Ten Mile Creek Watershed Storm Water Master Plan

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EXECUTIVE SUMMARY

This summary presents that findings and recommendations of the Ten Mile Creek Watershed Storm Water Master Plan.

Background

In 1997, the Knox County SWAC identified the three principal objectives of a storm water master plan, as shown in Table 1 below.

Table 1. Master Plan Objectives

The **Needs and Issues** objective will: ➢ address major and minor flooding issues, and identify flood solution alternatives to fix existing problems and determine ways to avoid future problems; ➢ provide "what if" analysis capability for planning and storm water management purposes; ➢ inventory the drainage system to the level desired by County staff; ➢ prioritize capital improvement projects (CIPs); ➢ utilize existing GIS data and create new layers of information for use in planning, maintenance, CIPs and complaint handling; and ➢ address water quality, both holistically and in response to regulatory permitting pressures.
The **Regulatory Instruments** objective will: ➢ extend the regulatory floodplains beyond the floodplain boundaries required by FEMA for flood insurance purposes; ➢ be used in the plans approval process to assist with defining requirements for new developments and redevelopment in the Ten Mile Creek watershed.
The **Storm Water Planning** objective will: ➢ provide an overall land use guide for storm water management; ➢ provide a tool to assist planners with Sector Plan and zoning decisions; and, ➢ be a policy tool to assist policy makers.

The 15-square mile Ten Mile Creek watershed was chosen for storm water master planning because of the rapid on-going development of the watershed, the existing flood problems, and the increased frequency of extreme flooding at Ebenezer Sinkhole. Currently, the majority of land use in the watershed is residential and commercial, and development of the remaining open land is continuing a quick pace. Based on the 15-Year Development Plans for Knox County, the Metropolitan Planning Commission predicts that 96% of the watershed will be developed within 15-years. The most prominent future land use developments are now and will continue to be medium-density residential areas and commercial development to support the residential areas.

Flooding of roadways and residences located in the vicinity of Ebenezer Sinkhole has been documented since the early 1900's, however a number of recent flood events at the sinkhole indicate an increased frequency of extreme flooding. Upstream of the sinkhole, the County has received complaints of localized flooding in houses located in the downstream portion of the watershed along Echo Valley Tributary, and in several ground floor apartments located in the upstream portion of the watershed on Stonebrook Drive. In addition, there have been complaints of severe stream bank erosion in a small tributary located south of the BriarGlen subdivision. The County has identified all of these flood/erosion areas as "Priority Areas" for the examination and consideration of flood or erosion solution alternatives.

Water Quality

Ten Mile Creek receives pollutants from suburban runoff and construction activities. Sediment from construction sites is a major pollutant and high levels of pesticides, fertilizers and roadway oils and greases are discharged from developed areas. A program to collect baseline water quality data in Beaver Creek and its tributaries was performed as part of the master planning effort and concluded that the water quality of the main stem is in poor condition. Sediment and nutrient influx from new development, and the loss of riparian vegetation were determined to be the greatest contributors to the degradation of water quality.

In March 2003, Knox County will be required to obtain a permit to discharge storm water to waters of the State, under the National Pollutant Discharge Elimination System (NPDES) Phase II regulations. The permit requires the county to maintain a storm water program that addresses the following six minimum controls:

- public education and outreach;
- public involvement;
- illicit discharge detection and elimination;
- construction runoff controls;
- post construction runoff controls; and
- best management practices for municipal operations.

Based on the impending Phase II regulations and the results of the water quality surveys performed for the master plan, recommendations were made to address water quality in the Ten Mile Creek watershed:

1. Educate the public on the source and reduction of the primary pollutants and how to police their own watershed. Focus on residential source pollutants and sediment.

2. Encourage the use of effective BMPs for businesses and communities in the watershed.

3. Implement and maintain a strong erosion control program for all land disturbances in the watershed.

4. Identify and repair existing stream bank erosion problems and regularly inspect areas where erosion has been a problem.

5. Springs, wetlands and other sensitive areas should be identified and protected as they can enhance water quality in the stream.

6. Commercial storm drains and other potential illicit (non-storm water) discharges should be investigated and eliminated.

7. Follow-up monitoring should be conducted in the future to develop long term water quality trends.

8. Find ways to work with the City of Knoxville in implementing and maintaining consistent BMPs throughout the watershed.

Flooding and Flood Potential

Hydrologic and hydraulic models were developed of the watershed and stream systems to evaluate peak discharges and flood elevations based on the runoff resulting from existing and future land use conditions. The models simulated rainfall/runoff processes and associated changes in flood elevations in the creeks for the 2-, 10-, 25-, 100- and 500-year events. Existing condition models were developed for purposes of the *Ten Mile Creek Watershed Flood Study* for submittal to the Federal Emergency Management Agency as part of the National Flood Insurance Program. The *Flood Study* was published in February, 2000. The future condition and flood solution alternative analyses were performed as part of this master plan.

Based on the results of the models, the following conclusions can be made about the Ten Mile Creek watershed and streams:

1. Peak discharges and corresponding flood elevations on the main stem and the tributaries are most sensitive to inflows from the surrounding contributing drainage areas. Flood elevations at Ebenezer Sinkhole are most sensitive to the volume of runoff that discharges to the area and the discharge capacity of Ebenezer Cave.

2. Based on the existing condition analysis, Ten Mile Creek flows out of bank at many locations during the 2-year, 24-hour event. The main stem and the modeled tributaries are consistently out of bank throughout the streams during the 10-year, 24-hour event.

3. One the main stem, the average difference between existing and future flood elevations is approximately one foot. On the tributaries, the average difference is approximately 0.5 feet. At Ebenezer Sinkhole, the difference between the 100-year existing and future condition flood elevations is 1.54 feet.

4. There are approximately 87 habitable structures located inside the mapped existing condition floodplains (100-year and 500-year). Of these structures, 46 are located along Ten Mile Creek and 41 are located along tributaries. Nine structures are located in the floodway.

5. Finished floor elevations were surveyed at 75 of the 87 habitable structures located in the existing condition floodplains on Ten Mile Creek and the tributaries. Twenty-six were found to have FFE flood potential for the 100-year existing condition event, five of which are located in the Ebenezer Sinkhole backwater area.

6. The future condition flood potential in the watershed, based on surveyed FFEs, does not increase significantly from existing conditions. The FFE flood potential for the 100-year future condition event is 30 structures. Six of these structures are located in the Ebenezer Sinkhole backwater area.

7. Based on analysis with the HEC-1 model, blocked outflow conditions at Ebenezer Cave could cause flood elevations in the Ebenezer Sinkhole backwater area to rise approximately 4.3 feet for the 100-year existing condition. The 100-year existing condition FFE flood potential will increase from five structures when the cave is discharging freely, to eleven with blocked cave conditions.

General Storm Water Management Alternatives

In the Ebenezer Sinkhole backwater area, large-scale structural alternatives to relieve extreme flooding at the sinkhole, such as a high flow channel or tunnel, are highly expensive will be extremely difficult to implement. Since only six structures that are located in the vicinity of the Sinkhole have a future condition flood potential, property buyout(s) or flood proofing are more reasonable alternatives for mitigating any existing FFE flooding. Acceptance of occasional flooded roadways and the implementation of non-structural alternatives to limit the future flood potential for habitable structures are more viable methods for storm water management near Ebenezer Sinkhole. Such non-structural alternatives include:

- operational and regulatory/policy measures to protect the discharge capacity of Ebenezer Cave;

- regulatory/policy measures to protect the storage volume (i.e., prohibit filling, require stringent erosion control in new developments upstream) of Ebenezer Sinkhole; and

- regulatory/policy measures to control new development in the backwater area.

Upstream of Ebenezer Sinkhole on Ten Mile Creek, the severity of the predicted FFE flood potential and the relatively slight difference between the existing and future condition flood potential limit the management alternatives that the County can choose to mitigate flooding. For example, non-structural policy measures that would limit peak discharges and/or runoff volumes from newly developed areas would not be successful in substantially reducing the flood potential in the watershed. Also, typical structural measures, such as channel improvements and regional detention ponds were determined to be too costly and/or ineffective for reducing flooding in areas on the main stem where FFE flood potential is predicted at multiple structures.

For localized, small-scale flooding, structural alternatives are more feasible. Limited non-structural measures, such as more stringent detention requirements on select new developments, could also be effective in localized areas. The models developed for the Master Plan could be utilized to perform "what if" analysis to determine whether a site would require a higher level of control.

One non-structural alternative determined to be effective in reducing the future flood potential watershed wide was the limitation of flood fringe encroachment to a ½ flood fringe encroachment line. Future condition flood elevations on the main stem are predicted to increase approximately two feet if full encroachment of the floodplain is allowed. The increase is approximately one foot if ½ flood fringe encroachment limits are utilized. Throughout the watershed, using a ½-flood fringe encroachment limit for development in the floodplain was determined to be an effective control on the increase in flood elevations due to future development.

Flood Solution Alternatives for Priority Areas

Specific flood solution alternatives were evaluated for Priority Areas identified by Knox County as in need of evaluation, and along Hardwicke Drive, where the HEC-RAS models of Ten Mile Creek and Sinking Creek predicted FFE flooding for the 100-year existing condition and larger events at 20 structures. In general, the alternatives analyzed include purchase of flood-prone properties, channel and culvert/bridge improvements (where feasible), and regional detention (where feasible). Cost estimates were developed for each alternative and provided along with the analysis of the effectiveness of the alternatives and a list of pros and cons if the alternatives were implemented. Recommendations were provided based on cost and effectiveness, should the County decide to implement a flood solution alternative for any of the Priority Areas.

Recommendations

Based on the analyses and findings of the Ten Mile Creek Watershed Storm Water Master Plan, the following recommendations were made:

1. Institute regulatory controls on new development and re-development in the Ebenezer Sinkhole backwater area. Consider applying the Sinkhole Policy to Ebenezer Sinkhole, and clearly defining floodplain and no-fill boundaries. Require highly stringent erosion control measures for construction sites and disturbed lands near the sinkhole backwater area.

2. Perform regular cleaning and debris removal visits to the cave. Because trash and urban debris will continue to be a problem in the watershed, consider structural measures to protect the inlet.

3. Implement and maintain a strong erosion control program for all land disturbances in the creek. Establish stringent erosion control requirements for construction sites and disturbed lands located adjacent to a stream. Identify any areas of large-scale stream bank erosion located within the watershed. Take steps to stabilize eroding areas as quickly as possible.

4. Continue development of regulations to limit flood fringe filling to a ½ fringe encroachment line on Ten Mile Creek and its tributaries.

5. Make available the hydrologic and hydraulic models of Ten Mile Creek and the tributaries developed for this master plan. Require developers to use them to determine the impact of specific developments on flooding downstream.

6. Develop a program to educate Ten Mile Creek watershed residents, schoolchildren and business owners on the general findings of the master plan and the impending NPDES Phase II regulations.

7. Find ways to work with the City of Knoxville in implementing and maintaining consistent BMPs throughout the watershed.

1 INTRODUCTION

1.1 Background

Ten Mile Creek is located in west Knox County. The largely suburban Ten Mile Creek watershed has a contributing drainage area of approximately 15 square miles and the creek has a length of approximately 6 miles. For clarity in this report, the complete Ten Mile Creek drainage area is termed "the watershed". The watershed is unique in that it discharges to a large sinkhole (hereafter, Ebenezer Sinkhole), which drains to a cave (Ebenezer Cave).

Over the past two decades, the Ten Mile Creek watershed has experienced rapid increase in the development of medium residential subdivisions and supporting commercial and office/business land uses. Today, approximately 81% of the watershed is developed, with residential areas covering greater than half of the developed areas. One of the consequences of this growth has been a significant increase in the problems associated with increased storm water runoff and pollution, such as flood problems, eroding streambanks and stream turbidity. These problems have served to highlight the need for the County to review its approach to managing storm water in the Ten Mile Creek watershed.

The need for storm water master planning of priority watersheds in Knox County was identified in the *Storm Water Management Program Assessment and Action Plan for Knox County* (Ogden, 1997) by the Knox County Storm Water Advisory Committee (SWAC). The SWAC consists of a broad cross-section of County residents and staff, political leaders, and technical experts. The SWAC identified the storm water problems and issues in Knox County, assessed the County's storm water program, and provided recommendations on program improvement and priorities. One of the major priorities identified was to implement storm water master planning in key watersheds to assist Knox County with handling the storm water regulatory and planning issues in those areas. The general consensus of the SWAC was that the County should have the authority to manage the watershed based on the findings of the master plans.

Knox County and the SWAC selected the Beaver Creek and Ten Mile Creek watersheds as priority watersheds for Master Planning and studies began in 1998. However, in late 1998 the Federal Emergency Management Agency (FEMA) initiated a flood insurance restudy of Knox County to update the 1982 Flood Insurance Study (FIS). It was determined that the results of the models that were being developed as part of the master planning effort could be submitted to FEMA for inclusion in the County-wide restudy. This enabled the County to ask FEMA to restudy other County streams, avoiding duplicate studies on Ten Mile Creek and increasing the number of County streams that are part of the National Flood Insurance Program (NFIP). Because of the timing of the FEMA restudy, the Ten Mile Creek master planning study was initially started as a "FEMA-style" flood study of the creek and its tributaries.

The results of the flood study were presented to Knox County in a report titled *Ten Mile Creek Watershed Flood Study* (Ogden, 2000). The objective of that report was to provide floodplain and floodway information to update the effective 1982 FIS. Essentially, the flood study provided the 100-year and 500-year floodplain boundaries, the 100-year floodway boundaries, and flood profiles for the 2-, 10-, 25-, 100- and 500-year events for Ten Mile Creek and selected tributaries for baseline (i.e., existing) land use conditions.

Once the Ten Mile Creek flood study was finished, the master planning effort could continue. This report constitutes the Master Plan for the Ten Mile Creek Watershed. It is a continuation of the flood study and includes a detailed discussion of existing condition results, hydraulic analyses of full build-out (i.e., future land use) conditions, analyses of general storm water management alternatives, specific flood solution alternatives, and stream water quality information.

1.2 Storm Water Master Planning – Definition and Approach

Knox County is facing rapid development pressure. While improvements to things such as transportation, water supply and wastewater treatment are typically planned and constructed as development increases, drainage concerns are rarely addressed on a level above individual site construction. For areas where new development or re-development is imminent, a storm water master plan for the overall drainage system can be a useful tool because it gives land use planners and storm water managers a better understanding of the dynamics of the watershed and stream systems. Master plans are developed using a "total watershed approach", meaning that solutions to storm water problems are designed to have the local desired effect, but are also analyzed in terms of the overall effect on the watershed or stream system. The hydrologic and hydraulic computer models developed in the master planning process will allow community planners and engineers to assess the impacts of proposed land use changes and to recommend mitigation measures ahead of development. Master plans also assist in the development of cost effective capital improvement plans for existing problems in the watershed, and allow the potential for regional or coordinated solutions to problems, rather than piecemeal changes and corrections.

The master planning approach involves using mathematical computer models to simulate rainfall on the watershed for different land use conditions, determine the quantity and general timing of runoff hydrographs, and predict flood elevations resulting from the combination of rainfall, land use and storm water conveyance system data. The models are developed and calibrated for existing (i.e., baseline) land use conditions. Existing condition data is developed using extensive field observations, watershed-wide survey data, and any available topographic and planimetric mapping. The watershed and storm water conveyance systems are modeled in sufficient detail for planning and regulatory purposes, and to enable analyses of system improvements to reduce flooding and improve or maintain water quality. Once the models are developed and calibrated, they can be used to predict storm water quantity and flood elevations for future and/or proposed land use conditions, and analyze structural (e.g., detention ponds, channel improvements) and non-structural (e.g., open space and land use management, regulatory management) flood and water quality improvement alternatives.

The key element of a master plan that makes it such a useful tool is the future condition analyses, allowing a prediction of the potential flood and water quality problems due to the planned development in the watershed and the associated encroachments in the floodplain. Because of this predictive capacity, the master plan enables the County to identify and assign priorities for capital improvements, develop meaningful regulatory controls for new development, and protect the safety and welfare of residents and businesses in the watershed.

However, as important as master plans are to any comprehensive storm water program, by themselves they will not solve problems or prevent flooding, drainage or water quality problems. The master plans represent a blueprint for action that must be taken if these problems are to be solved or prevented. Too often people see the master plan as the end product and forget that if the plans are not implemented little good will result from the completed work. The real work begins when the master plan is complete.

1.3 Master Plan Objectives

The principal objectives of this storm water master plan, as identified by the Knox County SWAC, can be broken into three main categories: addressing needs and issues, providing a regulatory instrument, and assisting with planning.

In addressing storm water **needs and issues**, the master plan will:

- address major and minor flooding issues, and identify flood solution alternatives to fix existing problems and determine ways to avoid future problems;
- provide "what if" analysis capability for planning and storm water management purposes;
- inventory the drainage system to the level desired by County staff;
- present information to allow prioritization of capital improvement projects (CIPs);
- utilize existing GIS data and create new layers of information for use in planning, maintenance, CIPs and complaint handling; and,

- address water quality, both holistically and in response to regulatory permitting pressures.

For **regulatory instruments**, the master plan will provide the necessary information to:

- extend the regulatory floodplains in Ten Mile Creek and its tributaries beyond the floodplain boundaries required by FEMA for flood insurance purposes;
- be used in the plans approval process to assist with defining requirements for new developments and redevelopments in the Ten Mile Creek watershed.

For **planning** purposes, the master plan will:

- provide an overall land use guide for storm water management in the watershed;
- provide a tool to assist planners with Sector Plan and zoning decisions; and,
- be a policy tool to assist policy makers.

1.4 Scope of Study

This study is the second of two planned reports in a comprehensive study of the Ten Mile Creek watershed. The first report, titled *Ten Mile Creek Watershed Flood Study* (Ogden, 2000), provided floodplain and floodway information to update the effective FIS performed in 1982. This study provides the following information to the Knox County Department of Engineering and Public Works for storm water management purposes as defined by the objectives listed previously. Specifically, this master plan provides:

- stream water quality information for Ten Mile Creek and its tributaries;
- the 100- and 500-year floodplain boundaries for the selected stream reaches for existing (FEMA) conditions (submitted in entirety in the *Ten Mile Creek Watershed Flood Study*);
- a detailed delineation of the contributing drainage area for the Ten Mile Creek watershed;
- a detailed delineation of the hydrologic soils types in the Ten Mile Creek watershed;
- a detailed delineation of the existing and future land use conditions in the Ten Mile Creek watershed;

- existing and future land use condition hydrologic models of the Ten Mile Creek watershed with frequency discharge information at the sub-basin (approximately 100 acre) level;
- existing and future land use condition hydraulic models of Ten Mile Creek and selected tributaries;
- an analysis of flood solution alternatives for priority areas identified by Knox County; and,
- an analysis and discussion of structural and non-structural alternatives for storm water management in the watershed.

Because "existing conditions" is variable with time, the following definition applies to this study: **existing conditions is defined as the state of the watershed as of November 1998**. This date corresponds to the date of completion for the existing condition model for the FEMA Flood Study. Future conditions are defined as the planned land use conditions in the watershed according to the 15-Year Growth Plan developed by the Metropolitan Planning Commission (MPC). More information on the future urbanization in the watershed is presented in Chapter 5.

2 STUDY AREA DESCRIPTION

2.1 The Watershed

Figure 2-1 shows the Ten Mile Creek watershed boundary and the location of Ten Mile Creek and its major tributaries. The Ten Mile Creek watershed is located in Knox County, as shown in the small locator map in the lower left corner of Figure 2-1. The watershed has a contributing drainage area of approximately 15 square miles and is bounded by Black Oak Ridge to the north and Nubbin Ridge to the south. Both of these ridges run southwest to northeast in Knox County. The maximum elevation (1327 ft) in the watershed is found on Black Oak Ridge. The minimum elevation (836 ft) is located in a sinkhole where the creek discharges (Ebenezer Sinkhole). The watershed is located entirely within Knox County, however the City of Knoxville covers most of the eastern side of the watershed and dissects the watershed along the I-40/75 and Kingston Pike corridors. Approximately one-third of the watershed is within the City of Knoxville limits.

The Ten Mile Creek watershed is located in a highly karst area and is pocketed with sinkholes and springs. Ten Mile Creek is unique in that it discharges to a large sinkhole (Ebenezer Sinkhole), which drains to a cave (Ebenezer Cave) that serves as the main throat of the sinkhole. The location of the cave and the topography surrounding the sinkhole are shown in Figure 2-2. The storage volume in the sinkhole was calculated as approximately 4960 acre-feet at elevation 888, which is the elevation at which the sinkhole would overflow if filled with water. Topography maps provided by KGIS indicate that the cave entrance is located at elevation 836. Previous studies have shown the connectivity of Ebenezer Cave to Fort Loudoun Lake on the Tennessee River (MCI, 1987).

The rate of flow into the cave and through the subterranean system is unpredictable and can be influenced by several factors, including the water table, sediment and debris at the cave entrance, and shifting of the subsurface passages. For the majority of rainfall events, any water stored in the sinkhole is drained fairly quickly through the cave according to local observations. However, flooding of nearby roadways (Peters Road, Westland Drive, Ebenezer Road) for extended periods due to backwater in the sinkhole and slow drainage through the cave system has been documented on occasion since the 1920's. Flooding at the sinkhole has become a more frequent event in recent years, occurring three times since 1994. Sinkhole flooding is usually associated with high volume or extended period rainfall events combined with high water table conditions.

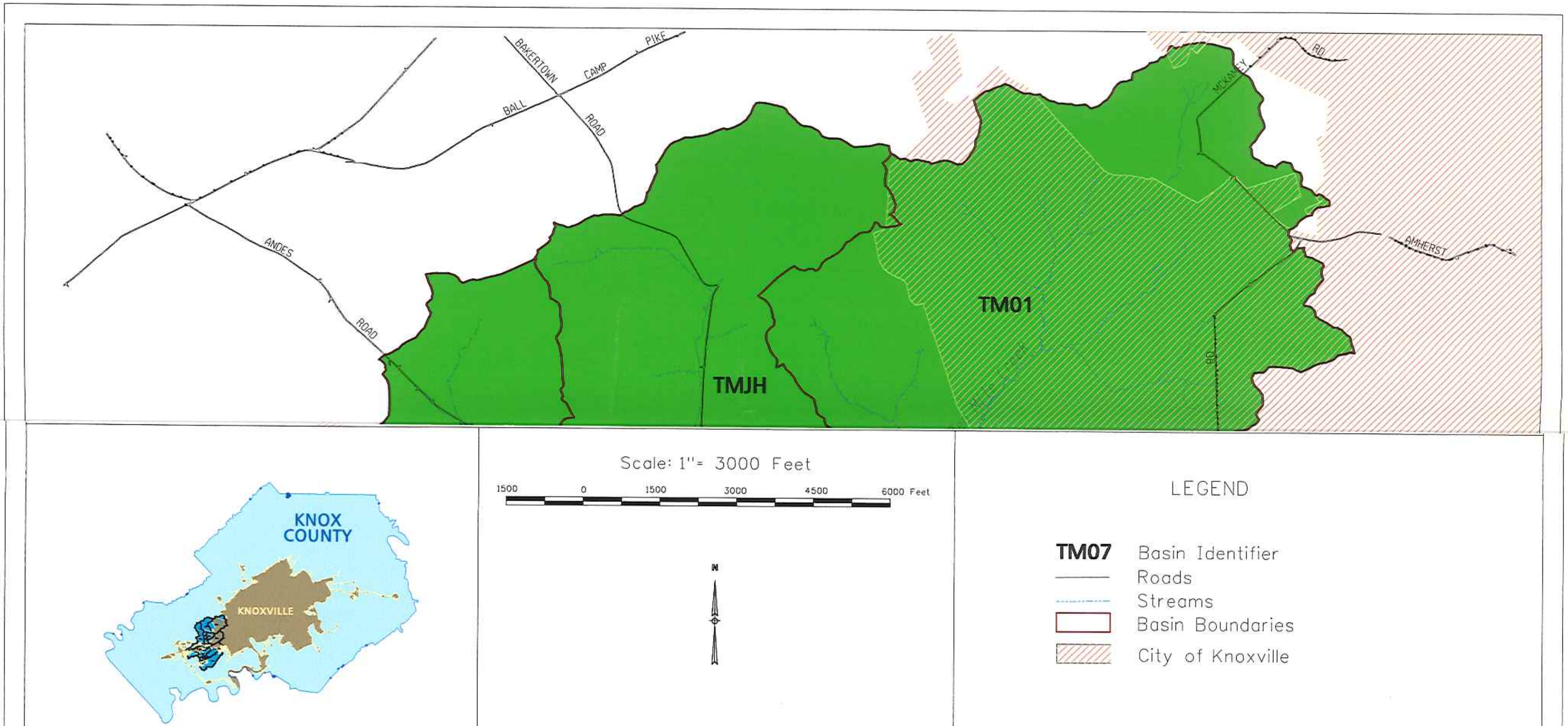

Figure 2-1. Ten Mile Creek Watershed

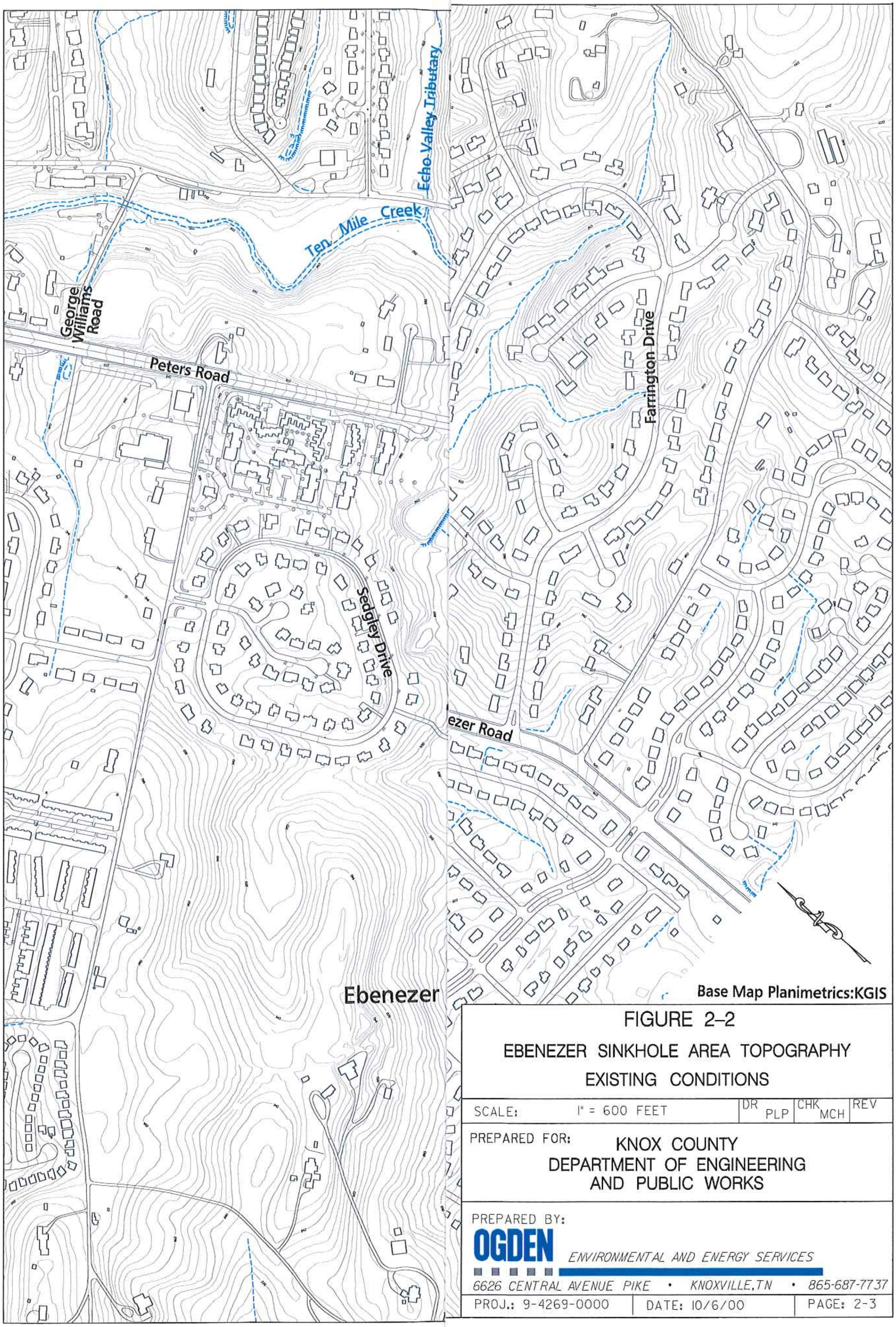

FIGURE 2-2

EBENEZER SINKHOLE AREA TOPOGRAPHY

EXISTING CONDITIONS

SCALE: 1" = 600 FEET	DR PLP	CHK MCH	REV

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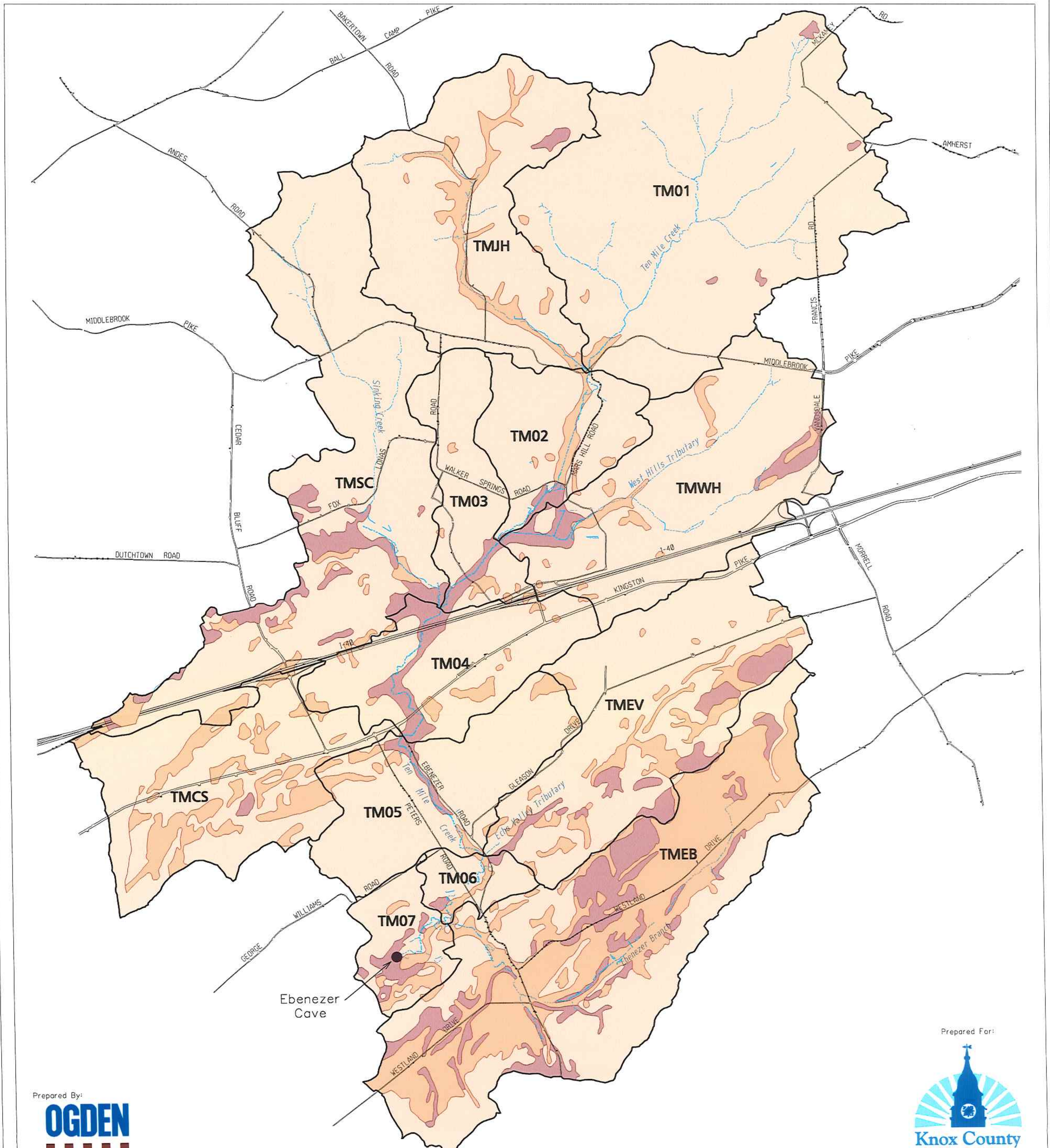


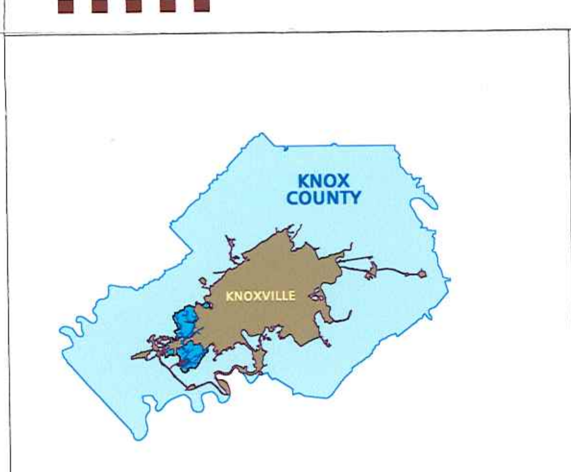
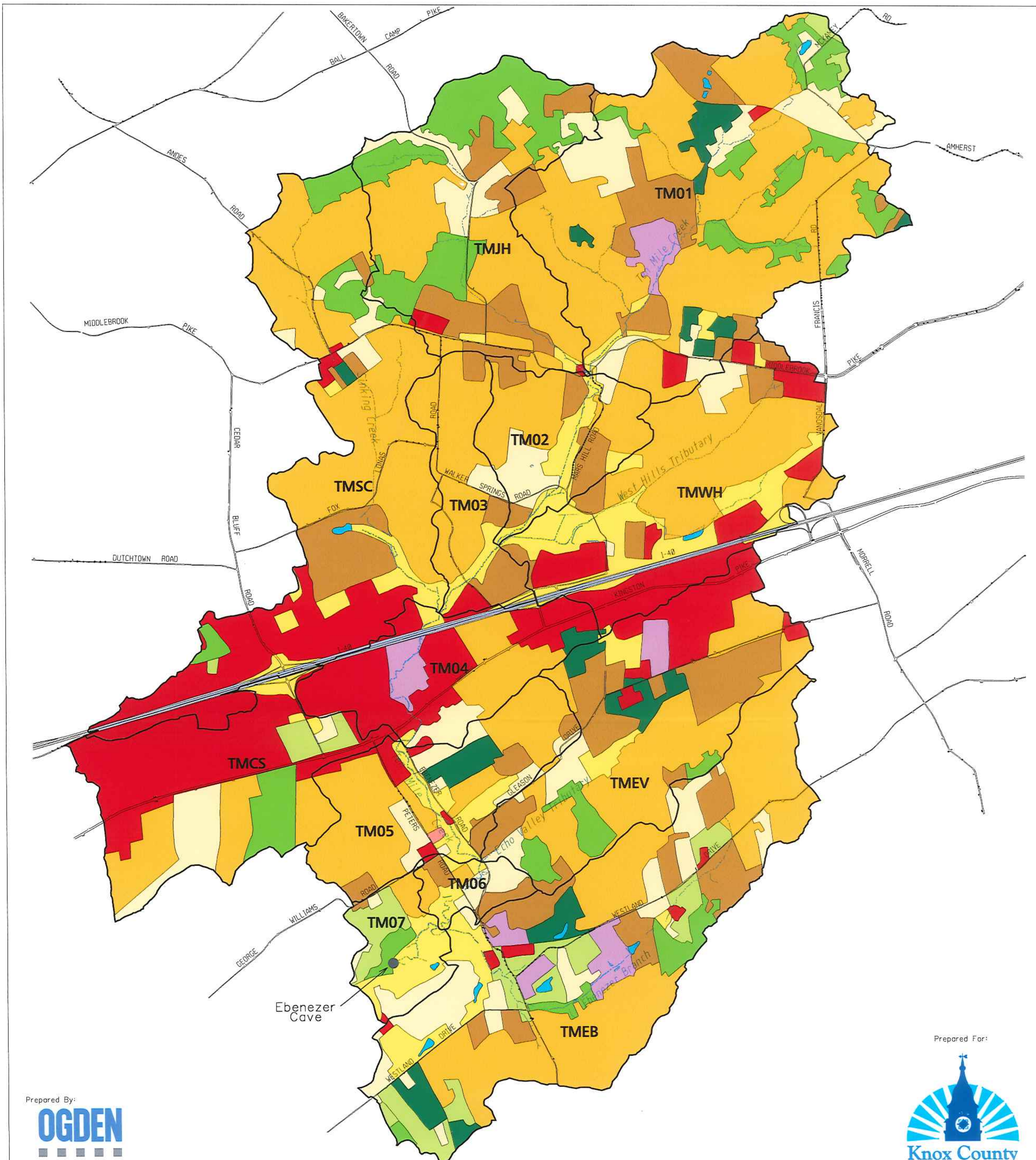


Figure 2-3 Ten Mile Creek Watershed Hydrologic Soil Groups



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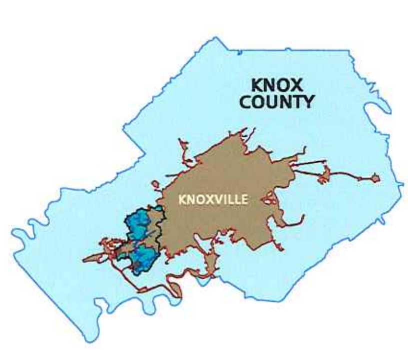
OGDEN

Prepared For:

Knox County



Scale: 1"= 3000 Feet

1500 0 1500 3000 4500 6000 Feet

N

Figure 2-4 Ten Mile Creek Watershed Existing Condition Land Use

LEGEND

- Roads
- Streams
- Basin Boundaries

SCS Land Use Categories

Commercial	Shopping Areas, Convenience Stores, Office Parks, Businesses
Industrial	Industrial Areas, Schools, Prisons, Churches, Utility Areas, Technology Areas
Residential (High Density)	Multi-family, Condos, Apartments, Trailer Parks
Residential (Medium Density)	Single Family, Lot Size 1 to $\frac{1}{4}$
Residential (Low Density)	Single Family, Lot Size 1 Acre or Larger
Disturbed / Transitional	Gravel Parking, Quarries, Land Under Development
Open Land	Urban Green Space, Parks, Golf Courses, Cemeteries, Grazed Pasture
Meadow	Hay Fields, Tall Grass, Ungrazed Pasture
Woods (Thin Cover)	Lightly Wooded Areas, Stream Protection Areas, Tree Farms
Woods (Thick Cover)	Heavily Wooded Areas, Slope Protection Areas
Impervious	Parking Lots, Roadways, Large Shopping Malls
Water	Streams, Rivers, Ponds, Lakes

tributary to Ten Mile Creek, drains the southern portion of the watershed directly to the Ebenezer Sinkhole area. To date, reported flooding in Ebenezer Branch has been limited to roadway overtopping of Ebenezer Road and Westland Drive. The Echo Valley tributary discharges to Ten Mile Creek approximately one mile upstream of the sinkhole. Roadway flooding has occurred along the Echo Valley Tributary due to backwater from the Ebenezer Sinkhole.

Table 2-1. General Information – Ten Mile Creek Drainage Basins

Stream Name	Basin Identification	Drainage Area (mi^2)	Number of Sub-basins	Area Draining to Sinkholes (mi^2)
Ten Mile Creek 01	01	2.666	16	0.025
Joe Hinton Road	JH	1.426	9	0.188
Ten Mile Creek 02	02	0.569	5	0.174
West Hills Trib.	WH	1.452	12	0.0
Ten Mile Creek 03	03	0.517	5	0.187
Sinking Creek	SC	2.059	18	0.134
Ten Mile Creek 04	04	0.769	7	0.0
Cedar Springs	CS	1.138	9	0.0
Ten Mile Creek 05	05	0.863	6	0.0
Echo Valley	EV	1.450	10	0.088
Ten Mile Creek 06	06	0.165	2	0.0
Ebenezer Branch	EB	2.326	16	0.0
Ten Mile Creek 07	07	0.300	2	0.0
Watershed Totals	-	**15.702**	**117**	**0.797**

2.2 Soils Coverage

Because most urban and suburban areas are only partially covered by impervious surfaces, the soils and surface cover types will continue to have a significant influence on runoff generated from the Ten Mile Creek watershed even after it is fully developed. Figure 2-3 presents a map of the hydrologic soil groups present in the watershed. The hydrologic soil group is an indication of the amount of infiltration the soil will allow. Sandy soils will allow significant infiltration while rock formations tend to allow no infiltration. The definition of each hydrologic soil group is given in Table 2-2.

Table 2-2. Definition of Hydrologic Soil Groups

Hydrologic Soil Group	Soil Group Characteristics
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Source: Soil Conservation Service, June 1986 *Urban Hydrology for Small Watersheds, Technical Release 55*

As with most of Knox County, the predominant soil group in the Ten Mile Creek watershed is the type B soil. These moderately well drained soils cover approximately 80% of the watershed. The remaining 20% of the watershed is covered with the poorly drained soils of groups C and D. The group C and D soils are predominant throughout the Ebenezer Branch basin, in the Ebenezer Sinkhole and along streambeds. A summary of the soil group distribution for the watershed is provided in Table 2-3. More detailed soil group information at the basin level is provided in the *Ten Mile Creek Watershed Flood Study* (Ogden, 2000).

Table 2-3. Hydrologic Soil Group Distribution – Ten Mile Creek Watershed

	DISTRIBUTION OF HYDROLOGIC SOIL GROUPS (%)			
	A	B	C	D
Watershed Totals	0	80	14	6

2.3 Land Use and Urbanization

The effect of urbanization and associated impervious cover on storm water processes and flood frequency has been well-documented (Debo, 1997; USGS, 1984). As urbanization within a watershed increases, the changes in land use from undeveloped conditions to developed conditions can cause significant changes in the hydrologic, hydraulic and water quality characteristics of the watershed. From a flooding standpoint, increases in impervious area coverage will cause subsequent rises in the volume of runoff and flood elevations. Man-made storm water control devices such as curb and gutter systems and underground drainage systems (e.g., storm sewers) can drastically change the natural timing of a watershed resulting in changes to peak discharge rates, flood frequencies, and velocities within the streams. From a water quality standpoint, development in a watershed increases the number of pollutant sources while decreasing some of the natural features (open spaces, riparian zones, vegetated areas) that can serve to reduce pollutant loading to water bodies.

The Ten Mile Creek watershed has already experienced many changes to the hydrologic, hydraulic, and water quality characteristics of the watershed. In the 1950's, land use in the watershed was predominantly rural, and residential and limited commercial development was largely confined to the I-40/75 and Kingston Pike transportation corridors. Today, residential developments cover more than 60% of the watershed and commercial developments cover another 14%. There are two greenways in the watershed. The John C. Bynon West Hills Greenway is located along the upper portion of the West Hills Tributary north of Interstate-40. The Walker Springs Park greenway, which is currently under development, will extend between Gallaher View Road near Wal-Mart and Interstate-40. There are on-going efforts to acquire the land needed to join the two existing greenways, and to extend them north along the upstream portions of Ten Mile Creek.

Figure 2-4 shows the existing land use conditions in the Ten Mile Creek watershed, as of November 1998. Table 2-4 provides a summary, in percent by land use category, of the existing land use conditions in the Ten Mile Creek watershed. More detailed existing land use information at the basin level is provided in the *Ten Mile Creek Watershed Flood Study* (Ogden, 2000).

Table 2-4. Existing Condition Land Use Distribution in the Ten Mile Creek Watershed

	DISTRIBUTION OF LAND USES BY LAND USE CODE (%)												
	Res HI	Res MD	Res LO	Com	Ind	Dst	Ag	Open good	Mead	Thk wds	Thn wds	Imp	water
Watershed	12	43	9	14	0	2	0	7	3	7	2	1	0

2.4 Channels and Floodplains

Table 2-5 provides general information about Ten Mile Creek and the major tributaries analyzed for the master plan. Ten Mile Creek, also referred to as "the main stem" in this report, is approximately 6.4 miles in length. The headwaters of Ten Mile Creek are located north of Middlebrook Pike in Knox County and the creek flows southwest through both City of Knoxville and Knox County areas to Ebenezer Cave located at Ten Mile Creek River Mile (RM) 0.0.

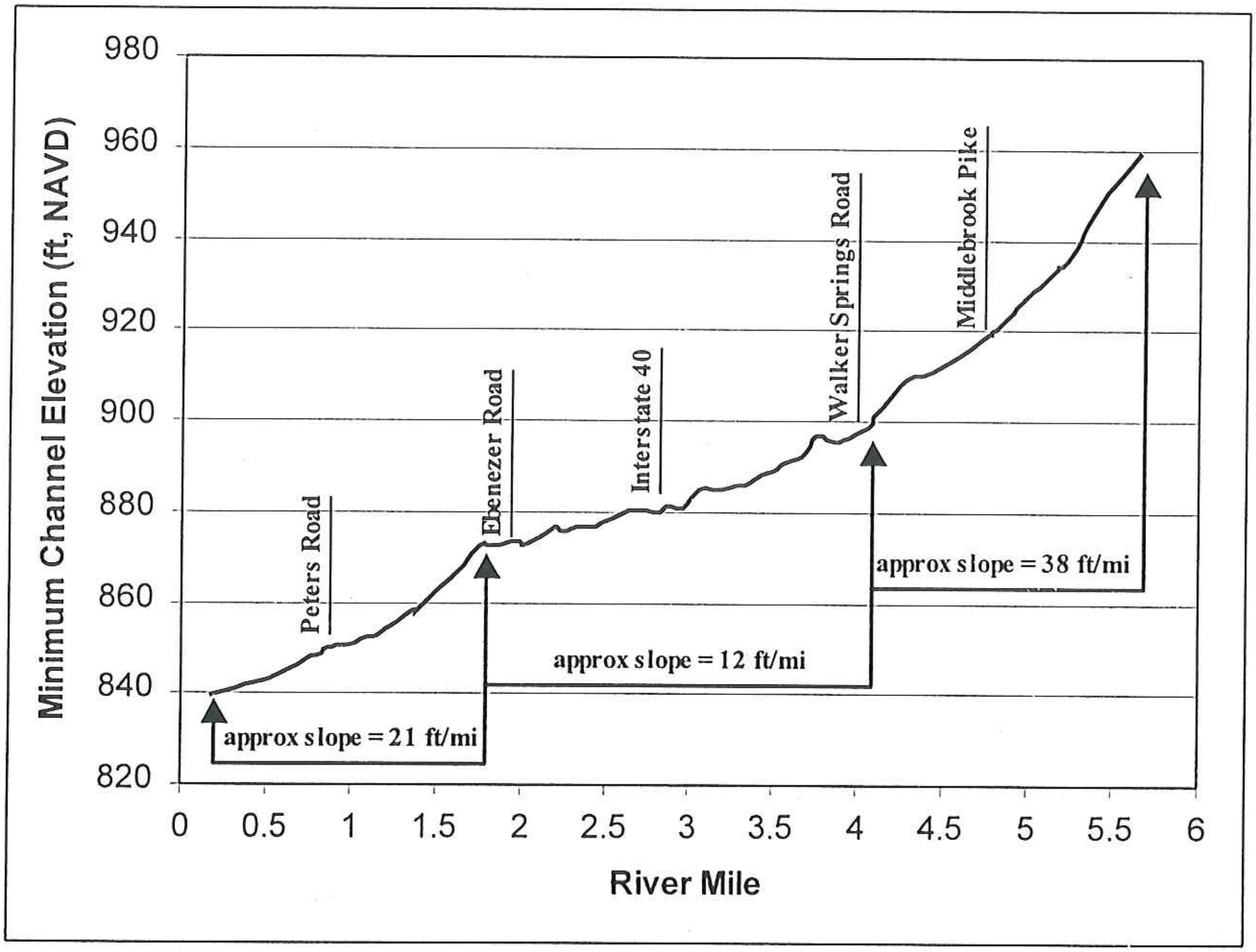
Table 2-5. General Information – Ten Mile Creek and Tributaries (starting upstream)

Tributary Name	Location of Confluence (River Mile)	Stream Length (miles)	Average Slope (ft/mile)	Recorded Flooding?
Ten Mile Creek	Ebenezer Cave RM 0.0[1]	7.05	39.78	Yes
Joe Hinton Road	Ten Mile Creek RM 4.809	1.64	79.41	No
West Hills Tributary	Ten Mile Creek RM 3.662	1.71	55.55	No
Sinking Creek	Ten Mile Creek RM 3.068	2.64	90.77	No
Cedar Springs	Ten Mile Creek RM 1.967	1.61	62.15	No
Echo Valley	Ten Mile Creek RM 1.073	1.51	59.78	Yes
Ebenezer Branch	Ten Mile Creek RM 0.463	2.12	47.45	Yes

1 – River Mile given is at the discharge point of the stream, not at a confluence of two streams

The general characteristics of Ten Mile Creek vary along its length. Figure 2-5 shows the elevation of the channel bed along the studied length (5.6 miles) of Ten Mile Creek. The slope of the main stem is steep (approximately 38 ft/mile) at the upstream end and decreases in the lower two-thirds. The remaining unstudied portion of the main stem, upstream of the studied length, is very steep and raises the average slope of the entire stream (from headwaters located approximately at RM 7.0, to the sinkhole) to almost 40 ft/mile. The low-flow channel can be described as fairly clean and winding, with some large boulders and cobbles and very few pools of significant depth. After most normal rainfall events, the stream can be described as "flashy", with fairly rapid increases in flow and water surface elevation. Portions of the main stem do flow out-of-bank on a frequent basis (i.e., at least once every year), however this frequent bank overtopping is typically short-lived and usually does not impact nearby roads or structures. Flood events that impact roads and structures occur on a less frequent basis. To date, the most significant reported flooding has been confined to the Ebenezer Sinkhole area.

Figure 2-5. Profile of Ten Mile Creek Channel Bed



The width and characteristics of the natural floodplain of Ten Mile Creek vary along its length. The most significant floodplain areas along the main stem can be found between Mars Hill Road (RM 4.787) and Walker Springs Road (at RM 4.082), at the confluence of some major tributaries (West Hills and Sinking Creek), and in the vicinity of the Ebenezer Sinkhole. There has been some development in the floodplains, most notably near Kingston Pike and Interstate-40, and construction of new roadways (Mars Hills Road, Gallaher View Road and Walker Springs Road) had just begun in the floodplains along the main stem and at the confluence of the West Hills Tributary. Based on field observations and MPC projections, it is anticipated theses areas will be developed with commercial and residential properties. The effect of floodplain encroachment along Ten Mile Creek is discussed in Chapter 6.

Vegetation in the floodplain and along the stream bank varies in amount and condition, and is largely dependent upon the land use in the floodplain. Open land and woods are the predominant land uses along the stream banks. Erosion along the stream banks is not uncommon, but no critical areas for erosion, from a property damage standpoint, have been identified or observed on the main stem.

The general characteristics of the tributaries differ from the main stem. Tributary stream channels generally are straighter and much steeper than the main stem, resulting in higher channel velocities and less floodplain storage. Tributary channel bottoms vary in constitution, but tend to have more rocks and small cobbles than the main stem. The tributaries also have more residential land uses located along the channel banks, and therefore floodplain vegetation is commonly short grasses and thin woods.

2.5 Previous Studies

As development increased in the watershed and residents began to experience problems associated with increased storm water discharges to Ten Mile Creek, a number of reports and studies were produced to analyze the creek and cave drainage system. This section provides an overview of the significant reports and studies on the creek. Comparison of the results of several of these studies with the results of the existing condition models developed for the Ten Mile Creek flood study is contained in the flood study report (Ogden, 2000).

The Tennessee Valley Authority (TVA) produced one of the first reports on the creek, entitled "*Floods on Ten Mile and Sinking Creeks in Knox County Tennessee*". The study was prompted by a flood event that occurred in the watershed in March 1973. The report listed historical flood elevations in Ebenezer Sinkhole, and flood stages along Ten Mile Creek. In addition, the report quantified estimates for the regional (or 500-year) flood elevations. It was observed that the regional flood would be several feet higher than the flood experienced in 1973, and it was noted that flooding in Ten Mile Creek was largely unnoticed prior to the 1973 flood, most likely because of a lack of development in the watershed.

After the major floods that occurred during the winter and spring of 1972-73, TVA produced a second report in 1974 at the request of the Knox County Commission. This report was entitled "*Possible Flood Relief Measures Ten Mile Creek Sink – Knox County, Tennessee*" (TVA, 1974), and its purpose was to identify and evaluate flood relief measures for Ebenezer Sinkhole. The report briefly explained the interconnecting Ten Mile Creek cave system that comprised the discharge pathway for Ebenezer Sinkhole and warned against the accumulation of debris and sediment at the mouth of the cave and blasting or construction activities that could collapse underground passages. The study examined flood relief measures at the sinkhole for the 1% annual chance storm (i.e., the 100-year storm event), and allowed for ponding of stored water to elevation 860 and a cave discharge capacity of 900 cfs. Four alternatives were examined, starting with excavation of an open channel from the sinkhole to Fort Loudoun Lake (at the

Sinking Creek embayment), and two alternatives that combined the channel excavation with tunnels of various length. The fourth alternative considered construction of a 1.12 million gallon per minute storm water pump station. Costs for the alternatives ranged from a low of $1,300,000 for the excavated channel to $7,000,000 for the pump station. A fifth alternative using a combination of structural (raising affected roadways, floodproofing affected residences and structures) and non-structural measures (regulating future construction, obtaining flood insurance) measures was also identified, but the cost of this alternative was not estimated.

The effective Knox County Flood Insurance Study (FIS) was published in 1982 (FEMA, 1982). TVA studied Ten Mile Creek, Sinking Creek and two tributaries to Ten Mile Creek in detail. The tributaries are identified as Tributary 1 and Tributary 2 in the FIS, and are studied and identified as the West Hills Tributary and Echo Valley Tributary (respectively) in the most recent flood study (Ogden, 2000) and in this master plan. In the 1982 FIS, peak flows were determined using regional regression equations. Urbanization in the watershed was considered in the peak discharge estimation by applying a factor to the rural regression analysis based on impervious area. Peak stage in Ebenezer Sinkhole was determined using routing calculations. The Corps of Engineers HEC-2 Water Surface Profiles computer model was used to calculate water surface profiles in the studied streams.

In 1987, MCI Consulting Engineers published a study entitled "Engineering and Geologic Study of Ten Mile Creek Drainage Basin" (MCI, 1987). The purpose of the study was to provide a characterization of the hydraulics and hydrology of the Ten Mile Creek watershed and to assess the sinkhole systems. The report relied heavily on previous hydraulic and hydrologic studies by TVA and attempted to quantify increases in flood potential from development. Peak discharge and flood stage estimates for future conditions, as related to percent impervious surface, were estimated. The role of Ebenezer Cave in flood potential was discussed extensively. The MCI report identified structural and non-structural alternatives that could serve to minimize the impact of flooding along the creek. Recommendations for non-structural alternatives included establishing a special Drainage District funded by those directly affected by drainage issues within the basin, establishing certain administrative methods to make flood history and flood potential information more readily available and useful, and establishing more stringent regulations in regards to development in the Ten Mile Creek watershed. Structural recommendations included regular cleaning and maintenance of the mouth of Ebenezer Cave and the outlet of the cave at the Sinking Creek embayment, and further consideration of channel excavation or tunneling to release stored water from the sinkhole during large events.

In 1992, the Corps of Engineers Nashville District performed a Reconnaissance Study of Knoxville and Knox County, which included Ten Mile Creek (USACE, 1992). The scope of the study was limited to studying Ebenezer Cave and providing alternative analyses for flooding in and around Ebenezer Sinkhole. A hydrologic model was developed using the Ebenezer Cave outlet geometry and Ebenezer Sinkhole storage capacity data to determine frequency stages in the sinkhole and evaluate flood solution alternatives. The study did consider flood elevations in the sinkhole during natural (i.e. open throat) conditions and clogged (i.e., zero flow into the cave) conditions. Flood solution alternatives considered included enlarging and protecting the cave inlet and a high flow channel to bypass the cave. A 200-foot wide open-cut channel starting at elevation 863 was designed to provide flood protection up to 868 feet MSL for the 100-year flood event. A cost estimate for the high flow channel was not determined.

2.6 Flood History

As established in the previous section, flooding in the Ten Mile Creek watershed has occurred on a number of occasions. Table 2-6 presents a summary of reported high water marks at Ebenezer Sinkhole.

Table 2-6. Summary of Historical Flooding at Ebenezer Sinkhole

Date of Flood	Reported High Water Elevation	Source
April 12, 1920	871.6	TVA, 1973
July 10, 1939	868.5	TVA, 1973
September 30, 1944	864.1	TVA, 1973
November 18, 1957	864.2	TVA, 1973
March 12, 1963	863.8	TVA, 1973
December 10, 1972	867.0	TVA, 1973
March 16, 1973	873.3	TVA, 1974
May 7, 1984	862.9	MCI, 1987
April 19, 1998	871.1	Ogden, 2000

Note: All elevations converted to NAVD by subtracting 0.4 ft. from the original NGVD values. The April 19, 1998 elevation was surveyed to 1988 NAVD.

Typical problems that have been documented as early as 1972 include extended periods of flooding on Peters Road, Ebenezer Road (near Ebenezer Sinkhole) and Westland Drive which on occasion have isolated from access by road a number of residences and businesses in the area. Kingston Pike and Ebenezer Road near Kingston Pike have also flooded in the recent past, but typically this flooding is fairly shallow and short-lived. While yard and other nuisance-type flooding is a common occurrence along the creek, a number of residences along the creek have been flooded, most of which are located in the vicinity of the sinkhole where seven houses flooded during the March 1973 flood (TVA, 1974). The most recent occurrence of residential flooding occurred at 8900 Cedar Brook Lane, located at RM 0.869 and in close vicinity to the

Ebenezer Sinkhole. The resident has experienced flooding due to backwater in the sinkhole on a number of occasions, and has even raised the structure once already in an effort to floodproof the lowest finished floor.

Because most of the urbanization of the Ten Mile Creek watershed has occurred since the majority of the historical floods of record, there is potential for an increase in observed flood height solely based on increased impervious area. Therefore, a less frequent event (such as the 100- or 500-year) event could produce stages not previously observed or anticipated in historical records and analysis.

Most recently, the County has received complaints of significant storm water related problems in the locations listed below, prompting the County to identify these locations as *priority areas* for which specific flood/erosion solution alternatives should be evaluated. The priority areas and associated problems in the Ten Mile Creek watershed are:

1. Flooding of roadways and residences due to backwater from the Ebenezer Sinkhole.

2. Flooding of the finished floor at 426 Echo Valley Road, located in the Echo Valley Tributary.

3. Flooding of the ground floor apartments at 1805 Stonebrook Drive and 1732 Robinson Road, located in the upper portion of the Ten Mile Creek watershed.

4. Significant stream bank erosion along a small tributary located behind the BriarGlen subdivision, in Ten Mile Creek basin 05.

3 WATER QUALITY

3.1 Background

Because of the urban nature of the watershed, continual degradation of the water quality in Ten Mile Creek and its tributaries is expected. While there are no regulated point source discharges in the watershed, the fact that more than 80% of the watershed is developed with residential/commercial type land uses indicates that the non-point pollutant sources contribute greatly to the degradation of water quality. The likely major pollutant sources for the Ten Mile Creek watershed are:

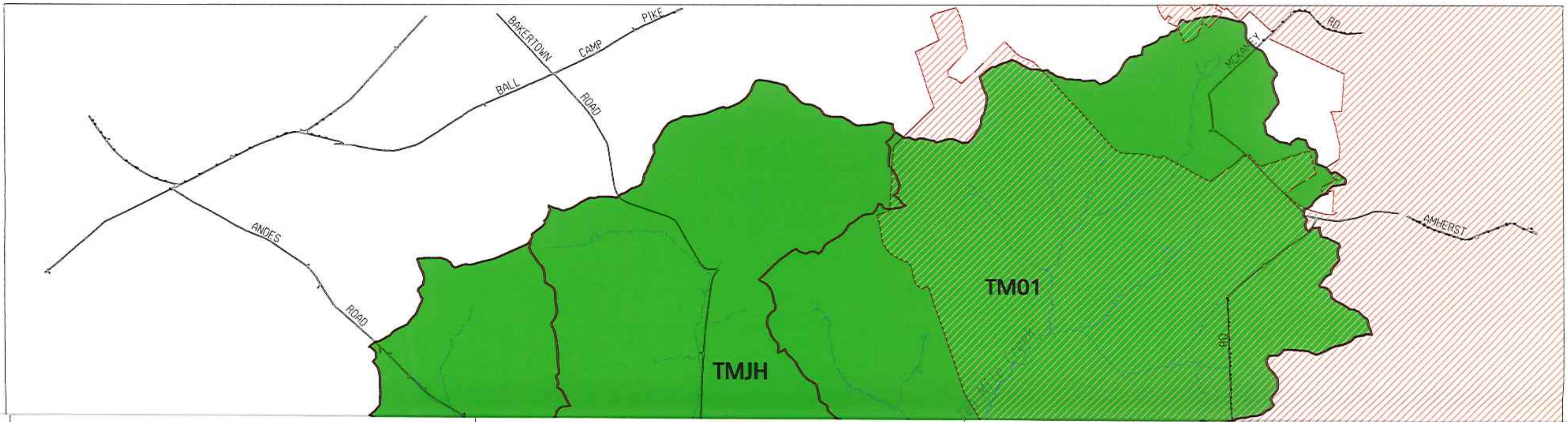
- runoff from residential and office park lawn and landscapes (fertilizers and weed control/pesticides);
- road, highway, and parking lot runoff (oils, gas, antifreeze, heavy metals, asbestos, acids etc.,);
- construction runoff (primarily sediment);
- and illicit discharges.

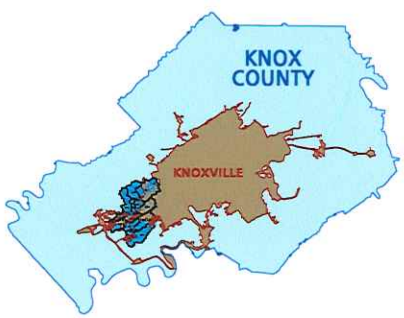
Regardless of the potential for high pollutant loads in the stream, the designated uses that the Tennessee Department of Environment and Conservation (TDEC) has assigned to Ten Mile Creek suggest a higher expectation for its water quality. The following stream uses have been designated by TDEC for Ten Mile Creek (from the sink to the origin):

- fish & aquatic life,
- recreation,
- irrigation,
- livestock watering, and
- wildlife.

These classifications are based on various standards of water quality that must be maintained in order to preserve the designated use of the given stream (Chapters 1200-4-3 & 1200-4-4 - Rules of the Tennessee Water Quality Control Board).

TDEC also issues statewide biennial status reports of water quality in Tennessee in the 305(b) report; as required by the Federal Clean Water Act of 1987. The 305(b) report assesses general water quality conditions in rivers, streams, lakes and ground water and identifies the causes and potential sources of water pollution. Although Ten Mile Creek was not listed, both Turkey





Scale: 1"= 3000 Feet

1500 0 1500 3000 4500 6000 Feet

N

Figure 3-1. Ten Mile Creek Water Quality Survey

LEGEND

TM07 Basin Identifier
Roads
Streams
Basin Boundaries
City of Knoxville
Water Quality Site

Note:
Station #1-Walker Springs Road
Station #2-Kingston Pike
Station #3-Ebenezer Area

Creek and the Sinking Creek Embayment (in Fort Loudoun Lake), which are located within the same geographic area and have the same designated stream uses as Ten Mile Creek, have been assessed by TDEC and are listed in the 305(b) report. Both creeks are designated to be "Not Supporting" of their designated stream use classifications due to impacts from urban runoff, land development, pastureland runoff and municipal point sources (mainly septic system failures). The non-supporting designation means the creek does not have a quality in which most organisms could survive and reproduce. Based on its proximity to similar streams such as Turkey Creek and Sinking Creek, it would be reasonable to assume that Ten Mile Creek also has the potential to be considered a non-supporting stream.

In June 1995 and 1998, the Tennessee Valley Authority (TVA), Water Management Group River Action Teams (RAT) conducted biological assessments at a location in Ten Mile Creek. The biological assessments included cursory surveys of fish and benthic macroinvertebrates (aquatic insects). The data collected from the surveys were analyzed and used to assess the water quality in the creek. The findings of the assessment, which are summarized in Table 3-1, indicate continued degradation of water quality in Ten Mile Creek, suggesting that the creek is not able to support its designated uses.

Table 3-1. TVA-RAT Team Water Quality Assessment for Ten Mile Creek

Location	Year	Drainage Area (Sq mi)	Water Quality Based On:		Overall Assessment
			Fish	Benthics	
Ten Mile Creek at Kingston Pike	1995	9.9	Poor (28)	Poor	Poor
	1998	9.9	Poor (30)	Poor	Poor

3.2 Water Quality Stream Surveys - Assessments and Results

As part of the master planning process, Knox County initiated a survey program to collect baseline water quality data in Ten Mile Creek. A summary of the survey results is presented in this report while a detailed discussion of the survey methods used and the data collected was presented in a previously published report: *Water Quality Survey, Ten Mile Creek, Knox County* (Ogden, May 26, 1999).

Three study stations on Ten Mile Creek and selected tributaries were included in a biological stream survey performed on September 29, 1998. The location of each station is shown in Figure 3-1. The surveys included the systematic collection and identification of biological organisms, typically benthic macro-invertebrate organisms (i.e., bugs) and fish. The number, type and condition of the benthic macro-invertebrates and fish were recorded, along with habitat and basic water chemistry data. Together, this data was used to assess overall water quality for the streams. The results of the stream surveys are summarized in Table 3-2. The "overall assessment" column shown in Table 3-2 is a combination of the various assessment methods applied to the data, tempered with professional judgment based on observations collected during the field survey.

Table 3-2. Water Quality Assessment Summary, Ten Mile Creek

	Benthic Macro-Invertebrates			Fish	Habitat	
Survey Location	**NBC/NCBI**	**Percent Contribution of EPT Taxa**	**TN RBP III Biological Score**	**Total IBI Score**	**Assessment Score (200 possible)**	**Overall Assessment**
STATION 1 Walker Springs Road	5.65 Fair - fairly significant pollution	5.1 %	38% Moderately Impaired	27 Poor	102	**Poor**
STATION 2 Kingston Pike	5.83 Fair - fairly significant pollution	20.0 %	33% Moderately Impaired	28 Poor	110	**Poor**
STATION 3 Ebenezer Area	5.4 Good - Some pollution	12.1 %	48% Moderately Impaired	26 Poor	130	**Poor -Fair**

The results from this survey show that the combination of pollutant discharges to the Ten Mile Creek watershed have impacted water quality along Ten Mile Creek. Although the stations sampled for this survey were generally located in residential or light-commercial areas, the streams receive runoff from a number of different land uses that contribute a variety of pollutants, as defined previously. The reduction in, and/or absence of, intolerant fish and benthic macro-invertebrate species at the most upstream survey stations (Walker Springs and Kingston Pike), indicated by the percent EPT, implies that water quality conditions are compromised and a fairly significant pollution contribution is being made to the watershed. The slightly better conditions at the Ebenezer Road station may be attributed to better habitat availability, a less developed riparian zone and increased flow volume from the influx of Ebenezer Branch.

The increase in impervious land through construction of roads, parking lots and buildings, greatly reduces the watershed's ability to naturally filter and treat (through bacterial action) storm water runoff. Under present conditions, unfiltered rainwater, which in a natural system would seep through the ground and become filtered groundwater, flashes across impervious materials and flows straight into the creek. The bypassing of natural treatment, in conjunction with man-made contaminants entering the stream, is resulting in a system-wide reduction in water quality. This is a readily identifiable problem in the Ten Mile Creek watershed, where commercial businesses that have large amounts of impervious area are located in close proximity to the creek and contributing drainage systems (e.g., Wal-Mart/Sams Club, Lowes, Carmike Cinemas, the Town & Country Shopping Area). While discharge enters detention basins, the detention is not sufficient to reduce pollutant loads when the flow enters the creek.

In addition, as found in other local streams, sediment influx appears to be a major contributor to water quality and habitat degradation in Ten Mile Creek. The creek substrates were often covered with sediment deposits that at some stations were 5 to 8 inches deep. Suspended sediments were also observed throughout the watershed. Sediments physically impair aquatic organisms and their habitat, transport chemicals (toxicants), nutrients, oils and greases and organic salts into the creeks. The low levels of benthic macro-invertebrate shredders and filter feeders suggest the presence of toxicants in the system.

Construction sites and other disturbed lands are likely the major contributor of sediment in the Ten Mile Creek watershed. Because of the developed nature of the watershed, many construction sites are "directly-connected" to the creek system. This means that there are often no natural buffers that can provide partial sediment removal before the runoff enters a stream. Instead, sediment-laden runoff that is allowed to discharge off-site quickly enters a stormdrain or gutter system and ends up in the creek system.

Streambank erosion can also contribute large amounts of sediment to a stream in a single storm event. The high peak discharges from a developed watershed, combined with mild to steep streambed slopes cause higher than normal velocities that can easily erode unstable or unprotected streambanks. Extreme cases of erosion exist in the watershed, most notably in the wet weather conveyance located behind the BriarGlen subdivision in Basin 05. Less serious erosion has been noted on Ten Mile Creek upstream of the Robinson Road stream crossing.

3.3 NPDES Phase II Regulation Implications

In December 1999, EPA promulgated the National Pollutant Discharge Elimination System (NPDES) regulations known as Phase II. Under these regulations the County will be required to obtain a permit to discharge storm water from urbanized areas to "Waters of the State". This permit will require Knox County to develop and maintain a storm water program that addresses the following six minimum controls for water quality:

1. Public Education and Outreach
2. Public Involvement
3. Illicit Discharge Detection and Elimination
4. Construction Runoff Controls
5. Post Construction Runoff Controls
6. Best Management Practices for Municipal Operations

The highly karst nature of the Ten Mile Creek watershed, and the fact that the creek discharges to a sinkhole will likely influence TDEC in their examination of the best management practices (BMPs) that Knox County proposes to comply with the six minimum controls. Not only do the BMPs impact surface stream quality, but groundwater quality as well. Due to the urban nature of the watershed and the influence of individual businesses and owners on non-point pollution, the citizens of Knox County and the City of Knoxville (not the City and County Storm Water staff) are the most effective means to control further degradation of water quality through education and pollution prevention. BMP strategies should focus on preventing pollution from entering the drainage system.

Methods or practices that would be useful for improving water quality in Ten Mile Creek and its tributaries can also be utilized for compliance with the Phase II regulations. Some suggested methods that are particularly well-suited for the Ten Mile Creek watershed are listed in Table 3-3. Because the watershed covers both County and City land, it is highly recommended that the two entities work together to develop similar methods or identical BMPs strategies, particularly for the construction site, post construction, and municipal operations controls.

Table 3-3. Suggested Water Quality BMPs for the Ten Mile Creek Watershed

Phase II Control	Suggested Practices:
1 and 2. Public Education and Public Involvement	• Target education activities to major pollutant sources (e.g., advise homeowners on landscape practices). • Develop a 1-hour presentation on storm water pollution prevention for schoolchildren. (This can be particularly effective for Ten Mile Creek, as there are 7 schools located inside the watershed boundaries). • Educate residents such that they can police their watershed by advising the County of possible violations. Educational subjects can include illicit discharge identification (oily sheen, odor, foaming), construction site sediment control requirements, the impact of trash on the sinkhole, etc. • Continue citizen involvement through SWAC participation. • Promote and support Adopt-a-Creek, River Rescue, or similar volunteer-type initiatives to help remove debris and trash along the Creek and tributaries on a regular basis.
3. Illicit Discharges	• Utilize sub-basin delineations and land use mapping generated by the master plan to plan outfall investigations and pinpoint water quality "hot-spots".
4. Construction Runoff Control	• Require stringent sediment and erosion control from construction sites located adjacent or in close vicinity to a stream. Regularly inspect these sites if possible. Require several levels of control as necessary based on site parameters. (buffer strips, sediment ponds, daily cleanups, etc) • Require less stringent, but more than normal, sediment and erosion control from all other sites located in the watershed.
5. Post-Construction Runoff Control	• Require minimum buffer strips for new developments located near streams. • Develop incentives for owners of large impervious areas to implement water quality friendly BMPs.
6. Municipal BMPs	• Perform regular street sweeping and catch basin cleaning activities. • Perform regular inspections and debris/sediment removal activities at Ebenezer Cave. • Encourage and support the continuing Greenway initiatives. • Identify and repair areas of streambank erosion.

3.4 Water Quality Management Recommendations

Based on the results of the water quality surveys in the Ten Mile Creek watershed and the impending Phase II regulations, the following recommendations are made to improve or maintain water quality in Ten Mile Creek and its tributaries.

1. The County should find ways to educate the public on the source and reduction of the primary pollutants and how to police their own watershed (e.g., how to identify and report a potential illicit discharge). Since most of the County land in the watershed is residential, education should focus on residential source pollutants.

2. The County should encourage the use of effective BMPs for businesses and communities in the watershed. Examples of methods used to encourage such practices are "environmental friend" awards or similar public acknowledgements and "fast-track" permitting processes or fee reductions for new construction or re-developments.

3. **Sediment load reduction is extremely important in Ten Mile Creek, from both a water quality and flooding standpoint.** The County should implement and maintain a strong erosion control program for all land disturbances in the watershed. For construction activities, sediment controls need to be established and maintained prior to, and throughout the duration of, all construction activities, including those located away from the creek. The County should repair existing stream bank erosion problems and regularly inspect areas where erosion has been a problem.

4. Springs, wetlands and other sensitive areas should be identified and protected as they can enhance water quality in the stream.

5. Commercial storm drains and other potential illicit (non-storm water) discharges should be investigated and eliminated.

6. Follow-up monitoring should be conducted in the future to develop long term water quality trends.

7. The County should find ways to work with the City of Knoxville in implementing and maintaining consistent BMPs throughout the watershed.

4 EXISTING CONDITION ANALYSIS

This section presents a brief summary of the methodology used to analyze the Ten Mile Creek watershed and creeks for existing conditions, and a detailed discussion of the results of the existing condition analysis. The scientific and engineering methods utilized to study Ten Mile Creek are well-documented in previous reports presented to Knox County, and for brevity will not be discussed extensively in this report. The reader is referred to the *Ten Mile Creek Watershed Flood Study* (Ogden, 2000) for a detailed discussion of the modeling approach, the data used, and the methods employed to calibrate and verify the hydrologic and hydraulic models of the Ten Mile Creek watershed.

4.1 Methodology

4.1.1 Hydrology

Hydrologic modeling is necessary to predict the response of a watershed to specific rainfall events and changing watershed conditions. Different conditions include theoretical rainstorms, urban development, channel improvements, and detention ponds. The HEC-1 Flood Hydrograph Package (USACE, 1998) computer model was used to facilitate the hydrologic calculations for the Ten Mile Creek watershed. Design rainfall events were used along with SCS curve number and Clark unit hydrograph methods, to predict watershed response and generate design storm hydrographs at each calculation point in the watershed. Peak discharge rates from the design storm hydrographs generated by the HEC-1 model were used as input for the hydraulic models. The existing condition HEC-1 model is based on the land use conditions in the watershed as of November 1998, when the model was developed for the FEMA flood study. It is the intent that the existing condition HEC-1 model will be periodically updated to reflect changes in land use or floodplain storage that would impact frequency discharges.

Input for the hydrologic model includes precipitation data, sub-basin data (area, standard SCS runoff curve number, time of concentration, and the Clark storage coefficient), stream data (channel length, slope, roughness value, and geometry or storage-elevation relationship), and storage node data (storage-elevation-discharge relationships). A 24-hour balanced storm approach was used to simulate the design rainfall in the Ten Mile Creek HEC-1 model. Because the Ten Mile Creek watershed is approximately 15 square miles in area, areal reduction of point rainfall was performed in the manner recommended by the Corps of Engineers for large watersheds (USACE, 1998). The rainfall events used for hydrologic simulation had frequencies of 2-, 10-, 25-, 100- and 500-years. Consideration of base flow was not included in the Ten Mile Creek HEC-1 model. A computation interval of 3-minutes (0.05 hrs) was chosen for the HEC-1 model of the Ten Mile Creek watershed.

Existing Condition Curve Numbers

The land use categories used for curve number estimation are shown in Table 4-1. All curve numbers used for hydrologic modeling in the Ten Mile Creek watershed represent AMC II soil moisture conditions. No adjustment was made for other soil moisture conditions.

Table 4-1. SCS Land Use Categories and Associated Curve Numbers

Land Use Code	Description	Average % Impervious	Curve Number by Hydrologic Soil Group				Typical Land Uses
			A	B	C	D	
1	Residential (High Density)	65	77	85	90	92	Multi-family, Apartments, Condos, Trailer Parks
2	Residential (Med. Density)	30	57	72	81	86	Single-Family, Lot Size ¼ to 1 acre
3	Residential (Low Density)	15	48	66	78	83	Single-Family, Lot Size 1 acre and Greater
4	Commercial	85	89	92	94	95	Strip Commercial, Shopping Ctrs, Convenience Stores
5	Industrial	72	81	88	91	93	Light Industrial, Schools, Prisons, Treatment Plants
6	Disturbed/Transitional		76	85	89	91	Gravel Parking, Quarries, Land Under Development
7	Agricultural		67	77	83	87	Cultivated Land, Row crops, Broadcast Legumes
9	Open Land – Good		39	61	74	80	Parks, Golf Courses, Greenways, Grazed Pasture
10	Meadow		30	58	71	78	Hay Fields, Tall Grass, Ungrazed Pasture
11	Woods (Thick Cover)		30	55	70	77	Forest Litter and Brush adequately cover soil
12	Woods (Thin Cover)		43	65	76	82	Light Woods, Woods-Grass combination, Tree Farms
13	Impervious	95	98	98	98	98	Paved Parking, Shopping Malls, Major Roadways
14	Water	100	100	100	100	100	Water Bodies, Lakes, Ponds, Wetlands

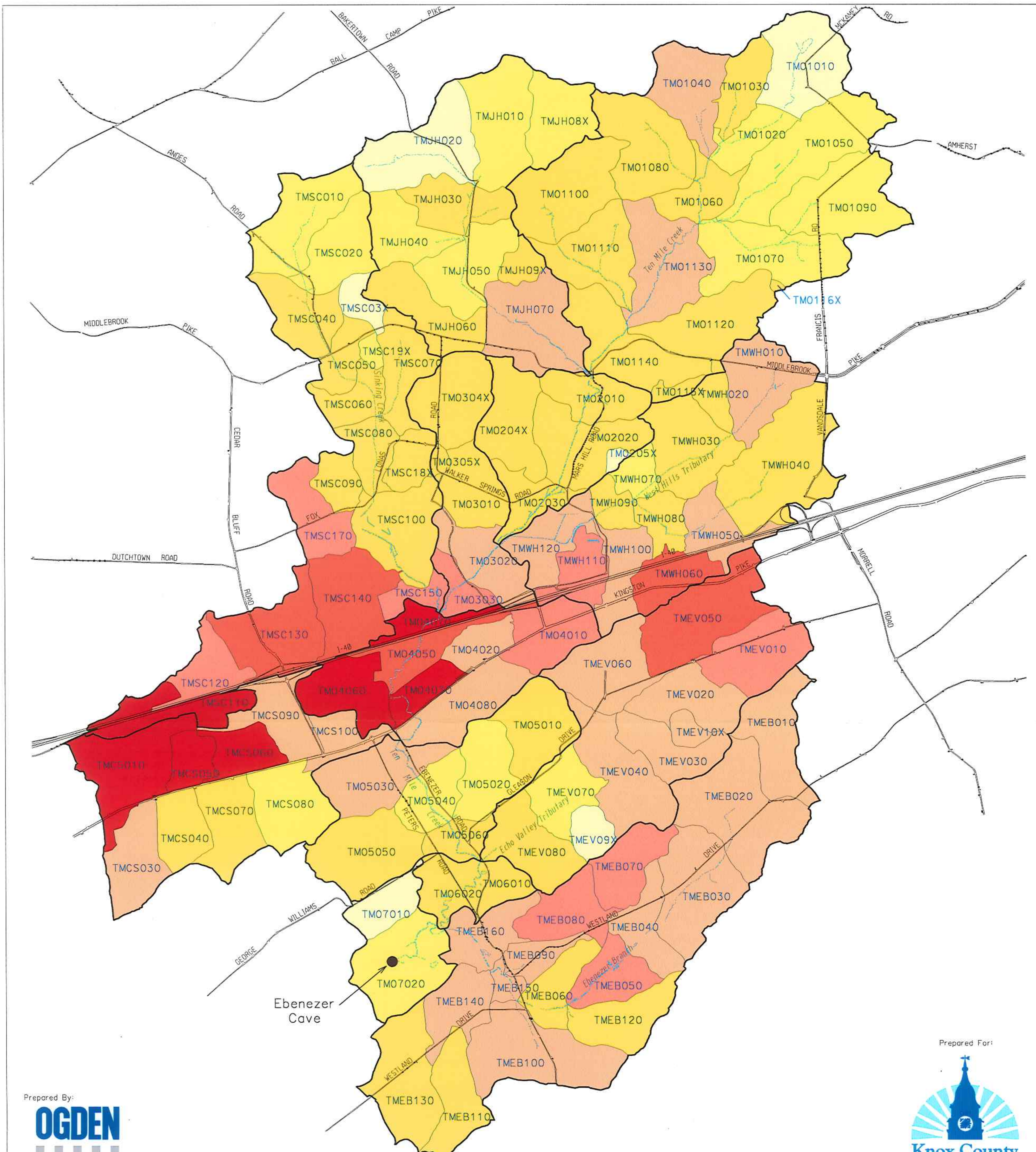
Ebenezer Cave and Sinkhole

As stated previously, Ten Mile Creek discharges to Ebenezer Cave, which is located at the bottom of a sinkhole, termed Ebenezer Sinkhole. Proper routing of the sinkhole is a key component of the HEC-1 model of Ten Mile Creek, because flood elevations at the sinkhole are largely controlled by the efficiency of the cave to discharge flood flows and by the volume of runoff from the watershed. Flooding due to backwater in Ebenezer Sinkhole can extend upstream to approximately River Mile 1.50 on Ten Mile Creek, which is upstream of George Williams Road.

For this study, it was determined that the most appropriate rating curve for reservoir routing at the sinkhole could be obtained by using the inlet rating curve (i.e., discharge-elevation information), represented by an orifice in the USACE study (USACE, 1994), in conjunction with 2-foot contour information (i.e., elevation-area information) obtained from recent topographic maps. These data were combined to develop stage-storage-discharge information (i.e., the rating curve) for the sinkhole. The rating curve was calibrated using rainfall and flood elevation data collected in the sinkhole backwater area during the storm event of April 1998. The rainfall information was used as input into the HEC-1 model and predicted elevations at the sinkhole were compared with measured high water marks. With slight adjustments to the orifice area (less than 10%), predicted elevations at the sinkhole matched the surveyed high water mark within 0.2 ft. Based on these results it was felt the HEC-1 watershed model provided an accurate estimate of stage at the sinkhole.

4.1.2 Hydraulics

The HEC-RAS computer program version 2.2 (USACE, 1998) was used to perform the hydraulic modeling and develop water surface profiles (i.e., flood elevations) for Ten Mile Creek and its tributaries. The streams studied in hydraulic detail are Ten Mile Creek, Sinking Creek, West Hills Tributary(1982 FIS reference: Tributary No. 1 to Ten Mile Creek), and Echo Valley Tributary (1982 FIS reference: Tributary No. 2 to Ten Mile Creek). The scope of detailed hydraulic analysis on each stream, shown in Table 4-2, was determined through discussions with County staff and review of previous studies.



Scale: 1" = 3000 Feet

1500 0 1500 3000 4500 6000 Feet

N

Figure 4-1 Ten Mile Creek Watershed Existing Condition Curve Numbers

LEGEND

TMEB130 Sub-basin Identifier
Roads
Streams
Basin Boundaries
Sub-basin Boundaries

Curve Number Ranges

30-65
66-70
71-75
76-80
81-85
86-90
91-95

Table 4-2. Limits of the HEC-RAS Models for Ten Mile Creek and Tributaries

Stream	Downstream Limit		Upstream Limit	
	Landmark	River Mile	Landmark	River Mile
Ten Mile Creek	Ebenezer Cave	0.0	Elmhurst Way (just upstream)	5.642
West Hills Tributary	Ten Mile Creek (RM 3.662)	0.0	Corteland Drive (just upstream)	1.072
Sinking Creek Tributary	Ten Mile Creek (RM 3.068)	0.0	Middlebrook Pike (just upstream)	1.875
Echo Valley Tributary	Ten Mile Creek (RM 1.073)	0.0	Echo Valley Road (just upstream)	0.436

Separate HEC-RAS models were developed for each stream utilizing stream channel and hydraulic structure surveys, topographic mapping of the watershed provided by KGIS, and field investigation of the streams. Stream cross-sections on Ten Mile Creek and the tributaries were numbered by river mile (RM). On Ten Mile Creek, RM 0.0 was defined at the location of Ebenezer Cave, as indicated on topographic maps. For tributaries, RM 0.0 was defined at the point along the centerline of Ten Mile Creek where the tributary met the main stem. Cross-section data includes geometry, reach length, Manning's n values, expansion and contraction coefficients and ineffective flow areas.

Peak discharges were obtained from the existing condition HEC-1 model. Flow change points were determined based on the relative locations of HEC-1 operations and HEC-RAS cross-section locations. Cross-section river miles in HEC-RAS were associated with appropriate HEC-1 operations. The starting water surface elevations for Ten Mile Creek were set equal to the predicted stage in the sinkhole at Ebenezer Cave, obtained from the elevation predicted at the sinkhole by the HEC-1 model. Starting water surface elevations for all other streams were obtained using the slope-area method. Encroachment analyses were performed with the HEC-RAS models using Encroachment Method 1 to define the left and right encroachment stations.

4.2 Analysis and Results

4.2.1 Land Use and Curve Numbers

Table 4-3 presents a summary of the existing land uses in the Ten Mile Creek watershed. The majority of the watershed (81%) is comprised of developed land uses (e.g., single family residential, commercial centers) that have a great contribution to runoff quantity. Open land uses that have a relatively low amount of impervious surfaces (e.g., cemeteries, golf courses and parks) account for 7% of the total area, and completely undeveloped areas (woods and meadows) cover the remaining 12% of the watershed.

Table 4-3. Land Use Distribution in the Ten Mile Creek Watershed

	DISTRIBUTION OF LAND USES BY LAND USE CATEGORY (%)											
	Res HI	Res MD	Res LO	Com	Ind	Imp	Dst	Ag	Open good	Mead	Thk wds	Thn wds
Watershed	12	43	9	14	0	1	2	0	7	3	7	2
	81% developed land uses							19% undeveloped, open land uses				

Figure 4-1 presents a map of the existing condition curve numbers for each sub-basin, calculated based on the hydrologic soil coverage and existing condition land uses, shown previously in Section 2. The average curve number for the watershed is 76. As shown in the figure, existing condition curve numbers ranged from a basin average high of 85 in Basin 04 near Interstate-40 to a 67 in Basin 07 near the Ebenezer Sinkhole, which is comprised largely of grasses and wooded areas. As expected, the highest curve numbers can be found in sub-basins located near the Kingston Pike/Interstate-40 area where commercial development is the predominant land use. The lowest curve numbers can be found in sub-basins located along the northern boundary of the watershed or near the Ebenezer Sinkhole, where developed areas are less prevalent.

Table B-1. Ten Mile Creek Existing Condition Sub-basin Information (Contributing Areas Only)

Basin	Area (mi^2)	CN	Tc (hrs)	R Coeff	Peak Flow (cfs)				
					2-yr	10-yr	25-yr	100-yr	500-yr
EV060	0.183	77	0.303	0.30	80	200	260	350	430
EV070	0.120	70	0.468	0.47	20	80	100	150	190
EV080	0.159	75	0.487	0.49	50	120	160	220	270
JOE HINTON ROAD BASIN									
JH010	0.206	67	0.593	0.59	30	100	130	200	250
JH020	0.224	63	0.565	0.56	20	80	120	190	250
JH030	0.131	73	0.542	0.54	30	90	120	160	200
JH040	0.123	70	0.567	0.57	20	70	90	130	170
JH050	0.167	69	0.472	0.47	30	100	140	200	250
JH060	0.153	72	0.685	0.69	30	80	110	160	200
JH070	0.234	77	0.643	0.64	60	160	210	290	360
SINKING CREEK BASIN									
SC010	0.193	68	0.628	0.63	30	90	130	180	240
SC020	0.143	70	0.433	0.43	30	100	130	180	230
SC040	0.134	71	0.548	0.55	30	80	110	150	190
SC050	0.075	75	0.653	0.65	20	50	60	90	110
SC060	0.082	72	0.398	0.40	20	60	80	120	150
SC070	0.130	71	0.430	0.43	30	90	120	170	220
SC080	0.084	72	0.370	0.37	20	70	90	120	160
SC090	0.065	72	0.352	0.35	20	50	70	100	120
SC100	0.197	75	0.567	0.57	50	140	180	250	310
SC110	0.130	93	0.467	0.47	100	180	210	270	310
SC120	0.099	84	0.472	0.47	50	110	130	170	210
SC130	0.208	89	0.455	0.46	140	260	320	410	480
SC140	0.203	86	0.722	0.72	90	180	220	280	340
SC150	0.050	84	0.542	0.54	20	50	60	80	100
SC170	0.132	82	0.362	0.36	70	160	200	260	310
WEST HILLS BASIN									
WH010	0.179	80	0.398	0.40	80	190	240	320	380
WH020	0.044	72	0.502	0.50	10	30	40	60	70
WH030	0.191	72	0.785	0.78	30	100	130	180	230
WH040	0.319	75	0.545	0.54	90	230	300	410	520
WH050	0.110	79	0.465	0.47	40	100	130	170	210
WH060	0.101	90	0.142	0.14	130	240	280	360	410
WH070	0.051	70	0.562	0.56	10	30	40	60	70
WH080	0.072	71	0.447	0.45	20	50	70	90	120
WH090	0.052	75	0.300	0.30	20	50	70	90	120
WH100	0.110	80	0.375	0.38	50	120	150	200	240
WH110	0.098	84	0.408	0.41	60	120	140	190	220
WH120	0.125	79	0.422	0.42	50	120	160	210	260

4.2.2 Peak Discharges

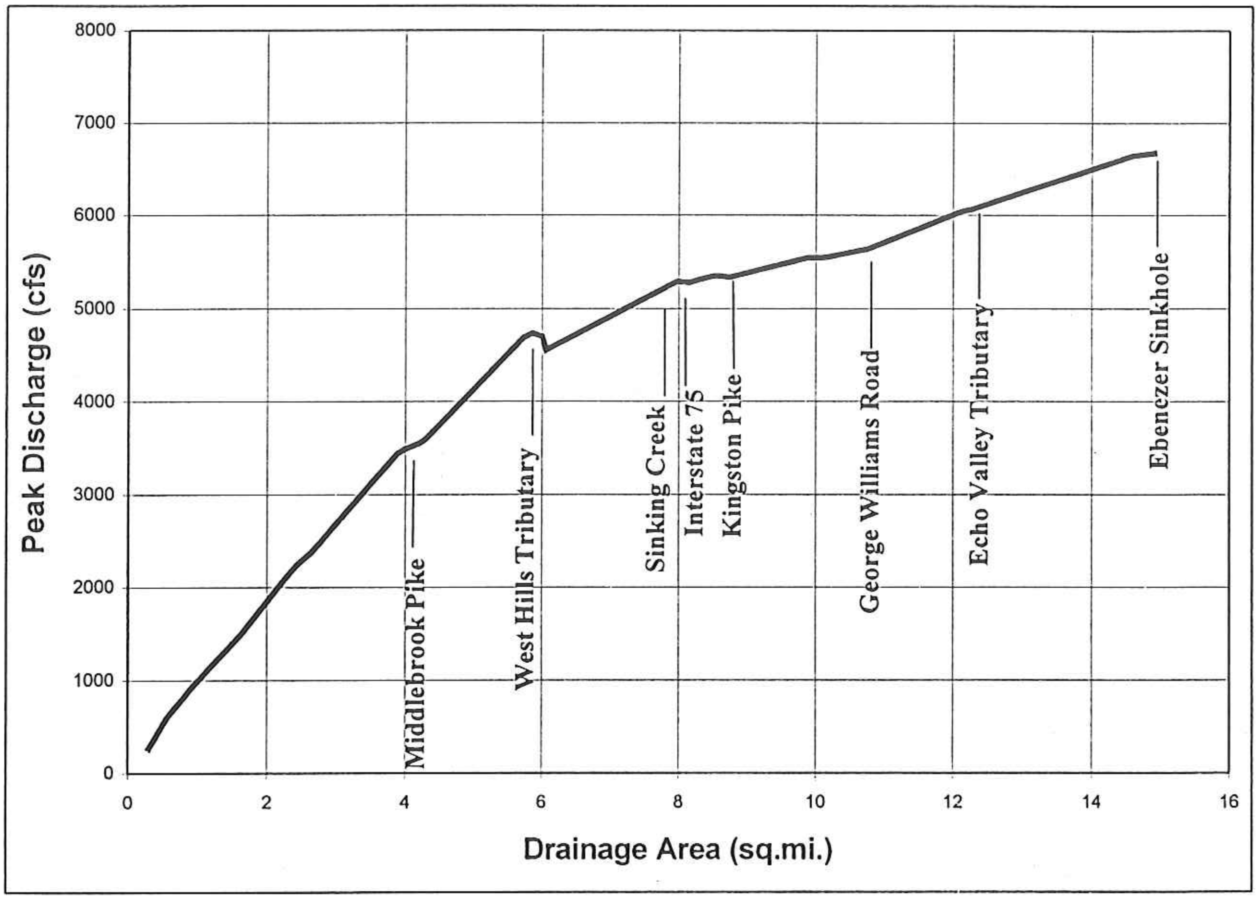
Table B-1 in Appendix B presents the HEC-1 model input data (area, curve number, Tc and R) and the existing condition peak discharges for the 2-, 10-, 25-, 100- and 500-year storm events calculated by the HEC-1 model for every sub-basin that contributes to runoff in the Ten Mile Creek watershed. Table 4-4 presents existing condition peak flow rates at selected locations.

Table 4-4. Existing Condition Peak Discharges at Selected Locations

Landmark	DA (sq. mi.)	HEC-1 Operation	Peak Discharges (cfs)				
			2-yr	10-yr	25-yr	100-yr	500-yr
TEN MILE CREEK							
Middlebrook Pike	2.64	01140C	420	1240	1670	2370	3060
Walker Springs Road	4.19	02020C	590	1820	2500	3550	4640
Bridgewater Road	6.00	03020D	780	2420	3330	4700	6110
Interstate-40	8.04	04070C	920	2750	3720	5280	6790
Kingston Pike	8.58	04030D	930	2690	3760	5340	6870
Ebenezer Sinkhole	14.90	07020D	1520	3830	4900	6670	8730
SINKING CREEK							
Middlebrook Pike	0.47	SC040C	80	250	350	490	640
Fox Lonas Rd.	0.84	SC080C	140	460	590	840	1080
Mouth	1.92	SC150C	470	1180	1560	2090	2600
WEST HILLS TRIBUTARY							
Corteland Drive	0.41	WH030C	120	290	380	520	640
Walker Springs	1.12	WH090C	220	660	910	1300	1640
Mouth	1.45	WH120D	320	850	1180	1700	2160
ECHO VALLEY TRIBUTARY							
Echo Valley Rd	1.20	EV070C	310	730	920	1220	1480
Mouth	1.36	EV080C	340	810	1040	1380	1680

Figure 4-2 presents a plot of drainage area versus the 100-year peak discharge for Ten Mile Creek. The figure shows that the peak flow increases linearly with drainage area, indicating that peak discharges are highly sensitive to inflows from the contributing drainage area. Upstream of the confluence of Ten Mile Creek with the West Hills Tributary, peak discharges increase approximately 790 cfs per square mile of drainage area. Downstream of that location, peak discharges increase approximately 240 cfs per square mile, suggesting that discharges in the creek become somewhat sensitive to factors other than the surrounding drainage area, such as storage in the floodplain or off-stream storage areas (e.g., detention ponds). However, based on results of the HEC-1 model, it is evident that peak discharges in both the main stem and tributaries are most sensitive to the size and characteristics (e.g., land use, storm water conveyance system, etc.) of the surrounding drainage area.

Figure 4-2. 100-Year Existing Condition Peak Discharges Along Ten Mile Creek



4.2.3 Watershed Timing

Understanding the relative timing of peak inflows and hydrographs as they discharge from tributary basins into the main stem is an important factor in effectively managing storm water in the Ten Mile Creek watershed. Figure 4-3 displays the main stem hydrograph at the upstream and downstream ends of Ten Mile Creek. The drainage area upstream of the Joe Hinton Road basin is 2.64 square miles, upstream of the Ebenezer Branch is 12.3 square miles, and at Ebenezer Sinkhole is 14.9 square miles. The hydrograph at the sinkhole is the hydrograph that enters the sinkhole (i.e., the unrouted hydrograph).

Figure 4-3. 100-Year Flood Hydrographs on Ten Mile Creek

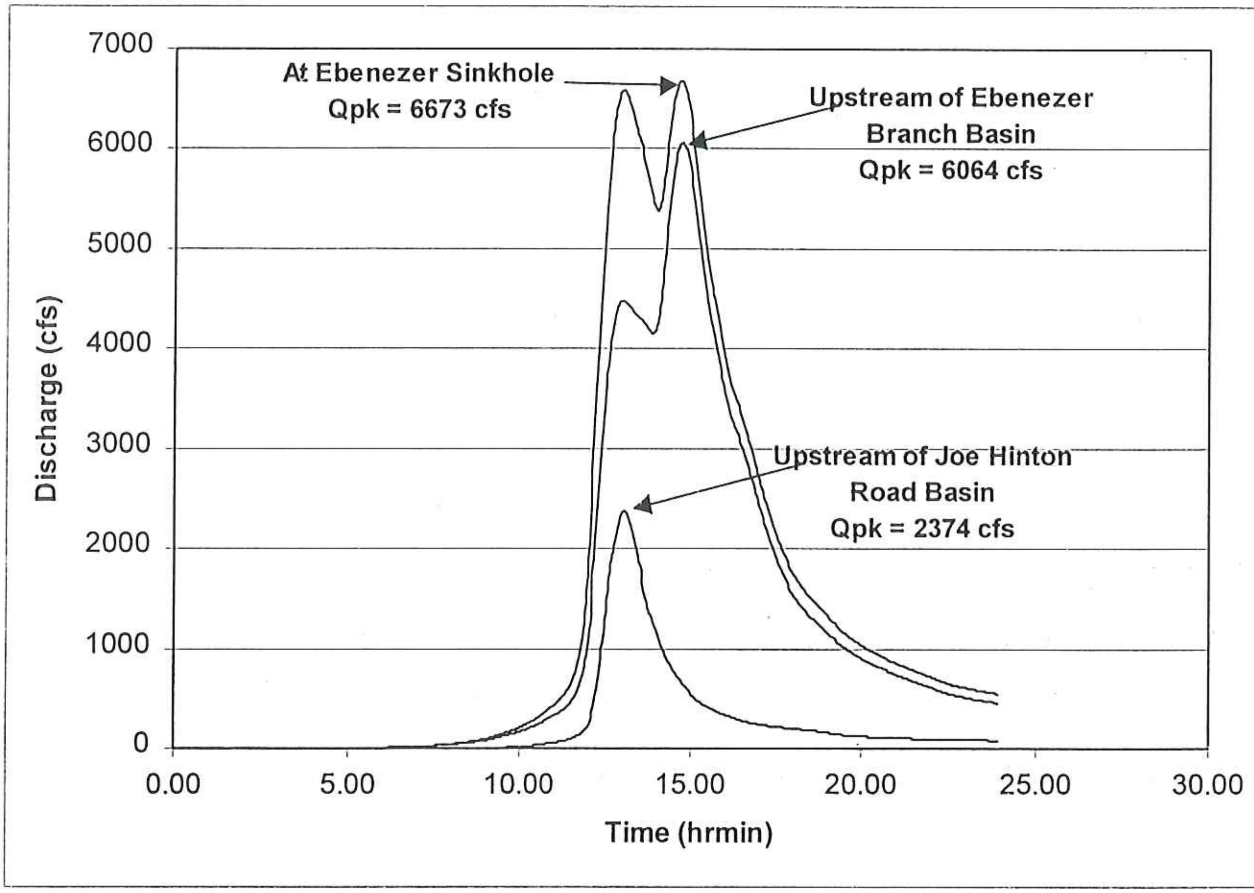


Figure 4-3 shows that the time-to-peak of the main stem hydrograph is delayed from the upstream end (near Joe Hinton Road) to the downstream end (near Ebenezer Branch) by only slightly more than 1.5 hours. This implies that inflows from tributaries to Ten Mile Creek will increase the peak discharge on the main stem, because the occurrence of the main stem and tributary peak discharges will occur fairly close in time. Table 4-5 presents a timing summary of the Ten Mile Creek watershed, along with the impact of each tributary inflow, expressed as the percent increase in the peak discharge on the main stem at the confluence with the tributary. While the information shown in Table 4-5 was generated for the 100-year event, the relative times and impacts will differ only slightly for other events and land use conditions, unless future structural controls (e.g., regional detention ponds) are installed in the stream(s) or the storage characteristics of the streams(s) are altered.

Table 4-5. 100-Year Existing Condition Peak Discharge Timing Summary

Tributary Name[1]	Time-to-peak at confluence after start of rainfall (hr:mm)		Increase in main stem peak discharge caused by tributary (%)
	Tributary	Ten Mile Creek	
Joe Hinton Road	12:54	13:03	45%
West Hills Tributary	12:45	13:18	31%
Sinking Creek	12:51	14:15	16%
Cedar Springs	13:03	14:39	4%
Echo Valley	12:48	14:45	7%
Ebenezer Branch	13:00	14:42	10%

1 – Only those tributaries that discharge directly to Ten Mile Creek are shown.

4.2.4 Flood Elevations Analysis

Table 4-6 provides a listing of flood elevations for existing condition storm events at selected locations along Ten Mile Creek and its tributaries. An observation that can be made using the results of the HEC-RAS models is that flood elevations are consistently out-of-bank throughout the entire main stem and at most cross-sections in the tributaries in the 10-year, 24-hour event. Flood elevations for 2-year, 24-hour event are out of bank at a majority of the cross-sections on the main stem and tributaries, although tributary flooding is generally less extensive and less frequent.

Table 4-6. Existing Condition Flood Elevations at Selected Locations

Landmark	Location (R.M.)	Elevation (ft)				
		2-yr	10-yr	25-yr	100-yr	500-yr
TEN MILE CREEK						
Middlebrook Pike	4.896	927.18	930.98	932.66	936.50	938.31
Walker Springs Road	4.087	907.27	909.03	909.71	910.49	911.15
Bridgewater Road	3.318	892.08	897.60	898.43	900.73	902.83
I-40/75	2.925	888.75	892.45	893.82	895.76	897.38
Kingston Pike	2.231	882.67	887.05	888.10	889.01	889.77
Ebenezer Sinkhole	0.000	859.40	868.80	871.96	876.33	880.10
SINKING CREEK						
Middlebrook Pike	1.852	989.63	991.89	992.98	994.35	995.68
Fox Lonas Rd.	0.920	912.44	917.01	918.49	919.32	919.82

Table 4-6. Existing Condition Flood Elevations at Selected Locations

Landmark	Location (R.M.)	Elevation (ft)				
		2-yr	10-yr	25-yr	100-yr	500-yr
WEST HILLS TRIBUTARY						
Corteland Drive	1.028	927.25	929.68	930.01	930.39	930.65
Walker Springs	0.613	909.44	914.28	914.74	915.17	915.46
ECHO VALLEY TRIBUTARY						
Echo Valley Rd	0.419	876.69	879.97	880.36	880.82	881.01

The 100-year and 500-year floodplain elevations calculated by the HEC-RAS models were mapped using KGIS topographic mapping. These maps are required by FEMA for flood insurance purposes, and therefore were generated primarily for the *Ten Mile Creek Watershed Flood Study* (Ogden, 2000). The floodplain maps for the main stem and tributaries are presented in that document and therefore are not presented in this report, except in areas where flood solution alternatives are evaluated and discussed (Chapters 6 and 7).

The mapped floodplains were used in conjunction with planimetric mapping showing structures (houses, businesses, churches, schools, etc…) to get an *estimate* of the number of habitable structures located inside, or touching, the 100-year and/or 500-year floodplains. It was determined that 87 structures lie inside, or are touching, mapped floodplains for Ten Mile Creek and the modeled tributaries. Nine structures are located inside the 100-year floodway. Based on the floodplain maps, locations where *multiple* residential and/or business/industrial structures are located in the floodplains include:

1. the Ebenezer Sinkhole backwater area;
2. Kingston Pike near Ten Mile Creek bridge;
3. along Hardwicke Drive in the Crestwood Hills subdivision (at the confluence of Ten Mile Creek and Sinking Creek); and,
4. on Echo Valley Road near the bridge over the Echo Valley Tributary.

It is important to note that a structure positioned inside or touching a floodplain does not necessarily mean that the structure is flooded during the 100-year and/or 500-year event. The structure is considered flooded only if the lowest finished floor is inundated with water. To assess the flood potential for a given structure, it is necessary to survey the lowest finished flood elevation (FFE) for comparison with flood elevations predicted by the HEC-RAS models. Therefore, surveyed FFEs were obtained at 75 structures. Efforts to survey FFEs focused on priority areas where Knox County has received complaints of flooding problems and has identified a need to evaluate flood solution alternatives, and areas in the County where the flood elevations predicted by the HEC-RAS models indicated flooding of homes or businesses.

Table 4-7 presents a summary of the results of the FFE comparison with the elevations calculated by the Ten Mile Creek and the tributary HEC-RAS models. The table also includes the number of buildings in the floodway, the number of structures located in the floodplains, and the number of structures surveyed.

Table 4-7. Existing Condition FFE Survey Results

Stream Name (general survey information)	**Number of Flooded Structures (based on surveyed structures only)**					**# Structures in Floodway**
	2-Year	**10-Year**	**25-Year**	**100-Year**	**500-Year**	
Ten Mile Creek 46 structures shown in mapped floodplains 37 structures surveyed, 9 not surveyed	0	6 (2)	10 (2)	19 (2)	22 (2)	6
Sinking Creek 18 structures shown in mapped floodplains 15 structures surveyed, 3 not surveyed	0	1	2 (1)	4 (1)	6 (1)	0
West Hills Tributary 5 structures shown in mapped floodplains 5 structures surveyed, 0 not surveyed	0	0	0	1 (1)	1 (1)	1
Echo Valley Tributary 18 structures shown in mapped floodplains 18 structures surveyed, 0 not surveyed	1	1	1	2	8	2
TOTALS **87 structures shown in mapped floodplains** **75 structures surveyed, 12 not surveyed**	**1**	**8** (2)	**13** (3)	**26** (4)	**37** (4)	**9**

(#) - number of structures that are located within City of Knoxville limits

Detailed information on the structures, both surveyed and not surveyed, that were identified as potentially threatened by flooding based on proximity to the mapped floodplains is contained in Table C-1 in Appendix C. The list contains a structure identification number, the address of the structure (if collected by the surveyor), the river mile of the structure, the surveyed FFE elevation (if surveyed), and the depth of flooding for all storm events in both the existing and future conditions (a negative depth indicates that the structure is not flooded).

4.2.5 Roadway Flooding

The extent of roadway flooding at bridges and culverts in the watershed was examined. Table 4-8 provides a summary of the roadway bridges and culverts in the Ten Mile Creek watershed that will overtop during a given storm event for existing conditions. The locations listed in Table 4-8 are stream crossings included in the HEC-RAS models of Ten Mile Creek and the tributaries. Roadway names, descriptions, and classifications along with the overtopping event and the depth of water at overtopping are provided in this table. The roadways are ranked from highest to lowest importance based upon road-use, frequency of overtopping, and depth of water on the road for the initial overtopping event. After the ranking was completed, any road overtopping less than 0.25 feet in the 100-year or less-frequent event was eliminated.

To perform the ranking, the roadways were first separated into categories, based upon the roadway definitions given in the Sector Plans developed by the MPC: interstate, major arterial (MA), minor arterial (ma), major collector (MC), and minor collector (mc). According to the Sector Plans, arterials are constructed to accommodate the highest volumes of traffic and move traffic through the area. Collectors carry traffic from the arterials and provide increased access to and circulation within residential and employment areas (MPC, varied dates). Streets not listed in the Sector Plans as an interstate, arterial or collector were deemed minor local streets and were not included in the overtopping analysis.

Table 4-8 shows that about half of the bridges and culverts that are predicted to overtop in the Ten Mile Creek watershed lie within the City of Knoxville. The two highest ranked County roads are Peters Road (ranked 2nd) and Ebenezer Road (ranked 4th). Flooding at Peters Road is caused by backwater storage in Ebenezer Sinkhole. Ebenezer Road is predicted to flood more frequently, overtopping in the 2-year event by headwater conditions on the Echo Valley Tributary, and flooding in the 10-year and less frequent events due to backwater in Ebenezer Sinkhole.

Table 4-8. Predicted Existing Condition Roadway Flooding at Bridges and Culverts

Rank	Road Name	Stream	HEC-RAS RM	Roadway Classification	Overtopping Event	Flood Depth (ft)
1	Kingston Pike (within City limits)	Ten Mile	2.221	MA	10-yr	0.15
2	Peters Road	Ten Mile	0.812	ma	10-yr	4.37
3	Mars Hill Road (within City limits)	Ten Mile	4.787	ma	100-yr	1.93
4	Ebenezer Road	Echo Valley	0.015	MC	2-yr	0.39
5	Bridgewater Road (within City limits)	Ten Mile	3.310	MC	10-yr	3.00
6	Cross Park Drive (within City limits)	Sinking Creek	0.198	MC	10-yr	2.48
7	Walker Springs Road (within City limits)	West Hills	0.608	MC	10-yr	1.73
8	Walker Springs Road	Ten Mile	4.082	MC	10-yr	1.63
9	George Williams Road	Ten Mile	1.385	MC	25-yr	1.74
10	Fox Lonas Road	Sinking Creek	0.913	MC	25-yr	0.49
11	Robinson Road (within City limits)	Ten Mile	5.155	mc	10-yr	1.15
12	Corteland Drive (within City limits)	West Hills	1.021	mc	10-yr	1.08
13	Ebenezer Road	Ten Mile	1.995	mc	10-yr	0.40

MA = Major Arterial, ma = minor arterial, MC = Major Collector, mc = minor collector
Note: The flood depth represents the depth of flooding for the overtopping event, not the depth of flooding for a common flood frequency.

Table 4-9 presents a list of roadways predicted to flood due to backwater storage in Ebenezer Sinkhole. Many of the locations listed the table are not stream crossings, and therefore are not explicitly modeled using HEC-RAS. At non-modeled locations, the depth of flooding was estimated based on spot elevations shown in available topographic mapping. It should be noted that the topographic data was not yet updated to show the reconstruction of the north Westland Drive intersection with Ebenezer Road, therefore the depth and frequency of predicted flooding may be suspect at this location. Visual observations indicate the intersection is now higher in elevation.

Topographic mapping indicates that the only roads listed in Table 4-9 where flooding would isolate residents from access are Broken Shaft Drive in the Gettysvue subdivision and the private driveway that intersects with Ebenezer Road near the south intersection of Ebenezer Road and Westland Drive.

Table 4-9. Roadway Flooding Due to Ebenezer Sinkhole Backwater

Location	HEC-RAS RM	Roadway Classification	Overtopping Event	Flood Depth (ft)
Peters Road over Ten Mile Crk.	0.812	ma	10-yr	4.37
Ebenezer Road over Echo Valley Trib.	0.015	MC	10-yr	7.30
Intersection of Westland Drive and Ebenezer Road (north intersection)	-	MC	10-yr	1.40
George Williams Road	1.385	MC	100-yr	4.19
Westland Drive (west of south intersection with Ebenezer Road)	-	MC	100-yr	1.03
Ebenezer Road (north of south intersection with Westland Drive)	-	MC	100-yr	0.33
Private Driveway, north of Farrington Drive, east side Ebenezer Road	-	Private road	25-yr	1.96
Broken Shaft Drive (Gettysvue Subdivision)	-	Local road	100-yr	0.23
Shadow Brook Drive (Gettysvue Subdivision)	-	Local road	100-yr	2.33
Wesley Place Drive (Wesley Place Condos)	-	Private road	500-yr	2.10
Colchester Ridge Road (Benington Subdiv)	-	Local road	500-yr	0.40

Note: The flood depth represents the depth of flooding for the overtopping event, not the depth of flooding for a common flood frequency.

4.2.6 Blocked Condition at Ebenezer Cave

The outlet area of Ebenezer Cave was modified in the existing condition HEC-1 model to determine the impact of completely blocked conditions at the cave on flood elevations in Ebenezer Sinkhole. For this analysis, it was assumed that Ebenezer Cave would be completely clogged (i.e., zero discharge from the cave). Table 4-10 presents the results of this analysis in terms of the flood elevation at the sinkhole for all events, and the flood potential in the sinkhole backwater area. It should be remembered that the flood potential is determined using only those FFEs that were surveyed based on the 100-year or 500-year *existing* condition floodplains determined with open Cave conditions. The flood potential listed in Table 4-10 does not reflect any additional structures that lie inside the blocked condition floodplain, and is likely lower than the actual flood potential that would be determined if all structures were surveyed.

Table 4-10. Results of Analysis of Blocked Conditions at Ebenezer Cave

	Elevation at Ebenezer Sinkhole (ft NAVD)		Flood Potential in Sinkhole Backwater Area (based on surveyed FFEs only)	
Storm Event	**Open Outlet**	**Blocked Outlet**	**Open Outlet**	**Blocked Outlet**
2-yr	859.40	865.45	0	0
10-yr	868.80	874.11	2	4
25-yr	871.96	877.02	3	5
100-yr	876.33	880.64	5	11
500-yr	880.10	884.01	10	18

Table 4-10 shows that blocked conditions in the cave increase flood elevations at the sinkhole an average of 4.9 feet, considering all events. The backwater region for the 100-year event under blocked conditions extends to RM 1.656, approximately 1430 feet upstream of George Williams Road. The flood elevation for existing condition 100-year event with normal, free-flowing cave conditions was predicted to occur at approximately a 10-year to 25-year event frequency under blocked conditions.

5 FUTURE CONDITIONS ANALYSIS

5.1 Methodology

Future conditions in the Ten Mile Creek watershed were simulated by modifying curve numbers, times of concentration (Tc) and storage coefficients (R) in the HEC-1 model. The curve numbers were determined using a future condition land use map, which was created by updating the undeveloped areas in the existing condition land use map in accordance with the planned land uses shown in the 15 Year Development Plans published by MPC (MPC, varied dates). Developed areas on the existing condition map were only adjusted to future conditions when the curve number for the land use planned by MPC was higher than the existing condition curve number. While the SCS land use categories do not correspond precisely with the land use designations defined by the MPC, translation between them is fairly straightforward. Table 5-1 presents a listing of the SCS land uses and the corresponding MPC land use description.

Table 5-1. MPC to SCS Land Use Description Conversions

MPC Land Use Description[1]	SCS Land Use Description	SCS Land Use Examples
Agricultural and Rural Residential (max density of 1 du/ac)	Residential (Low Density)	Single-Family, Lot Size 1 acre and Greater
Low Density Residential (1-5 du/ac)	Residential (Medium Density)	Single-Family, Lot Size 1/4 to 1 Acre
Medium Density Residential (5-12 du/ac)	Residential (High Density)	Multi-Family, Apartments, Condos, Row Houses, Trailer Parks
Commercial	Commercial	Strip Commercial, Shopping Centers, Convenience Stores
Heavy Industrial	Industrial	Light Industrial, Schools, Prisons, Treatment Plants
Light Industrial	Industrial	Light Industrial, Schools, Prisons, Treatment Plants
Office	Commercial	Strip Commercial, Shopping Centers, Convenience Stores
Parks & Public Open Space	Open Land – Good	Urban Green Space, Parks, Golf Courses, Cemeteries
Public Institutional	Industrial	Light Industrial, Schools, Prisons, Treatment Plants
Slope Protection Area	Woods (Thick Cover)	Forest Litter and Brush adequately Cover Soil
Stream Protection Areas	Woods (Thin Cover)	Light Woods, Wood-Grass Combination, Tree Farm, Orchards
Technology Park	Industrial	Light Industrial, Schools, Prisons, Treatment Plants
Transportation	Impervious	Paved Parking, Shopping Malls, Major Roadways, Paved Ditches

[1] – du/ac = dwelling units per acre

For the future condition HEC-1 model, times of concentration were decreased only for those sub-basins where the curve number increased by 10% or more. Tc adjustments were made by changing the land cover type for the overland flow and shallow concentrated flow portions of the flowpath that was defined to determine the existing condition Tc. The land cover type for the overland flow portion of the time of concentration flowpath, typically woods or dense grass for an undeveloped sub-basin in the existing condition, was changed to short grass in the future condition. The land cover type of the shallow concentrated portion of the flowpath was changed from unpaved to paved. No modifications were made to the flow path lengths or slopes, or to the channel portion of the flowpath. In keeping with the methodology used in the existing condition model, the Clark storage coefficient (R) was set equal to the time of concentration in each sub-basin. The *Ten Mile Creek Watershed Flood Study* contains a detailed discussion of the methods used to determine Tc and R (Ogden, 2000).

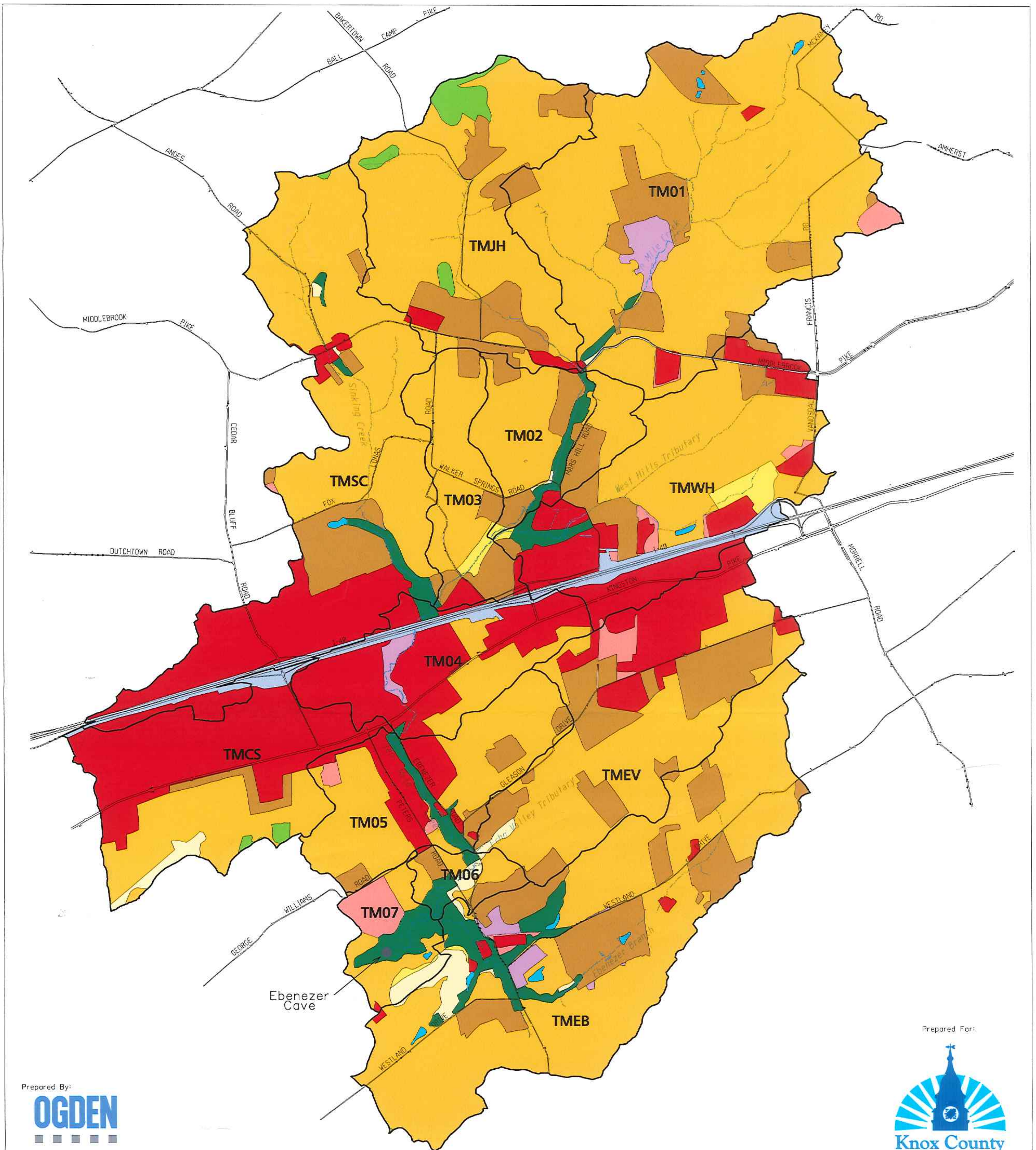
The future condition data (curve numbers, Tc, R) were used as input in the future condition HEC-1 model. Peak discharges from HEC-1 were used as input to the HEC-RAS models to determine future condition flood elevations. No other changes were made to the HEC-RAS models.

5.2 Analysis and Results

5.2.1 Land Use and Curve Numbers

The future condition land use map is shown in Figure 5-1. Table 5-2 provides a breakdown of the future condition land use for each basin. Nearly the entire (96%) Ten Mile Creek watershed is planned for residential and other developed land uses. Residents with ¼ to 1-acre lots (i.e., medium density residential) account for 59% of the watershed, commercial land use constituted the next highest percentage at 18%. The remaining undeveloped areas will be primarily wooded areas (3%) located along stream banks and near Ebenezer Sinkhole.

Figure 5-2 presents the range of future condition curve numbers in the Ten Mile Creek watershed sub-basins. The average curve number for each basin is presented in Table 5-3, which also lists the change in average curve number from existing to future conditions. On a watershed-wide basis, the average area-weighted curve number for existing conditions was 76. The average area-weighted curve number for future conditions increased to 80.



Scale: 1" = 3000 Feet

1500 0 1500 3000 4500 6000 Feet

N

Figure 5-1 Ten Mile Creek Watershed Future Condition Land Use

LEGEND

- Roads
- Streams
- Basin Boundaries

SCS Land Use Categories

Commercial	Shopping Areas, Convenience Stores, Office Parks, Businesses
Industrial	Industrial Areas, Schools, Prisons, Churches, Utility Areas, Technology Areas
Residential (High Density)	Multi-family, Condos, Apartments, Trailer Parks
Residential (Medium Density)	Single Family, Lot Size 1 to $^1/_4$
Residential (Low Density)	Single Family, Lot Size 1 Acre or Larger
Disturbed / Transitional	Gravel Parking, Quarries, Land Under Development
Open Land	Urban Green Space, Parks, Golf Courses, Cemeteries, Grazed Pasture
Meadow	Hay Fields, Tall Grass, Ungrazed Pasture
Woods (Thin Cover)	Lightly Wooded Areas, Stream Protection Areas, Tree Farms
Woods (Thick Cover)	Heavily Wooded Areas, Slope Protection Areas
Impervious	Parking Lots, Roadways, Large Shopping Malls
Water	Streams, Rivers, Ponds, Lakes

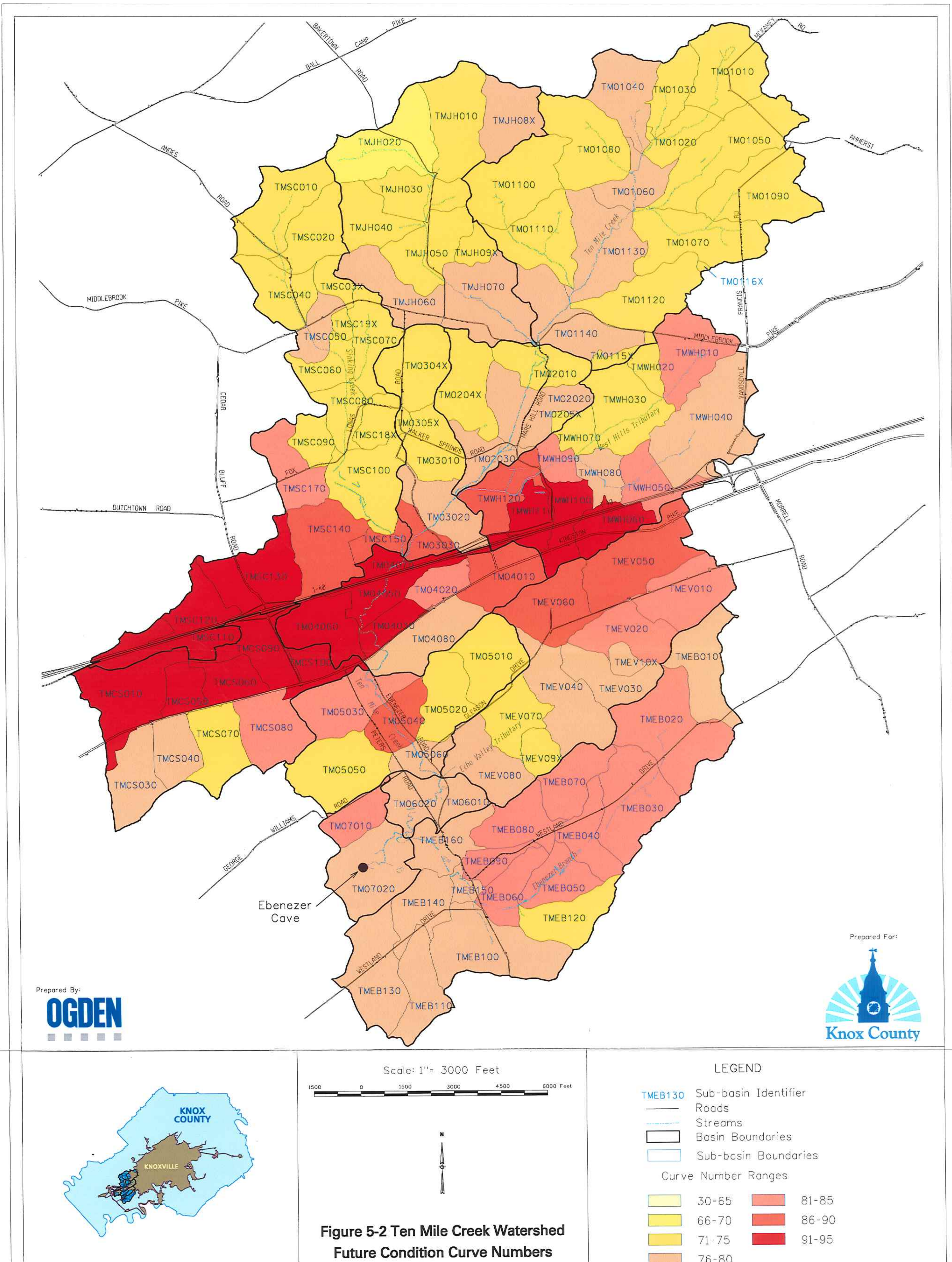


Figure 5-2 Ten Mile Creek Watershed Future Condition Curve Numbers

Table 5-2. Future Condition Land Use Distribution in the Ten Mile Creek Watershed

Basin Identifier	DISTRIBUTION OF LAND USES BY LAND USE CODE (%)												
	Res HI 1	Res MD 2	Res LO 3	Com 4	Ind 5	Dst 6	Ag 7	Open good 9	Mead 10	Thk wds 11	Thn wds 12	Imp 13	water 14
01	13	81	0	1	1	3	0	0	0	0	1	0	0
JH	19	72	0	2	0	0	0	0	0	7	0	0	0
02	25	64	0	2	0	0	0	1	0	0	8	0	0
WH	9	45	0	30	2	0	0	4	0	0	3	7	0
03	20	69	0	6	0	0	0	4	0	0	0	1	0
SC	10	57	0	27	0	0	0	0	0	0	3	3	0
04	0	23	0	63	0	4	0	0	0	0	2	8	0
CS	4	33	3	56	0	0	0	0	0	1	0	3	0
05	9	64	0	20	2	0	0	0	0	0	5	0	0
EV	27	47	1	22	3	0	0	0	0	0	0	0	0
06	28	42	11	1	0	0	0	0	0	0	18	0	0
EB	18	69	3	1	0	2	0	0	0	0	6	0	1
07	0	38	10	1	25	0	0	2	0	0	24	0	0
Watershed	14	59	1	18	1	1	0	0	0	1	3	2	0

Table 5-3. Comparison of Existing and Future Condition Curve Numbers (by Basin)

Basin Name	Basin Identifier	Drainage Area (mi^2)	Average Curve Number		Change in CN
			Existing	Future	
Ten Mile Creek 01	01	2.666	71	75	4
Joe Hinton Road	JH	1.426	70	75	5
Ten Mile Creek 02	02	0.569	73	76	3
West Hills Tributary	WH	1.452	77	82	5
Ten Mile Creek 03	03	0.517	75	76	1
Sinking Creek	SC	2.059	77	80	3
Ten Mile Creek 04	04	0.769	85	88	3
Cedar Springs	CS	1.138	80	86	6
Ten Mile Creek 05	05	0.863	73	78	5
Echo Valley	EV	1.450	78	83	5
Ten Mile Creek 06	06	0.165	73	76	3
Ebenezer Branch	EB	2.326	77	80	3
Ten Mile Creek 07	07	0.300	67	78	11
Watershed Avg.	-	-	**76**	**80**	**3**

5.2.2 Peak Discharges

Table B-2 in Appendix B presents the future condition data and peak discharges for the 2-, 10-, 25-, 100- and 500-year storm events calculated by the HEC-1 model for every sub-basin in the Ten Mile Creek watershed. Figure 5-3 presents a plot of existing and future condition peak discharges along Ten Mile Creek. The average percent increase in peak discharges from existing to future conditions along the main stem was 21% for the 100-year event. In comparison, the average predicted increase in the 100-year event discharge in the tributaries was approximately 8%. Table 5-4 presents a comparison between the existing and future condition peak discharges for the 10-year and 100-year events at key locations along Ten Mile Creek and the HEC-RAS modeled tributaries.

Figure 5-3. Peak Discharges Along Ten Mile Creek – Existing and Future Conditions

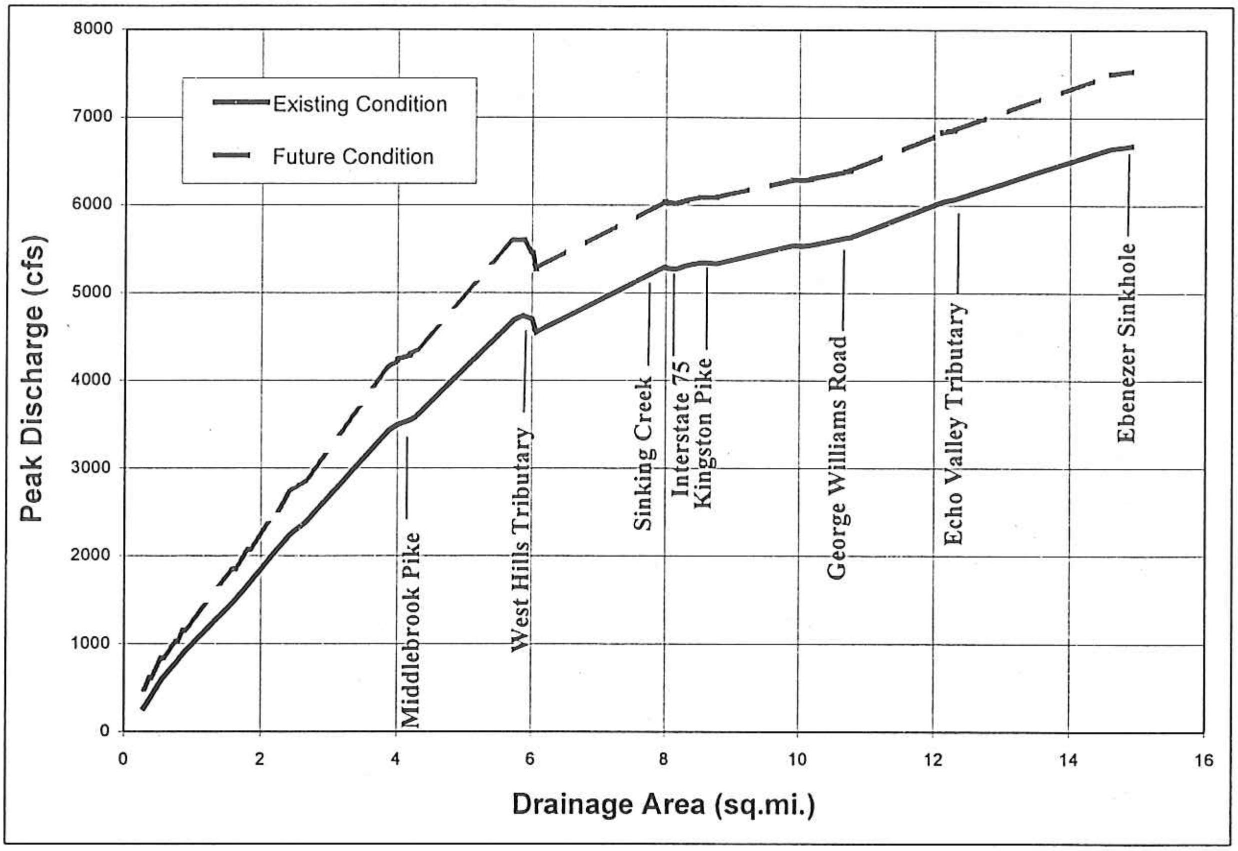


Table 5-4. Comparison of Existing and Future Condition Peak Discharges at Selected Locations

Landmark	10-Year Peak Discharges (cfs)			100-Year Peak Discharges (cfs)		
	Existing	Future	% Increase	Existing	Future	% Increase
TEN MILE CREEK						
Middlebrook Pike	1240	1560	26	2370	2860	21
Walker Springs Rd.	1820	2310	27	3550	4290	21
Bridgewater Road	2420	3000	24	4700	5460	16
I-40/75	2750	3290	20	5280	6020	14
Kingston Pike	2690	3290	22	5340	6090	14
Ebenezer Sinkhole	3830	4440	16	6670	7530	13
SINKING CREEK						
Middlebrook Pike	250	290	16	490	540	10
Fox Lonas Rd.	460	500	9	840	900	7
Mouth	1180	1260	7	2090	2220	6
WEST HILLS TRIBUTARY						
Corteland Drive	290	310	7	520	540	4
Walker Springs	660	750	14	1300	1380	6
Mouth	850	940	11	1700	1770	4
ECHO VALLEY TRIBUTARY						
Echo Valley Rd	730	850	16	1220	1340	10
Mouth	810	950	17	1380	1530	11

5.2.3 Flood Elevations Analysis

In general, the 100-year flood elevation increased from existing to future conditions an average of 0.9 feet on the main stem and 0.5 feet on the tributaries. On Ten Mile Creek, the maximum 100-year increase of 1.56 ft occurs at cross-section 4.896, located just upstream of the Middlebrook Pike culvert. At Ebenezer Sinkhole the average increase in the 100-year flood elevation from existing to future conditions is 1.54 feet. The Sinking Creek tributary exhibits an average increase in flood elevations from existing to future conditions of 0.17 ft, except in the downstream most portion, where backwater from Ten Mile Creek raises flood elevations by 1.12 ft in the 100-year event. In the West Hills tributary, the average increase in flood elevations from existing to future conditions is only 0.13 feet.

Table 5-5 presents a comparison of existing and future condition flood elevations at key locations along Ten Mile Creek and the tributaries modeled in HEC-RAS for the 10-year and 100-year storm events.

Table 5-5. Comparison of Existing and Future Flood Elevations at Selected Locations

Landmark	10-Year Event Elevations (ft)			100-Year Event Elevations (ft)		
	Existing	Future	Increase	Existing	Future	Increase
TEN MILE CREEK						
Middlebrook Pike	930.98	932.22	1.24	936.50	938.06	1.56
Walker Springs Road	909.03	909.54	0.51	910.49	910.95	0.46
Bridgewater Road	897.60	897.92	0.32	900.73	901.79	1.06
I-40/75	892.45	893.24	0.79	895.76	896.57	0.81
Kingston Pike	887.05	887.75	0.70	889.01	889.37	0.36
Ebenezer Sinkhole	868.80	870.55	1.75	876.33	877.87	1.54
SINKING CREEK						
Middlebrook Pike	991.89	992.23	0.34	994.35	994.81	0.46
Fox Lonas Rd.	917.01	917.71	0.70	919.32	919.46	0.14
WEST HILLS TRIBUTARY						
Corteland Drive	929.68	929.76	0.08	930.39	930.43	0.04
ECHO VALLEY TRIBUTARY						
Echo Valley Rd	879.97	880.23	0.26	880.82	880.87	0.05

The County uses the existing 500-year flood elevation plus freeboard as the regulatory benchmark for finished floor elevations in proposed developments. Thus, the future 100-year water surface elevations were compared with existing 500-year elevations to identify areas where the County may need more stringent FFE guidelines. The analysis shows that the existing 500-year elevation is higher than the future 100-year water surface elevations in all locations along Ten Mile Creek and in its tributaries.

The future condition flood elevations were compared to surveyed FFEs in the Ten Mile Creek watershed to determine the increase in the number of habitable structures that are predicted to flood during future events. Table 5-6 presents a summary of this comparison. More detailed information on the predicted depth of future flooding for each structure is contained in a reference table (Table C-1) that comprises Appendix C. In Table C-1, a negative depth indicates that the structure is not flooded.

Table 5-6. Comparison of Existing and Future Condition FFE Flooding

Stream Name	Number of Flooded Structures -based on surveyed FFEs only									
	Existing Condition					Future Condition				
	2-Yr	10-Yr	25-Yr	100-Yr	500-Yr	2-Yr	10-Yr	25-Yr	100-Yr	500-Yr
Ten Mile Creek	0	6 (2)	10 (2)	19 (2)	22 (2)	0	9 (2)	15 (2)	20 (2)	28 (4)
Sinking Creek	0	1	2 (1)	4 (1)	6 (1)	0	1	2 (1)	6 (1)	8 (1)
West Hills Trib.	0	0	0	1 (1)	1 (1)	0	0	0	1 (1)	1 (1)
Echo Valley Trib.	1	1	1	2	8	1	1	1	3	10
TOTALS	**1**	**8** (2)	**13** (3)	**26** (4)	**37** (4)	**1**	**11** (2)	**18** (3)	**30** (4)	**47** (6)

(#) - number of structures that are located within City of Knoxville limits

5.2.4 Roadway Flooding

Table 5-7 presents a summary of the roadway overtopping analysis performed using the results of the future condition HEC-RAS models. The ranking of the roadway in existing conditions is presented in the table as well. Similar to the existing condition ranking, the two County-owned roads with the highest predicted incidence of flooding are Peters Road (ranked 2nd) and Ebenezer Road (ranked 5th) which are overtopped by backwater from Ebenezer Sinkhole.

Table 5-7. Predicted Future Condition Roadway Flooding at Bridges and Culverts

Rank	Road Name	Existing Cond. Rank	Stream	HEC-RAS RM	Roadway Class.	Overtopping Event	Flood Depth (ft)
1	Kingston Pike (within City limits)	1	Ten Mile	2.221	MA	10-yr	0.85
2	Peters Road	2	Ten Mile	0.812	ma	10-yr	6.11
3	Mars Hill Road (within City limits)	3	Ten Mile	4.787	ma	25-yr	1.12
4	Middlebrook Pike (within City limits)	Not ranked	Ten Mile	4.876	ma	100-yr	0.36
5	Ebenezer Road	4	Echo Valley	0.015	MC	2-yr	0.82
6	Cross Park Drive (within City limits)	6	Sinking Creek	0.198	MC	10-yr	3.66
7	Bridgewater Road (within City limits)	5	Ten Mile	3.310	MC	10-yr	3.32
8	Walker Springs Road	8	Ten Mile	4.082	MC	10-yr	2.14
9	Walker Springs Road (within City limits)	7	West Hills	0.608	MC	10-yr	0.55
10	George Williams Road	9	Ten Mile	1.385	MC	10-yr	0.52
11	Fox Lonas Road	10	Sinking Creek	0.913	MC	25-yr	0.72
12	Robinson Road (within City limits)	11	Ten Mile	5.155	mc	10-yr	1.77
13	Ebenezer Road	13	Ten Mile	1.995	mc	10-yr	1.2
14	Corteland Drive (within City limits)	12	West Hills	1.021	mc	10-yr	1.16

MA = Major Arterial, ma = minor arterial, MC = Major Collector, mc = minor collector
Note: The flood depth represents the depth of flooding for the overtopping event, as opposed to the depth of flooding for a common flood frequency.

5.2.5 Blocked Condition at Ebenezer Cave

The future condition HEC-1 model to simulate completely blocked conditions at the cave. It was determined that, with blocked conditions at Ebenezer Cave, the backwater region for the 100-year event extends to RM 1.656, approximately 1430 feet upstream of George Williams Road. Furthermore, the blocked outlet 100-year future condition flood elevation is 3.65 feet higher than the future condition elevation calculated with the open outlet.

Table 5-8 presents the results of this analysis in terms of the flood elevation at the sinkhole for all events, and the flood potential in the sinkhole backwater area. It should be remembered that the flood potential is determined using only those FFEs that were surveyed based on the 100-year or 500-year *existing* condition floodplains determined with open Cave conditions. The flood potential listed in Table 5-8 does not reflect any additional structures that lie inside the blocked condition floodplain, and is likely lower than the actual flood potential that would be determined if all structures were surveyed.

Table 5-8. Results of Analysis of Blocked Conditions at Ebenezer Cave

	Elevation at Ebenezer Sinkhole (ft NAVD)			Flood Potential in Sinkhole Backwater Area (based on surveyed FFEs only)		
Storm Event	Existing Condition (Open Outlet)	Future Condition (Open Outlet)	Future Condition (Blocked Outlet)	Existing Condition (Open Outlet)	Future Condition (Open Outlet)	Future Condition (Blocked Outlet)
2-yr	859.40	861.48	866.73	0	0	1
10-yr	868.80	870.55	875.13	2	3	5
25-yr	871.96	873.62	877.94	3	4	6
100-yr	876.33	877.87	881.52	5	6	14
500-yr	880.10	881.46	884.73	10	12	18

6 GENERAL STORM WATER MANAGEMENT ALTERNATIVES

When the flood potential for property and structures is high, mitigation measures are often considered to alleviate expected flood damages. Mitigation measures can be categorized as structural and non-structural flood solution alternatives. Structural alternatives typically include construction or modification of the storm water conveyance to control floodwaters, such as a channel improvement or construction of a levee, dam, or reservoir. Structural measures can also include localized flood protection such as flood proofing, floodwalls, etc. Non-structural alternatives typically do not involve construction but rather consist of policies, planning, regulations, land acquisitions, or other measures that reduce the potential for flooding or keep individuals from building in a flooded or potentially flooded area. Structural measures are more expensive and are typically used as a reaction to existing problems. Non-structural alternatives can be used as a planning tool to prevent anticipated flooding problems.

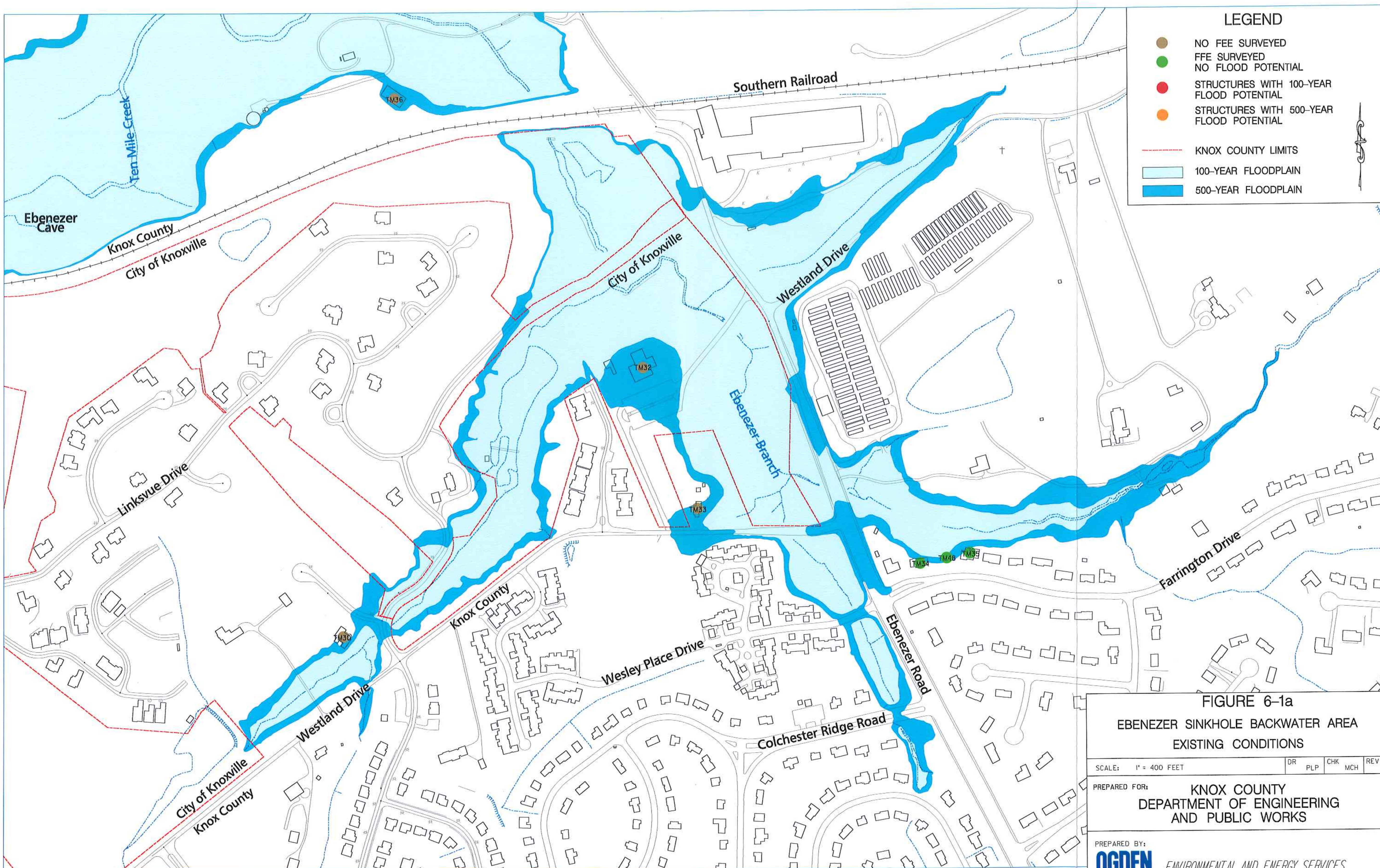
This section presents analyses and discussions of various general structural and non-structural alternatives that can be utilized by Knox County to reduce the flood potential on Ten Mile Creek and its tributaries. The discussion focuses separately on alternatives that can be implemented in the backwater area at Ebenezer Sinkhole, where conventional structural alternatives are not feasible, and a presentation of more typical options to combat flooding in the remainder of the watershed.

6.1 Ebenezer Sinkhole and Ebenezer Cave

6.1.1 Background

In the past twenty years, Knox County has received many complaints of flooding in the area surrounding Ebenezer Sinkhole. Major roadways have been flooded due to backwater stored in Ebenezer Sinkhole, most notably Peters Road and Ebenezer Road. The HEC-1 model predicts that these roads will overtop during a 10-yr event by more than 4 feet. Residential flooding is also a problem. Most recently, the home at 8900 Cedarbrook Lane was flooded during the April 1998 storm event. This residence has been flooded on a number of occasions in the past, and was raised in the early 1980's to provide some measure of flood protection.

Figures 6-1a and 6-1b present the existing condition floodplains and the flood potential for the 100-year and 500-year events in the Ebenezer Sinkhole area, which extends from Colchester Ridge Road on the south, to George Williams Road (RM 1.385) on the north.



Base Map Planimetrics:KGIS

FIGURE 6–1a

EBENEZER SINKHOLE BACKWATER AREA

EXISTING CONDITIONS

SCALE: 1" = 400 FEET | DR PLP | CHK MCH | REV

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PREPARED BY: OGDEN ENVIRONMENTAL AND ENERGY SERVICES

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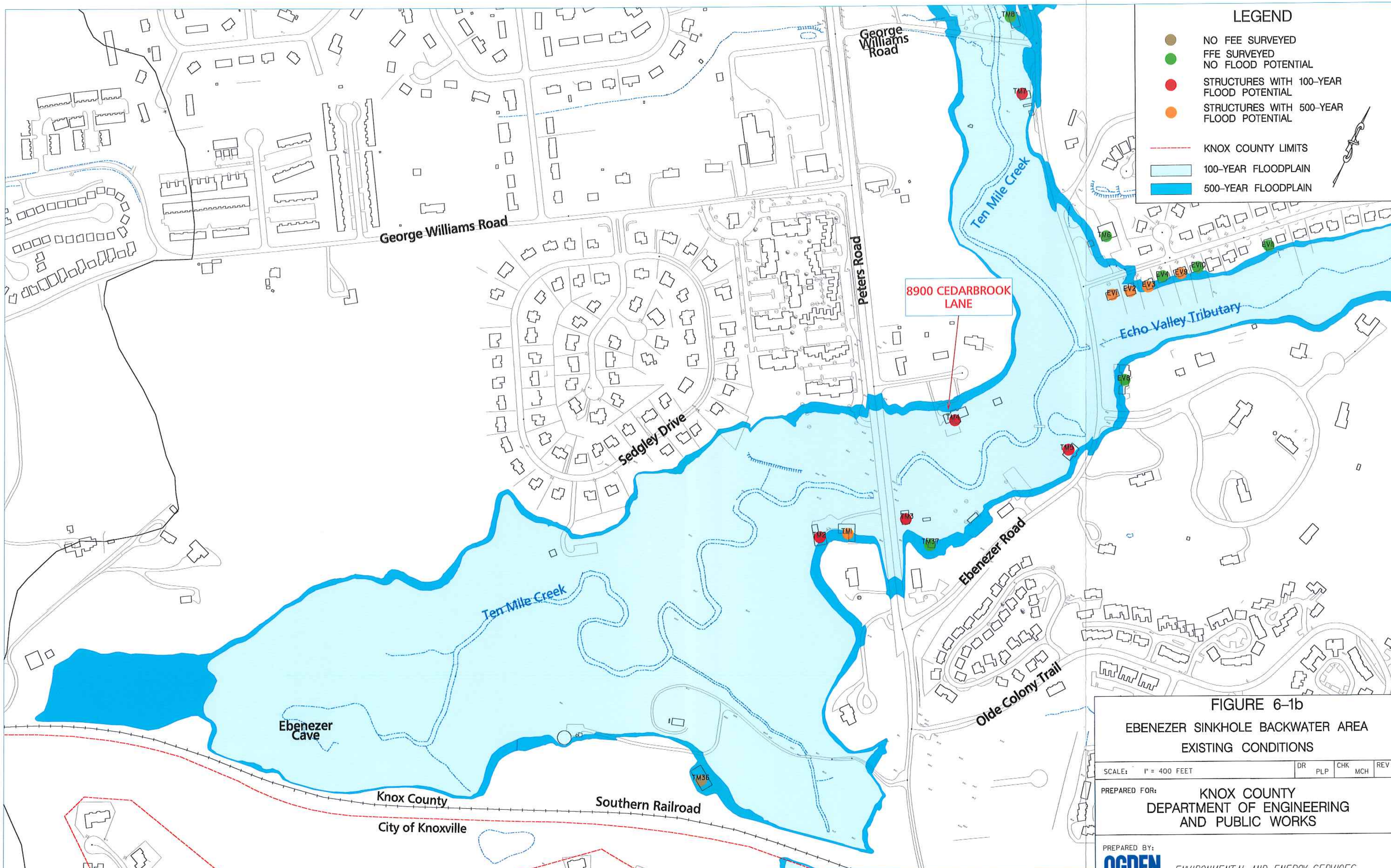

Base Map Planimetrics:KGIS

FIGURE 6-1b

EBENEZER SINKHOLE BACKWATER AREA

EXISTING CONDITIONS

SCALE: 1" = 400 FEET	DR PLP	CHK MCH	REV

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Table 6-1 presents an estimate of the flood potential in the area, based on comparison of surveyed FFEs of structures located in the area with HEC-RAS model results.

Table 6-1. Structures with FFE Flood Potential – Ebenezer Sinkhole Area

	Number of Houses Flooded (based on surveyed FFEs)	
Storm Event	**Existing Condition**	**Future Condition**
2-yr	0	0
10-yr	2	3
25-yr	3	4
100-yr	5	6
500-yr	10	12

Note: All structures with FFE flood potential are located in Knox County

Table 6-2 presents a list of the addresses of homes that have existing condition FFE flood potential, along with the depth of flooding for all events for the structures and roadways that have flood potential in the 100-year event. The total value of the properties listed in Table 6-2 is $502,600.

Table 6-2. Structures with 100-Year Existing FFE Flood Potential Ebenezer Sinkhole Area

Structure #	Location	Overtopping Elevation or FFE (ft NAVD)	Existing Condition Depth of Flooding (ft)[1, 2]				
			2-Year	10-Year	25-Year	100-Year	500-year
TM2	717 S. Peters Rd; Bldg. 2	872.15	-12.63	-3.31	-0.15	4.22	7.99
TM3	716 S. Peters Road	865.92	-6.15	2.95	6.09	10.46	14.23
TM4	8900 Cedarbrook Ln.	869.53	-9.38	-0.61	2.52	6.88	10.64
TM5	Ebenezer Road (address unknown)	868.10	-7.79	0.86	3.98	8.33	12.09
TM7	411 Ebenezer Road	875.22	-13.35	-6.01	-2.95	1.36	5.09

1 - (a negative sign indicates the FFE is above the flood elevation)
2 – shaded blocks indicate predicted FFE flooding

As discussed in Chapter 2, flooding due to backwater stored in Ebenezer Sinkhole can be caused by one or more factors. Periods of extended flooding are caused by one or more large volume rain events or rain events that occur during saturated (i.e., high runoff) conditions, which are often combined with poor outlet conditions at Ebenezer Cave. Discharge through the Ebenezer Cave system can be affected by the elevation of the water table, changes in the subsurface flow routes, or debris and sediment blocking the cave entrance.

The importance of a free and open entrance to Ebenezer Cave is clarified in the results of the blocked condition analysis presented in Chapters 4 and 5. With a blocked cave entrance, flood elevations increase by approximately three to seven feet (depending upon the event) above flood elevations calculated with an open outlet condition. The Corps of Engineers also analyzed extreme events with blocked conditions in their 1994 report. That analysis showed that the number of houses and roadways that were predicted to flood in the 100-year event were almost doubled under the clogged cave condition.

Preservation of the existing sinkhole storage volume is another key to reducing the future flood potential in the area. Studies that have analyzed flooding in Ebenezer Sinkhole, including this master plan, have assumed that the storage volume of the sinkhole will be preserved as future development occurs. This is an important aspect of controlling the flood potential at the sinkhole, because loss of storage volume will most certainly cause higher flood elevations during extreme events.

6.1.2 Structural Alternatives

The natural occurrence of backwater storage in Ebenezer Sinkhole limits the flood management alternatives that can be utilized in this area. Typical structural flood solution alternatives that are normally applied upstream or within a flood damage reach, such as channel improvements or regional detention, will not provide flood relief at the sinkhole because these options do not decrease the volume of water to the sinkhole. A channel improvement modifies conveyance and channel storage, and a detention facility changes the peak flow and timing. Ideally, a retention pond could limit the volume of water delivered to the sinkhole area because it does not discharge the amount of water it receives. However, this is not a feasible option in the Ten Mile Creek watershed because no area large enough to retain the required volume of water exists upstream of the sinkhole.

As discussed in Section 2.5, several past studies examined possible structural alternatives to reduce flood elevations at the sinkhole during extreme events (TVA, 1974, USACE, 1994). Alternatives considered include high flow flood relief channels, combinations of tunnels and channels, and a large volume storm water pump station. Each of these options were intended to limit the 100-year flood elevation at the sinkhole to elevation 860 or less by providing a secondary means of discharge during extreme events. If effective, these alternatives would eliminate flooding for the structures listed in Table 6-2, and would provide a means to lower flood elevations in the event of a blocked throat or catastrophic rainfall event. However, the cost to implement any of these alternatives is high. In the 1974 TVA study, the estimated cost for each of these alternatives ranged between $1,300,000 and $7,000,000. Of course, today's costs for land acquisition, design, construction and maintenance would be much greater.

Additional factors to consider when evaluating structural alternatives include:

1. the combined property value of structures that have an existing 100-year event flood potential is much less than the cost of the least expensive structural alternative, making property buyouts an attractive option;

2. the master planning analyses predict that the flood potential in the sinkhole area does not increase significantly in the future condition (i.e., only one additional structure, valued at $126,800, is flooded);

3. the potential consequences and liabilities associated with flooding at the sinkhole due to a catastrophic rainfall event or a clogged sinkhole throat;

4. the acceptability of occasional periods of flooding of Peters Road and Ebenezer Road (assuming the roadways are not raised), and other areas located in the vicinity of the sinkhole; and,

5. the acceptability of applying less-costly, but stringent non-structural policy measures to control *future* flood elevations and flood potential at the sinkhole, in lieu of costly structural alternatives to alleviate flooding during extreme events.

Based on factors 1 and 2, it could be concluded that the cost to implement structural alternatives to lower existing condition flood elevations in Ebenezer Sinkhole would outweigh the benefit realized. The last three factors may more difficult to evaluate.

Assuming large-scale structural measures to lower flood elevations at Ebenezer Sinkhole are not performed, flood solution alternatives for residences and businesses that have existing condition flood potential include property buyout or flood proofing. Property buyout is the more attractive option because the flood potential is completely eliminated, and there are no lingering maintenance and liability issues. When the property owner will not accept a buyout, localized flood proofing options such as levees, floodwalls or house-raising may be viable structural alternatives, and should be evaluated on a case-by-case basis.

For example, the residence at 8900 Cedarbrook Lane could be a candidate for consideration of a floodwall or berm. The property sits at the edge of the floodplain, and a preliminary investigation indicates that a flood protection structure could be built to protect the home without obstructing access to the property. However, negative aspects to a floodwall or berm include a maximum height of more than 7 feet in some areas and the removal of flood storage area for the sinkhole. A flood protection structure of substantial size may not be economically feasible and would require maintenance of the structure and drainage mechanism (e.g., a pump) by the homeowner or County for the life of the structure. Of course, the resident would also have to agree to the construction.

There are several structural options that could be utilized to reduce the potential of clogging at Ebenezer Cave by filtering out sediment and debris during dry weather periods (i.e., base flow conditions) and possibly during high frequency, low volume rainfall events. These options range from a rock berm with trash racks located just upstream of the mouth to the cave to a constructed wetland or forebay area to aid in the filtering of sediment. Such alternatives would require a detailed examination and design to provide an effective filtering mechanism during low flows yet still remain effective after flood events. As with most structural measures, these options would require some level of regular maintenance by the County.

6.1.3 Non-structural Alternatives– Application of Knox County's Sinkhole Policy

There are a number of non-structural methods that can be employed by the County to control future flooding in the Ebenezer Sinkhole area. These are:

1. operational and policy measures to protect the entrance to Ebenezer Cave;
2. policy measures to preserve the existing storage volume of the sinkhole and keep new development from flooding; and,
3. policy measures that control future increases in the volume of runoff discharging to the sinkhole.

The County may opt to apply these methods using the *Interim Policy Statement for Development in Sinkhole Areas*, henceforth called the "sinkhole policy", that has been implemented by Knox County starting in January 1999. A copy of the policy is presented in Appendix D of this report. The sinkhole policy was originally developed to address flooding due to development in or near sinkholes in Knox County, and to protect the outlet and storage volume of sinkholes that operate as the sole or primary drainage outlet for runoff. The policy was developed in response to flooding that occurs in the Dutchtown Road Sinkhole Area, but has been applied to a number of areas since its adoption by Knox County. The remainder of this section discusses the applicability of the existing sinkhole policy to the Ebenezer Sinkhole and the Ten Mile Creek watershed.

Operational and Policy Measures to Protect Ebenezer Cave

The Knox County Sinkhole Policy does not permit the placement of substances and objects in the sinkhole, filling or obstructing the outlet, and the use of explosives near the sinkhole throat. These statements are certainly applicable to Ebenezer Cave, and can be used to address issues such as an individual dumping trash or debris within the sinkhole or construction activities in the vicinity of the sinkhole. However, because there is relatively little human activity near Ebenezer Cave, most of the debris that accumulates at the mouth to the cave are floatables that have been transported to the sinkhole by the Creek, as opposed to trash deliberately dumped in the sinkhole. Therefore, application of the policy alone will not keep Ebenezer Cave clear.

Sediment-laden stream flow after a storm event is a common site in the watershed. Observations in the watershed suggest that sediment in the stream could be due to both erosion of sediment from construction sites and erosion along stream banks. The sinkhole policy addresses erosion and sediment control on new and re-development areas located *in the drainage area for the sinkhole (i.e., the watershed)* that include over 20,000 square feet of total impervious area. Essentially, site operators are required to provide "adequate structural and non-structural erosion and sediment controls on their site", and must protect the sinkhole throat. No specific additional controls are required in the policy. The policy contains no statements regarding the stabilization of streams that discharge to sinkholes.

From an operational standpoint, the County has performed debris removal at Ebenezer Cave on an as needed basis. However, based on observations of debris and sediment in the sinkhole and creek, regularly scheduled debris/sediment removal visits to the site are warranted. Volunteer "Adopt-A-Stream" and "Adopt-A-Road" programs could also help to reduce the amount of floatables that make it to the Cave, and could be used to comply with the upcoming NPDES Phase II regulations (discussed in Chapter 3). From a policy standpoint, Knox County's standard for "adequate" controls for land disturbances in the Ten Mile Creek watershed should be more stringent than the normal County requirements, particularly at those sites located adjacent to a stream or wet weather conveyances. Regular inspection of sediment and erosion control measures in these areas should also be considered. The County should also repair existing stream bank erosion problems and regularly inspect areas where channel and overbank erosion has been a problem.

Policy Measures to Protect the Sinkhole Storage Volume

Development and encroachment in the sinkhole are already limited because the sinkhole is included in the FIS and has regulatory 100-year and 500-year floodplain elevations and a regulated floodway, as shown in Figures 6-1a and 6-1b. The regulatory floodway boundary in the Ebenezer Sinkhole area is equal to the existing condition 100-year floodplain. In accordance with the NFIP, the County is required to prohibit encroachments in the floodway unless it can be demonstrated through hydrologic and hydraulic analyses that a proposed encroachment would not result in increased flood elevations. If the results of the hydraulic analysis shows no increase in flood elevations, the development can be constructed. Knox County also requires that finished floor elevations be equal to or higher than one foot above the 500-year floodplain elevation, which would keep most development to a location near the 500-year floodplain boundary.

The use of the FEMA floodway as a means to control development in the Ebenezer Sinkhole is attractive because the floodway is a *mapped* boundary and the NFIP regulations are familiar to local developers and Knox County. However, this approach does not protect the storage volume of the sinkhole because there are no requirements for compensating cut and fill. In addition, it has the potential to allow encroachment "creep" into the sinkhole because flood elevations would not be sensitive to small, individual developments that are analyzed on a case-by-case basis.

Application of the Knox County Sinkhole Policy to Ebenezer Sinkhole can protect and preserve the existing the storage volume. Section 6 of the policy requires the establishment of "floodplain" and "no fill" lines and elevations for sinkholes from which the County can regulate new development and corresponding fill. Applying the policy to the Ebenezer Sinkhole, the floodplain line would be defined by the sinkhole lip (elevation 888) or at the future condition 100-year flood elevation (elevation 877.87 at RM 0.189). The elevation chosen would be at the discretion of the County. Unlike the other sinkholes where the policy has been applied, the 100-year floodplain elevation is not constant and increases as one moves upstream in the backwater area. The no-fill elevation could increase as well, using the difference between the no-fill elevation and 100-year elevation at the most downstream location.

The sinkhole floodplain storage volume is defined by the policy as the volume of storage beneath that elevation. Finally, the no-fill line is established as the contour line for the elevation that defines 60% of the floodplain storage volume. Fill is not allowed below the no-fill line, and any fill added between the floodplain and no-fill lines will require compensating excavation below the floodplain elevation, therefore preserving the storage volume of the sinkhole. The finished floor of any habitable structures constructed adjacent to a sinkhole must be at least one foot above the established floodplain elevation. This FFE requirement would likely limit most new developments to a location close to the floodplain line, however it is conceivable that a structure with an unfinished or open ground floor could be constructed closer to the no-fill line.

There are other options to protect the storage volume of the sinkhole. One option would be to combine the more useful aspects of both regulatory measures to protect the sinkhole storage volume. Use of the regulatory floodway elevation at the sinkhole as the floodplain boundary in the sinkhole policy gives the County a mapped regulatory boundary that can be used to preserve 100% of the storage volume. Another option is to apply the sinkhole policy with more stringent elevations. For example, the County could decide that no new development should occur below the maximum flood elevation ever encountered at the sinkhole (873.3), or at some higher elevation. A list of advantages and disadvantages for non-structural methods to preserve sinkhole volume are listed in Table 6-3.

Table 6-3. Advantages and Disadvantages of Volume Preservation Methods

Advantages	Disadvantages
A. FEMA Regulatory Floodway	
• Floodway line is conservative (i.e., it is 3 ft higher in elevation than the max flood elevation encountered in the sinkhole). • Floodway line is already mapped and can be made readily available to local developers and homeowners. • Knox County FFE requirements would likely keep most development limited to the vicinity of the floodplain boundary.	• Does not preserve the existing storage volume. • Some potential for "creep" of small, individual developments into floodway. • No compensating cut-and-fill requirements. • Provides lowest level of flood protection for new developments near the sinkhole.
B. Existing Sinkhole Policy (Floodplain at 100-Year Future Elevation)	
• No-fill and compensating cut-and-fill provisions preserve the existing storage volume up to the 100-year future flood elevation. • 100-year future floodplain elevation is conservative when compared to the max flood elevation encountered in the sinkhole (873.3). • Sinkhole Policy FFE requirements would likely keep most development limited to the vicinity of the floodplain boundary.	• Floodplain elevation and no-fill boundaries are not mapped. • Development would be allowed above the no-fill line which is approximately 1.65 feet lower than max flood elevation encountered at the sinkhole (873.3).

C. Combination Regulatory Floodway/Sinkhole Policy	
• No-fill and compensating cut-and-fill provisions preserve the existing storage volume up to the 100-year existing condition flood elevation. • 100-year existing floodplain elevation is conservative when compared to the max flood elevation encountered in the sinkhole (873.3). • Sinkhole Policy FFE requirements would likely keep most development limited to the vicinity of the floodplain boundary. • Uses mapped regulatory floodway boundary as the sinkhole floodplain elevation.	• Development would be allowed above the no-fill line which is 2.9 feet lower than max flood elevation encountered at the sinkhole (873.3).
D. Sinkhole Policy with Greater Level of Protection	
• Preserves the existing storage volume. • Development would not be allowed below max flood elevation encountered in sinkhole (873.3 ft). • Provides highest level of protection for new developments in the sinkhole.	• Highly stringent policy. Acceptance by property owners looking to develop areas near the sinkhole may prove difficult.

Policy Measures to Control the Volume of Runoff

Section 7 of the sinkhole policy addresses requirements for developments in sinkhole drainage areas. For the Ebenezer Sinkhole, the policy would encompass development in the entire Ten Mile Creek watershed. The purpose of this portion of the policy is to mitigate the future flood potential at sinkholes by limiting the additional volume of runoff from new and re-developed areas. The policy is limited to developments that include over 20,000 square-feet of total impervious area constructed upstream of volume sensitive sinkholes. New developments would be required to limit the *volume* of runoff leaving their site from from the post-development 24-hour 100-year event to the *volume* of runoff that leaves the site for the 100-year event under pre-development conditions. The volumes are calculated using wet antecedent moisture conditions (AMC III). The policy explicitly encourages limiting impervious area coverage to achieve this volume-based standard.

Application of this portion of the sinkhole policy to the Ten Mile Creek watershed would be complicated and the benefits would be limited. The following factors should be considered when evaluating controlling the volume of new developments:

- Significant portions of the watershed lie within the City of Knoxville and would not be subject to such controls without the City adopting similar requirements. If adopted by the County alone, the policy would be only marginally successful in limiting future increases in runoff volume;
- Because the cost of this policy would be borne almost entirely by the development community, acceptability of such a measure on a large scale would likely be difficult;
- The master planning analysis predicts that, without such a policy, the flood potential does not increase significantly in the future condition at Ebenezer Sinkhole (i.e., only one additional structure is flooded) or throughout the watershed (four additional structures are flooded). Is the benefit of such a policy worth the higher level of effort required on the part of County staff and the development community to implement it?

6.1.4 Recommendations

Based on Master Planning analysis, review of historical studies, and field observations the following recommendations can be made for flood solution alternatives for Ebenezer Sinkhole:

- Based on historical flood events at Ebenezer Sinkhole and the flood potential predicted by the master planning analysis, the benefits of structural alternatives to relieve the existing flood potential in the sinkhole backwater area do not outweigh the cost and difficulties of construction. Property buyouts or flood proofing of residences or business that have existing flood problems should be considered on a case-by-case basis.
- The County should take steps to protect and preserve the outlet structure (Ebenezer Cave) and the sinkhole storage volume. Such steps can include performing regular debris removal activities, maintaining a strong erosion and sediment control program that includes inspection and repair of stream bank erosion, getting the public involved in regular watershed and/or stream clean up activities, and implementing possible structural measures to protect the cave.
- Portions of the Knox County Sinkhole Policy could help preserve and protect the cave and sinkhole. The County should consider using the more applicable portions of the policy for Ebenezer Sinkhole.

6.2 Ten Mile Creek and Tributaries - Structural Alternatives

Drainage systems can be managed to control flood discharges and stages by constructing structural measures to reduce and/or control flooding levels. The two most common structural alternatives used to control flooding are detention of floodwaters using reservoirs or dams and increased conveyance of the system of channels, pipes, and streams used to transport floodwaters. Simple examples of these alternatives can be seen in a typical urban development. As land is developed, natural conveyance systems are replaced with concrete lined channels and pipes to quickly move drainage away from buildings and developed property. Unfortunately, this practice can have the effect of increase peak discharges and flood elevations downstream. In response, most municipalities, including Knox County, require new developments to use detention to offset increases in peak flows for certain design storms. A portion of the site is dedicated to flood in the form of a detention pond constructed at the downstream portion of the site. Therefore, flooding has not been eliminated but rather moved to a controlled area.

When using structural alternatives, the flood potential is usually not eliminated, but simply moved either upstream (as the case of detention) or downstream (as the case of conveyance improvements). Any time structural improvements are considered, the impacts of the project upstream and downstream must be considered. Channel improvements that lower flood stages will typically decrease natural storage along a stream and potentially increase peak discharges downstream. Large regional detention ponds that significantly decrease downstream discharges will increase flood elevations and inundate areas located upstream of the pond that were not flooded previously. These factors must be considered in the planning of any flood control design. In addition, large-scale structural flood solution alternatives can alter the geomorphology of a stream and have significant environmental impacts that may not be apparent on first inspection.

Localized structural measures such as flood proofing, elevating finished floor space, and small floodwalls can be used on a site-specific basis. In comparison to larger channel improvement or regional detention alternatives, these alternatives typically do not have significant impact on upstream and downstream flooding.

6.2.1 Channel Improvements

Channel improvements on Ten Mile Creek or one of its tributaries can be a feasible option for controlling peak flood elevations. Upstream of Ebenezer Sinkhole, predicted flood problems at multiple structures are concentrated in certain areas (Hardwicke Drive, Kingston Pike). In these areas the streams are fairly straight, steep, and have peak discharges that would allow for reasonable channel improvements. However, because channel improvements decrease in-channel storage, they have the effect of not only increasing peak discharges downstream, but also speeding-up the time-to-peak. This modification in the relative timing of the watershed could have the effect of raising flood elevations downstream of the damage reach for which the improvement is constructed.

Based on the watershed timing analysis presented in Section 4.2.3, the times-to-peak for the most tributaries in the Ten Mile Creek watershed occur before the peak on the main stem. Therefore, channel improvements on Ten Mile Creek would likely move the main stem peak discharge forward in time and closer to the tributary peaks, possibly resulting in an increase in flood elevations downstream of the improved area. Conversely, channel improvements on a tributary will increase the time between the tributary and main stem peak and could lower peak discharges and flood elevations downstream. Therefore, any channel improvements considered in the Ten Mile Creek watershed should be evaluated on a case-by-case basis using the HEC-1 and HEC-RAS models developed in the master planning process.

Table 6-4 provides a list of advantages and disadvantages for channel improvement alternatives.

Table 6-4. Advantages and Disadvantages of Channel Improvements

Pros	Cons
• Decrease in flood elevations in and potentially upstream of improved areas.	• Potential for increasing flood elevations downstream of improved areas. • Potential for channel instability in improved areas. • Potentially high cost. • Potential for significant changes in environmental condition of the channel. • Possible difficulties in obtaining environmental permits.

Limited channel improvements were investigated at two locations in the Ten Mile Creek watershed where the County identified existing flood problems: the Echo Valley Road and the Stonebrook Drive priority areas. Flood solution alternatives for both locations, including channel improvements, are discussed in detail in Chapter 7. Channel improvement is not a viable alternative to mitigate the flood potential for the Hardwicke Drive damage reach. The cause of flooding in the area is backwater stored upstream of the Interstate-40 bridge over Ten Mile Creek, and a channel improvement alone would not relieve the problem.

6.2.2 Regional Detention Facilities

The purpose of a detention facility is to temporarily store storm water runoff and release it to the downstream conveyance system at a decreased rate. Detention facilities can range from small ponds designed to detain runoff originating from a localized area or single development, to large regional facilities (e.g., on-line lakes) designed to reduce peak flows on a major stream. The location and size of the facility are very important factors in the effectiveness of the pond in controlling flooding in the desired area, and the impact of the pond on peak discharges in other areas. A general rule of thumb is that the facility should be located as close as possible to the location where flooding is to be controlled.

Regional detention facilities can provide the maximum reduction in peak discharges, but require large undeveloped areas set-aside for storage. Because of their size and storage capability, regional detention ponds can significantly affect the timing of the stream in which they are constructed. Timing of the peak discharge from the detention facility relative to the timing of inflows from other basins is key to its effectiveness in reducing flood potential and must be considered.

In the Ten Mile Creek watershed, regional detention would be most effective on reducing flood elevations if the pond were located on the main stem as opposed to a tributary. First, the majority of flooding in the Ten Mile Creek watershed occurs on the main stem and there are no concentrated areas of flooding on tributaries. Second, while a regional detention pond located on a tributary may be highly effective in lowering peak discharges on the tributary, it would likely have a negative impact on the main stem downstream of the confluence with the tributary. The HEC-1 model of the Ten Mile Creek watershed determined that the tributaries discharge to the main stem prior to the time-to-peak for the main stem, therefore a regional pond on a tributary would likely increase peak discharges and corresponding flood elevations downstream of the confluence with the main stem.

Because of the developed nature of the watershed, possible locations for regional detention on the main stem are limited. A brief investigation of a regional pond located upstream of Walker Springs Road on Ten Mile Creek was performed to determine if a pond could reduce the flood potential in the Hardwicke Road area. Because of the severity of flooding in that area, regional detention was not determined to be a viable alternative. The regional pond is discussed in more detail in Section 7.4.

6.2.3 Local Detention Facilities

Single local detention ponds, constructed as part of a new development, will provide some measure of protection immediately downstream of the pond, but the effects will quickly diminish as the flood wave travels further downstream. Multiple small storage facilities constructed in a basin can also eliminate flooding in localized areas, but will affect the timing of the flood hydrograph in the basin. This could cause adverse affects in different locations downstream in the basin, or on a regional level after the basin peak discharge combines with the main stem. To manage storm water effectively using local detention, one must have a complete understanding of the impact of multiple detention facilities on both the local and regional scale.

The effect of local detention in the watershed and the benefit, if any, of more stringent detention in key areas of the watershed was assessed using the Ten Mile Creek future condition HEC-1 model and several equations developed by Ogden to simplify analysis of multiple local detention ponds using HEC-1. The equations are presented in the *Beaver Creek Watershed Master Plan* (Ogden, 2000) and therefore are not presented in detail here. The analysis focused on requiring 100-year pre-to-post local detention in new developments located in Knox County.

It was determined that more stringent local detention requirements would not reduce predicted flood elevations enough to provide a significant reduction in the flood potential along Ten Mile Creek. The 100-year future condition flood potential was reduced by one structure. Analysis of 100-year pre-to-post detention at new developments in *both* the County and the City did not yield substantially better results. Based on the results of the analysis, the difficulties that the County would likely encounter trying to apply a more stringent detention requirement in the watershed must be weighed against the limited benefit such a policy would provide.

6.2.4 Flood Proofing

Flood proofing is another structural flood mitigation measure that can be used to eliminate the flood potential for structures located in or near the floodplain. The most standard flood proofing options include the construction of floodwalls or berms for small-scale projects, levees for large-scale projects, and relocation or elevation of the flooded structure. The most applicable option depends upon many factors, including the cause of flooding, the extent of flooded area near the structure, and the depth of flooding. The advantages and disadvantages of each option are summarized in Table 6-5.

Table 6-5. Advantages and Disadvantages of Typical Flood Proofing Measures

Advantages	Disadvantages
Floodwalls, berms and levees	
• Substantially reduces the flood potential. • No need to make structural modifications to homes or business. • Property owners retain their existing structure and property.	• Requires property acquisition for easements or ownership. • Requires periodic maintenance by property owner or County. • Requires installation and maintenance of sump pumps, check valves, and pipes. • May require local, State and Federal permits. • May increase flooding elsewhere due to a loss of storage or impedance of flow. • May give property owners a false sense of security about flood protection. • Acceptance by property owners may be difficult.
Structure Elevation	
• Reduces the flood potential. • Property owners retain their existing structure and property.	• Can be extremely expensive for a single structure. • The potential for damage due to hydrodynamic forces during flood events may not be eliminated. • Site access problems during flood events may not be eliminated. • The potential for "post-project" problems and continued maintenance associated with the elevated structure is high. • Warranties or implied warranties after the move can be problematic and persistent.
Structure Relocation	
• Eliminates the flood potential. • Property owners retain their existing structure.	• Can be extremely expensive for a single structure. • The potential for "post-project" problems and continued maintenance associated with the move of the structure is high. • Warranties or implied warranties after the move can be problematic and persistent.

Floodwalls and/or levees can sometimes be undesirable options because the loss of floodplain storage due to the wall or levee could increase flood elevations elsewhere. Large projects, such as a levee or berm behind the houses in the Hardewick Drive damage reach, can be expensive from a property acquisition and construction standpoint, and also are potentially difficult to maintain. Ideally, floodwalls or berms are much more feasible on a smaller-scale, in places where storage is not a significant issue, flood depths are relatively low, and the extent of flood potential is fairly localized.

While not inexpensive, floodwalls or berms tend to be cheaper than structure raising. However, the sensitivity of the local residents must also be considered when considering floodwalls or levees. Past experiences with the construction of floodwalls or berms on existing residential property indicates that homeowners may not accept it as a viable alternative for several reasons. First, the construction of the structure usually occurs on private property, sometimes in close proximity to the home. Homeowners may have concerns that the property located "on the other side of the wall" will become unusable to them, and that the structure will be unsightly and not maintained. In addition, there could be the perception by residents located near the flooded areas, whether unfounded or not, that visible flood proofing measures like floodwalls and levees reduce property values and discourage potential homebuyers. The County should take steps to inform residents that property value and sales potential are also adversely affected if the area is known to flood and does not have protection.

From the County's standpoint, relocation or elevation of homes is an unattractive option and should be considered only in cases where all other reasonable alternatives fail. Elevating a structure can be expensive, starting at approximately $75,000 per 2 feet in elevation for a 1200 square ft structure, as estimated by the U.S. Army Corps of Engineers (http://www.usace.army.mil/inet/functions/cw/cecwp/nfpc.htm). The process becomes more difficult and expensive as other factors are added, such as the existence of a basement, additions, or multi-story buildings. Other major drawbacks include the potential for post-project problems with the structure that has been moved, the possibility of future maintenance and implied warranties.

6.3 Ten Mile Creek and Tributaries - Non-Structural Alternatives

6.3.1 Development Management

A number of non-structural alternatives for stormwater management purposes can be grouped into a general category called development management. Development management can, but does not necessarily, mean limiting the amount of development in an area. It can also include a number of planning or regulatory/policy measures aimed at limiting increases in runoff volume or peak discharges, or preventing the further degradation of receiving water quality. Such alternatives have been addressed for Ebenezer Sinkhole previously in this Chapter. This section discusses the pros and cons of such options for the remainder of the watershed.

There are a number of methods that the County can use to manage storm water runoff from new development, such as:

- land use planning and zoning requirements that limit new developments to those that typically have a low amount of impervious area (e.g., low density residential);
- buying property for the purpose of open space maintenance;
- more stringent regulatory requirements for new developments such as limits on the amount of impervious area, more stringent detention requirements (investigated in Section 6.1, allowing no increase in post-development runoff volume, stringent flood fringe encroachment requirements, etc);
- tax incentives or other inducements for existing developments that retrofit or redesign to conform to more stringent water quantity and/or quality standards.

Besides controlling future flood potential, another positive aspect of development management is that it can be used by the County to comply with the NPDES Phase II permit that will be issued in March of 2003. The Phase II regulation requires that the County implement a program to prevent or minimize the impacts on stream water quality from runoff discharging from new developments and re-developments. Examples of non-structural alternatives that can be used to comply with this control measure include policies and ordinances that direct growth to certain areas, maintain or increase open spaces, protect riparian areas and wetlands, minimize impervious surfaces, etc. In the NPDES Phase II regulation, EPA suggests that the alternatives should attempt to maintain pre-development conditions.

From a flooding standpoint, application of alternatives that control runoff volumes or peak flows will not have a great impact because the future flood potential in the Ten Mile Creek watershed is not significantly greater than the existing condition flood potential. Furthermore, many new developments will be located within the City of Knoxville, and would not subject to the same requirements. An analysis of the capability of such management alternatives was performed using HEC models of the Ten Mile Creek watershed. It was assumed that there would be zero increase in runoff from new developments located in Knox County. The analysis resulted in a decrease in the future flood potential of two structures in the 10-year flood potential, and three structures in the 100-year event.

From a water quality standpoint it can be argued that implementation of development management alternatives are always a good idea. Alternatives such as open space maintenance, stringent sediment and erosion controls, requiring new developments to address water quality issues, establishing riparian buffers, and supporting and expanding greenways will lessen impacts from new development on stream water quality and address some of the NPDES Phase II regulations.

6.3.2 Floodplain Encroachment Limitations

As a community that participates in the National Flood Insurance Program (NFIP), Knox County is required to adopt the following *minimum* NFIP regulations (44 CFR § 60.3d):

1. Select and adopt a regulatory floodway based on the principle that the area chosen for the floodway must be designated to carry the base flood without increasing the water surface elevations by more than one-foot (i.e., a one-foot surcharge).

2. Prohibit encroachments within the adopted regulatory floodway unless it has been demonstrated through hydrologic and hydraulic analyses that the proposed encroachment would not result in any increase in flood levels.

The NFIP requirements were developed for the purpose of reducing the loss of life, property damage, and disaster relief costs associated with flooding by requiring improved building practices, guiding future development away from flood hazard areas, and requiring property owners to obtain flood insurance. However, one of the shortfalls in the NFIP requirements is a reliance on floodplain management boundaries that are based on existing conditions, and a misconception that the floodway delineation takes into account all of the factors that could increase flood elevations. The typical FEMA floodway delineation accounts for the hydraulic impacts of flood fringe encroachments, but not the hydrologic impacts of the loss of floodplain storage. In addition, future upstream land development is not considered in floodway delineation.

Some communities account for future effects by using a reduced maximum floodway surcharge, in most case 0.1 ft., future development flows, or a compensating cut requirement for flood fringe fill. All of these methodologies are valid regulatory mechanisms to reduce the impacts of flood fringe filling on flood elevations. Currently, Knox County accounts for impacts on future development by using the existing condition 500-year flood elevation as the baseline for finished floor requirements (i.e., the finished floor elevation for all new construction in the flood fringe must be 1-foot above the 500-year flood elevation).

The effect of building in the regulatory flood fringe was analyzed using the floodways developed for submission to FEMA in the *Ten Mile Creek Watershed Flood Study* (Ogden, 2000). The floodways were developed using the HEC-RAS models of Ten Mile Creek and its tributaries in accordance with NFIP rules (i.e., the floodway was developed using a maximum 1-foot surcharge). Storage-discharge relationships were extracted from the HEC-RAS floodway models and were used as input for the channel routings in the HEC-1 existing and future condition models. This accounts for the reduction of storage in the floodplains caused by encroachment of new development in the flood fringe. Flood elevations can then be determined by using the peak discharges from the HEC-1 model as input to the HEC-RAS floodway models.

Four flood fringe encroachment analyses were performed using the methods explained above:

1. existing condition hydrology, encroachment to the 100-year floodway boundary with channel storage adjusted;

2. existing condition hydrology, encroachment to a line one-half the distance between the 100-year floodplain boundary and the 100-year floodway boundary (i.e., one half of the flood fringe) with channel storage adjusted;

3. future condition hydrology, encroachment to the 100-year floodway boundary with channel storage adjusted; and

4. future condition hydrology, encroachment to a line one-half the distance between the 100-year floodplain boundary and the 100-year floodway boundary (i.e., one half of the flood fringe) with channel storage adjusted.

Table 6-6 presents the results of this analysis for Ten Mile Creek, Sinking Creek and the West Hills Tributary. Table 6-7 presents the flood potential for all analyzed conditions for the structures where FFEs were surveyed. The Echo Valley Tributary is not included because the majority of the modeled stream is subject to backwater from Ebenezer Sinkhole and therefore the floodway is set equal to the 100-year floodplain.

The results of the analysis indicated that flood elevations are sensitive to flood fringe encroachments. Under future conditions without flood fringe filling the average increase in flood elevations is just less than one foot. However, if the flood fringe is filled, as is allowed under existing regulations, the average increase in flood elevations on the main stem is approximately three feet and the flood potential rises accordingly. However, if development is regulated using the one-half flood fringe encroachment line, the future flood potential is fully mitigated throughout the watershed.

Table 6-7. Results and Comparison of Flood Fringe Encroachment Analysis

Stream	Existing Conditions increase in elevation (ft)				Future Conditions increase in elevation (ft)			
	Full Encroachment		Half Encroachment		Full Encroachment		Half Encroachment	
	Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
Lower Ten Mile Crk. Confluence to I-40	0.79	1.71	0.11	0.38	1.91	2.76	1.14	1.55
Upper Ten Mile Crk. Interstate-40 to 5.642	0.93	1.80	0.10	0.34	1.96	3.19	0.98	1.91
West Hills Tributary	0.66	1.04	0.07	0.20	0.78	1.22	0.18	0.33
Sinking Creek	0.68	1.31	0.14	0.43	0.92	1.54	0.33	0.53

Table 6-8. Results and Comparison of 100-Year FFE Flood Potential

Stream Name	Number of Flooded Structures -based on surveyed FFEs only					
	No Encroachment		Half Encroachment		Full Encroachment	
	Existing Condition	Future Condition	Existing Condition	Future Condition	Existing Condition	Future Condition
Ten Mile Creek	19 (3)	20 (3)	19 (3)	20 (3)	25 (5)	28 (5)
Sinking Creek	4 (1)	6 (1)	4 (1)	6 (1)	7 (1)	9 (1)
West Hills Trib.	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
TOTALS	**24** (5)	**27** (5)	**24** (5)	**27** (5)	**33** (7)	**38** (7)

(#) - number of structures that are located within City of Knoxville limits

Although this particular method of regulation is not typically used in other communities, it is comparable to the efforts of other communities in its objective to control the effects of future development using alternative floodplain management techniques. The one-half fringe encroachment line (i.e., the no-fill line) is intended to accomplish the same objective as a more restrictive allowable floodway rise or a future condition floodway. In short, the no fill line is an accounting for the future development in the watershed. This regulatory instrument is presented as a management alternative to control future flood elevations that should be considered by Knox County.

7 FLOOD SOLUTION ALTERNATIVES - PRIORITY AREAS

This section presents an analysis and discussion of specific flood solution alternatives for flood priority areas that have been identified by Knox County or through the results of the HEC-RAS models of Ten Mile Creek and its tributaries. A cost estimate for each alternative was developed, based on a conceptual alternative or design. These costs should be used for planning purposes only.

Costs are in present day (2000 dollars) and include property acquisition, construction costs including utility relocation costs, and design fees. Estimated costs for purchase of residential and commercial properties were based on values gathered from the County tax assessor. An additional $3500 was added to each individual property purchase to account for County staff time to review, initiate and perform property purchases, and the necessary fees and expenses associated with property transfers. Property acquisition costs for drainage easements were based on the estimated area of easement and an estimated land value. Land value estimates were based on estimates given by several local real estate agents. Construction costs were estimated for activities such as mobilization, excavation, fill and compaction, sewer line relocation, and channel restoration. Design and construction management costs were based on a percentage of the overall construction costs.

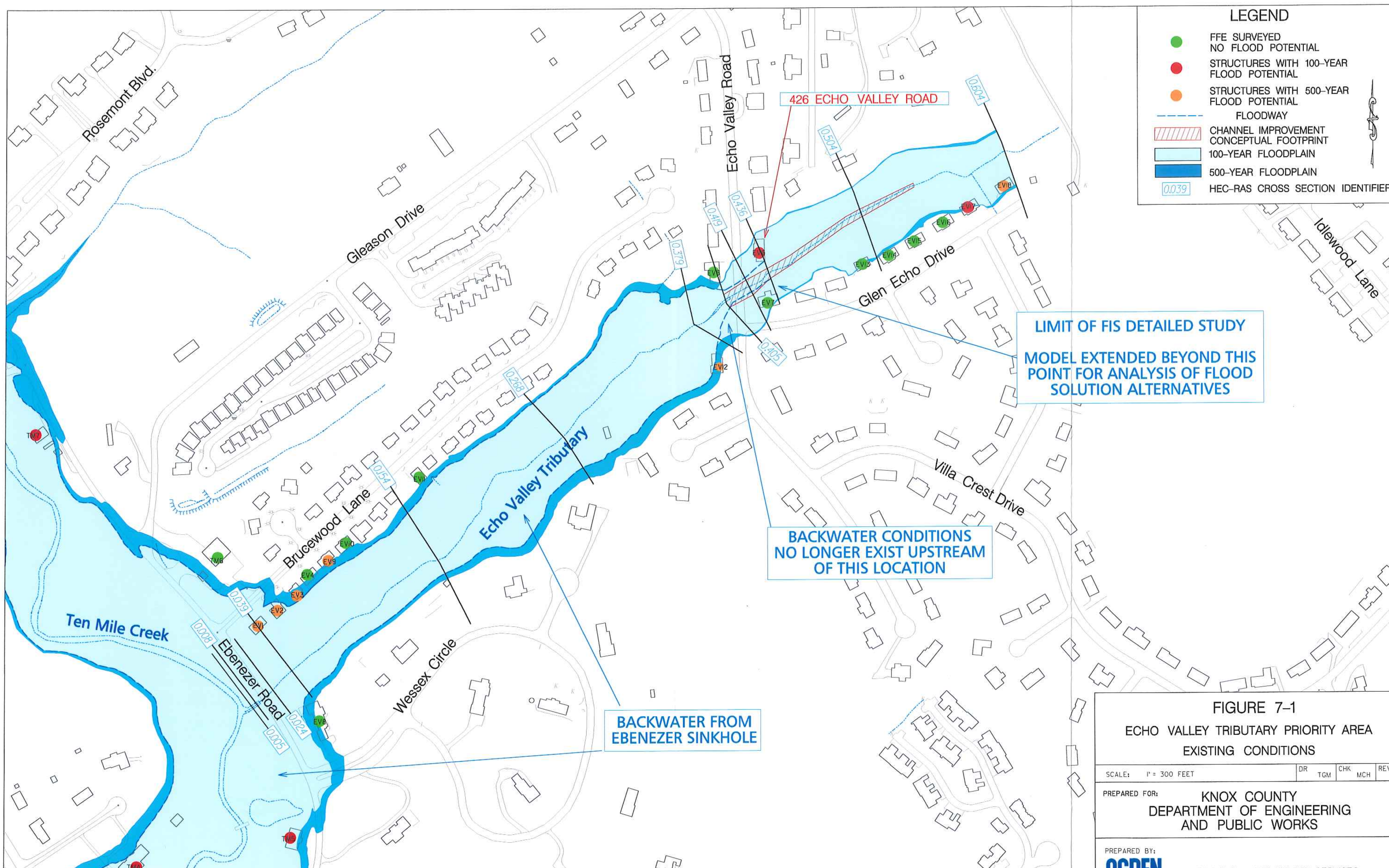
7.1 Echo Valley Priority Area

7.1.1 Background

During an intense storm event in the spring of 1998, the Knox County Department of Engineering and Public Works received a complaint of flooding at 426 Echo Valley Road. The house is located adjacent to the Echo Valley Tributary at approximately RM 0.436. The complaint prompted Knox County to further examine the flood potential for the residence on Echo Valley Road and other houses located along the Echo Valley Tributary upstream of Echo Valley Road.

Figure 7-1 shows the location of the 100-year and 500-year existing condition floodplains along the Echo Valley Tributary. Within the damage reach, structures with FFE flood are located along Echo Valley Road and Glen Echo Drive.

To determine the extent of the flood potential in these areas, the surveyed FFEs were compared to flood elevations from the HEC-RAS model. The structures that have FFEs below the 100-year and 500-year flood elevations are indicated in Figure 7-1. Table 7-1 presents flood potential in the damage reach and in the entire Echo Valley Tributary for all events in both the existing and future conditions.



Base Map Planimetrics:KGIS

FIGURE 7-1

ECHO VALLEY TRIBUTARY PRIORITY AREA

EXISTING CONDITIONS

SCALE: 1" = 300 FEET	DR TGM	CHK MCH	REV

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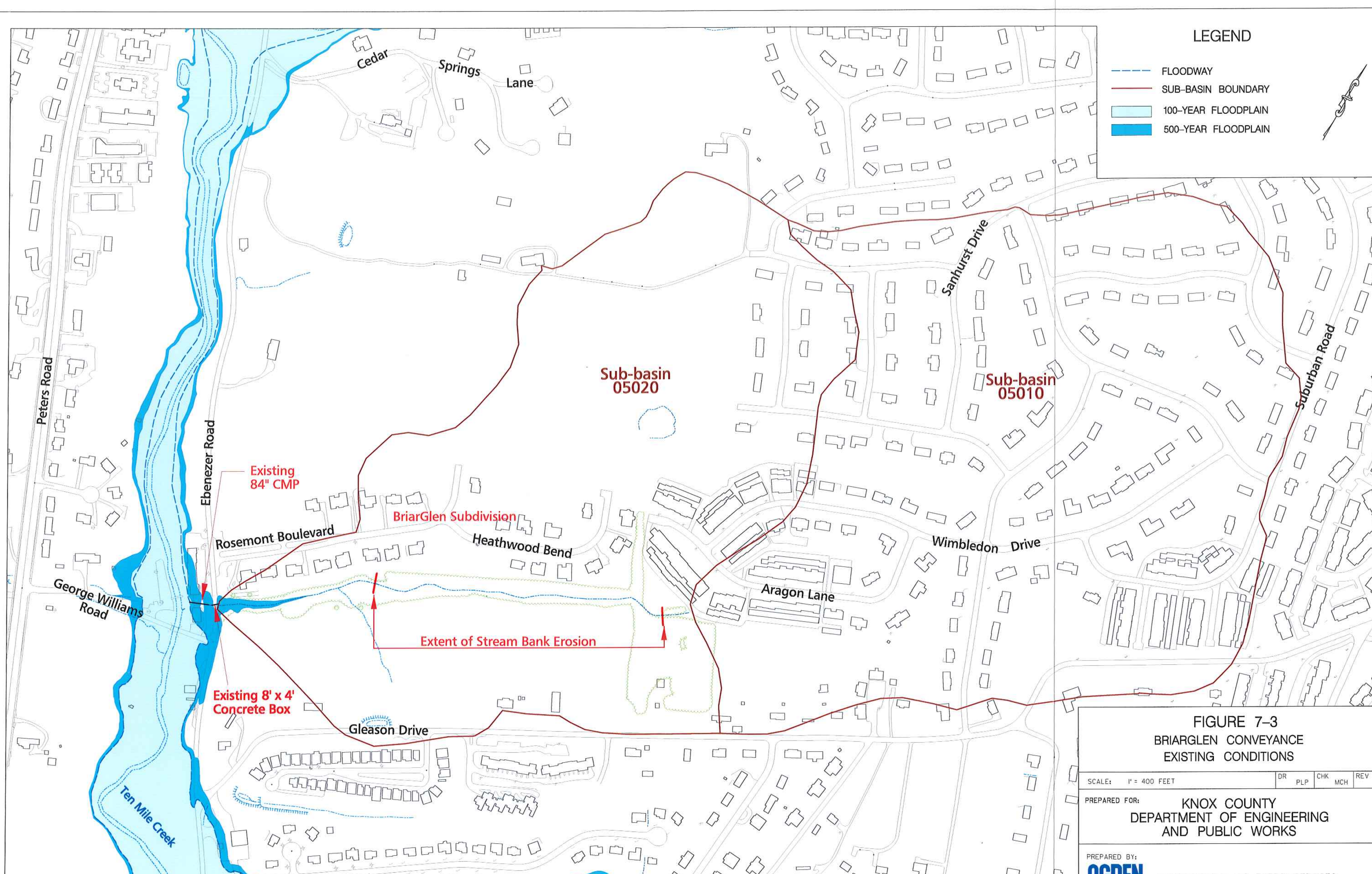

Base Map Planimetrics:KGIS

FIGURE 7-3
BRIARGLEN CONVEYANCE
EXISTING CONDITIONS

SCALE: 1" = 400 FEET	DR PLP	CHK MCH	REV

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Table 7-1. Structures with FFE Flood Potential – Echo Valley Tributary

	Number of Structures Flooded (based on surveyed FFEs)			
	Echo Valley Priority Area		Entire Echo Valley Tributary	
Storm Event	Existing	Future	Existing	Future
2-yr	1	1	1	1
10-yr	1	1	1	1
25-yr	1	1	1	1
100-yr	2	2	2	3
500-yr	4	4	8	10

Note: All structures are located in Knox County

Table 7-2 is a list of the addresses and the flood depths for all events for the surveyed structures located along in the priority area that have flood potential in the 100-year existing condition event.

Table 7-2. Structures with 100-Year Existing Condition Flood Potential - Echo Valley

Structure #	Address	FFE (ft NAVD)	Existing Condition Depth of flooding (ft)[1,2]				
			2-Year	10-Year	25-Year	100-Year	500-year
EV6	426 Echo Valley Rd.	876.65	0.11	3.31	3.71	4.16	4.34
EV17	8637 Glen Echo Dr.	883.67	-1.82	-0.69	-0.34	0.12	0.42

1 - (a negative sign indicates the FFE is above the flood elevation)
2 – shaded blocks indicate predicted FFE flooding

The flood potential at the two structures listed in Table 7-2 is caused by headwater conditions in Echo Valley Tributary, therefore structural measures, such as channel and culvert improvements, are likely viable alternatives to mitigate flooding. Since the existing flood potential is most serious at the 426 Echo Valley Rd. residence and Knox County has already received complaints of FFE flooding at that site, flood solution alternatives examined for the Echo Valley Tributary focused on relief of flooding at this residence. The flood potential at 8637 Glen Echo Drive is slight in the existing 100-year event, therefore if the County wishes to mitigate the flood potential at this location, a floodwall or berm may be an attractive option. The flood potential on the Echo Valley tributary downstream of the damage reach is due to backwater storage in Ebenezer Sinkhole. Flood solution alternatives for the sinkhole backwater area are discussed in Section 6.1 of this report.

The goal of the analysis was to eliminate the 100-year existing condition flood potential at the 426 Echo Valley Rd. residence and reduce the flood potential for future condition events. Regional detention upstream of the residence was not considered because a pond would need considerable storage volume to reduce peak discharges for the 100-year and larger events. The cost for property acquisition, construction and maintenance of the pond would be much greater than the effective cost to purchase one residence.

Flood proofing, in the form of a floodwall on the south side of the house was examined as a possible alternative. However, it was determined that a floodwall constructed to allow the resident to retain a portion of his current yard would encroach into the floodway. Based on HEC-RAS analysis, the loss of storage in the floodway would increase upstream flood elevations for the 100-year existing condition event approximately 0.2 feet, increasing the flood potential and complicating FEMA regulatory issues associated with construction in a floodway. A wall located closer to the house is not feasible as it would be more than six feet high at some locations.

Therefore, two conceptual alternatives were considered and are discussed in detail below:

1. purchase of property located at 426 Echo Valley Road; and
2. channel and culvert improvements.

7.1.2 Alternative 1: Purchase of flood-prone property

Table 7-3 shows the estimated cost to purchase he structure at 426 Echo Valley Road. It was assumed that the structure would be demolished after purchase, and the cost for demolition is reflected in Table 7-3. Other uses for the purchased property may change these costs. Of course, the purchase of the home would be contingent on the resident's agreement to sell.

Table 7-3. Estimated Costs, Echo Valley Area Property Purchases

Task	Estimated Cost
Property purchase (1 residential)	$135,300
Additional miscellaneous costs	$3,500
Demolition, waste removal, regrading	$23,085
SUBTOTAL	$162,605
10% contingency	$16,261
TOTAL COST	$178,866

7.1.3 Alternative 2: Channel and culvert improvements

The flood potential for 426 Echo Valley Road may be reduced through implementing channel improvements upstream of Echo Valley Road and enlarging the culvert on Echo Valley Road. Improved channel and culvert conveyance was analyzed using the Echo Valley Tributary HEC-RAS model, which was extended approximately 900 feet to facilitate analysis.

The existing culvert at Echo Valley Road consists of two 5-foot CMPs. HEC-RAS analysis indicates that road is overtopped during the 10-year existing condition storm event. It was determined that three 8' x 10' box culverts will pass the existing condition 100-year flood beneath the roadway and eliminate the 100-yr existing flood potential at the residence. Echo Valley Road would be raised approximately two feet to elevation 880.

In addition to the culvert replacement, the channel will need to be widened and re-graded from the culvert to a point approximately 700 feet upstream of the crossing. The minimization of the estimated channel improvement footprint was a primary concern during the analysis, due to the close proximity of residences to the study reach. The estimated footprint of the conceptual channel improvement is shown in Figure 7-1. The improved reach extends from RM 0.405 to RM 0.554 and consists of a trapezoidal cut of maintained grass, having a 26 foot base near the culvert reducing to an 8 foot base at RM 0.554, 2:1 side slopes (H: V), and a slope of 0.010 ft/ft. The excavation requirements for this channel are approximately 1956 cu yd, and would disturb a strip of land adjacent to the channel, having a width ranging from 20 to 52 feet depending upon location and depth of the channel. Table 7-4 shows the estimated cost associated with the channel and culvert conveyance improvement alternative.

Table 7-4. Estimated Costs, Echo Valley Area Channel/Culvert Improvements

Task	Estimated Cost
Culvert Improvement	$101,660
Channel Improvement	$54,384
Drainage Easement Purchase	$35,400
Contingency (10%)	$19,144
TOTAL COST	**$210,588**

A negative aspect to the channel improvement that should be considered is that it could increase nuisance flooding and the flood potential downstream of the damage reach (during high frequency, non-backwater events) because of the loss in storage upstream of the Echo Valley Road culvert.

7.1.4 Conclusions

A comparison of costs and effectiveness of the two flood solution alternatives for Echo Valley is presented in Table 7-5. The effective cost is the cost required to eliminate the 100-year existing condition FFE flood potential *at the 426 Echo Valley Road residence.*

Table 7-5. Summary Table of Alternatives for the Echo Valley Damage Reach

	Costs (in present day dollars)		
Alternative	**Construction**	**Structure Acquisition**	**Effective Cost**
Property Purchase	$0	$173,036	**$178,866**
Culvert Improvement	$210,588	$0	**$210,588**

Both alternatives achieves elimination of the flood potential for the 426 Echo Valley Road residence, however there are positive and negative factors associated with the alternatives that should be considered. The advantages and disadvantages for each alternative are listed in Table 7-6.

Table 7-6. Summary of Advantages and Disadvantages for Echo Valley Alternatives

Alternative	Advantages	Disadvantages
1. Purchase Flooded Property	• Eliminates flood potential at 426 Echo Valley Rd. • No construction of storm water facilities or associated maintenance required. • Least expensive alternative.	• Does not lower flood stages. • Owner may not be willing to accept a buyout.
3. Channel and Culvert Improvements	• Reduces flood potential at 426 Echo Valley Rd to the 500-yr existing condition event. • Eliminates existing condition flood potential at 8637 Glen Echo Drive. • Reduces overtopping potential at Echo Valley Road. • Reduces nuisance flooding along Echo Valley Drive and Glen Echo Drive.	• Requires possibly unpopular property acquisitions. • May increase downstream nuisance-flooding and flood potential during high frequency, non-backwater events. • Potential environmental permitting requirements for construction. • Highest cost alternative considered.

7.1.5 Recommendations

Should the County decide to take action to relieve flooding at 426 Echo Valley Road, purchase of the residence should be examined as the primary alternative, based on the lower estimated cost and the relative ease of achieving a permanent solution. This option both eliminates the flood potential at the site and does not impact surrounding properties. If the County takes action for the residence at 8637 Glen Echo Drive, flood proofing in the form of a low berm is recommended due to the infrequent and slight flood potential.

7.2 1805 Stonebrook Drive Priority Area

7.2.1 Background

Knox County has received complaints of flooding in ground floor apartments located at 1805 Stonebrook Drive and 1732 Robinson Road. Figure 7-2 shows the area of concern. The properties are located adjacent to a wet weather conveyance that discharges to Ten Mile Creek at RM 5.231. Discussions with residents during a field investigation of the area indicate that high water has flooded ground floor apartments. Residents also stated that Stonebrook Drive has overtopped on several occasions, yet Ten Mile Creek was not out-of-bank. This indicates that the culvert that drains the conveyance under Stonebrook Drive has insufficient capacity for moderate rainfall events.

The existing culvert under Stonebrook Drive consists of one 72-inch diameter CMP in fairly good condition. Significant erosion is evident on the downstream end of the culvert. Analysis of the culvert and upstream channel using peak discharges calculated by the HEC-1 model of Ten Mile Creek confirms that overtopping of Stonebrook Drive and potential flooding in ground floor apartments is due to insufficient capacity of the culvert. The analysis predicts that overtopping of Stonebrook Drive occurs during the 10-yr existing condition event. The ground floor apartments at 1805 Stonebrook Drive are predicted to flood in the 25-year existing condition event and the apartments at 1732 Robinson Road are predicted to flood in the 100-year existing condition event.

During extreme flood events, backwater from Ten Mile Creek can extend through the culvert under Stonebrook Drive. However, the elevation of the backwater predicted by the HEC-RAS model is not high enough to cause complete roadway overtopping or residential FFE flooding alone. During larger events, backwater can reduce the discharge capacity of the culvert and the upstream channel.

The drainage area contributing to the flow at this location is almost entirely developed, thus future peak flows and predicted flood potential do not greatly increase above the existing condition values. However, backwater from Ten Mile Creek increases approximately 0.5 to 1 foot from the existing to future condition.

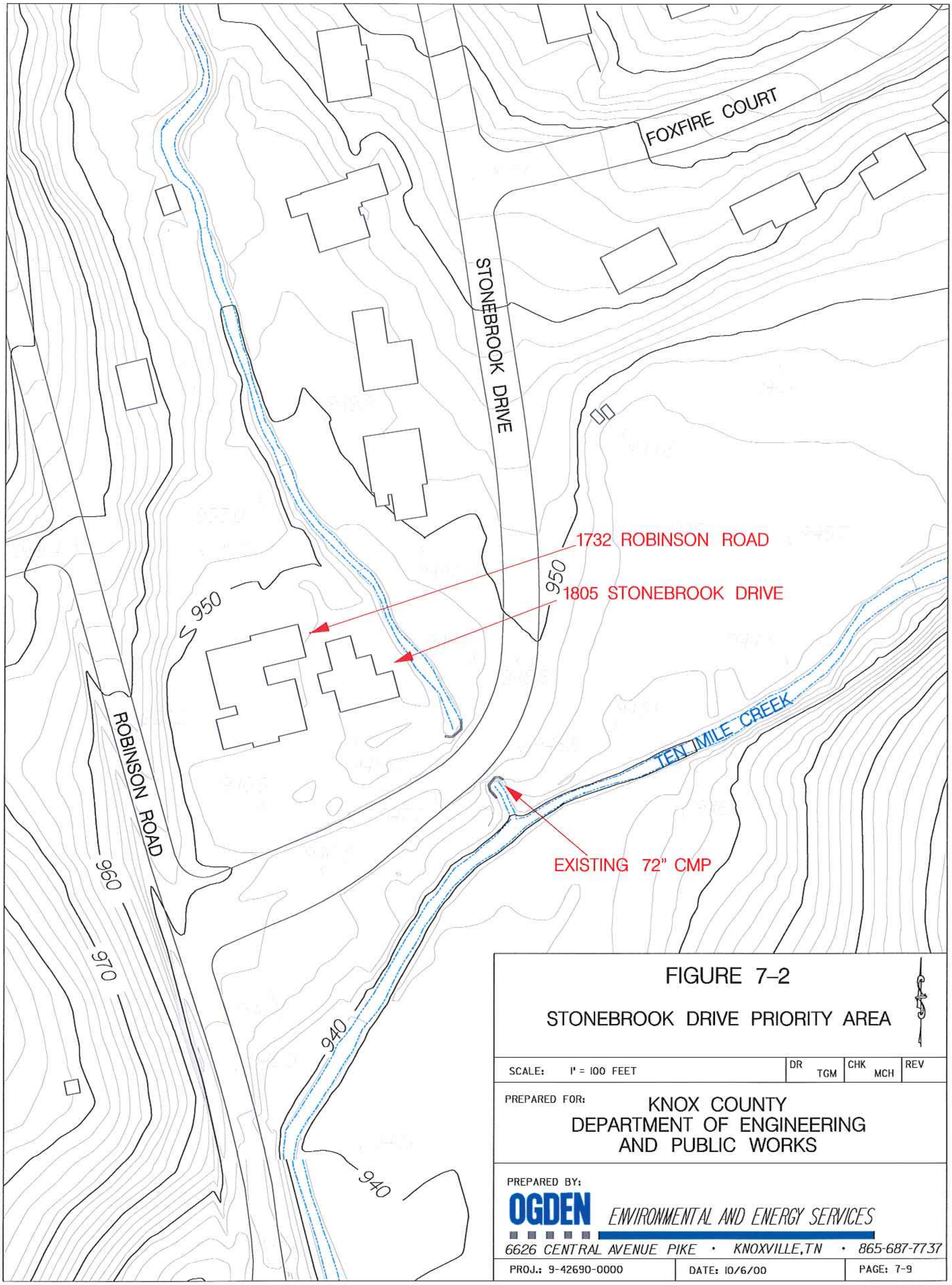

FIGURE 7–2

STONEBROOK DRIVE PRIORITY AREA

SCALE: 1" = 100 FEET	DR TGM	CHK MCH	REV

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7.2.2 Flood Solution Alternatives

The goal of the solution analysis was to eliminate the 100-year existing condition flood potential at the 1805 Stonebrook Drive and 1732 Robinson Road apartments and reduce the flood potential for future condition events. The flood potential can be reduced through enlargement of the culvert on Stonebrook Drive. Improved culvert conveyance was analyzed using standard hydraulic calculations which incorporated the backwater effects from the Ten Mile Creek HEC-RAS model. It was determined that two additional 48" CMPs will allow the culvert to pass the existing condition 25-year flood beneath the roadway and eliminate the 100-yr existing flood potential at these residences. Some channel modifications will be required to accommodate the new culvert configuration, however Stonebrook Drive would not need to be raised. Also, a spill apron should be constructed on the downstream side of the culvert to combat erosion.

Table 7-7 shows the estimated cost associated with the culvert improvement alternative.

Table 7-7. Estimated Costs, Stonebrook Drive Culvert Improvements

Task	Estimated Cost
Culvert Improvement	$54,643
Contingency (10%)	$5464
TOTAL COST	**$60,107**

Other alternatives for this priority area were not examined based on the relative higher costs and difficulty levels of other structural alternatives, such as upstream detention or flood proofing, when compared to adding two new culverts under Stonebrook Drive. Purchase of the properties at 1805 Stonebrook Drive and 1732 Robinson Road can relieve flooding at the site, however the estimated value of the two properties is $330,500.

7.2.3 Recommendations

Should the County decide to take action to relieve flooding in the Stonebrook damage reach, culvert improvements to increase conveyance on Stonebrook Drive is recommended.

7.3 BriarGlen Priority Area

7.3.1 Background

Knox County has received complaints of stream bank erosion in a stream located south of the BriarGlen subdivision, in the lower portion of the Ten Mile Creek watershed. The location of the stream is shown in Figure 7-3. In its current condition, the stream serves as a wet weather conveyance for the surrounding drainage area. However, it is shown as a "blue line" stream on the USGS Quadrangle and probably supported an intermittent base flow and aquatic life in the past. A bio-assay of the stream channel to determine if it currently supports aquatic life has not been conducted.

The stream receives drainage from sub-basins 05010 and 05020, and discharges the runoff through an 8' x 4' concrete box culvert under Ebenezer Road, then through an 84" diameter CMP under a commercial business area before discharging to Ten Mile Creek at RM 1.404. The total drainage area to the stream is 193 acres, the majority of which is comprised of medium density residential (1 to ¼ acre lot size) housing and two condominium complexes. Approximately 30% of the total drainage area to the stream is ungrazed pasture and meadow that has a high potential for development in the next few years. Currently, a condominium development is proposed for construction on a large tract of land located on the south side of the reach in sub-basin 05020.

Table 7-8 lists the peak discharges at the upstream and downstream portion of the erosion reach, as calculated by the HEC-1 model of the Ten Mile Creek watershed. These discharges were used to develop conceptual alternatives for mitigation of erosion in the channel.

Table 7-8. Peak Discharges in the BriarGlen Priority Area

	Upstream End of Erosion Reach		Near Culvert Under Ebenezer Road	
Event	**Existing**	**Future**	**Existing**	**Future**
2-year	44	47	61	77
10-year	120	126	182	208
25-year	159	165	245	274
100-year	220	226	343	376
500-year	275	282	435	470

A field visit was performed to investigate the extent of erosion and the hydraulic and hydrologic conditions in the areas of interest. The extent of observed erosion was approximately 1400 feet long, as indicated in Figure 7-3. The reach showed signs of high velocity flow, with undercut banks, and exposed root systems. Photographs of sections of the eroded reach are shown in Figures 7-4 and 7-5. It has become deeply entrenched through years of erosion, and many trees and shrubs have fallen or will soon fall into the stream as the channel banks slough into the reach. Based on field observations and knowledge of the development expected for the area, lateral erosion along the banks can be expected to continue, as the streambanks will slough into the reach until the slopes have reached a natural state of repose.

Figure 7-4. Briar Glen priority area– Erosion region (looking downstream)

Figure 7-5. Briar Glen priority area– Erosion region with debris (looking upstream)

Three intact concrete check dams within the study reach were noted during the field visit and the remnants of an additional five check dams were also found. The history of the check dams is not known. Each intact check dam suffers from lack of maintenance and exhibits some degree of instability. The channel bed upstream of the dams are level with the dam crest, indicating significant soil deposition upstream of each dam, and additional erosion above the top of the structure. Based on field observations, it was felt that the check dams could no longer serve to stem erosion within the conveyance. Therefore, each of the structural alternatives presented in the next section requires removal of all check dams.

7.3.2 Erosion Solution Alternatives

The ultimate objective in mitigating the current erosion problem in the BriarGlen stream is the protection of Ebenezer Sinkhole and Ebenezer Cave from sediment deposition. Regional detention upstream of the eroded reach is not a viable alternative because there is insufficient undeveloped land to place a pond of the size needed to reduce peak discharges for large events.

Therefore, mitigation of erosion will require improvement of the stream to a stable condition. Five channel improvement alternatives were examined, each varying in the degree of improvement in the channel. The conceptual options were designed using the *future* condition peak discharges calculated by the HEC-1 model.

All channel improvement options require replacement of the culvert under Ebenezer Road, which was determined to be inefficient for both the existing and future channel configurations. The new culvert would be comprised of an 8' x 5' concrete box and would be placed approximately 3 feet lower in the channel than the existing culvert to allow development of sufficient headwater to effect adequate drainage in the upstream channel. This reconstruction will impact the landscaped backyard of the BriarGlen residence located at the corner of Rosemont Boulevard and Ebenezer Road.

The erosion solution alternatives are listed in Table 7-9 along with their estimated cost. They are explained in the following paragraphs.

Table 7-9. Conceptual Alternatives, BriarGlen Conveyance

Alternative	Estimated Cost
1. No Action	$0
2. Trapezoidal channel with bio-stabilization	$350,209
3a. Armor 2-year channel, bio-stabilize 100-year channel	$354,324
3b. Armor 100-year channel	$312,115
4. Fill existing channel, create new, armored 100-year channel	$567,440
5. Pipe drainage from sub-basin 05010, channelize drainage from 05020	$1,230,808

7.3.3 Alternative 1 – No Action

To date, there has been no reported property damage associated with the erosion in the BriarGlen conveyance and no structures appear to be in danger of impact by the eroding streambanks. This is certainly the least expensive alternative, because there is no cost to the County if no action is taken. However, doing nothing will not protect Ebenezer Sinkhole and Ebenezer Cave from sediment deposition due to future erosion in the conveyance. Based on field observations, the conveyance will continue to erode until it has reached a natural state of repose. In other words, the erosion will likely not stop until well after the area draining to it has fully developed. Houses currently bordering the creek may never be in danger, however the problem will become more visible to surrounding homeowners in the future as existing vegetation falls victim to the gradually eroding stream banks.

7.3.4 Alternative 2 – Trapezoidal Channel with Bio-stabilization

Figure 7-6 depicts a typical cross-section of the conveyance before and after Alternative 2. The existing side slopes of the conveyance will be cut-back on a maximum 2:1 side slope and the 100-year channel will be stabilized with rip-rap and native vegetation (bio-stabilization grasses). Common vegetation will be allowed above the 100-year channel, as desired by the property owners living along the conveyance. The top width of the improved channel will vary, based on the depth of the existing channel. In most areas, the top width was estimated to be about 46 feet (i.e., 23 feet on both sides measured from the centerline of the channel), based on an 8 ft depth. The maximum top width of the excavated channel, based solely on field observations, was *estimated* to be approximately 80 feet.

This channel provides the maximum erosion and flood protection because the channel depth and side slopes are maximized. While this option requires the removal of a major portion of the existing tree line along the conveyance, replacement of trees and other vegetation above the 100-year channel would be permissible and likely encouraged, as the root system will gradually increase the stabilization. As with any channel, property owners should be encouraged to maintain the area and not to fill in the channel.

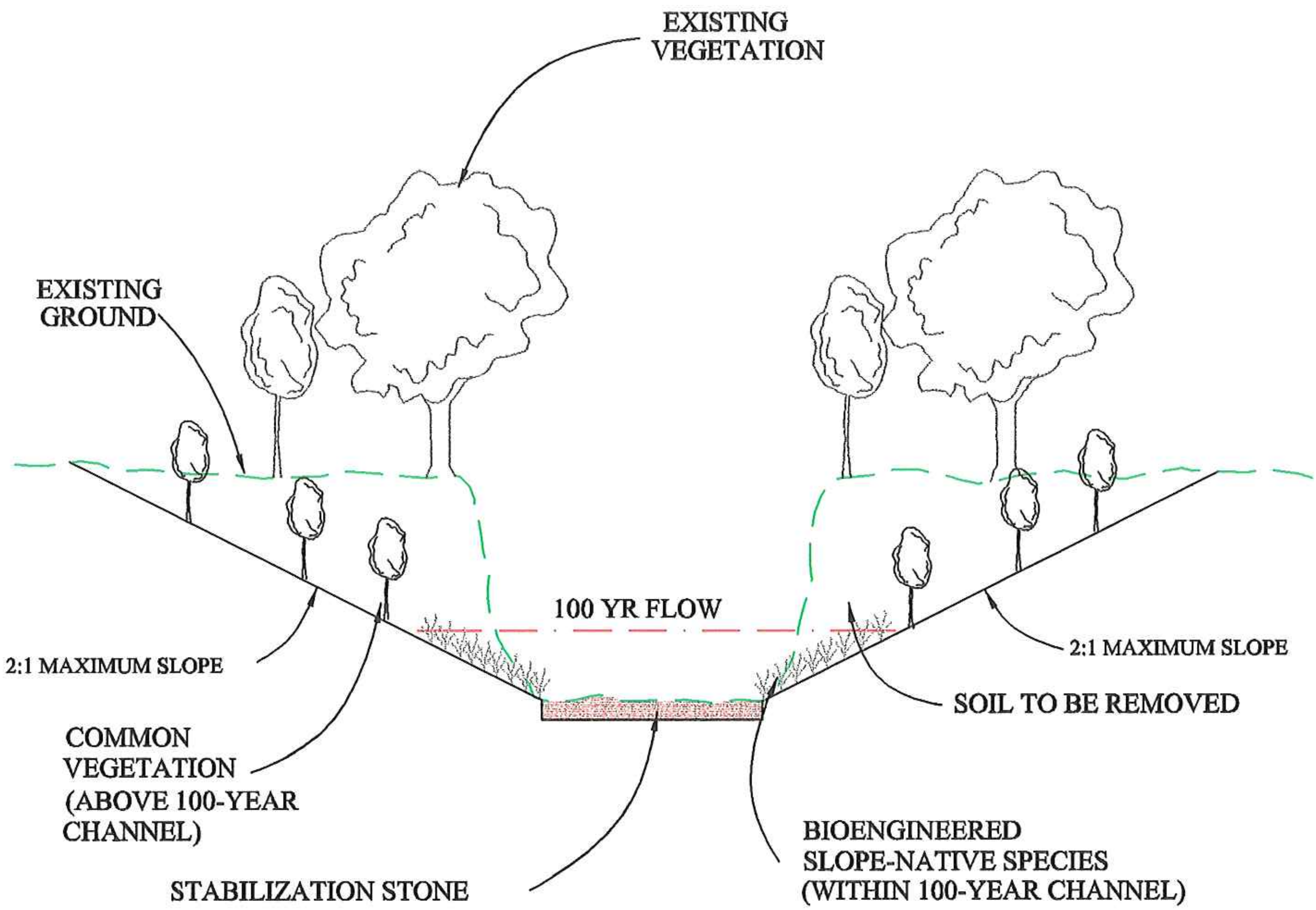

FIGURE 7-6
ALTERNATIVE 2

NOT TO SCALE

7.3.5 Alternative 3a – Armor 2-year channel, bio-stabilize 100-year channel

A typical cross-section for Alternative 3a is presented in Figure 7-7. This alternative was developed in an effort to minimize the cut-backs required to stabilize the slopes, but still utilize the existing channel for drainage conveyance. The channel bed will be raised to take advantage of the wider channel widths that exist higher in the current channel, and decrease the depth of the engineered channels required to safely discharge the 2-year and 100-year peak flows. The depth of fill required will vary along the channel, but the existing channel bed slope of 2% will be maintained. The remaining channel banks will be cut-back at a minimum 1:1 slope to stabilize the banks. The amount of cut-back can vary along the improved reach based on slope of the existing channel and the severity of erosion. The 2-year channel will be armored with rip-rap, and the 100-year channel will be stabilized using native vegetation (bio-stabilization).

Alternative 3a does impact the existing vegetation along the conveyance, but to a lesser degree than Alternative 2 because the side-slopes are steeper. Some natural erosion within and above the 100-year channel should be expected to occur with this alternative. In addition, 1:1 and steeper side slopes could make bio-stabilization difficult to establish. Of course, the size slopes could decrease as needed to establish stabilizing vegetation, however this would result in a wider channel and more loss of vegetation within the existing tree line.

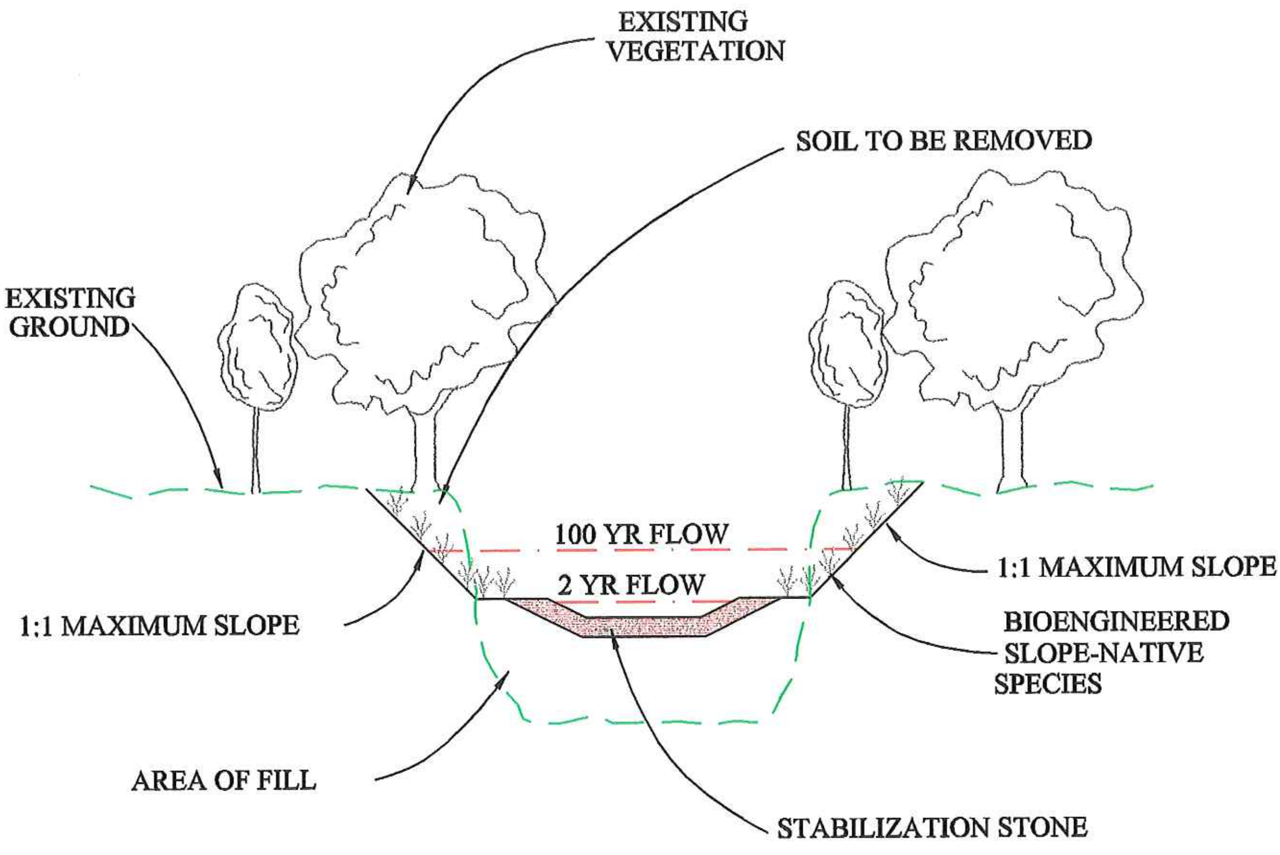

FIGURE 7-7

ALTERNATIVE 3A

NOT TO SCALE

7.3.6 Alternative 3b – Armor the 100-year (high flow) channel

A typical cross-section for Alternative 3b is presented in Figure 7-8. This alternative was also developed in an effort to minimize the cut-backs required to stabilize the slopes and still utilize the existing channel for drainage conveyance, but does not require bioengineering for channel stabilization. Like Alternative 3a, the channel bed will be raised to take advantage of the wider channel widths that exist higher in the current channel, and decrease the depth of the engineered channels required to safely discharge the 100-year peak flow. The depth of fill required will vary along the channel, but the existing channel bed slope of 2% will be maintained. The 100-year channel will be armored with rip-rap.

With Alternative 3b, the majority of the existing vegetation will remain and cut-backs are limited at the discretion of the design engineer and Knox County in order to maintain the existing tree line as much as possible. However, because of the limited cut-backs, this is a "risk-based" method and some natural erosion above the 100-year channel should be expected to occur with this alternative. The design storm is contained in the stabilized channel, further erosion from this and lesser storms is reduced, but the banks above the channel will continue to slough during larger events until a natural angle of repose is realized.

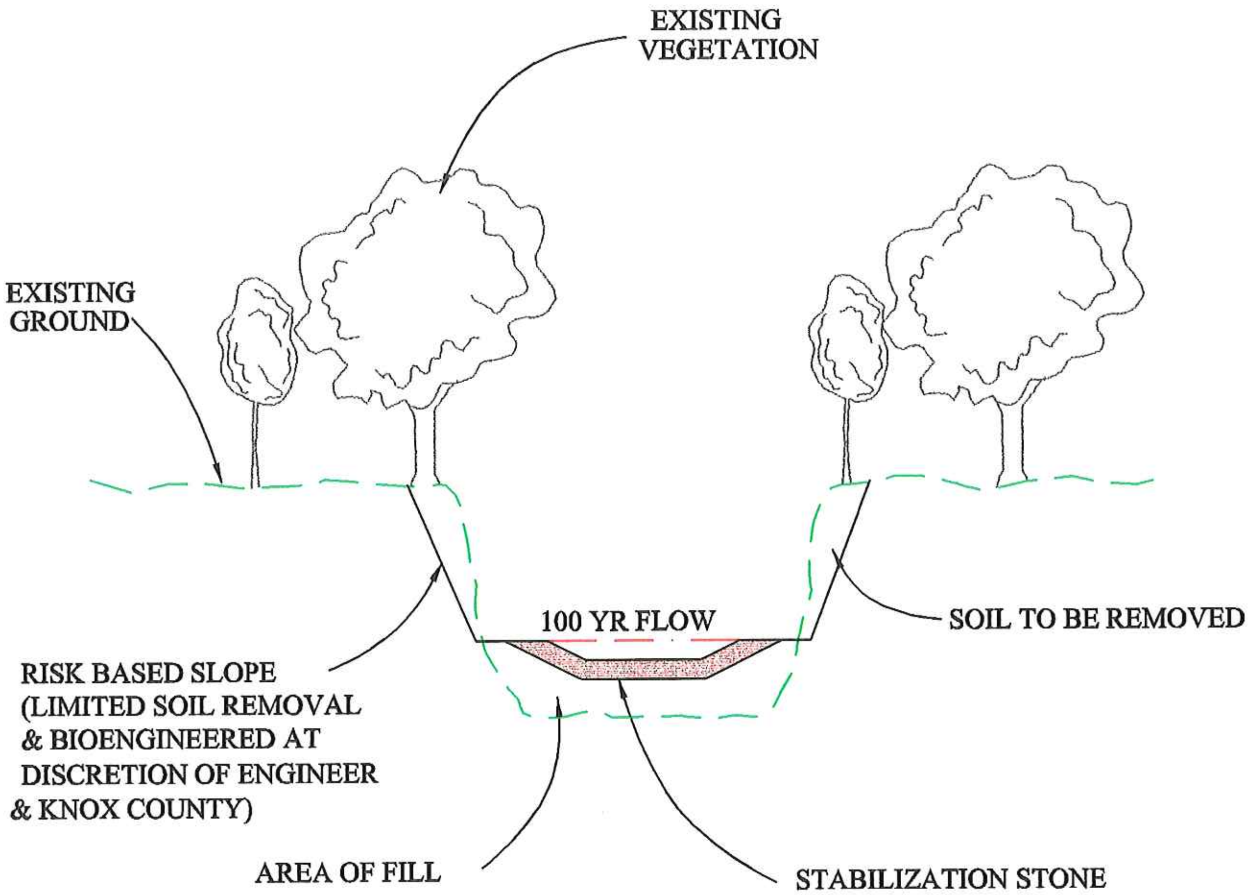

FIGURE 7-8
ALTERNATIVE 3B

NOT TO SCALE

7.3.7 Alternative 4 – Fill the existing channel, create new 100-year armored channel

Figure 7-9 presents a typical cross-section for Alternative 4. This alternative requires complete filling of the existing channel and construction of a 100-year channel in the same location. Based on peak discharges from the *future* condition HEC-1 model of the Ten Mile Creek watershed, the conceptual 100-year channel would has a bottom width of 12 feet, and a depth of 3 feet. With 2:1 side slopes, the top width of the channel would be approximately 24 feet. The entire channel would be armored with rip-rap (or natural stone). Based on field observations, loss of existing vegetation and encroachment of the channel onto surrounding property would be moderate.

A variation on Alternative 4 would be to construct a low flow (i.e., 2-year) channel in lieu of the 100-year channel, and create a 100-year conveyance on the currently undeveloped side of the creek. This would limit cut-backs and the loss of vegetation in the backyards of existing homes, however the property owner on the south side of the stream would have to agree to the measure. Another option would be to use bio-stabilization methods instead of rip-rap to stabilize the channel. Of course, this would increase the cost of the alternative and would require continued observation and maintenance on the part of property owners and/or the County to see that the vegetation is maintained in the proper manner.

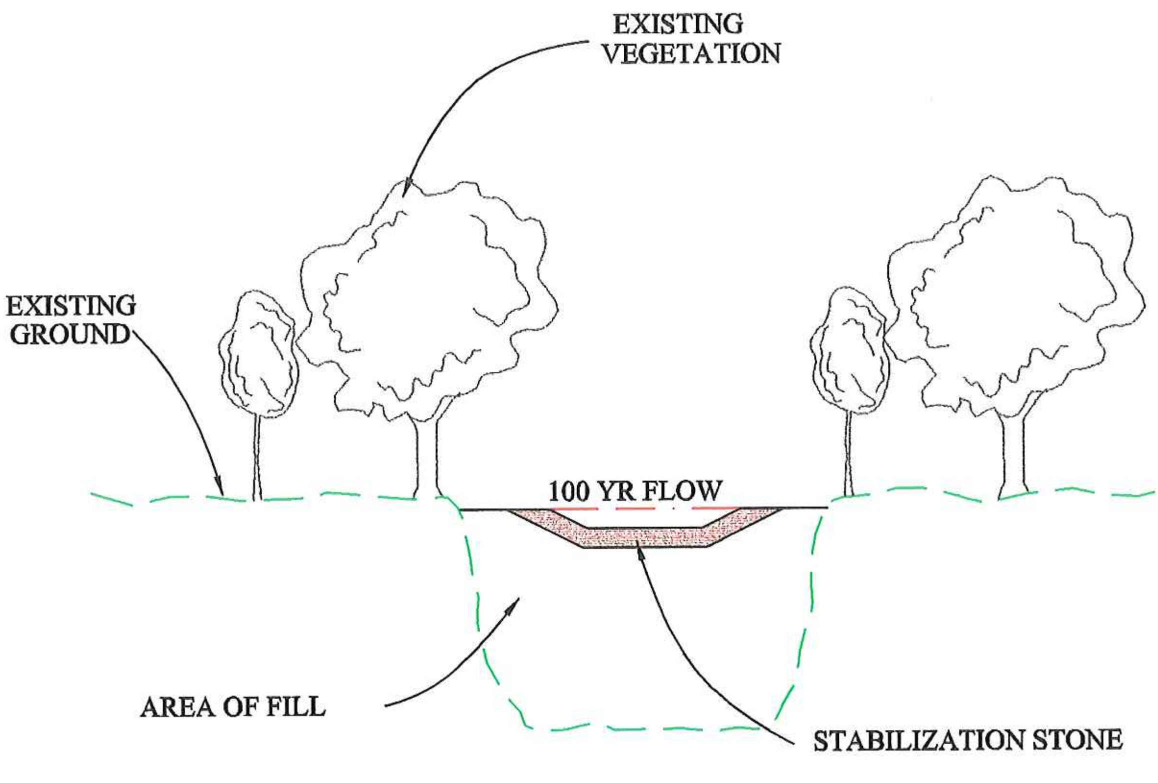

FIGURE 7-9
ALTERNATIVE 4

NOT TO SCALE

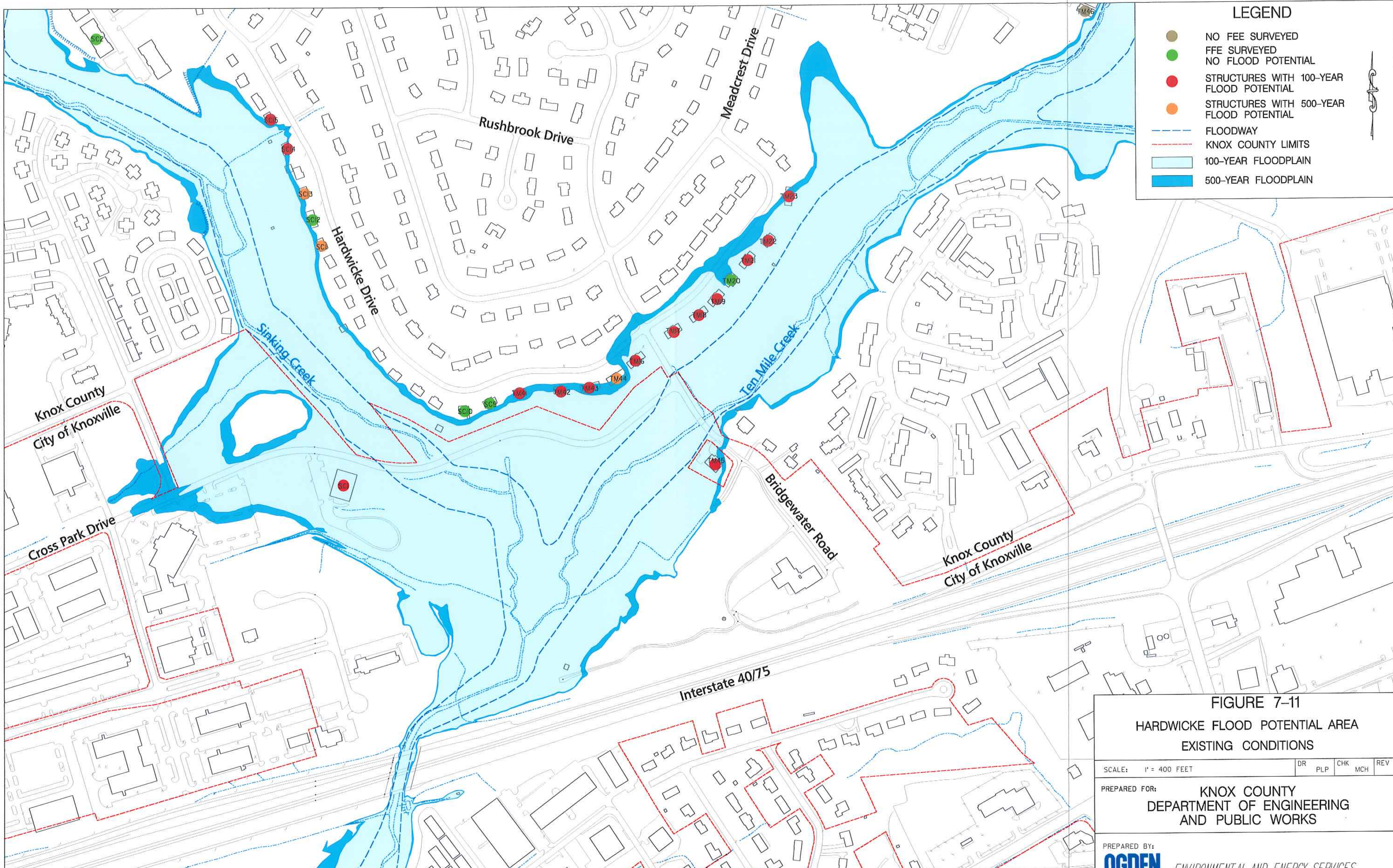

FIGURE 7-11

HARDWICKE FLOOD POTENTIAL AREA

EXISTING CONDITIONS

SCALE: 1" = 400 FEET | DR PLP | CHK MCH | REV

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7.3.8 Alternative 5 – Pipe drainage from sub-basin 05010, channelize drainage from 05020

Figure 7-10 presents a typical cross-section for Alternative 5. Drainage from upstream sub-basin 05010 would be piped via a 2100 ft long 8' x 5' box culvert constructed at the bottom of the existing channel. The remaining channel would be filled and an open channel would be constructed above the pipe to convey drainage from sub-basin 05020. Based on peak discharges from the *future* condition HEC-1 model of the Ten Mile Creek watershed, the conceptual 100-year channel would has a bottom width of 6 feet, and a depth of 3 feet. With 2:1 side slopes, the top width of the channel would be approximately 18 feet. The entire open channel would be armored with rip-rap (or natural stone). Based on field observations, loss of existing vegetation and encroachment of the channel onto surrounding property would be moderate.

While this option requires the least amount of land disturbance, maintenance of the lengthy culvert to keep it open and free of debris would be highly difficult. In the event of failure or clogging, the flooding of nearby structures and yards would be possible. Finally, a culvert of such great length presents a safety concern for children and pets during both wet and dry periods.

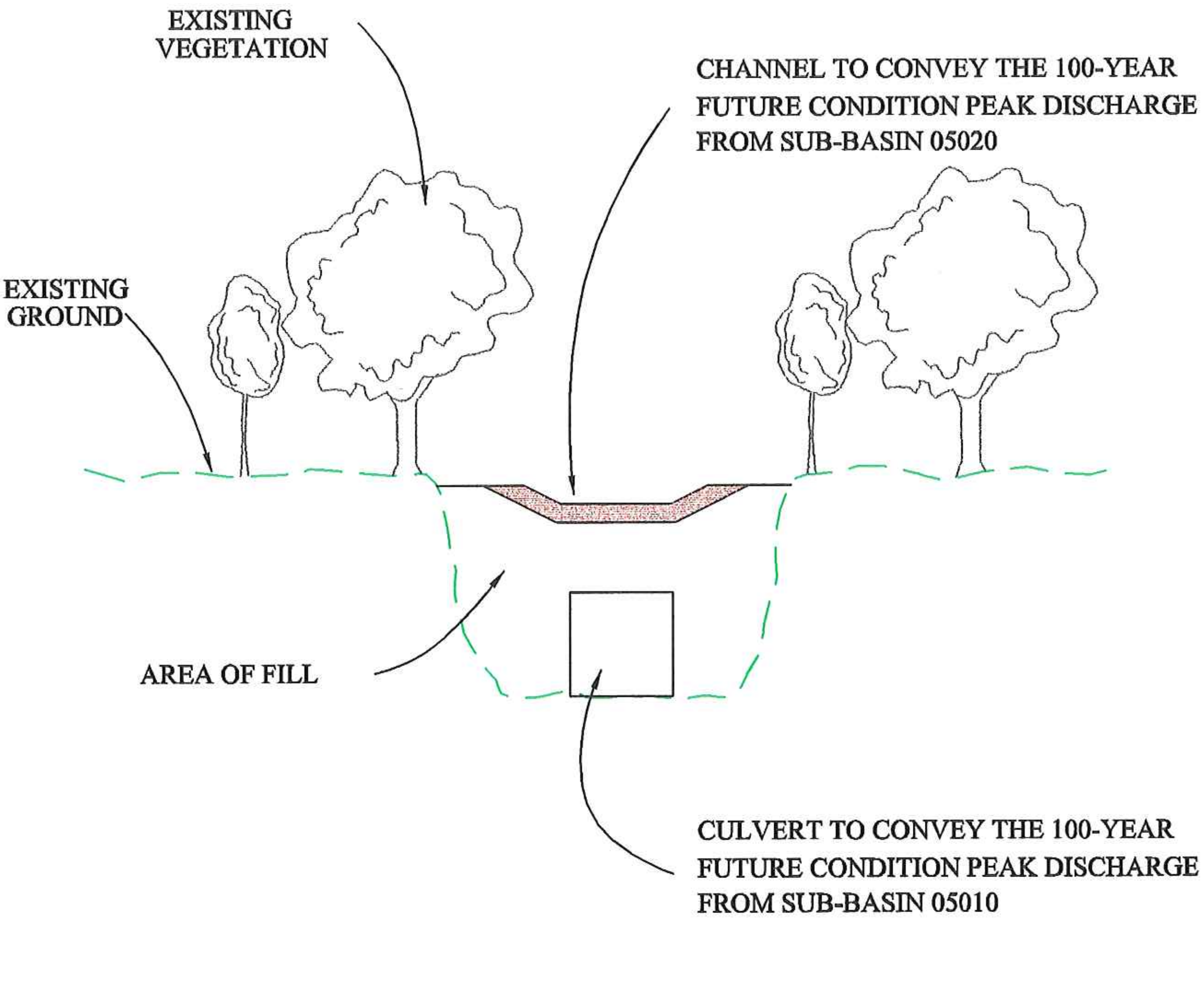

FIGURE 7-10
ALTERNATIVE 5

NOT TO SCALE

7.3.9 Downstream Impacts

The impact of the examined channel and culvert improvements on downstream flood elevations in Ten Mile Creek and Ebenezer Sinkhole was investigated. It was determined that flood elevations on the main stem and in Ebenezer Sinkhole would not increase as a result of improvement of the channel.

7.3.10 Discussion

Maintenance of Existing Vegetation

Concerns about the removal of the existing vegetation that now surrounds the channel have been voiced by a number of people that are aware of the erosion problem and the possible solutions. On one hand, if no action is taken to relieve the erosion in the channel, the existing vegetation will eventually be lost due to erosion. On the other hand, for any of the channel improvement alternatives, at least some vegetation will be removed just to allow the construction of an improvement measure. Further impact on the vegetation beyond construction-related removals will vary, depending upon the alternative chosen. Of the channel improvement options, Alternatives 4 and 5 have the least amount of impact on vegetation but are the most expensive options. Conversely, Alternative 2 has the most impact on the vegetation, but is less expensive and provides the highest protection against erosion and flooding. From a cost standpoint, Alternative 3b is the least expensive and provides some protection of the existing vegetation. However, some additional erosion will probably occur above the 100-year channel.

From an aesthetics standpoint, one could argue that the loss of vegetation means different things to different people. Some property owners that bound the conveyance may enjoy the wooded, un-maintained look that is currently in place and Alternatives 3, 4, and 5 attempt to maintain. Others may desire a more open setting that could be created with Alternative 2, which proposes a wide, grassed channel and trees planted as desired by property owners.

ARAP Permitting

Any of the channel improvement alternatives examined will require approval of the Tennessee Department of Environment and Conservation (TDEC) through its Aquatic Resources Alteration Permit (ARAP) program. Even though the channel is strictly a wet weather conveyance, the channel is shown as a "blue line stream" on the USGS Quadrangle and is therefore probably considered "waters of the State". Channel improvements have the effect of altering of the environmental conditions and impacting the habitat for life in the channel, therefore TDEC must be involved. Prior to the design and permit process, one cannot guess as to the potential

3b. Armored 100-year channel	• Lowest cost. • Utilizes the existing channel to the maximum extent. • Removal of existing vegetation and overbanks will be reduced. • Encroachment of channel into surrounding property reduced.	• Limited cut-backs will be required. There will be some removal of existing vegetation along the banks. • Complete armoring of the channel, no bio-stabilization. • Will allow reduced natural erosion above the high flow channel. • Detailed survey and modeling required for design.
4. Fill channel, create new 100-year channel	• No cut-backs required. Existing vegetation can remain on overbanks. • No channel encroachment into surrounding property. • Second best alternative from the design, construction and maintenance standpoints. • Would disturb the least amount of land during construction.	• High cost. • May require additional design measures upstream to ensure flood protection.
5. Pipe and Channel	• No cut-backs required. Existing vegetation can remain on overbanks. • No channel encroachment into surrounding property.	• Most expensive alternative. • High potential for maintenance issues associated with the pipe. • High potential for flooding in the event of pipe failure, clogging, etc. • Potentially serious safety issues associated with pipe. • Construction of culvert will disturb a fair amount of surrounding land.

Of course, there are variations or combinations of the alternatives discussed above that could be performed to achieve the desired solution. For example, if complete bio-stabilization of the channel is preferred over armoring in Alternatives 3a, 3b, 4 and 5, the cut-backs required to establish the vegetation will increase, and the difficulty and cost of the project will rise as well. Or, if an armoring alternative is considered, the use of natural stone would increase the aesthetics of the improved channel. This would also increase the cost of the project.

7.3.11 Recommendations

There are many issues that the County and surrounding property owners must consider when examining potential alternatives for mitigating the erosion problem. This process will take time to weigh all the potential design, permitting, public acceptance and funding issues associated with a project of this magnitude. Because there are proposed developments ready to move forward toward construction in the drainage area, the County should take steps to prevent construction in land along the conveyance needed for the alternative that would require the widest cut-backs (Alternative 2) until an alternative is selected and construction completed. This would allow the County and property owners the continued capability to consider all of the alternatives and adjust designs throughout the selection, design and construction process.

Based on the analysis, Alternatives 1 and 5 are the least attractive options and are not recommended. Alternative 1 fails to provide protection for Ebenezer Sinkhole and Ebenezer Cave. As discussed in Section 6, erosion and sediment control upstream of the sinkhole area is a key measure to keeping the cave entrance clear and open to drainage. For Alternative 5, the cost and potential maintenance and safety issues are too difficult to overcome to be considered a viable option.

Alternative 2 is attractive because the ease of design and construction, minimal future maintenance and the opportunity for involvement of the County and impacted members of the community in a significant bio-stabilization project. However, the level of acceptance for that alternative by potentially impacted property owners should be assessed early in the selection process to determine if the option is really viable.

Of the remaining three alternatives, the design, construction and future maintenance of Alternative 4 is much easier than Alternatives 3a and 3b. For the design, detailed modeling to determine water surface profiles is not needed. For construction, cut-backs and bio-stabilization would not be performed, limiting the disturbance along the channel. And maintenance would be easier because the channel is not as deep, does not require establishment of bio-stabilizing vegetation, and would be limited to occasional inspection to clear any accumulated debris. Alternative 4 also provides a higher level of erosion protection than Alternatives 3a and 3b because there is no remaining channel above the 100-year channel that has the potential to erode. However, Alternative 4 is substantially more costly than 3a and 3b.

Therefore, should the County decide to take action to relieve erosion in the BriarGlen priority area, selection of Alternative 2, 3a, 3b, or 4 should be decided based on cost, public acceptance and the potential permitting issues associated with each.

7.4 Hardwicke Drive Area

7.4.1 Background

HEC-RAS analysis predicts high flood potential for a number of structures located along Hardwicke Drive, near the confluence of Ten Mile Creek and Sinking Creek. The models predict that 21 structures are located in the existing condition 500-yr floodplain at that location. Because no complaints of structure flooding have been received from residents in the Hardwicke Drive area, a detailed examination of flood solution alternatives was not performed. Instead, this section provides documentation of the cause and extent of flood potential predicted for the area, and presents a discussion of general alternatives for flood mitigation.

Figure 7-11 presents the existing condition floodplains and the flood potential for the 100-year and 500-year events in the flood damage reach from the confluence of Sinking Creek (RM 3.053) to RM 3.521 on Ten Mile Creek and RM 0.552 on Sinking Creek. Table 7-11 presents an estimate of the flood potential in the area, based on comparison of surveyed FFE's with HEC-RAS model results.

Table 7-11. Structures with FFE Flood Potential – Hardwicke Drive Area

	Number of Houses Flooded - based on Surveyed FFE's			
	Hardwicke Drive Area		Entire Ten Mile Creek and Tributaries	
Storm Event	Existing Condition	Future Condition	Existing Condition	Future Condition
2-yr	0	0	1	1
10-yr	2	4	8 (2)	11 (2)
25-yr	6 (1)	9 (1)	13 (3)	18 (3)
100-yr	14 (1)	16 (1)	26 (4)	30 (4)
500-yr	17 (1)	19 (1)	37 (4)	47 (6)

(#) - number of structures that are located within City of Knoxville limits

Table 7-12 is a list of the addresses and the depth of flooding for all events for the 14 structures with FFE flood potential in the 100-year event. The structures listed in Table 7-12 are comprised of 13 residential properties and 1 business. The average predicted flood depth for the 100-year existing condition event is 2.3 feet. Only two structures have a predicted flood depth of less than one foot and six have flood depths greater than two feet. This severity of flooding will limit possible flood solution alternatives for the area.

Table 7-12. Structures with 100-Year Existing FFE Flood Potential – Hardwicke Drive

Structure #	Address	FFE (ft NAVD)	Existing Condition Depth of flooding (ft)				
			2-Year	10-Year	25-Year	100-Year	500-year
TM16	401 Hardwicke Drive	899.28	-7.55	-3.28	-1.33	1.29	3.46
TM17	308 Bridgewater Road	897.76	-5.44	-0.14	0.70	2.99	5.09
TM18	337 Hardwicke Drive	896.24	-3.16	1.55	2.44	4.68	6.75
TM19	333 Hardwicke Drive.	899.15	-5.85	-1.31	-0.41	1.82	3.88
TM21	325 Hardwicke Drive	900.91	-7.16	-2.97	-2.04	0.17	2.20
TM22	321 Hardwicke Drive	898.35	-4.23	-0.32	0.62	2.80	4.82
TM23	313 Hardwicke Drive	899.25	-4.06	-0.93	0.03	2.11	4.08
TM41	417 Hardwicke Drive	899.44	-8.59	-3.68	-1.65	1.03	3.22
TM42	413 Hardwicke Drive	898.77	-7.62	-2.93	-0.93	1.73	3.91
TM43	409 Hardwicke Drive	898.78	-7.39	-2.89	-0.90	1.75	3.92
TM45	229 Bridgewater Road.	894.37	-2.71	1.60	3.56	6.19	8.36
SC1	8904 Cross Park Drive	897.35	-4.72	-1.71	0.34	3.03	5.22
SC14	605 Hardwicke Drive	899.51	-5.17	-3.87	-1.82	0.87	3.06
SC15	609 Hardwicke Drive.	899.12	-4.71	-3.48	-1.43	1.26	3.45

1 - (a negative sign indicates the FFE is above the flood elevation)
2 – shaded blocks indicate predicted FFE flooding

The primary factor controlling water surface elevations and increasing the flood potential in the Hardwicke Drive damage reach is backwater from the Interstate-40 culvert on Ten Mile Creek (RM 2.891). This limits the viable alternatives that can be utilized to mitigate the flood potential. Channel improvements alone upstream of the Hardwicke Road area would not be effective, and the severity of flooding and the number of structures involved make flood proofing in the form of raising homes an expensive and highly unattractive alternative.

From an engineering standpoint, a levee constructed along the affected reach between the creek and the Hardwicke Drive residences is an option to reduce the flood potential at 10 of the 14 properties. However, there are a number of negatives to this option:

- the cost to purchase the required land and design, construct and permit the levee could be as much or more than the cost to purchase the flooded structures;
- the County would be burdened with continual permitting (i.e., Safe Dams) and maintenance responsibilities;
- the potential for flood problems on the upstream side of the flood protection structure;
- the loss of floodplain storage due to the levee could cause flood problems elsewhere on Ten Mile Creek and/or Sinking Creek; and,
- planimetric and topographic mapping indicate a construction of a levee would likely require the purchase of non-flooded property, or would impact residents that are currently not flooded.

Regional detention was eliminated as an option as well. A possible site for a regional detention pond located upstream of Walker Springs Road was selected because the HEC-1 model indicates that, based on the relative timing of peak discharges, a pond located upstream of the confluence of Ten Mile Creek and West Hills Tributary would have greater chance of substantially reducing peak flows. In addition, the area is relatively undeveloped and has been discussed as a potential location for expansion of the Cavetts Station Greenway now under construction. However, Gallaher View Road (currently under construction) limits the storage area and peak flood elevation for a pond. A preliminary analysis indicated that a regional pond could not provide a reduction in flood potential along Hardwicke Drive without substantial flooding of Gallaher View Road and overtopping of the Walker Springs Road bridge. Even with some roadway flooding, the reduction in flood potential was limited to one structure. Investigation of a combination of several regional ponds was not performed because of the severity of the flood potential, and the corresponding difficulty in reducing peak flows enough to have significant impact in the damage reach. The cost of the required land acquisition alone for one or more ponds of sufficient size to impact the damage reach would far outweigh the cost to purchase the properties.

7.4.2 Potential Alternatives

In the event that the flood potential predicted by the HEC-RAS model is realized by residents and businesses in the Hardwicke Drive area, two alternatives remain for the Hardwicke Road damage reach:

1. purchase of flood-prone properties; and
2. improvement of the culvert under Interstate-40 and channel improvements along the damage reach.

The main advantage of Alternative 1 is that it completely eliminates the flood potential for the purchased properties. The current combined property value for the 13 properties in the Hardwicke Drive area (located in Knox County) that have 100-year flood potential is $1,262,000. Of course, the added expenses to purchase and demolish the properties would increase the final cost for a property purchase by at least 25%. It is important to note that most of the properties bound public land set aside for development of the Walker Springs Park and the Cavetts Station Greenway. The purchased properties could possibly be utilized for additional greenway/public use land.

Alternative 2 would require coordination and approval by the State of Tennessee. The Interstate-40 bridge over Ten Mile Creek was replaced in the mid-1990's by the Tennessee Department of Transportation when interstate exits for Cedar Bluff Road and Gallaher View Road were re-constructed and the interstate was widened. Further work on the bridge is probably unlikely without actual realization of the 100-year to 500-year flood potential upstream of the bridge.

8 CONCLUSIONS AND RECOMMENDATIONS

8-1. Conclusions

Conclusions that can be made based on the data gathered in the Ten Mile Creek watershed and the analyses and results of the HEC-1 and HEC-RAS models are as follows:

1. With approximately 81% of the watershed having developed land uses (e.g., residential, commercial), the Ten Mile Creek watershed is close to being fully developed. According to the 15-Year Growth Plan developed by MPC, development will cover approximately 96% of watershed in the future.

2. Water quality in the Ten Mile Creek watershed was found to be poor. Sediment, urban runoff and non-storm water discharges are the major sources of pollutants to streams in the watershed.

3. Peak discharges on the main stem are most sensitive to discharges from the contributing drainage area.

4. The time-to-peak for tributary basins is generally earlier than the time-to-peak on the main stem. This implies that regional detention or large site detention facilities located on any of the tributaries could potentially increase peak discharges on the main stem.

5. Based on existing condition analysis, Ten Mile Creek flows out of bank at many locations during the 2-year, 24-hour event. The main stem and the modeled tributaries are consistently out of bank throughout the streams during the 10-year, 24-hour event.

6. One the main stem, the average difference between existing and future flood elevations is approximately one foot. On the tributaries, the average difference is approximately 0.5 feet. At Ebenezer Sinkhole, the difference between the 100-year existing and future condition flood elevations is 1.54 feet.

7. There are approximately 87 habitable structures located inside the mapped existing condition floodplains (100-year and 500-year). Of these structures, 46 are located along Ten Mile Creek and 41 are located along tributaries. Nine structures are located in the floodway.

8. Finished floor elevations were surveyed at 75 of the 87 habitable structures located in the existing condition floodplains on Ten Mile Creek and the tributaries. Of the 75 surveyed structures, 26 were found to have FFE flood potential for the 100-year existing condition flood. This number increases to 30 for the 100-year future condition flood.

9. Five of the 26 structures found to have FFE flood potential for the 100-year existing condition flood are located in the Ebenezer Sinkhole backwater area (i.e., the flood potential is due to backwater flooding at the sinkhole).

10. Based on analysis with the HEC-1 model, blocked outflow conditions at Ebenezer Cave could cause flood elevations in the Ebenezer Sinkhole backwater area to rise approximately 4.3 feet for the 100-year existing condition.

11. Future condition flood elevations on the main stem are predicted to increase approximately two feet if full encroachment of the floodplain is allowed. The increase is approximately one foot if ½ flood fringe encroachment limits are utilized. Throughout the watershed, using a ½-flood fringe encroachment limit was determined to be an effective control on the increase in flood elevations due to future development.

12. Large-scale structural alternatives to reduce the flood potential in the Ebenezer Sinkhole backwater area, such as a high flow channel or tunnel, have been examined in the past by TVA and COE. The cost to design and implement such measures would greatly exceed the cost to buy property that has 100-year future condition flood potential.

13. Non-structural and operational measures to protect Ebenezer Cave and the storage volume in Ebenezer Sinkhole, and policy and regulatory measures to limit development in the sinkhole backwater area are key measures for limiting the future condition flood potential in the backwater area.

14. Upstream of the backwater area, non-structural alternatives that limit peak discharges and/or runoff volumes from newly developed areas are not successful in substantially reducing the existing flood potential in the watershed.

15. Upstream of the backwater area, the reduction of existing flood elevations in areas where multiple structure flooding is predicted (e.g., the Hardwicke Road area) is difficult due to the severity and cause(s) of flooding. Structural measures are generally not viable alternatives for such areas, due to the large-scale of the project(s) that would be required to effect a reduction in the flood potential. On tributaries, structural alternatives are more feasible for reducing the existing flood potential.

16. Limited non-structural measures, such as more stringent detention requirements on select new developments, could be effective in localized areas. The models developed for the Master Plan could be utilized to determine whether a site would require a higher level of control. Of course, engineering judgment on the part of the Knox County Engineering is required to determine which proposed developments would require model analysis.

8-2. Recommendations

The major component of this master plan is to recognize and provide solutions for potential for future flooding and water quality problems in the Ten Mile Creek watershed. Existing flooding problems (and future flooding consequences at these locations) have been studied and recommendations for flood solution alternatives in specific priority areas are given after the discussion of each area presented in Chapter 7. The following is a list of recommended actions to mitigate future flooding and water quality problems in Ten Mile Creek.

1. Institute regulatory controls on new development and re-development in the Ebenezer Sinkhole backwater area. Consider applying the Sinkhole Policy to Ebenezer Sinkhole, and clearly defining floodplain and no-fill boundaries. Require highly stringent erosion control measures for construction sites and disturbed lands near the sinkhole backwater area.

2. Protection of the Ebenezer Cave from sediment and debris build-up is greatly important in the ability to control flood elevations at the sinkhole. Perform regular cleaning and debris removal visits to the cave. Because trash and urban debris will continue to be a problem in the watershed, consider structural measures to protect the inlet.

3. Sediment load reduction is extremely important in Ten Mile Creek, from both a water quality and flooding standpoint. Implement and maintain a strong erosion control program for all land disturbances in the creek. Establish stringent erosion control requirements for construction sites and disturbed lands located adjacent to a stream. Identify any areas of large-scale stream bank erosion located within the watershed. Take steps to stabilize eroding areas as quickly as possible.

4. Continue development of regulations to limit flood fringe filling to a ½ fringe encroachment line on Ten Mile Creek and its tributaries.

5. If property purchase is a flood solution alternative that the County chooses to utilize, consider a prioritization system for the purchase of flooded properties. Purchases could be prioritized based on the following factors:

   - flood history;

   - predicted flooding of finished floor for the 25-year (or more frequent event) existing conditions event;

   - location of the habitable structure in the existing floodway;

- predicted flooding of finished floor for the 100-year event existing conditions; and
- predicted frequency of flooding for future conditions with the 100-year event providing the threshold event for protection.

7. Flood proofing measures, such as raising flooded structures or constructing levees, could be considered in cases where flood depths are small and the property owner will not accept other options.

8. Make available the hydrologic and hydraulic models of Ten Mile Creek and the tributaries developed for this master plan. Require developers to use them to determine the impact of specific developments on flooding downstream.

9. Develop a program to educate Ten Mile Creek watershed residents, schoolchildren and business owners on the general findings of the master plan and the impending NPDES Phase II regulations. Educational topics can include:

   - why Ebenezer Sinkhole floods on occasion and the importance of protection of Ebenezer Sinkhole and Ebenezer Cave to flood elevations in Ten Mile Creek;
   - the importance of undeveloped, natural floodplains for flood storage and management and water quality preservation;
   - how to police the watershed in terms of water quality (e.g., how to identify and report poor sediment control, how to identify and report illicit discharges, etc.)
   - the importance of sediment and debris management in this watershed; and
   - the impact of residential, commercial and industrial development on water quality, and ways to reduce impacts.

10. The County should encourage the use of effective BMPs for businesses and communities in the watershed. Examples of methods used to encourage such practices are "environmental friend" awards or similar public acknowledgements and "fast-track" permitting processes or fee reductions for new construction or re-developments.

11. The Ten Mile Creek watershed has many springs which can enhance the water quality in the stream. These areas, as well as wetlands, sinkholes and other sensitive areas should be identified and protected.

12. Commercial storm drains and other potential illicit (non-storm water) discharges should be investigated and eliminated.

13. Follow-up water quality monitoring should be conducted in the future to develop long term trend monitoring.

14. Find ways to work with the City of Knoxville in implementing and maintaining consistent BMPs throughout the watershed.

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APPENDIX A
Ten Mile Creek Watershed Basin and Sub-basin Naming Convention

A naming convention was developed for the watersheds in Knox County to facilitate use of the master planning models and flood study maps within the County's GIS system. In addition, a useful sub-basin naming scheme is critical in keeping the HEC-1 model organized, easing model setup and user navigation during analysis. The naming convention is utilized in this report to discuss model results, therefore it is explained in the following paragraphs.

Watersheds in Knox County were assigned long names that correspond to the creek of interest: Ten Mile Creek, Beaver Creek, Turkey Creek, etc. Watersheds were also assigned a two-character code. The code for Ten Mile Creek is TM. In addition, each basin delineated in the watershed was assigned a two-character code, based on the surface feature to which the basin drains. Basins that drained directly to the main stem (e.g., Ten Mile Creek) were assigned a two-*digit* number from upstream to downstream. Basins that drained to tributaries were assigned a two-*letter* code based on the assigned name for the tributary on the USGS quadrangle map or a local feature in that basin.

Examples:

Ten Mile Creek watershed, most downstream basin on Ten Mile Creek......TM07

Ten Mile Creek watershed, Sinking Creek basin (tributary).........................TMSC

Each sub-basin is additionally assigned a three-digit code. The first two digits are used initially and the third digit is set to zero and reserved for possible future divisions of the sub-basin (e.g., 010, 150). In most cases, sub-basins are numbered from upstream to downstream. Therefore, the sub-basins in the most upstream part of the basin should have lower sub-basin numbers. The watershed and basin identifiers are used along with the three-digit sub-basin code to provide a unique identifier for each sub-basin.

Examples:

Ten Mile Creek watershed, Sinking Creek basin, first sub-basin.................TMSC010

Ten Mile Creek watershed, basin 07, twelfth sub-basin...............................TM07120

The last piece of the naming convention is specification of the HEC-1 computation operation. Several computational operations can be performed in HEC-1, and must be identified in the HEC-1 data set. The operation identifier is limited to 6 alpha-numeric characters. A single-letter code is used to identify each operation.

<u>Code</u> <u>Operation</u>

H Compute a hydrograph from sub-basin parameters.

C Combine two or more computed hydrographs. Subsequent combines, if necessary, are D, E, etc.

R Route a hydrograph through a sub-basin. Subsequent routings are X, Y, etc.

P Route a hydrograph through a detention pond. A subsequent detention routing, if necessary is Q.

Therefore, each computational operation in the HEC-1 model is identified using basin and sub-basin identifiers and code letter of the operation being performed, giving a total of 6 alpha-numeric characters. The watershed identifier is not used since the HEC-1 model is unique for the watershed. Example of operation identifiers in the Ten Mile Creek HEC-1 model are listed below.

<u>Examples:</u>

Compute the hydrograph from sub-basin TMSC010....................................SC010H

Route the hydrograph through TM07120 ....07120R

APPENDIX B
Ten Mile Creek Sub-basin Data and Peak Discharges

Table B-1. Ten Mile Creek Existing Condition Sub-basin Information (Contributing Areas Only)

Basin	Area (mi^2)	CN	Tc (hrs)	R Coeff	Peak Flow (cfs)				
					2-yr	10-yr	25-yr	100-yr	500-yr
BASIN 01									
01010	0.205	64	0.547	0.55	20	80	120	180	240
01020	0.086	68	0.473	0.47	10	50	70	100	130
01030	0.100	72	0.510	0.51	20	70	90	120	160
01040	0.165	76	0.548	0.55	50	120	160	220	270
01050	0.271	67	0.728	0.73	30	110	150	220	290
01060	0.102	75	0.297	0.30	40	100	140	180	230
01070	0.227	67	0.700	0.70	30	100	130	190	250
01080	0.221	72	0.768	0.77	40	110	150	210	260
01090	0.233	70	0.773	0.77	30	110	140	200	260
01100	0.228	72	0.545	0.54	50	140	190	270	340
01110	0.177	73	0.560	0.56	40	120	150	210	270
01120	0.195	72	0.665	0.66	40	110	140	200	260
01130	0.223	79	0.740	0.74	60	150	200	260	320
01140	0.208	73	0.735	0.74	40	110	150	210	260
BASIN 02									
02010	0.121	73	0.622	0.62	20	70	100	140	170
02020	0.187	75	0.497	0.50	50	140	190	260	320
02030	0.087	72	0.460	0.46	20	60	80	110	140
BASIN 03									
03010	0.131	73	0.620	0.62	30	80	110	150	180
03020	0.140	77	0.420	0.42	50	130	160	220	280
03030	0.059	82	0.347	0.35	30	70	90	120	140
BASIN 04									
04010	0.145	83	0.238	0.24	100	220	280	360	430
04020	0.071	78	0.407	0.41	30	70	90	120	140
04030	0.068	91	0.270	0.27	70	120	140	180	210
04050	0.110	89	0.433	0.43	80	140	180	220	260
04060	0.149	92	0.365	0.37	130	230	280	340	400
04070	0.058	91	0.092	0.09	90	160	190	240	280
04080	0.168	76	0.603	0.60	40	120	150	210	260
BASIN 05									
05010	0.164	74	0.487	0.49	40	120	160	220	280
05020	0.138	68	0.670	0.67	20	60	90	120	160
05030	0.181	77	0.438	0.44	60	160	210	280	350
05040	0.107	68	0.407	0.41	20	70	90	130	170
05050	0.207	73	0.465	0.47	50	150	200	280	350

Table B-1. Ten Mile Creek Existing Condition Sub-basin Information (Contributing Areas Only)

Basin	Area (mi^2)	CN	Tc (hrs)	R Coeff	Peak Flow (cfs)				
					2-yr	10-yr	25-yr	100-yr	500-yr
05060	0.066	74	0.455	0.46	20	50	70	90	120
BASIN 06									
06010	0.094	73	0.580	0.58	20	60	80	110	140
06020	0.071	74	0.397	0.40	20	60	80	110	130
BASIN 07									
07010	0.086	65	0.298	0.13	20	70	100	150	200
07020	0.214	68	1.170	0.50	30	100	130	190	250
CEDAR SPRINGS BASIN									
CS010	0.219	92	0.410	0.41	180	320	380	480	560
CS030	0.141	77	0.577	0.58	40	100	140	180	230
CS040	0.103	73	0.470	0.47	30	70	100	140	170
CS050	0.068	93	0.120	0.12	110	180	210	260	300
CS060	0.089	93	0.120	0.12	140	230	280	350	400
CS070	0.141	71	0.330	0.33	40	110	150	220	270
CS080	0.164	69	0.705	0.71	20	80	100	150	190
CS090	0.134	77	0.497	0.50	40	110	140	190	240
CS100	0.079	78	0.435	0.44	30	70	90	130	160
EBENEZER BRANCH BASIN									
EB010	0.171	77	0.557	0.56	50	130	170	230	280
EB020	0.285	80	0.480	0.48	120	270	340	450	550
EB030	0.227	76	0.598	0.60	60	160	210	280	350
EB040	0.110	80	0.867	0.87	30	70	90	120	150
EB050	0.112	82	0.492	0.49	50	110	140	180	220
EB060	0.097	73	0.637	0.64	20	60	80	110	140
EB070	0.125	84	0.525	0.52	60	130	160	210	250
EB080	0.130	81	0.343	0.34	70	150	200	260	310
EB090	0.061	78	0.455	0.46	20	60	70	100	120
EB100	0.264	78	0.795	0.80	70	170	210	290	360
EB110	0.136	72	0.587	0.59	30	80	110	150	190
EB120	0.135	73	0.373	0.37	40	110	150	210	260
EB130	0.208	72	0.498	0.50	50	140	180	260	330
EB140	0.118	76	0.273	0.27	50	130	170	230	290
EB150	0.028	76	0.492	0.49	10	20	30	40	50
EB160	0.119	76	0.567	0.57	30	90	110	150	190
ECHO VALLEY BASIN									
EV010	0.177	83	0.663	0.66	70	150	190	250	300
EV020	0.143	79	0.475	0.47	60	130	170	220	270
EV030	0.125	77	0.333	0.33	50	130	170	230	280
EV040	0.211	77	0.650	0.65	60	150	190	260	320
EV050	0.244	88	0.612	0.61	130	250	310	400	470

Table B-2. Ten Mile Creek Future Condition Sub-basin Information (Contributing Areas Only)

Basin	Area (mi²)	CN	Tc (hrs)	R Coeff	Peak Flow (cfs)				
					2-yr	10-yr	25-yr	100-yr	500-yr
BASIN 01									
01010	0.205	73	0.259	0.26	70	210	270	380	470
01020	0.086	73	0.473	0.47	20	60	80	120	140
01030	0.100	74	0.510	0.51	30	70	100	130	160
01040	0.165	78	0.548	0.55	50	130	170	230	280
01050	0.271	72	0.728	0.73	50	140	190	260	340
01060	0.102	77	0.297	0.30	50	110	140	200	240
01070	0.227	74	0.285	0.28	80	230	300	420	520
01080	0.221	75	0.768	0.77	50	130	170	230	280
01090	0.233	74	0.773	0.77	50	130	170	230	290
01100	0.228	74	0.545	0.54	60	160	210	290	360
01110	0.177	73	0.560	0.56	40	120	150	210	270
01120	0.195	75	0.665	0.66	50	120	160	220	280
01130	0.223	80	0.740	0.74	70	160	200	270	330
01140	0.208	76	0.735	0.74	50	130	170	230	280
BASIN 02									
02010	0.121	75	0.622	0.62	30	80	100	140	180
02020	0.187	78	0.497	0.50	60	160	200	280	340
02030	0.087	79	0.460	0.46	30	80	100	140	170
BASIN 03									
03010	0.131	74	0.620	0.62	30	80	110	150	190
03020	0.140	79	0.420	0.42	60	140	180	240	290
03030	0.059	86	0.347	0.35	40	80	100	130	150
BASIN 04									
04010	0.145	87	0.238	0.24	130	250	300	390	460
04020	0.071	84	0.407	0.41	40	80	100	140	160
04030	0.068	92	0.270	0.27	70	120	150	180	210
04050	0.110	93	0.433	0.43	90	160	190	240	270
04060	0.149	93	0.365	0.37	130	230	280	350	400
04070	0.058	93	0.092	0.09	100	170	200	240	280
04080	0.168	80	0.603	0.60	60	140	180	230	280
BASIN 05									
05010	0.164	75	0.487	0.49	50	130	160	230	280
05020	0.138	74	0.670	0.67	30	80	110	150	190
05030	0.181	82	0.438	0.44	90	190	240	320	380
05040	0.107	87	0.181	0.18	110	210	260	330	380
05050	0.207	74	0.465	0.47	60	160	210	280	360
05060	0.066	80	0.455	0.46	30	60	80	110	130
BASIN 06									

Table B-2. Ten Mile Creek Future Condition Sub-basin Information (Contributing Areas Only)

Basin	Area (mi^2)	CN	Tc (hrs)	R Coeff	Peak Flow (cfs)				
					2-yr	10-yr	25-yr	100-yr	500-yr
06010	0.094	76	0.580	0.58	30	70	90	120	150
06020	0.071	76	0.397	0.40	20	60	80	110	140
BASIN 07									
07010	0.086	83	0.179	0.18	70	150	190	240	290
07020	0.214	76	0.171	0.17	120	300	390	520	640
CEDAR SPRINGS BASIN									
CS010	0.219	92	0.410	0.41	180	320	380	480	560
CS030	0.141	78	0.577	0.58	40	110	140	190	230
CS040	0.103	76	0.470	0.47	30	80	110	150	180
CS050	0.068	93	0.120	0.12	110	180	210	260	300
CS060	0.089	93	0.120	0.12	140	230	280	350	400
CS070	0.141	75	0.330	0.33	50	140	180	240	300
CS080	0.164	82	0.247	0.25	110	240	300	390	470
CS090	0.134	93	0.292	0.29	140	240	290	360	410
CS100	0.079	92	0.240	0.24	90	150	180	230	260
EBENEZER BRANCH BASIN									
EB010	0.171	78	0.557	0.56	60	140	180	240	290
EB020	0.285	81	0.480	0.48	120	280	350	460	560
EB030	0.227	82	0.598	0.60	90	200	250	330	400
EB040	0.110	84	0.867	0.87	40	80	100	130	160
EB050	0.112	84	0.492	0.49	60	120	150	190	230
EB060	0.097	82	0.290	0.29	60	130	160	210	260
EB070	0.125	85	0.525	0.52	60	130	160	210	250
EB080	0.130	82	0.343	0.34	70	160	200	260	320
EB090	0.061	84	0.455	0.46	30	70	80	110	130
EB100	0.264	79	0.795	0.80	70	170	220	300	360
EB110	0.136	76	0.587	0.59	40	100	130	170	210
EB120	0.135	73	0.373	0.37	40	110	150	210	260
EB130	0.208	79	0.498	0.50	80	180	240	320	390
EB140	0.118	78	0.273	0.27	60	140	180	250	300
EB150	0.028	80	0.492	0.49	10	30	30	40	50
EB160	0.119	78	0.567	0.57	40	90	120	160	200
ECHO VALLEY BASIN									
EV010	0.177	84	0.663	0.66	70	160	190	250	300
EV020	0.143	85	0.475	0.47	80	160	200	260	310
EV030	0.125	80	0.333	0.33	60	150	180	250	300
EV040	0.211	80	0.650	0.65	70	160	210	280	340
EV050	0.244	90	0.612	0.61	140	260	320	410	480
EV060	0.183	87	0.176	0.18	190	360	440	560	650
EV070	0.120	75	0.468	0.47	40	90	120	170	210

Table B-2. Ten Mile Creek Future Condition Sub-basin Information (Contributing Areas Only)

Basin	Area (mi^2)	CN	Tc (hrs)	R Coeff	Peak Flow (cfs)				
					2-yr	10-yr	25-yr	100-yr	500-yr
EV080	0.159	79	0.487	0.49	60	140	180	240	300
JOE HINTON ROAD BASIN									
JH010	0.206	73	0.593	0.59	40	130	170	240	300
JH020	0.224	70	0.565	0.56	40	130	170	240	310
JH030	0.131	75	0.542	0.54	40	90	120	170	210
JH040	0.123	72	0.567	0.57	20	80	100	140	180
JH050	0.167	74	0.472	0.47	50	130	170	230	290
JH060	0.153	79	0.685	0.69	50	110	140	190	230
JH070	0.234	80	0.643	0.64	80	180	230	310	380
SINKING CREEK BASIN									
SC010	0.193	72	0.628	0.63	40	110	150	210	260
SC020	0.143	72	0.433	0.43	40	100	140	200	250
SC040	0.134	72	0.548	0.55	30	80	110	160	200
SC050	0.075	80	0.653	0.65	20	60	70	100	120
SC060	0.082	73	0.398	0.40	20	60	90	120	150
SC070	0.130	72	0.430	0.43	30	100	130	180	220
SC080	0.084	72	0.370	0.37	20	70	90	120	160
SC090	0.065	72	0.352	0.35	20	50	70	100	120
SC100	0.197	75	0.567	0.57	50	140	180	250	310
SC110	0.130	94	0.467	0.47	100	180	220	270	310
SC120	0.099	93	0.222	0.22	120	200	240	300	350
SC130	0.208	93	0.455	0.46	160	290	340	430	500
SC140	0.203	90	0.722	0.72	100	200	240	310	360
SC150	0.050	87	0.542	0.54	30	50	70	90	100
SC170	0.132	83	0.362	0.36	80	160	200	260	320
WEST HILLS BASIN									
WH010	0.179	82	0.398	0.40	90	200	250	330	400
WH020	0.044	75	0.502	0.50	10	30	40	60	80
WH030	0.191	72	0.785	0.78	30	100	130	180	230
WH040	0.319	77	0.545	0.54	100	250	320	440	540
WH050	0.110	85	0.465	0.47	60	120	150	200	240
WH060	0.101	93	0.142	0.14	150	250	300	370	420
WH070	0.051	73	0.562	0.56	10	30	40	60	80
WH080	0.072	78	0.447	0.45	30	60	80	110	140
WH090	0.052	84	0.175	0.17	50	100	120	150	180
WH100	0.110	91	0.225	0.22	120	220	260	330	380
WH110	0.098	92	0.408	0.41	80	140	170	220	250
WH120	0.125	87	0.249	0.25	110	210	260	330	380

APPENDIX C

Table C-1. FFE and Flood Depth Reference Table for Structures located in or near Existing Condition Floodplains – Ten Mile Creek Watershed

Structure Number	Address	River Mile	FFE (ft, NAVD)	Existing Condition Depth of Flooding (ft)					Future Condition Depth of Flooding (ft)				
				2-yr	10-yr	25-yr	100-yr	500-yr	2-yr	10-yr	25-yr	100-yr	500-yr
TEN MILE CREEK													
TM1	717 S. Peters Road	0.785	878.08	-18.57	-9.23	-6.07	-1.70	2.06	-16.53	-7.48	-4.41	-0.16	3.42
TM2	717 S. Peters Road; Bldg. 2	0.760	872.15	-12.63	-3.31	-0.15	4.22	7.99	-10.58	-1.56	1.51	5.76	9.35
TM3	716 S. Peters Road	0.826	865.92	-6.15	2.95	6.09	10.46	14.23	-3.93	4.69	7.75	12.00	15.59
TM4	8900 Cedarbrook Lane	0.926	869.53	-9.38	-0.61	2.52	6.88	10.64	-7.22	1.12	4.17	8.41	12.00
TM5	701 Ebenezer Road	0.983	868.10	-7.79	0.86	3.98	8.33	12.09	-5.71	2.58	5.63	9.86	13.44
TM6	600 Ebenezer Road	1.161	883.23	-22.20	-14.13	-11.04	-6.73	-2.98	-20.44	-12.43	-9.40	-5.19	-1.63
TM7	411 Ebenezer Road	1.345	875.22	-13.35	-6.01	-2.95	1.36	5.09	-12.41	-4.32	-1.31	2.88	6.44
TM8	Ebenezer Road	1.404	883.63	-18.61	-11.90	-8.84	-6.37	-3.13	-17.78	-10.05	-7.77	-5.38	-1.86
TM9	Ebenezer Road.	1.423	883.88	-18.31	-12.02	-9.01	-6.55	-3.32	-17.51	-10.21	-7.95	-5.56	-2.06
TM10	Kingston Pike	2.019	889.14	-7.72	-4.23	-3.09	-1.68	-0.48	-6.89	-3.56	-2.49	-1.12	0.09
TM11	Kingston Pike	2.047	888.89	-7.38	-3.91	-2.77	-1.35	-0.15	-6.56	-3.24	-2.16	-0.79	0.42
TM12	Kingston Pike	2.097	889.18	-7.50	-4.08	-2.93	-1.49	-0.29	-6.70	-3.41	-2.32	-0.93	0.28
TM13	8906 Kingston Pike	2.191	888.50	-6.32	-2.92	-1.71	-0.23	1.01	-5.59	-2.20	-1.08	0.36	1.59
TM14	8858 Kingston Pike	2.249	886.97	-4.35	0.10	1.16	2.12	2.91	-3.60	0.83	1.57	2.49	3.36
TM15	8865 Kingston Pike	2.249	886.85	-4.23	0.22	1.28	2.24	3.03	-3.48	0.95	1.69	2.61	3.48
TM16	401 Hardwicke Drive	3.302	899.28	-7.55	-3.28	-1.33	1.29	3.46	-6.86	-2.15	-0.20	2.40	4.53
TM17	308 Bridgewater Road	3.330	897.76	-5.44	-0.14	0.70	2.99	5.09	-4.50	0.19	1.63	4.06	6.15
TM18	337 Hardwicke Drive	3.394	896.24	-3.16	1.55	2.44	4.68	6.75	-2.44	1.93	3.36	5.73	7.79
TM19	333 Hardwicke Drive	3.413	899.15	-5.85	-1.31	-0.41	1.82	3.88	-5.19	-0.91	0.52	2.87	4.92
TM20	329 Hardwicke Drive	3.432	906.99	-13.46	-9.10	-8.18	-5.96	-3.92	-12.88	-8.69	-7.26	-4.93	-2.88
TM21	325 Hardwicke Drive	3.451	900.91	-7.16	-2.97	-2.04	0.17	2.20	-6.64	-2.54	-1.12	1.20	3.23

Table C-1. FFE and Flood Depth Reference Table for Structures located in or near Existing Condition Floodplains – Ten Mile Creek Watershed

Structure Number	Address	River Mile	FFE (ft, NAVD)	Existing Condition Depth of Flooding (ft)					Future Condition Depth of Flooding (ft)				
				2-yr	10-yr	25-yr	100-yr	500-yr	2-yr	10-yr	25-yr	100-yr	500-yr
TM22	321 Hardwicke Drive	3.470	898.35	-4.23	-0.32	0.62	2.80	4.82	-3.75	0.13	1.53	3.83	5.85
TM23	313 Hardwicke Drive	3.512	899.25	-4.06	-0.93	0.03	2.11	4.08	-3.60	-0.44	0.90	3.12	5.10
TM24	531 Mars Hill Road	4.374	916.70	-2.32	-0.87	-0.33	0.40	1.05	-1.97	-0.47	0.08	0.85	1.47
TM25	Mars Hill Road	4.402	918.69	-3.58	-2.13	-1.59	-0.87	-0.23	-3.23	-1.73	-1.19	-0.42	0.19
TM26	Mars Hill Road	4.431	919.39	-3.52	-2.07	-1.54	-0.83	-0.20	-3.16	-1.68	-1.14	-0.38	0.22
TM28	1732 Robinson Road	5.255	948.77	-7.43	-3.22	-2.47	-1.44	-0.70	-6.43	-2.62	-1.85	-0.88	-0.14
TM29	1805 Stonebrook Drive	5.255	948.30	-6.96	-2.75	-2.00	-0.97	-0.23	-5.96	-2.15	-1.38	-0.40	0.33
TM30	925 Broken Shaft Drive	0.435	Not Surveyed										
TM32	1001 Ebenezer Road	0.435	Not Surveyed										
TM33	8925 Westland Drive	0.435	Not Surveyed										
TM34	1002 Farrington Drive	0.435	887.06	-27.61	-18.23	-15.08	-10.71	-6.94	-25.54	-16.48	-13.42	-9.17	-5.58
TM35	1004 Farrington Drive	0.435	886.92	-27.47	-18.09	-14.94	-10.57	-6.80	-25.40	-16.34	-13.28	-9.03	-5.44
TM36	807 S. Peters Road	0.435	880.00										
TM37	724 S. Peters Road	0.888	887.04	-26.99	-18.14	-15.01	-10.64	-6.88	-24.79	-16.41	-13.35	-9.11	-5.52
TM38	Kingston Pike	1.978	Not Surveyed										
TM39	8871 Kingston Pike	2.249	Not Surveyed										
TM40	8841 Kingston Pike	2.249	Not Surveyed										
TM41	417 Hardwicke Drive	3.185	899.44	-8.59	-3.68	-1.65	1.03	3.22	-7.65	-2.51	-0.50	2.14	4.29
TM42	413 Hardwicke Drive	3.223	898.77	-7.62	-2.93	-0.93	1.73	3.91	-6.77	-1.77	0.21	2.84	4.98
TM43	409 Hardwicke Drive	3.252	898.78	-7.39	-2.89	-0.90	1.75	3.92	-6.62	-1.74	0.24	2.86	4.99
TM44	405 Hardwicke Drive	3.280	902.10	-10.49	-6.15	-4.18	-1.55	0.62	-9.78	-5.01	-3.05	-0.44	1.69
TM45	229 Bridgewater Road	3.290	894.37	-2.71	1.60	3.56	6.19	8.36	-2.00	2.74	4.69	7.30	9.43
TM46	Off Walker Springs Road	3.822	Not Surveyed										

Table C-1. FFE and Flood Depth Reference Table for Structures located in or near Existing Condition Floodplains – Ten Mile Creek Watershed

Structure Number	Address	River Mile	FFE (ft, NAVD)	Existing Condition Depth of Flooding (ft)					Future Condition Depth of Flooding (ft)				
				2-yr	10-yr	25-yr	100-yr	500-yr	2-yr	10-yr	25-yr	100-yr	500-yr
TM47	Robinson Road	5.175	Not Surveyed										
TM48	1008 Farrington Drive	0.435	886.50	-27.05	-17.67	-14.52	-10.15	-6.38	-24.98	-15.92	-12.86	-8.61	-5.02
SINKING CREEK													
SC1	8904 Cross Park Drive	0.269	897.35	-4.72	-1.71	0.34	3.03	5.22	-4.61	-0.53	1.50	4.15	6.30
SC2	Fox River Way	0.682	908.91	-10.68	-9.63	-9.33	-8.39	-6.34	-10.56	-9.55	-9.10	-7.41	-5.26
SC3	Fox River Way	0.812	912.47	-6.68	-5.68	-4.79	-4.10	-3.57	-6.46	-4.99	-4.64	-3.98	-3.45
SC4	Fox Lake Road	0.782	911.72	-8.56	-7.26	-6.99	-6.66	-6.34	-8.43	-7.16	-6.91	-6.57	-6.25
SC5	8908 Farne Island	1.434	957.45	-5.25	-2.81	-1.33	-0.59	-0.24	-4.89	-2.33	-1.03	-0.45	-0.15
SC6	8930 Farne Island	1.624	975.72	-7.18	-3.76	-2.89	-2.35	-2.00	-6.94	-3.18	-2.70	-2.23	-1.91
SC7	1012 Summerwood Road	1.771	991.70	-6.41	-5.35	-4.99	-4.58	-4.15	-6.20	-5.23	-4.90	-4.46	-4.02
SC8	960 Middlebrook Pike	1.799	987.93	-1.19	0.22	0.63	1.09	1.44	-0.91	0.36	0.74	1.24	1.53
SC9	425 Hardwicke Drive	0.178	903.01	-12.49	-7.37	-5.32	-2.63	-0.44	-11.47	-6.19	-4.16	-1.51	0.64
SC10	429 Hardwicke Drive	0.210	904.21	-12.72	-8.57	-6.52	-3.83	-1.64	-12.48	-7.39	-5.36	-2.71	-0.56
SC11	517 Hardwicke Drive	0.429	901.38	-7.41	-5.74	-3.69	-1.00	1.19	-7.29	-4.56	-2.53	0.12	2.27
SC12	521 Hardewicke Drive	0.459	902.80	-8.82	-7.16	-5.11	-2.42	-0.23	-8.70	-5.98	-3.95	-1.30	0.85
SC13	525 Hardewicke Drive	0.478	900.93	-6.80	-5.29	-3.24	-0.55	1.64	-6.69	-4.11	-2.08	0.57	2.72
SC14	605 Hardewicke Drive	0.506	899.51	-5.17	-3.87	-1.82	0.87	3.06	-5.07	-2.69	-0.66	1.99	4.14
SC15	609 Hardewicke Drive	0.514	899.12	-4.71	-3.48	-1.43	1.26	3.45	-4.62	-2.30	-0.27	2.38	4.53
SC16	8940 Farne Island Blvd.	1.402	Not Surveyed										
SC17	960 Middlebrook Pike	1.771	Not Surveyed										
SC18	960 Middlebrook Pike	1.783	Not Surveyed										
WEST HILLS TRIBUTARY													
WH1	Walker Springs Road	0.620	916.15	-5.53	-1.77	-1.29	-0.81	-0.48	-5.31	-2.77	-1.17	-0.72	-0.40
WH2	8338 Corteland Drive	0.988	930.86	-5.85	-4.67	-4.26	-3.77	-3.40	-5.77	-4.58	-4.19	-3.69	-3.34

Table C-1. FFE and Flood Depth Reference Table for Structures located in or near Existing Condition Floodplains – Ten Mile Creek Watershed

Structure Number	Address	River Mile	FFE (ft, NAVD)	Existing Condition Depth of Flooding (ft)					Future Condition Depth of Flooding (ft)				
				2-yr	10-yr	25-yr	100-yr	500-yr	2-yr	10-yr	25-yr	100-yr	500-yr
WH3	8344 Corteland Drive	1.007	933.80	-8.35	-7.04	-6.59	-6.06	-5.67	-8.26	-6.94	-6.51	-5.98	-5.60
WH4	8212 Ainsworth Drive	1.053	930.38	-2.16	-0.51	-0.16	0.24	0.52	-2.00	-0.41	-0.10	0.29	0.56
WH5	8343 Corteland Drive	1.039	941.03	-13.47	-11.28	-10.93	-10.55	-10.28	-13.20	-11.19	-10.88	-10.50	-10.24
ECHO VALLEY TRIBUTARY													
EV1	8866 Bruce Wood Lane	0.039	877.71	-15.61	-8.71	-5.59	-1.26	2.50	-15.19	-6.99	-3.94	0.28	3.85
EV2	8860 Bruce Wood Lane	0.053	879.14	-17.04	-10.14	-7.02	-2.69	1.07	-16.62	-8.42	-5.37	-1.15	2.42
EV3	8854 Bruce Wood Lane	0.067	879.51	-17.42	-10.51	-7.39	-3.06	0.70	-16.99	-8.79	-5.74	-1.52	2.05
EV4	8850 Bruce Wood Lane	0.082	887.36	-25.27	-18.36	-15.24	-10.91	-7.15	-24.84	-16.64	-13.59	-9.37	-5.80
EV5	425 Echo Valley Road	0.405	885.42	-14.60	-13.28	-12.83	-8.97	-5.21	-14.33	-13.00	-11.65	-7.43	-3.86
EV6	426 Echo Valley Road	0.436	876.65	0.11	3.31	3.71	4.16	4.34	1.68	3.58	3.94	4.21	4.91
EV7	8717 Glen Echo Drive	0.436	883.40	-6.64	-3.44	-3.04	-2.59	-2.41	-5.07	-3.17	-2.81	-2.54	-1.84
EV8	8833 Weesex Road	0.039	881.26	-19.16	-12.26	-9.14	-4.81	-1.05	-18.74	-10.54	-7.49	-3.27	0.30
EV9	8844 Brucewood Lane	0.096	879.27	-17.19	-10.27	-7.15	-2.82	0.94	-16.75	-8.55	-5.50	-1.28	2.29
EV10	8838 Brucewood Lane	0.110	881.32	-19.24	-12.32	-9.20	-4.87	-1.11	-18.80	-10.60	-7.55	-3.33	0.24
EV11	8814 Brucewood Lane	0.182	893.54	-30.66	-24.54	-21.42	-17.09	-13.33	-30.25	-22.82	-19.77	-15.55	-11.98
EV12	501 Echo Valley Road.	0.379	879.16	-9.84	-8.63	-7.04	-2.71	1.05	-9.45	-8.37	-5.39	-1.17	2.40
EV13	8707 Glen Echo Drive	0.495	890.67	-12.49	-10.41	-9.93	-9.35	-9.03	-11.85	-10.09	-9.64	-9.23	-8.78
EV14	8705 Glen Echo Drive	0.515	883.97	-5.09	-3.31	-2.84	-2.26	-1.92	-4.65	-2.99	-2.55	-2.12	-1.73
EV15	8703 Glen Echo Drive	0.534	884.46	-4.67	-3.09	-2.66	-2.11	-1.78	-4.28	-2.80	-2.40	-1.97	-1.60
EV16	8701 Glen Echo Drive	0.555	885.05	-4.25	-2.89	-2.50	-2.00	-1.68	-3.91	-2.63	-2.27	-1.86	-1.51
EV17	8637 Glen Echo Drive	0.577	883.67	-1.82	-0.69	-0.34	0.12	0.42	-1.53	-0.46	-0.14	0.26	0.58
EV18	8633 Glen Echo Drive	0.601	884.83	-1.83	-0.95	-0.65	-0.24	0.04	-1.60	-0.75	-0.48	-0.10	0.19