Excerpted from the Preliminary Draft, "The Upper Paint Branch Watershed Planning Study," September, 1995.

Factors that Contribute to the Degradation of a Stream System

The cover and uses of the land that drains to a stream greatly influences the quality and health of that stream. Uses that involve extensive land disturbance, the elimination of vegetative cover, especially forest cover, and the replacement of pervious surfaces with impervious surfaces result in the degradation of the receiving stream system.

1. Change In Land Use

When a piece of land is cleared of trees, graded and developed, several features of the land change. The natural surface water runoff storage capacity is lost by removing the protective canopy of trees, grading of natural depressions, and removal of spongy topsoil and leaf litter. With the compaction of soil and placement of impervious materials on the land (e.g., buildings, roads, sidewalks, driveways, parking lots), the natural feature of the land that enables rainfall to percolate into the soil is lost. Essentially, all the water from rainfall and other precipitation events become surface runoff that travels directly to receiving streams.

If the development of land covers a significant portion of a watershed, the receiving stream system will be adversely affected. Clearing and grading of land can generate sediment that enters the stream, even with sediment and erosion control measures in place. Loss of forest cover within and around the stream valley increases the potential for unstable and eroding soils, exposes the stream to sunlight and raises water temperatures in the summer months, and eliminates the main energy source for the stream system. With the loss of forest material as an energy source, the stream system must rely on other sources, such as sunlight and algae; and the aquatic organisms that depend on leaf litter and woody material disappear.

2. Impervious Surfaces

The placement of extensive impervious surfaces in the watershed eliminates recharge areas for groundwater that feeds stream baseflow. Since impervious surfaces cover up the natural recharge areas for groundwater, more water from precipitation events (e.g., rainfall and snowfall) enters the stream as surface stormwater runoff and less as groundwater-derived baseflow. Stream baseflow becomes irregular and can be very small or eliminated during dry weather periods. Decreased baseflow reduces the ability of small streams to dilute and "neutralize" the effects of pollutants.

During warm weather (e.g., summer), extensive impervious surfaces can elevate the temperature of stormwater that travels over these surfaces prior to entering the stream, even with the use of stormwater management controls; this is because impervious surfaces absorb and reflect heat, and water travelling over these surfaces will pick up this heat. Warm stormwater runoff can adversely increase the temperatures of the receiving stream waters.

3. Stormwater Runoff

Stormwater runoff entering the streams may also be erosive and carry adverse levels of pollutants and trash, even with stormwater management controls in place. Increased land development and urbanization in a watershed usually results in increased pollutant-generating activities, such as motor vehicle uses (which generate oils and greases, metals, salts, sand, etc.), care and maintenance of lawns and other landscaped areas (which generate pesticides, fertilizers, etc.), use and disposal of various material (which generates trash), and care of pets (which generates animal waste).

To adjust to increases in stormflows due to increased impervious surfaces in the watershed, a stream will widen its channel, creating higher sediment loads and severely disturbing the stream bank area through undercutting, treefall, and slumping. Much of the sediment forms sandbars and silt deposits in the channel; these bars and deposits are constantly shifting and adds to the streambank erosion process by deflecting stream flows into erodible bank areas.

4. Sediment Loads

The increased sediment load in the stream can severely degrade or eliminate the natural runs, riffles, and pools that are present in healthy streams. This change in the stream morphology greatly reduces the diversity and availability of habitat for aquatic organisms.

The sediment may also be deposited within the small spaces between cobbles and gravels in riffle areas. This is known as embedding. Embedding greatly limits the quality and availability of spawning areas for fish, especially trout. It also reduces the circulation of water, organic matter, and oxygen to the filter-feeding aquatic insect larvae that live among and under the riffle areas.

5. Species Diversity and Composition of the Stream Community

The significant changes in the stream's morphology, hydrology, and water quality that occur when land development increases in a watershed degrades the health and viability of the biological community in the stream. The number and variety of species found in the stream community typically drops when the physical and chemical features of the stream degrade. Species that need steady, cold, clean, relatively silt-free stream flow often cannot go through parts or all of their life cycles in degraded streams; these species, which have relatively narrow ranges of tolerances of stream conditions, may be greatly reduced in numbers or disappear altogether in a degraded stream.

Species that have narrow tolerances for degraded stream conditions are often used as indicators or "markers" for the overall good health of a stream. Examples of these indicator species include certain aquatic insect larvae such as stoneflies (Plecoptera family[8]) and certain species of mayflies (Ephemeroptera family) and caddis flies (Trichoptera family). Fish have also been used as indicators of long-term (i.e., several years) stream health because they are relatively long-lived and mobile. In Maryland Piedmont streams, trout are often used as indicators of a healthy stream.

Assessing Urbanization Impacts on a Stream System

1. Stream Monitoring

The health of a stream system can be documented in various ways. The ideal way is to methodically and consistently quantify the physical, chemical, and biological conditions within the streams over time. Such a monitoring program would be able to document the water chemistry; physical features of the stream channel's shape, size and stream bottom characteristics; and the size, composition and diversity of the entire biological community in the stream. If the stream system degrades, the ideal monitoring program would be able to document the declining changes within the streams' physical, chemical and biological conditions. In addition, the ideal monitoring program would also be able to track specific changes to the land uses in the watershed and pinpoint the causes of degradation to the streams.

In reality, stream systems within Montgomery County rarely have been or can be monitored in a truly comprehensive manner. This is because monitoring resources are always limited, compared to the numerous streams that should be monitored because of their potential for declining quality. Often, only certain components of the stream system are monitored, such as limited water chemistry parameters or certain groups of organisms (e.g., fish or aquatic macroinvertebrates). And the monitoring program usually is set up so that only a very limited number of widely-spaced monitoring stations can be put in place, with very limited time periods available for collecting data. Because of limited resources, monitoring programs usually include methods to identify the presence or absence of species or groups of species that have small tolerance ranges for "unhealthy" stream conditions (i.e., indicator species); these methods enable the health of a stream to be documented fairly accurately without having to implement an extensive monitoring program. However, such monitoring programs usually do not include methods to track or identify the specific causes of degradation of the streams.

If stream monitoring resources are limited, one way of assessing the health or changing conditions of a stream system and the factors that affect its health is to examine all available data on the streams' conditions, in conjunction with characterizing the watershed's impervious cover.

2. Level of Watershed Imperviousness

Impervious cover in a watershed can be viewed as an easily quantified, planning-level measure of human impact on the aquatic resources in the watershed, including the stream system. The proportion of a watershed covered in impervious surfaces can indicate the degree to which stream and wetlands baseflows, water temperatures, water quality and stream morphology are adversely altered. It can also signify the susceptibility of the watershed to unstable and erodible

[8] This and other scientific names referenced in this study are part of a standardized scientific system for plants and animals. This classification system categorizes plants and animals into a hierarchy of groups. The major types of taxonomic categories are as follows, listed in order of decreasing inclusiveness (e.g., a phylum includes a wider range of organisms than a species): phylum, class, order, suborder, family, subfamily, genus, species.

soil conditions, and loss of vegetative cover (e.g., due to grading and construction activities).

In general, the greater the proportion of a watershed covered in impervious surfaces, the lower the quality and health of the stream system found in the watershed. The absolute imperviousness levels tolerated by different stream systems vary. This is because many variables affect how well a stream is buffered from the negative effects of urbanization. These variables include the characteristics of the soils, geology, and topography in the watershed, the size and configuration of the stream, the extent, location, and type of vegetation cover in the watershed, the importance of baseflow in the stream's overall flow patterns, and the extent and location of urban land uses with respect to the stream.

A study of 27 small watersheds in the Maryland Piedmont region found a direct relationship between stream quality and watershed imperviousness (Klein, 1979). The study concluded that generally, stream quality impairment is observed when watershed imperviousness reaches between 12 and 15 percent. Severe degradation occurs when watershed imperviousness is at about 30 percent. For more sensitive stream systems, such as those supporting naturally-reproducing trout populations, the study recommends that watershed imperviousness should not exceed 10 percent to maintain the quality and integrity of these streams.

Since the Klein study, other studies have been conducted to determine the relationship of stream quality and watershed imperviousness and urbanization. These studies cover a variety of physiographic areas in the United States and one area in Canada; their findings and conclusions are clearly summarized in a research article on impervious cover (Schueler, 1994).

Although these studies cover a wide range of stream systems (for example, ranging from the Jones and Clark study [1987], which looked at several streams draining to the Potomac River in northern Virginia, to streams in the state of Washington [Booth and Reinelt, 1993]), they lead to the same general conclusion: Few, if any, streams with moderate to high levels of watershed imperviousness (25 percent or more) can support diverse, healthy insect communities. With respect to a stream's ability to support pollution-sensitive fish such as trout and salmon, the Schueler article found that the general upper limits of trout or salmon streams are in the range of 10 to 15 percent watershed imperviousness; and declines in trout spawning success are evident above 10 percent imperviousness.

The Interstate Commission on the Potomac River Basin (ICPRB) has noted that, in general, stream quality is "impaired when urbanization (developed areas) reaches 10 percent of a watershed. Normally, a stream is severely impaired" when at least 25 percent of the area it drains is impervious. (ICPRB, Spring 1992).

A Metropolitan Washington Council of Governments (MWCOG) study of water temperature impacts of urbanization and stormwater management (SWM) facilities on small headwater streams in the eastern Montgomery County area revealed that summer stream temperatures increase linearly with increasing watershed imperviousness. The study showed that watershed imperviousness has a negative effect on stream temperatures under both baseflow and stormflow conditions, regardless of whether SWM controls are present or absent in the watershed. Stream temperature regime changes occur when watershed imperviousness exceeds about 12 percent. The results of the study strongly suggest that coldwater organisms, such as trout, will most likely be lost when watershed imperviousness exceeds 12 to 15 percent (Galli, 1990).

The Anacostia Watershed Restoration Committee's (AWRC) Upper Paint Branch Work Group recognized the lack of specific watershed imperviousness "thresholds" to establish limits in which stream degradation will definitely occur. The work group references a range of upper limits for watershed imperviousness (between 10 and 15 percent) beyond which Coldwater stream systems in Maryland become severely degraded or are destroyed (AWRC, 1994).

In addition to the amount of impervious cover, the location of the impervious surfaces in the watershed is important in determining the degree with which such land cover will adversely impact the stream system. For example, paved surfaces located adjacent to or within the regulatory stream buffer will have a greater adverse affect on the stream than the same paved areas located 200 feet uphill of the stream buffer. As another example, paved surfaces located in the extreme headwaters of a stream system will create greater adverse impacts on the system than paved surfaces located further down in the watershed of the stream system.

Techniques for Reducing Urbanization Impacts on Streams

1. Land Use Controls

The control or management of land uses placed in a watershed is generally considered the most effective tool in influencing the health of a stream system.

Management of land uses that maximizes retention of vegetation cover, especially forest, and minimizes disturbance and modification of soils and topography is the most effective method to protect the high quality conditions of a stream system. Preservation of a watershed's vegetation cover is especially important in that part of a watershed that drains to small streams (i.e., commonly defined as first to third order streams) because of the limited ability of these streams to withstand and counter adverse impacts. Retention of vegetation cover, especially forest, is also crucial in the area surrounding a stream channel.

The tools to manage land cover and uses in a watershed include zoning, overlay zoning, performance criteria for land development and the use of legally-protected conservation areas in and around sensitive natural features. If urbanization or suburbanization is to take place in a watershed, and the preservation of the stream system is a goal, land use tools that greatly limit the overall impervious cover should be implemented in those areas of the watershed that drain to small streams. Urban and suburban uses that result in high impervious cover should be located in areas that drain to larger streams and rivers (fourth order streams or larger), although the overall watershed imperviousness should still be relatively small. In addition, areas in and around streams should be placed in protected conservation areas throughout the watershed.

2. Best Management Practices

When a land use will result in significant clearing of vegetation, disturbance of soils, modification of the natural topography and/or creation of impervious surfaces, stormwater management and sediment and erosion control measures are usually required by State and County laws to be put in place. Such measures are termed best management practices (BMP) and are designed to reduce the adverse impacts of land disturbance and land development on aquatic resources. A best management practice (BMP) is a method or measure considered to be the most effective and practicable means available to prevent or reduce the amount of pollutants or other detrimental water resource impacts generated from non-point sources[9]. BMPs vary in their effectiveness in protecting water resources.

This limited effectiveness is due to various factors: inherent limitations of engineering designs to completely replicate natural conditions and features, limitations of performance efficiencies of the control measures, poor construction of these measures and/or poor inspection and maintenance of these measures after they are put in place and are operational.

In a research article on impervious cover, Schueler (1994) notes that many types of water quality pollutants generated from urban land uses can be lowered by the use of a variety of stormwater management practices. However, he also points out that "even when effective practices are widely applied, we eventually cross a threshold of imperviousness, beyond which we cannot maintain predevelopment water quality" (Schueler, 1994).

A study of sediment control measures in Maryland showed that the sediment traps and basins used at the time of the study were not very effective (Schueler and Lugbill, 1990). The study found that only a 46 percent sediment removal rate could be considered to be a representative estimate of the effectiveness of existing sediment control designs in Maryland. No sediment control measures were found to be 100 percent effective over the entire length of time they were in operation. In addition, it was found that small-sized sediments (i.e., extremely fine clays and colloids) may be very difficult, if at all possible, to trap within the control measures. It should be noted that the Maryland and Montgomery County sediment and erosion control design standards have been revised to increase sediment-trapping efficiencies, because of the results of the study; it is not known how much improvement has occurred on land development sites with these changes in design standards. Even with improved designs, however, the success of sediment control measures are highly dependent on proper construction, inspection and maintenance of these measures on the site.

Some characteristics of healthy stream systems that are typically diminished or eliminated by extensive land development in the watershed cannot be mitigated by engineered measures. Reduced stream baseflow due to impervious surfaces covering groundwater recharge areas cannot be brought back to pre-development flow patterns with current engineered best management practices. Several types of stormwater management facilities can generate warm water discharges, including those that previously were thought to be thermally neutral (e.g., infiltration-dry ponds) (Galli, 1990).

Some engineered best management practices are effective at mitigating some of the impacts resulting

[9] Non-point source pollution is that which originates from diffuse sources and not from discernible, confined or discrete sources. For example, fertilizers or pesticides on a lawn that are carried in surface water runoff to a stream are non-point source pollutants. In contrast, nitrogen and phosphorus compounds discharged into a stream from a wastewater treatment plant outfall pipe are point source pollutants.

from urbanization, but may exacerbate or create other adverse conditions. A well-known example of this is the SWM retention facility (i.e., wet pond). This type of facility can be effective at trapping many water quality pollutants, but it introduces warm water discharges into the stream.

Methodology and Technical Approach of Study

The study of water quality and imperviousness was performed in three steps: The staff compiled stream quality data from various sources, conducted limited baseline stream quality and stream habitat sampling and estimated and evaluated impervious cover and land uses for the Paint Branch watershed within eastern Montgomery County.

The assumption underlying analysis of watershed imperviousness is that the higher the level of land development in a watershed, the greater the degradation in stream quality. As has been summarized above, this relationship between stream quality and watershed imperviousness has been well documented in other studies and is widely accepted in the water resources field. Factors such as stormwater management measures, improved sediment and erosion controls and best management practices do help reduce the frequency and severity of impacts, but their effectiveness is limited. In watersheds where the biological communities in the streams contain pollution-intolerant indicator species, the limited effectiveness of engineered measures may not be enough to maintain and protect the high quality and healthy conditions of these streams. The watershed's land cover and use, in and of itself, is still the overriding factor in predicting impacts to a stream system at the master planning level.

Defining Subwatersheds

For the purposes of this study, the watersheds within eastern Montgomery County were divided into subwatersheds. A subwatershed is defined in such a way so that, in most cases, it contains at least one first- or second-order[10] stream and the land uses and/or potential for change in land use throughout the subwatershed are relatively similar.

[10] The size of a stream can be characterized in a relative manner according to where it fits within the larger system of streams. A first-order stream is one in which no other stream drains to it. A second-order stream is a stream which is formed by the joining of at least two first-order streams.

Compiling Stream Quality Data

Within the subwatersheds, the study has collected limited information on aquatic macroinvertebrate communities and stream habitat conditions in areas where no consistent monitoring has been done in the past in order to better characterize existing conditions. Environmental Planning Division staff collected data on macroinvertebrates and stream habitat conditions at two stations using the Rapid Bioassessment Protocol II developed by the U.S. Environmental Protection Agency (Plafkin et al., 1989). A modified and more rigorous version of this methodology for assessing stream quality is being used by MCDEP in their stream monitoring program.

The original intent of this stream monitoring effort was to collect data for at least three seasons and, ideally, for a longer time period However, because of staff time limitations, only one season, the 1993 summer season, could be sampled; therefore, the macroinvertebrate and stream habitat data collected by staff is limited in nature and must be used with caution in characterizing existing stream quality conditions.

The stream sampling stations set up by the Environmental Planning Division for the 1993 summer monitoring is shown in Figure 2. Stream sampling stations within the eastern Montgomery County portion of Paint Branch that have been set up as part of past or present monitoring programs by other agencies are also shown in Figure 2.

Data on stream quality collected by other agencies have been compiled in order to comprehensively characterize as best as possible the past and present conditions of the various streams and any changes in the quality and health of these streams since the adoption of the 1981 *Eastern Montgomery County Master Plan*.

Calculating Existing Subwatershed Imperviousness

This study estimates subwatershed imperviousness for current conditions and projects the impervious cover assuming buildout conditions under the 1981 Master Plan zoning. The methodology in this study used GIS data to estimate impervious cover for current conditions and added on estimated impervious cover by zoning category to project subwatershed imperviousness for future conditions.

The first step in estimating impervious cover was to define subwatershed boundaries. These boundaries were drawn on 1" = 200' topographic maps and clipped to each of the GIS planimetric layers (i.e., files) for buildings, roads, streets and parking lots, cultural features and sidewalks. These planimetric layers form the foundation of the County's geographic information system (CGIS). The information was entered into digital format from aerial photos by the Technology and Research Center of the M-NCPPC Montgomery County Department of Park and Planning.

For the study, the layers that represented current conditions reflected 1990 conditions. There has been a relatively small amount of development in the eastern Montgomery County area since 1990 due to traffic moratorium conditions, so that land use conditions reflected by the 1990 planimetric data were assumed to closely represent present existing conditions. That is, 1990 planimetric data were used to characterize existing conditions with respect to land uses and land cover. GIS was used to measure all paved surfaces and building rooftops that are shown in the planimetric layers for each subwatershed. These layers include all features that are considered to be impervious surfaces except for sidewalks and driveways for single-family detached houses (see below for the estimating impervious surface area attributable to sidewalks and residential driveways). This method of measuring impervious surfaces differs from past studies (i.e., staff analysis of imperviousness in upper Paint Branch for the 1981 *Eastern Montgomery County Master Plan* work [M-NCPPC 1981], staff analysis of imperviousness in Paint Branch due to proposed development in 1979 (Gresh, 1979) and the "Anacostia: Technical Watershed Study" [CH2M Hill, 1982]) in that previous methods relied largely on imperviousness factors by land use or development category to estimate subwatershed imperviousness under "current" or "existing" conditions; to calculate imperviousness within a given subwatershed, the factor would be multiplied by the amount of corresponding land use or development category occurring in the subwatershed, and the estimated impervious surfaces for the various land use or development categories would be summed.

The actual measure of impervious surface on the land, which has only recently become possible due to the development of GIS technology, provides a more accurate measure of imperviousness for "current" or "existing" conditions. It can also provide a reference against which to evaluate past and present methods of estimating imperviousness by land use category.

As part of this study, the GIS layers were compared to 1993 aerial photographs to check and verify the accuracy of the data. This comparison revealed that substantial paved area exists in the form of driveways on single-family detached residential lots which are not included in the planimetric database. In order to calculate the area of driveways not already accounted for, the building, road/street and parking layers were evaluated and an approximate count obtained of the number of buildings (primarily residential single family in subdivisions; rear yard structures assumed to be sheds and the like were not counted) for which a driveway existed but did not appear in the planimetric layer. This number was then multiplied by the average area for a driveway in each subwatershed, which was obtained from the required front-yard setback for the predominant residential zones within the watershed multiplied by an assumed width of 15 feet.

Sidewalks are a feature in the GIS data that are shown as lines and not as polygons. The area of sidewalks was determined by multiplying the length (taken from the planimetric layer) by an assumed width of four feet.

In addition to the GIS layers for paved features (buildings, driveways, roads, streets and parking, cultural and sidewalks), the "impervious" contribution of non-paved land cover was calculated, based on the assumption that these surfaces also contribute to surface water runoff for some precipitation events. Remaining non-paved land was categorized as either forested or non-forest, non-paved. Non-forest, non-paved land includes lawn, pasture and crop fields and is referred to as meadow. Forest cover is assigned an imperviousness factor of 1 percent; non-forest green cover is assigned a factor of 3 percent. A 1 percent imperviousness factor for forest cover has been used in other studies that focus on land use imperviousness (Northern Virginia Planning District Commission, 1980; Gall, 1983; CH2M Hill, 1982). For non-forested green cover, a wider range of imperviousness factors have been used (i.e., 0 to 7 percent). This study uses 3 percent imperviousness factor for non-forested green cover because it is roughly the middle of the range of values that have been used in other studies, it is the factor used in the Paint Branch compendium (Gall, 1983) and it reflects the greater benefits of forest cover compared to meadow or grass cover on streams.

Projecting Subwatershed Imperviousness

To estimate the effects of the 1981 Master Plan zoning recommendations on the ultimate subwatershed imperviousness levels, the study projected imperviousness by zoning.

For each subwatershed, properties were identified according to their development status as of 1990:

already developed, developable, committed or pipeline (i.e., properties that have an approved development plan, preliminary plan, or site plan, or are recorded lots, but were not constructed as of 1990). Developable and committed/pipeline properties were further characterized by zoning. For land in each category of zoning and development status, the amounts of forest and non-forest cover and associated impervious surfaces under 1990 conditions were calculated through the use of M-NCPPC Montgomery County Department of Park and Planning Arc/Info layers and databases. The projected impervious covers on a category of land, if or when it develops under either the master plan zoning or an approved plan, was calculated using imperviousness factors by zones. To estimate the total subwatershed impervious cover assuming 1981 Master Plan buildout, the projected impervious covers for all categories of land were added to the 1990 calculated impervious coverage and 1990 impervious surfaces for developable and committed/pipeline land were subtracted.

Imperviousness factors by zone were primarily derived from estimates of percent impervious cover by land use type that were compiled as part of a study of nonpoint pollution from uncontrolled urban and rural-agricultural land uses in northern Virginia (Northern Virginia Planning District Commission, 1980). These land use types are comparable to the zones found in Montgomery County. In addition, the eastern Montgomery County watershed study calculated impervious cover for selected residential subdivisions that have been constructed in eastern Montgomery County using data on the GIS system. The calculated impervious cover for these subdivisions are comparable to the impervious cover estimates in the northern Virginia study.

Table 1 presents the imperviousness factors by zones that have been used to Project the total subwatershed imperviousness under the 1981 Master Plan buildout. These imperviousness factors by zone have also been used to project subwatershed imperviousness under various buildout scenarios that deviate from the 1981 Master Plan zoning recommendations for specific subwatersheds to determine how changes to the 1981 Master Plan may affect impervious cover.

Imperviousness Factors by Zone

Table 1

Zoning Category	Imperviousness Factor (Percent)
RC	6
RE-2	9
RE-2C	9
RE-1	11
R-200	19
R-90	20
R-200/TDR 5	35
R-150/TDR 5	35
R-90/TDR 5 TO 8	37
R-60/TDR 8 TO 9	40
R-20	60
PD-2	20
C-1, C-2, C-3	90
O-M	90
I-1	60
I-2	80
I-3	60
I-4 in West Farm	60