# Assessment of the Hydrological Effects of Urbanization on the Lower Alum Creek Watershed of Central Ohio

Jack Byrom

**ABSTRACT**

The lower Alum Creek watershed encompasses portions of Delaware and Franklin counties of central Ohio. This area is experiencing rapid population growth and concomitant changes in land use. Previous researchers have documented that the process of urbanization alters the hydrology of a watershed by short-circuiting the hydrologic cycle. Our hypothesis was that the Alum Creek watershed would exhibit similar hydrologic changes. The study used GIS data from aerial photographic surveys and Landsat to quantify the percentage of the Alum Creek watershed urbanized in years 1976, 1979, 1994, and 1998. Water discharge data from U.S. Geological Survey gaging stations were analyzed to determine the hydrologic impact of localized urbanization. Urbanized land use increased from 66 % to 80 % in the Franklin County portion of the watershed between 1976 and 1998. Examination of hydrologic data included analysis of percent exceedance, seven-day low flow, and peak discharge data from 1942-2000. Results of these analyses suggest higher flows and shorter lag times between precipitation and surface discharge events often associated with urbanization. This is supported by decreasing 7-day low flows and decreasing percent exceedance. However, the Spearman and Spearman-Conley serial correlation tests did not support a trend indicating increased discharge and shorter lag times (at 95 % CI). Further analysis utilizing climatologic data such as hourly rainfall records may be necessary to offer additional evidence of the impact of urbanization within the Alum Creek watershed.

## INTRODUCTION

Many areas of the United States have experienced significant human population growth during the last several decades. Increases in population have led to changes in land use and to the growth of cities into areas formerly classified as rural. The term *urbanization* describes the changes that occur when formerly undeveloped lands or agricultural areas are transformed by humans into less natural landscapes. Construction of roads, parking lots, buildings, and modified drainage systems are all anthropogenic processes that contribute to urbanization. Typically, the percentage of land that is covered with impervious surfaces (*e.g*., parking lots, roads, or rooftops) increases as urbanization progresses and this process can affect the hydrologic characteristics of a watershed.

A body of research has shown that changes in land use can modify the hydrology of a watershed (Shaw, 1994). Due to increased construction of impervious surfaces, areas undergoing urbanization typically experience a decrease in the amount of water infiltrating through the vadose zone. As groundwater and surface water systems are inextricably linked, a decrease in infiltration eventually leads to reduced baseflow to surface streams. In addition, storm hydrographs of areas undergoing urbanization show a trend toward flashier discharge immediately after storms; stream discharge begins to increase more rapidly in response to storm events and also recedes more rapidly after storm events (Shaw, 1994).

Various statistical methods of monitoring the effects of urbanization on surface water discharge have been developed. Leopold stated that annual maximum discharge, rate of stormflow recession and the lag time between rainfall and runoff can indicate the hydrologic effects of urbanization (Konrad & Booth, 2002).

Konrad and Booth (2002) developed a new surface water statistic, percent of year annual mean discharge is exceeded (TQ-Mean). They outline the development of this statistic in their study, “Hydrologic Trends Associated with Urban Development for Selected Streams in the Puget Sound Basin.” The TQ-Mean statistic was created in an attempt to measure the effects of urbanization using a method less dependent on natural variations in stream discharge, which can be considerable (Konrad & Booth, 2002). In unmodified streams with gradual recession rates and sustained baseflows, TQ-Mean is often higher than in urbanized watersheds. Konrad (Konrad & Booth, 2002) found an inverse relationship between TQ-Mean and urban development as measured by road density in a western Washington State study. A trend of decreasing TQ-Mean over a long period of time provides an indicator of the flashier streamflows that develop with urbanization (Konrad & Booth, 2002).

Peak discharge rates and 7-day low flows are some of the other aspects of surface water discharge that show to be susceptible to modification by urbanization. Peak discharge rates in watersheds altered by urbanization often increase due to a decrease in infiltration and associated increase in overland flow observed during storm events (Guay, 1995). The 7-day low flow measurement gives an indication of the severity of annual droughts (Konrad & Booth, 2002). Decreasing 7-day low flows can indicate the associated reduction in groundwater recharge seen occurring in the urbanization process (Shaw, 1994). Citing Ferguson and Suckling in support, Fetter (2001) notes that within urbanized watersheds, total runoff can decrease during dry periods because increasing evapotranspiration induces lower streamflows.

Alum Creek is a tributary of the Scioto River that drains a 189 square-mile area within the Morrow, Delaware and Franklin counties of central Ohio. In 1974, the Army Corps of Engineers constructed the Alum Creek Reservoir in the middle portion of this 58-mile creek. The reservoir has a surface area of 3,387 acres of water and was created to ensure a water supply for the city of Columbus, provide flood control for the area south of the reservoir, and yield recreational opportunities (ODNR, 2003). The fast-growing metropolitan area of Columbus has continued to expand with rapid growth in Franklin and Delaware counties occurring in the 1990s (see Table 1). In 2002, Delaware County was considered to be the 15$^{th}$ fastest growing county in the U.S. and the fastest growing county in Ohio (U.S. Census, 2002).

Table 1. Changes in population growth in the area within and directly adjacent to the lower Alum Creek watershed.

| Year | Franklin County population | Delaware County population |
|---|---|---|
| 1970 | 833,249 | 42,908* |
| 1990 | 961,437 | 66,929 |
| 2002 | 1,086,814 | 125,399 |

Source: U.S. Census Bureau (http://factfinder.census.gov/). Accessed 8/4/03.
* Ohio Department of Development, cited in FACT Inventory (2003)

Over the last few decades, portions of this watershed have experienced extensive changes in land use as agricultural use has given way to residential and commercial uses. The aim of this study was to investigate whether changes in land use had affected these hydrological aspects of the Alum Creek discharge.

## METHOD

GIS (Geographical Information System) data generated from aerial photographic surveys and Landsat satellite infrared (IR) spectral analysis were obtained from the Ohio Department of Natural Resources, ODNR (www.dnr.state.oh.us/gims). Utilizing these land-use data, GIS (ESRI ArcGIS 8.3) and Excel spreadsheet software, a quantitative assessment of changes in land use in the lower Alum Creek watershed was completed. The lower watershed was defined as that portion draining the area immediately downstream of the Alum Creek Dam and ending at the mouth of Alum Creek in southern Franklin County (see report cover figure, Overview of Alum Creek Watershed). Land-use data were categorized as either non-urban or urban and computed for the years 1976, 1979, 1994 and 1998, years for which land-use data were available.

The Anderson land-use coding system is the general standard public agencies use to code and map digital land use information and a version of this system is utilized by ODNR (Anderson, Hardy, Roach, & Witmer, 1976). All Anderson land use coding done by ODNR was classified as urban or non-urban for spreadsheet analysis. For example, “Residential use” land tracts (code 0011) were classified as *urban* use. “Cropland (0211)” and “pastures (0212)” were re-classified as *non-urban* use. An Excel database program was then used to re-classify all 55 types of Anderson land codes used as urban or non-urban.

Landsat satellite IR spectral analysis data were obtained from the ODNR GIMS website. The seven land use categories of the original Landsat-generated data were urban, agriculture/open urban areas, shrub/scrub, wooded, open water, non-forested wetlands, and barren. These data were reclassified as either *urban* or *non-urban* use by combining the original “urban” category with the “barren” category and then reclassifying remaining categories as “non-urban.”

Using U.S. Geological Survey discharge records for Alum Creek at Africa and Columbus stations (see Figures 1a & 1b), the following discharge characterizations were generated: peak-discharge, 7-day low flow, and fraction of year that annual mean is exceeded, TQ-Mean. Columbus station records from 1942-2000 and Africa station records from 1974-2001 were analyzed. Correlation between various surface water flow characteristics was determined using the Spearman and Spearman-Conley statistical methods, two non-parametric tests for serial correlation (McCuen, 2003). The Spearman tests were utilized for bivariate correlation analysis between two data arrays, discharge at the Columbus and Africa stations. Spearman-Conley tests were used for univariate correlation analysis of the Columbus station discharge.

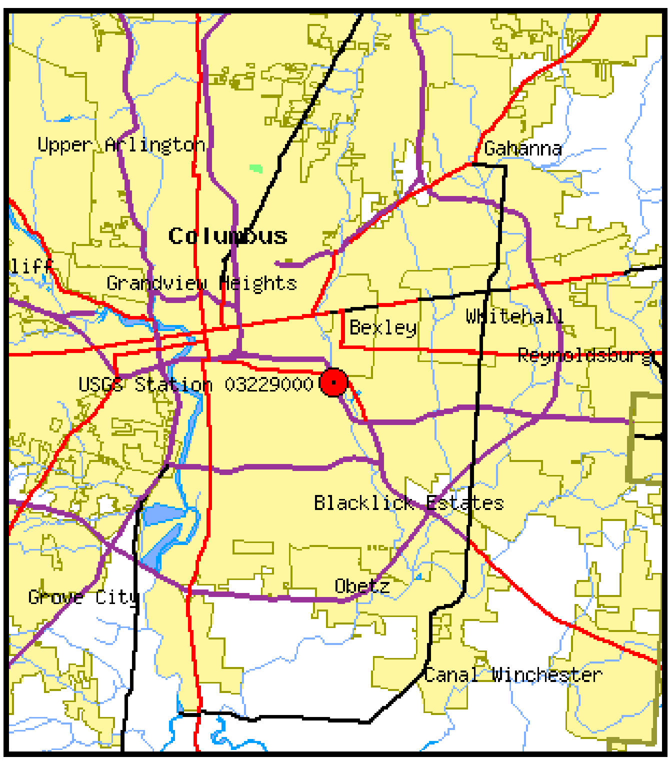


Figure 1a. Africa gaging station, [indicated by dot] 1400 feet downstream from Alum Creek dam (USGS Map, station 03228805).

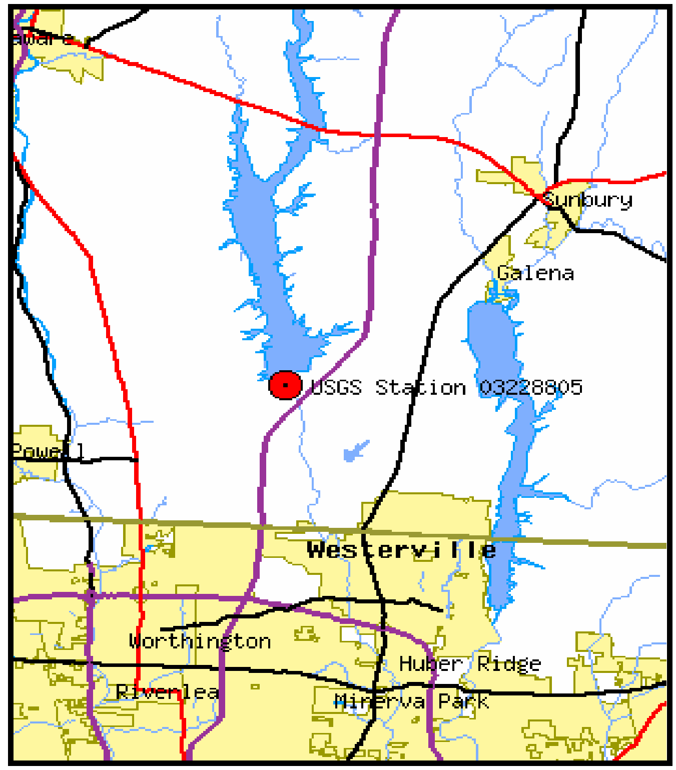


Figure 1b. Columbus gaging station, [indicated by dot] 6 miles upstream from river mouth (USGS Map, station 03229000).

**RESULTS**

Analysis of land use information obtained from ODNR aerial photographic surveys and from NASA Landsat IR surveys of the Alum Creek watershed reveals that the lower watershed became more urbanized between 1976 and 1998 (see Table 2).

**Table 2.** Percent urbanized area of Franklin and Delaware counties, 1976-1998.

| Year | Franklin Co. Urban (%) | Delaware Co. Urban (%) |
|---|---|---|
| 1998 | 80.4 | - |
| 1994* | 45.9* | 6.0* |
| 1979 | - | 16.1 |
| 1976 | 65.9 | - |

* Data from Landsat IR Scan method

Computed seven-day low flows from 1942 to 2000 ranged from 0.1 to 25 CFS with the data divided into two major sections, flows before dam construction and flows after dam construction (Figure 2). Figure 3 indicates computed percent of year annual mean discharge exceeded (TQ-Mean) for years 1942-2000; these data ranged from 9 to 43 % and were divided into pre-Alum Creek dam and post-Alum Creek dam sections, as well. Peak discharge for the years 1974 to 2001 ranged from 40 CFS (Africa station lowest value) to 8600 CFS (Columbus station maximum value) (Figure 4).

Table 3 shows the Spearman-Conley (SC) statistical test results for the years 1942-1973 at Columbus and indicates serial correlation for an increase in the 7-day low flow trend (Figure 2). A Spearman-Conley test of discharge data at the Columbus station for the years 1974-1998 shows that no serial correlation for the negative trend in 7-day low flows is significant (Table 3). The SC test shows that the negative trend in percent exceedance at Columbus from 1974-1998 (Figure 3) is not significant for serial correlation (95% CI).

Table 3. Spearman-Conley statistical tests for the Columbus station of Alum Creek (univariate test).

| *Test* | *Years* | *Rsc (test Statistic)* | *Critical value (95% CI)* |
|---|---|---|---|
| 7-day low flow, correlation for increasing trend (one-tail, positive) | 1942-1973 | 0.474 | 0.267 |
| 7-day low flow, correlation for increasing trend (one-tail, negative) | 1974-1998 | 0.243 | -0.379 |
| Percent exceedance, correlation for increasing trend (one-tail, negative) | 1974-1997 | 0.083 | -0.379 |

The Spearman test for trend correlating between two variables was used to compare discharge data from the Columbus station with the Africa station. Percent exceedance and 7-day low flow data were compared for the years 1974-1999 (95 % CI) and no trend of statistical correlation was found in either case (Table 4).

Table 4. Spearman tests for correlation between Columbus and Africa Stations (bivariate test).

| *Test* | *Years* | *Test Statistic , Rs* | *t* | *Critical Value (95% CI)* |
|---|---|---|---|---|
| Percent exceedance, Columbus to Africa trend correlation (one-tail) | 1974-1999 | 0.091 | 0.449 | 1.318 |
| 7-day low flow, Columbus to Africa trend correlation (one-tail) | 1974-1998 | 0.205 | 1.006 | 1.74 |

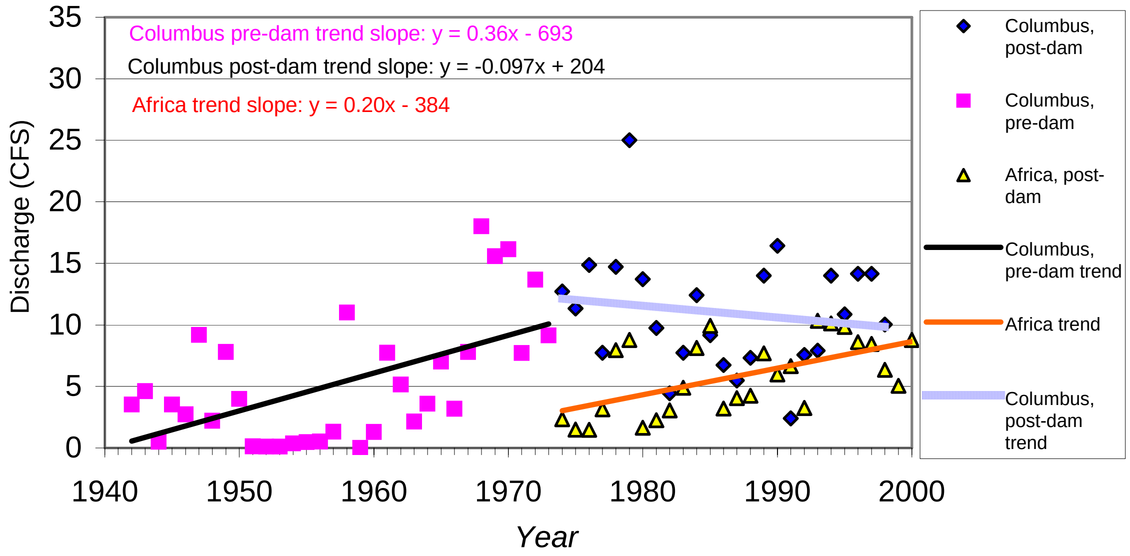


Figure 2. Alum Creek 7-day low-flow, Columbus and Africa gaging stations, before and after dam construction, years 1942-2000.

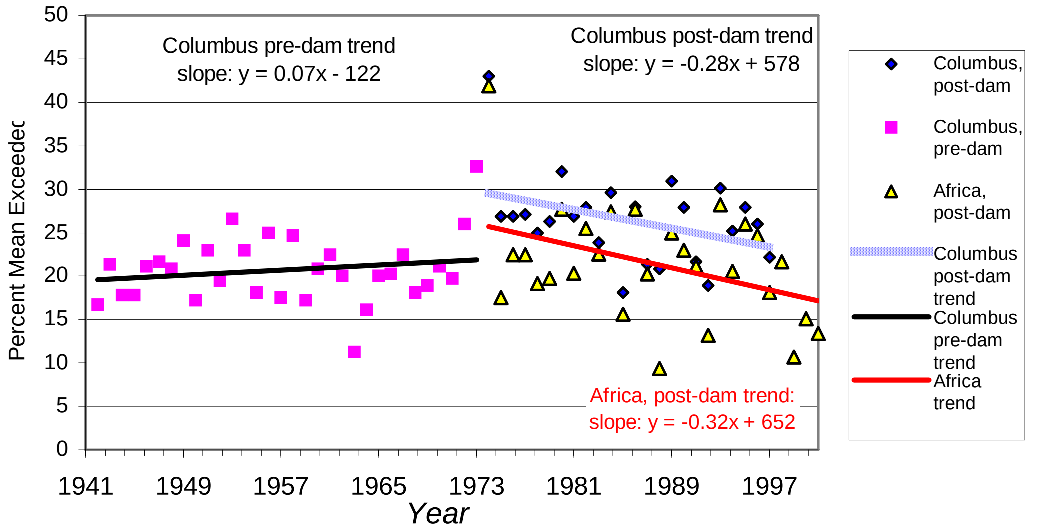


Figure 3. Alum Creek, Columbus and Africa gaging stations, percent of year mean annual discharge exceeded (TQ-Mean) before and after dam construction, years 1942-2000.

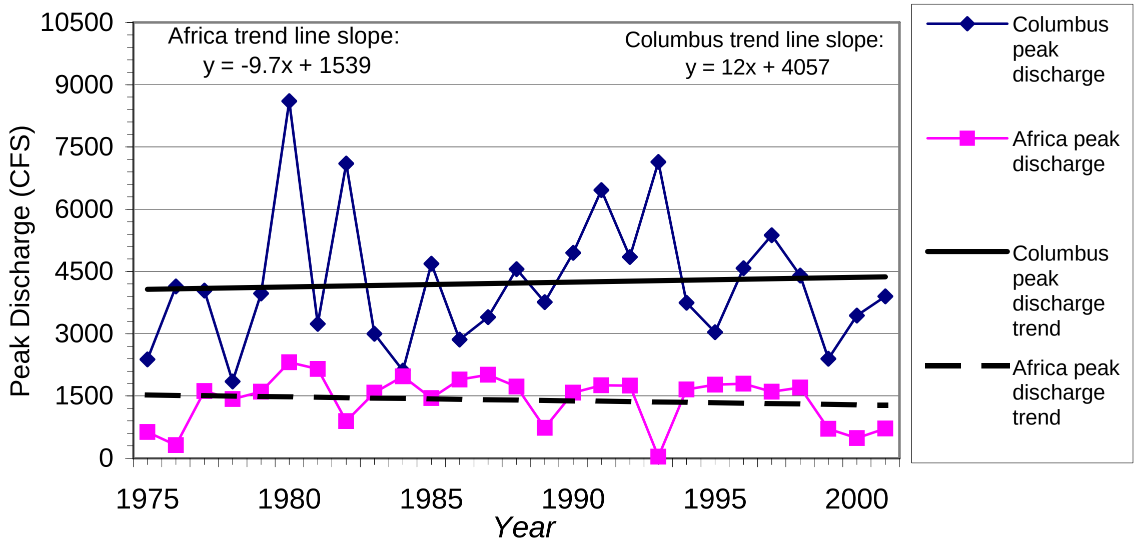


Figure 4. Peak discharge at Alum Creek, Columbus and Africa gaging stations, years 1974-2001.

**DISCUSSION**

The analysis of GIS-format aerial-photo survey data indicates that the lower Alum Creek watershed has become more urbanized since 1976. The urbanized Franklin County portion of the watershed was calculated to have increased from 65.9 % in 1976 to 80.4 % in 1998. This change is clearly visible when the 1976 GIS map (Figure 6) is compared to the 1998 GIS map (Figure 7). The alternative method of calculating the urbanized area in the study area used 1994 Landsat IR scan data and showed a percent urbanized area of Franklin County of 45.9 %, compared to 65.9 % in 1976 calculated using aerial photo survey data. Despite the lack of correlation between the two methods, the satellite data are useful because they quantify urbanization from a reliable method and because they also provide baseline data for future studies (Figure 5).

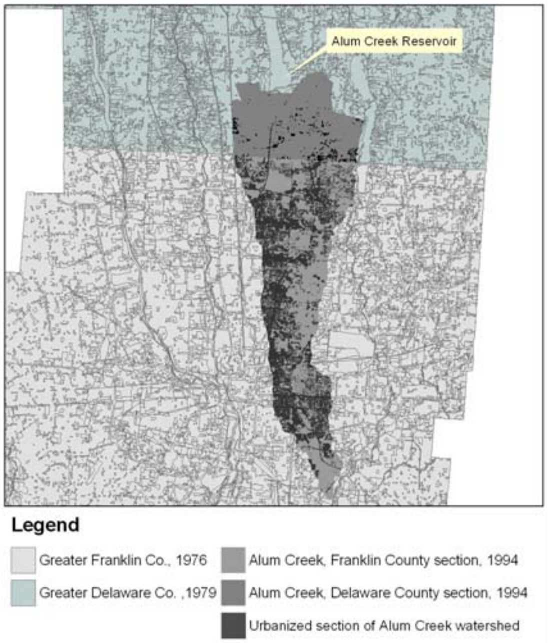


**Figure 5. [Landsat] Urbanized Area of Lower Alum Creek watershed in Franklin and Delaware Counties, 1994.**

Data from LandSat Satellite IR scan ( ODNR 1994)

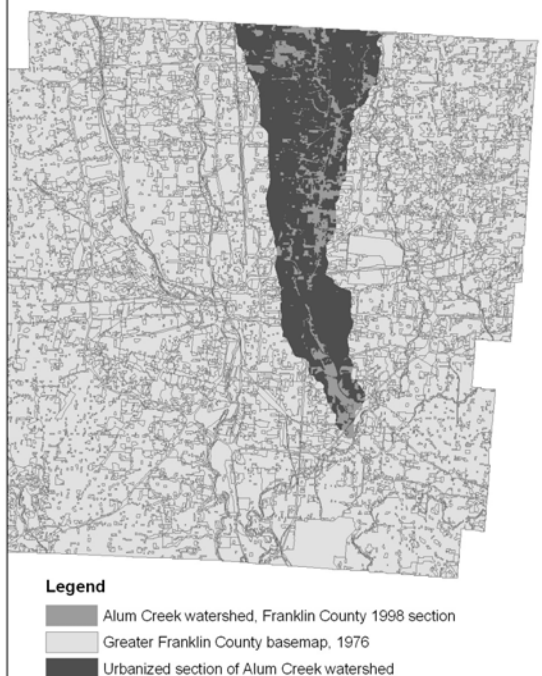


**Figure 7. Urbanized Area of Lower Alum Creek Watershed in Franklin County, 1998.**

Data from Aerial Photo Surveys, ODNR 1998

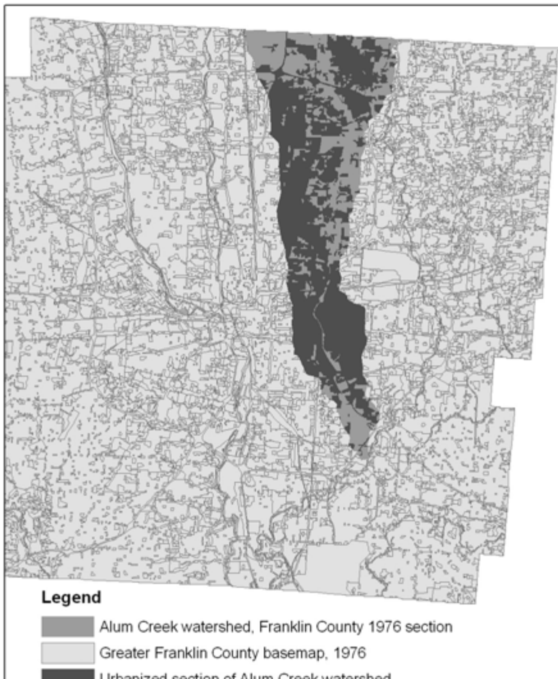


**Figure 6. Urbanized Area of Lower Alum Creek Watershed in Franklin County, 1976**

Data from Aerial Photo Surveys, ODNR 1976

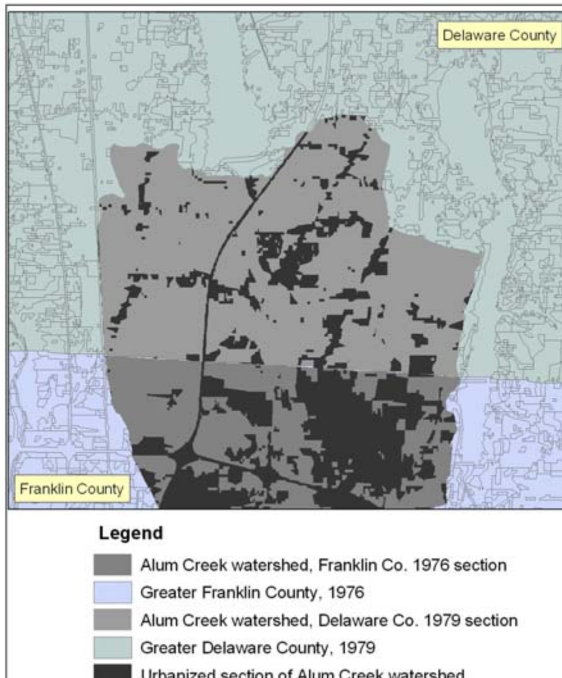


**Figure 8. Urbanized Area of lower Alum Creek watershed in Franklin (1976) and Delaware (1979) counties.**

Data from aerial photo surveys, 1976 and 1979 ( ODNR)

The study was limited by a lack of data from the Delaware County portion of the watershed. ODNR aerial photo-survey data were analyzed and used to determine that Delaware Co. was 16.1 % urbanized in 1979 (see Figure 8 for illustration), but this cannot be compared with any other data obtained from the same method. Landsat IR-scan data were used to calculate a percent-urbanized area of 6.0 % in 1994, a number at variance with the percentage generated from the aerial photo-survey method (see Figure 5 for illustration). Nonetheless, these two calculated percentages of urbanized area in the Delaware County portion of the watershed are consistent with the recognized fact that this county remains a more rural area than the urbanized Franklin County.

Hydrological analysis of the watershed was complicated by the fact that the Alum Creek dam has controlled much of the surface water flow through the lower Alum Creek watershed since 1974. Nonetheless, a few conclusions from this data were made and are compared to the land-use/urbanization conclusions generated from the GIS-data.

Due to lack of year-to-year land-use data, the statistical analysis of the hydrological aspects of Alum Creek flow affected by urbanization was dependent on a univariate statistical analysis, the Spearman-Conley test (SC). This test is useful in analyzing water discharge data to check for significant trends via serial correlation analysis (McCuen, 2003). As the Africa and Columbus stations divided the discharge data, statistical analysis was also used to compare the two areas of the watershed represented. Seven-day low flow and percent exceedance (TQ-Mean) were compared using the Spearman test; this bivariate analysis tested serial correlation between the two stations. Comparison of the discharge data from Columbus versus Africa for the same type of flows helped clarify what effects were due to controlled water releases at the Alum Creek dam and what effects were due to natural water flows or from the effects of urbanization.

Decreasing 7-day low flows at Columbus (Figure 3) show that urbanization may be altering surface water flow in the watershed between the Alum Creek dam (at the Africa station) and the Columbus gaging station. Despite a trend of reservoir water release at the Africa station towards greater 7-day lows (years 1974-2000), the trend at the downstream Columbus station for the same period (1974-1998) indicates decreasing 7-day lows. Decreasing 7-day lows are an indicator of urbanization. The lack of statistical correlation via the Spearman test for the two sets of discharge data may indicate that urbanization is altering the hydrology of the lower Alum Creek area (Table 4). A gradual increase in the impervious area in the watershed below the dam would discourage aquifer recharge and encourage a concomitant decrease in annual 7-day low flow. However, as indicated by the Spearman-Conley test (Table 3), it cannot yet be shown that 7-day low flow at Columbus shows a statistically significant trend for negative serial correlation. As changes in land-use continue, data may show that the watershed is indeed experiencing decreasing 7-day low flows.

Some patterns seemed to emerge in the percent exceedance (TQ-Mean) data. Before the Alum Creek Dam was constructed in 1974 (years 1942-1973), the Columbus station showed a gradual trend towards increasing percent exceedance, TQ-Mean (Figure 3). This trend would not generally be associated with the effects of increasing urbanization. However, after the dam was finished in 1974, both the Columbus and Africa stations show a trend toward flashier discharge of water indicated by a pattern of decreasing TQ-Mean for the years 1974-2000 (1974-1998 for Columbus). Despite the appearance of decreasing TQ-Mean at Africa and Columbus after 1974 (see Figure 3) this trend is not significant for correlation. However, it is suspected that urbanization is indeed creating flashier discharge patterns in the area of the creek below the dam and that as time passes serial correlation tests may show a statistically significant decreasing TQ-Mean trend.

The peak discharge of water through Alum Creek at Africa and Columbus stations is controlled by the Alum Creek dam. Water flow at the Africa station is completely controlled by the U.S. Army Corps of Engineers. However, the Columbus station is approximately 20 miles downstream and drains a large watershed so it should be considered to have its own significance in this regard. Discharge from the reservoir contributes to peak discharge at Columbus but does not completely control it. Analysis of the peak discharge records for Columbus, years 1974-2000, indicates that the trend is towards slowly increasing peaks (see Figure 4). It is not considered that this trend is significant or that it accurately reflects any effects of urbanization.

## CONCLUSION

The lower Alum Creek watershed has been altered by the process of urbanization. GIS-software analysis of aerial photographic-survey data shows that the portion of the watershed within Franklin County that was urbanized increased from 66 % in 1976 to 80 % in 1998. An analysis of changes in the surface water flow for this area is less conclusive. However, it is suspected that a trend to flashier flows in the Franklin County portion of the Alum Creek watershed is becoming established and that over the next 10-20 years the trend will become more evident. But at this time there is insufficient statistical evidence that urbanization has led to flashier discharge in the lower watershed. Inadequate data for the Delaware County portion of the watershed made it difficult to draw conclusions about the change in percent urbanized area. More data in a format consistent with prior surveys conducted within Delaware County could assist in tracking changes in land use over time. A computer watershed modeling system comparison of hourly rainfall intensity with the water discharge data for this area would also be useful in validating these conclusions.

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