old Town. Also included in the compilation is a study by Froelich and others (1978) that describes the hydrogeologic characteristics of the Pleistocene alluvium along the Potomac River, which includes the Old Town terrace of this report.

Data Sources and Methods

How the Map Was Made: The information presented on plate 6 is based on a combination of hydrogeologic features and data directly visible in the modern landscape, as well as earlier geologic and historical observations concerning water resources. During the fieldwork for the present study, particular attention was paid to recording the locations of visible ground-water discharge; such places include the banks of streams and ravines, as well as more isolated springs and seeps on uplands. For purposes of mapping the piezometric surface of the Cameron Valley sand, outcrops with visible ground-water discharge provide a useful control on water-level elevations because they indicate that the aquifer is saturated at that location and elevation. All of these outcrops occur along the banks of the major streams and in perennial ravines, chiefly in the western part of the map area. Likewise, outcrops of sand that are not discharging ground water are also useful, since they indicate that the zone of saturation lies below the altitude of the exposure. The locations of outcrops exhibiting evidence of ground-water discharge are shown on the plate; for comparison, the distribution of all outcrops observed during the study, whether discharging ground water or not, appears on plate 1. Numerous springs, seepage faces, seepage swamps, and wetlands resulting from water perched on poorly-permeable sediment were observed in other parts of the city, often associated with strata other than the Cameron Valley sand. Their locations are also indicated on the plate. The locations and extents of major historical wetlands on the Old Town terrace were determined from historical records available in the city library, and by direct observation of the soils, hydrology, and vegetation present in these areas.

Water-Level Data: The Cameron Valley sand is by far the largest and most prolific aquifer in the city, and for the most part, it is readily mappable by virtue of its stratigraphic position at the base of the Potomac Formation and atop the bedrock surface. The majority of all wells historically present in the city—and virtually every high-capacity well of any type—were developed in this aquifer. Although most of the wells shown on plate 6 no longer exist, historical water-level measurements made in many of them are summarized by Johnston (1961) and Johnston and Larson (1977), and provide a widely distributed source of water-level data. Although these water-level measurements date from decades ago, some as far back as the 1930's, they are nevertheless valuable for understanding the general configuration of water levels in the aquifer, and the response of water levels to high-capacity pumpage that occurred in the eastern part of the map area up until the mid 1970's. Additional water-level data collected within the past several years were available from several ground-water monitoring wells screened in the Cameron Valley sand, whose records are on file with the city. These are part of the geotechnical boring data set described in connection with plate 1.

In addition to the wells, numerous geotechnical borings also terminated in the Cameron Valley sand. All of the borings were uncased, which means that they were open (and potentially receiving water) from the entire interval between the ground surface and the bottom of the boring. In many cases, the water levels reported on the boring records were made between 24 hours and one week after the boring was completed (assuming the borehole hadn't caved in); such "stabilized" water levels have largely equilibrated with their surroundings and represent some form of composite piezometric level. Most of these sites are under one of two types of hydrogeologic conditions that suggest that the water level observed in the borings will generally be similar to that in the Cameron Valley sand: 1) the Cameron Valley sand is at the surface (or beneath thin surficial materials) and is, therefore, under water-table conditions; or 2) the Cameron Valley sand is overlain by Linconia silty clay or other poorly permeable strata that contribute a relatively smaller flow of water to the borehole; moreover, the Cameron Valley sand at the bottom of these borings is so much more permeable than the fine-grained units above it that it will essentially drain any excess water out of the borehole above and beyond the natural piezometric level of the sand, much like what happens during a slug test to measure hydraulic conductivity. For these reasons, the water levels reported in the borings are judged to be relatively reliable, if not exact, indicators of the actual water level in the Cameron Valley sand. Virtually all of these borings were made between 1999 and 2006, so they are reflective of current water-level conditions. The locations of all historical water-supply wells, monitoring wells, and geotechnical boring sites developed in or open to the Cameron Valley sand are shown on plate 6, along with the reported water level.

Data Limitations: The piezometric contours were made using all of the aforementioned data. Considering that the water levels shown in the various wells and borings were measured over a wide span of time, and under a range of pumping conditions (e.g., a considerable cone of depression was known to have existed beneath the southeastern part of the map area up to the mid 1970's), the piezometric contours should be regarded not as absolute indicators of water levels at any specific point, but more as a general guide to the configuration of hydraulic head in the aquifer system. Stated a bit differently, there is likely to be some variation between the mapped water level and what actually exists at any given point, but the overall shape of the contours is expected to be consistent with the actual shape of the piezometric surface. This assertion is based in part on the fact that two previous maps of the piezometric surface (Johnston and Larsen, 1977) exhibited similar configurations. If anything, the present map may be more accurate because, unlike the earlier ones, it takes into account the intersection of the aquifer system with surface waters into which the aquifer system is actively discharging, and which thus control the water levels at those places. For the same reason, the contours are expected to more closely reflect the true water levels in the aquifer system in the western part of the map area, where the aquifer system is largely under water-table conditions and is extensively in contact with perennial streams.

On the other hand, in the southeastern part of the map area, there may be considerable divergence between mapped water levels and what actually exists, for two main reasons. First, high-capacity wells that pumped large volumes of water from the aquifer up until the mid-1970's were concentrated in and just southeast of Old Town. The aquifer system below this area is documented to have been significantly dewatered by the early 1960's (see Johnston and Larsen, 1977, and Froelich, 1985), with water levels in some wells being drawn down as much as 300 feet below sea level, producing a deep, composite cone of depression beneath the southeastern part of the map area. Data presented by Johnston and Larsen (1977) suggest that considerable, but incomplete, recovery of water levels took place in parts of this area between 1960 and 1976; however, no systematic water-level measurements have been made since then, in no small measure because most of the original wells used in these earlier measurements have been destroyed. It is tempting to speculate that water levels have returned substantially to their natural levels, but the presence of ongoing large-scale pumpage of the aquifer system across the river in Indian Head and other places in Maryland casts doubt on such a conclusion. Therefore, the degree to which water levels have continued to recover in the 30 years since the work of Johnston and Larsen (1977) is unknown. Plate 6 shows the approximate boundary of the area of depressed water levels shown by these authors as of 1976.

A second factor that may affect the reliability of water levels in the eastern part of the map area is the nature of the aquifer system itself. In this study, the Cameron Valley sand is divided into two main units, a relatively homogeneous lower unit composed almost entirely of sand (and some gravel), and a more heterogeneous upper unit that, while composed predominantly of sand bodies, also contains a significant number of lenses of silty clay, whose frequency appears to increase upward in the section. The largest clay lenses are mapped separately on plates 4 and 6. Such lenses are poorly permeable and are thus expected to disrupt hydraulic continuity within the aquifer system, potentially leading to the existence of one or more perched water tables at places. Such places may include streams where ground-water discharge was observed, as well as wells screened in higher parts of the aquifer system. In both cases, a perched condition would cause apparent water levels to be somewhat to considerably higher than the actual water level at greater depth in the system. Stated differently, there is a greater possibility of strong vertical hydraulic gradients in the upper unit of the Cameron Valley sand, whereas lateral gradients are likely to predominate in the sandy lower unit.

Hydrogeology

General Observations: Alexandria is endowed with a bountiful supply of both surface water and ground water. A considerable volume of surface water flows into the city from other jurisdictions via the Potomac River and its three major tributaries (Backlick, Holmes, and Four Mile Runs); otherwise, all other water available in the city originates within the city. And, other than surface runoff following major storms, virtually all of that is ultimately derived from ground water. Most of the city occupies a major topographic high, where both ground water and surface water originate and flow outward towards the deeply entrenched valleys that form the city's boundaries. This constant flow of water is driven by large-scale differences in hydraulic head between the highlands, which occupy a major piezometric high and thus act as a regional ground-water recharge area, and the surrounding valleys, which form major piezometric valleys and thus serve as regional ground-water discharge areas.

Surface Drainage: The western two thirds of the city are located on a major regional topographic high. This feature could accurately be described as an incompletely dissected plateau, because it is characterized by concordant summit elevations and extensive, nearly flat upland areas that lack integrated surface drainage. The plateau actually consists of several step-like surfaces, each developed on a successively lower abandoned river terrace. The core of the highlands consists of the Seminary and Chinquapin Village terraces, which are the least dissected of the lot and generally lack any through-going surface drainages. The edges of the plateau are being actively incised by numerous short, straight ravines, some of which are poorly integrated with existing drainages. Most of these ravines are unnamed, and there are only three major, named tributary streams in the city: Lucky Run, Timber Branch, and Taylor Run. Other sizable drainages include the unnamed streams that flow through Fort Williams Park and Winkler Nature Preserve. Most of the ravines in the city are rapidly downcutting in response to Pleistocene glaciation, which repeatedly lowered sea level by hundreds of feet and caused the large streams that bound the city to cut deep Pleistocene valleys. The smaller streams are now adjusting in an attempt to "catch up" and equalize their gradients relative to the large streams they flow into.

All of the ravines and streams that originate in the city are fed to some degree by ground water, and the water budget of every perennial stream is dominated by ground water. It is not coincidental that the headwaters of virtually all of the ravines are found near the edges of the upland terraces. As detailed below, these locations are ideal for the development of the springs and seeps that sustain all of these drainages. Although all of the surface drainages in the city can and do carry large volumes of urban storm-water runoff, this typically occurs only for a relatively short period following major storms. The rest of the time, base flow in these drainages is comprised of ground water discharge. This is also true for the major streams that bound the city. Cameron, Backlick, Holmes, and Four Mile Runs occupy regional discharge areas, and large volumes of ground water are constantly discharging into them along the edges of the city. The Potomac River is the master stream and ground-water discharge area. Not only does all surface drainage from the city end up in the river, but a substantial amount of ground water also discharges to the river from the Old Town terrace, which is composed chiefly of sand and gravel and fronts the river for several miles.

Ground Water Recharge: Extensive areas of the upland terraces that make up the Alexandria highlands lack significant surface drainage. These terraces are frequently typified by flat to very slight surface gradients that tend to cause precipitation to pond on the surface. Some parts of the terrace surfaces exhibit hummocky microtopography, which is even more effective in trapping runoff. Sizable portions of the terrace surfaces are underlain by relatively permeable gravel, a situation that favors ground-water recharge. Although it is much lower in the landscape, the same situation applies to the Old Town terrace, which underlies a substantial portion of the eastern part of the city.

Large parts of the terraces overlie fine- and medium-grained sediments of the Potomac Formation, which are significantly less permeable than the unweathered terrace gravel. The permeability contrast commonly leads to a perched water table in the gravel. During major recharge events, one or more ground-water mounds are likely to develop in the gravel, and water will flow laterally away from these toward the edges of the terraces. Hydraulic gradients, however, are likely to be slight due to the relatively even elevation of the terraces. Local ground-water flow direction at any given place in the terrace gravels is likely to be highly site specific and will be controlled by local irregularities in the base of the gravel, such as places where the terrace gravels are channeled into the underlying Potomac Formation. Such channels are likely to be significant conduits for ground-water flow under the terraces, and even a difference of a few feet in the base elevation of the terrace may make a large difference in the direction and rate of ground-water flow.

Several possible flow paths await ground water that recharges beneath the terraces. A portion of it flows laterally to the edges of the terraces, where it discharges in springs and diffuse seeps localized along the contact of the gravel and fine-grained sediments in the underlying Potomac Formation. Concave sections of the slopes bordering the terraces are favorable for spring development, because they act like a bowl, “focusing” the flow of shallow ground water inward toward the central, lowest point. Many such springs emerge at the heads of ravines, as noted before, and furnish the base flow that keeps the ravines moist year around. The heads of ravines exemplify the concept of ground-water focusing in concave hillsides. The opposite is also true: convex hillsides tend to spread out the flow of shallow ground water, and make it less likely that it will emerge as large, discrete springs. Not all of the ground water that discharges along the terrace edges does so as visible, discrete springs and seeps. Some of it is removed by evapotranspiration during the growing season. Some of it also continues downslope as interflow—moisture that moves through the relatively permeable mantle of colluvium and soil close to the surface. The phenomenon of interflow is most readily observable from one to several days following a major soaking rain: precipitation that infiltrated near the top of the slope moves downslope, parallel to and just beneath the soil surface, and eventually seeps out near the base. This phenomenon is largely responsible for producing the moist, mesic growing conditions characteristic of many toeslopes.

Depending on the thickness of the terrace gravel, the amount of open land cover available for ground-water recharge, and other factors, the water table beneath any given part of a terrace (and the springs and seeps that emerge from it) may be either perennial or ephemeral. The largest perennial springs are typically found where the heads of the deepest ravines coincide with channels in the bases of the terrace gravel, or with large colluvial fans that derive and store water from the adjacent terrace gravel. Good examples are visible in the wooded ravine on the west side of St Stephens School, and in the heads of the twin ravines in Clermont Woods Park in Fairfax County. Unfortunately, the edges of all of the upland terraces are popular places for development because of the expansive views they typically offer, and most of the original springs that once existed in this setting have been destroyed or obscured by urbanization. Typically, the "headwaters" of most of these ravines now emerge from outfalls.

Some of the precipitation that falls on the terraces stays with them. Parts of these terraces are swamps developed on low-permeability silts and other relatively fine-grained sediment that caps the terraces. A good example is the extensive swampy area along both sides of Quaker Lane south of King Street, encompassing both the southeast part of the Seminary as well as sizable portions of Chinquapin Village and Chapel Hill. Water frequently ponds in slight depressions and swales on this landscape, which is underlain at places by upwards of ten feet of clayey silt. The silt hugs the inboard edge of the terrace, lying in a distinct band near the base of the scarp that separates this terrace from the higher Seminary terrace. Numerous large specimens of pin oak, sweet gum, red maple, and other swamp indicators attest to the hydric conditions of this high-elevation landscape. The hydrology of these swamps is probably complex, featuring a considerable amount of interaction between surface water and shallow ground water, with ground water slowly seeping out of one side of a swale or depression, and back into the other. There are typically no surface streams in this landscape.

Not all of the water that infiltrates into the terraces comes out as lateral discharge. Some of it migrates vertically downward into the underlying Potomac Formation. Parts of the terraces overlie sandy or mixed units in the Potomac Group, such as the Cameron Valley and Winkler sands, and the Chinquapin Hollow member. This condition is especially prevalent in the far western and the northeastern parts of the highlands, where the Cameron Valley sand and Chiquapin Hollow member form the surface of the Potomac Formation over wide areas, and to a lesser extent along the Winkler outcrop belt near Shirley Highway. The permeabilities of these units are moderate to high—comparable at places to the terrace gravel—so any permeability contrast between the terrace gravel and the underlying sediment is relatively small. In these places, there is likely to be little ground water perched in the terrace gravel, and much of the recharge that occurs through the terraces continues to moves vertically downward into subjacent aquifers. It seems probable, for example, that the Cameron Valley sand receives abundant ground-water recharge just west of the city limits, especially in the Baileys Crossroads and Lincolnia Heights areas, where its feather edge subcrops directly beneath the gravel of the Dowden terrace.

On the other hand, large parts of the terraces are floored by fine-grained members of the Potomac, such as the Arell clay and Lincolnia silty clay, but even these relatively poorly permeable sediments are capable of transmitting some ground water through networks of interconnected fractures and small sand bodies. To the best of my knowledge, no one has ever attempted to measure how much ground water leaks through these confining units in northern Virginia, but the piezometric high that exists in the underlying Cameron Valley sand beneath some of these clayey sediments is substantial, and indicates that appreciable recharge is occurring through these units. In the glaciated Midwest, clayey tills probably behave similarly, and have been shown to transmit between 2 and 4 inches per year of water into underlying aquifers. This is probably a reasonable estimate of the amount of vertical leakage through thick sections of Arell clay and similarly tight confining units.

In summary, the Alexandria highlands (along with adjacent parts of Fairfax County) appear to constitute a major ground-water recharge area, with much of that recharge occurring on the flat, poorly drained landscapes of the upland terraces.

Significance of the Cameron Valley Sand Aquifer System: Aquifers occur at a variety of horizons in Alexandria. These include fractured and weathered bedrock, sands at various positions in the Potomac Formation, and the upland terrace gravels. Johnston (1961, 1964) documented wells developed in all of these units within the city. As noted above, the terrace gravels commonly contain a perched water table; based on water level data from Johnston (1961), it appears that the terrace gravels are seldom saturated to more than 5 or 6 feet above their bases. As aquifers, the terrace gravels are suited only to shallow, low-capacity domestic wells. Before the advent of widespread public water supply systems, many residences on the terraces obtained water from large-diameter dug wells, which seldom yielded more than a few gallons per minute (gpm) and were subject to frequent water-level declines during droughts. The crystalline bedrock was also utilized as a source of water for domestic wells, as well as for a few installations requiring greater capacity. Typically, the bedrock yields appreciable water only where a well intersects several interconnected, open fractures. Typical bedrock well yields reported by Johnston (1961, 1964) for northern Virginia are less than 10 gpm, with a few very deep and/or large-diameter wells capable of yielding up to 100 gpm. Some dug wells were also developed in the mantle of weathered residuum, known as saprolite, that commonly overlies the fresh, unweathered bedrock on uplands. Like the terrace gravels, the saprolite typically produces low-yielding wells.

Sand units capable of yielding adequate water to a typical domestic well occur at a variety of horizons in the Potomac Formation; however, none can compare to the Cameron Valley sand at the base of the formation. This unit contains the only aquifers capable of consistently yielding large quantities of water to either a domestic well, or to a high-capacity well (defined as >100 gpm). Large-diameter wells developed in this aquifer system in and near Alexandria commonly yielded more than 250 gpm, and a few yielded between 500 and 1,000 gpm, according to Johnston (1961). This is easily understood in terms of the geology: the Cameron Valley commonly contains 50-100 feet of sand at its base, and at some places in the Cameron and Four Mile Run Valleys, the upper part of the unit also consists almost entirely of sand, resulting in composite sections of sand on the order of 100 to (exceptionally) 200 feet thick. Such thicknesses of permeable material are not duplicated anywhere else in this part of northern Virginia. On the other hand, productivity is limited by the presence of silty clay lenses at various places in the unit, especially in the upper part, and by deep Tertiary weathering that has transformed much of the original feldspar to clay, thereby reducing the transmissivity of the aquifer system from what it would be in an unweathered state. Nevertheless, it is not surprising that high-capacity wells developed in the Cameron Valley sand played an important role in the city's past industrial legacy.

Piezometric Surface and Ground-Water Flow Patterns: The piezometric surface shown in plate 6 reveals the overall ground water flow patterns in the Cameron Valley aquifer system, from which the direction of ground-water flow and its relationship to streams can be deduced. As noted earlier, the piezometric surface is defined by the level to which ground water will rise in a well open to the aquifer system. Another way of stating this is that the piezometric surface represents the distribution of hydraulic head (which itself is a combination of elevation and pressure head) in the aquifer system. At some places (indicated by the green color on plate 6), the aquifer system is unconfined, which means that it is not capped by poorly-permeable confining units. In these places, the aquifer system is under water-table conditions, and the piezometric surface simply represents the elevation of the water table. At other places, such as along Seminary Road, the Cameron Valley sand is capped by moderate to thick sequences of clayey sediment that impede the movement of water into and out of the aquifer system. Over parts of the capped area, water levels in the aquifer system stand higher than the top of the aquifer system (or the base of the confining unit), resulting in a truly confined, or artesian, condition. In other words, the entire thickness of the aquifer system is saturated. At other places, however, especially in the western portions of the map area, the aquifer system is technically not under artesian conditions because water levels do not rise to the base of the confining unit. In such places, the aquifer system is more or less still under water table conditions, and is more accurately referred to as being "capped" or "semi-confined" by fine-grained sediment, as opposed to "confined" or "artesian".

Despite the complications and limitations described earlier in relation to the construction and interpretation of the piezometric contours, the map pattern clearly shows that regional ground-water flow in the Cameron Valley sand is east-southeast, with many local variations around the larger streams. The major recharge areas are inferred to coincide with the highest parts of the piezometric surface in the far western parts of the city and adjacent areas in Fairfax County. For the most part, the inferred recharge areas correspond to the subcrop of the aquifer system along the eroded surface of the Potomac Formation (see plate 4) beneath the Dowden terrace (see plate 5), but piezometric highs continue eastward beneath parts of the landscape where the aquifer system is capped by the Lincolnia silty clay and younger units, suggesting that there may be appreciable leakage through these overlying units into the aquifer system in that area.

The piezometric contours deflect sharply around major and intermediate streams, especially where these streams are entrenched into the aquifer system, indicating that the streams exert a strong influence on the direction of ground-water flow. The configuration of the contours indicates that the local ground-water flow direction is likely to be perpendicular to, or obliquely downstream towards any stream in direct contact with the aquifer system. All of these streams act as discharge areas, and are fed by ground water that recharged somewhere upgradient, presumably on the piezometric high. Most of the perennial streams in Alexandria are known as "gaining streams" because their discharge increases downstream in response to the ongoing discharge of ground-water along their beds and banks. This is especially true of Four Mile and Holmes Runs, whose discharges increase markedly as they pass the city. These two streams are deeply entrenched into the heart of the Cameron Valley sand, from which they receive a large volume of ground-water discharge along their courses through the city.

Ecological Significance of Ground Water: Ground water plays a crucial role at most of the natural areas in the city and surrounding areas. Many of these areas are situated along ravines and, as noted previously, every perennial ravine in the city is ultimately fed by ground water. By definition, seepage swamps are located where ground water discharges, most commonly from the Potomac Formation. Most of these swamps are strongly acidic, with such acid-loving species as sphagnum moss, poison sumac, and sweetbay magnolia reflecting a lack of calcium in the ground water and a generally nutrient-poor condition. The best example is the large magnolia swamp along Four Mile Run at Barcroft Park in southern Arlington County, which is characterized by ground-water discharge on the order of 150+ gallons per minute, but there are numerous smaller examples in the city. The small magnolia swamps in an unnamed ravine in Dora Kelley Park are clearly fed by ground-water discharge from a gravelly unit in the Cameron Valley sand, for example, while another similar swamp in Rynex derives its water either from sand at the base of the same aquifer system or from weathered bedrock. The seepage swamp in Chinquapin Hollow appears to receive ground water from a colluvial fan, but it is more likely that a sandy unit of the Chinquapin Hollow member of the Potomac Formation is the true source, concealed beneath a mantle of gravelly hillside sediment. The attentive observer can find small seepage swamps at many places, typically in concave places near the base of hillsides. Unfortunately, most are not in parks and have been degraded by changes in land use, so they do not possess the characteristic vegetation, even though the basic seepage swamp hydrology is still evident. Seepage swamps and other places of ground-water discharge observed during the course of the fieldwork for this project are noted on plate 6.

In addition to the more obvious swamps, ground-water discharge of a somewhat more diffuse nature is responsible for the moist conditions that prevail throughout most of the major ravines. There is typically a constant discharge of ground water along the toeslopes and stream banks in these ravines, producing the steady supply of moisture required to sustain mesic plant communities, amphibians, and related ecological communities requiring constant moisture. Both Chinquapin Hollow and Monticello Park are excellent examples of this kind of discharge: a traverse down either stream will reveal springs, seeps, and moist spots emanating from permeable sand lenses and fractured clay units in the Potomac Formation, and from various surficial sediments, such as colluvium and alluvium.

Prior to its channelization, Cameron Run was perhaps the most spectacular example of all. This stream formerly meandered through a broad valley that contained a variety of wetlands. In addition to massive amounts of ground-water discharge from the valley walls, there was undoubtedly considerable interchange between surface water in the stream and shallow ground water beneath the wetlands and alluvial terraces fringing the creek. Although most of the natural hydrologic function of this valley has been obliterated by urbanization, some sense of what it was like can be gleaned from a few isolated places, such as the back of Cameron Regional Park, and an unnamed slough immediately across the railroad tracks from the dam on Backlick Run at Cameron Station and Brenman Park. Large swales that cross parts of the Old Town terrace also appear to have been major swamps, but other than scattered hydric trees, there is little left of these wetlands. Likewise, Oronoco Bay appears to have been a sizable marsh, but it was completely filled in early in the city's history.

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