Appendix A

# Baseline Analysis and Evaluation of Hydrologic, Water Quality, and Hydrogeologic Data

# Baseline Analysis and Evaluation of Hydrologic, Water Quality, and Hydrogeologic Data

Prepared for

**Loudoun County**

Department of Building and Development

October 2008

CH2MHILL

# Executive Summary

Loudoun County has been ranked as one of the fastest growing counties in the nation during the past 10 years. With a current population of approximately 280,000, an additional 200,000 residents are forecast by 2030. Associated with this rapid growth, development and changes to land use are occurring, many of which can affect the County's surface water and groundwater resources. In order to have scientifically-based information about the condition of the County's water resources in the face of this rapid growth and development, the Loudoun County Board of Supervisors allocated funding for an independent assessment of existing and available hydrologic, water quality, and hydrogeologic data. This baseline assessment, which was recommended by the Board's Water Resources Technical Advisory Committee, would evaluate surface water and groundwater conditions in the County which could be used to help guide future policy and water resource management decisions.

The preliminary phase of the project, conducted by Loudoun County Department of Building and Development staff, consisted of identifying all available data sets that might potentially be used in the assessment of water resource conditions. Data sets were obtained from a variety of sources including federal, state, and local governments, water utilities, and conservation groups.

All data sets and analyses were provided by the County to CH2M Hill for further analyses, evaluation, and interpretation to establish baseline conditions, characterize the County's groundwater and surface water quantity and quality, and identify and discuss areas of concern and pertinent trends that may exist. The data analyzed included the following:

- **Precipitation:** Description of the monitoring sites, frequency of measurements, collection methods, and identification of missing data. The data supplied by the County included daily, monthly, and annual data sets.
- **Stream discharge:** Data included daily, monthly, and annual sets, description of the monitoring sites, frequency of measurements, collection methods, and identification of missing data.
- **Stream water quality:** Data available included description of the monitoring sites, frequency of measurements, collection methods, and information gaps.
- **Wells and groundwater quantity:** Data include general descriptions of the data, the monitoring sites, and collection methods. Additional information exists on well depth, depth to bedrock, well type, yield, spatial distribution of yields, static water levels, specific capacity, transmissivity, and storativity.
- **Groundwater quality:** Data sets include general descriptions of the data, the monitoring sites, and collection methods. Related information include maximum contaminant levels (MCLs), method detection limit (MDL) and other criteria. Sample analyses reported to the County include results for 98 analytes.
- **On-site Sewage Disposal Systems:** The data includes location and type of OSDS. Additional relevant information was available from GIS layers depicting soil types,

proximity to water sources, and other factors that may indicate effects of the OSDS on water quality.

A groundwater budget was developed to assess availability in the County. Trends in water quantity and quality were identified and summarized on the 17 major watersheds in the County boundary. The groundwater budget considered recharge estimates and community and private well withdrawals.

The available hydrologic, hydraulic, and water quality data were evaluated to determine the baseline conditions in Loudoun County. The general conclusions that could be drawn from this analysis are presented below.

**Precipitation**

- On average, the County receives 41 inches of rain annually, although this has fluctuated from 30 to 60 inches.
- February typically is the lowest precipitation month, but monthly precipitation volume is relatively consistent throughout the year.
- Precipitation data do not show any significant geographic trend across the County.
- Precipitation records are limited in the northern portion of the County.

**Streamflow**

- There are 10 USGS stream gauges, representing 10 of the County's 17 major watersheds.
- Streamflow characteristics are relatively consistent across the County, allowing for extrapolation of flow data to the unmonitored watersheds of the County based on watershed size.
- The exception is Broad Run watershed, where storm flows are higher and baseflows lower. The cause of this variation may be a result of higher impervious surfaces, and should be evaluated in more detail.

**Surface Water Quality**

- Data analyzed from 16 DEQ long term monitoring stations, 12 located within Loudoun County, 9 of 17 watersheds monitored.
- Surface water quality data were limited for some stations.
- Most water quality standards met on an average basis. Exception is bacteria

**Groundwater**

- Well depths average 200 to 300 feet across the 17 watersheds.
- Static water levels average 25 feet below ground surface across the 17 watersheds.
- With the exception of the Broad Run watersheds, well yields are typically less than 50 gpm.

**Groundwater Quality**

- Overall, excellent groundwater quality
- Groundwater quality shows low TDS, neutral to alkaline pH, and calcium bicarbonate water chemistry consistent with recharge from a meteoric source (rainfall).
- Nitrate concentrations are typically less than MCLs and are not correlative with geology, land use, or density of impervious surface.
- Elevated TDS concentrations correlate well with sedimentary rocks of the Culpeper Basin, and elevated hardness.

**Recharge**

- Under average recharge conditions, all watersheds exhibit positive residual values (Recharge minus Demand)
- Under drought conditions, all watershed exhibit positive residual values (Recharge minus Demand)
- Excessive withdrawal reduces baseflow in streams

**Onsite Sewage Disposal Systems**

- Higher OSDS densities in central part of the County
- Some locations show increased risk, partly due to proximity to wells

**Data Gaps**

- There is limited precipitation data available for the northern portion of the County
- Few long term stream gauges
- Some stream quality data based on limited measurements
- No long term groundwater quality data; only snapshots at multiple locations
- Continued long-term monitoring based on the County's existing water resources monitoring program will help fill these data gaps.

As a follow-up to this analysis, additional environmental data, including stream assessment databases, will be evaluated, and a watershed management plan will be developed for the County. The following tasks identified in this report will be incorporated into the Watershed Management Plan:

- Collection of long-term data to improve existing water quantity and water quality data
- Preservation of existing good ground water quality
- Remedial actions associated with surface water quality concerns (e.g., bacteria)
- Protection of the stream baseflow to ensure survival of aquatic species
- Prioritization of repairs to OSDS sites that are of risk to water quality

- Evaluation of
  - Stormwater management and floodplain management
  - Wetlands
  - Agricultural practices

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SECTION 1

# Introduction

Loudoun County, located in northern Virginia approximately 25 miles west of Washington D.C., has been ranked as one of the fastest growing counties in the nation during the past 10 years. With a current population of approximately 280,000, an additional 200,000 residents are forecast by 2030. Associated with this rapid growth, development and changes to land use are occurring, many of which can affect the County's surface water and groundwater resources. In order to have scientifically-based information about the condition of the County's water resources in the face of this rapid growth and development, the Loudoun County Board of Supervisors allocated funding for an independent assessment of existing and available hydrologic, water quality, and hydrogeologic data. This baseline assessment, which was recommended by the Board's Water Resources Technical Advisory Committee, would evaluate surface water and groundwater conditions in the County which could be used to help guide future policy and water resource management decisions. The County, through the Department of Building and Development, contracted with CH2M HILL, Inc. to conduct the assessment and this report summarizes their analyses and findings.

Loudoun County covers an area of 520 square miles and is bordered on the north and north-east by the Potomac River and on the west by the Blue Ridge Mountains. Recent growth has primarily been a mix of commercial and residential development in the eastern suburban portion of the County and mostly residential subdivisions developed on agricultural land in the more rural western portion of the County. Figure 1-1 shows some of the major features of the County including the incorporated towns and Washington Dulles International Airport and Figure 1-2 shows the 17 major watersheds.

Throughout the project, County staff and CH2M Hill made several presentations providing project progress updates and findings to two committees that work on water resource issues: the Board appointed Water Resources Technical Advisory Committee and the independent Loudoun Watershed Management Stakeholder Steering Committee. Both of these groups provided valuable constructive comments and recommendations which improved this report.

## Data Compilation and Preliminary Analyses

The preliminary phase of the project, conducted by Loudoun County Department of Building and Development staff, consisted of identifying all available data sets that might potentially be used in the assessment of water resource conditions. Data sets were obtained from a variety of sources including federal, state, and local governments, water utilities, and conservation groups. A list of the identified data sources, brief descriptions of the data sets, and data quality information is provided in Appendix A1. These data sets were evaluated for data type, frequency, completeness, period of record, and levels of data collection quality assurance protocols. Selected data sets were further evaluated using a series of graphical analyses and descriptive statistics such as range, mean, median, standard deviation, etc. (Loudoun County, 2007).

FIGURE 1-1
Loudoun County Major Features

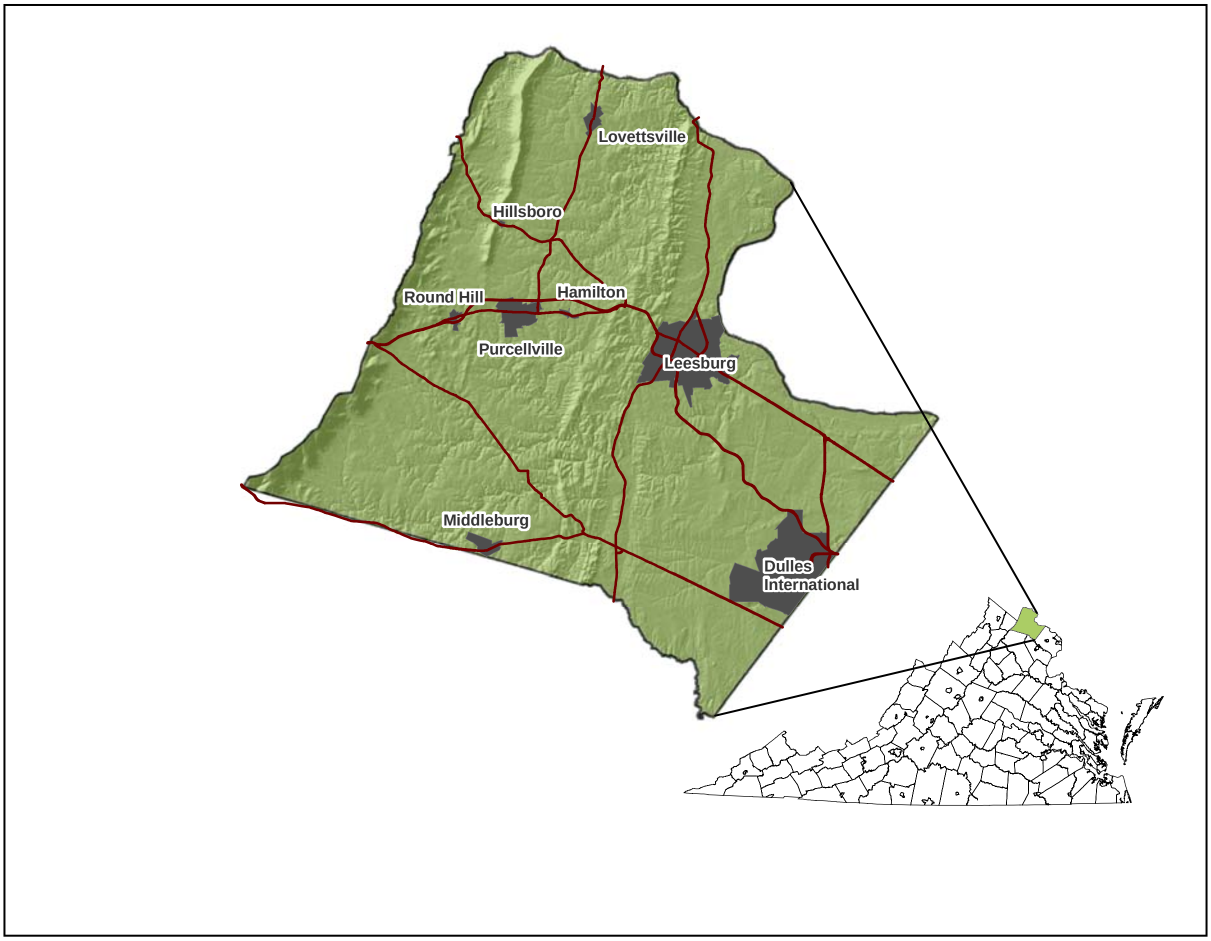

FIGURE 1-2
Loudoun County Watersheds


All data sets and analyses were provided by the County to CH2M Hill for further analyses, evaluation, and interpretation to establish baseline conditions, characterize the County's groundwater and surface water quantity and quality, and identify and discuss areas of concern and pertinent trends that may exist.

The data analyzed included the following:

- **Precipitation:** Description of the monitoring sites, frequency of measurements, collection methods, and identification of missing data. The data supplied by the County included daily, monthly, and annual data sets.
- **Stream discharge:** Data included daily, monthly, and annual sets, description of the monitoring sites, frequency of measurements, collection methods, and identification of missing data.

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- **On-site Sewage Disposal Systems:** The data includes location and type of OSDS. Additional relevant information was available from GIS layers depicting soil types, proximity to water sources, and other factors that may indicate effects of the OSDS on water quality.

A groundwater budget was developed to assess availability in the County. Trends in water quantity and quality were identified and summarized on the 17 major watersheds in the County boundary. The groundwater budget considered recharge estimates and community and private well withdrawals.

The remaining sections of this report describe the analyses conducted and the results obtained.

SECTION 2

# Precipitation

## 2.1 Available Data

There are seven precipitation gauges in the County and immediately adjacent areas. Five are maintained and operated as National Weather Service (NWS) cooperative stations and two by the U.S. Geological Survey (USGS). Table 2-1 summarizes the period of record and data gaps at each gauge. Figure 2-1 provides the locations of the 5 NWS precipitation gauges. Daily records were obtained for the full period of record at each of the precipitation gauges.

The two USGS Gauges provide a much shorter period of record and have gaps that cause the data to be questionable. Data gaps are a particular problem at the Lovettesville gauge, where nearly 30 percent of the records are missing or estimated, with a significant data gap between October 2003 and September 2004. A review of the estimated values identifies several days during which significant precipitation is recorded at Leesburg and zero is estimated at Lovettesville. This observation indicates that the estimated values may be suspect. Due to the limitations in the data from the USGS gauges, these data sets were not included in the analyses for this report, unless specifically noted.

The elimination of Lovettesville as a reliable dataset leaves a significant data gap in the northern part of the County. The County has looked for other data to fill the gap, including NWS precipitation gauges in Maryland and West Virginia, and Citizen Weather Observer Program stations. There are several Citizen Weather Observer Program stations in Loudoun County, but records are relatively short, and quality control is uncertain. The County will continue to evaluate options for filling this data gap.

The data analyses herein focus on the five NWS datasets to seek consistent data quality. These records provide the most valuable information about long-term trends.

## 2.2 Analyses Conducted

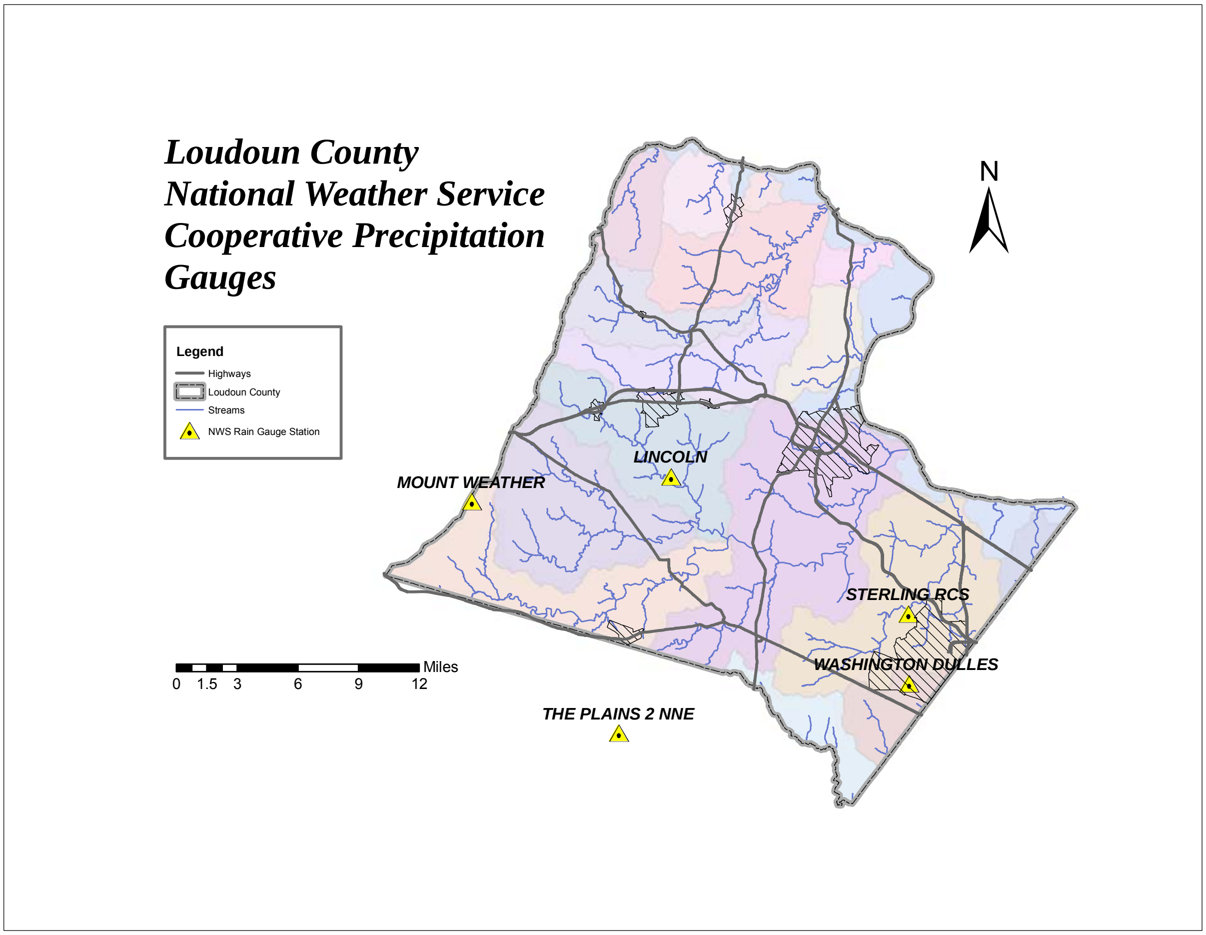
The precipitation data were analyzed to identify typical precipitation conditions and spatial and temporal trends in the data. The County conducted preliminary statistical analyses and CH2M HILL performed additional complementary analyses. Gaps in the daily precipitation records were filled before all analyses. The gaps were filled by averaging data available for that day from all other stations. The analyses included the following:

- Median, minimum, and maximum annual precipitation by station
- Total annual precipitation over time
- Deviation from average annual precipitation
- Average, minimum, and maximum monthly precipitation
- Median and maximum daily precipitation
- Development of precipitation duration curves
- Statistical spatial trends
- Localized temporal trends

TABLE 2-1
Summary of Available Precipitation Data

| Station Name | ID # | Start Date | End Date | Number of Days | Number of Records | Number of Missing Days | Missing periods |
|---|---|---|---|---|---|---|---|
| Lincoln | 444909 | 1/1/1930 | 7/31/2006 | 27,971 | 27,787 | 184 | 10/1/50–10/31/50, 1/1/94–1/31/94, 7/1/94–7/31/94, 11/1/96–11/30/96, 1/1/05–1/31/05, 6/1/06–6/30/06 |
| Mt. Weather | 445851 | 8/1/1948 | 7/31/2006 | 21,184 | 21,124 | 60 | 11/1/03–11/30/03, 6/1/06–6/30/06 |
| Sterling RCS | 448084 | 9/1/1977 | 7/31/2006 | 10,561 | 10,469 | 92 | 1/1/82–1/31/82, 5/1/90–5/31/90, 6/1/06–6/30/06 |
| The Plains | 448396 | 4/1/1954 | 7/31/2006 | 19,115 | 18,596 | 519 | 5/1/54–5/31/54, 1/1/66–1/31/66, 12/1/74–1/31/75, 5/1/75–5/31/75, 12/1/78–12/31/78, 2/1/03–11/30/03, 6/1/06–6/30/06 |
| Dulles | 448903 | 11/1/1962 | 10/31/2001 | 14,214 | 14,245 | 31 | 12/1/62–12/31/62 |
| Leesburg | 03909270<br>77330900 | 12/3/2002 | 8/16/2007 | 1,717 | 1,685 | 32 | 11/1/04–12/3/04 |
| Lovettsville | 03915560<br>77381600 | 9/29/2002 | 8/16/2007 | 1,783 | 1,258 | 525 | 300 missing values throughout record, and<br>225 estimated values between 10/2003 and 9/2004 |

FIGURE 2-1
Location of Rain Gauges




## 2.3 Description of Conditions

Long-term records from the five NWS stations indicate that annual precipitation for Loudoun County has ranged from 20.4 inches to 63.4 inches since 1930 and averages 41.7 inches. Precipitation is relatively evenly distributed throughout the year, but it does tend to be lowest in February and highest in the summer (Figure 2-2). There also tends to be more variability in precipitation in the summer, as can be seen in the higher maximum values in Figure 2-2. The records show that there is measurable precipitation roughly 3 out of 10 days.

FIGURE 2-2
Average Monthly Precipitation Based on Average of Five NWS Precipitation Stations

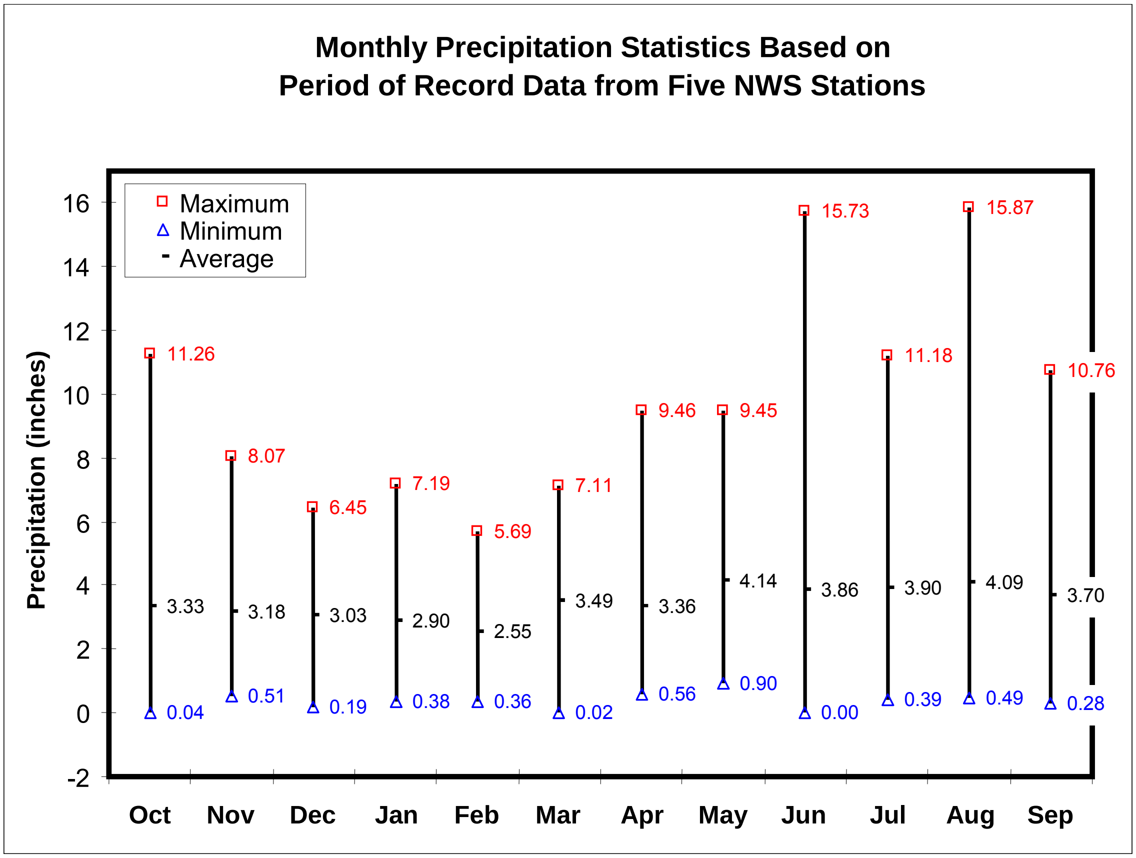



Figure 2-3 provides total annual precipitation over time based on an average of the data from the five NWS stations. The figure shows that there is a high variability in annual precipitation in this region, and there can be several years when precipitation is below normal (as in the 1950s) but those often are preceded or followed by several years of above average precipitation. This behavior can also be seen in Figure 2-4, which presents the cumulative deviation from normal precipitation. The analysis begins in 1931 to avoid the skew caused by the first year of record, which was an extreme drought but could not be offset by the presumed previous wet years that were not available in the record.

FIGURE 2-3
Total Annual Precipitation Over Time Based on Average of Five NWS Precipitation Stations

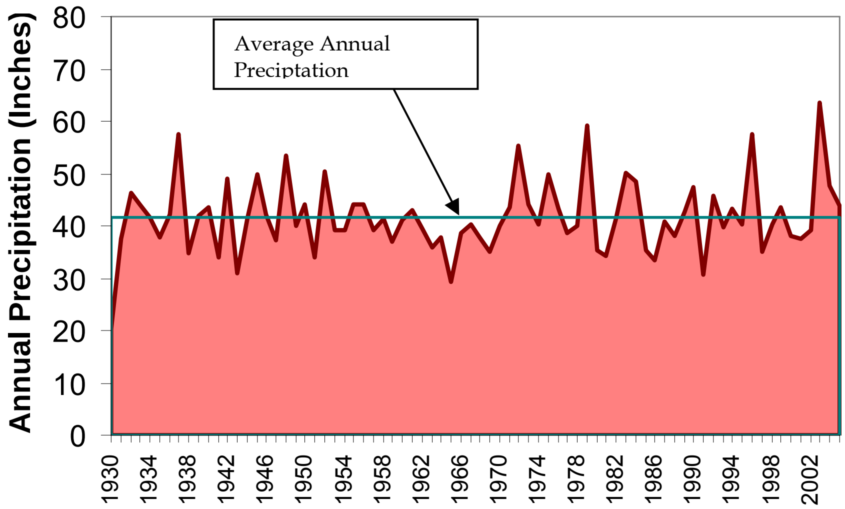
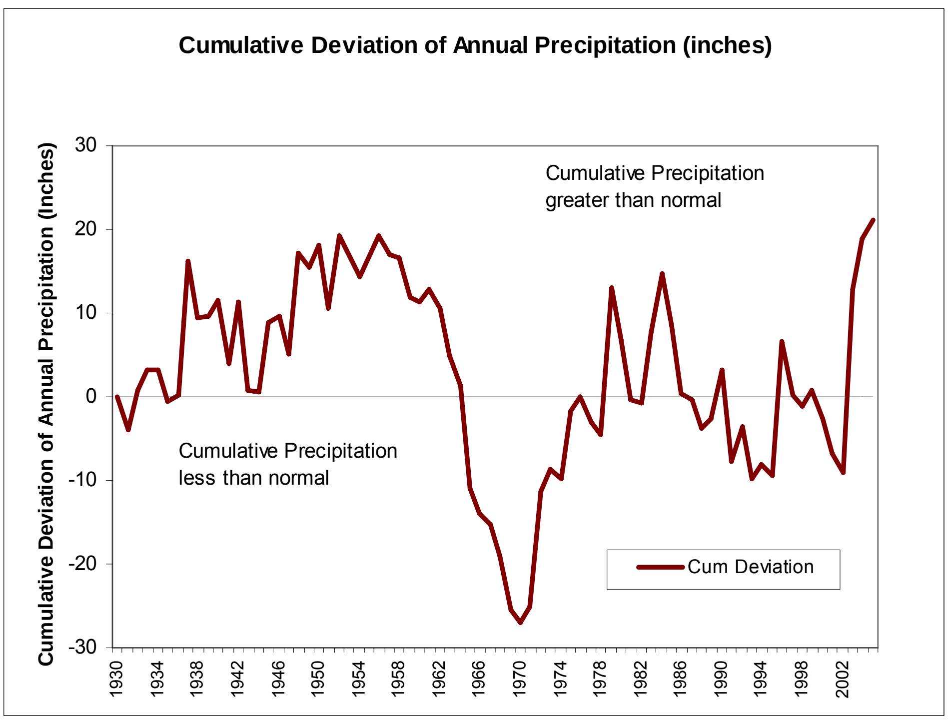
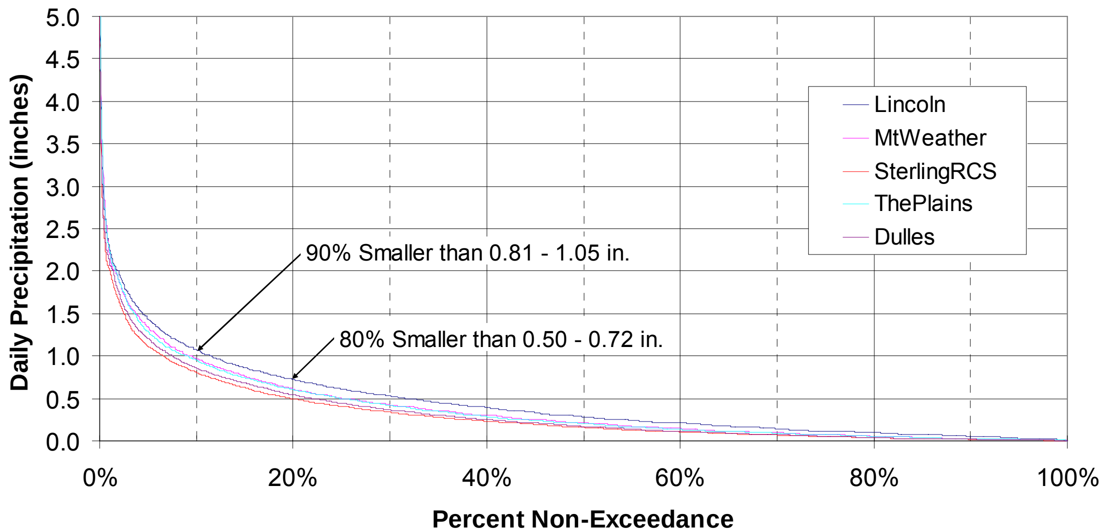



FIGURE 2-4
Cumulative Deviation of Annual Precipitation Based on Average of Five NWS Precipitation Stations




Daily precipitation was evaluated through the development of precipitation flow-duration curves to characterize typical storm events (Figure 2-5). Flow-duration curves typically are used in identifying design criteria for stormwater management facilities, based on events that are most common and have the most impact on the environment. Frequency-duration curves typically are developed using hourly data to determine total event volume, however hourly data were unavailable. Therefore daily values were used to construct the curves. The use of daily data has a tendency to limit the variation within the frequency-curve because they do not capture short-duration storms that occur within a day or storms that occur over multiple calendar days. Figure 2-5 provides the precipitation frequency curve for each of the five NWS stations, based on the full period of record. Appendix B1 contains the individual curves developed for each month.

FIGURE 2-5
Precipitation Frequency Curves for the Five NWS Precipitation Stations, Based on the Full Period of Record




*Based on all days with precipitation > 0.00 in.*

## 2.3.1 Spatial Variation

The datasets from the five NWS stations were compared to identify variations and trends. In general the variability among the five gauges is not great. The difference in the average annual precipitation between the gauge with the highest value and that with the lowest is 6.5 inches; 6.0 inches if the medians are compared. The difference for any given year ranges between 1.6 inches to 14.5 inches. Figure 2-6 summarizes annual precipitation statistics for each station. Figure 2-7 provides the total annual precipitation over time and Figure 2-8 the average monthly precipitation at each of the five stations to depict the variability among them.

FIGURE 2-6
Annual Precipitation Statistics for five NWS Precipitation Stations

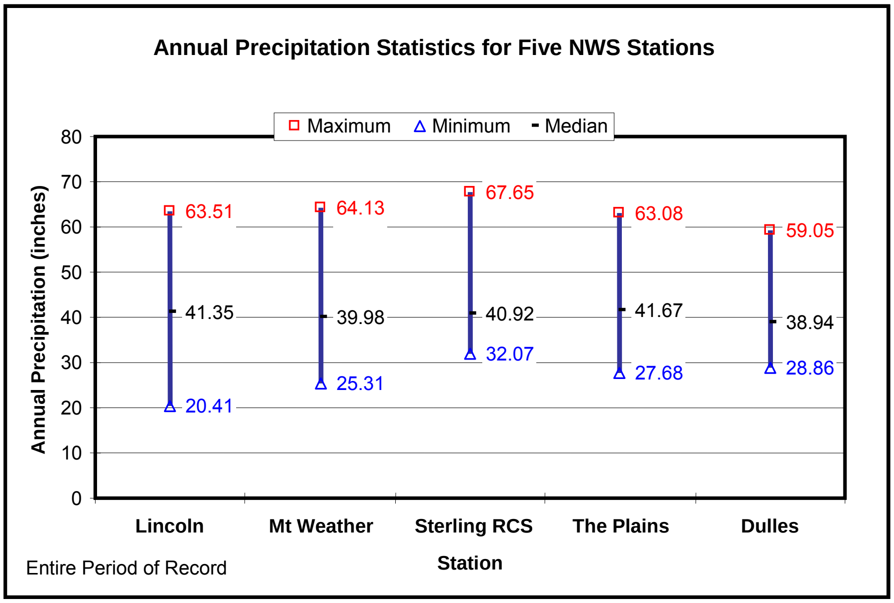



FIGURE 2-7
Total Annual Precipitation over Time at the Five NWS Precipitation Stations

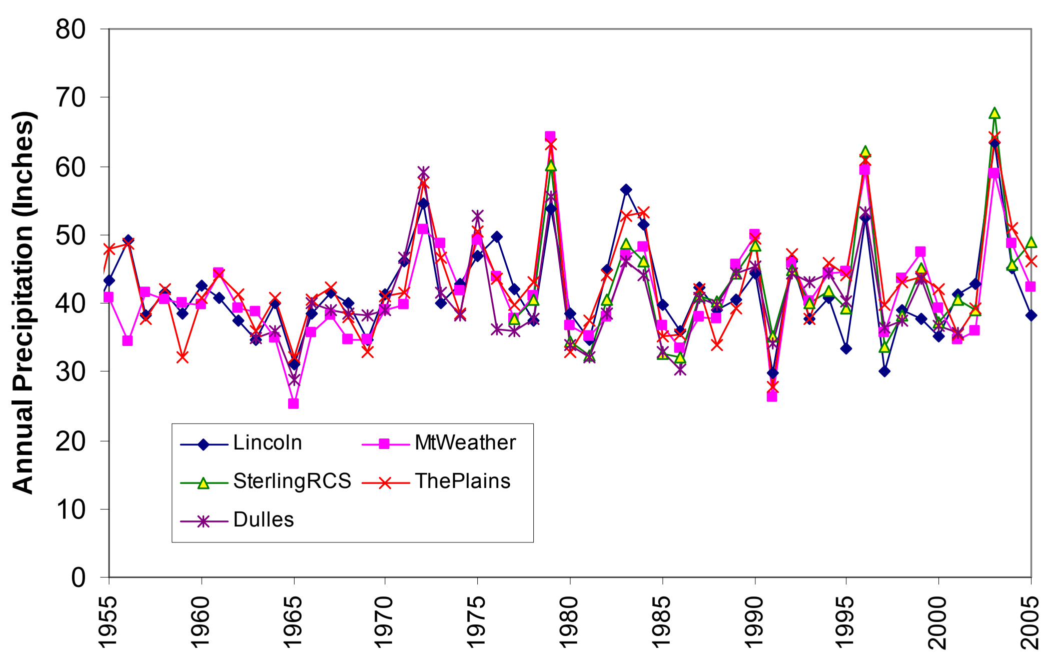
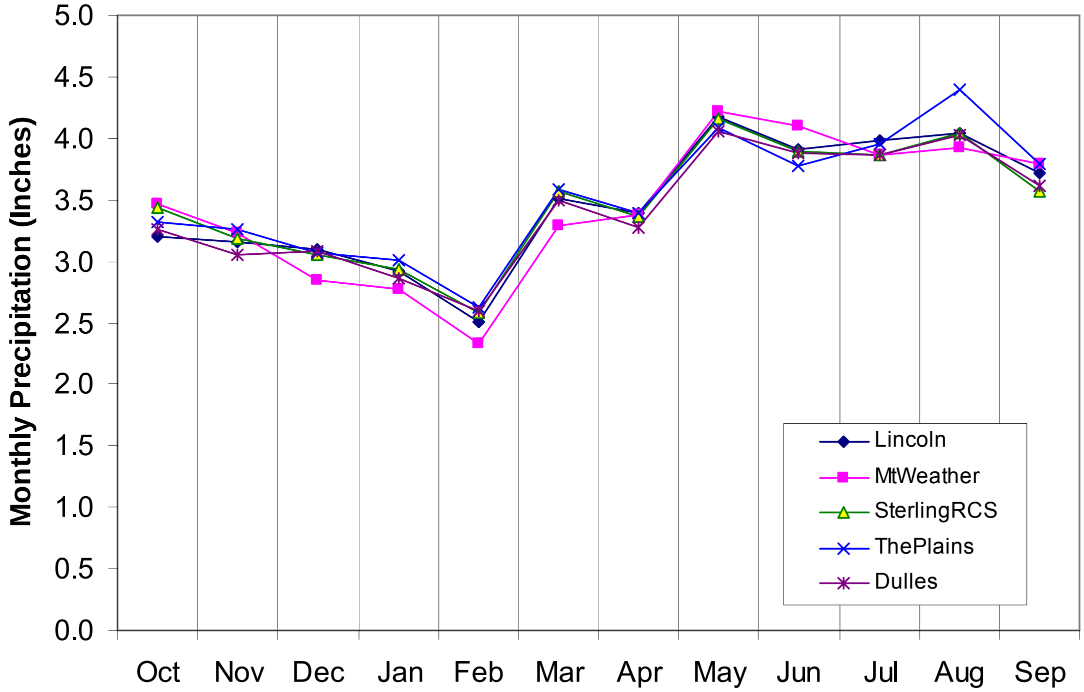


FIGURE 2-8
Average Monthly Precipitation at the Five NWS Precipitation Stations




The daily precipitation records were compared to the average daily records for the five stations using a Student's t-test with a two-tailed distribution. The statistics were run only during the period when data from all five stations were available (September 1977 to October 2001). The result identified one station, the Plains, that was statistically different from the average, within a 5 percent confidence level. The Plains average annual precipitation during the common period of record is 5 percent higher than the average. The average annual precipitation at the Plains is higher than the average for the 5 stations for 18 of the 25 common years of record. The Plains is the southernmost station, but because data for the northern part of the County are limited, it is difficult to make any solid conclusions about spatial variations.

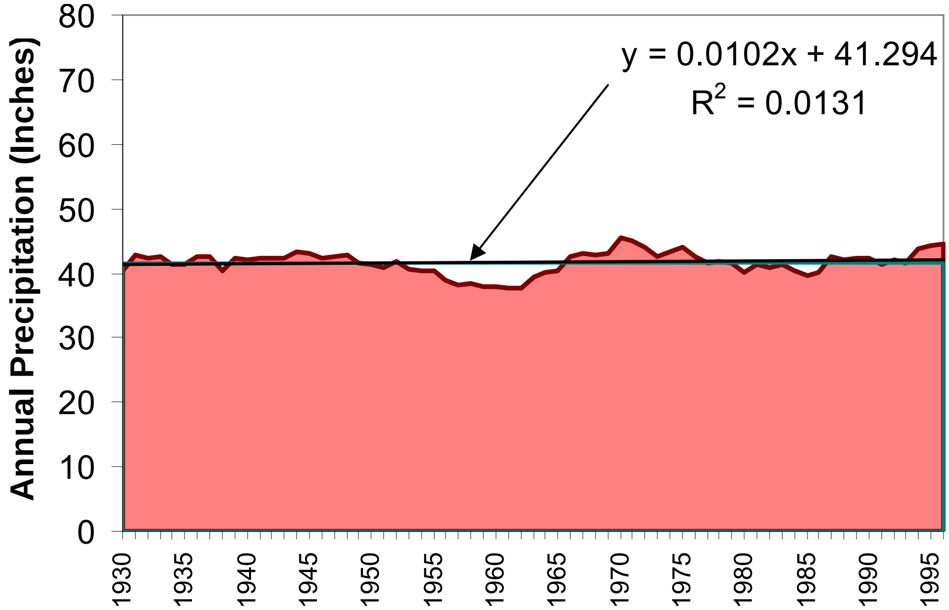
Although there were insufficient data to conduct a statistically valid analysis, the Lovettesville data were compared to the NWS data to identify trends. Significant gaps in the Lovettesville data between 2003 and 2004 prevent a comparison of the earlier years. The County has purchased only the NWS data through 2005; therefore, the period of comparable data is limited to 2005. Based on these data, there is no identifiable difference in the precipitation at Lovettesville compared to the NWS data.

### 2.3.2 Temporal Variation

Given the concern about weather changes that may be resulting from global climate change, the data were evaluated to identify any recognizable long-term temporal trends in the precipitation data. A 10-year rolling average of total annual precipitation was computed to minimize the impacts of short-term wet and dry periods. A linear best-fit line through the

10-year average showed a low R-square value (Figure 2-9), which does not suggest a statistically significant long-term trend in the precipitation data.

FIGURE 2-9
10-Year Rolling Average Precipitation over Time Based on Average of the NWS Precipitation Stations



SECTION 3

# Stream Discharge

## 3.1 Available Data

There are ten USGS streamflow gauges in the County watersheds. These include three long-term gauges and seven gauges that have been in place since 2002. Table 3-1 summarizes the period of record and watershed characteristics for each gauge. Figure 3-1 provides the locations of the ten streamflow gauges. Daily mean flow and daily peak flow records were obtained for the full period of record at each stream gauge station. Recently, 15-minute flow data have become available for all ten stations. The 15-minute data have not yet been fully evaluated, but they can be used to evaluate the time of concentration of each upstream watershed.

TABLE 3-1
USGS Stream Gauge Station Characteristics

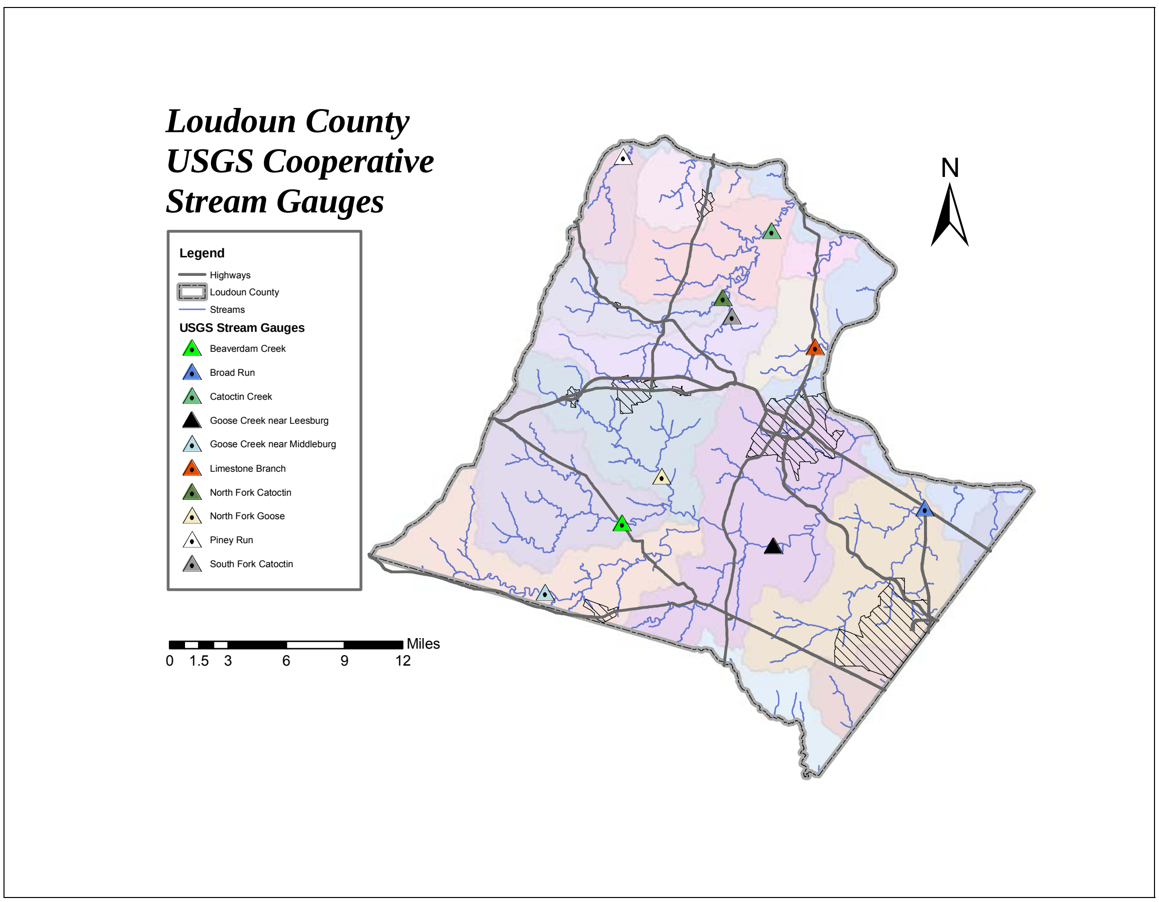
| Gauge ID | Watershed | Period of Record | Gauged Drainage Area ($mi^2$) | Watershed Drainage Area ($mi^2$) | % Impervious |
|---|---|---|---|---|---|
| 1643590 | Limestone Branch | 2002–present | 7.88 | 16.1 | 3.2 |
| 1636690 | Piney Run | 2002–present | 13.5 | 14.8 | 2.1 |
| 1638420 | North Fork Catoctin | 2002–present | 23.1 | 23.3 | 2.8 |
| 1638350 | South Fork Catoctin | 2002–present | 31.6 | 33 | 4.9 |
| 1643805 | North Fork Goose Creek | 2002–present | 38.1 | 44.4 | 5.6 |
| 1643880 | Beaverdam Creek | 2002–present | 47.2 | 53.5 | 3.1 |
| 1644280 | Broad Run | 2002–present | 76.1 | 91.3 | 16.0 |
| 1638480 | Catoctin | 1972–present | 89.5 | 92.4 | 3.6 |
| 1643700 | Upper Goose Creek (Middleburg) | 1966–present | 122 | 48.8 | 2.8 |
| 1644000 | Lower Goose Creek (Leesburg) | 1910–present | 332 | 386.3 | 8.2 |

## 3.2 Analyses Conducted

The streamflow data were analyzed to identify typical flow conditions in each watershed and to determine if it was possible to extrapolate from them the flow characteristics in the rest of the County. The County compiled and summarized the available data and conducted low-flow analyses using the EPA program DFLOW3. CH2M HILL performed with complementary analyses to identify trends with watershed characteristics. The following analyses were conducted:

- Low-flow analyses 7Q2 and 7Q10. The lowest 7-day average flow rate with a 2-year and 10-year return period. 7Q10 could only be computed at three locations because a minimum of 10 years of data are required for this analysis.
- Average annual flow computation for the entire period of record for all days with nonzero flow.
- Base flow computation. Average flow rate for all days when there was less than 0.01 inch of precipitation
- Analysis of flow normalized by watershed area to develop relationships that can be extrapolated to the rest of the County
- Flow-duration curves based on mean daily flow and peak daily flow
- Flow-duration curves normalized by drainage area.

FIGURE 3-1
Location of Streamflow Gauges



## 3.3 Description of Conditions

Table 3-2 summarizes the average flow conditions for the monitoring stations. The data were normalized to account for watershed size (see Table 3-3). The normalized average flow and baseflow are relatively consistent across the 10 stream gauges. The most obvious outlier is Broad Run. Average flows in Broad Run are higher than all but one of the other watersheds, and baseflows (for which the rainy days have been removed) are lower than for the other watersheds.

TABLE 3-2
Summary of Flow Data from USGS Gauges

| Gauge | Gauged Drainage Area (mi$^2$) | % Impervious | Avg. Flow (cfs) | Dry Weather Baseflow (cfs) | 7Q2 (cfs) | 7Q10 (cfs) |
|---|---|---|---|---|---|---|
| 1643590 Limestone Branch | 7.88 | 3.2 | 10 | 6.2 | 1.4 | n/a |
| 1636690 Piney Run | 13.5 | 2.1 | 15 | 11 | 1.0 | n/a |
| 1638420 North Fork Catoctin | 23.1 | 2.8 | 25 | 18 | 0.6 | n/a |
| 1638350 South Fork Catoctin | 31.6 | 4.9 | 38 | 25 | 1.8 | n/a |
| 1643805 North Fork Goose Creek | 38.1 | 5.6 | 60 | 36 | 3.1 | n/a |
| 1643880 Beaverdam Creek | 47.2 | 3.1 | 57 | 38 | 0.3 | n/a |
| 1644280 Broad Run | 76.1 | 16.0 | 123 | 54 | 4.0 | n/a |
| 1638480 Catoctin | 89.5 | 3.6 | 107 | 77 | 4.8 | 0.63 |
| 1643700 Goose Creek (Middleburg) | 122 | 2.8 | 144 | 106 | 4.6 | 0.02 |
| 1644000 Goose Creek (Leesburg) | 332 | 8.1 | 392 | 294 | 10.4 | 1.77 |

**7Q2, 7Q10—**The lowest 7-day average flow rate with 2- and 10-year return periods.
**Average Flow—**Average flow rate for the period of record between 2001–2007.
**Dry Weather Base Flow—**Average flow rate on any day when there was less than 0.01 inch of precipitation. Based on 2001–2007 data.

TABLE 3-3
Summary of Flow Data Normalized to Drainage Area, Based on USGS Gauges

| Gauge | Gauged Drainage Area (mi$^2$) | % Impervious | Average Flow (cfs/ mi$^2$) | ry Weather eflow* (cfs/mi$^2$) | 7Q2 (cfs/ mi$^2$) | 7Q10 (cfs/mi$^2$) |
|---|---|---|---|---|---|---|
| 1643590 Limestone Branch | 7.88 | 3.2 | 1.3 | 0.78 | 0.18 | n/a |
| 1636690 Piney Run | 13.5 | 2.1 | 1.1 | 0.84 | 0.08 | n/a |
| 1638420 North Fork Catoctin | 23.1 | 2.8 | 1.1 | 0.77 | 0.02 | n/a |
| 1638350 South Fork Catoctin | 31.6 | 4.9 | 1.2 | 0.79 | 0.06 | n/a |
| 1643805 North Fork Goose Creek | 38.1 | 5.6 | 1.6 | 0.95 | 0.08 | n/a |
| 1643880 Beaverdam Creek | 47.2 | 3.1 | 1.2 | 0.80 | 0.01 | n/a |
| 1644280 Broad Run | 76.1 | 16.0 | 1.6 | 0.71 | 0.05 | n/a |
| 1638480 Catoctin | 89.5 | 3.6 | 1.2 | 0.86 | 0.05 | 0.0070 |
| 1643700 Goose Creek (Middleburg) | 122 | 2.8 | 1.2 | 0.87 | 0.04 | 0.0002 |
| 1644000 Goose Creek (Leesburg) | 332 | 8.1 | 1.2 | 0.88 | 0.03 | 0.0053 |

**7Q2, 7Q10—**The lowest 7-day average flow rate with 2- and 10-year return periods.
**Average Flow—**Average flow rate for period of record between 2001 and 2007.
**Dry Weather Base Flow—**Average flow rate on any day when there was less than 0.01 inch of precipitation. Based on 2001–2007 data.

This trend may be attributed to a large amount of impervious areas. Broad Run is the most developed watershed for which streamflow data are available (16 percent impervious). The typical impact of impervious surface on streamflow is to increase surface runoff to the stream because of reduced infiltration, and decrease interflow (shallow groundwater flow) and baseflow (groundwater flow into the streams), which tend to reach the stream several days following precipitation events. The streamflow data indicate that this may be the case in Broad Run. The North Fork of Goose Creek has a somewhat higher average flow per square mile of drainage area. The larger watershed has a low percent impervious surface (6%).

Figure 3-2 presents the relationship between the computed flows and the contributing drainage area. The strong linear relationship further depicts the consistency of flow characteristics at most of the stream gauges, and the relative differences at Broad Run.

Figure 3-3 presents the mean annual stream flow over time at each of the stream gauges. Generally all of the stream gauges follow the same temporal trends, responding primarily to increases and decreases in precipitation. The one outlier of note is Broad Run. Flows in Broad Run remained relatively constant in 2005 and 2006, while flows at the other ten gauges decreased significantly in response to reduced precipitation. The cause of this is uncertain, however it may be a result of lawns being watered in this more highly developed watershed. There are also several NPDES discharge permits at facilities within the Broad Run watersheds. These discharges could increase baseflow relative to other watersheds.

FIGURE 3-2
Relationship of Flow to Drainage Area

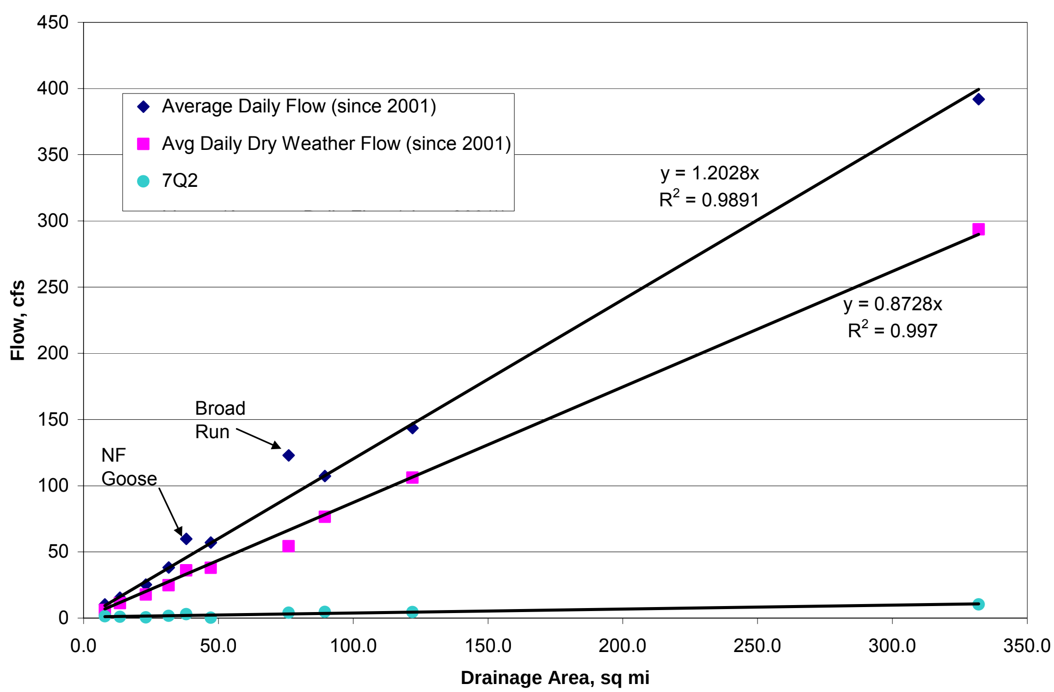
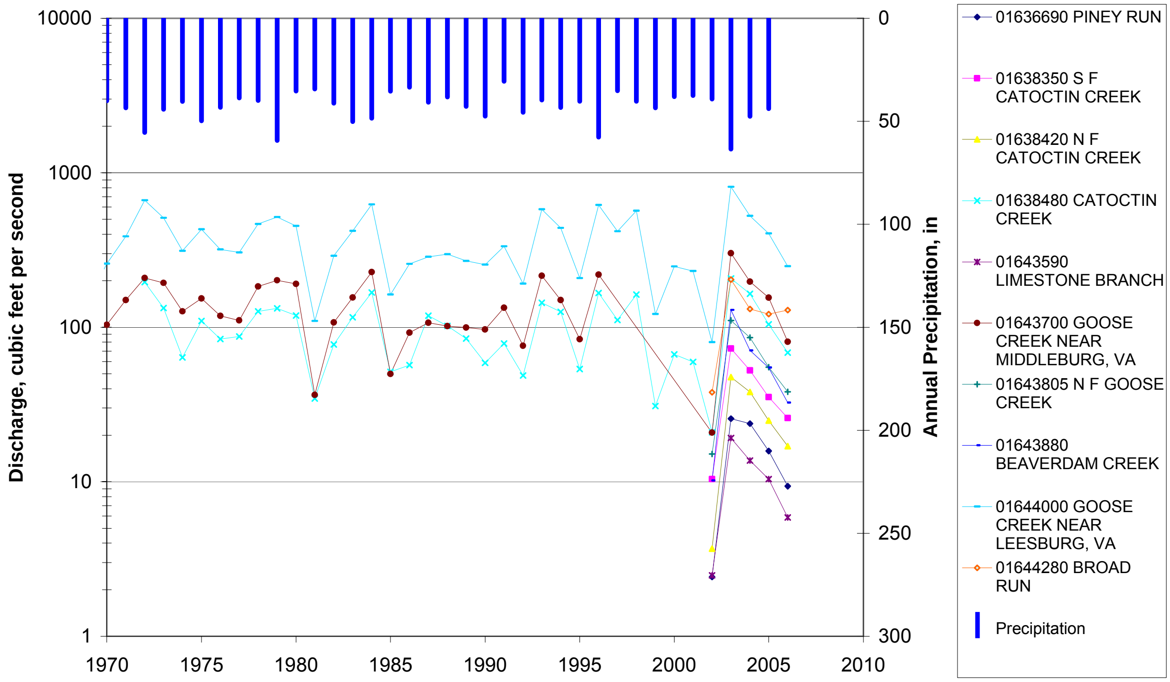


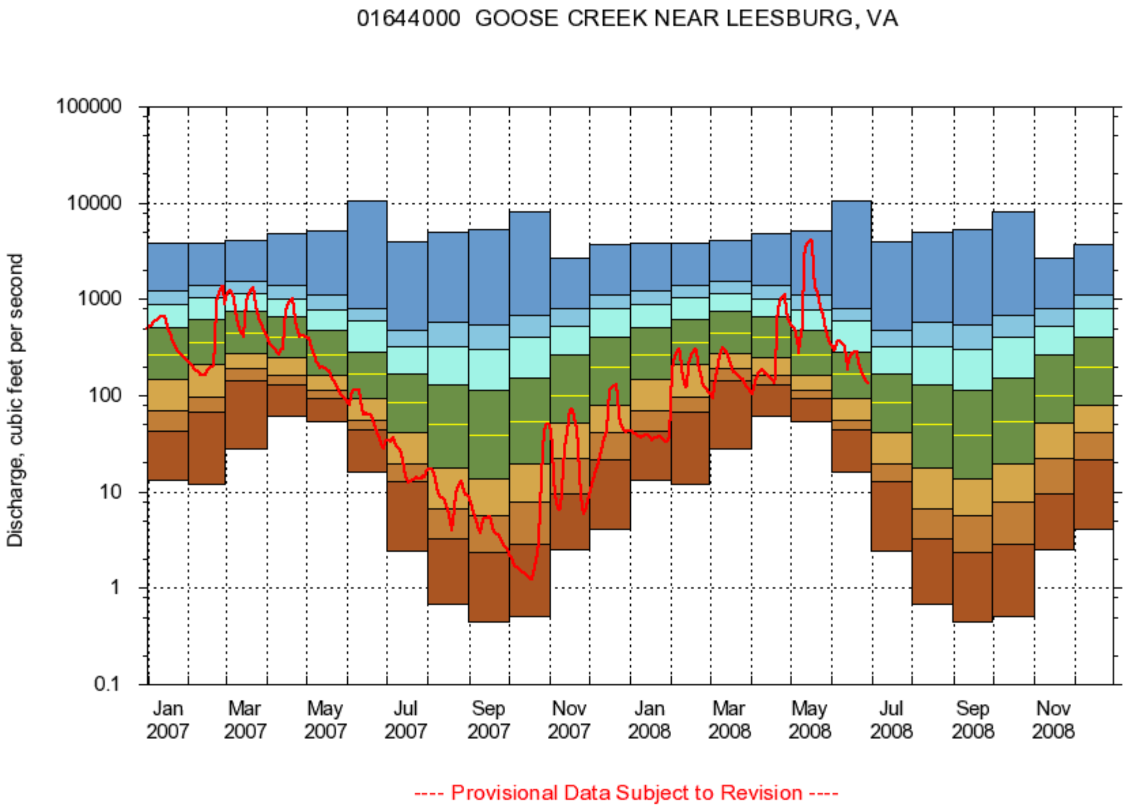
FIGURE 3-3
Mean Annual Stream Flow Over Time




Note: Incomplete data for Goose Ck Middleburg 1997-2001

Recent flow records available from USGS, can be plotted in comparison to long-term monthly flow statistics. Figure 3-4 presents an example of the available figures. The most recent flow records were obtained for each of the 10 stream gauges (Appendix B1). When reviewing the figures in Appendix B1, it is important to recognize that the long-term statistics for most of the gauges are based on only 5 years of data and thus do not represent a wide range of wet and dry conditions. The figures in Appendix B1 show the impact that drought conditions have had on stream flow since September 2007. With the exception of North Fork of Goose Creek, flows at all the gauges drop into the 5th percentile and below in September and October. Broad Run recovered to typical flows (25th to 75th percentile range) by November. Baseflow at the other eight streams remained below the 25th percentile into the winter. The reasons for these behaviors cannot be determined from the information available to date. However, knowledge of specific conditions allows some conjectures. For example, there are several industrial wastewater dischargers in the Broad Run watershed. These may have allowed the baseflow in Broad Run to rebound more quickly. In addition, the watering of residential lawns in Broad Run may have increased the flow immediately after the drought. The North Fork of Goose Creek did not experience the same drought conditions observed at the other stream gauges. The higher baseflow in North Fork of Goose Creek may be partially a result of the constant flows from the Basham Simms wastewater facility.

FIGURE 3-4
Comparison of Recent Flows in Goose Creek near Leesburg with Long-Term Statistics




Flow duration curves were generated for the 10 stream gauges using streamflow statistics available from USGS (Figure 3-5). Flow-duration curves also were generated for each month (Appendix B1). With a longer record, the curves can be used during stream restoration and other in-stream work to identify critical flow rates for design. They can also be used to evaluate watershed conditions that alter flow regimes, such as high imperviousness, which tend to increase the frequency of high flows and decrease the frequency of low flows. The curves were normalized based on drainage area at each gauge (Figure 3-6). The normalized curves show that the flow regimes for most of the streams are similar. The primary outlier is Broad Run, which tended to have higher flows for precipitation events (left side of graph) and lower flows under baseflow conditions (middle to right side of the graph).

FIGURE 3-5
Flow-Duration Curves by Stream Gauge

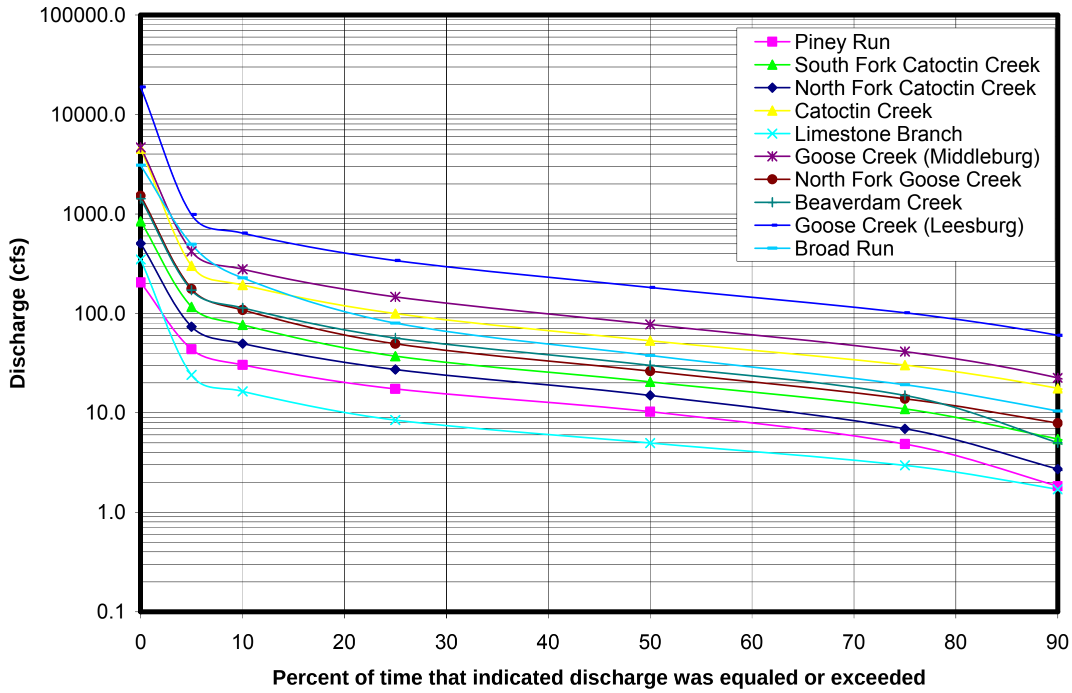
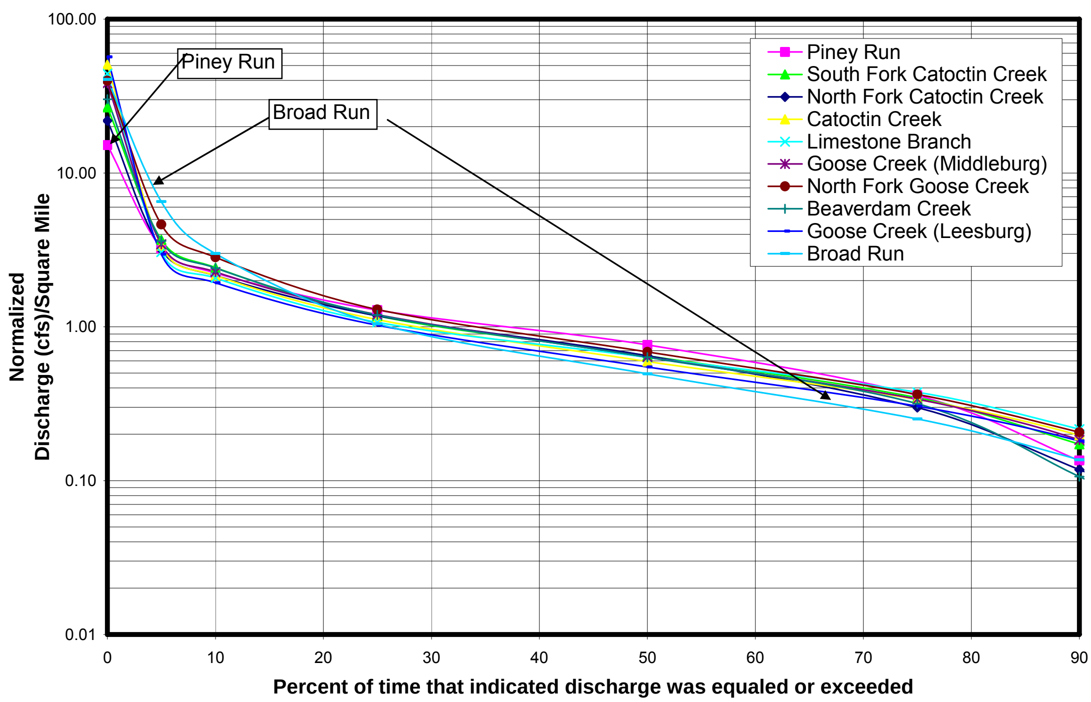



FIGURE 3-6
Flow-Duration Curves by Stream Gauge, Normalized Based on Contributing Drainage Area



SECTION 4

# Stream Water Quality

## 4.1 Available Data

TABLE 4-1
Long-Term Stream Water Quality Monitoring Stations

| Stream | Station ID | Watershed |
|---|---|---|
| Beaverdam Creek | 1ABEC004.76[a] | Beaverdam Creek |
| Broad Run | 1ABRB002.15[a] | Broad Run |
| Horsepen Run | 1AHPR003.87 | Broad Run |
| Bull Run | 1ABUL025.94[a] | Bull Run |
| Little Bull Run | 1ALII003.97 | Bull Run |
| Catoctin Creek | 1ACAX004.57[a] | Catoctin Creek |
| Limestone Branch | 1ALIM001.16[a] | Limestone Branch |
| Lower Goose Creek | 1AGOO002.38[a] | Lower Goose Creek |
| Tuscarora Creek | 1ATUS000.37 | Lower Goose Creek |
| Sycolin Creek | 1ASYC002.03 | Lower Goose Creek |
| North Fork Goose Creek | 1ANOG005.69[a] | North Fork Goose Creek |
| South Fork Catoctin Creek | 1ASOC001.66[a] | South Fork Catoctin Creek |
| Sugarland Run | 1ASUG004.42[a] | Sugarland Run |
| Upper Goose Creek | 1AGOO022.44[a] | Upper Goose Creek |
| Cromwells Run | 1ACRM001.20 | Upper Goose Creek |
| Upper Goose Creek | 1AGOO044.36 | Upper Goose Creek |

[a] Representative station for watershed

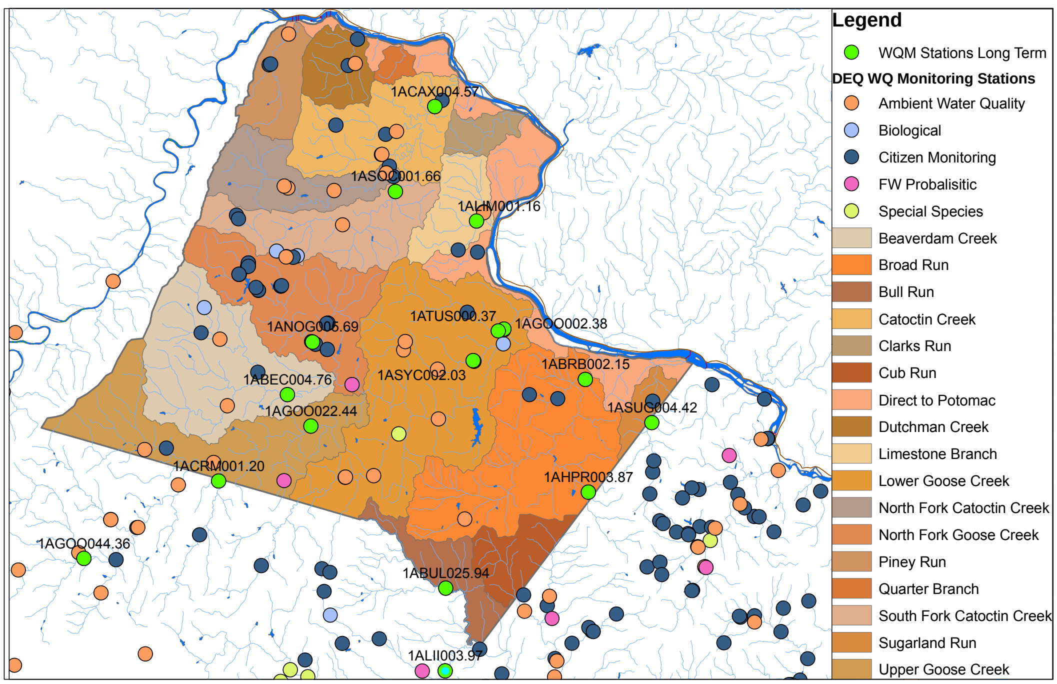
The Virginia Department of Environmental Quality's (DEQ) database includes 94 monitoring stations located either in Loudoun County or on streams that drain into the County. Forty-three stations were used to collect ambient water quality data, 4 were used to collect biological data, 44 were citizen monitoring stations that collected benthic macroinvertebrate data, and 3 involved other types of monitoring. Most of the ambient stations contained limited data in terms of number of samples, period of record, and pollutants analyzed. Only 16 stations could be considered to have long-term data. Table 4-1 summarizes the 16 monitoring stations and their watersheds.

Twelve of the 16 stations are located within Loudoun County and in 9 of the County's 17 watersheds. Three are located in the Lower Goose Creek watershed and two in the Broad Run watershed (Table 4-1). Tuscarora Creek and Sycolin Creek are small tributaries to Lower Goose Creek. Their monitoring stations are not representative of the larger watershed's water quality because of their small size in relation to the Lower Goose Creek Watershed. The same logic applies to Horsepen Run with regards to Broad Run. The station on Sugarland Run is located outside the County but is representative of the watershed.

Of the remaining monitoring stations, two are located in Fauquier County, one on Upper Goose Creek, and one on Cromwells Run, a tributary to Upper Goose Creek. The Upper Goose Creek station (1AGOO044.36) is less representative of the watershed than the next downstream station (1AGOO022.44). The station on Cromwells Run monitors a smaller stream that flows into Upper Goose Creek and thus is not representative of the receiving stream. The station on Little Bull Run monitors a stream segment outside Loudoun County and flowing away from the County and is also not considered representative.

The result is that 6 of the 16 long-term monitoring stations were eliminated from further analysis. The remaining 10 watersheds represent 79 percent of Loudoun County's total area. All the monitoring stations are shown in Figure 4-1. While many of the eliminated monitoring station data sets lacked sufficient spatial coverage or period of record for this analysis, they may prove useful for more detailed subwatershed evaluations in the future.

FIGURE 4-1
Loudoun County DEQ Water Quality Monitoring Stations




## 4.2 Water Quality Evaluation

Preliminary evaluations included a broad range of data analysis of all available stream water quality data. Data sources included the following:

- Broad Run Water Quality Monitoring Program
- Loudoun Soil and Water Conservation District stream monitoring
- DEQ Water Quality data (trend and ambient stream monitoring including benthic macroinvertebrates)

The Broad Run data are from a monitoring station located upstream of the Loudoun Water (formerly Loudoun County Sanitation Authority, LCSA) plant, under construction at the time of this analysis. Sampling started in 1990 and consists of water chemistry and flow. Samples were collected every two weeks and analyzed for 20 to 50 constituents. The Loudoun Soil and Water Conservation District (LSWCD) has 14 monitoring stations that have been monitored since 1999. Sampling has focused primarily on pathogens (fecal coliform and *E. coli*). A limited amount of water quality and macroinvertebrate sampling was also conducted by citizen monitoring groups.

The statistical analyses focused exclusively on the DEQ data because of a higher level of quality control, better spatial distribution, and longer records. Unless otherwise noted, statistical analysis included the following:

- Count
- Mean
- Median
- Standard deviation
- Coefficient of variation
- Minimum
- Maximum
- Range
- Lower quartile
- Upper quartile
- Interquartile range
- Standard skewness
- Standard kurtosis

Analysis was divided into five different groups. One group included all the field data collected by the DEQ. Field data include pH, dissolved oxygen (probe), dissolved oxygen (Winkler test), temperature, and specific conductance. The data were grouped both in total as well by individual monitoring station. Table 4-2 summarizes of the number of stations analyzed for each constituent.

TABLE 4-2
Number of Stations Evaluated for Several Water Quality Parameters

| Constituent | Stations |
|---|---|
| Specific conductance | 87 |
| Temperature | 122 |
| Dissolved oxygen (probe) | 86 |
| Dissolved oxygen (Winkler test) | 93 |
| pH | 133 |

The next group was monthly averages for several field and laboratory constituents including total suspended solids, dissolved oxygen (probe), total phosphorus, total nitrogen, turbidity, and temperature. Monthly averages were not calculated at the individual monitoring station level.

The third group is composed of statistics for 72 constituents sampled over 142 monitoring stations. As with the previous group, these statistics were not computed at the individual monitoring station level.

The fourth group underwent a more detailed analysis for 20 monitoring stations and 13 major constituents. Table 4-3 shows a summary of the count of the samples analyzed by station and constituent.

The fifth group included statistical and graphical analysis for individual constituents for all monitoring stations with long-term records. Pollutants analyzed included:

- Total nitrogen
- Ammonia
- Nitrate
- Nitrite
- Total phosphorus
- Orthophosphorus
- Chloride
- Sulfate
- Fluoride
- Arsenic
- Lead
- Zinc
- Manganese
- Specific conductance
- Turbidity
- $BOD_5$
- Chemical oxygen demand
- pH
- Total organic carbon

TABLE 4-3
Sample Count by Monitoring Station and Constituent

| Monitoring Station | Conductivity | Total Organic Carbon | Alkalinity | pH | Turbidity | Total Phosphorus | Nitrate | Ammonia | Chloride | Sulfate | Fluoride | BOD | COD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1ABUL025.94 | 51 | 24 | 47 | 46 | 32 | 69 | 51 | 232 | 46 | 46 | 10 | 46 | 33 |
| 1ALII003.87 | 45 | 23 | 45 | 45 | 31 | 69 | 45 | 0 | 45 | 45 | 9 | 45 | 32 |
| 1ASUG004.42 | 60 | 180 | 107 | 107 | 32 | 189 | 189 | 0 | 70 | 66 | 32 | 203 | 151 |
| 1ABRB002.15 | 115 | 173 | 160 | 160 | 72 | 238 | 258 | 302 | 137 | 120 | 29 | 228 | 192 |
| 1AHPR003.87 | 53 | 130 | 88 | 88 | 31 | 163 | 167 | 189 | 64 | 62 | 26 | 157 | 145 |
| 1AGOO002.38 | 144 | 229 | 195 | 195 | 86 | 273 | 277 | 319 | 146 | 141 | 48 | 286 | 217 |
| 1ASYC002.03 | 57 | 24 | 45 | 45 | 42 | 57 | 57 | 57 | 46 | 46 | 48 | 46 | 33 |
| 1ATUS000.37 | 66 | 176 | 134 | 135 | 42 | 173 | 242 | 268 | 68 | 64 | 9 | 214 | 149 |
| 1ABEC004.76 | 56 | 20 | 41 | 41 | 42 | 74 | 55 | 102 | 41 | 41 | 31 | 43 | 28 |
| 1ANOG005.69 | 54 | 99 | 54 | 54 | 38 | 150 | 201 | 242 | 41 | 40 | 7 | 123 | 106 |
| 1ACRM001.20 | 53 | 21 | 41 | 41 | 41 | 53 | 53 | 53 | 41 | 42 | 8 | 42 | 30 |
| 1AGOO022.44 | 137 | 185 | 162 | 162 | 84 | 244 | 266 | 294 | 139 | 138 | 7 | 240 | 207 |
| 1AGOO030.75 | 0 | 0 | 0 | 0 | 0 | 24 | 40 | 194 | 0 | 0 | 0 | 0 | 0 |
| 1AGOO44.36 | 135 | 87 | 142 | 143 | 78 | 173 | 164 | 74 | 130 | 130 | 45 | 145 | 118 |
| 1ALIM001.16 | 35 | 195 | 29 | 29 | 32 | 55 | 46 | 271 | 29 | 29 | 0 | 30 | 211 |
| 1ACAX004.57 | 135 | 96 | 203 | 203 | 77 | 263 | 238 | 55 | 144 | 139 | 42 | 251 | 105 |
| 1ANOC000.42 | 44 | 0 | 52 | 52 | 28 | 0 | 0 | 0 | 45 | 44 | 48 | 116 | 0 |
| 1ANOC004.38 | 12 | 0 | 12 | 12 | 12 | 12 | 26 | 52 | 12 | 12 | 0 | 13 | 0 |
| 1ASOC001.66 | 45 | 101 | 55 | 55 | 31 | 132 | 150 | 173 | 47 | 12 | 8 | 123 | 110 |
| 1APIA001.80 | 51 | 0 | 43 | 43 | 36 | 71 | 51 | 65 | 44 | 44 | 9 | 44 | 0 |

The summary statistics were similar to the other groups. Scatter plots and normal probability plots were also used to examine the data. Additional analyses were conducted to evaluate seasonal or long-term trends for the 10 stations identified above. Monthly median, mean, maximum, minimum, and standard deviations were calculated for the above pollutants as well as fecal coliforms and *E. coli*. Other analysis includes plots of concentration versus time (e.g., Figure 4-2) and plots of concentration for each sample by month (Figure 4-3). Counts of water quality violations were compiled for parameters that have water quality standards.

FIGURE 4-2
Example of pH versus Time Plot – Lower Goose Creek (1AGOO002.38)

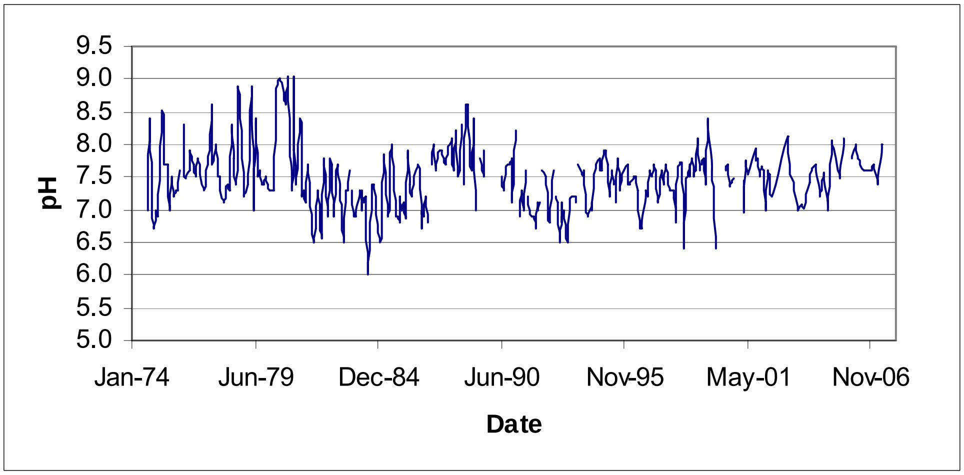
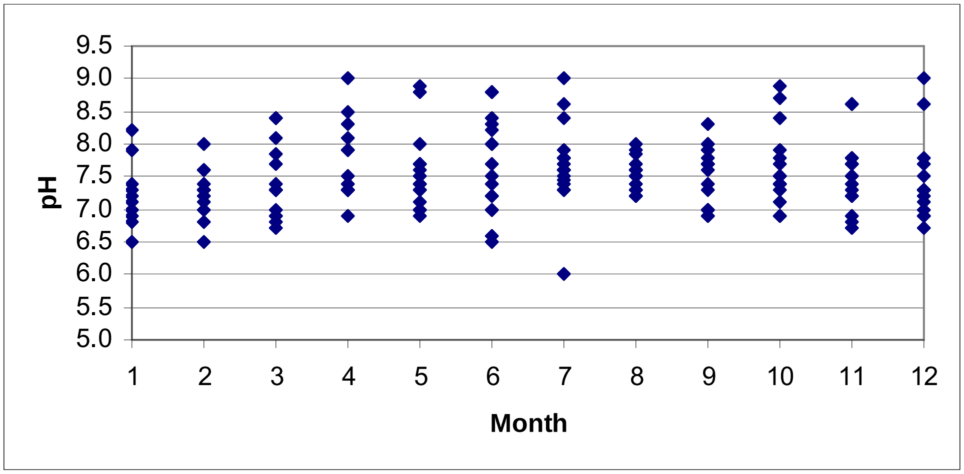



FIGURE 4-3
Example of pH by Month Plot (calendar year) – Lower Goose Creek (1AGOO002.38)



## 4.3 Description of Conditions

### 4.3.1 Primary Pollutants of Concern

#### Total Phosphorus

Phosphorus is a common nutrient that is important to plant life. Often the limiting nutrient in freshwater systems, excess phosphorus can stimulate both algae and macrophyte (large aquatic plant) growth. Excessive growth in turn can lead to water quality problems, such as low dissolved oxygen resulting from decomposition of plant matter. Virginia does not currently have water quality standards for phosphorus in freshwater streams and rivers but is in the process of developing such standards. The U.S. EPA has published a guidance criterion of 0.37 mg/L of total phosphorus.

Average values for the ten stations could be separated into two ranges. Six stations had monthly averages less than 0.12 mg/L, and four had averages in the 0.12 to 0.24 mg/L range. As seen in Figure 4-4, monthly median values were significantly lower. Monthly medians were typically in the 0.02 to 0.10 mg/L range. North Fork Goose Creek (1ANOG005.69) had monthly medians that were slightly higher from June through November. Many of the median values were at or below the detection limits for total phosphorus. In the 1990s the detection limit was 0.100 mg/L but improved in the current decade to 0.010 mg/L.

The downward shift in minimum detection limit makes it difficult to identify total phosphorus trends over time. Figure 4-5 and Figure 4-6 show total phosphorus by date for Beaverdam Creek and Lower Goose Creek respectively. The general trend appears to be decreasing over the last 7 years, but that can be explained by the lower detection limit. However, there does appear to be a trend where the highest points are lower over time.

FIGURE 4-4
Monthly Median Total Phosphorus by Monitoring Station

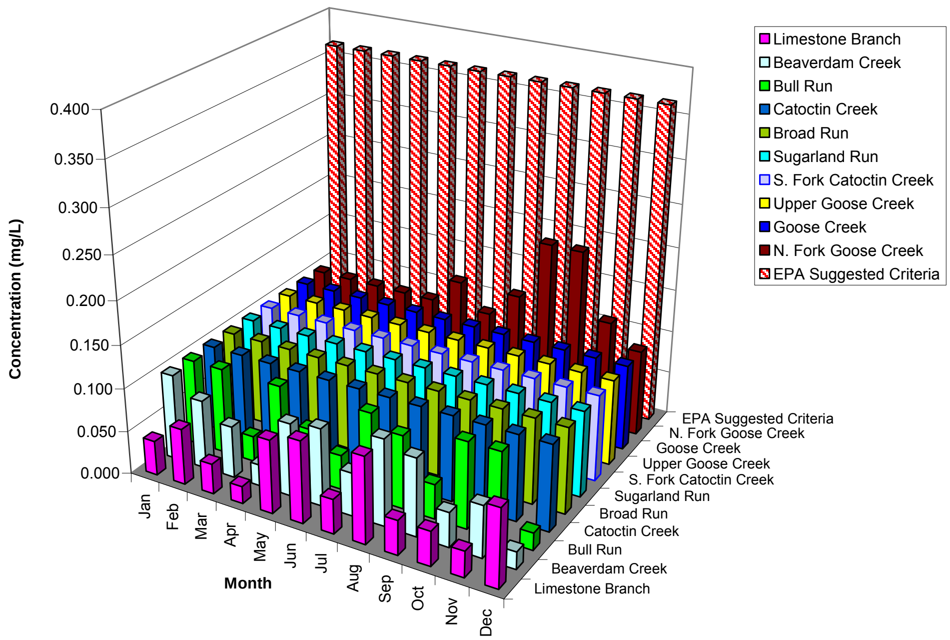



FIGURE 4-5
Total Phosphorus: Long-Term Record—Beaverdam Creek

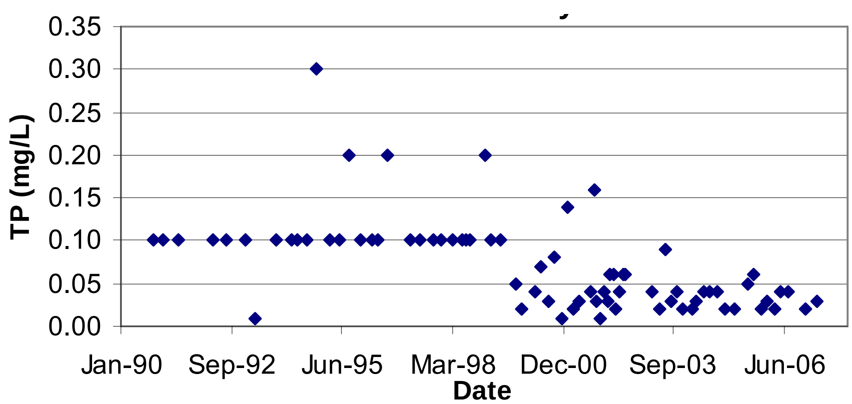
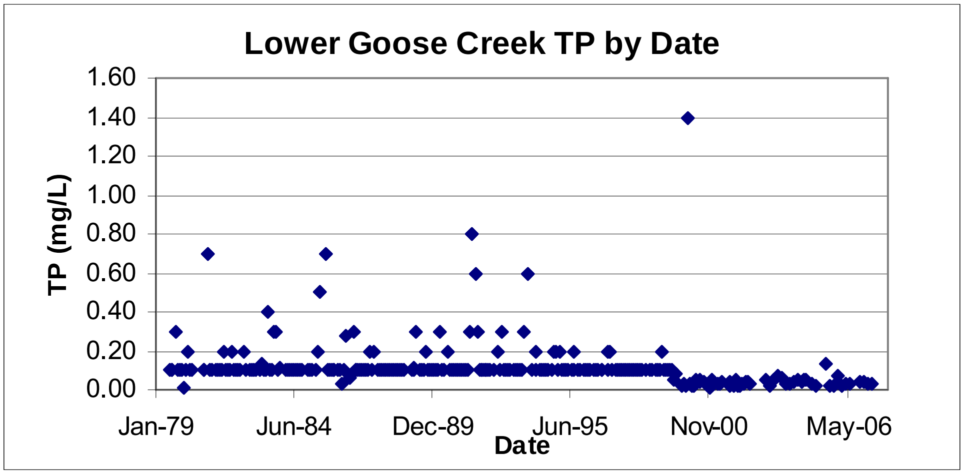


FIGURE 4-6
Total Phosphorus: Long-Term Record—Lower Goose Creek




## pH

pH is the measure of hydrogen ion concentrations in water. A value less than 7 is considered acidic and a value greater than 7 is considered basic. pH is unique in that it has a lower and upper water quality standard. Violations occur when pH is less than 6 or greater than 9. This reflects the ability of aquatic organisms to survive in more basic conditions. pH values for the 10 locations were typically in the 6.5 to 7.5 range.

The initial analysis was conducted using the data from laboratory measurements. Certain inconsistencies brought into question whether the laboratory pH data were valid. Discussion with DEQ's Northern Regional Office (NRO) confirmed that the laboratory measurements were invalid and that the field measurements should be used for data analysis. Figure 4-7 shows that monthly median values for all 10 locations fell within the 6.5 to 8.0 range. Indeed, 97 percent of the monthly medians were less than 7.8, and all but two were greater than 7.0.

FIGURE 4-7
Monthly Median pH by Monitoring Station

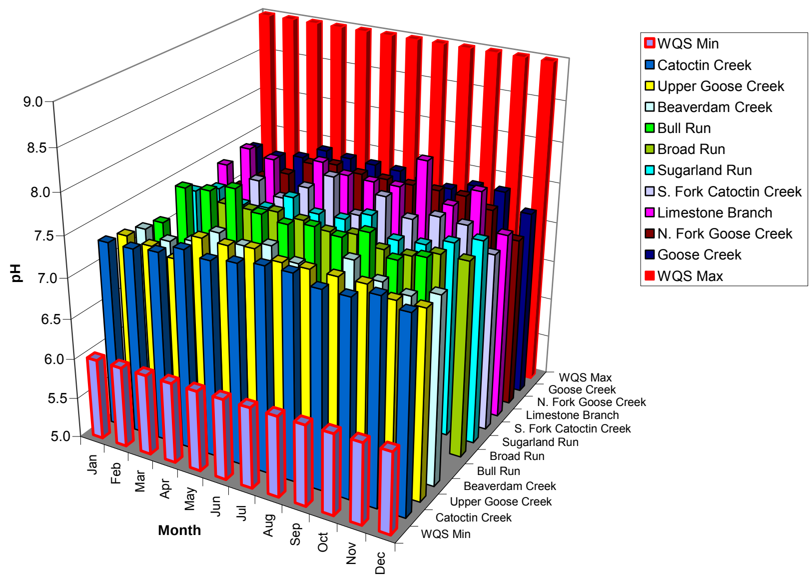



Table 4-4 summarizes the number of exceedances. With some exceptions, there have been more exceedances at the upper limit than the lower limit. However, all the upper limit exceedances were recorded in the late 1970s and early 1980s.

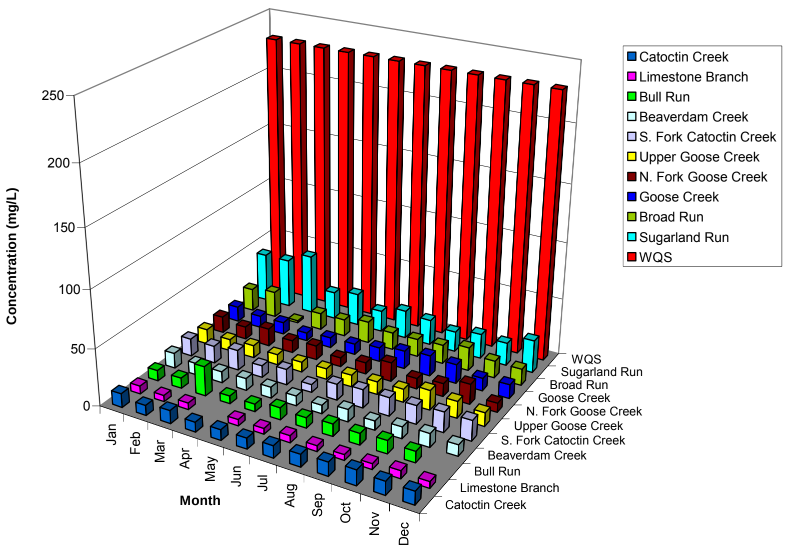
TABLE 4-4
pH Water Quality Violations

| Stream | pH<6 | pH>9 |
|---|---|---|
| Number of Occurrences | | |
| **Bull Run** | **0** | **2** |
| **Beaverdam Creek** | **5** | **0** |
| **Broad Run** | **0** | **0** |
| **Sugarland Run** | **1** | **1** |
| **Catoctin Creek** | **0** | **4** |
| **S. Fork Catoctin Creek** | **0** | **4** |
| **Limestone Branch** | **5** | **4** |
| **Upper Goose Creek** | **0** | **2** |
| **N. Fork Goose Creek** | **8** | **11** |
| **Lower Goose Creek** | **0** | **3** |

## Chloride

Typically monthly averages fell in the 5 to 25 mg/L range, while monthly median values fell in the 5 to 20 mg/L range. These ranges are significantly less than the freshwater water quality standards for chlorine (230 mg/L). 5 mg/L was the limit of detection for most of the water quality analyses. Two locations show a distinct seasonal variation in the chlorine monthly median. Sugarland Run and Broad Run had higher median values in January to March, lower values during the spring through fall months (April to November), and increasing values in December. This behavior can be attributed to using salt to treat for snow and ice in the winter and higher level of development in the two watersheds. Figure 4-8 shows the monthly median chloride concentrations with the water quality standard.

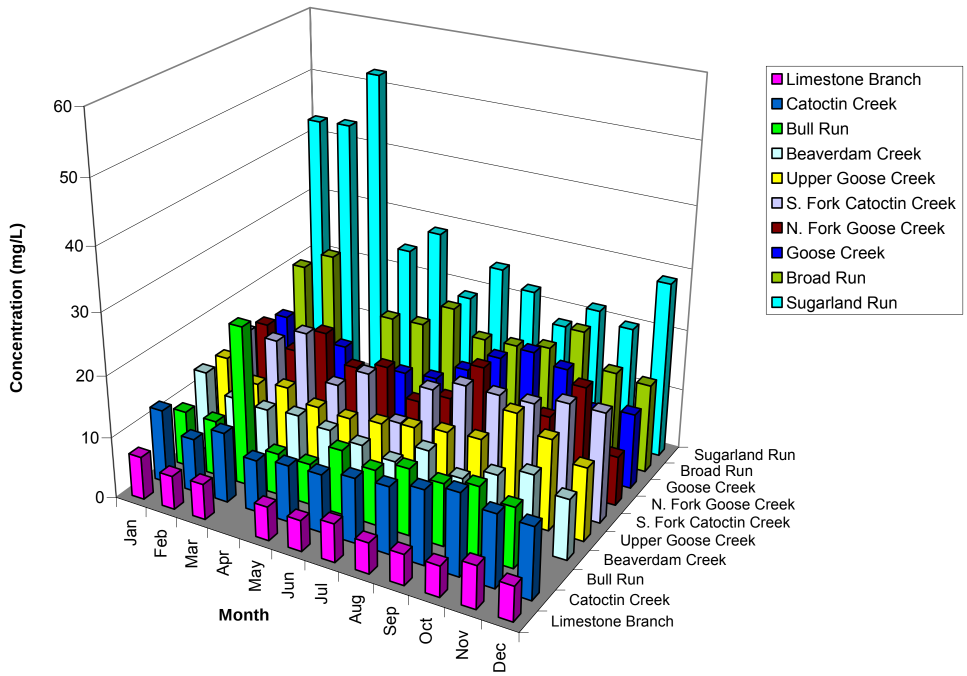
FIGURE 4-8
Monthly Median Chloride by Monitoring Station with Water Quality Standards




## Fecal Coliforms

Before 2002, the standard for bacteria in freshwater was fecal coliforms. As with most bacteria water quality standards, fecal coliform was used as an indicator that more harmful organisms may be present in the tested water body. The more harmful organisms, including bacteria and viruses, are more difficult to isolate and detect as compared to the indicator. The fecal coliform water quality standard has subsequently been revised to support total maximum daily load (TMDLs) for waterbodies that were listed as impaired because of fecal coliforms before 2002. The water quality standard is either 200 bacteria/100 mL geometric mean for a calendar month, or 10 percent of samples exceeding 400 bacteria/100 mL for a calendar month.

FIGURE 4-9
Monthly Median Chloride by Monitoring Station




There have been many water quality violations over the years for fecal coliforms. Figure 4-10 demonstrates that in many cases, the monthly median exceeds the 400 bacteria/100 mL standard. As can be seen in Table 4-5, the number of exceedances is high for all 10 sampling stations. In several cases there is a summer peak that is more pronounced than other months. Bacteria seem to be the most significant water quality issue for Loudoun County's waters.

FIGURE 4-10
Monthly Median Fecal Coliform by Monitoring Station

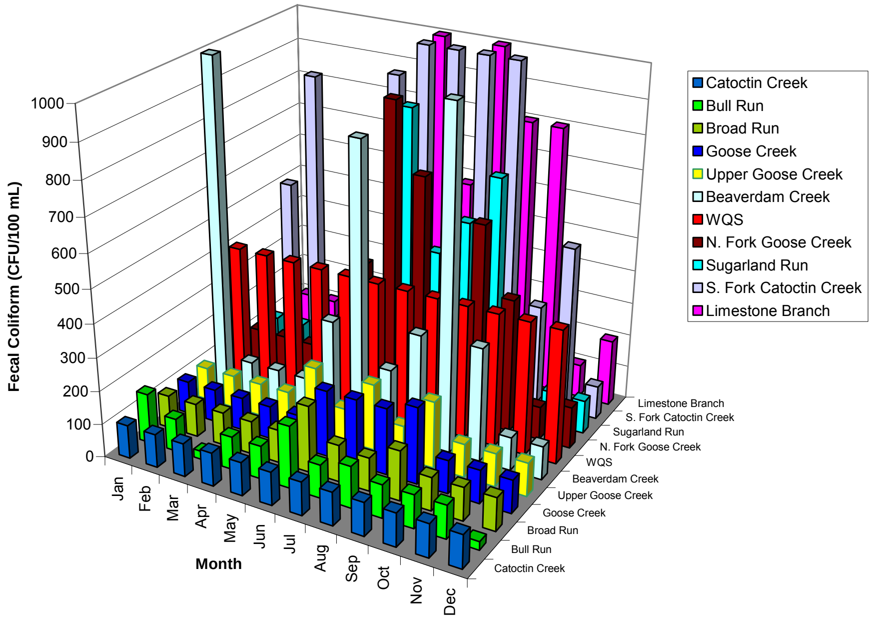



TABLE 4-5
Fecal Coliform Water Quality Violations

| Stream | Geometric Mean > 200 bacteria/100mL | 10% of Samples > 400 bacteria/100mL |
|---|---|---|
| Bull Run | 0 | 3 |
| Beaverdam Creek | 0 | 33 |
| Broad Run | 1 | 44 |
| Sugarland Run | 1 | 76 |
| Catoctin Creek | 3 | 77 |
| S. Fork Catoctin Creek | 2 | 91 |
| Limestone Branch | 0 | 31 |
| Upper Goose Creek | 1 | 58 |
| N. Fork Goose Creek | 4 | 93 |
| Lower Goose Creek | 1 | 55 |

## *Escherichia coli*

Virginia began to use *E. coli* as the bacteria indicator for freshwater quality standards in 2002. This change occurred in response to U.S. EPA publishing guidance stating that *E. coli* was more indicative of water quality problems resulting from bacteria and virus contamination.

The standard is 235 bacteria/100 mL. *E. coli* monitoring began only recently. Most sample sizes are between one and three, which is insufficient to determine trends. Figure 4-11 shows the monthly medians for the available data. Table 4-6 summarizes the number of violations for *E. coli*.

FIGURE 4-11
Monthly Median *E. coli* by Monitoring Station

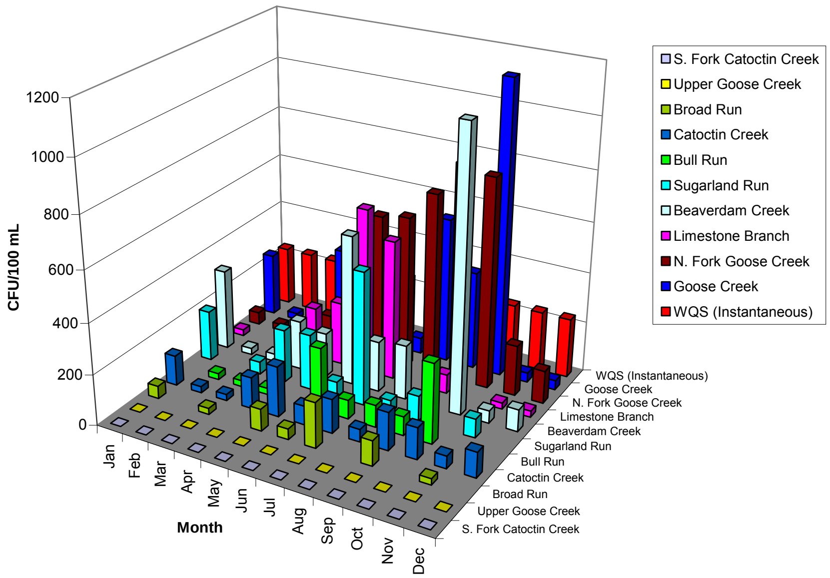



TABLE 4-6
*E. coli* Water Quality Violations

| Stream | Number of Violations |
|---|---|
| Bull Run | 4 |
| Beaverdam Creek | 8 |
| Broad Run | 1 |
| Sugarland Run | 6 |
| Catoctin Creek | 7 |
| S. Fork Catoctin Creek | 3 |
| Limestone Branch | 7 |
| Upper Goose Creek | 1 |
| N. Fork Goose Creek | 13 |
| Lower Goose Creek | 6 |

## 4.3.2 Other Pollutants Analyzed

### Nitrate

Nitrate ($NO_3$) is another common nutrient in freshwater. As with total phosphorus, Virginia does not have a freshwater water quality standard for $NO_3$. However, a standard of 10 mg/L is in place for surface waters used as water supply. Monthly averages were found to be less than this water quality standard. Monthly medians (Figures 4-12 and 4-13) were all less than 2.7 mg/L and nearly half of the medians were less than 1.0 mg/L. Catoctin Creek and Broad Run each had a single value above the standard in the mid-1980s.

FIGURE 4-12
Monthly Median Nitrate by Monitoring Station Compared to Surface Water Drinking Standard

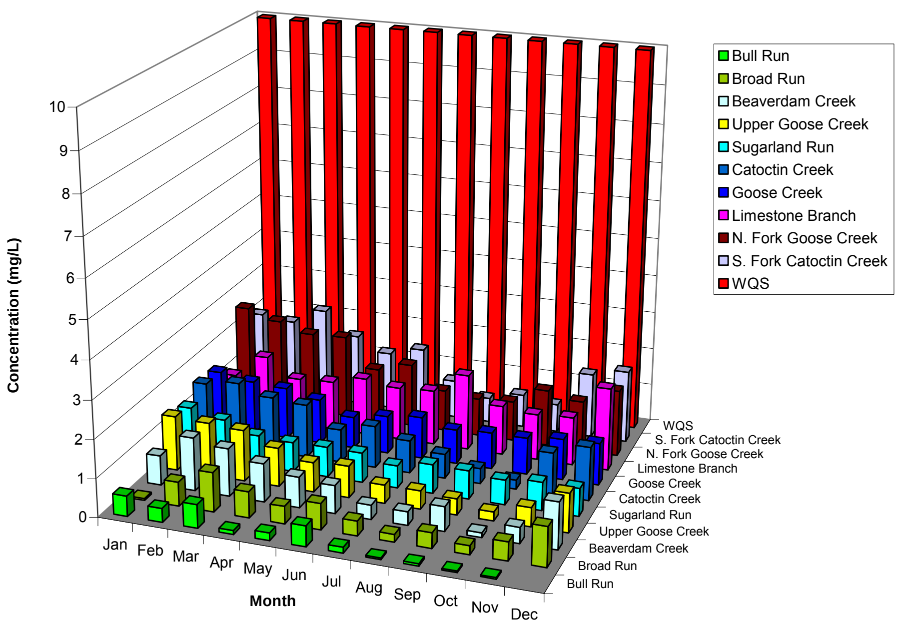
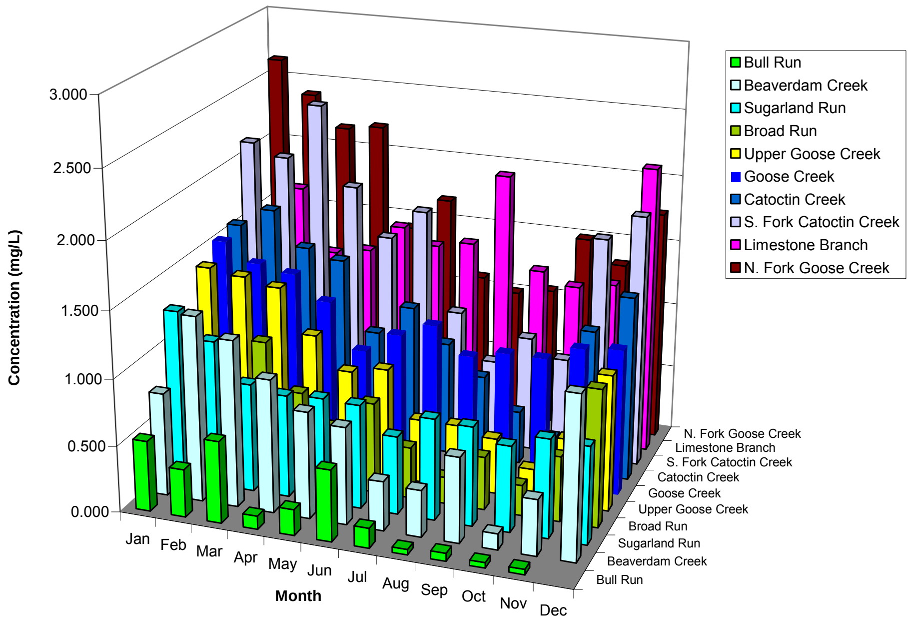


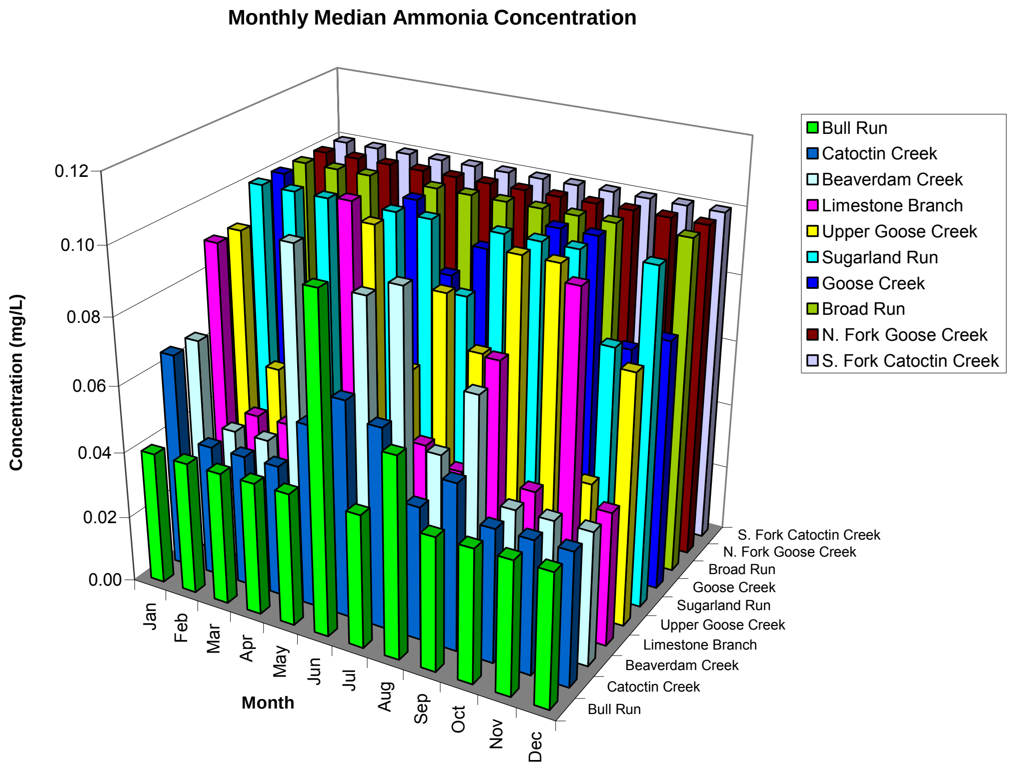
FIGURE 4-13
Monthly Median Nitrate by Monitoring Station




## Ammonia

Another nitrogen compound of interest is ammonia ($NH_3$). The water quality standard for ammonia varies with pH. A neutral pH (7.00) has a standard of 36.1 mg/L. The concentration decreases as pH increases. Thus, a pH of 7.5 has a water quality standard of 19.9 mg/L and a pH of 6.5 has a standard of 48.8 mg/L. Most stations had monthly averages in the 0.0–0.2 mg/L range, while two were in the 0.2–0.5 mg/L range. Monthly medians had a range of 0.04 to 0.1 mg/L. There were no identifiable seasonal variations. Additionally, there were no water quality standards exceedances.

FIGURE 4-14
Monthly Median Ammonia By Monitoring Station




## Alkalinity

Alkalinity is the measure of the buffering capacity of a water body. Its concentration is expressed as mg/L of calcium carbonate ($CaCO_3$). There are no water quality standards for alkalinity in Virginia. Average and median monthly values tend to be lower in the January–April period and then increase through the summer. Figure 4-15 displays the monthly medians for the 10 monitoring stations.

## Total Organic Carbon

Total organic carbon is the measure of the biologically available carbon. Virginia does not have a water quality standard for total organic carbon. The analysis shows that many stations' monthly averages seem to peak in February, decline through April, and then increase, peaking once again in the summer and early fall. Monthly averages fell into the 4-8 mg/L range while monthly medians fell into the 2–8 mg/L range. As can be seen in Figure 4-16, the medians were highly variable with no clear seasonal trends.

FIGURE 4-15
Monthly Median Alkalinity by Monitoring Station

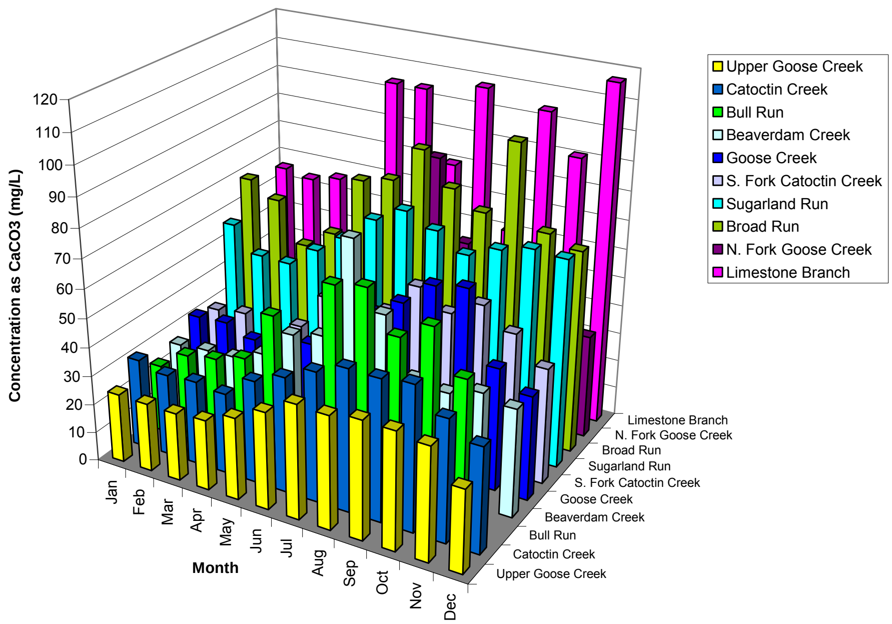
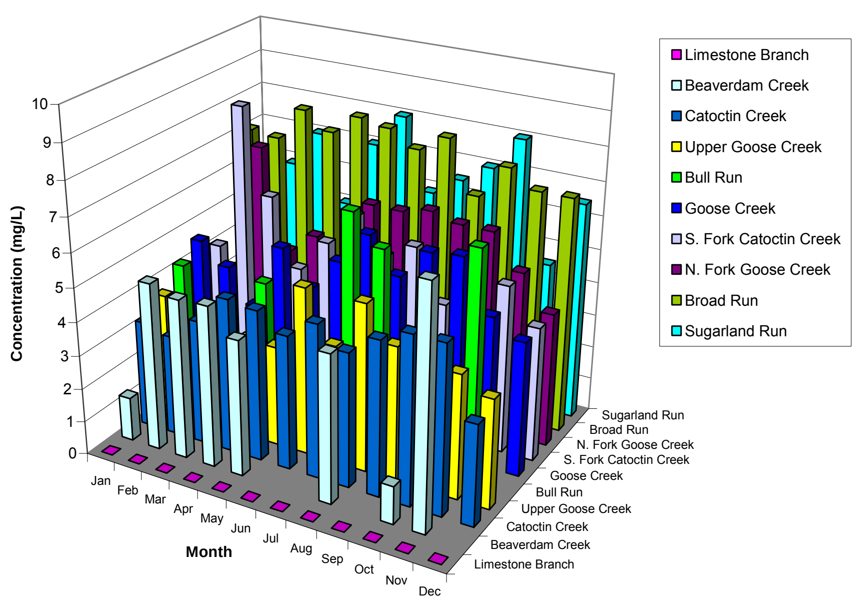


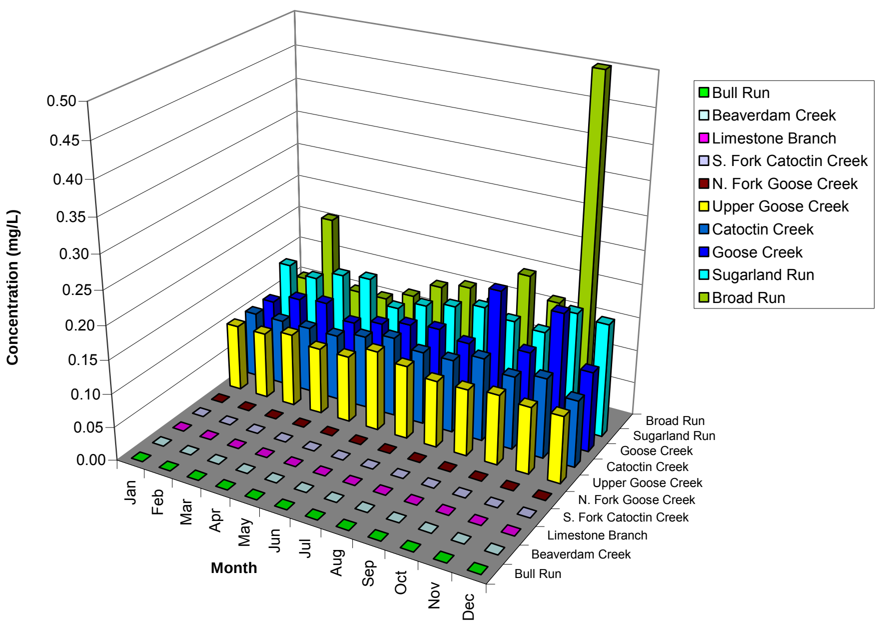

FIGURE 4-16
Monthly Median Total Organic Carbon by Monitoring Station



## Fluoride

Fluoride is a chemical that is more commonly found in groundwater than in surface waters. There is no water quality standard for fluoride, but there is a secondary maximum contaminant level (SMCL) of 2 mg/L. The SMCL only applies to treated water. Compared to other parameters, fluoride has a limited number of data points. For the most part, the sampling appears limited to quarterly monitoring in the 1990–91 period. As can be seen in Figure 4-17, not every station or month has been sampled. Sample counts were 9 to 12 total samples per station for those stations sampled.

FIGURE 4-17
Monthly Median Fluoride by Monitoring Station




## Sulfate

Sulfate ($SO_4$) in surface waters can be the result of groundwater and surface water interaction. Virginia does not currently have a water quality standard for $SO_4$. Monthly averages of sulfate typically were in the 10–30 mg/L range and monthly medians in the 10–20 mg/L range. A weak seasonal variation similar to that of chloride was observed for many sites. The variation is noted by high values in the winter followed by a decline from April to November followed by an increase in December.

## Specific Conductance

Specific conductance is an indirect measure of the total dissolved solids in a water sample. Virginia does not have a water quality standard for specific conductance. Monthly median values typically are higher in the built up watersheds (Sugarland Run and Broad Run), implying a connection to impervious cover. Monthly median values are in the range of 250 to 350 micromhos, as compared to the other 8 watersheds, which have monthly median values in the range of 125 to 250 micromhos.

FIGURE 4-18
Monthly Median Sulfate by Monitoring Station

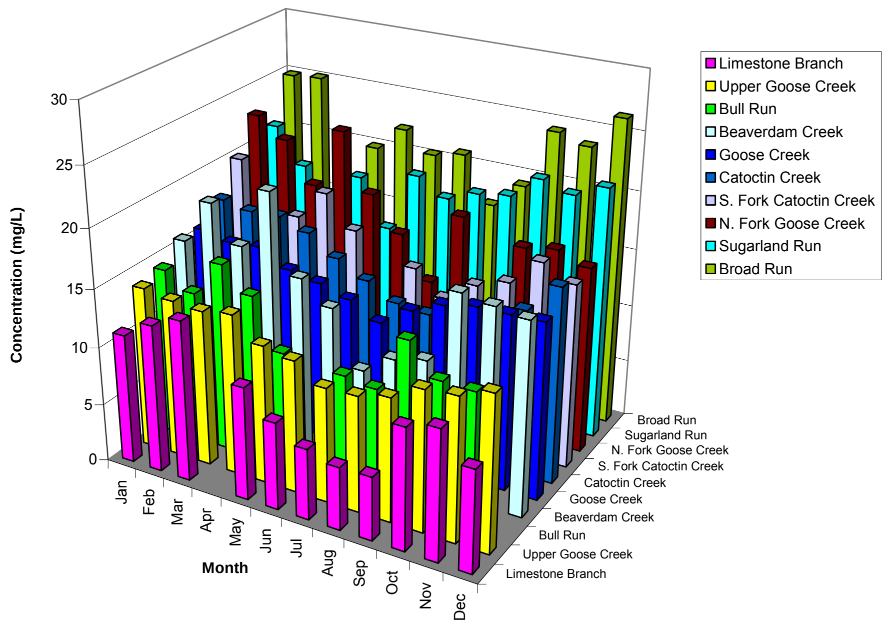
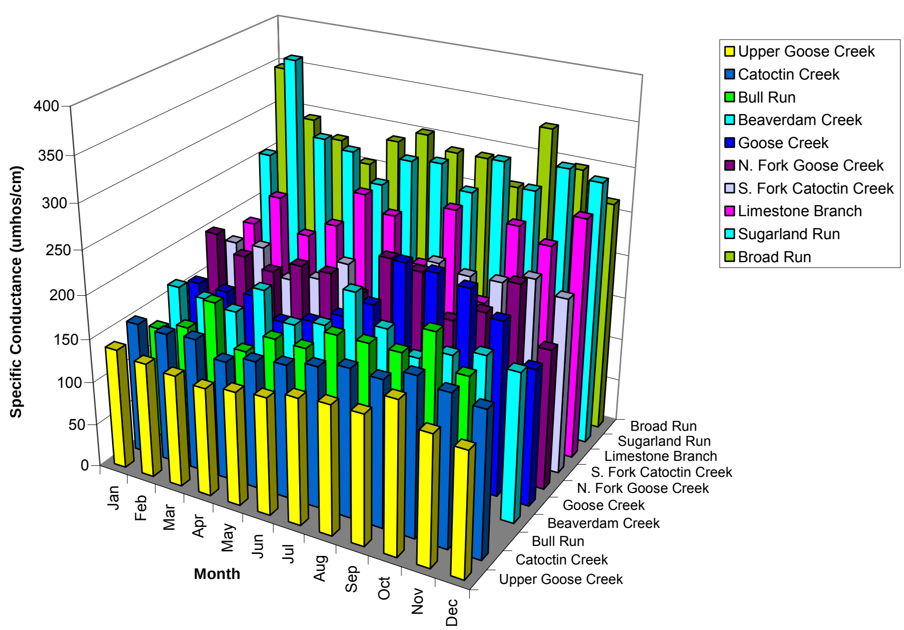


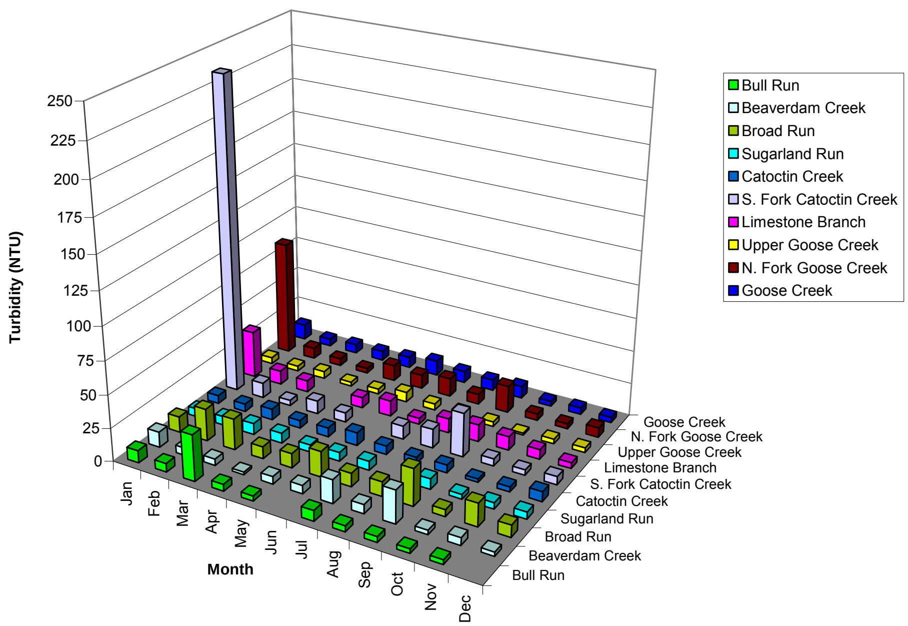

FIGURE 4-19
Monthly Median Specific Conductance by Monitoring Station



## Turbidity

Turbidity is the measure of the amount of suspended particles in a water sample and their ability to scatter light. It is not a measure of total suspended solids. Virginia does not have a water quality standard for turbidity. As with the fluoride data, the turbidity data consist of a limited number of data points, 9 to 12 samples per station. Not every month was represented by the data, and many months were represented by only two data points. This lack of data precludes extensive statistical analysis. Figure 4-20 is included as reference only.

FIGURE 4-20
Monthly Median Turbidity by Monitoring Station




## Chemical Oxygen Demand

Chemical oxygen demand is the measure of the amount of oxygen consumption exerted during the degradation of organic matter by chemical processes. Virginia does not have a water quality standard for chemical oxygen demand. The monthly median values were in the range of 5 to 25 mg/L with higher values clustering around the more developed watersheds, such as Broad Run, Sugarland Run, and Bull Run (see Figure 4-21).

## Biochemical Oxygen Demand

Biochemical oxygen demand is the measure of the amount of oxygen consumption exerted during the degradation of organic matter by microorganisms. Virginia does not have a water quality standard for BOD. The monthly median values were in the range of 1 to 4 mg/L (see Figure 4-22). No seasonal variations were detected.

FIGURE 4-21
Monthly Median Chemical Oxygen Demand by Monitoring Station

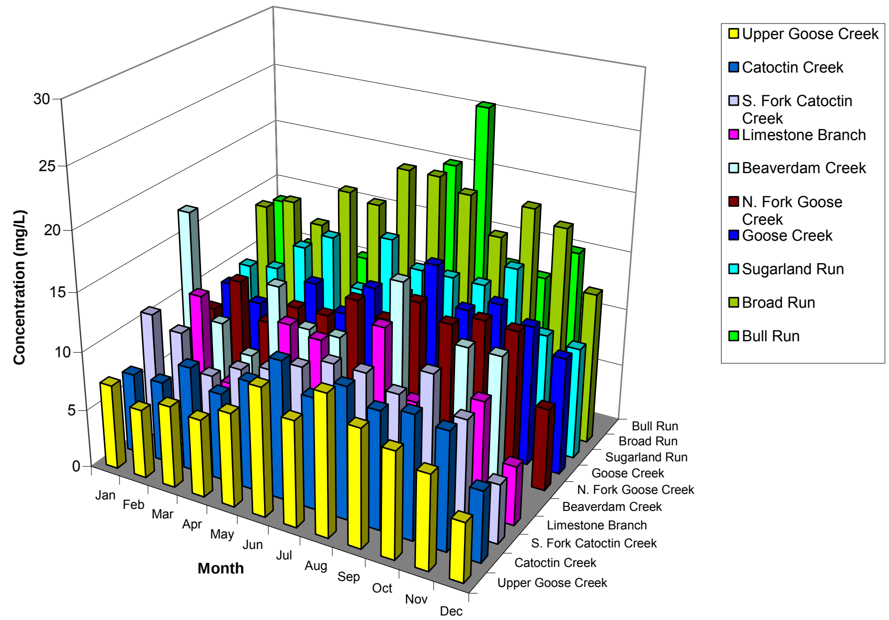



FIGURE 4-22
Monthly Median Biochemical Oxygen Demand by Monitoring Station

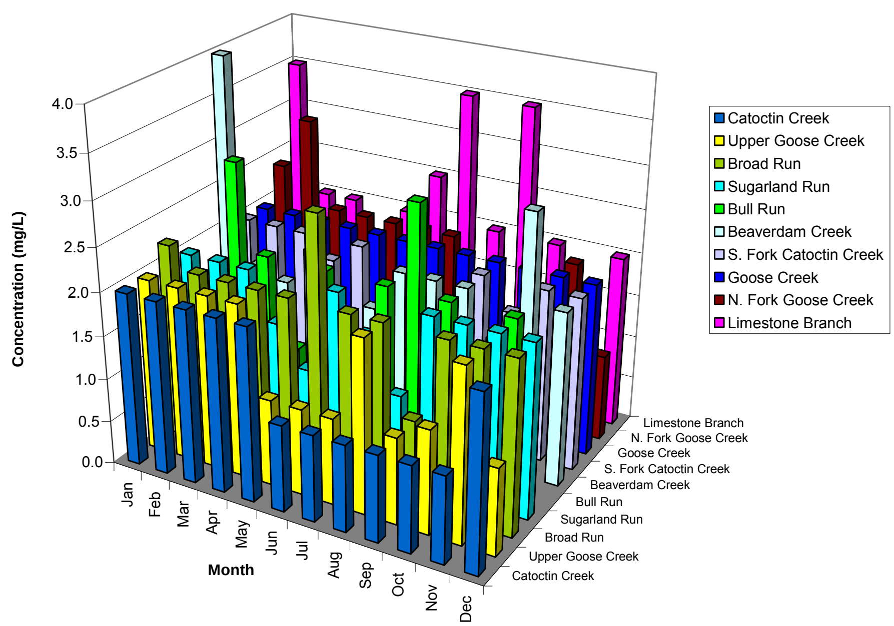



Table 4-7 is a summary of all of the analysis for the water quality data.

TABLE 4-7
Water Quality Data Analysis Summary

| Parameter | Units | Water Quality Standard | Range of Monthly Medians | Number of Violations | Trends and Notes |
|---|---|---|---|---|---|
| Total Phosphorus | mg/L | 0.37* | 0.02 - 0.20 | 0 | |
| Nitrate ($NO_3$) | mg/L | 10** | 0.04 - 2.64 | 1 | Low level Nitrate increase in summer in Limestone Branch |
| Ammonia ($NH_2$) | mg/L | 36.1 @ pH 7 | 0.04 - 0.11 | 0 | |
| Alkalinity | mg/L as $CaCO_3$ | N/A | 24 - 117 | N/A | Lower in winter, Higher in summer |
| pH (Field) | units | <6 and 9< | 6.5 - 8.0 | 19 and 27 | Lab data disregarded based on conversation with DEQ. |
| Total Organic Carbon (TOC) | mg/L | N/A | 1.1 - 8.5 | N/A | Several stations higher in February and summer months. |
| Fluoride (Fl) | mg/L | SMCL = 2 | 0.1 - 0.5 | N/A | Limited data. |
| Chloride (Cl) | mg/L | 230 | 2 - 52 | 1 | Sugarland Run and Broad Run higher in winter |
| Sulfate ($SO_4$) | mg/L | N/A | 2 - 26 | N/A | Weak seasonal variation similar to Cl. |
| Specific Conductance | µmhos/cm | N/A | 125 - 373 | N/A | Sugarland Run and Broad Run 250-350, others 125-250 |
| Turbidity | NTU | N/A | 1.5 - 236 | N/A | Limited data. |
| Fecal Coliform | CFU/100mL | 200 (Monthly GM), 400 Single Sample | 81 - 9171 | 13, 561 | Summer Spikes. Many violations, even for monthly medians |
| E. Coli | CFU/100mL | 126 Monthly GM, 235 Single Sample | 25 - 1150 | N/A, 49 | Relatively New Water Quality Standard. Limited Data Points |
| Biochemical Oxygen Demand (BOD) | mg/L | N/A | 1 - 4 | N/A | |
| Chemical Oxygen Demand (COD) | Mg/L | N/A | 5 - 25 | N/A | |

* and ** not referenced

### 4.3.3 Rainfall–Water Quality Comparison

To assess the impact of rainfall on water quality the rainfall record was compared against the turbidity data from two watersheds. Turbidity was selected assuming that it would be responsive to changes in flow. Beaverdam Creek and Broad Run were selected as the test watersheds because of their different impervious values and different locations in the County. Beaverdam Creek is located in the undeveloped western section of the County that is 3 percent impervious. Broad Run is within the more heavily developed eastern part of the County and is 16 percent impervious.

Rain gage selection for the two monitoring stations was based on the Theissen polygons provided by the NWS. Daily rainfall totals corresponding to the sample dates were plotted versus the turbidity values (see Figures 4-23 and 4-24). The results show that neither dataset had good correlation between daily rainfall and turbidity. Beaverdam Creek's slightly better correlation may have more to do with 3 days with rainfall greater than 1 inch than with imperviousness values.

The poor correlation can be attributed to the sample methodology employed by DEQ. DEQ's sampling goal was to take monthly samples at the two locations to develop a long-term monitoring record, but samples were not taken in conjunction with precipitation events. Indeed, many were probably taken prior to the rainfall or long enough after to not reveal the impacts on the two streams. Since the field screening did not show any trends that were worth pursuing in detail, further analysis was not conducted.

FIGURE 4-23
Broad Run Daily Rainfall and Turbidity

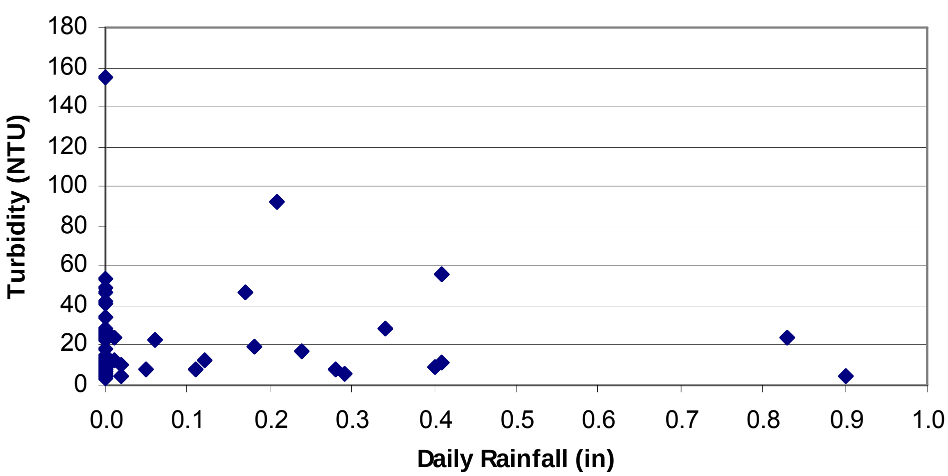
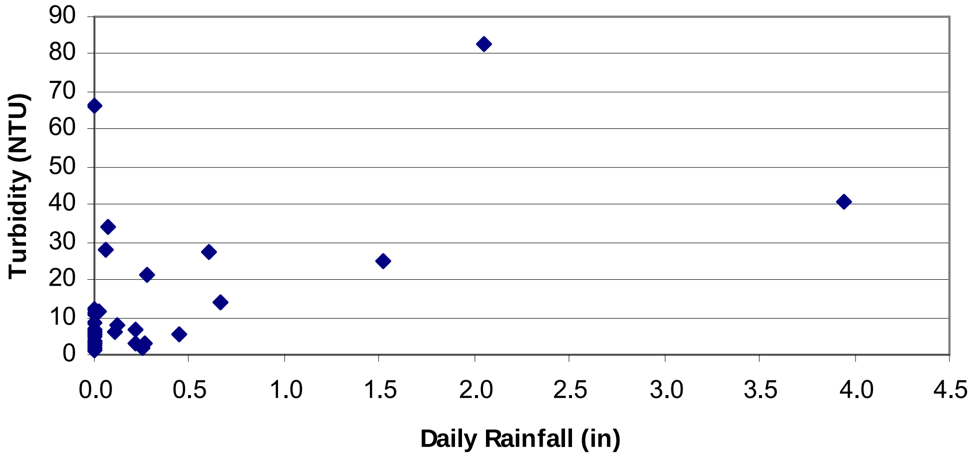


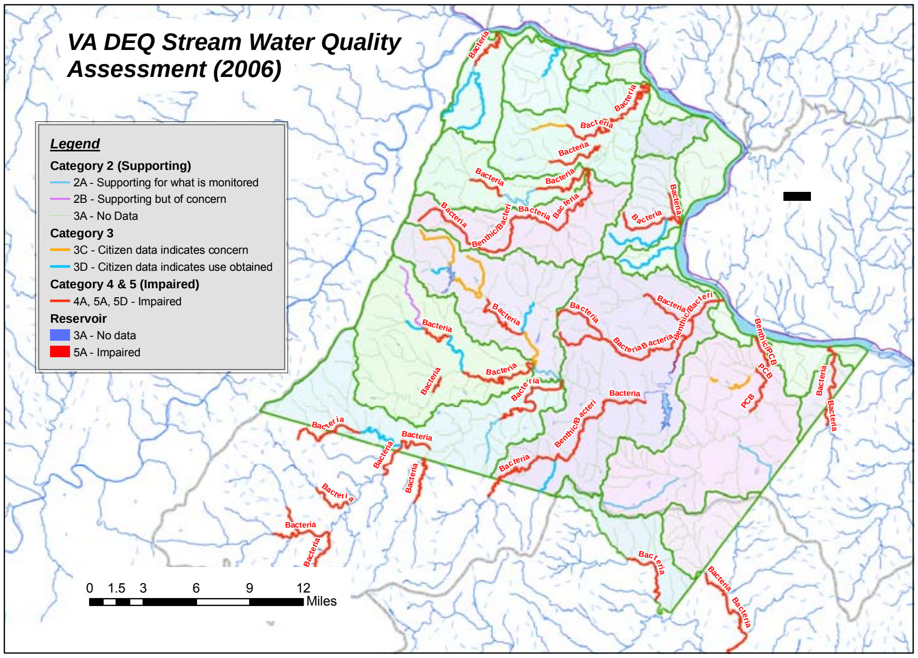
FIGURE 4-24
Beaverdam Creek Daily Rainfall and Turbidity




### 4.3.4 Loudoun County Streams Listed as Impaired

An important part of the DEQ's water quality monitoring process is to determine whether a water body is impaired and should be listed on Virginia's biannual 303(d) list. Inclusion on the 303(d) list generally means that a TMDL will be required to determine the sources of the impairment, their relative contributions, and the reductions to eliminate the impairment. Figure 4-25 shows the impaired waters based on the 2006 list submitted by DEQ and approved by the EPA. This list is not based on the separate data analysis described above but on DEQ's conclusions. Those streams that are listed as complete have an approved TMDL. Those listed as required are scheduled to have a TMDL subsequent to 2006. The "multiple" qualifier indicates that a TMDL is pending for multiple pollutants.

FIGURE 4-25
Streams Classified as Impaired by Virginia DEQ




Over the past few years DEQ has prepared several TMDL reports for streams in Loudoun County, mostly due to bacterial impairments. In response to a consent decree, DEQ has aggressively been preparing TMDL's' throughout the state. Table 4-8 summarizes the TMDLs that have been completed and approved for waters in Loudoun County.

TABLE 4-8
Approved TMDLs in Loudoun County

| TMDL Project | Watershed ID | Pollutant(s) | EPA Approval Date | SWCB Approval Date |
|---|---|---|---|---|
| Catoctin Creek | A02R | Fecal Coliform | 5/31/2002 | 6/17/2004 |
| Goose Creek and Little River | A08R | Sediment | 4/26/2004 | 8/31/2004 |
| Goose Creek | A04R, A05R, A06R, A07R, A08R | Fecal Coliform | 5/1/2003 | 6/17/2004 |
| Limestone Branch | A03R | E. Coli | 7/6/2004 | 12/2/2004 |
| Piney Run | A01R | E. Coli | 7/6/2004 | 12/2/2004 |

The five TMDL reports include: Catoctin Creek Bacteria (2002), Goose Creek Watershed Bacteria (2003), Limestone Branch Bacteria (2004), Piney Run Bacteria (2004), and Goose Creek and Little River Benthic (2004).

Each report is highly detailed and includes waste load modeling using a deterministic stream flow and waste load model or a statistical analysis of water quality data. In some TMDL reports, additional field work and stream monitoring data are included.

The Catoctin Creek TMDL study was followed with an Implementation Plan (IP). The creek was first listed as impaired in 1996. The final TMDL was published in 2002. The Catoctin Creek IP includes implementation of the agricultural component of the Catoctin Creek TMDL and is being funded annually with 319 Grant funds from DCR to LSWCD to work specifically with landowners in the Catoctin Creek watershed. Landowners in this watershed are provided financial and technical assistance for the installation of targeted agricultural BMPs, and education programs that encourage landowners to exclude livestock access to Catoctin Creek and its tributaries. The LSWCD is now entering their second five-year grant with DCR to continue these efforts. To date, approximately $79,000 of cost share money has been used on 22 properties within the watershed.

Grant funding is available for the correction of fecal coliform contributions from both livestock and failing onsite wastewater treatment systems. The U.S. Environmental Protection Agency (EPA) with the Virginia Department of Conservation and Recreation (DCR) provides grant money to homeowners to pay for a percent of repairs and upgrades to existing individual wastewater systems, the program is administered locally by the Loudoun County Department of Health. A total of 20 systems have been repaired or upgraded in the watershed to date using approximately $165,000 in grant monies.

SECTION 5

# Wells and Groundwater Quantity

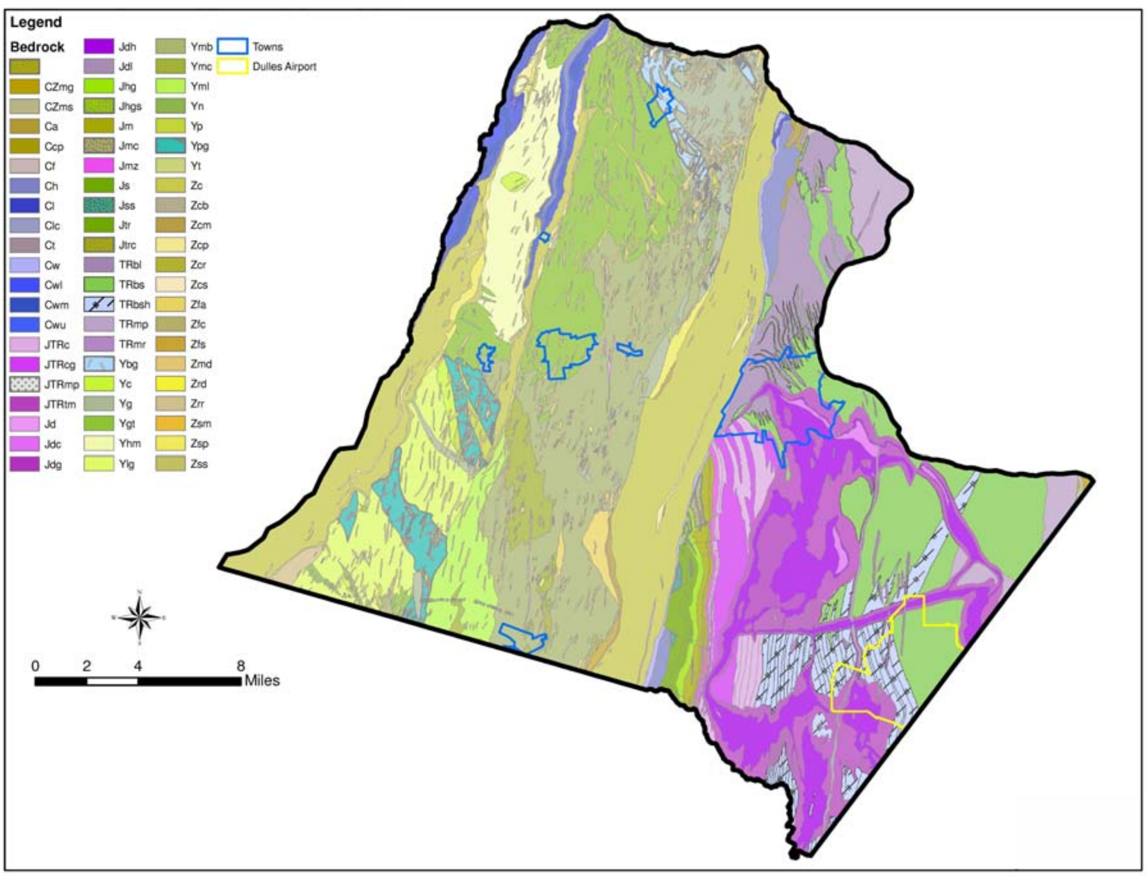
## 5.1 Geology

The watershed management investigation into the geology of Loudoun County, Virginia (Figure 5-1) was governed by three goals:

- To assess the diversity of subsurface conditions
- To compare physical characteristics between watersheds
- To evaluate the spatial distribution of transmissivity across the County

Investigation of these goals was important for evaluating the capacity of watersheds, and subwatersheds in supplying groundwater to residents of the County. The lithology and chemical composition of the soils and rocks underlying the County strongly influence variations in groundwater quality.

FIGURE 5-1
Geologic Map of Loudoun County



### 5.1.1 Unconsolidated Deposits

Examination of data included in more than 18,000 well records provides a detailed look at the depth at which bedrock was encountered in each well boring throughout Loudoun County. In the northeastern part of the U.S., saturated unconsolidated deposits overlying bedrock can represent significant aquifers provided sufficient thickness of permeable sands and gravel are present.

Most of Loudoun County is underlain by a relatively thin layer of regolith ranging from 0 to 25 feet below grade. The material usually is composed of fine-grained silts, clays and saprolite. Saprolite is a soft, decomposed rock rich in clay. When cross-referencing the depth to bedrock and the water table, the water table depth appears to occur at or slightly above the elevation of the top of bedrock. Thus, most of the deposits are unsaturated yet still are considered to be an aquifer for sustaining even low capacity (less than 10 gallon per minute) wells.

A relatively continuous area of unconsolidated material with a thickness ranging from 25 to 50 feet extends roughly north-south through the Catoctin Creek (North and South Forks), Limestone Branch, and Lower Goose Creek watersheds in the central part of the County. The deposits appear to have accumulated along the base of valleys. Within this extended body which appears to mark buried valley–type deposits some areas range over 50 feet thick.

Figure 5-2 is a depiction of the deposit thickness derived from bedrock depth data. Locations with the thickest overburden depth include areas south of Leesburg and just east of the Bull Run Fault.

### 5.1.2 Bedrock

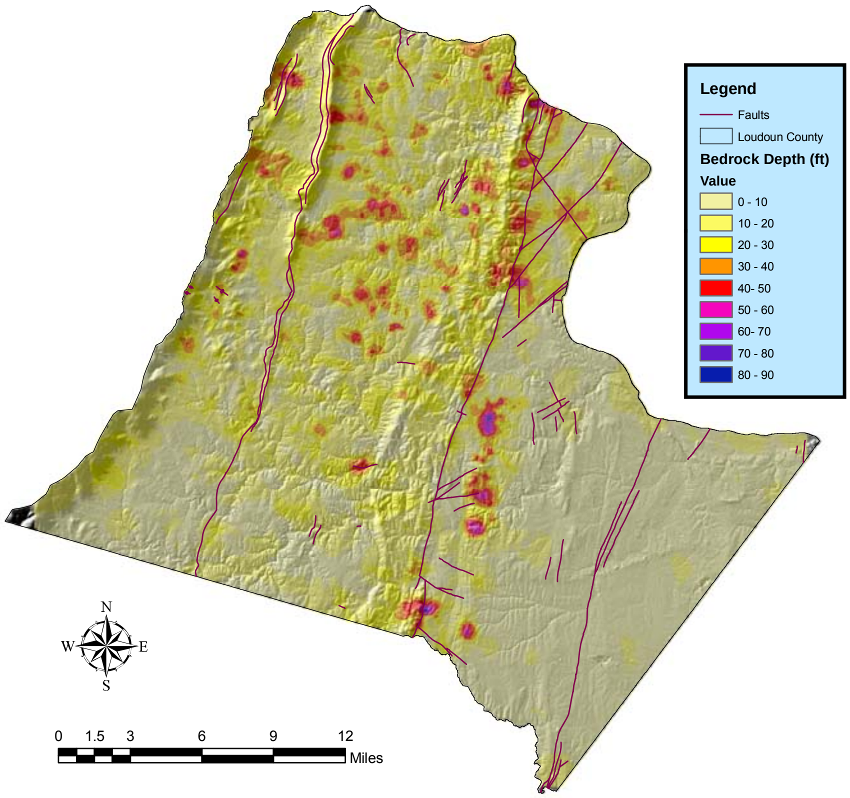
Loudoun County can be separated into two primary rock groups based on the age of formation and time of deformation: the Blue Ridge Province and the Early Mesozoic Culpeper Basin (Southworth et al., 1999). The Blue Ridge Province is found in the western half of the County; the Mesozoic Basin (also known as the Triassic Basin) lies in the eastern half (Figure 5-3). The Blue Ridge Province and Culpeper Basin are separated by the Bull Run Fault, a major normal/oblique fall system generally oriented north to south.

#### Blue Ridge Province

The western half of Loudoun County comprises a wide variety of rock types. These units can be metasedimentary in origin, such as a marble, metagreywacke, and meta-arkose. Igneous rocks such as diabase and granite are present in plutons, along with metamorphosed igneous rocks as metagranite and phyllite. Rock units typically strike north-south. The section is shortened by an extensive number of northeast trending fold axes and northeast striking faults.

The Blue Ridge Province features rocks of ages that range from the Late Pre-Cambrian to the Jurassic. In the Blue Ridge Province, Jurassic rocks consist of diabase dikes associated with Jurassic age deformation in the Culpeper Basin. Excluding the dikes, the youngest rocks in the Blue Ridge Province of Loudoun County are Cambrian.

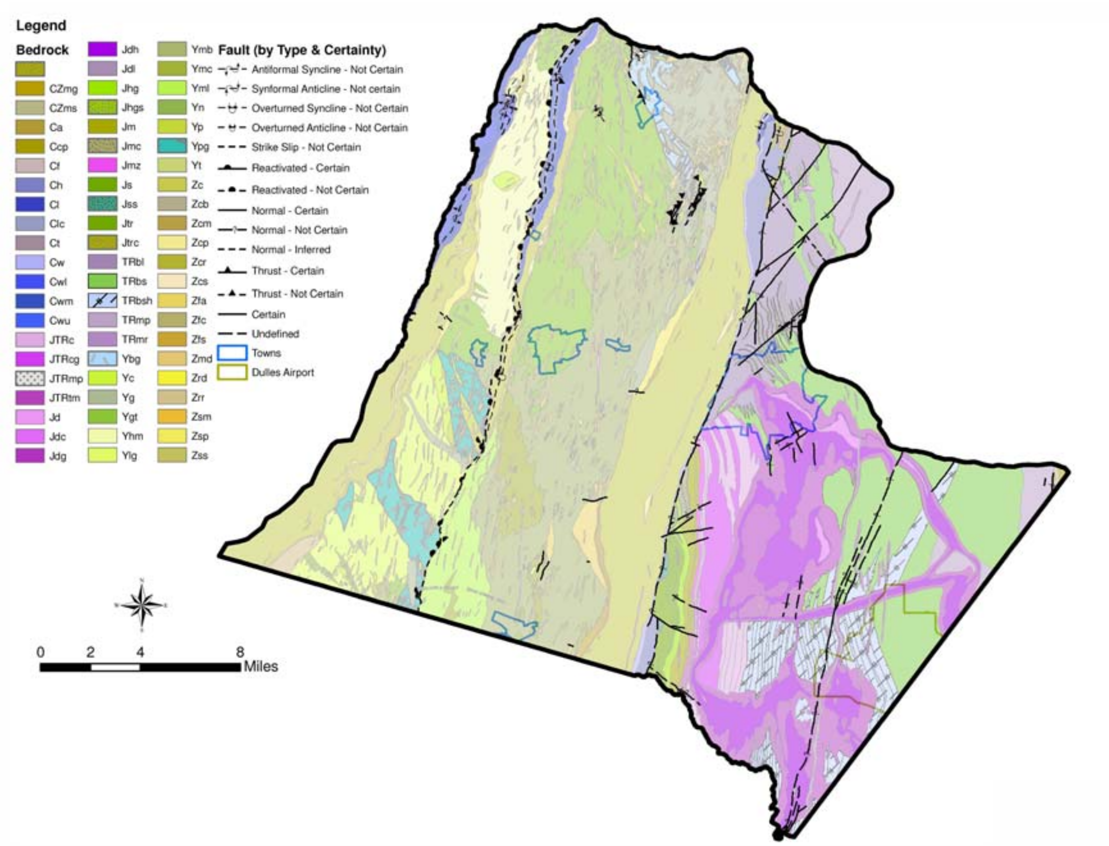
FIGURE 5-2
Loudoun County Bedrock Depth




Igneous and metamorphic rocks of the Blue Ridge Province are crystalline and exhibit low primary porosity. Water migrates through these rocks in secondary porosity features, such as fracture fabrics caused by cleavage, joints, and faults. Rocks of the Blue Ridge Province exhibit minimal storage.

The structures of the Blue Ridge Province originate from compressive tectonism following the Cambrian and the emplacement of dikes during the genesis of the Culpeper Basin (Figure 5-2). The section in the Blue Province is shortened by folding and thrust faults. Deformation was pervasive, and rock groups can be allocthonous and autocthonous, with displacement along major fault systems. Unlike the rocks of the Culpeper Basin the crystalline rocks of the Blue Ridge province are relatively resistant to weathering. Thus, fracture systems are not subject to widening, or to lengthening by chemical dissolution.

FIGURE 5-3
Structural Map of Loudoun County




## Culpeper Basin

Rocks comprising the Culpeper Basin, which lies in the eastern half of the County, are primarily Triassic and Jurassic in age. Rocks of the Culpeper Basin are part of the Newark Supergroup, which extends from Massachusetts southeastward into Georgia. These rocks define the rifting of North America and northwestern Africa. Most rocks are sedimentary in origin and were deposited in a series of basins where beds tilt to the northwest. Among the sedimentary rock units are shales, conglomerates, siltstones, and sandstones. Conglomerates, including units containing large limestone clasts, lie adjacent to the Bull Run Fault and mark periods of major vertical movement along the fault. Lacrustrine limestones are also encountered east of the Bull Run fault.

Igneous rocks are also present in the basin in diabase dikes, sills, laccoliths, phacoliths, and basaltic extrusive flows. Intrusive rocks are comprised of massive diabase, while extrusive rocks are basalt. Some of the diabase units are large, occurring as conformable sills or cross cutting the section. Thin diabase dikes occur throughout the basin and extend into the Blue Ridge Province.

Similar to rocks of the Blue Ridge Province, rocks of the Culpeper Basin exhibit low primary porosity. However, the younger rocks contain more labile components, particularly carbonate units. Thus, rocks are subject to dissolution along the fracture surfaces causing widening, lengthening, and more pervasive networking of fracture systems. As a result, the rocks can transmit and store larger amounts of water. Wells installed in the sedimentary rocks of the Culpeper Basin exhibit greater yields than wells in the Blue Ridge Province.

Most of the sedimentary units in the Culpeper Basin strike to the northeast or north. Rocks of the Triassic Basin strike from N. 15° W. to N. 45° E. The rocks dip to the west or northwest from 0° to 45° (Roberts, 1928) toward the basin-bounding Bull Run fault. Total thickness of the section within the basin is estimated to be 1,000 to 1,500 feet. Intrusive diabase dikes, sills, and extensive normal faulting extend throughout the section in the basin.

## 5.2 Hydrogeology

A review of well records and aquifer testing from County databases was conducted to analyze various aspects of ground water wells and subsurface conditions. Some of the analysis was conducted with data organized by the County by watershed.

### 5.2.1 Water Levels

Static water levels measured at the time of well installation were analyzed by watershed by developing box-and-whisker diagrams. Water levels in the County typically range from 5 to 40 feet below grade, with an average around 25 feet. Outliers fall anywhere from the ground surface (0 feet below grade) to a depth of 182 feet below grade. No significant variations in the average water level depth were observed between watersheds. No data were available for the Cub Run and Sugarland Run watersheds.

Figure 5-4 depicts water levels over time. Data are from new wells drilled as part of the hydrostudy requirement. Data are the result of collection just prior to aquifer testing and are thus limited to unique snapshots of water levels over time. Figure 5-5 depicts the same waterlevels by watershed.

FIGURE 5-4
Water Level Distribution by Year

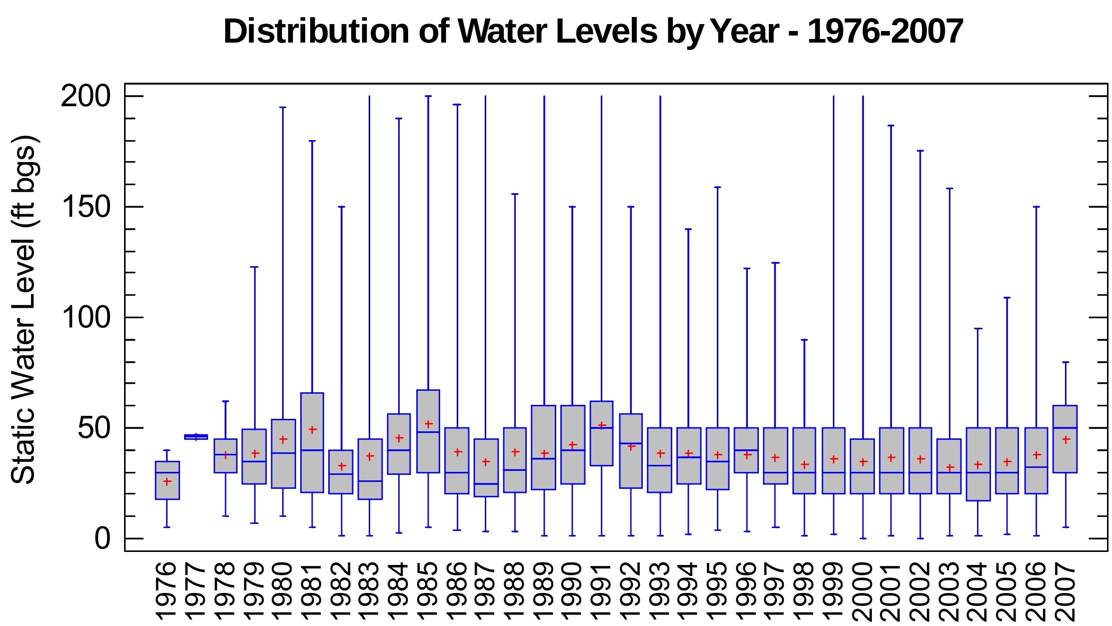
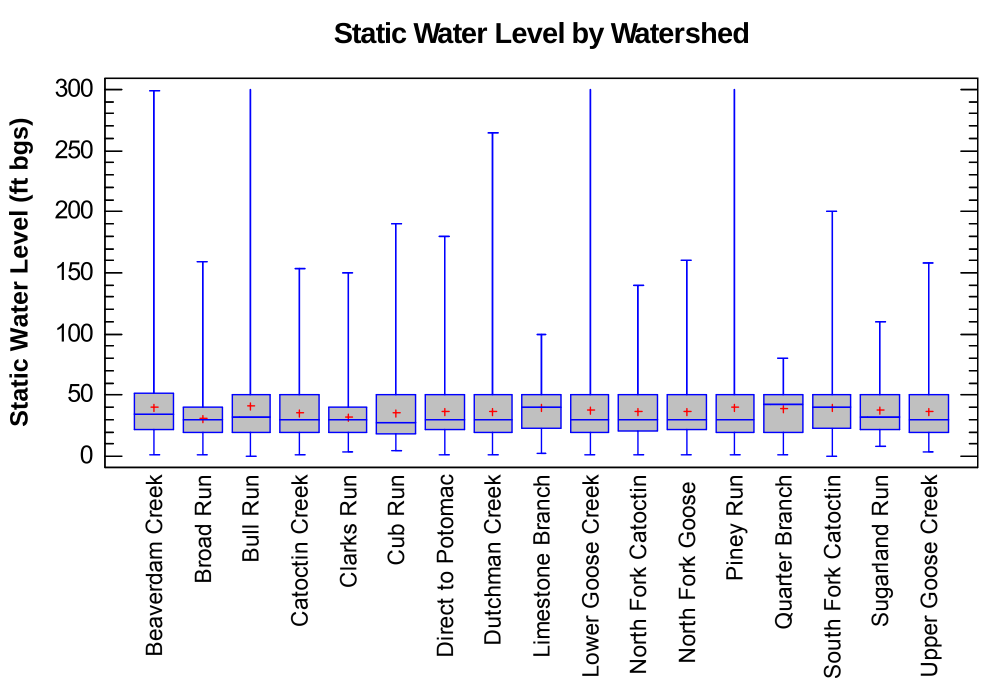



FIGURE 5-5
Distribution of Static Water Levels in Wells at the Time of Installation



Hydrographs of water level depths with time are also available from six to nine wells in the County. The period of record for the wells spans from 2005 through 2007. Water levels are around 25 feet below grade. Unlike many bedrock terrains where fluctuating water levels range tens of feet annually, defining a low storage matrix, water levels in the observation wells in Loudoun County were comparatively stable. Seasonal water levels ranged only 2 to 3 feet. Water levels were highest in the spring and lowest during late summer and early fall. No overall increasing or decreasing trends were observed over the period of record. Figure 5-6 shows the locations of the monitoring wells. Figure 5-7 depicts the monitoring wells' water level depth hydrographs.

FIGURE 5-6
Locations of Loudoun County Groundwater Monitoring Wells

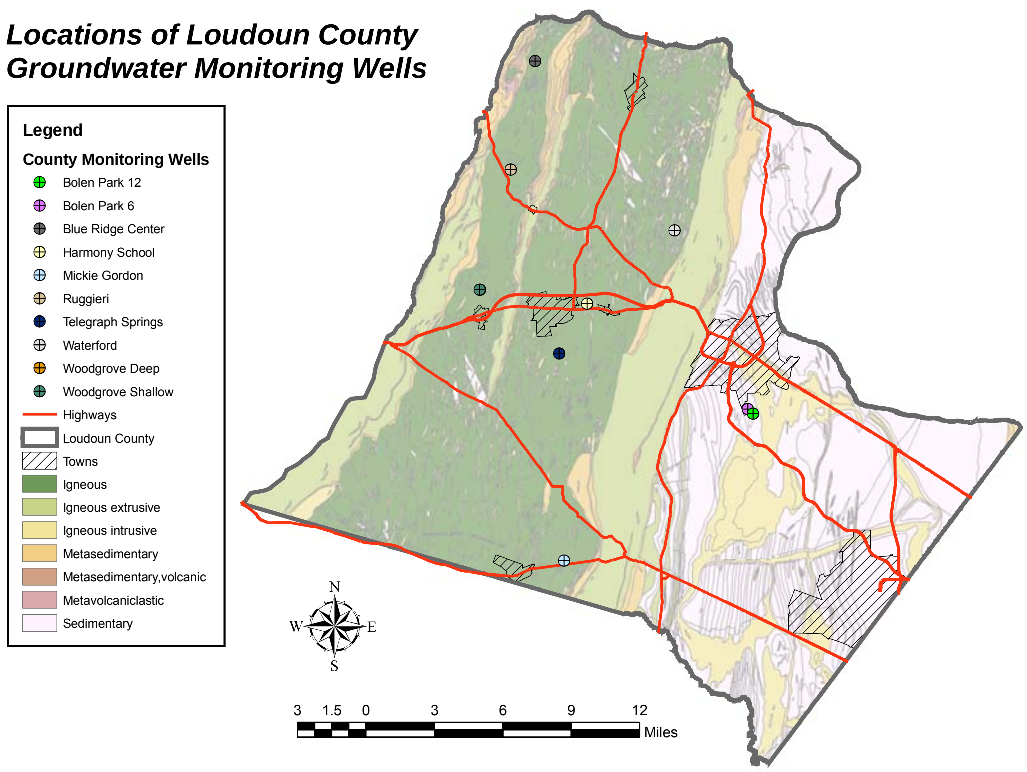
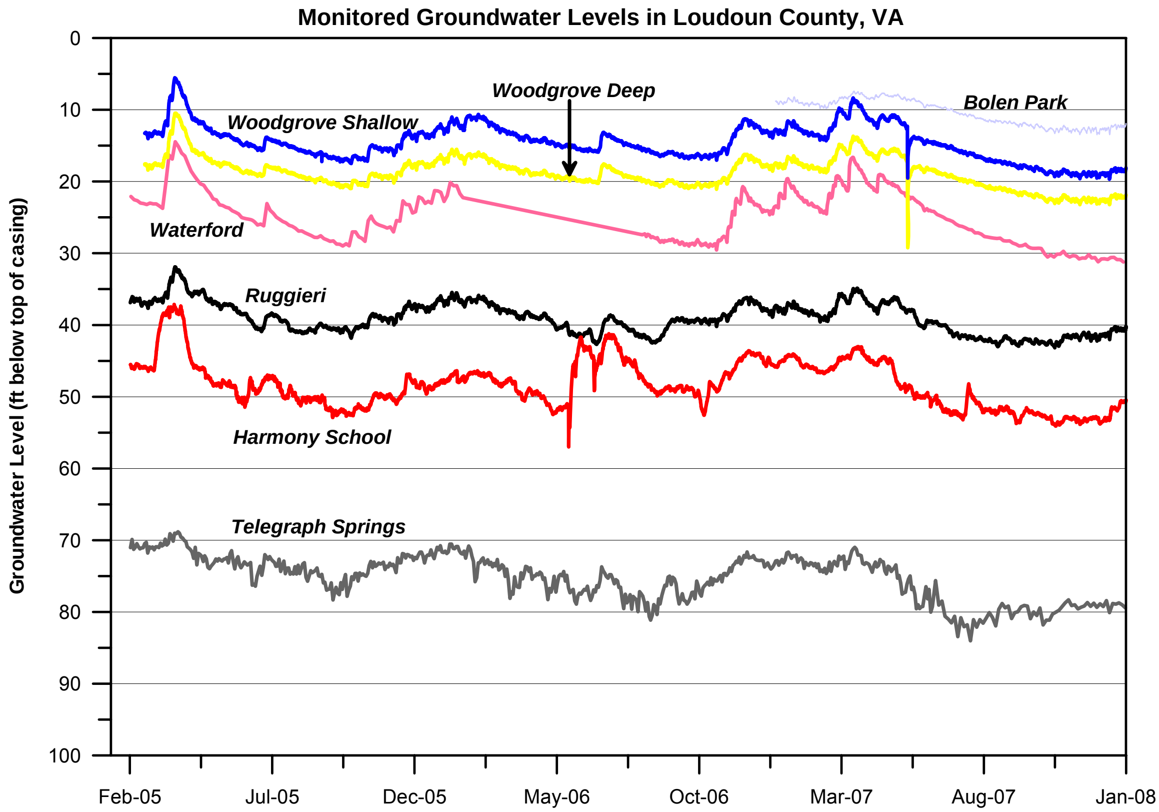


FIGURE 5-7
Hydrographs of Water Level Depths in Six Wells Monitored in the County

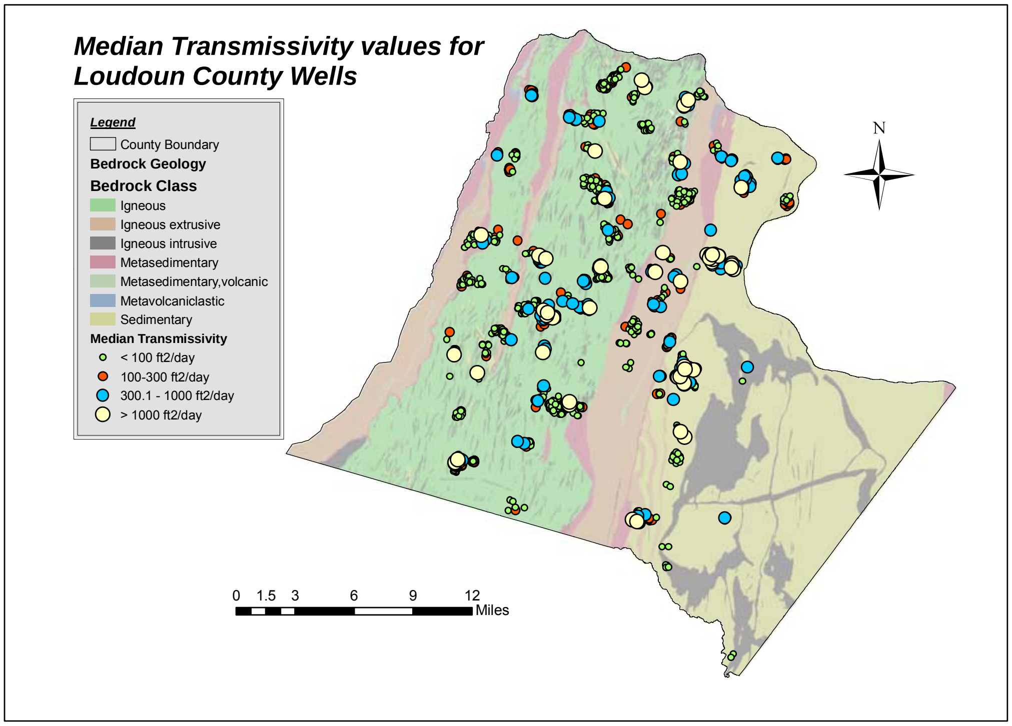



## 5.2.2 Transmissivity

Transmissivity describes the ability of a soil layer or rock formation to transmit water through a specified unit area. Well yields and the velocity of groundwater movement are strongly influenced by the transmissivity of rocks or soils. Transmissivity was mapped across Loudoun County using the Geohydrologic Database compiled from constant and stepped rate pumping tests.

Transmissivity in Loudoun County ranges from less the 250 $ft^2$/day to 8,500 $ft^2$/day (Figure 5-8). Most of the County is underlain by rocks exhibiting relatively low transmissivity (less than 250 ft/day). Areas of higher transmissivity occur east of the Bull Run fault in sedimentary rocks of the Culpeper Basin. The area of highest transmissivity coincides with the location of carbonate rocks. The proximity of other areas near the Bull Run Fault suggests that extensive fracture systems associated with a major fault zone may improve transmissivity of the rock units. However, this relationship has never been positively established.

FIGURE 5-8
Distribution of Aquifer Transmissivity

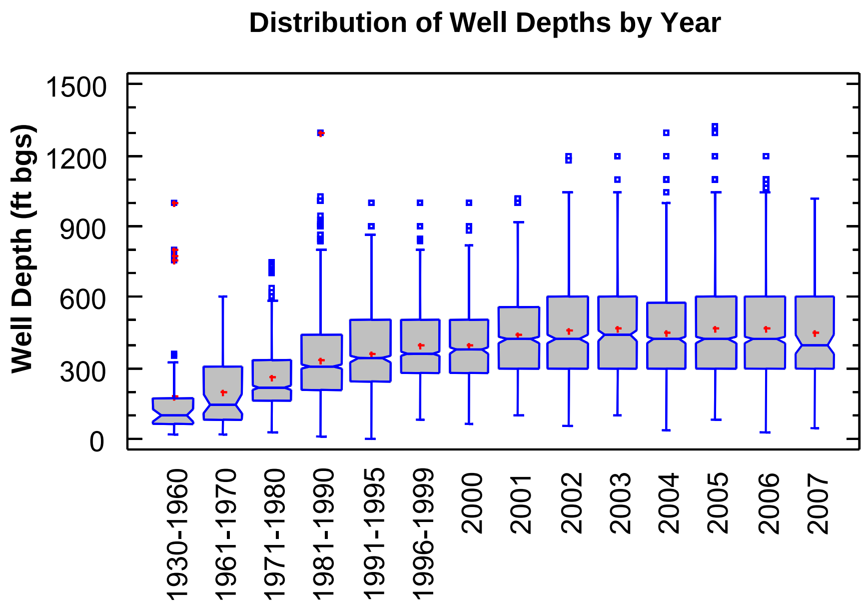



## 5.2.3 Well Characteristics

### Depth

Well depths in the County range from 200 to 600 feet below grade with some mild variation. Outliers extend from 10 to 1,320 feet below grade. Well depths have increased with time since the 1980s (Figure 5-9). The increase in well depths appears related to the advancement of drilling technology. Slower cable tool drilling methods have been replaced by air and mud rotary systems. Thus, wells that formerly required several weeks to drill can be completed within 1 or 2 days. Wells often are drilled deeper to provide owners with greater storage in relatively low-yielding bedrock terrains. Often increases in well depth are attributed to declines in water levels. However, water levels have not declined in Loudoun County.

FIGURE 5-9
Variation of Well Depth in Time




## Yield

Well yields were consistent among all watersheds with one exception (Figure 5-10). Most well yields fell into a range of 6 to 20 gallons per minute (gpm) except in the Broad Run watershed, where the rates were several times greater. Well yields in the Broad Run's watershed ranged from 23 to 150 gpm. Similar to the absence of water level data, no data were available for well yields from the Cub Run or Sugarland Run watersheds.

Yields were also grouped according to the rock type in which wells were installed. Most of the wells in the County are installed in some form of igneous rock, with lesser amounts in the sedimentary or metamorphic rocks (Figure 5-11). Well yields vary greatly within each rock type. Wells in igneous and sedimentary rocks exhibit wide ranges, with yields extending from less than 1.0 gpm to over 500 gpm. Yields in metamorphic rocks are more constrained, ranging from less than 1.0 gpm to 150 gpm.

FIGURE 5-10
Distribution of Well Yields

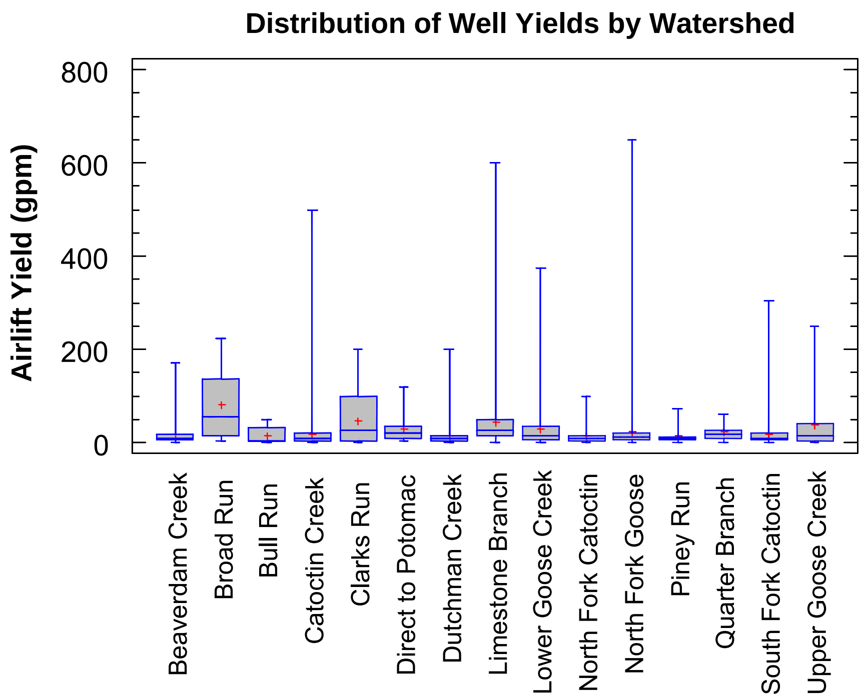
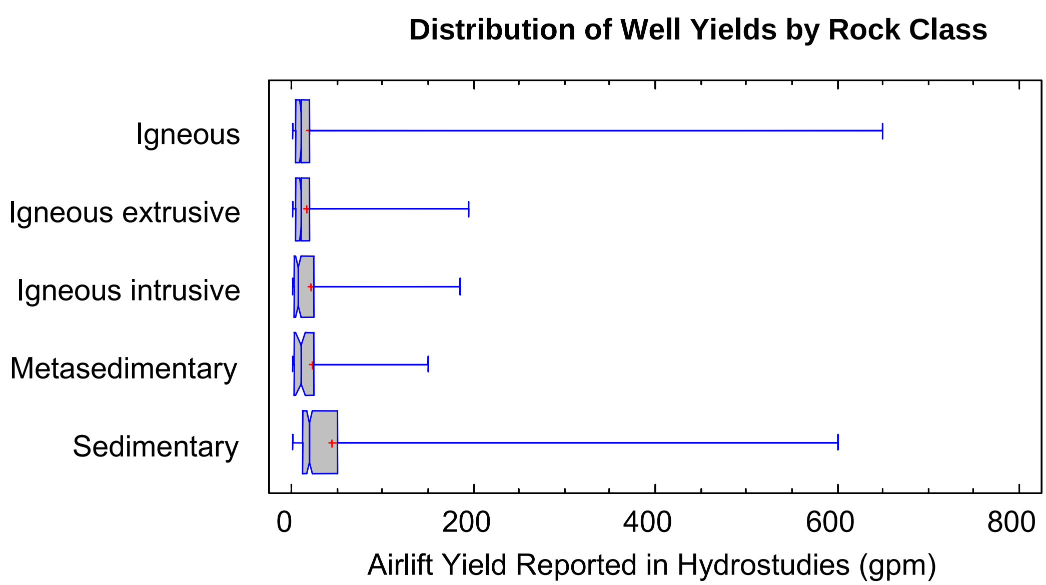



FIGURE 5-11
Distribution of Well Yield by Rock Class



**SECTION 6**

# Wells and Groundwater Quality

As part of the study, groundwater quality data were assessed across the County. The purpose of this component was twofold as:

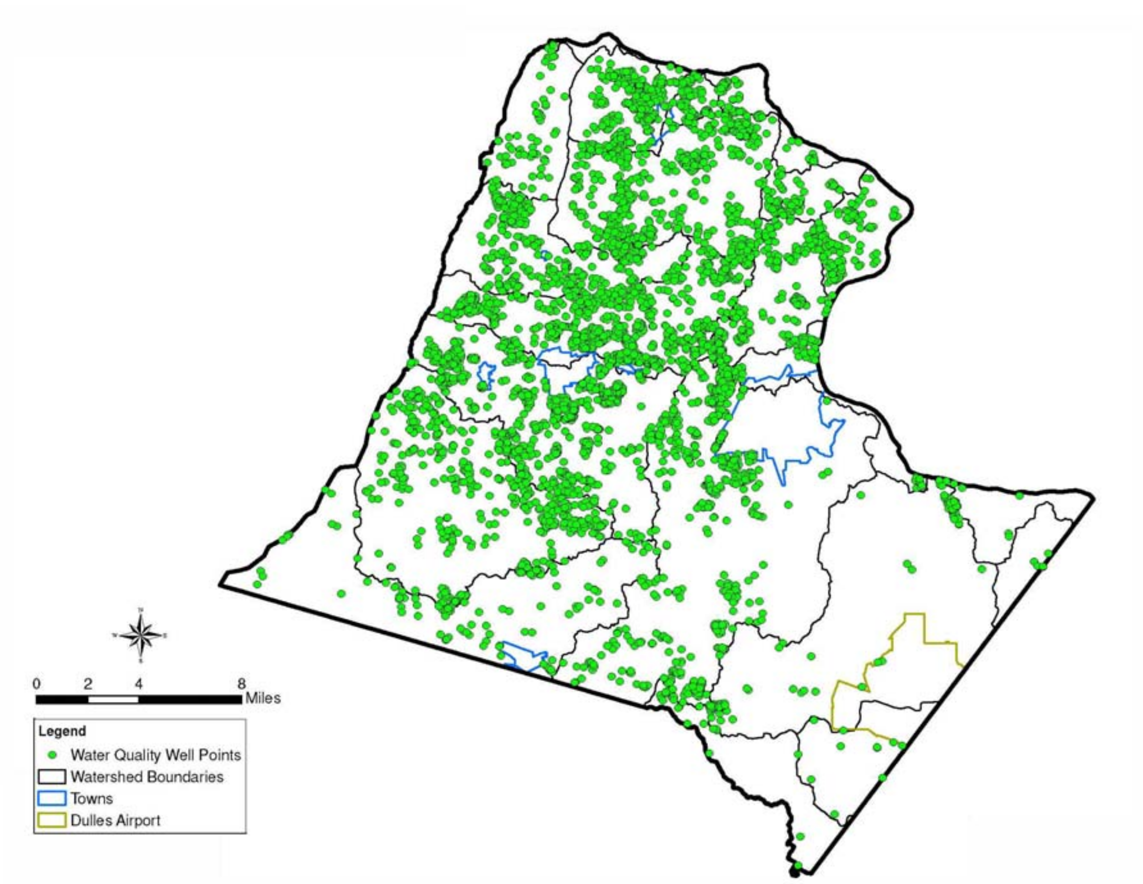
- To assess general water quality and variations across the County
- To examine individual constituent to identify conditions that can most influence quality

The approach to the groundwater quality study focused on variations in bulk water chemistry, rather than targeted anthropogenic pollutants from individual point sources. Several common conditions were examined, including presence of impervious surface, land use, geology, and tectonism, to evaluate their influence on individual chemical constituents.

## 6.1 Available Data

Groundwater quality was assessed from the County's databases maintained by the Building and Development and Health Departments. Water quality analyses were predominantly from initial samples collected at the time of well installation. Although the spatial distribution of wells and data are quite good, temporal (time series) data from individual wells is extremely limited. Data were obtained from two databases. One comprises a limited number of constituents for wells constructed and tested before 2002 (around 2,100 wells). A larger database (2,250 wells; Figure 6-1) containing up to 100 physical and chemical parameters per well was also used. The data provided digitally to Building and Development from National Testing Labs began in 2002.

FIGURE 6-1
Groundwater Quality Sampling Locations




## 6.2 General Quality

Groundwater quality in Loudoun County generally is very good, with a neutral to alkaline pH and, on average, low (less than 200 mg/L) total dissolved solids (TDS) concentrations (Table 6-2). The average cation/anion chemistry consisted of a calcium-bicarbonate type (Figure 6-2), typical of aquifers in contact with fresh recharge from precipitation. The calcium bicarbonate chemistry is remarkably uniform across rock types in the County, with only minor variations toward sodium and sulfate chemistries for individual samples (Building and Development, 2007).

FIGURE 6-2
Piper Diagram Showing Median Analyte Values by Rock Unit

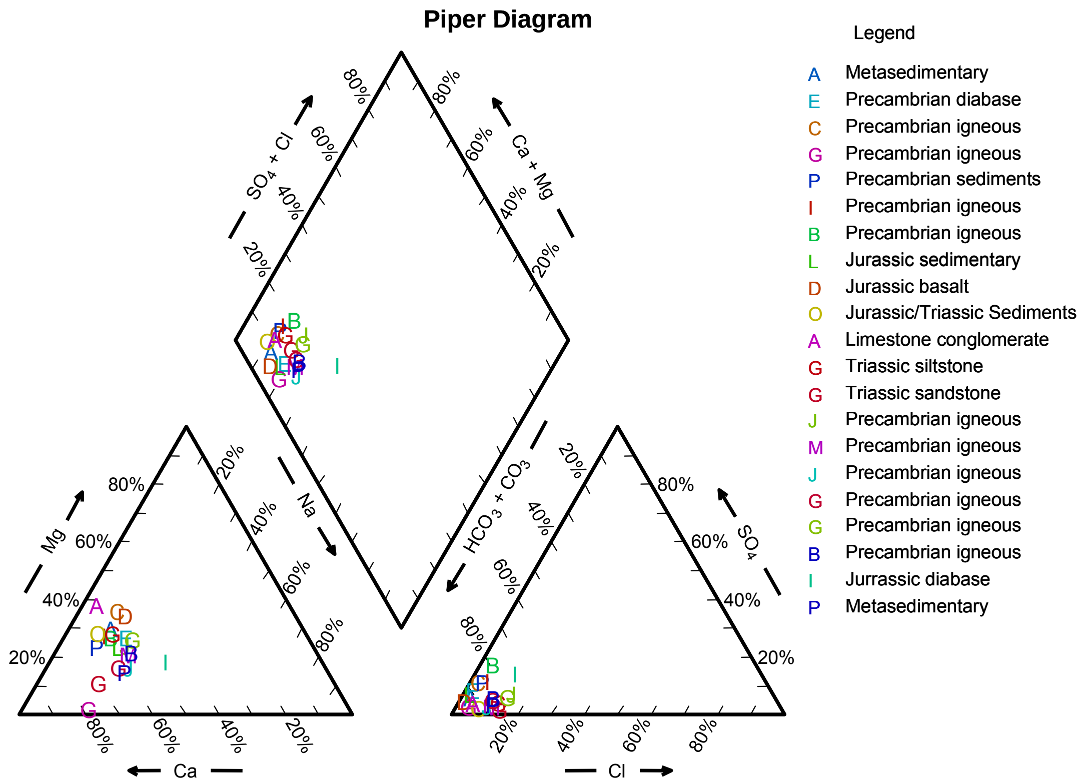
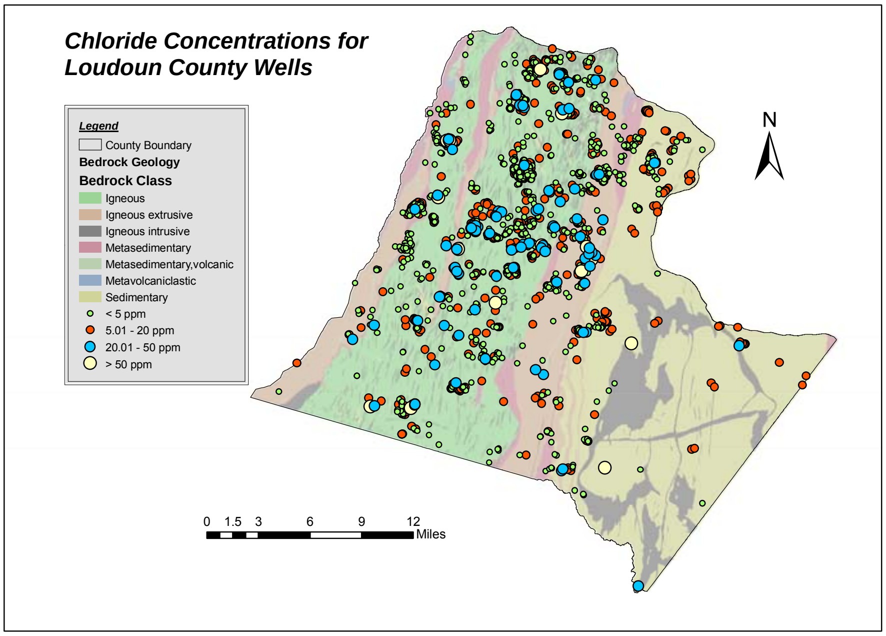


FIGURE 6-3
Chloride Concentrations




Chloride concentrations, an index of salinization from surface and connate sources, averaged less than 20 mg/L (Figure 6-3). No samples in the databases exhibited chloride concentrations exceeding the Virginia Drinking Water Standard limit of 250 mg/L. Sodium concentrations averaged 9.5 mg/L, but concentrations in a few samples ranged above the health guideline of 20 mg/L across all rock types.

Iron, manganese, and hardness concentrations are elevated, which is typical of bedrock aquifers that contain an abundance of metal-bearing minerals. Average iron and manganese concentrations of 2.4 and 0.14 mg/L exceeded the Virginia Drinking Water Standard of 0.3 and 0.05 mg/L, respectively. Hardness concentrations averaged 106 mg/L, classifying the groundwater as hard according to Hem's scale (1986). However, hardness concentrations commonly ranged greater than 300 mg/L (very hard) in rocks of the Culpeper Basin.

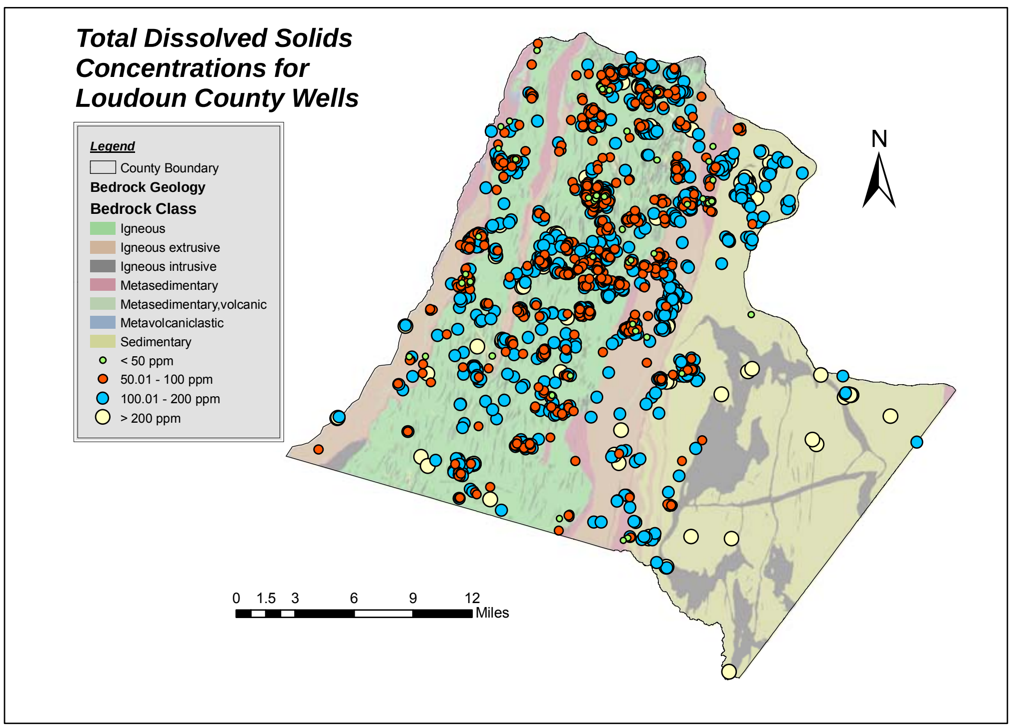
## 6.3 Evaluation of Individual Constituents

Two groundwater quality constituents, TDS and nitrates, were selected to assess their spatial distribution according to land use, geology (rock unit), and impervious surface/development. TDS is a broad, yet indirect indicator of several factors including dissolution of minerals, salinization, and quality of recharge from surface sources. Thus, TDS concentrations can be influenced by a range of natural and anthropogenic factors. Because of the kinetics of mineral dissolution, groundwater with longer residence times in bedrock should exhibit greater TDS concentrations than younger water in the same rock type. TDS concentrations are not greatly influenced by physio-chemical conditions like pH, temperature, or oxidation/ reduction (Eh).

Nitrates provide an indicator of fertilizer and septic infiltration from both point and nonpoint sources. Thus, nitrate provides an indication of human activities on groundwater quality. Often fertilizers and septic leachate are converted from ammonia ($NH_4$) to nitrate ($NO_3$-) by aerobic soil bacteria through the process of nitrification. Nitrate is prevalent in an anoxic environment, but can be reduced to nitrite.

TDS concentrations range from less than 50 mg/L in many areas across the western and central parts of the County to greater than 300 mg/L in the eastern part (Figure 6-4). Several elevated areas of TDS concentrations also occur in the western part of the County. Elevated TDS concentrations appear to correspond to the igneous and sedimentary rocks of the Culpepper Basin in eastern Loudoun County (Figure 6-5). Elevated TDS concentrations are consistent with the higher hardness concentrations in these rocks.

FIGURE 6-4
Distribution of Total Dissolved Solids Concentrations

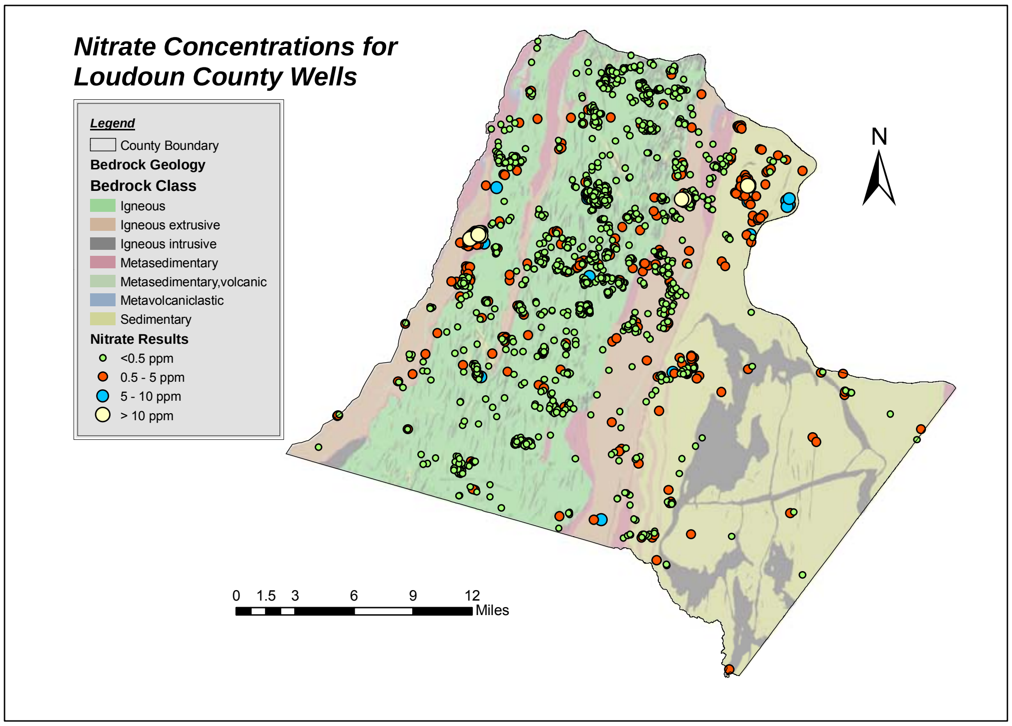



TDS concentrations appear randomly distributed when compared with the location of impervious surfaces/development. Elevated TDS concentrations were observed in groundwater beneath Dulles Airport but less elevated beneath Leesburg, Purcellville, and

Lovettsville. TDS concentrations appear to exhibit no correlation with the distribution of land use in Loudoun County.

Nitrate concentrations range from less than method detection limits (MDL) to 28 mg/L across the County (Figure 6-5). Concentrations equivalent to or greater than the Virginia Drinking Water Standard were observed in 11 locations across the County. Larger areas of elevated concentrations are located adjacent to the Bull Run Fault separating the igneous and sedimentary rocks of the Culpepper Basin from the metasedimentary, and igneous rocks of the Blue Ridge Province. Other smaller areas containing one or two points occurred in the western portion of the County. Elevated nitrate concentrations were not consistent to areas of impervious surface/development, and only mildly correlated with rural land uses (pasture, grass, deciduous forest).

FIGURE 6-5
Distribution of Nitrate Concentrations



SECTION 7
# Onsite Sewage Disposal Systems

Onsite sewage disposal systems (OSDS) are of particular concern, because there are many throughout Loudoun County, and if not maintained properly there is a high probability of contamination of either surface water or ground water. Contamination from these systems can cause increased nutrient and bacteria concentrations. Therefore this pollution source was evaluated independently.

## 7.1 Available Data

The evaluation of OSDSs was based upon two geodatabases:

- **Geodatabase of Onsite Systems—**Loudoun County Health Department database, listing all known onsite disposal systems, location, permit type, and capacity.
- **Soils Geodatabase—**Soils map linked to soils properties. The soils properties used in the onsite sewage systems analysis were slope, depth to water, and groundwater recharge because they are indicative of potential impacts on groundwater quality.

## 7.2 Description of Existing Systems

Figure 7-1 depicts the density of OSDS systems based on the current database. As might be expected, water supply wells are often installed on the same property as the OSDS. This can be seen by comparing the density of OSDS (units/acre) (Figure 7-1) to the density of water supply wells (units/acre) (Figure 7-2). The areas of high density wells and high density OSDS could have a higher potential for contamination of the water supply.

Figure 7-3 summarizes the number and type of OSDS installed each year. On initial review it appears that there has been a significant increase in the number of alternative pretreatment and conventional septic systems with pumps. However, anecdotal information indicates that in the 1970s as many as 20 percent of systems included a “pump,” and in the 1980s many systems were “low pressure.”

FIGURE 7-1
Density of OSDSs

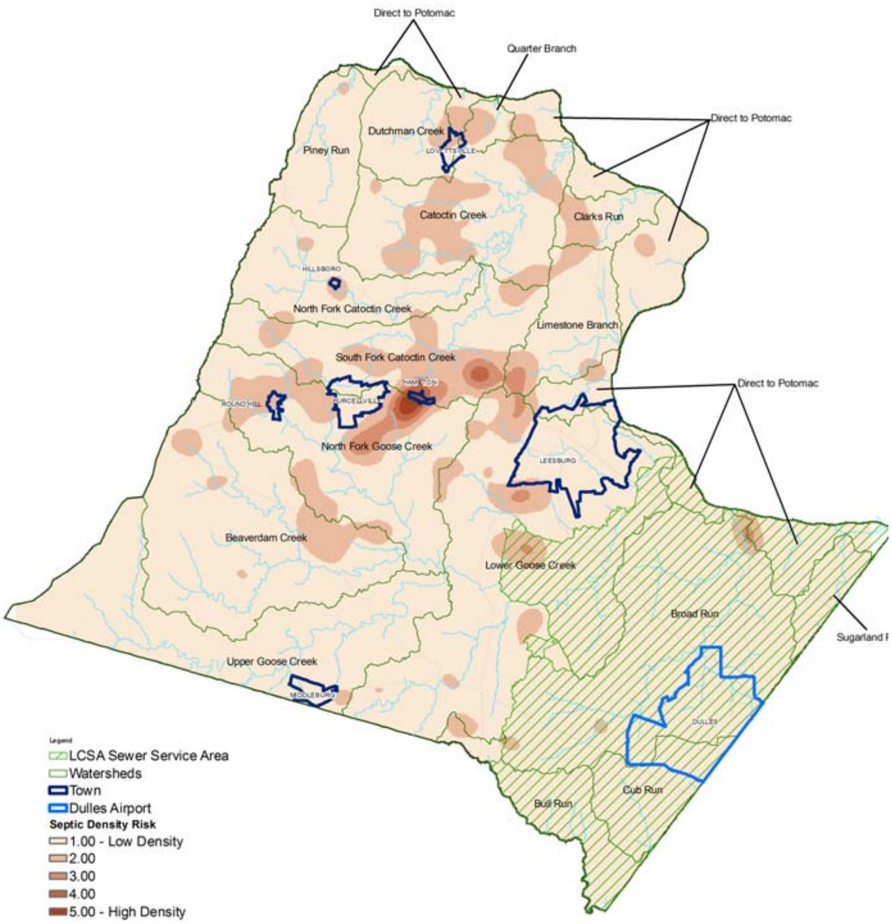


FIGURE 7-2
Density of Water Supply Wells

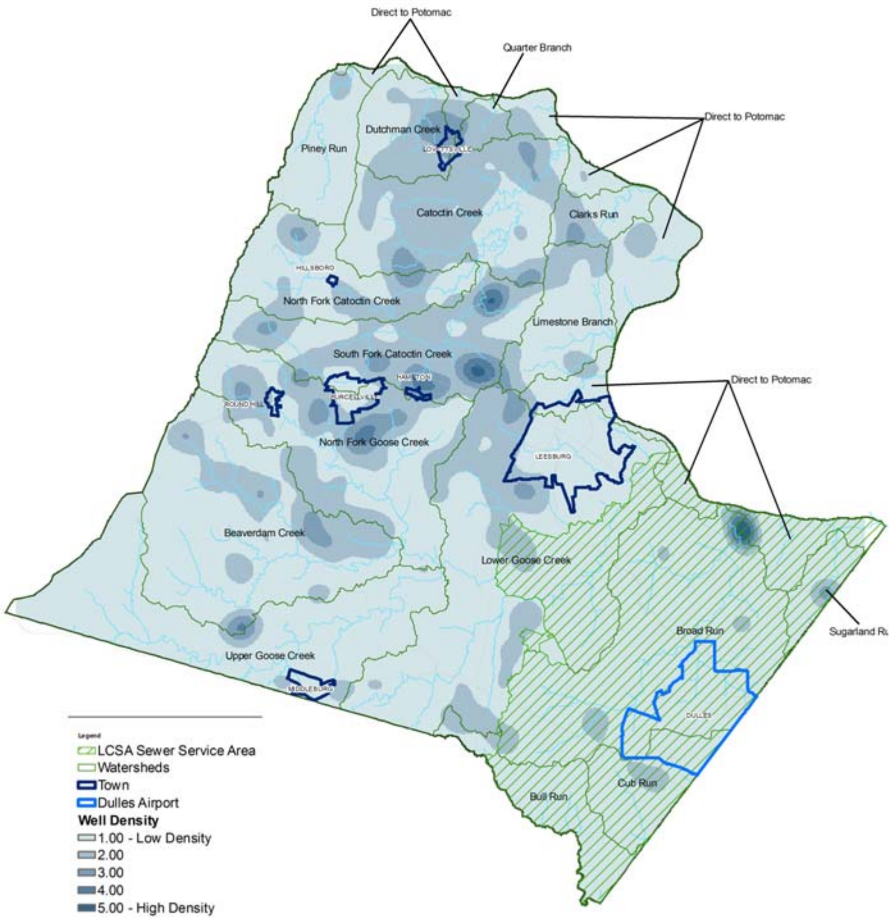
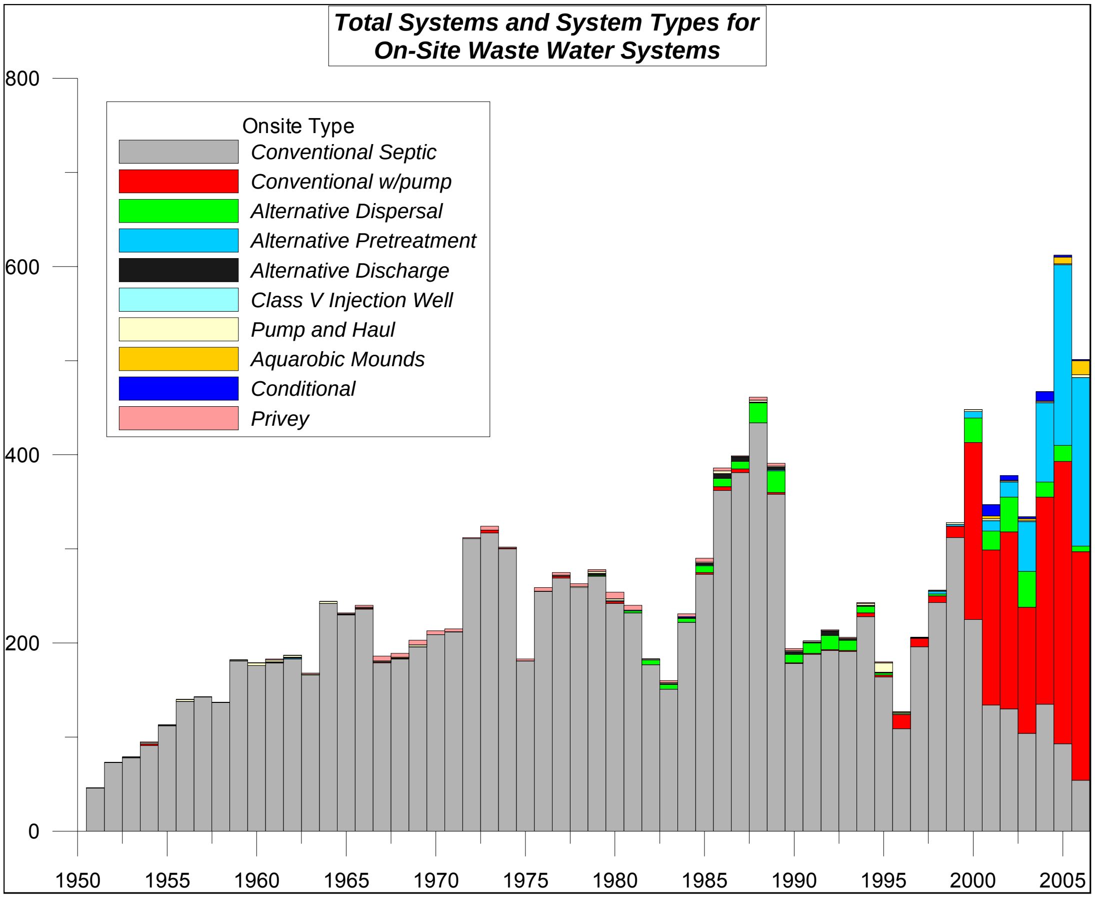


FIGURE 7-3
Onsite Sewage Disposal Systems Installed Over Time




# 7.3 Risk Analysis

## 7.3.1 Approach

The onsite disposal systems records were analyzed to identify the potential risk to water quality associated with each system. This analysis is not intended to assess likelihood of system failure. The risk analysis was conducted by evaluating six criteria associated with each system:

- **System age—**Obtained from the date included as part of the system identification. This date may be erroneous in some cases due to date entry inconsistencies, but is believed to provide accurate information for the vast majority of the sites.
- **Onsite Disposal Potential—**Scored based on a comparison of the system type, based on the permit type identified for the point, and the Onsite Disposal Potential, as identified in the County Soils Database (SL_ONSITE field)
- **Onsite Disposal System Density—**Computed as number of systems per acre using an automated GIS process.
- **Depth to Water Table—**As identified in the County Soils Database (SL_WATER_T field)

- **Land Slope—**As identified in the County Soils Database (SL_SLOPE_P field)
- **Distance to Surface Water—**Computed by identifying the nearest stream in the NHD and MajorDrains databases or wetland in the NWI database, and computing the distance from that feature to the onsite system.

A scoring system was developed for each criterion (Tables 7-1, 7-2, 7-3, and 7-4). A weight was assigned to each criterion, as shown in Table 7-5 to compute a total risk score for each onsite disposal systems. The weights were determined through a consensus process as an average indicative of potential risk to water quality. This total risk score can be used in future analyses to prioritize repair or elimination of onsite systems.

TABLE 7-1
Onsite Disposal Risk Scoring Criteria for System Age,

| Age | Decade | Score |
|---|---|---|
| 0–15 yr | 1990–Present | 1 |
| 15–25 yr | 1980s | 2 |
| 25–35 | 1970s | 3 |
| 35–45 | 1960s | 4 |
| 45–55 | 1950s | 5 |
| 55+ | 1940s +1939 | 5 |

TABLE 7-2
Onsite Disposal Risk Scoring Criteria for Distance to Surface Water

| Distance to Surface Water | Score |
|---|---|
| >1,000 ft | 1 |
| 500–1,000 ft | 2 |
| 300–500 ft | 3 |
| 100–300 ft | 4 |
| 0–100 ft | 5 |

TABLE 7-3
Onsite Disposal Risk Scoring Criteria Land Slope

| Slope Class | Score |
|---|---|
| 0–2 | 1 |
| 0–5 | 1 |
| 0–7 | 1 |
| 2–7 | 1 |
| 7–15 | 3 |
| 7–25 | 3 |
| 15–25 | 3 |
| 25+ | 5 |

TABLE 7-4
Onsite Disposal Risk Scoring Criteria for Depth to Water Table

| Water Table Category | Score |
|---|---|
| No known issues | 1 |
| Not applicable | 1 |
| Short duration (perched) | 3 |
| Short duration (perched) laterally moving | 3 |
| Short duration laterally moving | 3 |
| Seasonally high (apparent) | 5 |
| Seasonally high (perched) | 5 |
| Seasonally high (perched) laterally moving | 5 |
| Seasonally high laterally moving | 5 |
| Water | 5 |

TABLE 7-5
Onsite Disposal Risk Scoring Criteria for Onsite Disposal Potential

| Onsite Potential | Conventional (Septic with Gravity) | Conventional (Pump) | Alternative Dispersal System Only | Alternative Pretreatment System | Alternative Discharging | Commercial/ Class 5 Well | Pump & Haul | Experimental | Conditional | Privy |
|---|---|---|---|---|---|---|---|---|---|---|
| Conventional gravity and low pressure systems | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Not applicable | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Shallow-placed drip / alternative drainfields | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 |
| Spray irrigation | 4 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 |
| No potential | 5 | 5 | 4 | 3 | 1 | 1 | 1 | 1 | 1 | 5 |
| Water | 5 | 5 | 5 | 5 | 1 | 5 | 1 | 5 | 5 | 5 |
| Blank | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

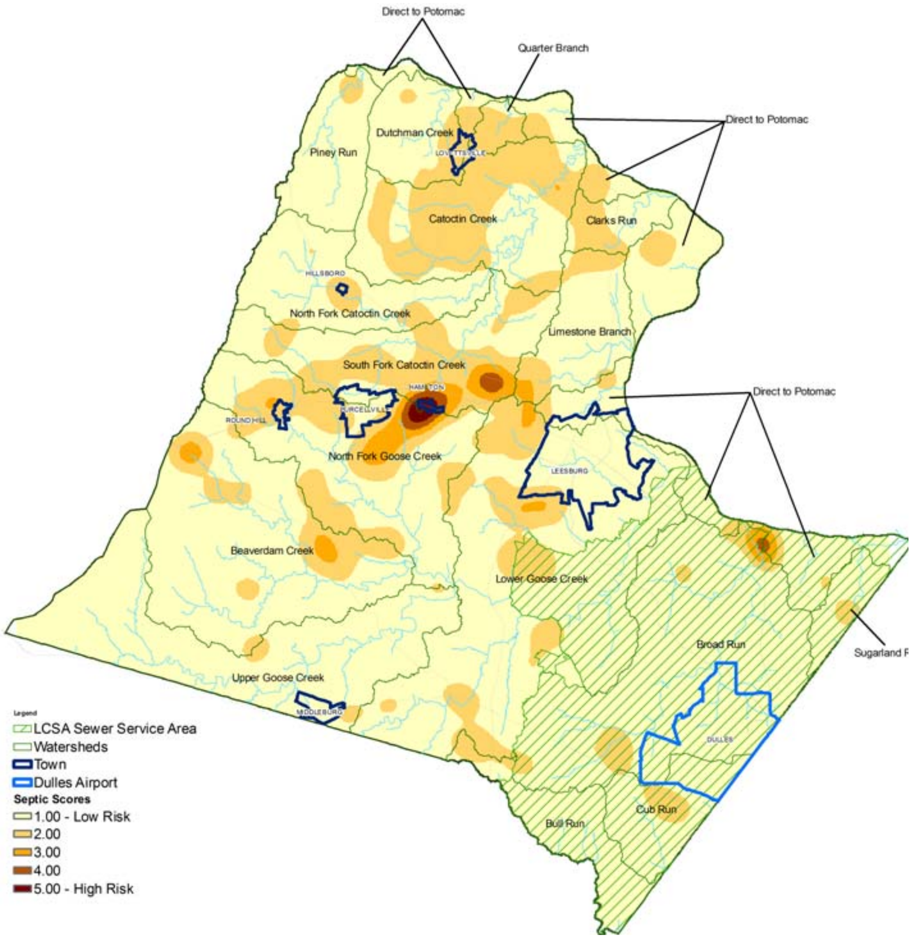
## 7.3.2 Results

The results of the risk analysis are summarized in a risk density map (Figure 7-4). Because system density is inherently included in development of a density map, this criteria was eliminated from the score computation prior to developing this maps. Figure 7-4 shows particularly high risk density in the areas around the Town of Hamilton (South Fork Catoctin Creek and North Fork Goose Creek Watershed), Paeonian Springs (South Fork Catoctin Creek), and Broad Run Farms (Broad Run Watershed).

TABLE 7-6
Weighting of Onsite Disposal Risk Criteria

| Factor | Weight |
|---|---|
| System age | 21% |
| Septic potential (per soils layer) | 21% |
| Density of OSDS | 19% |
| Depth to groundwater | 17% |
| Slope | 11% |
| Distance to surface water | 11% |

FIGURE 7-4
Score of Potential Risk to Water Quality Posed by OSDSs



SECTION 8

# Water Balance

## 8.1 General Water Balance

The data and analyses presented in this report are an initial evaluation of the water resources in Loudoun County. A fundamental concept to consider in evaluating and managing water resources is a water budget or water balance. The basic concept of a water budget is relatively simple; quantifying the flow of water into and out of a system or area. In this case, the area is Loudoun County. However, in reality the system can be quite complex and accurately measuring all of the components of a water budget is often not practical or even possible so assumptions are made and / or a simplified model is used to represent the system.

Figure 8-1 shows many of the elements that make up Loudoun County's water resources and demands. Figure 8-2 was created in order to better understand the complexity of Loudoun County's water resources and the different entities that they serve. The figure is set up to show the relative geography of the County, with the Potomac River to the north. However, components are placed to best fit the figure and not to capture perfect geography. Large surface water supplies (reservoirs, streams and river) are identified individually and are connected to their respective water treatment plants (WTP). The WTPs are connected to their demand (green hexagons) which in turn can be connected to either a wastewater treatment plant (WWTP), a direct return to a water resource or a loss to the countywide water resource system. Countywide groundwater resources are shown in aggregate along with their individual demands and recharge sources.

FIGURE 8-1
Water Balance Elements

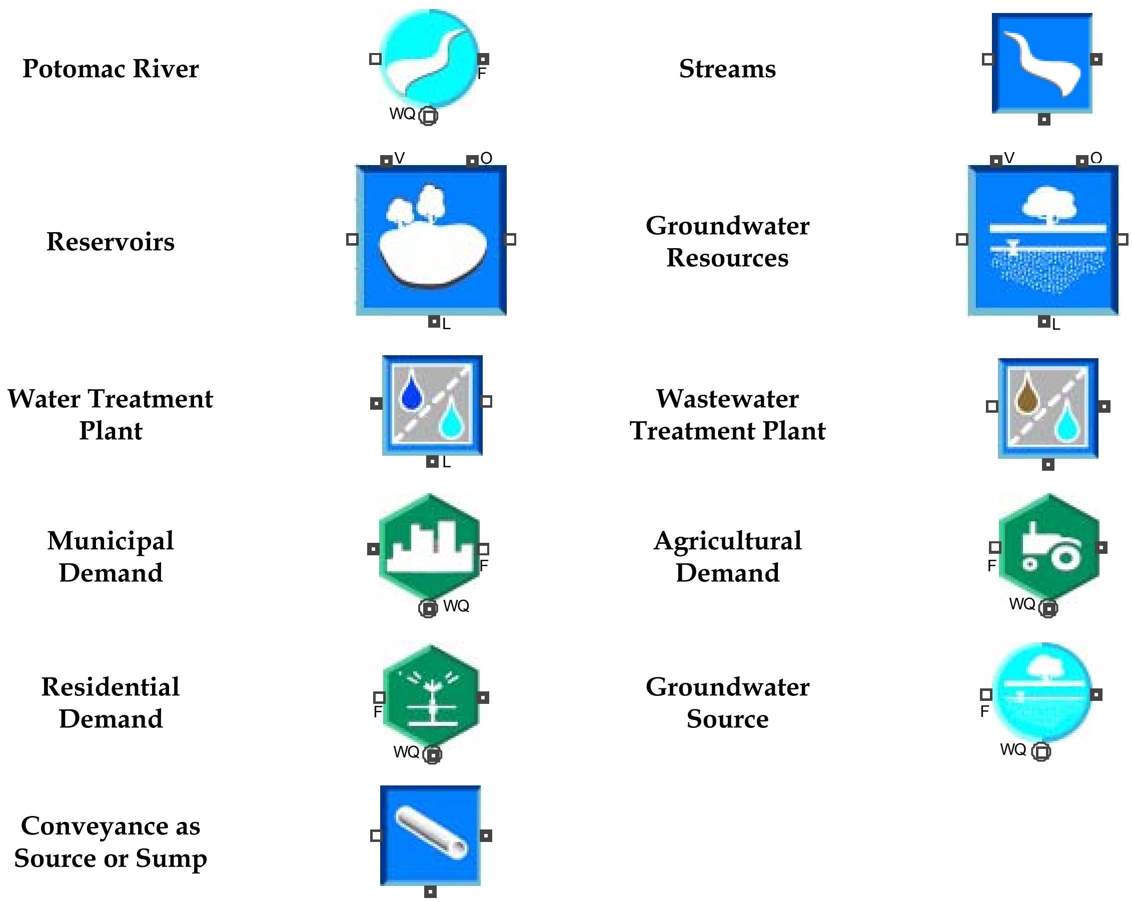
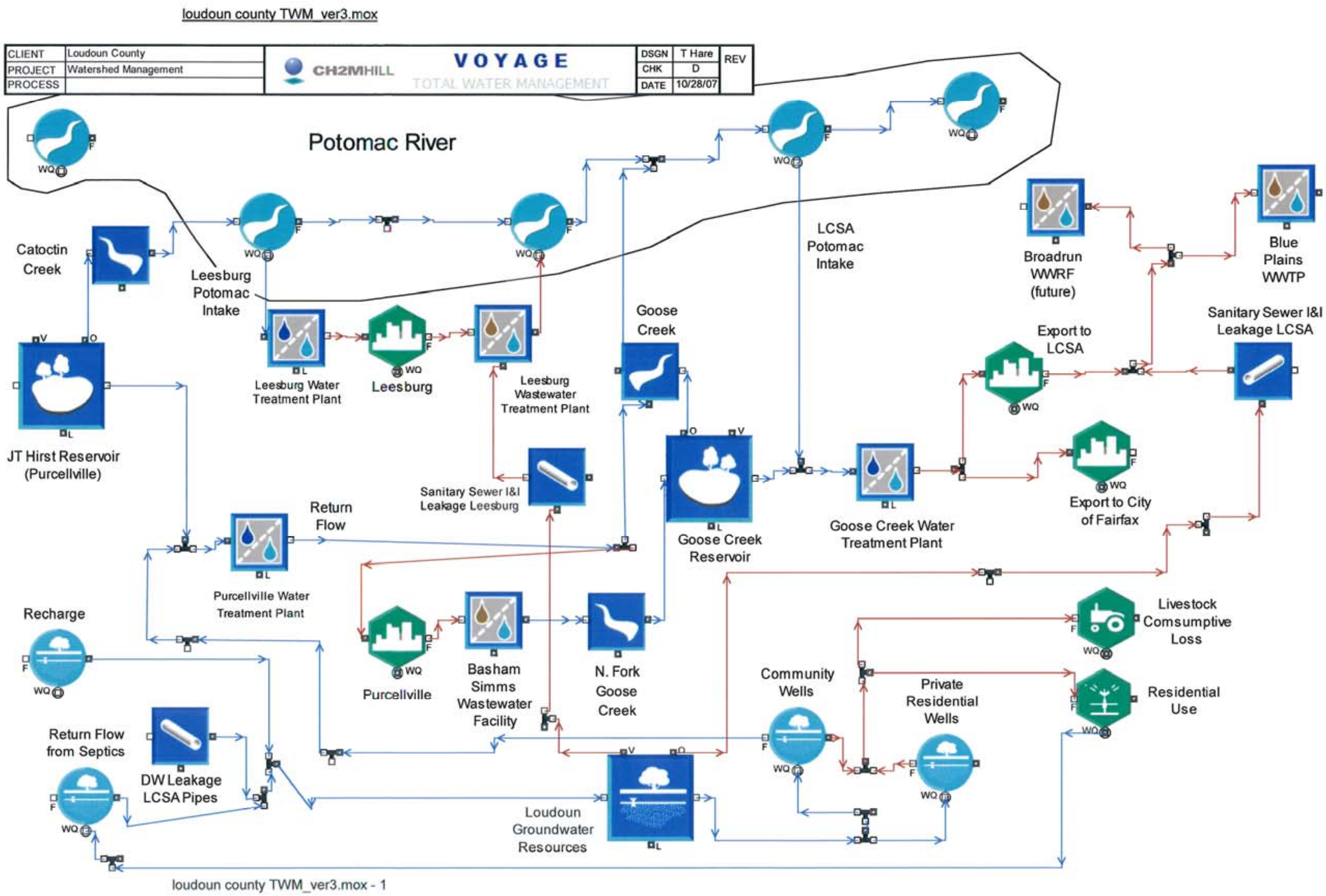


FIGURE 8-2
Loudoun County Water Sources and Users



# 8.2 Analysis of Groundwater Residuals

An investigation was conducted to determine the abundance of groundwater supplies in Loudoun County in relation to present demands (withdrawals) from wells and recharge. The investigation incorporated two approaches. First, groundwater residuals (available recharge minus groundwater demand) were determined for each of 17 watersheds. This approach focuses on the watershed as the basic hydrologic unit.

Because the density of wells (and demand) is not uniformly distributed throughout the watersheds, small areas with relatively large groundwater withdrawals, such as around municipal wellfields, would not be apparent on a watershed scale. To better understand the influence of groundwater demand on residuals, at a smaller scale, a second method was applied. In this second method, residuals were estimated in 5,000 foot by 5,000 foot cells laid out in a countywide grid (Figure 8-3).

## 8.2.1 Methods

### Groundwater Residuals by Watershed

Groundwater residuals were determined by subtracting water demands from available recharge. Recharge was estimated by Loudoun County staff using data from 10 gauging stations and the recession-curve-displacement method, from the USGS computer program RORA (USGS, 2007). For the seven watersheds without gauging stations, an average recharge value was applied as determined from the 10 watersheds containing stations. Groundwater demands were estimated from two categories of wells contained in separate databases. Demand from municipal, industrial, and public wells was based on actual pumpage from 2005. Demand from domestic wells was estimated by multiplying the number of wells by 250 gallons per day, a relatively conservative per capita value given historical usage in Loudoun County.

For both the watershed and unit area approaches, recharge was averaged using data from 1965 through 2006 for the long term estimate. To obtain a more conservative estimate, recharge was estimated using an average of the drought years 1965, 1966, 1999, and 2000. Estimated groundwater demand was not adjusted during the drought years.

### Groundwater Residuals by Unit Area

Using the unit area method, recharge from each watershed was divided by the number of unit area cells contained in the watershed. Groundwater demands were based on adding the demand from municipal, industrial, and public wells (actual pumpage: 2005) and domestic wells in each cell. Similar to the watershed method, average residuals were estimated for the years 1965 to 2006. In addition, residuals were estimated for the average of the drought years 1965, 1966, 1999, and 2006.

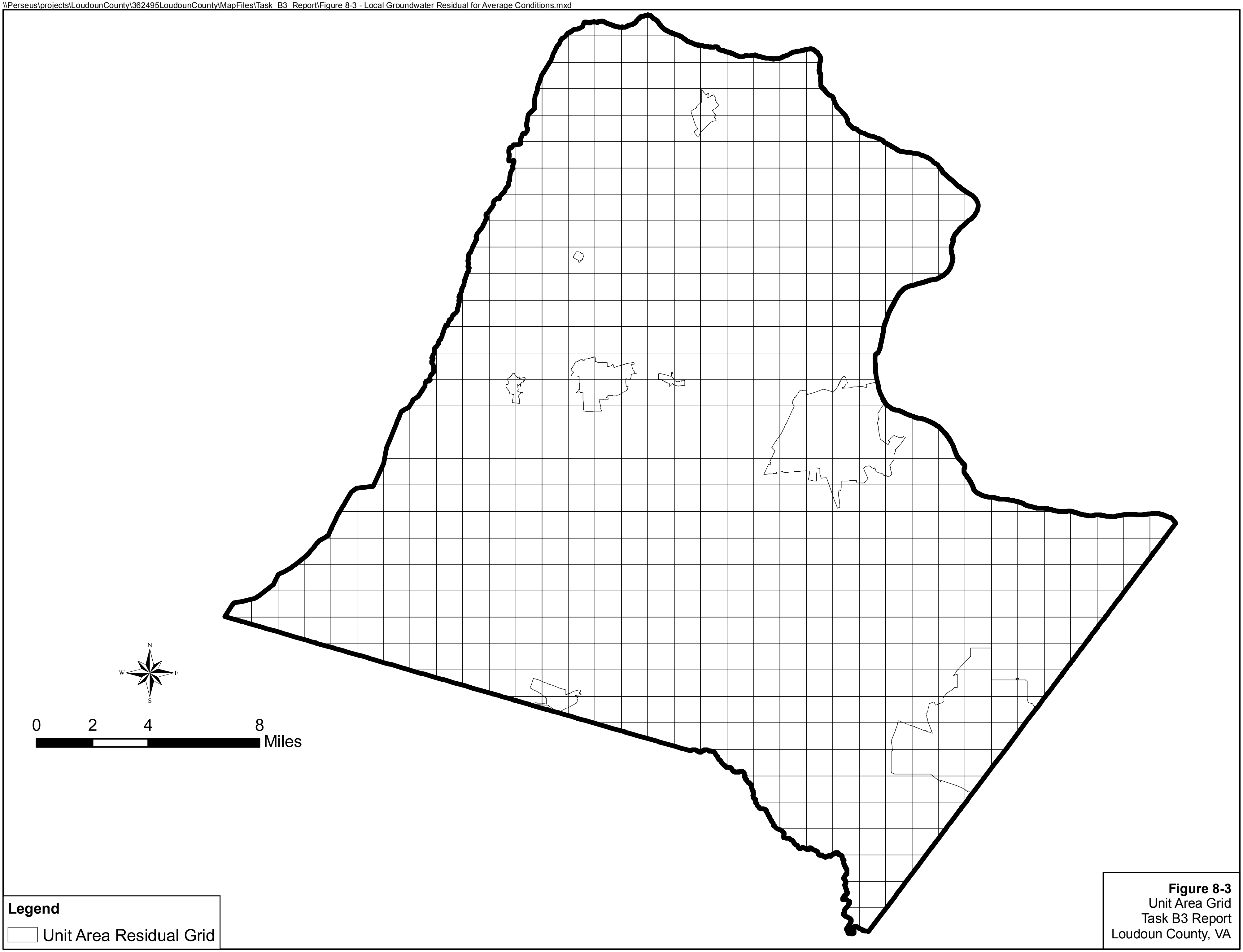



**Figure 8-3**
Unit Area Grid
Task B3 Report
Loudoun County, VA

## 8.2.2 Results

### Groundwater Residuals by Watershed

Over the long term, groundwater demands appear relatively low in comparison to recharge (Figure 8-4). Actual demands in each watershed range from less than 0.1 million gallons per day (mgd) in Quarter Branch to approximately 1.0 mgd in North Fork Goose Creek. The Lower Goose Creek and Beaverdam Creek watersheds exhibited the greatest available recharge values, ranging from 39 to 44 mgd over the long term. Recharge in the smallest watersheds (Quarter Branch, Clarks, and Sugar Brand creeks) ranged between 1 to 4 mgd.

Groundwater demand typically is less than 2 percent of recharge by volume (Figure 8-5). Only the South Fork of Catoctin Creek exhibits demands greater than 5 percent of the recharge. Groundwater demands in the North Fork Goose Creek, Upper Goose Creek, and Quarter Branch range from 3 to 4 percent of the recharge values.

Recharge values during average drought years were roughly 55 percent of the long-term record. Lower Goose Creek and Broad Run exhibited the greatest average drought recharge at 26 and 18 mgd, respectively, while Quarter Branch exhibited the lowest (Figure 8-6). The percentage of groundwater demands in comparison to recharge doubled to more than 10 percent in South Fork of the Catoctin Creek (Figure 8-7). Dutchman Creek, North Goose Creek, Quarter Branch, and Upper Goose Creek exhibited demands values ranging from 6 to 9 percent of the total recharge.

Groundwater residuals ranged from greater than 30 mgd in the largest watersheds at Lower Goose Creek at Beaverdam Creek to less than 5 mgd (Figure 8-4), at Quarter Branch and Charles Run for the long term record. Generally, residuals were in proportion with the land areas of the watersheds. During the average drought periods, residuals ranged up to 25 mgd in Lower Goose Creek (Figure 8-8). Nine of the smallest watersheds exhibited residuals less than 5 mgd.

### Unit Area Residuals

For the long term, groundwater residuals (0.58 to 0.7 mgd) were greatest along the western boundary, and in the west-central part of the County (Figure 8-9). Residuals appear to grade downward to less than 0.14 mgd in a large part of the southeastern part of the County. During the average drought years, the greatest residuals ranging between 0.26 and 0.29 mgd appear in the central part of the County (Figure 8-10). Small areas of elevated withdrawals were observed coincident with groups of municipal wells in the western part of the County west of Purcellville and Lovettsville.

The above exercise is a basic, simplified approximation of groundwater

\\Perseus\projects\LoudounCounty\362495LoudounCounty\MapFiles\Task_B3_Report\Figure 8-4 - Residual Groundwater Volumes by Watershed for Long-Term Record.mxd

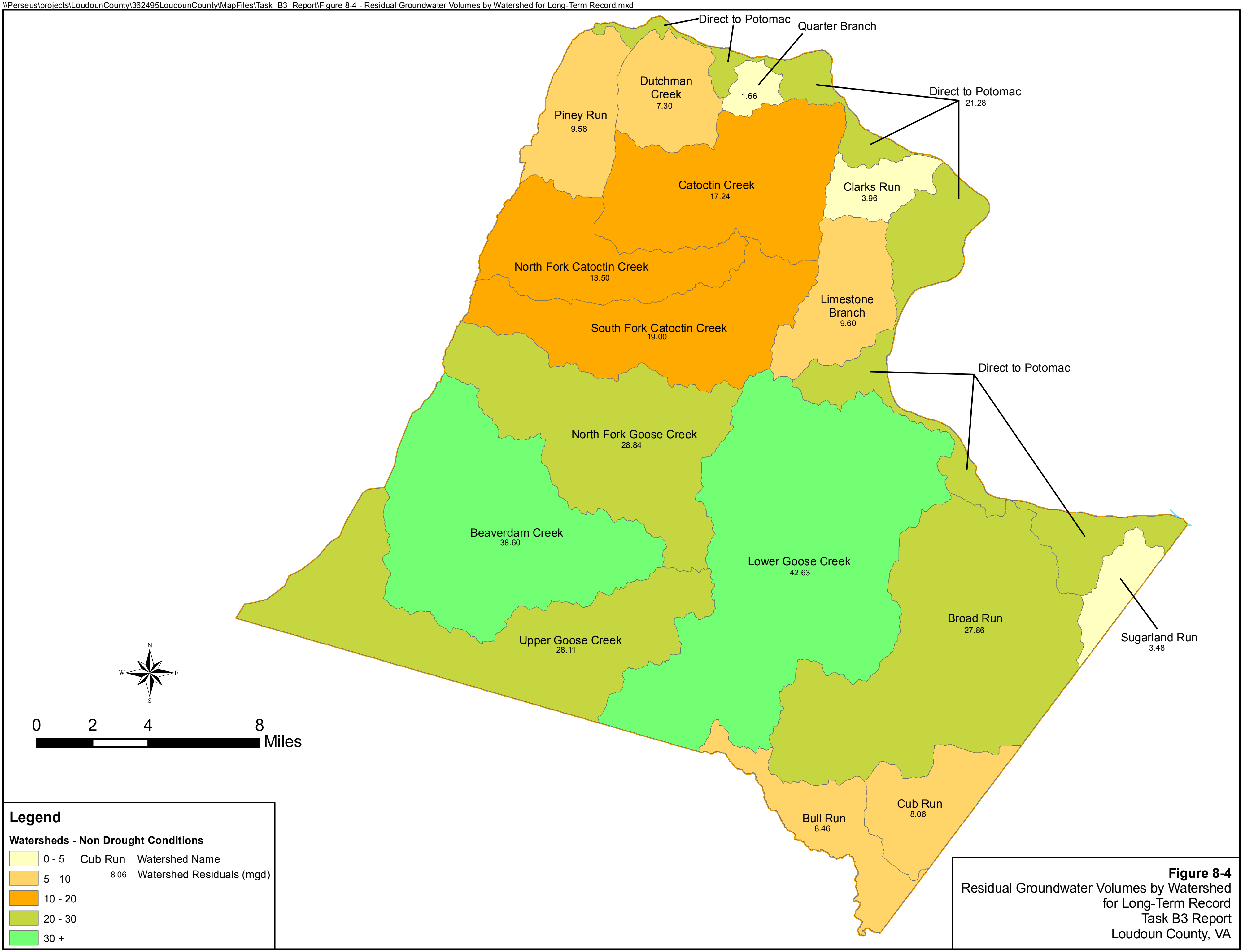



**Figure 8-4**
Residual Groundwater Volumes by Watershed for Long-Term Record
Task B3 Report
Loudoun County, VA

FIGURE 8-5
Demand as a Percentage of Recharge by Watershed for Long-Term Record (1965-2005)

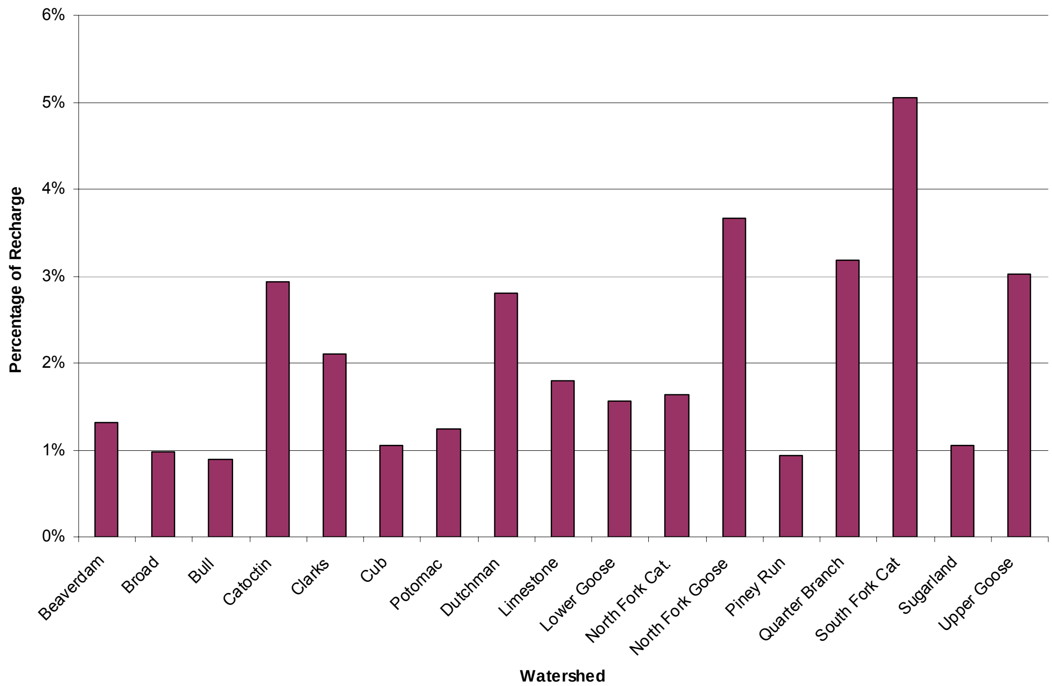



FIGURE 8-6
Recharge and Demand Estimates by Watershed for Drought Years (1965, 1966, 1999, 2002)

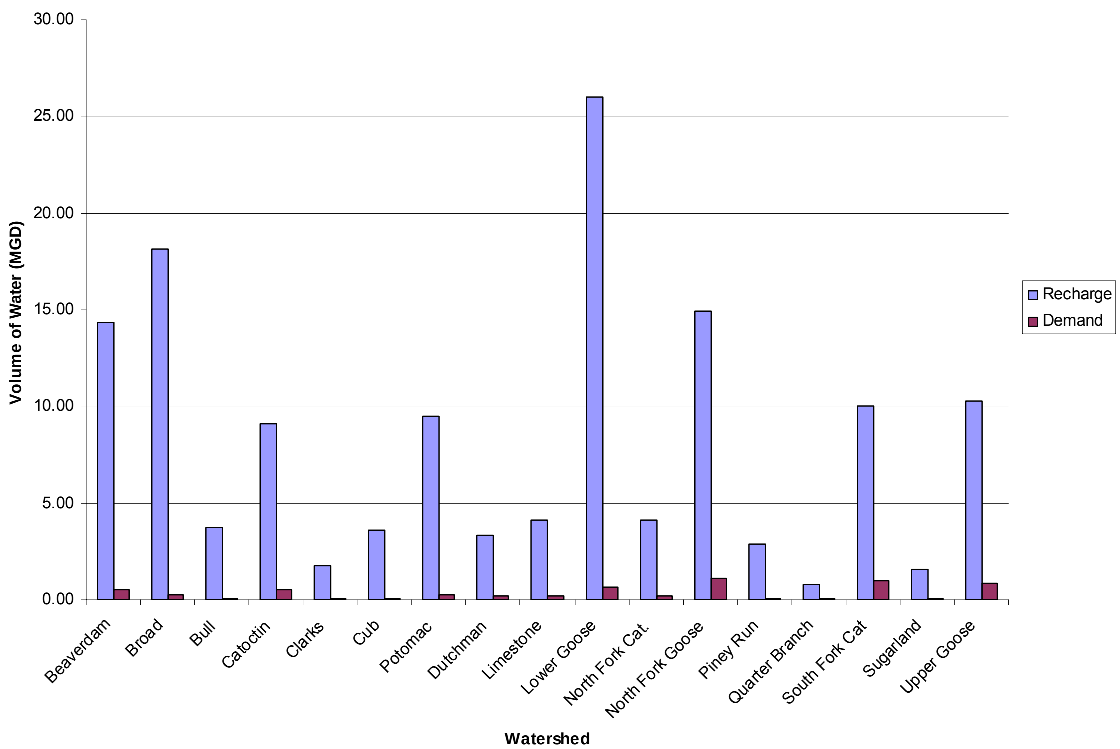
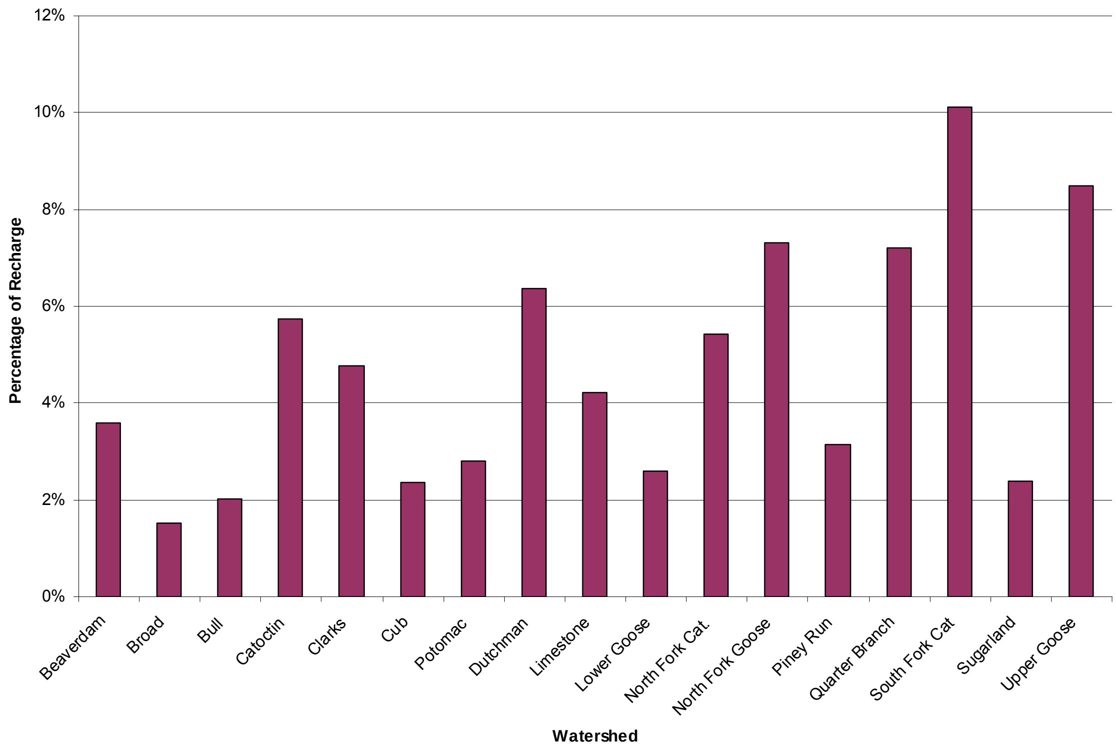


FIGURE 8-7
Demand as a Percentage of Recharge by Watershed for Drought Years (1965, 1966, 1999, 2002)



\\Perseus\projects\LoudounCounty\362495LoudounCounty\MapFiles\Task_B3_Report\Figure 8-8 - Recharge and Demand Estimates by Watershed for Drought Years (1965, 1966, 1999, 2002).mxd

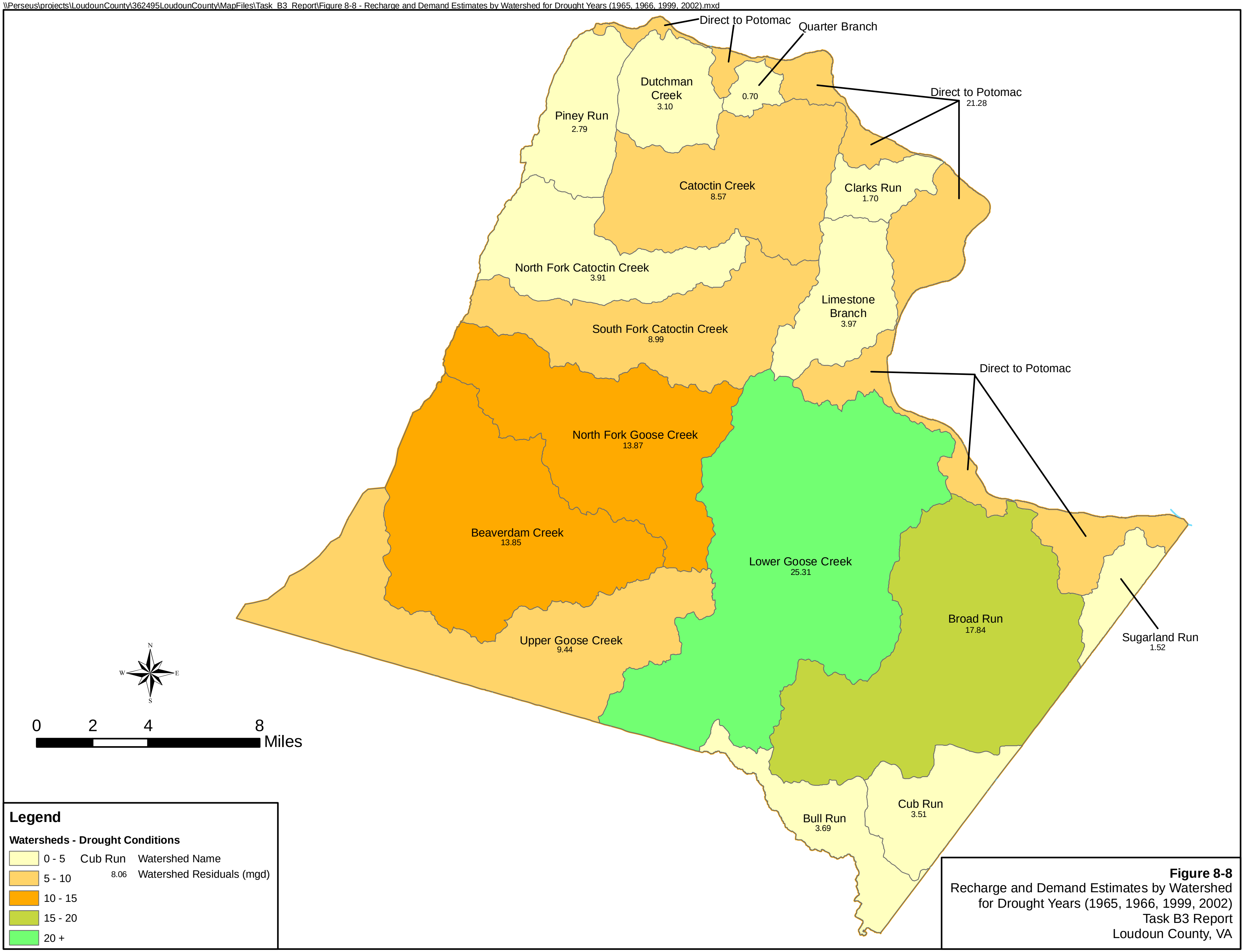
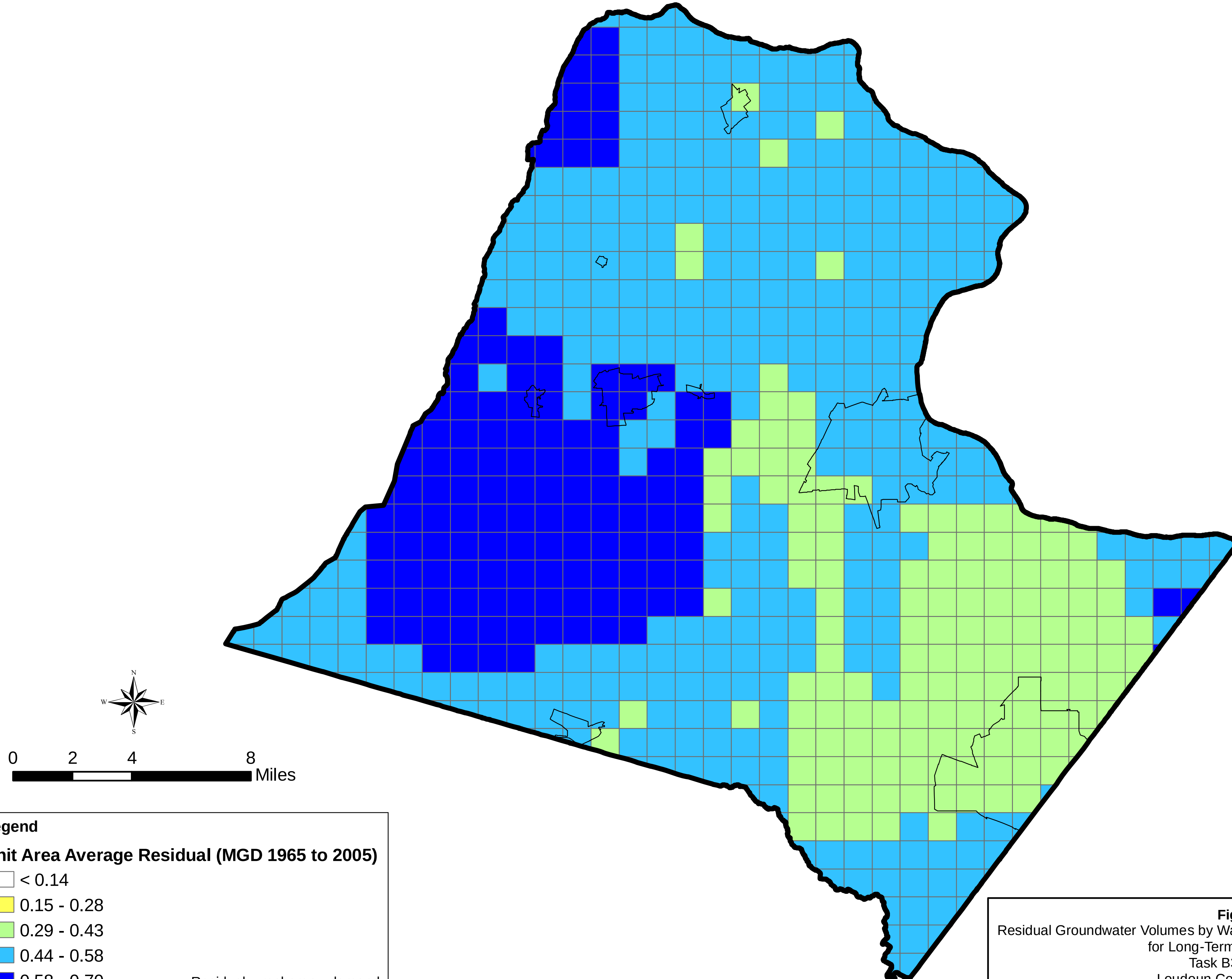



**Figure 8-8**
Recharge and Demand Estimates by Watershed
for Drought Years (1965, 1966, 1999, 2002)
Task B3 Report
Loudoun County, VA

\\Perseus\projects\LoudounCounty\362495LoudounCounty\MapFiles\Task_B3_Report\Figure 8-9 - Residual Groundwater Volumes by Watershed for Long-Term Record.mxd




**Legend**

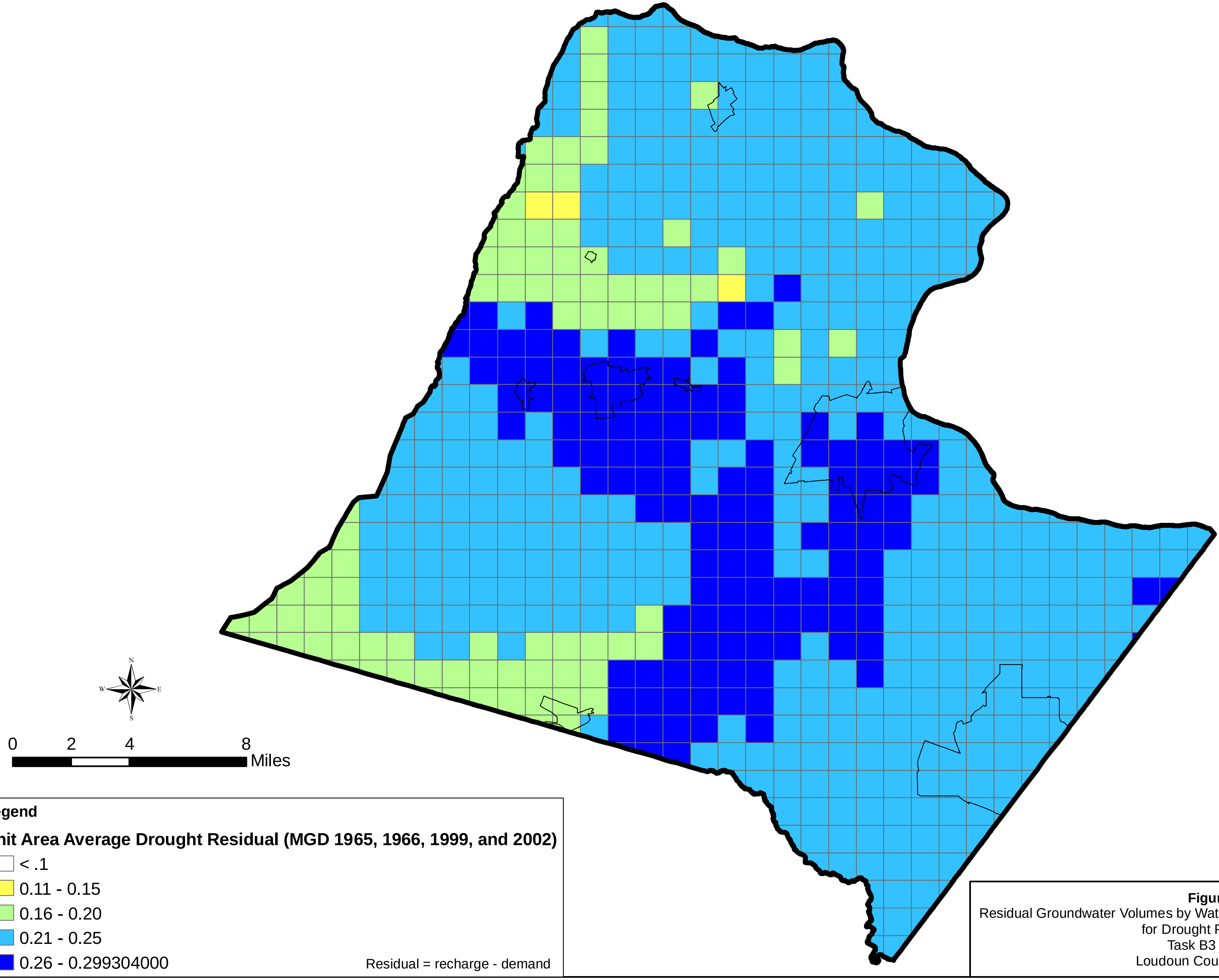
**Unit Area Average Residual (MGD 1965 to 2005)**

- < 0.14
- 0.15 - 0.28
- 0.29 - 0.43
- 0.44 - 0.58
- 0.58 - 0.70

Residual = recharge - demand

**Figure 8-9**
Residual Groundwater Volumes by Watershed
for Long-Term Record
Task B3 Report
Loudoun County, VA

\\Perseus\projects\LoudounCounty\362495LoudounCounty\MapFiles\Task_B3_Report\Figure 8-10 - Residual Groundwater Volumes by Watershed for Drought Periods.mxd




**Legend**

**Unit Area Average Drought Residual (MGD 1965, 1966, 1999, and 2002)**

- < .1
- 0.11 - 0.15
- 0.16 - 0.20
- 0.21 - 0.25
- 0.26 - 0.299304000

Residual = recharge - demand

**Figure 8-10**
Residual Groundwater Volumes by Watershed for Drought Periods
Task B3 Report
Loudoun County, VA

The above exercise is a basic, simplified approximation of groundwater sustainability based on a number of estimates and assumptions. The results suggest that, in general and over relatively large areas, there is sufficient groundwater available for current demand even during droughts when groundwater levels decline. However, wells that produce water only from relatively shallow water-bearing fractures may be susceptible to running dry during droughts even though there is still adequate groundwater available for most other wells, albeit at a greater depth. Because greater stress is placed on the groundwater system in areas of concentrated withdrawals, these areas should be more closely examined to assure long-term sustainability. In addition to the grid method described above (which is based on areas of nearly a square mile), identifying these potentially smaller areas of high demand can also be based on the density of water wells as depicted in Figure 7-2.

An important component not quantified in any of these estimates is the impact that groundwater withdrawals have on stream flow. When stream flow becomes very low, the aquatic habitat is stressed. In situations where groundwater withdrawals are not excessive and are not concentrated near streams, the reduced rate of stream baseflow due to groundwater withdrawals may not be significant to stream health during non-drought conditions. However, in situations where high rates of groundwater withdrawals occur in concentrated areas near streams and/or stream baseflow is already at low levels (such as during a drought), reductions in baseflow due to groundwater withdrawals can be significant on stream flow and negatively impact stream health. This issue warrants further investigation.

SECTION 9

# Conclusions

The available hydrologic, hydraulic, and water quality data were evaluated to determine the baseline conditions in Loudoun County. The general conclusions that could be drawn from this analysis are presented below.

## 9.1 Precipitation

- On average, the County receives 41 inches of rain annually, although this has fluctuated from 30 to 60 inches.
- February typically is the lowest precipitation month, but monthly precipitation volume is relatively consistent throughout the year.
- Precipitation data do not show any significant geographic trend across the County.
- Precipitation records are limited in the northern portion of the County.

## 9.2 Streamflow

- There are 10 USGS stream gauges, representing 10 of the County's 17 major watersheds.
- Streamflow characteristics are relatively consistent across the County, allowing for extrapolation of flow data to the unmonitored watersheds of the County based on watershed size.
- The exception is Broad Run watershed, where storm flows are higher and baseflows lower. The cause of this variation may be a result of higher impervious surfaces, and should be evaluated in more detail.

## 9.3 Surface Water Quality

- Data analyzed from 16 DEQ long term monitoring stations, 12 located within Loudoun County, 9 of 17 watersheds monitored.
- Surface water quality data were limited for some stations.
- Most water quality standards met on an average basis. Exception is bacteria

## 9.4 Groundwater

- Well depths average 200 to 300 feet across the 17 watersheds.
- Static water levels average 25 feet below ground surface across the 17 watersheds.
- With the exception of the Broad Run watersheds, well yields are typically less than 50 gpm.

## 9.5 Groundwater Quality

- Overall, excellent groundwater quality
- Groundwater quality shows low TDS, neutral to alkaline pH, and calcium bicarbonate water chemistry consistent with recharge from a meteoric source (rainfall).
- Nitrate concentrations are typically less than MCL's and are not correlative with geology, land use, or density of impervious surface.
- Elevated TDS concentrations correlate well with sedimentary rocks of the Culpeper Basin, and elevated hardness.

## 9.6 Recharge

- Under average recharge conditions, all watersheds exhibit positive residual values (Recharge minus Demand)
- Under drought conditions, all watershed exhibit positive residual values (Recharge minus Demand)
- Excessive withdrawal reduces baseflow in streams

## 9.7 Onsite Sewage Disposal Systems

- Higher OSDS densities in central part of the County
- Some locations show increased risk, partly due to proximity to wells

## 9.8 Data Gaps

- There is limited precipitation data available for the northern portion of the County
- Few long term stream gauges
- Some stream quality data based on limited measurements
- No long term groundwater quality data; only snapshots at multiple locations
- Continued long-term monitoring based on the County's existing water resources monitoring program will help fill these data gaps.

As a follow-up to this analysis, additional environmental data, including stream assessment databases, will be evaluated, and a watershed management plan will be developed for the County. The following tasks identified in this report will be incorporated into the Watershed Management Plan:

- Collection of long-term data to improve existing water quantity and water quality data
- Preservation of existing good ground water quality
- Remedial actions associated with surface water quality concerns (e.g., bacteria)
- Protection of the stream baseflow to ensure survival of aquatic species
- Prioritization of repairs to OSDS sites of risk water quality
- Evaluation of
  - Stormwater management and floodplain management
  - Wetlands
  - Agricultural practices

SECTION 10

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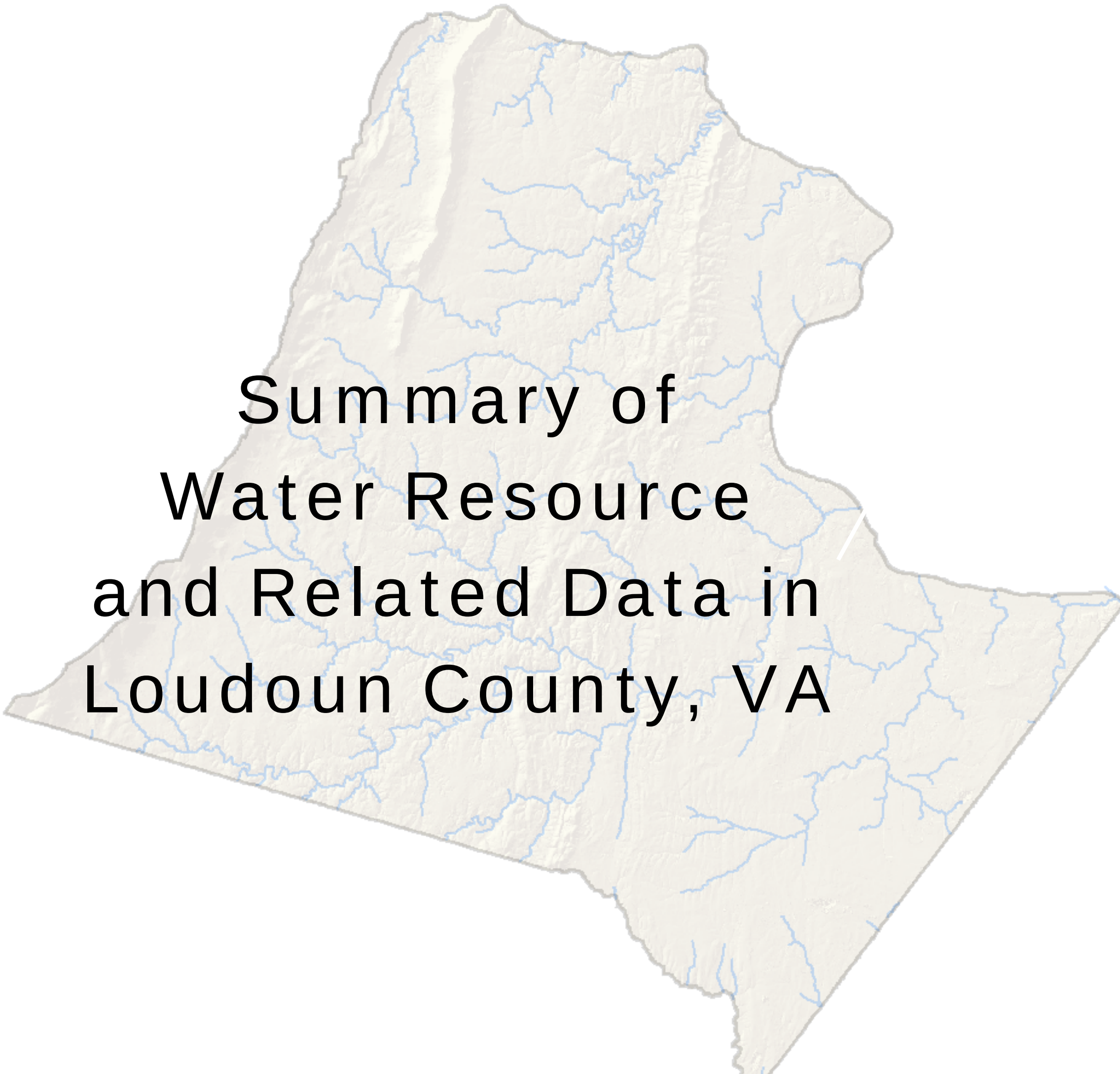
APPENDIX A1

# Water Resources Data Summary



# Summary of Water Resource and Related Data in Loudoun County, VA

Prepared by:

Loudoun County
Department of Building & Development
Water Resources Team

March, 2008

# Loudoun County - Water Resources Data Summary

*This data summary highlights those data most pertinent to overall water resource monitoring and hydrological analysis. The discussions include a brief description of the data source, a summary of the data contents and relevant notes regarding the data compilation and status.*

# 1. Groundwater Data

## 1.1 Loudoun County Groundwater, Well, and Pollution Sources

Well construction and groundwater information in database (MS Access) with locations in GIS maintained by B&D and Health Department. Source of most data from paper files generated during Health Department well permitting process (e.g., GW2 well construction form). Subset of the WellPoll database, which includes well data and pollution sources data. Data on ~18,500 wells dating from 1930 to present, with information of varying quality and completeness including: location (VA state plane coordinates), surface elevation (62% complete), well depth (70%), casing depth (65%), static water level (53%) {suspect accuracy}, total yield (60%), depth of primary yield zone (60%), and transmissivity (~250 values).

Also includes groundwater quality data. Water quality data for a limited number of parameters are entered in the database for some wells (~2,100) constructed and tested prior to 2002. Water quality data provided digitally to B&D by National Testing Labs started in 2002 and is available for approximately 2,250 wells. These data are considered level A quality and typically consist of 100 physical/chemical water quality parameters per well for a total of more than 200,000 individual analyses. NTL data linked to the groundwater database by Health Department Permit No.

Also includes data on potential pollution sources – primarily on-site sewage disposal systems (e.g., drain fields) but also other sites such as cemeteries, landfills, chemical storage sites, etc. Currently there are approximately 14,000 records with site ID numbers and corresponding points in GIS. Data in some of the old records may be obsolete. Currently, data are obtained primarily from the Health Department sewage disposal system permitting process.

## 1.2 USGS Groundwater Wells

The USGS operates three real-time water level measurement wells within Loudoun County or contributing watersheds. One well is located on the ridge of Short Hill north of Hillsboro (1963 to present), one is located east of Leesburg (1977 to present), and the third is in Prince William County, just south of the Loudoun County line in the Bull Run watershed (1968 to present). Data is added to B&D databases through automated web queries.

## 1.3 County Hydrogeologic Studies

These reports are valuable sources of high-quality groundwater data, including level data, geologic logs and aquifer testing data. The reports are required for most large subdivisions, as well as other developments with anticipated usage greater than 10,000 gallons per day.

The County has ~ 165 reports on file. Well construction and aquifer testing data from these reports are electronically stored in County databases. Over 1,950 wells have been drilled and tested through this process.

## 1.4 USGS NAWQA Wells

As part of the USGS National Water-Quality Assessment Program (NAWQA) program, fourteen wells in Loudoun County were sampled between 1994 and 2004 for a broad range of chemicals. Data are compiled in a personal geodatabase format with related time series table. As many as 140 analyses per sample were analyzed including pesticides, radionuclides and volatile organic compounds. Two well sites in Purcellville were sampled in 2003 and 2004 with over 500 analyses each and showed little change over time. The total number of water quality analyses reported exceeds 3,000.

## 1.5 WRMP Monitoring Wells

B&D started monitoring groundwater levels in the county in 2003 and, with two wells added in December 2006, currently monitors ten wells (with the goal of establishing 17-20 wells by 2009). Water levels recorded by automatic data loggers several times per day and manually downloaded. Records are incomplete for some wells. (Water quality sampling from many of these wells may begin by late 2008.)

## 1.6 Water Quality Data from LCSA and VADH Public Water Supplies

These data are collected by state and local agencies to monitor public water supply wells. The only data obtained is from the annually published Consumer Confident Reports (CCR).

## 1.7 Luck Stone Special Exception Water Quality Reports

As part of the County regulatory process, Luck Stone Quarries supply B&D with quarterly groundwater quality and level data from their Bull Run facility.

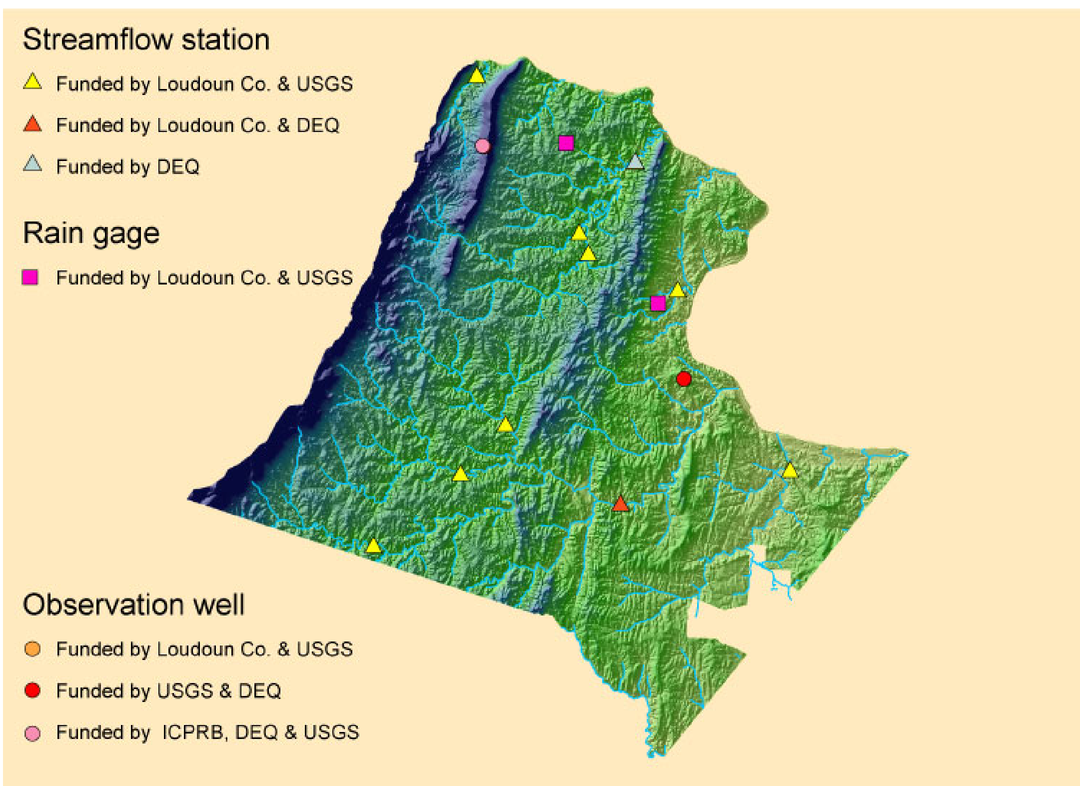
## 1.8 EPA Safe Drinking Water Information System (SDWIS)

Water Quality Data from Public water supply wells in Loudoun County. These data are routinely updated by EPA.

# 2. Government Hydrologic-related Data

## 2.1 Stream Stage & Discharge – USGS (and DEQ)

Ten stream gaging sites in Loudoun County (see map for locations) established by USGS and currently operated by USGS (8 sites) and DEQ (2 sites). Data include daily stage (ft) and discharge (cfs). Site locations and POR are: Broad Run at Rt. 7 (10/01-present), Limestone Branch at Rt. 15 (9/01-present), Goose Creek near Rt. 621 (1/30-present), Catoctin Creek at Taylorstown (11/70-present), S.F. Catoctin Creek at Rt. 698 (7/01-present), N.F. Catoctin Creek at Rt. 681 (8/01-present), N.F. Goose Creek at Rt. 734/Lincoln (8/01-present), Beaverdam Creek at Rt. 734/Mountvail (8/01-present), Goose Creek nr Middleburg (10/65-12/96 | 6/01-present), Piney Run at Rt. 671 (10/01-present). POR data and some statistics for these sites available on USGS web page. Since December 2006, the 15-minute "real-time" data available for only the last 30 days have been recorded as monthly snapshots, providing stage/discharge of provisional values for more detailed hydrographs. The Instantaneous Data Archive contained over 2.3 million records of 15-minute data since 1990.




Locations of stream gages, wells, and rainfall monitoring sites managed by, or in cooperation with, USGS.

## 2.2 Precipitation Data – National Weather Service / National Climatic Data Center

Daily precipitation (rain and frozen) collected as part of the National Weather Service Cooperative Station Network and purchased from NCDC. (These data sets are for distribution only by NCDC.) Five stations with relatively long and complete data sets in Loudoun County and vicinity currently purchased by B&D: Lincoln (1/30-7/06), Mt. Weather (8/48-7/06), Sterling RCS (9/77-7/06), Dulles Airport (3/63-7/06), and The Plains in Fauquier County (4/54-7/06). (See map for station locations.) Data sets have been converted from text files into Excel spreadsheets, missing records identified, and have monthly and annual totals calculated. **{Commercial data - restricted distribution}**

## 2.3 Precipitation Data – USGS

Two automated rain gauges (not heated to melt frozen precipitation) installed and activated for Loudoun County by the USGS in early 2003 (see map for locations). One station located in Lovettsville and one at Plains of Raspberry golf course. Stations equipped with telemetry devices for near-real time data posting to USGS web site. Equipment and reporting malfunctions resulted in impaired record quality to date.

## 2.4 USGS National Hydrology Data (NHD)

The NHD file, mapped at a 1:24,000 scale, provides a functional geometric network of all perennial and some intermittent streams. Stream locations are sometimes not consistent with recently developed suburban areas in eastern Loudoun. The geodatabase includes stream and water body naming consistent with GNIS.

## 2.5 USGS Elevation (NED)

The National Elevation Data available as a seamless download replaces the former DEM (Digital Elevation Model) tiles. Posting is 30 meters. Raster files are downloaded, converted to HARN and scaled from meter to feet.

## 2.6 National Wetlands Inventory (NWI)

The NWI inventory polygon file from the US Fish & Wildlife Service has been downloaded, merged and dissolved. In Loudoun the images dates are 1981 to 1994. Data are used for comparison with County wetlands models for eastern and western Loudoun.

## 2.7 Watershed Boundaries

There are several sources for watershed boundaries at different scales by several agencies.

**Loudoun County** watershed boundaries (aka "majsheds"), are mapped at 1:2,400 scale. There are 161 polygons, limited to Loudoun County. These are legacy, developed several years ago. Data is generally still current, though not necessarily completely consistent with the current "topo" layer. The mapping is to the 7th level. Naming is not consistent with federal efforts; however, naming is included for each level. Metadata is incomplete.

**VA DCR:** This includes 5th and 6th order of hydrologic units, mapped at 1:24,000 scale. The 6th order corresponds to the 12 digit HUC (12 digits - i.e. 020700040101). The 5th order corresponds to 10-digit HUC. Data is limited to state of Virginia.

**NRCS USDA:** Currently all of Virginia is “certified.” This includes 5th and 6th order (10 and 12-digit HUC). Data extends into MD. The naming is generally consistent with DCR, however they are not identical. The packaging of DCR and NRCS differs in that NRCS stores both 10 and 12-digit numbering in one file, but requires 6 files for County. DCR files require that table names be joined and there are separate files for the 10 and 12-digit layers. Note that there are no data available for WV at this time.

**USGS National Hydrology Data (NHD**): The boundaries are mapped at 1:100,000 scale. This extends beyond the County boundary and contains 2 polygons nominally. This comes in two resolutions, medium and high. The USGS only maps down to the 4th level or 8-digit HUC.

# 3. Government Environmental Studies

## 3.1 Geology – USGS/Loudoun County

Surficial and bedrock geology GIS layers and printed maps developed through mapping efforts by USGS with assistance from Loudoun County's former Department of Natural Resources. Bedrock map data updated by USGS in 1999. Following minor corrections with data labeling after consulting with USGS, layers incorporated into Loudoun County GIS in 2003.

## 3.2 VA DEQ Water Quality (Trend and Ambient Stream Monitoring)

The Dept of Environmental Quality (DEQ) operates numerous stream monitoring sites, often coincident with USGS stream flow gages. Water chemistry data includes basic cations and anions as well as pH, temperature, fecal/E.Coli. Trend stations are long-term sites and ambient stations are used on a rotating basis. Data are obtained from DEQ web site. There is a total of 57 monitoring sites in Loudoun County. Only nine of these are designated as "trend" sites. There are 98,000 water measurements on file.

## 3.3 VA DEQ 2006 Water Quality Assessment

The Dept of Environmental Quality (DEQ) publishes water quality impairments as part of the Water Quality Assessment Integrated Reporting of 305(b)/303(d) listings within the TMDL program. Stream reaches are assessed for exceedance of water quality standards for a particular use. Data are in GIS format for all of the stream reaches, not just the impaired sections.

## 3.4 Broad Run Water Quality Monitoring Program (OWML)

Since 1990, a station on Broad Run, upstream of the LCSA plant now under construction has been monitored for water chemistry and flow. Only an approximate site location is known. Over 430 sampling events have been recorded every two weeks with approximately 20 to 50 analyses per sample. In general the recent stream flow data were found to be consistent with the new USGS station on Broad Run. Review of the fecal concentration display the expected positive correlation with increased stream flow. Comparisons with DEQ data have not been examined. Data are available in raw Excel format only.

## 3.5 Fairfax County – SPS

In 1998, Fairfax County conducted stream monitoring for their Stream Protection Strategy. In 2002, a CD of the data was published that includes 2 sites in Loudoun County. Data also includes three sites upstream in Sugarland Run that flow into Loudoun County. Monitoring data is primarily related to macroinvertebrates using Rapid Bioassessment Protocol at over 120 sites. Other data include fish and habitat assessments. A GIS monitoring station file was received in 2003. The biological data reside in MS Application.

## 3.6 USGS NAWQA Surface Water

As part of the USGS National Water-Quality Assessment Program (NAWQA) program, five surface water samples were collected between 1992 and 2003 and analyzed for a broad range of chemicals. Data are compiled in a personal geodatabase format with a related time series table. As many as 80 analyses per sample were analyzed including pesticides and volatile organic compounds. At the Catoctin Creek -Taylorstown site, extensive sediment and analyses for PCBs were performed. The total number of water quality analyses reported exceeds 1,500 values.

## 3.7 Loudoun Soil & Water Conservation District Stream Monitoring

Since 1999, the LSWCD has monitored 14 stations in the Piney Run, Catoctin Creek, Little River, North Fork Goose Creek, and Beaver Dam watersheds for fecal coliform. This effort is related to the potential development of fecal coliform Total Maximum Daily Loads (TMDL) for these waterways, and was expanded to include E-Coli in 2003. Some water chemistry and macroinvertebrate data are also available. Data are periodically posted to the LSWCD web site (http://loudoun.vaswcd.org/) and the most recent data can be obtained by contacting the LSWCD office.

## 3.8 Fairfax County - Cub Run and Bull Run Watershed

In Fairfax County, watershed planning efforts extends into Loudoun in the Cub Run and Bull Run watershed. The watershed management plan includes maps of habitat assessment, stream obstructions, head cuts, utility crossings and dump sites. No tabular or GIS files have been requested. Identification of structural restoration projects (riparian buffer planting, pond retrofit, dump site removal, etc.) are limited to Fairfax County.

## 3.9 Occoquan Source Water Assessment and TMDL

The Occoquan River has headwaters in southeast Loudoun County. In the TMDL for bacteria, approximately 11 percent is attributed to Loudoun County. Modeling using HSPF indicates that a 90% reduction in Loudoun is needed to achieve TMDL goals. Modeling also addresses MS4 (storm water) loads from Loudoun County (42.3 ton/yr of sediments). No TMDL-specific field data was collected in Loudoun County. Note that recently, DEQ added a segment of Bull Run along the County border to the 2006 Category 5A listing as being impaired for bacteria.

## 3.10 Tributary Strategies

The EPA Tributary Strategies program in conjunction with Chesapeake Bay waste loading modeling has resulting in the preparation of “input decks.” Waste loadings are categorized and estimate loads computed. The Potomac watershed loads were then used to estimate the portion contributed by Loudoun County. These pollutant loadings are first order approximations only.

## 3.11 Wellhead Protection Plans

Well head protection plans prepared for several towns and community water systems within the past few years have been obtained for: Round Hill, Raspberry Falls, Lenah Run, and Beacon Hill. Plans for other communities are currently in development and will be obtained.

## 3.12 Town of Purcellville Water Supply Plan

In 2007, CH2M Hill and GeoTrans were contracted to conduct a water resources study for the town. Alternative water supply considerations included additional groundwater wells, reservoirs and surface water from the Potomac and Shenandoah Rivers.

# 4. Non-Government Environmental Studies

## 4.1 Rapid Stream Assessment Technique (RSAT) Survey by Council of Governments (COG)

Since 1997, five reports have been prepared by Metropolitan Washington Council of Governments COG providing assessments of the stream health in Loudoun County. The purpose is to document the baseline conditions for possible future watershed protection, restoration, monitoring and resource management initiatives and action. The RSAT technique provides a systematic evaluation of the physical, chemical and biological stream quality conditions. The six RSAT categories include: stream bank stability, channel scouring/sediment deposition, physical aquatic habitat, water quality, riparian habitat conditions and biological indicators (macroinvertebrates).

**RSAT of Sugarland Run Watershed - Phase I: Mainstem (1997).** Prepared for Virginia Environmental Endowment. The survey included 10.4 stream miles.

**RSAT of Sugarland Run Watershed - Phase II: Tributaries (1999).** Prepared for Virginia Environmental Endowment.

**Talbot Farm Tributary RSAT Survey (1998).** Prepared for the Virginia Department of Forestry, Loudoun Soil and Water Conservation District and Natural Resources Conservation Services. The Talbot Farm tributary is a third-order stream in the Catoctin watershed, near Waterford. The 3.7 square mile watershed is primarily cow pasture.

**Loudoun County Baseline Biological Monitoring Survey (2000-2002) - Phase I: Broad Run, Goose Creek, Limestone Branch, Catoctin Creek, Dutchman Creek and Piney Run Mainstem Conditions (2003).** Prepared for the National Fish and Wildlife Foundation. Streams were monitored at 26 stations and conditions were assessed for each of the six watersheds. To address channel morphology, a limited number of modified Rosgen Level I stream morphology analyses were performed and several one-time fecal coliform grab samples were performed.

**Loudoun County Baseline Biological Monitoring Survey (2004-2005), Phase II: Clark's Run, Catoctin Creek, Quarter Branch, Dutchmen Creek and Piney Run.** Prepared for the National Fish and Wildlife Foundation. In northern Loudoun, 16 stations were surveyed. Additional analysis included existing riparian buffer. Over 25 miles of stream do not meet the 35-foot riparian buffer. Over 270 potential reforestation sites were mapped and GIS coordinates available. Summary RSAT scores have been input into GIS format.

## 4.2 Goose Creek Demonstration Watershed Vulnerability Analysis

In 2003, PEC and the Goose Creek Association in consultation with the Center for Watershed Protection, reported on subwatershed plans. Report includes a summary table for 40 subwatersheds. The underlying GIS data (land use, imperviousness, etc.) are not readily available. Data is available from printed report only.

## 4.3 LCSA Goose Creek Source Water Protection

In 2003, LCSA developed a comprehensive source water assessment of their water intake in Goose Creek. The plan focuses on pollutant source, primarily within a 5-mile radius of the intake. Analysis includes waste loading calculating using PLOAD for suspended solids, nitrogen and phosphorous. In addition to a review of existing watershed characteristics, the study included 45 stream miles (10%) of assessments. Using EPA's Rapid Bioassessment Protocol, 68 reaches were characterized. Data is available from the printed report and primary stream assessment data has been input into GIS.

## 4.4 Goose Creek Vulnerability Analysis

In 2002 and 2003, PEC and the Goose Creek Association in consultation with the Center for Watershed Protection, completed its study of the Goose Creek watershed, covering both Loudoun and Fauquier counties. The project assessed the current and future health of the watershed on a subwatershed basis, with a field-verified, in-depth analysis of three subwatersheds and recommendations to improve or maintain their health. Data is available from printed report only.

## 4.5 Tuscorora Creek Field Work and Baseline Assessment

In 2007, PEC contracted the Center for Watershed Protection to perform field studies within the watersheds of the Town of Leesburg. Stream surveys and environmental assessments were documented along with sensitive areas inventory and recommendations for environmental improvement.

# 5. TMDL Studies

During the past several years, there have been five TMDL studies in Loudoun:

Catoctin Creek Bacteria (2002), Goose Creek Watershed Bacteria (2003), Limestone Branch Bacteria (2004), Piney Run Bacteria (2004), and Goose Creek and Little River Benthic (2004).

Each report is highly detailed and includes waste load modeling using a deterministic stream flow and waste load model or a statistical analysis of water quality data. In some TMDL reports, additional field work and stream monitoring data are included. All reports are available in Adobe format, though no data tables or GIS files have been received or recreated at this time.

The Catoctin Creek TMDL study was followed with an Implementation Plan (IP). The creek was first listed as impaired in 1996. The final TMDL was published in 2002. The Catoctin Creek IP includes implementation of the agricultural component of the Catoctin Creek TMDL Implementation Plan and is being funded annually with 319 Grant funds from DCR to LSWCD to work specifically with landowners in the Catoctin Creek watershed. Landowners in this watershed are provided financial and technical assistance for the installation of targeted agricultural BMPs, and education programs that encourage landowners to exclude livestock access to Catoctin Creek and its tributaries. The LSWCD is now entering their second five-year grant with DCR to continue these efforts. It is estimated that over $200,000 has been invested primarily in stream fencing during the past five years.

# 6. Citizen Stream Monitoring

## 6.1 Loudoun Wildlife Conservancy (LWC) and Loudoun Watershed Watch (LWW) - Benthic Stream Monitoring

The Loudoun Wildlife Conservancy (LWC) and has been collecting macroinvertebrate samples at 15 stations since the late 1990's. The LWC and other data were compiled by Loudoun Watershed Watch (LWW) in the 2002 and 2005 State of the Streams Reports. Data are available in report format and summary scoring has been input into GIS. Multiple measurements are available for most sites.

## 6.2 Catoctin Watershed Project (CWP)

In support of the Catoctin Creek TMDL Implementation, the Loudoun Wildlife Conservancy (LWC) volunteers have collected over 700 E. Coli samples at 14 stations in the Catoctin watershed between Lovettsville and Purcellville. Data are posted on web at Loudoun Watershed Watch (LWW) and used to constructed GIS layer with over 50 measurements per station.

## 6.3 Ashburn Pond (Student)

Several ponds in Ashburn have been monitored at fourteen locations for basic water parameters on a monthly basis since 2004. Measurements are in-field (LaMotte) and stored as Excel tables. Site locations coordinates are available.

## 6.4 EarthForce

In conjunction with several High Schools, Earth Force has collected about a dozen samples throughout the County in the fall 2005 and fall 2006. Water analysis includes: pH, turbidity, nitrate, phosphate, suspended solids, and E. Coli. Lab work was performed by Fairfax Water Authority. This data has not yet been compared with DEQ station data.

# 7. Basemap

## 7.1 Loudoun Drains and Water

At a scale of 1:2,400, the creek, stream ponds and drainage swales are mapped in GIS. Data has been updated using 2005 in western Loudoun and 2004 in eastern Loudoun. The drainage network is generally cartographically correct, though not ready for construction of a geometric network. All streams greater than 10 feet wide are mapped as polygons with stream centerlines arcs. Over 3,200 farm ponds with areas greater than 1/10 acre are mapped. Data is current as of 2005/2004 in western/eastern Loudoun.

## 7.2 Loudoun 3D Drains

In addition to drains, three-dimensional GIS shapefiles of the "drains" include the Z or elevation at all vertexes in the polyline layer. Elevation values are generally accurate to +/-0.1 feet.

## 7.3 Loudoun Historic Drains

The historic or preconstruction drainage GIS layer, mapped similar to "drains." The reaches are assigned a hydrologic attribute of alluvium, perennial, intermittent and not classified. This is not a complete drainage network and drains occasionally cross. The layer is maintained to be consistent with the "soils" layer. This data is helpful in understanding post construction wet basement problems.

## 7.4 Loudoun Topography

At 1:2,400 scale, 5-foot topography contours are mapped with null sections for buildings and roads. Data is current as of 2005/2004 in western/eastern Loudoun. There is no equivalent DEM or DTM, though these formats are anticipated later in 2007.

## 7.5 Loudoun Stormwater Infrastructure

A field survey of the stormwater infrastructure includes 46,000 inlets and pipe outfalls. There are over 600 miles of pipe and culvert. In support of maintenance, the GIS data include detailed specifications such as material type, size, flow direction and maintenance condition. The outfalls are snapped to the "drain" GIS layer. The inventory is supported by several photo libraries.

## 7.6 Loudoun Soil and Water Conservation District Agricultural BMPs

During the past 20 years, the LSWCD has worked with landowners to install agricultural best management practices (BMP stream fencing, alternate water systems, cover crops hardened crossings, etc.) to minimize non-point source pollution from agricultural sources in Loudoun County. Technical and financial assistance is available to landowners from the Virginia Agricultural BMP Cost-Share & Tax Credit Program and the USDA-Conservation Reserve Enhancement Program (CREP). Data though 2005 has been obtained through VA DOF. Data for Ag BMP in Catoctin watershed 2005-2008 have been obtained. In the Catoctin Watershed, data on the corrective actions performed by the Health Dept on private sewage disposal system has been obtained (2006-2008).

## 7.7 Loudoun County Sanitation Authority

The LCSA maps the water and sanitary in GIS. Data is primarily in eastern Loudoun and includes 50,000 water connection nodes, 17,000 sanitary sewer nodes, 650 miles of water lines and 838 miles of water lines. Tables include basic structural information. The geodatabase was restructured in 2007 and last updated in June 2007.

## 7.8 DC WASA

The Potomac Interceptor sanitary sewer line runs form Dulles airport north to the Potomac and also along Surgarland Run, eventually to the Blue Plains wastewater treatment plant in Washington DC. There are approximately 16 miles of pipe in GIS format. {Restricted data}

## 7.9 Virginia Conservation Lands Needs Assessment (VCLNA)

A statewide land use classification files have been obtained.

## 7.10 Virginia Department of Forestry Conservation Lands and Easements

The VFOD maps conservation easements and riparian buffer projects files have been obtained.

## 7.11 Orthoimagery

Loudoun County has numerous orthoimagery available for use in the GIS. These include:

Digital Orthoimage 2007 B&W
Digital Orthoimage 2005 B&W
Digital Orthoimage 2004 B&W (Partial – eastern Loudoun)
Digital Orthoimage 2002 Color (VGIN)
Digital Orthoimage 2003 Color Infrared (CIR - Partial)

Digital Orthoimage 1957 B&W Soils
Digital Orthoimage 2006 Color UDSA/NRCS NAIP (partial, lower quality)
Digital Orthoimage 2005 Color leaf-on Aerial Express (not on-line, requires 9.2)

## 7.12 DCR Land Use/Land Cover

The Dept Recreation and Conservation map land use. GIS files have been obtained.

## 7.13 USGS NLCD Land Use/Land Cover

The US Geological Survey offer land use classification. At present only eastern Loudoun County has been produced with the remainder soon to be posted on-line. Available files have been obtained.

## 7.14 Regulatory Stream Designations

Loudoun County has two scenic rivers, Catoctin and Goose Creek. These are mapped using arcs at several scales by Dept Recreation and Conservation (DCR) and by Loudoun County Office of Mapping. The arcs are buffered by 300 feet for zoning overlay analysis.

## 7.15 DCR Natural Heritage Screening

DCR maintains a natural heritage GIS layer, available though on-line web mapping via a subscription service. Loudoun County also received these data, subject to restrictions. “Natural heritage resources are defined as the habitat of rare, threatened, or endangered plant and animal species, rare or state significant natural communities or geologic sites, and similar features of scientific interest. DCR maintains a data system that is the most comprehensive and up-to-date repository of natural heritage resource information available. Information on potential impacts to natural heritage resources is crucial to a comprehensive environmental assessment of proposed developments or activities. “

# 8. GIS Zoning Overlays, Analysis and Models

## 8.1 Floodplain Overlay

The floodplain boundary includes the digital floodplain map of FEMA (DFIRM), as approved in July 2001. Additional to the floodplain layer include recent flood studies and floodplain alterations and do not necessarily edge match to the DFIRM.

The regulatory floodplain boundary reflects the limits of flooding resulting from a storm having an occurrence probability of 1%, identified as the 100 year storm. The floodplain boundary was recompiled from the listed sources onto the County's 1:2400 scale maps with five-foot interval topography.

Floodplain data is used to establish a Floodplain Overlay District (FOD) as defined in the Zoning Ordinance of Loudoun County, which restricts the allowable uses within the regulatory floodplain. Data is used to establish flood risk factors and eligibility to participate in the National Flood Insurance Program. Floodplain data are also used in land use planning and for taxation of land.

## 8.2 Mountainside Overlay

The Mountainside Development Overlay District is a zoning overlay district administered by the Department of Building and Development. Mountainside classifications are based upon the following criteria: critical elevation, soils, slope, and forest values. Critical elevation areas are determined from the County's digital topography, soil and slope values are based upon data the County's soil layer and digital forest data. For more information consult the metadata for those layers.

## 8.3 Limestone Overlay

The limestone overlay is an area represented by the Limestone Conglomerate Overlay District (LOD) is generally east from the Catoctin Mountain Range to the Potomac River (excludes Lost Corner), and from Leesburg north to Point of Rocks, MD. The LOD is a zoning overlay district administered by the Loudoun County Department of Building and Development. The Department is responsible for all development approvals, review procedures, modifications and density calculations in the LOD as governed by Article VI, "Development Process and Administration," of the Revised 1993 Zoning Ordinance, and procedures in Chapter 8 of the Facilities Standards manual.

The LOD is comprised of all or portions of the following geologic formations: Cf-Frederick Limestone, Ct-Tomstown Dolomite, JTRc-Catharpin Creek Formation, JTRcg-Catharpin Creek Formation Goose Creek Member, TRbl-Balls Bluff Siltstone Leesburg Member, and TRbs-Balls Bluff Siltstone Fluvial and Deltaic Sandstone Member.

NOTE: The Circuit Court of Loudoun County issued an opinion dated March 30, 2004 ruling that the Limestone Conglomerate Overlay District (LCOD) is void. The March 30, 2004 decision may be the subject of an appeal.

Purpose: The land area delineated by the boundaries of the LOD is comprised of limestone and "Karst terrain" areas. The terrain is also characterized by the presence of certain natural features, such as sinkholes and rock outcrops. Thus, development on Karst terrain has a direct correlation to the potential for collapse and ground slippage and the susceptibility of groundwater and surface water pollution, and spring contamination, posing serious risks to public health, safety and welfare. The provisions of Section 4-1900 of the Revised 1993 Zoning Ordinance are intended to regulate land use and development in areas underlain by limestone and in areas with Karst features and terrain as shown on the official Limestone Conglomerate Overlay District Map of Loudoun County.

## 8.4 Steep Slopes Overlay

The Steep Slope layer identifies areas with a slope greater than 15% in Loudoun County. Steep Slope assists in identifying steep slope areas. Improper uses and disturbances in steep slope areas cause erosion, result in structural failure of structures and roads, and lead to downstream flooding and other hazards.

## 8.5 River and Stream Corridor Overlay

The Circuit Court of Loudoun County issued an opinion dated March 30, 2004 ruling that the River and Stream Corridor Overlay District (RSCOD) is void. The Floodplain Overlay District (FOD) and the Scenic Creek Valley Buffer regulations in effect prior to adoption of the RSCOD on January 6, 2003, will apply in the administration of zoning regulations. The March 30, 2004 decision may be the subject of an appeal.

The River and Stream Corridor Overlay District (RSCOD) was created in the 2001 Comprehensive Plan. It was created to protect corridor resources, including water quality, aquatic and wildlife habit, and scenic value.

RSCOD is composed of:

a. Rivers and streams draining 100 acres or more

b. 100-year floodplains (includes major and minor)

c. adjacent steep slopes (25% or greater), starting within 50 feet of streams and floodplains but extending no further than 100 feet beyond

d. 50-foot management buffer around steep slopes and floodplain

e. 100-foot buffer measured from the scar line on both sides of streams that drain 100 acres or more

f. 300-foot buffers around state designated scenic rivers (Goose Creek, Bull Run, Catoctin Creek from the bridge at Route 698 at Waterford to the Potomac River); the Potomac River, and County reservoirs (Beaverdam and Goose Creek) the originating stream or floodplain

## 8.6 Wetlands Model(s)

Loudoun County has developed models to predict wetlands, under a grant from the United States Environmental Protection Agency. The model incorporates several sources of information and data available to the County to produce a weighted estimation of the presence of actual wetlands. Data inputs to the model include hydric soils, drainage, points for wet spots, marshes and springs, water bodies, slopes and National Wetlands Inventory. There are separate Wetlands model for the eastern and western Loudoun.

## 8.7 Impervious Surface Analysis

Using the basemap layers of roads and building, a composite feature class of "impervious surface" has been developed based on March 2005 conditions. Future refinements may include use of data for sidewalks and other impervious features not currently included.

## 8.8 Alternate Wastewater Disposal Potential Analysis

Using the soils classification table, areas favorable and unfavorable for alternate wastewater disposal sites are identified. The soils have been classified according to their soil mapping unit into the categories of no potential, spray irrigation, shallow-placed drip / alternative drain fields or conventional gravity and low pressure systems. This classification is an interpretation based on the soil mapping unit and its' basic characteristics.

## 8.9 Groundwater Recharge Analysis

Using the soils classification table, areas of groundwater recharge are mapped. Soil polygons are classified as being discharge areas, or having moderate to high or low to moderate recharge potential. This classification is an interpretation based on the soil mapping unit and its' basic characteristics.

## 8.10 LID Infiltration Potential Analysis

Using the soils classification table, areas of favorable low impact development (LID) infiltration are mapped. Classifications for infiltration potential include good, fair, poor, very poor, no potential or water. This classification is an interpretation based on the soil mapping unit and its' basic characteristics.

## 8.11 Open Space

The open space feature class contains permanent open space easements for Loudoun County. The open space feature class is utilized for taxation, planning and in the Purchase of Development Rights (PDR) Program (no longer in existence).

## 8.12 Planned Land Use

The planned land use feature class is a general reference relating to authorized land use. The data is used extensively by the Planning and Building and Development departments. The data layer is administered by the Planning and Development office.

## 8.13 Agricultural Districts

This data set identifies properties that participate in and are part of Agricultural overlay districts according to State enabling legislation per the Virginia State Code, Chapter 43, Section 15.2, Agricultural Districts. Economic Development administers the County's Agricultural District program. A parcel is not the smallest unit within an Agricultural District. A portion of any parcel can be in or out of a district, through appropriate reviews, without an official subdivision. This layer identifies properties within each of the Agricultural Districts, which are used by participants to preserve farmland and open space through parcel subdivision restrictions. Each Agricultural District has unique terms and subdivision restrictions.

***Data quality matrix for data sources employed by the Loudoun County Water Resources Monitoring Program.***

| *Data Quality Level* | *Quality Assurance Plan* | *Project Data Collection* | *Standard* | *Standard Reference* | *Data Acceptance Criteria* | *Data Use* |
|---|---|---|---|---|---|---|
| A | Internal QAPP approved by QA officer | Groundwater Level Monitoring: Data collected by Loudoun County and/or County contractors. | Loudoun County SOP for Groundwater Level Monitoring. | ASTM D 4750-87 | Precision ≤ ± 0.04' | Decision making for policy and regulatory processes. |
| | | Groundwater Quality Sampling: Data collected by Loudoun County and/or County contractors. | Loudoun County SOP for Groundwater Sample Collection | ASTM D 4448-85a USGS National Manual for the Collection of Water-Quality Data | Multiple water-quality field measurements using approved methods. | Decision making for policy and regulatory processes. |
| B | External QAPP | Groundwater Quality Analysis: National Testing Laboratories | External QA and SOP | EPA analytical techniques. | Approved method detection limits. | Decision making for policy and regulatory processes. |
| | | Precipitation: National Weather Service | External SOP | NWS Observation Handbook No 2: Cooperative Station Observations | Precision ≤ ± 0.01" | Decision making for policy and regulatory processes. |
| | | Stream Flow: USGS, VDEQ | External SOP | Rantz, S.E., 1982, Measurement and Computation of Streamflow: Vol. 1, Measurement of Stage and Discharge. U.S. Geol. Survey Water-Supply Paper 2175, 284 p. | Precision calculated as a function of discharge, discharge trend, stream geometry and apparatus. Acceptable error ≤ ± 2% of measured flow. | Decision making for policy and regulatory processes. |
| | | Surface Water Quality: VDEQ | External SOP | Standard Operating Procedures Manual for the Dept. of Env. Quality Office of Water Quality Monitoring and Assessment. | Approved method detection limits. | Decision making for policy and regulatory processes. |
| | | Groundwater Level Monitoring: VDEQ, ICPRB, USGS | External SOP | ASTM D 4750-87 | Precision ≤ ± 0.04' | Decision making for policy and regulatory processes. |
| | | Stream Assessment: VDEQ | External SOP | Galli, John, 1992, Rapid Stream Assessment Technique (RAST). Metropolitan Washington Council of Governments. | Approved methods. | Decision making for policy and regulatory processes. |

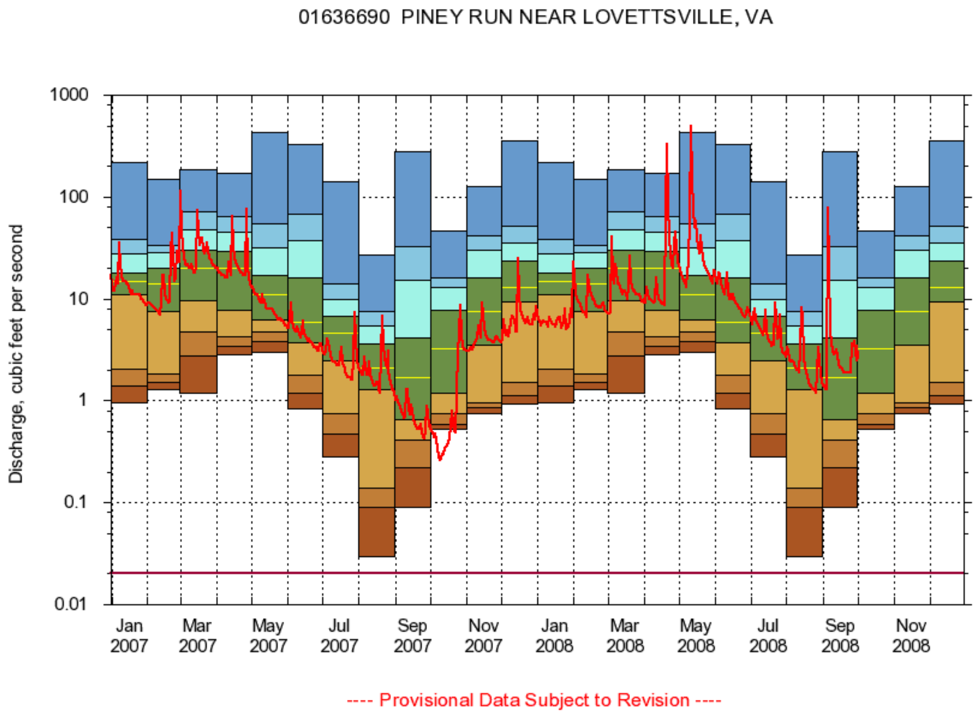
### *Data quality matrix for data sources employed by the Loudoun County Water Resources Monitoring Program.*

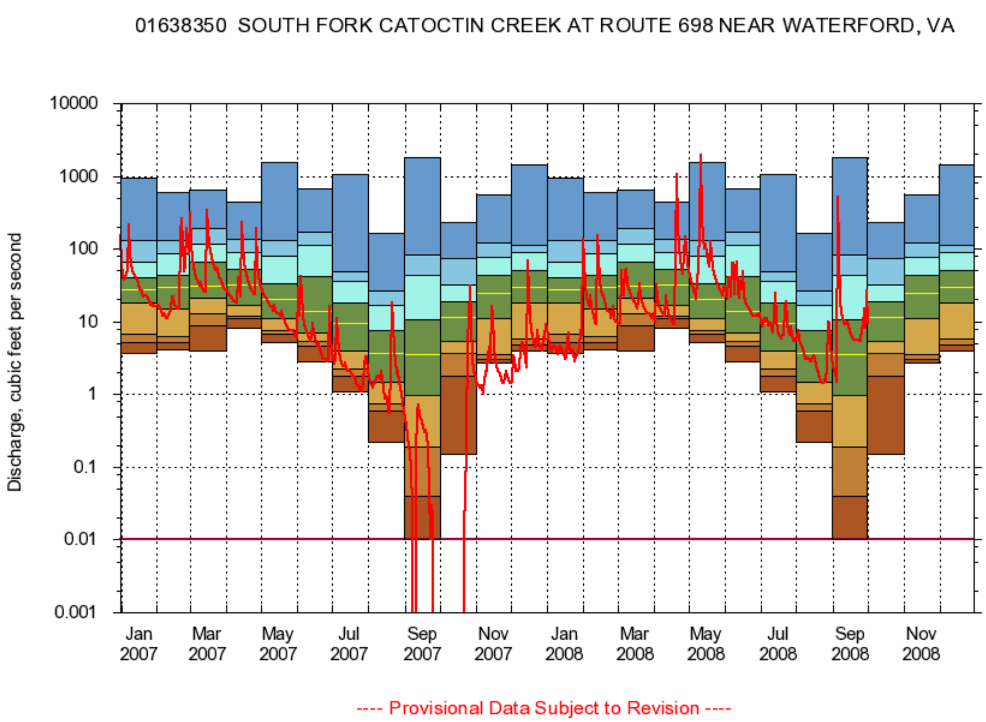
| *Data Quality Level* | *Quality Assurance Plan* | *Project Data Collection* | *Standard* | *Standard Reference* | *Data Acceptance Criteria* | *Data Use* |
|---|---|---|---|---|---|---|
| C | Minimum Data Acceptance Criteria met | Precipitation: USGS | No SOP | | Precision ≤ ± 0.01" | Back-up data source to fill gaps in NWS record. |
| D | Minimum Data Acceptance Criteria not met | Groundwater quality sampling: Data collected by LCDEH | No SOP | Sampling methods may be questionable | | Data used only as screening tool for probabilistic sampling strategy. |
| | | Stream Assessment: Volunteer Program | Guidance manual | | | Results used as screening tool to assess needs for Standard Stream Assessment. |

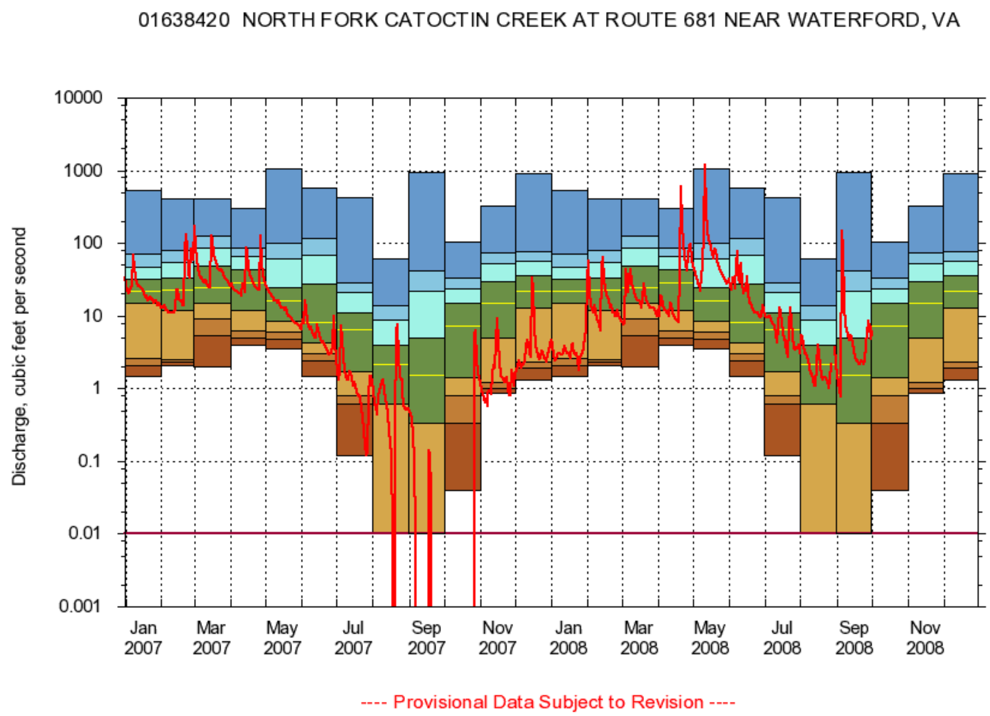
APPENDIX B1

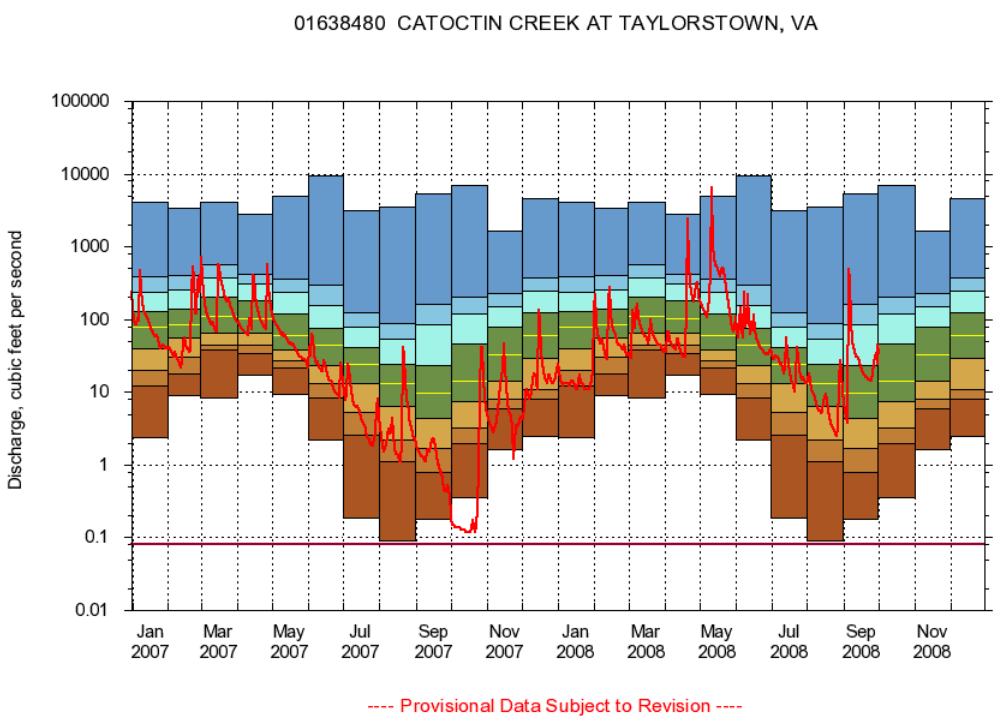
# Stream Flow and Rainfall

# B1.1 Comparison of Recent Flows with Long-Term Statistics

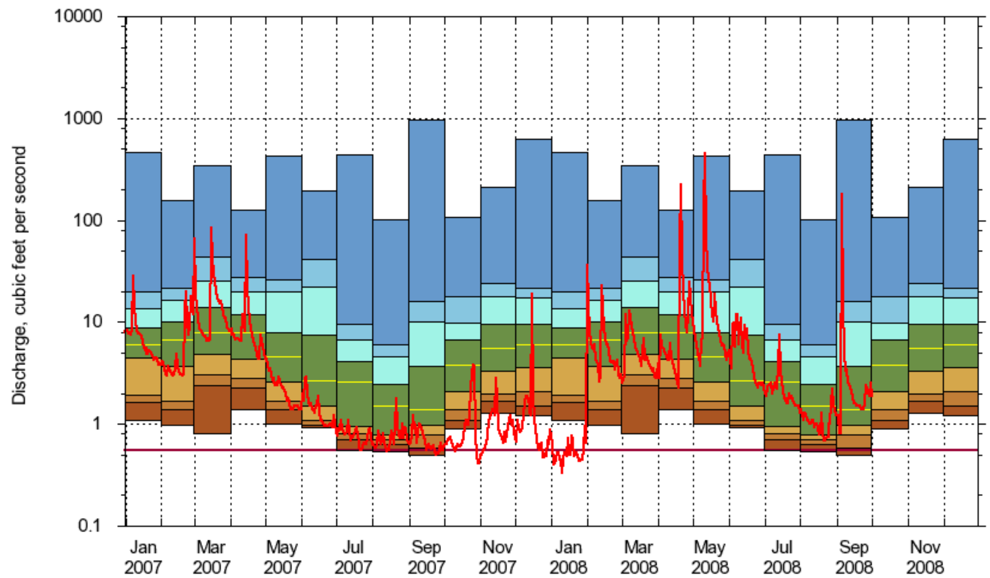



01638420 NORTH FORK CATOCTIN CREEK AT ROUTE 681 NEAR WATERFORD, VA
Discharge, cubic feet per second
10000
1000
100
10
1
0.1
0.01
0.001
Jan 2007
Mar 2007
May 2007
Jul 2007
Sep 2007
Nov 2007
Jan 2008
Mar 2008
May 2008
Jul 2008
Sep 2008
Nov 2008
---- Provisional Data Subject to Revision ----

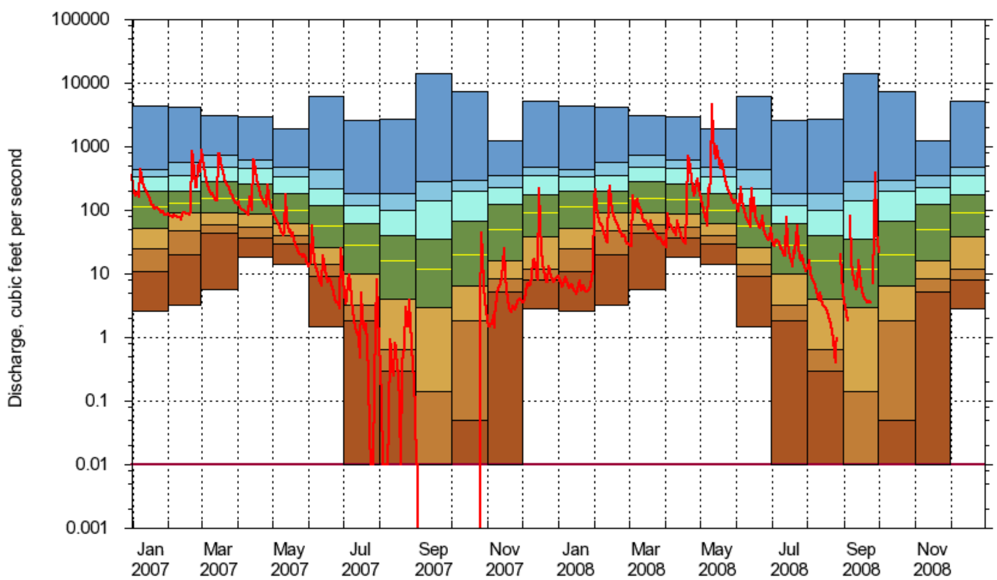

01638480 CATOCTIN CREEK AT TAYLORSTOWN, VA
Discharge, cubic feet per second
100000
10000
1000
100
10
1
0.1
0.01
Jan 2007
Mar 2007
May 2007
Jul 2007
Sep 2007
Nov 2007
Jan 2008
Mar 2008
May 2008
Jul 2008
Sep 2008
Nov 2008
---- Provisional Data Subject to Revision ----

01643590 LIMESTONE BRANCH NEAR LEESBURG, VA



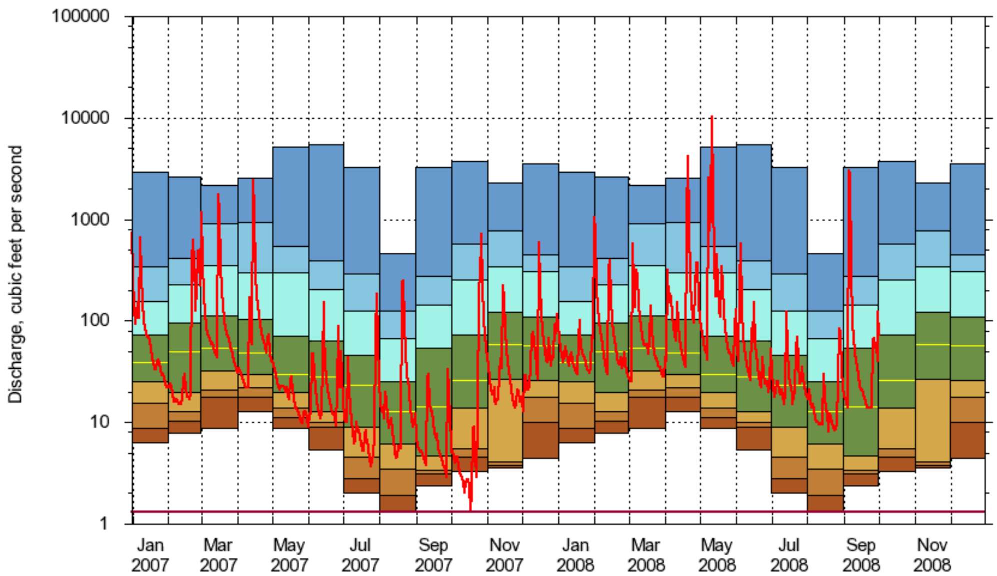

---- Provisional Data Subject to Revision ----

01643700 GOOSE CREEK NEAR MIDDLEBURG, VA



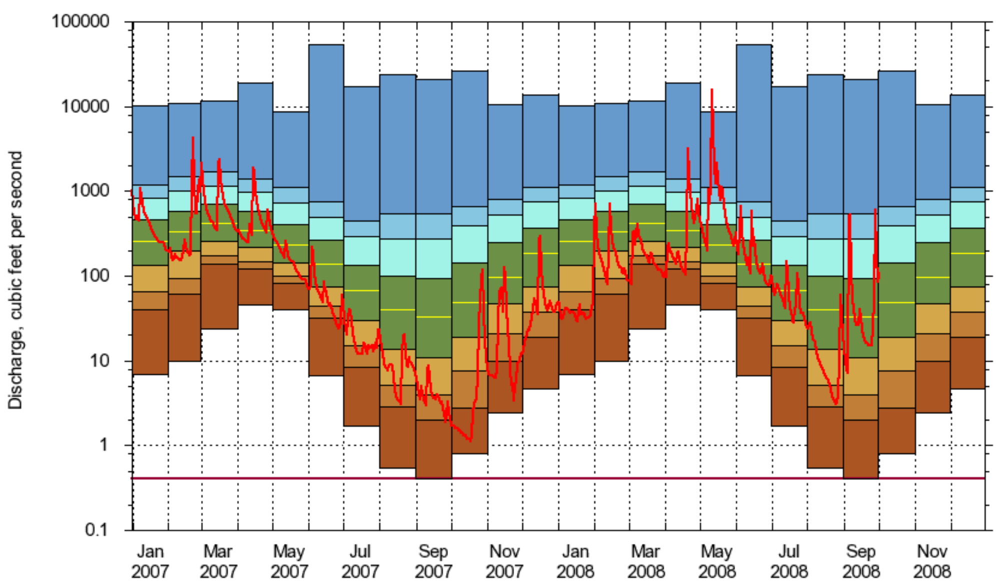

---- Provisional Data Subject to Revision ----

01644280 BROAD RUN NEAR LEESBURG, VA



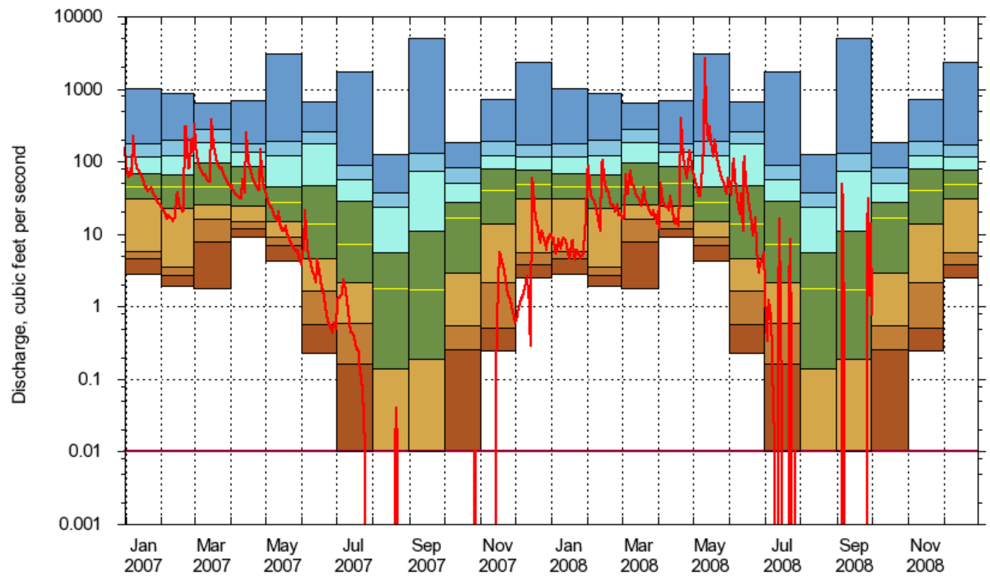

---- Provisional Data Subject to Revision ----

01644000 GOOSE CREEK NEAR LEESBURG, VA



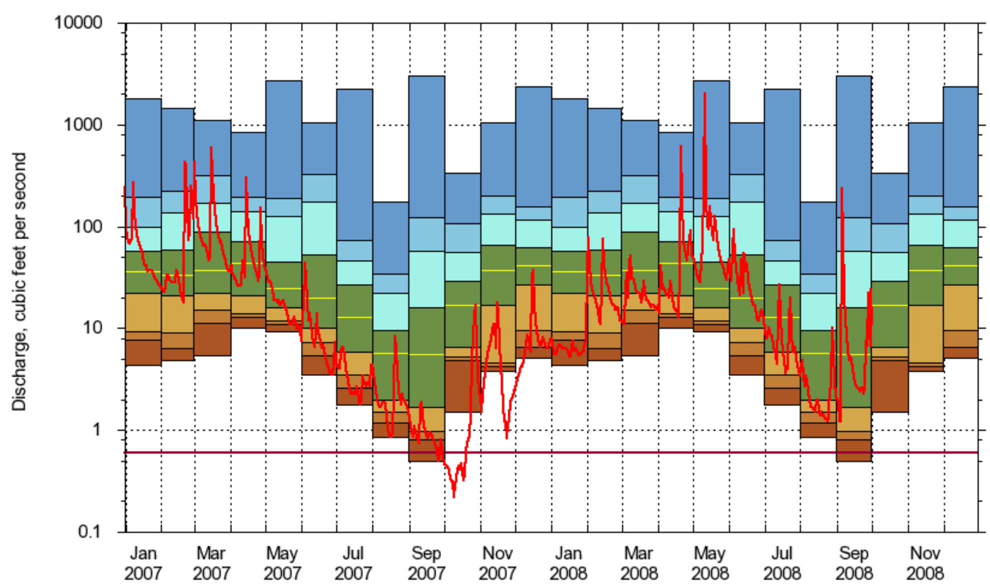

---- Provisional Data Subject to Revision ----

01643880 BEAVERDAM CREEK AT ROUTE 734 NEAR MOUNTVILLE, VA



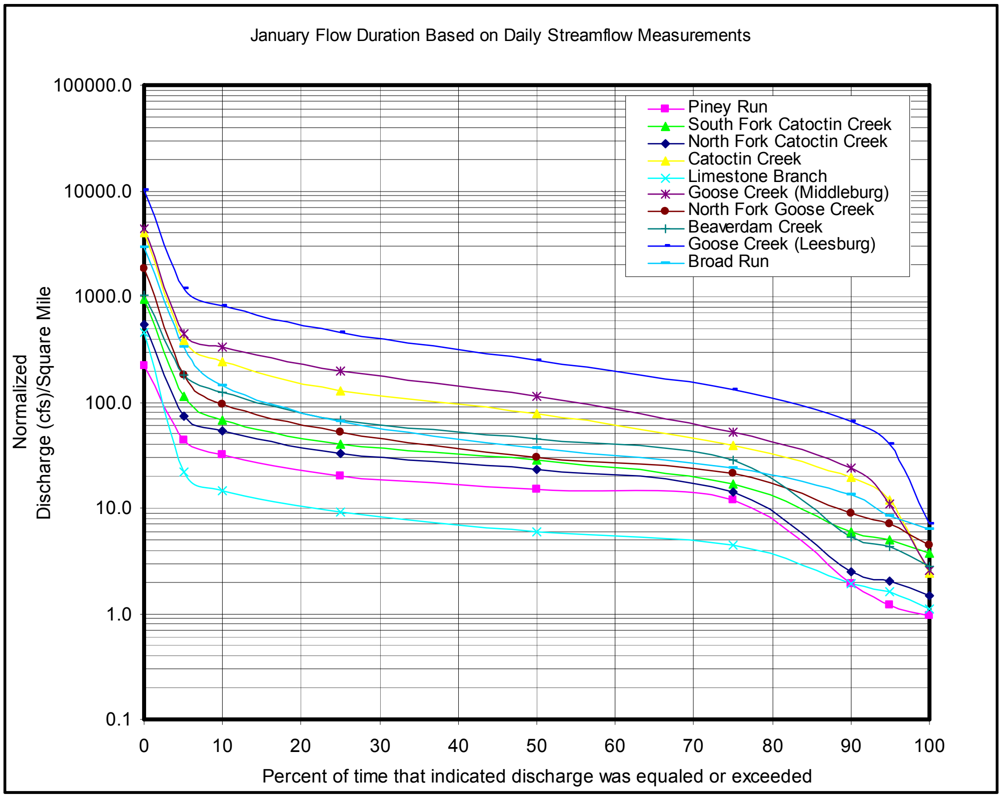

---- Provisional Data Subject to Revision ----

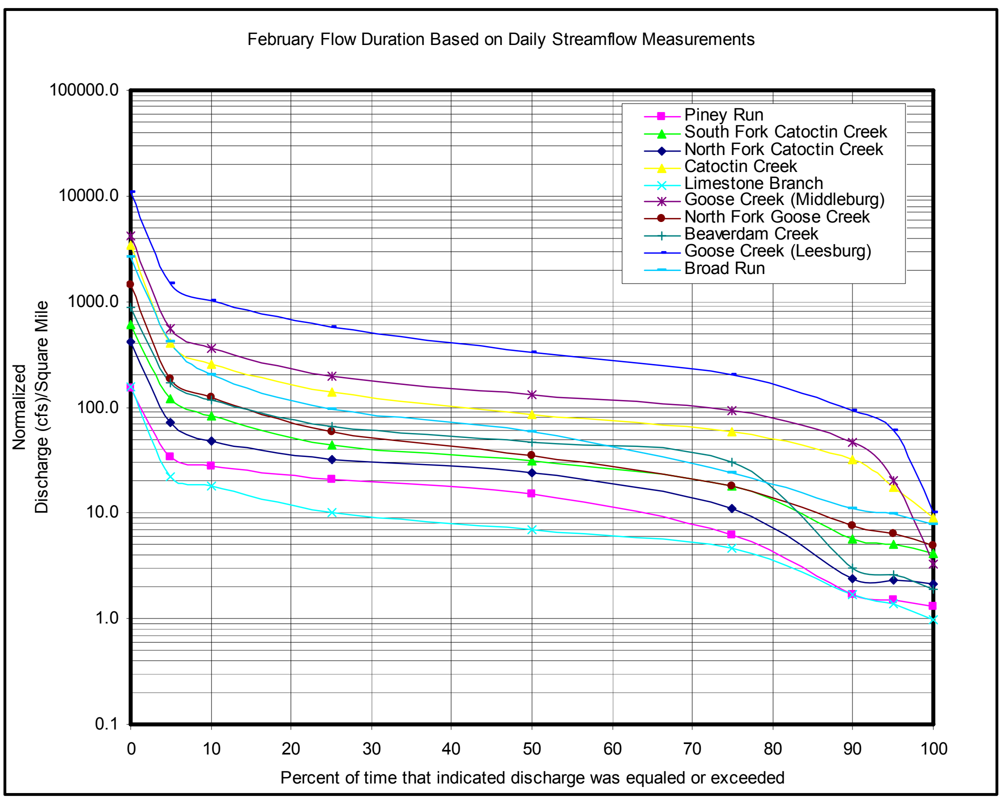
01643805 NORTH FORK GOOSE CREEK AT ROUTE 729 NEAR LINCOLN, VA

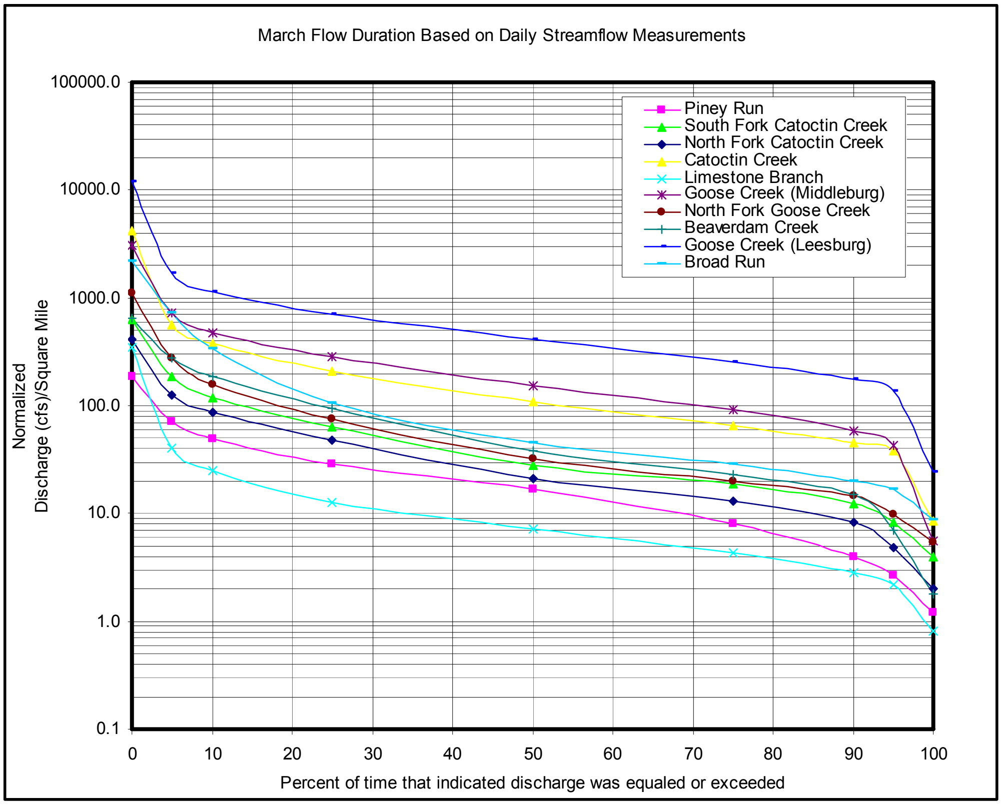


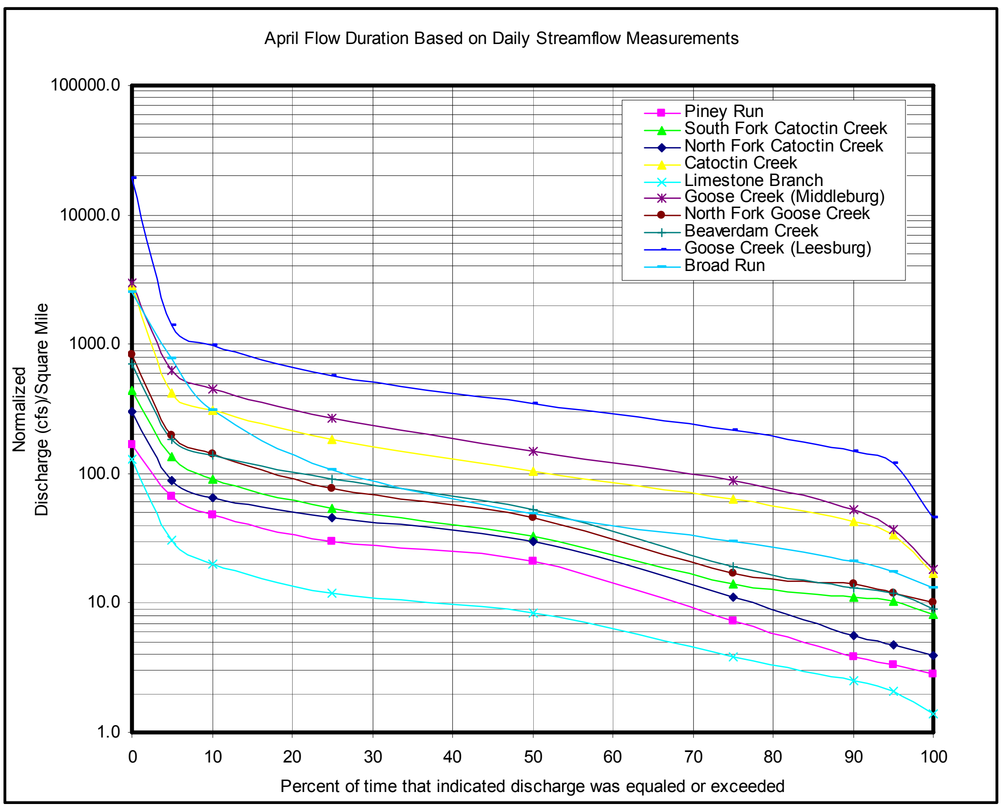

---- Provisional Data Subject to Revision ----

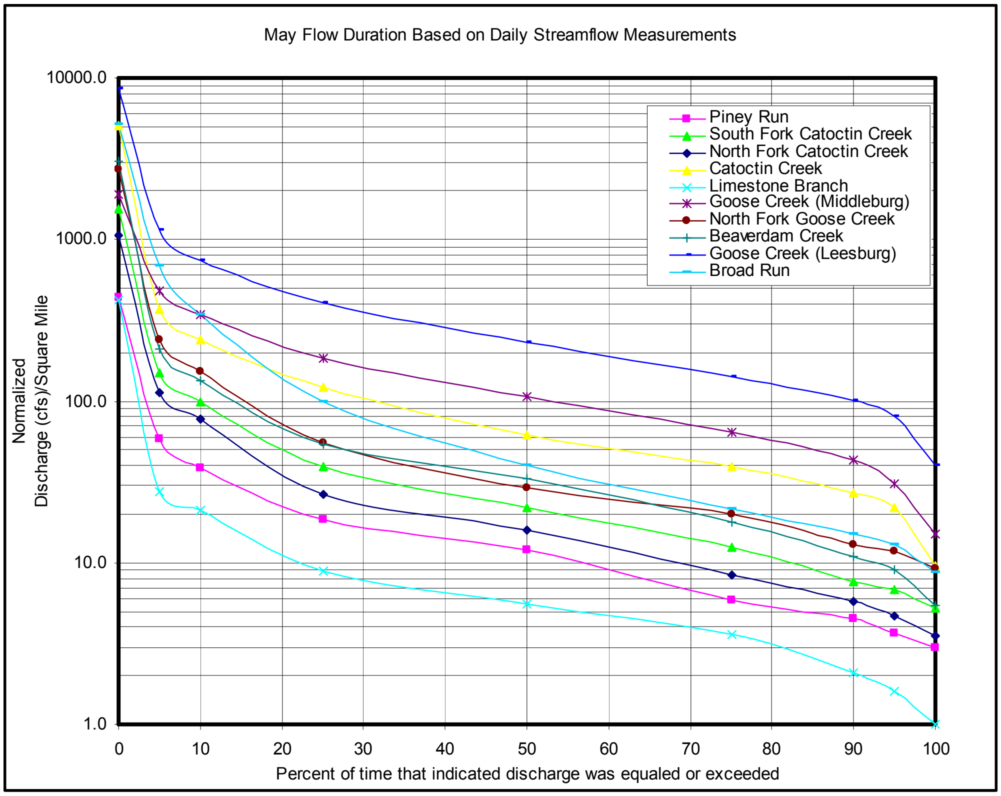
# B1.2 Stream Flow Duration Curves

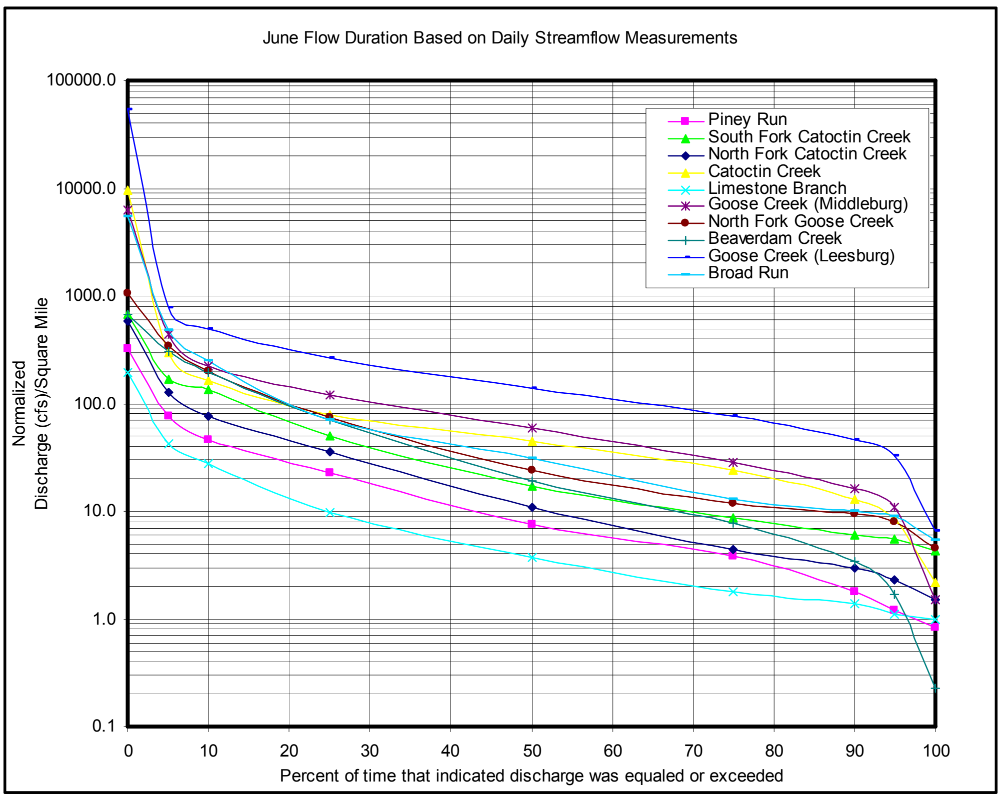


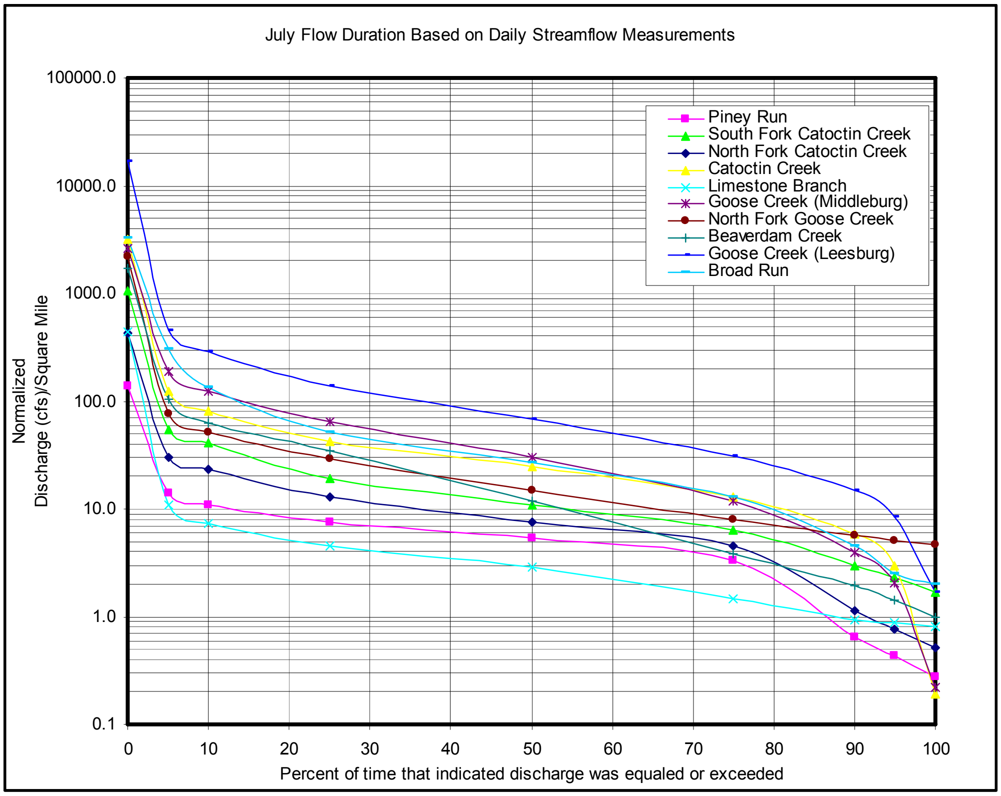




March Flow Duration Based on Daily Streamflow Measurements
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
Normalized
Discharge (cfs)/Square Mile
0
10
20
30
40
50
60
70
80
90
100
Percent of time that indicated discharge was equaled or exceeded
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

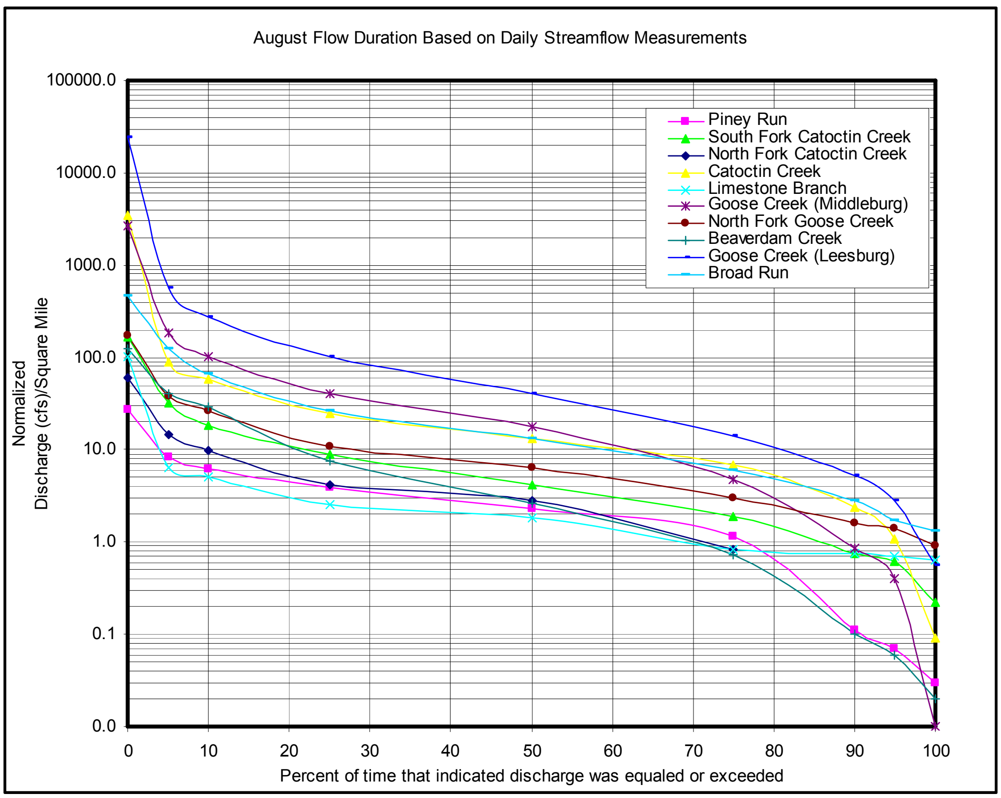

April Flow Duration Based on Daily Streamflow Measurements
100000.0
10000.0
1000.0
100.0
10.0
1.0
Normalized
Discharge (cfs)/Square Mile
0
10
20
30
40
50
60
70
80
90
100
Percent of time that indicated discharge was equaled or exceeded
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run


May Flow Duration Based on Daily Streamflow Measurements
Normalized Discharge (cfs)/Square Mile
Percent of time that indicated discharge was equaled or exceeded
10000.0
1000.0
100.0
10.0
1.0
0
10
20
30
40
50
60
70
80
90
100
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

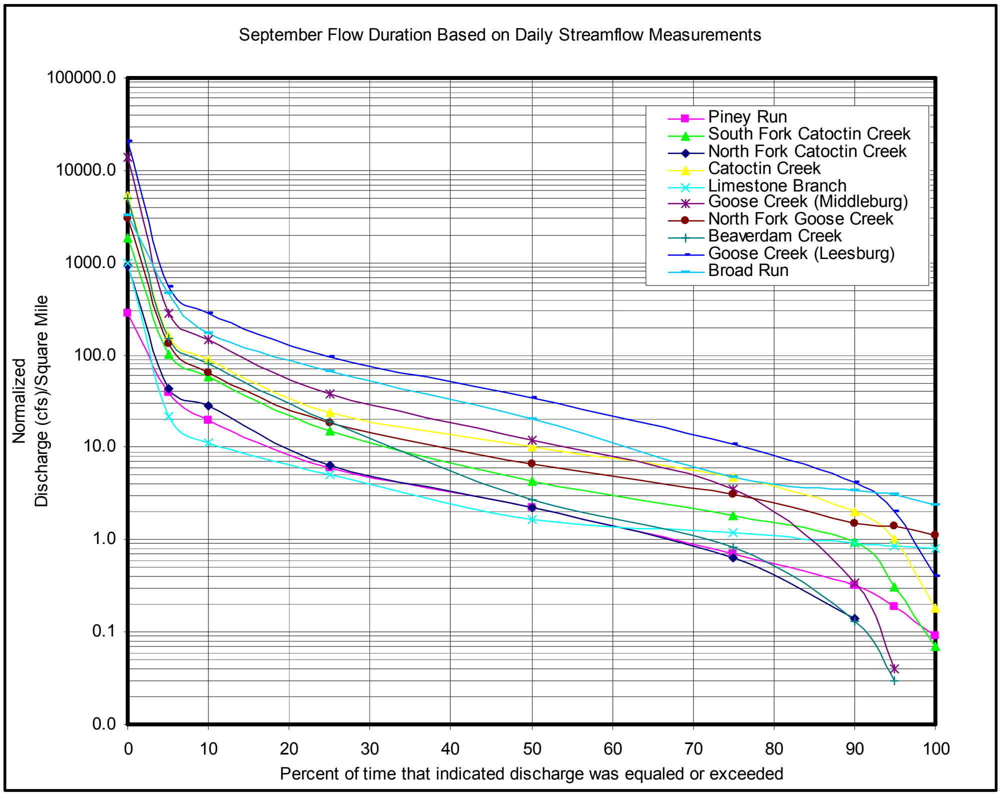

June Flow Duration Based on Daily Streamflow Measurements
Normalized Discharge (cfs)/Square Mile
Percent of time that indicated discharge was equaled or exceeded
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0
10
20
30
40
50
60
70
80
90
100
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

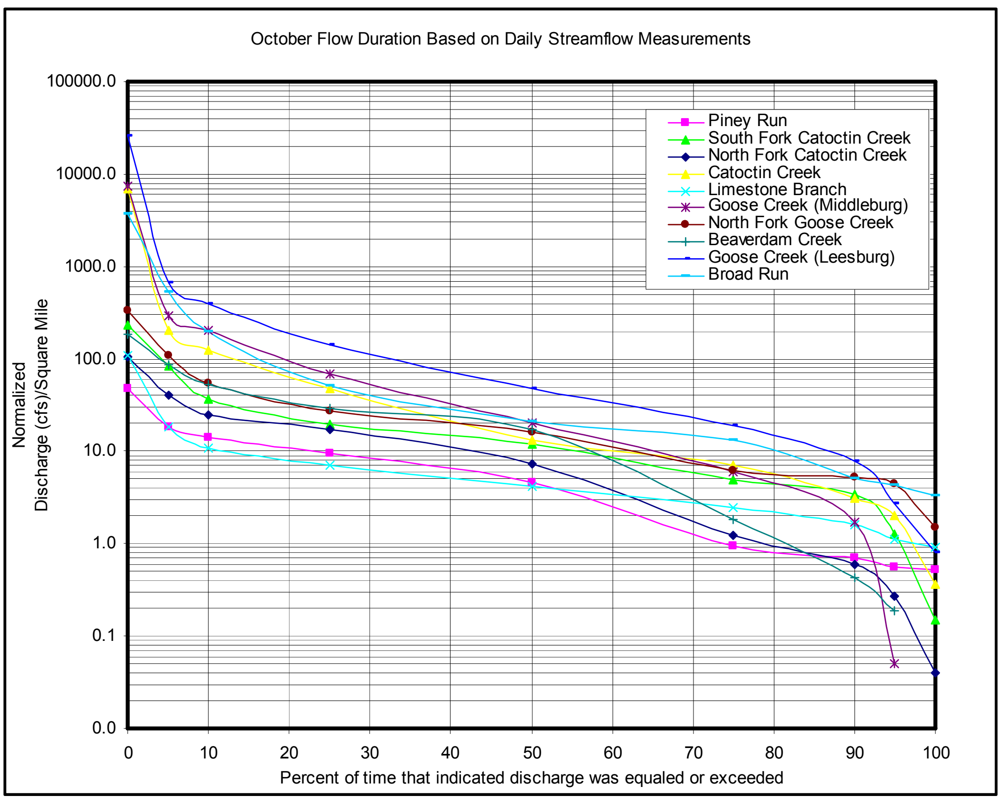


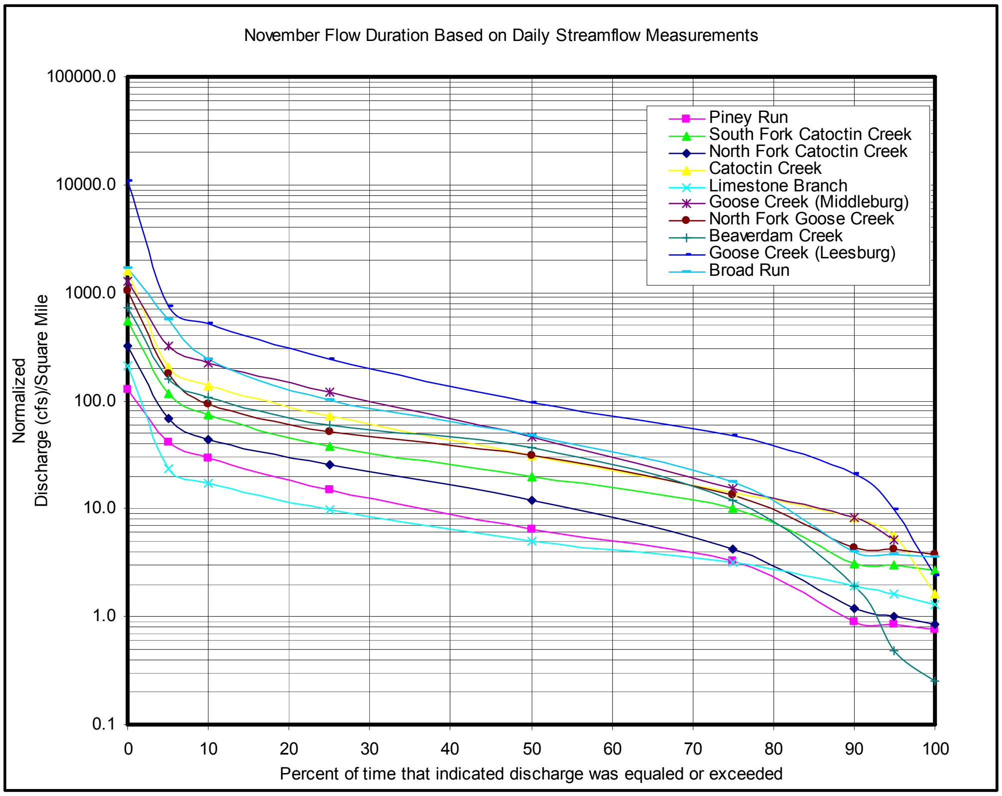
July Flow Duration Based on Daily Streamflow Measurements
Normalized Discharge (cfs)/Square Mile
Percent of time that indicated discharge was equaled or exceeded
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0
10
20
30
40
50
60
70
80
90
100
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

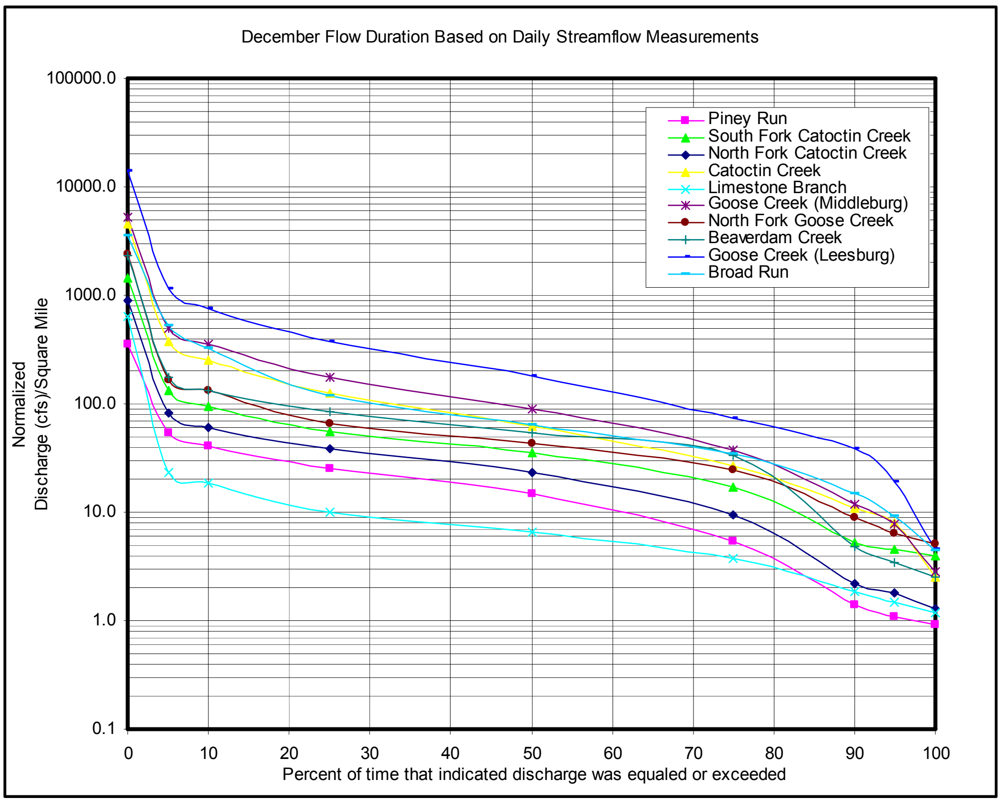



August Flow Duration Based on Daily Streamflow Measurements
Normalized Discharge (cfs)/Square Mile
Percent of time that indicated discharge was equaled or exceeded
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

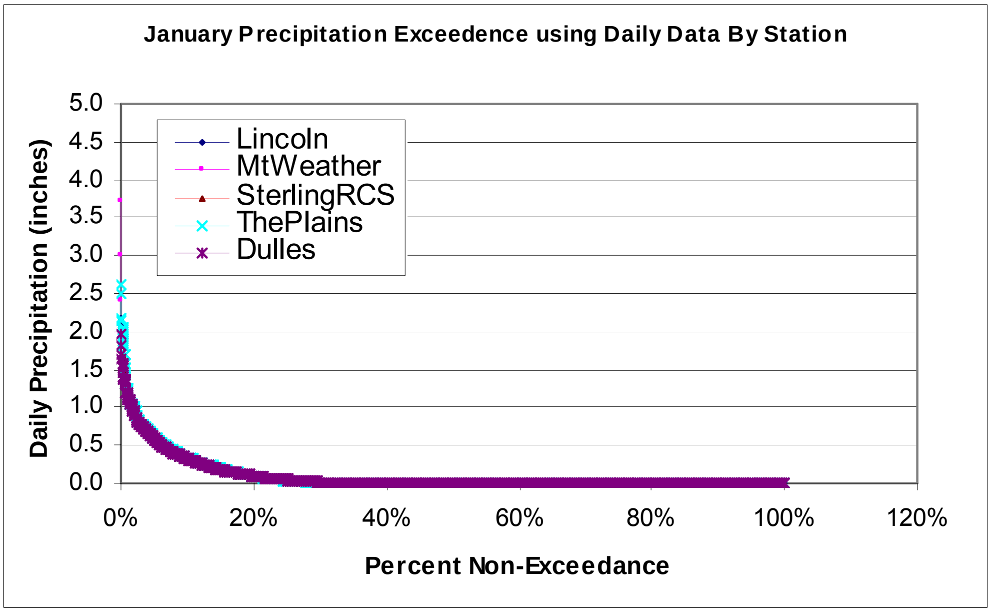

September Flow Duration Based on Daily Streamflow Measurements
Normalized Discharge (cfs)/Square Mile
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
Percent of time that indicated discharge was equaled or exceeded
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

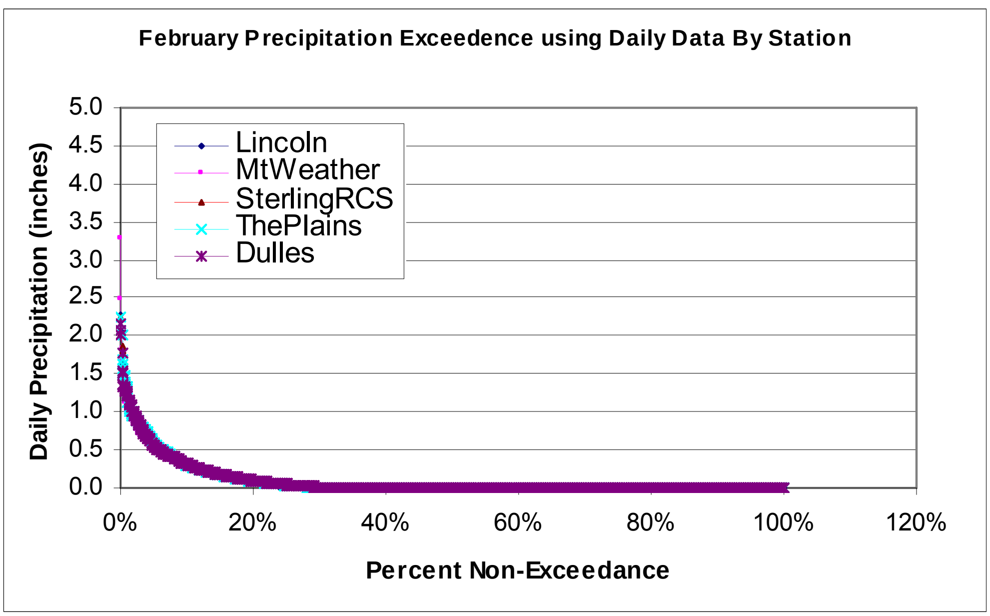

October Flow Duration Based on Daily Streamflow Measurements
Normalized Discharge (cfs)/Square Mile
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
Percent of time that indicated discharge was equaled or exceeded
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

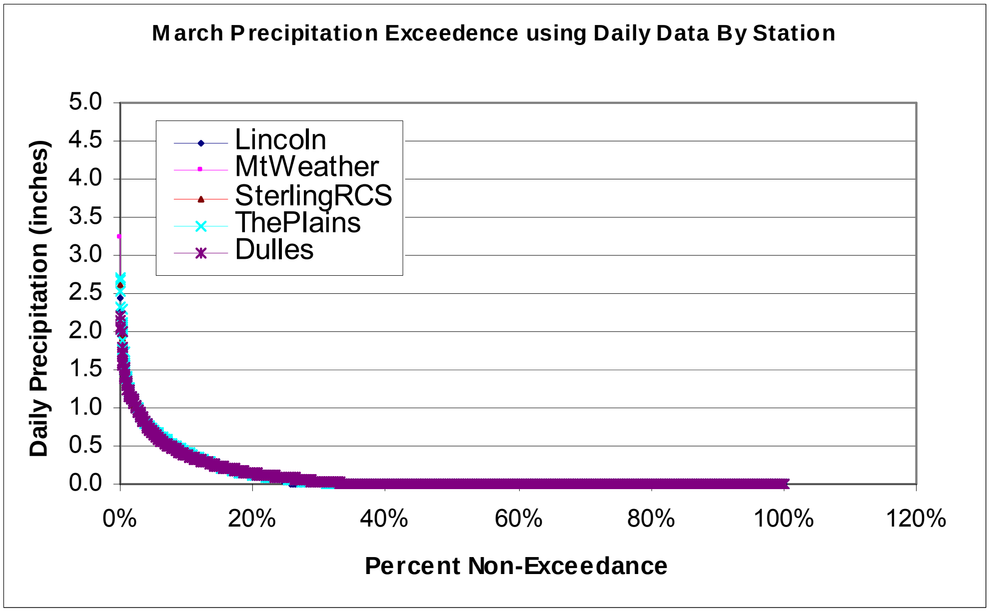

November Flow Duration Based on Daily Streamflow Measurements
Normalized Discharge (cfs)/Square Mile
Percent of time that indicated discharge was equaled or exceeded
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0
10
20
30
40
50
60
70
80
90
100
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

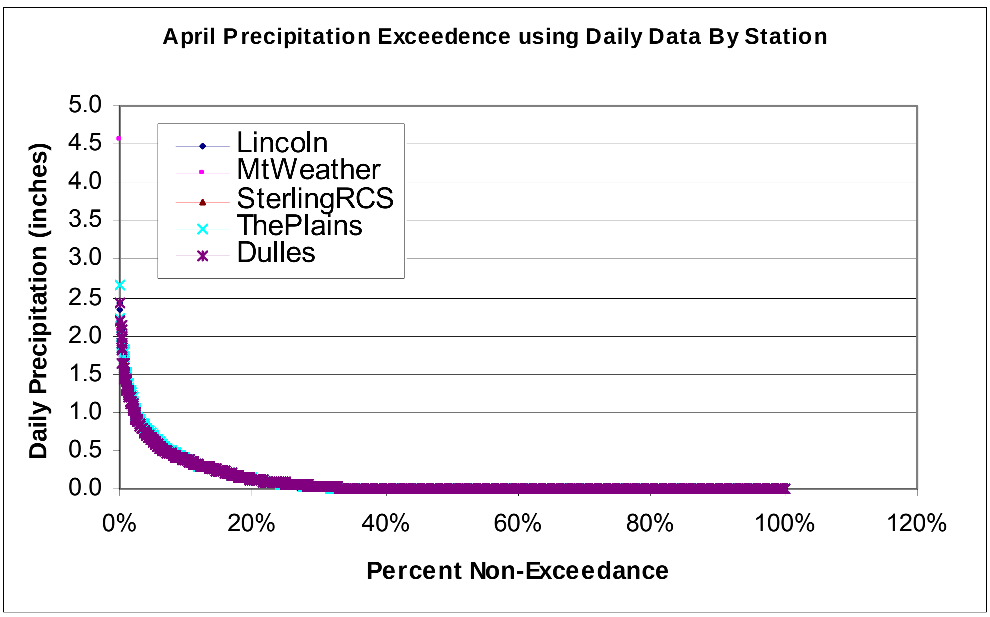

December Flow Duration Based on Daily Streamflow Measurements
Normalized Discharge (cfs)/Square Mile
Percent of time that indicated discharge was equaled or exceeded
100000.0
10000.0
1000.0
100.0
10.0
1.0
0.1
0
10
20
30
40
50
60
70
80
90
100
Piney Run
South Fork Catoctin Creek
North Fork Catoctin Creek
Catoctin Creek
Limestone Branch
Goose Creek (Middleburg)
North Fork Goose Creek
Beaverdam Creek
Goose Creek (Leesburg)
Broad Run

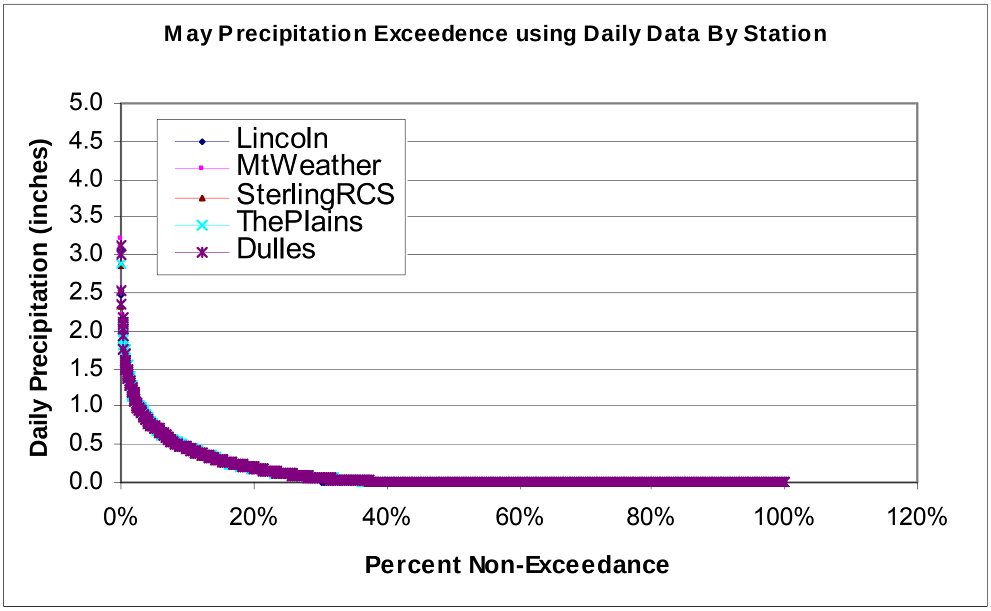
# B1.3 Rainfall Frequency Duration Curves

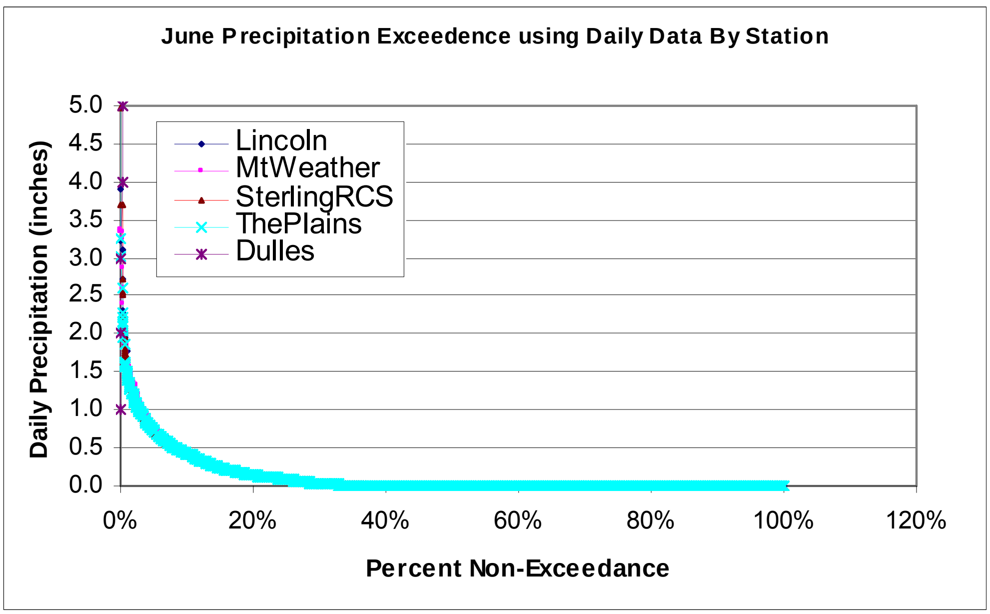


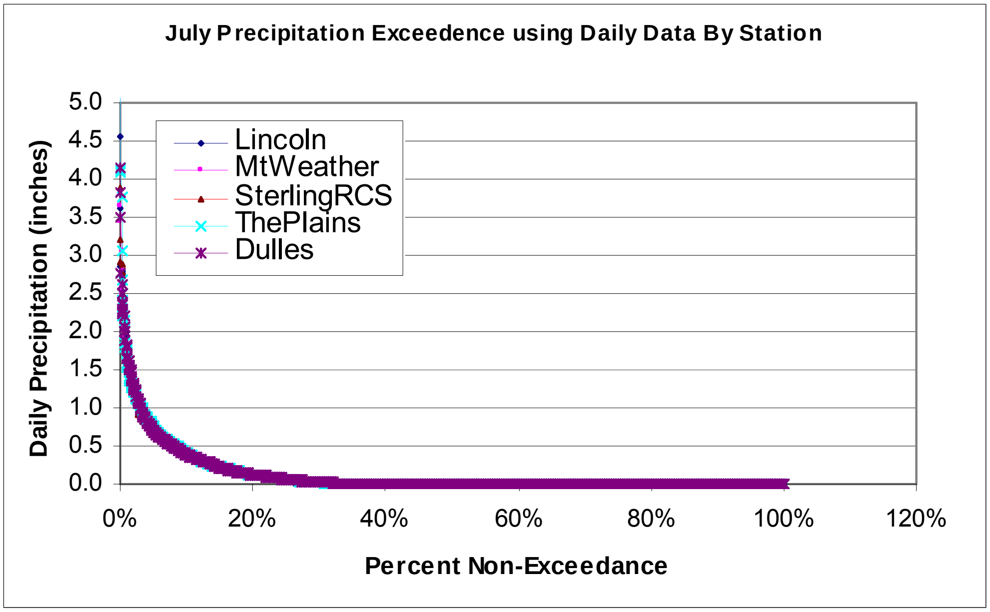



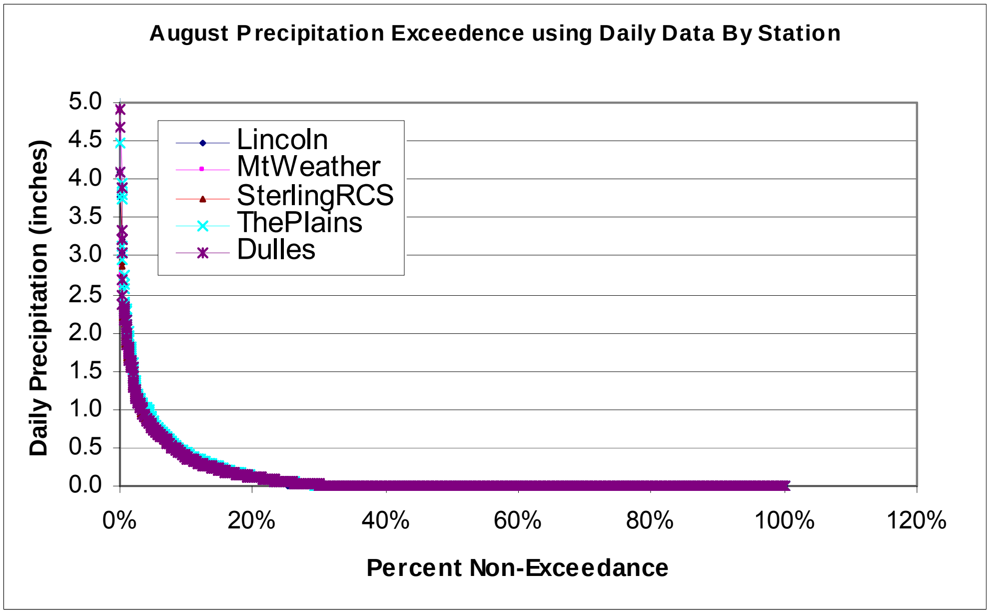

March Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles

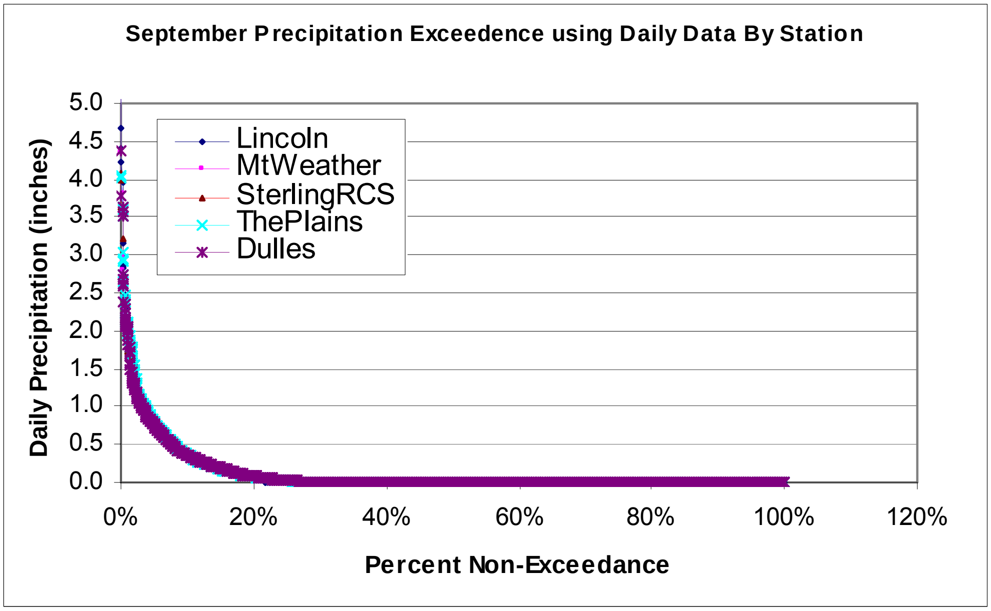

April Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles

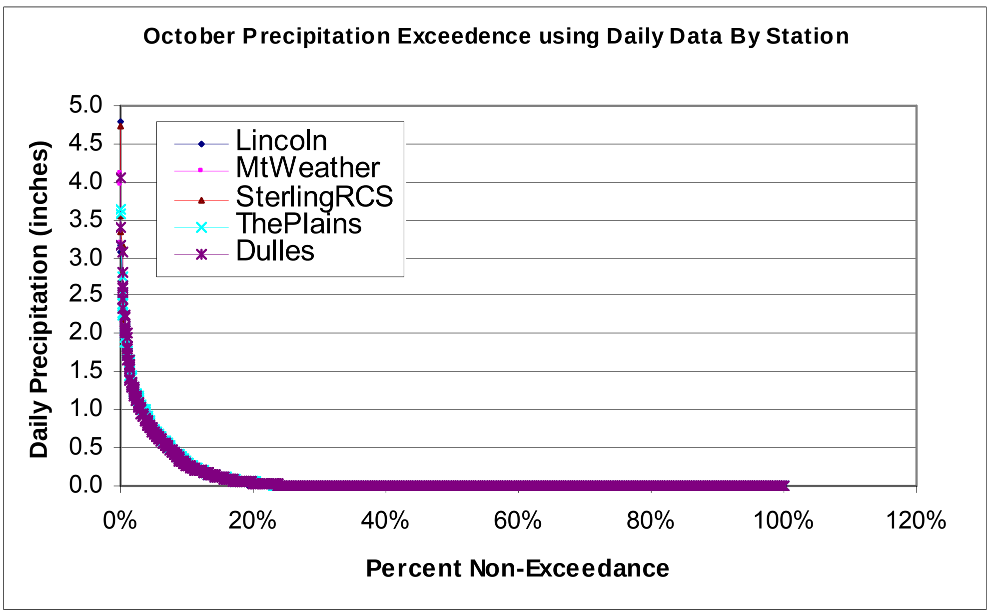

May Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance

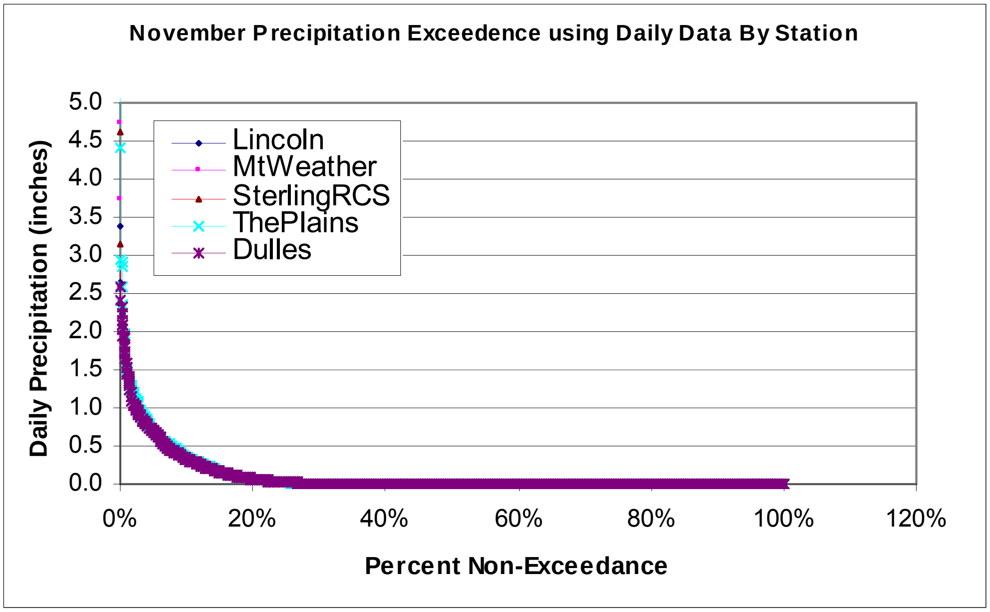

June Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance


July Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles

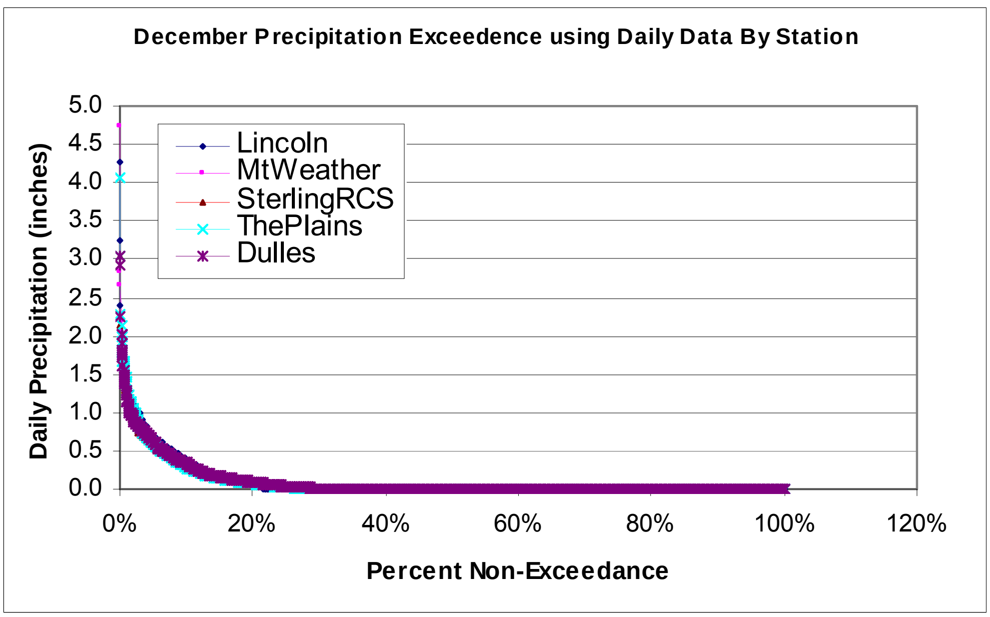

August Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles


September Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles


October Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles



November Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles

December Precipitation Exceedence using Daily Data By Station
Daily Precipitation (inches)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
120%
Percent Non-Exceedance
Lincoln
MtWeather
SterlingRCS
ThePlains
Dulles

Appendix C1

# Geologic Map Unit Description

| Map Unit | Formation Name | Lithologic Unit | Rock Classification | Depositional Environment | Age | Color |
|---|---|---|---|---|---|---|
| Ca | Antietam | Meta-Arkose | Metasedimentary | Deltaic | Early Cambrian | Brown |
| Ccp | Antietam | Phyllite | Metasedimentary | Deltaic | Early Cambrian | Gray |
| Cf | Frederick | Limestone | Sedimentary | Marine Shelf | Upper Cambrian | Light Gray |
| Ch | Harpers | Metasiltstone; Phyllite | Metasedimentary | Deltaic | Early Cambrian | Green; Brown |
| Cl | Loudoun | Phyllite | Metavolcaniclastic | Ashfall; Paleosoil | Early Cambrian | Blue; Black |
| Clc | Loudoun | Quartz Conglomerate | Metasedimentary | Fluvial Channels | Early Cambrian | White; Gray |
| Ct | Tomstown | Dolostone | Sedimentary | Marine Shelf | Early Cambrian | Light Gray |
| Cw | Weverton | Quartzite | Metasedimentary | Fluvial | Early Cambrian | White |
| Cwl | Weverton | Quartzite | Metasedimentary | Fluvial | Early Cambrian | White |
| Cwm | Weverton | Quartzite | Metasedimentary | Fluvial | Early Cambrian | White; Gray |
| Cwu | Weverton | Quartzite | Metasedimentary | Fluvial | Early Cambrian | Blue Gray |
| CZmg | Mather Gorge | Metagraywacke | Metasedimentary | Deep Water Turbidites | Neoproterozoic/ Early Cambrian | Gray |
| CZms | Mather Gorge | Schist | Metasedimentary | Deep Water Turbidites | Neoproterozoic/ Early Cambrian | Gray |
| Jd | | Diabase | Igneous Intrusive | | Early Jurassic | Black |
| Jdc | | Diabase Cumulate | Igneous Intrusive | | Early Jurassic | Black |
| Jdg | | Granophyric Diabase | Igneous Intrusive | | Early Jurassic | Black |
| Jdh | | High-Titanium Diabase | Igneous Intrusive | | Early Jurassic | Black |
| Jdl | | Low-Titanium Diabase | Igneous Intrusive | | Early Jurassic | Black |
| Jhg | Hickory Grove Basalt | Basalt | Igneous Extrusive | Lava Flows In Fluvial | Early Jurassic | Black |

| Map Unit | Formation Name | Lithologic Unit | Rock Classification | Depositional Environment | Age | Color |
|---|---|---|---|---|---|---|
| Jhgs | Hickory Grove Basalt | Sandstone; Siltstone | Sedimentary | Fluvial | Lower Jurassic | Red |
| Jm | Midland | Siltstone; Sandstone; Shale; Conglomerate | Sedimentary | Fluvial; Lacustrine | Lower Jurassic | Red |
| Jmc | Midland | Conglomerate; Arkose | Sedimentary | Fluvial; Lacustrine | Lower Jurassic | Red |
| Jmz | Mount Zion Church Basalt | Basalt | Igneous Extrusive | Lava Flows | Lower Jurassic | Black |
| Js | Sander Basalt | Basalt | Igneous Extrusive | Lava Flows In Fluvial | Lower Jurassic | Black |
| Jss | Sander Basalt | Sandstone; Siltstone | Sedimentary | Fluvial | Lower Jurassic | Red |
| Jtr | Turkey Run | Sandstone; Siltstone; Conglomerate; Shale | Sedimentary | Fluvial; Alluvial Fan | Lower Jurassic | Red |
| JTRc | Catharpin Creek; Turkey Run | Sandstone; Siltstone; Conglomerate; Shale | Sedimentary | Alluvial Fan; Fluvial | Lower Jurassic and Upper Triassic | Red |
| JTRcg | Catharpin Creek | Conglomerate; Sandstone | Sedimentary | Alluvial Fan | Lower Jurassic and Upper Triassic | Red |
| JTRtm | Balls Bluff Siltstone; Catharpin Creek; Manassas Sandstone | Arkosic Sandstone; Carbonate Conglomerate; Siltstone; Conglomerate; Sandstone; Diabase Cumulate; High-Titanium Diabase; Shale | Igneous Intrusive; Sedimentary | Alluvial Fan; Fluvial; Deltaic; Lacustrine | Lower Jurassic and Upper Triassic | |
| TRbl | Balls Bluff Siltstone | Carbonate Conglomerate; Siltstone | Sedimentary | Alluvial Fan | Upper Triassic | Pink |
| TRbs | Balls Bluff Siltstone | Sandstone; Siltstone | Sedimentary | Fluvial; Deltaic | Upper Triassic | Red |
| TRbsh | Balls Bluff Siltstone | Shale; Siltstone | Sedimentary | Lacustrine | Upper Triassic | Red |

| Map Unit | Formation Name | Lithologic Unit | Rock Classification | Depositional Environment | Age | Color |
|---|---|---|---|---|---|---|
| TRmp | Manassas Sandstone | Arkosic Sandstone | Sedimentary | Fluvial | Upper Triassic | Red |
| TRmr | Manassas Sandstone | Conglomerate | Sedimentary | Fluvial; Colluvial | Upper Triassic | Red |
| Ybg | | Biotite Granite Gneiss | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Gray |
| Yc | | Charnockite | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Black; Orange |
| Yg | | Leucocratic Metagranite | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Light Gray |
| Ygt | | Garnetiferous Leucocratic Metagranite | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Light Gray |
| Yhm | | Hornblende Monzonite Gneiss | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Tan Gray |
| Ylg | | Layered Granitic Gneiss | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Light Gray |
| Ymb | | Biotitic Marshall Metagranite | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Light Gray |
| Ymc | | Coarse Metagranite | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Light Gray |
| Yml | | Pink Leucocratic Metagranite | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Pink; Gray |
| Yn | | Metanorite And Metadiorite | Igneous | Mafic Igneous Intrusive | Mesoproterozoic | Dark Gray |
| Yp | | Paragneiss | Sedimentary | Sedimentary | Mesoproterozoic | Rusty Red |
| Ypg | | Porphyroblastic Metagranite | Igneous | Plutonic Igneous Intrusive | Mesoproterozoic | Gray |
| Zc | Catoctin | Metabasalt | Igneous Extrusive | Volcanic Lava Flows | Neoproterozoic | Green |

| Map Unit | Formation Name | Lithologic Unit | Rock Classification | Depositional Environment | Age | Color |
|---|---|---|---|---|---|---|
| Zcb | Catoctin | Metabasalt Breccia | Igneous Extrusive | Volcanic Lava Flows | Neoproterozoic | Green |
| Zcm | Catoctin | Marble | Metasedimentary | Shallow Lake | Neoproterozoic | Tan |
| Zcp | Catoctin | Phyllite | Metasedimentary; Volcanic | Volcanic Lava Flows | Neoproterozoic | Variegated |
| Zcr | Catoctin | Metarhyolite | Igneous Extrusive | Volcanic Lava Flows | Neoproterozoic | Cream |
| Zcs | Catoctin | Metasiltstone; Metasandstone | Metasedimentary | Fluvial In Lava | Neoproterozoic | Light Gray |
| Zfa | Fauquier | Meta-Arkose | Metasedimentary | Fluvial | Neoproterozoic | Brown; Gray |
| Zfc | Fauquier | Metaconglomerate | Metasedimentary | Colluvial | Neoproterozoic | Brown; Gray |
| Zfs | Fauquier | Metamudstone | Metasedimentary | Lacustrine | Neoproterozoic | Brown; Gray |
| Zmd | | Metadiabase Dike | Igneous Intrusive | Igneous Intrusive | Neoproterozoic | Green |
| Zrd | | Metarhyolite Dike | Igneous Intrusive | Igneous Intrusive | Neoproterozoic | Tan |
| Zrr | Robertson River Igneous Suite | Alkali Feldspar Quartz Syenite | Igneous Intrusive | Plutonic Igneous Intrusive | Neoproterozoic | Gray |
| Zsm | Swift Run | Marble | Metasedimentary | Shallow Lake | Neoproterozoic | Tan; Pink |
| Zsp | Swift Run | Phyllite | Metasedimentary | Fluvial | Neoproterozoic | Light Gray |
| Zss | Swift Run | Schist; Metasandstone | Metasedimentary | Fluvial | Neoproterozoic | Light Gray |

Reference: Southworth, 1999