Solutions Taking Shape.

DUTCHTOWN ROAD FLOOD STUDY REPORT KNOX COUNTY, TENNESSEE

1792

Knox County

Prepared By:

Ogden Environmental and Energy Services Co., Inc.
3800 Ezell Road, Suite 100
Nashville, Tennessee 37211

May 7, 1999

OGDEN ENVIRONMENTAL AND ENERGY SERVICES

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EXECUTIVE SUMMARY

This study was performed to evaluate the hydrologic characteristics of, and present flood solution alternatives for sinkholes located near Dutchtown Road in Knox County. Sinkholes in this area serve as the primary drainage feature for stormwater runoff. Over three square miles of residential and commercial property drain to a series of sinkholes along Dutchtown Road and Cedar Bluff Road. Hydrologic analysis was performed on the sinkholes located in close proximity to Dutchtown Road and Cedar Bluff Road. Analysis included the flood of April 1998. Approximately 8-inches of rain fell on saturated ground which caused flooding on Dutchtown Road which lasted for several weeks, and flooding on Fox Lonas Road, Pensacola Road, and in two locations on Cedar Bluff Road which lasted for several days. Floodwaters also threatened several residences in Dutchtown Harbor located close to the main sinkhole on Dutchtown Road.

A karst hydrogeological study was performed to characterize the groundwater flow in the subsurface environment in the study area and obtain a better understanding of the surface water to groundwater relationship. The study included a literature review, geology evaluation, an inventory of karst features, and a dye trace study. Results of the study indicate that direct flow paths can be interpreted from sinkholes in the Dutchtown Road and Cedar Bluff Road areas, to Ten Mile Creek and finally to Fort Loudoun Reservoir. The study also concluded that urbanization and poor erosion controls are the major contributing factor to flooding, rather than obstructions in the subsurface environment.

Flood solution alternatives were evaluated to determine the most feasible and cost effective alternatives to reduce flooding potential on County roads and residential homes. Specific alternatives considered include excavation of additional storage area, high flow channels and pipes, pump stations, raising roads, local flood protection (floodwalls) and purchasing flooded residences. Recommended alternatives include raising Pensacola Road and Dutchtown Road above predicted flood elevations, piping and channeling runoff from sinkholes adjacent to Cedar Bluff Road to more effective flood storage areas and erecting floodwalls adjacent to two residences in Dutchtown Harbor. The total cost of the recommended alternatives is estimated to be $610,930. General recommendations for the Dutchtown Road area include regular sinkhole throat maintenance and tighter enforcement of erosion control regulations around sinkholes.

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INTRODUCTION

The Dutchtown Road/Cedar Bluff Road Area, located in west Knox County, has experienced flooding during heavy rains in the past several decades. Recent flood events have forced the County to close major and intermediate roadways, and respond to complaints of flooding in several buildings and numerous yards located in close proximity to sinks and depressions. Past flood events, the potential for further development in the area, a lack of knowledge of the subsurface drainage characteristics of the area have prompted Knox County officials to request a study of the Dutchtown Road Area in an effort to determine solutions that will prevent future flooding. The objective of the Dutchtown Road Flood Study is to propose and evaluate flooding solution alternatives for flood-prone sinkholes located in the study area.

This study was conducted in two phases. Phase I was an initial hydrologic and hydrogeologic study of the area. Tasks in Phase I included delineating the study area, reviewing previous studies or other relevant data, performing an initial hydrologic analysis to determine floodplain elevations, and performing a karst inventory and fluorescent dye injection study of the subsurface system. Phase II was a study of flood solution alternatives. Tasks in Phase II included a refined hydrologic study, flood solution alternative development and cost estimate, and recommendations.

During the study, two large rainfall events occurred between the evening of April 16 and the early afternoon of April 19, 1998. A number of sinks and depressions along Dutchtown Road and Cedar Bluff Road were overtopped, forcing the County to close several roads, construct sandbag dams around threatened structures, and monitor flood elevations continuously for several days. A commercial strip mall experienced minor flooding and many yards located in close proximity to flooded sinkholes and depressions were under water for an extended period of time. Ogden and County personnel recorded field observations, interviewed residents, and surveyed high water elevations during and after that period. Data from these flood events was used to perform hydrologic analysis of the flooded sinks and to study potential flood solution alternatives in the area.

CAUSES OF FLOODING NEAR SINKHOLES

In their 1995 report on the impacts of developments in sinkhole areas, the Metropolitan Planning Commission (MPC) discussed the potential problems associated with land development on and modification of karst terrain. In karst areas, such as Knox County, the surface drainage is significantly influenced by the hydrogeologic flow regime; storm-water runoff is directed into the sinkholes, transmitted through the ground-water system through a network of interconnected conduits and finally discharged at resurgent locations (springs). If the storm-water runoff exceeds the capacity or rate of discharge of the sinkhole, flooding is probable to occur. MPC identified the Dutchtown Road area as a karst region that has been "significantly developed" and has "prominent flooding" problems (MPC, 1995). Knox County officials have been aware of the flood potential for this area for some time and have taken some steps to combat the problem on a site-by-site basis. For example, instead of requiring detention of runoff from the standard 10-year rainfall, the County has required several developments in the study area to detain runoff resulting from the 100-year rainfall.

Flooding in the study area is caused by a number of factors. First, there is no surface drainage feature (i.e., stream) in the area, therefore the numerous sinks and depressions in the area serve as the primary drainage outlets for stormwater runoff. Second, heavy residential, institutional (e.g., schools and churches) and commercial development has occurred in the study area during the past 10 to 15 years, and continues at the present time, increasing the volume of runoff that the sinkholes must handle. Finally, construction practices that may alter the karst terrain, such as sinkhole filling, blasting, and inadequate erosion control, can increase the potential for flooding. Partial or total filling of a sinkhole reduces the volume of surface storage available to contain stormwater runoff. Blasting can change the geometry of sink throats and underground caves affecting outflow pathways. A lack of adequate erosion control measures can increase the potential for silt and other debris to accumulate at sink throats, effectively reducing the outflow efficiency of sinks and caves in the region. These factors, combined with seasonal hydrologic conditions such as saturated soils and periods of heavy rainfall, result in increased potential for flooding.

OVERVIEW OF THE STUDY AREA

The Dutchtown Road Flood Study area is located in the north Cedar Bluff area of west Knoxville, at the northeast corner of Interstate-40 and the Pellissippi Parkway (see Figure 1 and Figure A-1). Forty-three sinkholes and depressions, and four lakes are present in the 3.26 square mile (sq. mi.) study area. Most development in the study area occurred during the past 10 to 20 years.

Ogden personnel visited the study area on several occasions to investigate the watershed and general sinkhole conditions. To facilitate the hydrologic analysis, the study area was broken into three areas based upon general *surface* drainage patterns: the Dutchtown Road Sinkhole Area, the Cedar Bluff Sinkhole Area, and the Dead Horse Lake Area. The Dutchtown Road Area encompasses the land draining to sinkholes located adjacent to Dutchtown Road. The Cedar Bluff Area includes the land draining to sinkholes located adjacent to Cedar Bluff Road. Historically, the Dutchtown Road and Cedar Bluff portions of the study area have been considered part of the Ten Mile Creek watershed. It is believed that the sinks ultimately drain, via subsurface routes to Ebenezer Cave, which serves as the outlet for Ten Mile Creek (MCI, 1987).

The Dead Horse Lake Area includes the land draining to Dead Horse Lake, Kirby Lake and any sinks or depressions located along the south end of the Dead Horse Lake Golf Course. The common belief among local residents is that Dead Horse Lake drains to Bluegrass Lake, located south of the intersection of Ebenezer Road and Northshore Drive. The Dead Horse Lake Area was included in this study due to its proximity to the Dutchtown Road area sinkholes.

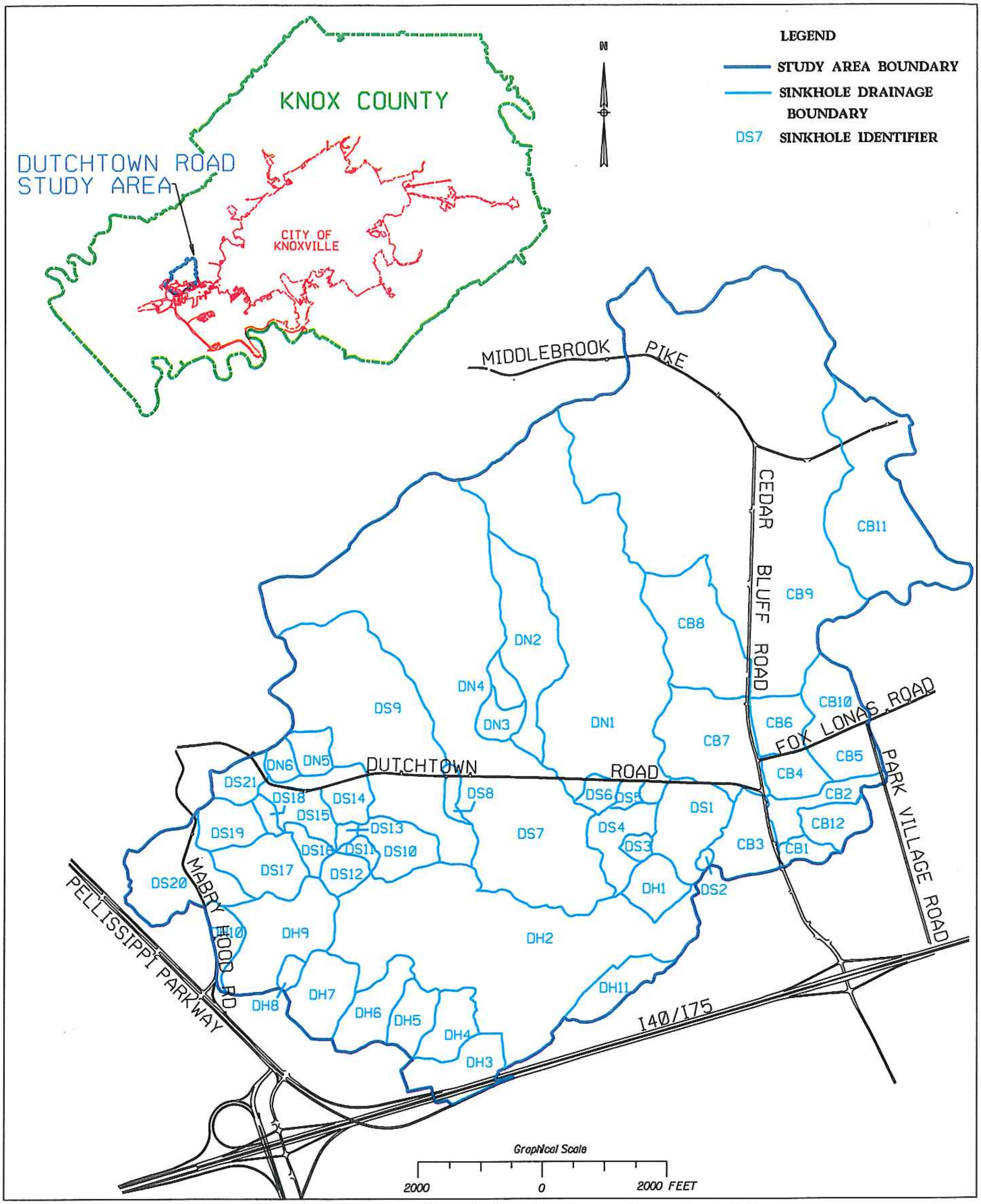


Figure 1. Dutchtown Road Study Area Location Map.

The Dutchtown Road Sinkhole Area

Existing landuse in the Dutchtown Road Sinkhole Area is primarily medium to high density residential. Some low-density residential areas still remain, primarily along the north side of Dutchtown Road. This area also includes a portion of the Webb School campus and the entire campus of the Christian Academy of Knoxville (CAK). MPC's 15-year Development Plan presents low to medium residential developments as the proposed future landuses for the area.

Approximately 1,005 acres drain to sinkholes located along Dutchtown Road. A significant portion of this area drains to two large sinkholes. The main sink, identified for this study as Dutchtown South #7 (DS7), is located between Dutchtown Road and Dead Horse Lake. Approximately 300 acres drain directly to DS7. Portions of this sinkhole have been filled during construction of Dutchtown Road, the Dutchtown Harbor Condominiums in 1995, and the current construction of new CAK facilities. DS7 holds water during wet periods and does not drain quickly. Dutchtown Road spans the northern portion of sinkhole and has been closed several times due to flooding.

Sinkhole Dutchtown North #1 (DN1) is located north of DS7, between Dutchtown Road and Sarasota Drive. Approximately 230 acres drain directly to DN1. Resident interviews revealed that one or more sinkhole throats were present in DN1, but past residents covered them with rocks and soil in an effort to prevent children from playing in the rocky outcroppings and cave openings. Although this area is typically dry, residents indicate that the area drains very slowly after heavy rainfall. Complaints about DN1 have been limited to nuisance flooding in yards adjacent to the sink and mosquito problems attributed to standing water during wet periods. It is believed that the remaining sinkholes and depressions in the Dutchtown Road area store water only after rainfall events.

The Cedar Bluff Road Sinkhole Area

Approximately 682 acres drain to sinkholes located along Cedar Bluff Road. Landuse in this area consists of a mix of medium to high-density residential, institutional, commercial and undeveloped areas. Most of the undeveloped area is located between Middlebrook Pike and Bob Gray Road, and behind the Sunchase Apartments on Cedar Bluff Road. A large tract of land at the corner of Cedar Bluff and Fox Lonas is currently under development of the Knoxville

Catholic High School. MPC's 15-year Development Plan projects landuse along Cedar Bluff to be a mix of commercial and office buildings, low to medium residential property, and public/institutional areas.

A large depression located to the east of Cedar Bluff Road between the Sunchase Apartments and Cedar Bluff Catholic Church Rectory Building drains 453 acres. This depression is identified in this study as Cedar Bluff #9 (CB9). Ideally, excessive water stored in this depression will discharge under Cedar Bluff Road to Sinkhole CB8 through an 18-inch diameter pipe once the water surface elevation in CB9 exceeds the invert of the pipe inlet. However, the pipe also carries runoff from the east side of Cedar Bluff Road and resident interviews have indicated that stormwater will backflow to CB9 through this pipe during extreme rainfall periods.

The CB8 Sinkhole located across Cedar Bluff Road from the most downstream portion of CB9, drains runoff from residential areas and the Cedar Bluff Elementary and Intermediate Schools. The sinkhole throat can be characterized as a deep, rocky outcropping with a fairly wide opening. A short 36-inch CMP has been positioned in one side of the throat to facilitate drainage to the subsurface system. Observations during recent events indicate that CB8 drains fairly rapidly.

CB6 and CB10 drain the Knoxville Catholic Church and High School area, which is currently under development at the corner of Cedar Bluff and Fox Lonas Roads. In an effort to reduce the potential for flooding in the Cedar Bluff area, Knox County requires the church to handle the runoff resulting from the 100-year, 24-hour duration storm event. Retention facility CB6, constructed in 1997, discharges to the subsurface environment via an injection well permitted by the State of Tennessee. CB10 is planned as a series of detention ponds that drain by gravity to second retention pond discharged via an injection well. At the time of this study, the permitting process for the CB10 injection well was in preliminary stages.

Feature CB7, roughly located just northwest of the Cedar Bluff Road and the Fox Lonas Road intersection, drains a portion of the Gulf Park subdivision and a combination of commercial and low density residential areas. Portions of CB7 have been filled to accommodate pool and tennis facilities for the Gulf Park subdivision and more recently, a 5-lot subdivision on the west side of

Pensacola Road. Resident interviews revealed that prior to suburban development of the area, CB7 was used as one of the main springs providing water to local residents.

Sinkhole CB4 and the series of sinkholes designated as CB5 are located on a 32-acre undeveloped tract of land. Field observations indicate that the CB5 Sinks are typically dry and drain relatively quickly after storm events. It is thought that CB4 continuously holds water throughout the year. Residents believe that many of the Cedar Bluff area sinks ultimately drain to CB4.

It is believed that Sinks CB2 and CB3 were, at one time, one large sinkhole that was partially filled during construction of Cedar Bluff Road creating the two separate sink areas. CB2 was then partially filled to facilitate construction of a strip mall located to the south east of the sink.

The Dead Horse Lake Area

Dead Horse Lake, designated as Dead Horse #2 (DH2) for purposes of this study, is a spring-fed lake located between the main Dutchtown Sinkhole (DS7) and Sherrill Road. The lake receives direct runoff from the surrounding Dead Horse Lake Golf Course and a portion of the Webb School campus. Additional drainage comes from Kirby Lake (DH9) via a natural stream channel, and from the Scripps-Howard lake (DH3). The only surface outlet for Dead Horse Lake is a pipe located at the north tip of the lake. When open, the pipe discharges to Sink DS7. Golf course operators open and close this pipe throughout the year to adjust lake elevations depending upon water needs. At this time, it is believed that there is some subsurface connection between Dead Horse Lake and Sink DS7 due to the close proximity of the two features. However, this connection is not believed to be significant, as the water surface elevations of the lake and DS7 typically do not equilibrate, most notably during dry periods. Dead Horse Lake (DH2) maintains a permanent pool and DS7 will totally drain during dry periods.

For esthetic reasons, the Scripps-Howard Lake (DH3) is kept at an approximate elevation of 952.0 ft, leaving very little available storage for stormwater runoff. When needed, a valved pipe located beneath the dam is opened to allow water to discharge to a surface stream that leads to Dead Horse Lake. Planned development of the Scripps-Howard area will increase runoff draining to the lake.

A number of small sinkholes located to southwest of Dead Horse Lake, identified as DH4 through DH7, do not provide much storage capacity for stormwater runoff. When overtopped, excess water will drain overland to Dead Horse Lake.

KARST HYDROGEOLOGIC STUDY

A basic understanding of how the surface drainage features and the subsurface drainage are hydraulically related is essential for efforts to reduce flooding in karst regions. To understand the hydraulic connections and ground-water flow paths of the area, Ogden performed a karst hydrogeologic investigation. The objective of the study was to characterize the ground-water flow in the carbonate rock formations in the Dutchtown Road and Cedar Bluff Road flooding areas and thus, obtain a better understanding of the complex relationship between the surface drainage and groundwater system. The following research procedures were used to accomplish the objectives of the study: review of available literature for the Knox County area, evaluation of the geology of the area, a field survey to gather a karst inventory, and a dye trace study. The karst inventory is performed to catalogue the karst features located in the study area and determine those features that could be used as dye injections or receptor sites in the dye trace study. The dye trace study is performed to gather knowledge on the connectivity of karst features. This portion of the study includes a determination of background fluorescence, fluorescent dye injection, and charcoal dye receptor retrieval and analysis.

Literature Review

Prior to performing any fieldwork associated with the dye trace study, Ogden personnel performed a literature review of the Knox County area to obtain any additional information that may be useful to the completion of the project. The literature review included the following resources pertaining to the karst features of the area: topographic maps, geologic maps, soil surveys, and previous studies performed in the area.

Preliminary Subsurface Evaluation (Geology)

Knox County is located in the Valley and Ridge physiographic region of Tennessee. The region is the remnants of the southern Appalachian mountain chain that was formed in the late Paleozoic geologic era by northwesterly compression forces; initially, the strata compressed by folding, but as the folding progressed, thrust faults relieved the localized pressure. The topography of the Valley and Ridge region is characterized by a series of alternating broad ridges and gently sloping valleys that have northeastwardly trends. Erosion has removed all but the roots of the folds and faults of the area. Weathering of the strata has resulted in soils (primarily clays) with depths of 50 to 100 feet in many areas of the region. In many locations, the exposures of the bedrock (outcrops) are limited to pinnacles that extend upward through the residuum.

The study area is underlain by a series of shale, limestone, and dolomite (Figure A-2). Dutchtown Road is situated on the approximate contact between the Newala and Lenoir Formations. The Newala is described as a light grey to blue grey dolomite with aphanitic limestone in the upper portion of the formation. The Lenoir Formation is dark blue limestone with wavy argillaceous parting planes. Between the Lenoir Formation and Dead Horse Lake is the Halston Formation contact; the Halston is described as a massive, coarse limestone. The Ottessee shale is situated between Dead Horse Lake and Interstate 40/75. The Ottessee is a mixture of shale, limestone, and some siltstone/sandstone; these units interfinger with one another throughout the formation. The Geologic Map of the Bearden Quadrangle shows a contact between the Halston and the Lenoir Formations within the DS7 surface depression or sinkhole. Six additional sinkholes within the Newala Formation are situated immediately north of Dutchtown Road.

Sinkholes, which range in size from small to large surface depressions, are the most prominent surface feature in limestone terrains, such as the Dutchtown Road Area. There are two different causes for the formations of sinkholes: the first is the vertical solution of the limestone bedrock beneath the soil mantle and the second is the collapse of the roof of bedrock over a subsurface cavern. The formation of sinkholes can also be influenced or have linear controls that coincide with contacts of different bedrock formations or prominent joints within the bedrock units. Typically, these contacts and/or joints allow for more turbulent ground-water flow than the surrounding bedrock and thus, the solutional removal of the limestone bedrock is greatly enhanced.

Sinkholes are also the primary feature for ground-water recharge in limestone terrains. Precipitation that falls on the ground surface is directed into the surface depressions; once in the sinkhole the water infiltrates and percolates into the subsurface through openings in the soil and underlying bedrock. Once in the subsurface, the water is transmitted through conduits that have been solutionally enlarged. The groundwater is transmitted through the system to emerge at resurgent locations or springs that are typically located along the base level stream of the area.

Ten-Mile Creek, the base level stream of the Dutchtown Road Area, is located approximately 1.5 miles east of Dead Horse Lake and has both perennial and ephemeral sections. Tributaries to Ten-Mile Creek originate on the southeastern side of the Black Oak Ridge. The stream flows south until sinks into a series of sinkholes approximately 1.5 miles on the south side of Interstate 40/75. The stream resurfaces at the base of a small outcrop at the edge of Fort Loudoun Reservoir.

Karst Inventory

On August 10 and 11, 1998, Ogden personnel performed the karst hydrogeologic inventory of the Dutchtown Road area. The western and northern limits of the study area were Mabry Hood Road and approximately 500 ft. north of Dutchtown Road, respectively. The study also included Sinking Creek from the Fox Lake Apartments (located on Fox Lonas Road) to its confluence with Ten Mile Creek, and Ten Mile Creek all the way to Fort Loudoun Reservoir.

The inventory was performed to identify the following karst features:

- Springs
- Seeps
- Sinkholes
- Swallets (i.e., sinking streams)
- Karst Windows

In the field, the features were located on a 7.5 minute topographic map. Each feature was given a name and a unique inventory number, and was photographed to complete the inventory record.

A general observation noted during the inventory was that many sinkholes in the area are filled with debris (some intentional and some due to storm events) and silt (due to poor erosion control near construction sites). These obstructions tend to slow the infiltration of stormwater runoff; therefore, because the water continues to flow into the surface depression faster than the sinkhole can transmit the water to the subsurface, flooding occurs.

Dye Trace Study Methodology

A dye trace study is used to determine the connectivity of the subsurface environment *at the time of the study*. The study is performed by placing activated charcoal receptors in the main flow at potential dye resurgent locations, identified during the karst inventory. The receptors construction consists of an activated coconut charcoal placed in a vinyl-coated fiberglass mesh screen. Fluorescent tracer dyes are then injected into the system by flushing a small amount of dye into a sinkhole (also identified during the karst inventory) using a large amount of potable water. If dye is present in the flow at the potential resurgent location, it passes through the receptor and is absorbed onto the activated charcoal. The receptor is collected and analyzed in the laboratory to determine dye concentration(s). Dye injection and receptor locations in the Dutchtown Road Study area are shown in Figure 2.

The first step in a dye trace study is performing a background fluorescence study to determine if any of the selected fluorescent tracer dyes are present in the ground-water system prior to dye injection. Results of the analyses are used to establish baseline concentrations of the dyes. On August 28, 1988, charcoal receptors were placed in the potential dye resurgent locations. On September 8, 1998, the background dye receptors were collected and submitted for analysis. It was decided to also incorporate the Ten Mile Creek sump and Ebenezer Spring #7 into the study; therefore, receptors were retrieved from these locations on September 14, 1998 and submitted for analysis. Results of the background analysis indicate that none of the dyes were present in the ground-water system prior to the dye injection.

On September 14, 1998, Ogden initiated the dye trace study by simultaneously injecting fluorescent dyes in three different karst features in the Dutchtown Road area. Dye injections locations are shown in Figure 2. One pound of Rhodamine WT dye was injected into a small sinking stream in the bottom of the main sinkhole, DS7. One pound of Fluorescein was introduced directly into the subsurface by injection into the throat of sinkhole DN2, located directly behind the residence at 9600 Tallahassee Lane in the Gulf Park subdivision. One pound of Eosine was injected into a storm drain pipe that leads directly into an open cavern in sinkhole CB8.

The charcoal packets that had been placed in possible resurgent locations were collected and submitted for analysis on a predetermined schedule (post-injection). The packets were collected on five separate occasions during a two-week period and were submitted for analyses. After each collection, a fresh charcoal packet was placed in the resurgent feature.

Dye Trace Study Results

The analytical results for the dye trace are presented in Table 1 with the dye trace flow routes illustrated on Figure 2. Analysis of the dye receptors collected on September 15, 1998 (within 24-hours of dye injection) determined that each of the dyes were injected into a moving ground-water system. All dyes were detected at locations other than the injection points. The most significant finding of the initial analysis was that a large slug of the Eosine dye was detected at CB4 with small amounts determined to be in Fox Lake Apartments Spring #3, which feeds directly into Ten Mile Creek. The dye had traveled approximately one mile within 24-hours of the dye injection.

Analysis of the receptors collected on the second and third day after injection, likewise, indicated that CB4 was a very important feature to overall drainage of the study area. The remaining two dyes, Rhodamine WT and Fluorescein were detected at this location at significant concentrations within 48-hours of injection. As expected, the dyes were also detected at the Fox Lake Apartments Spring #3; therefore, substantiating the direct connection of the karst features located in the Dutchtown Road area and Ten Mile Creek.

Table 1. Dye Trace Study Results

	9/14/98			9/15/98			9/16/98			9/17/98			9/21/98			9/25/98		
	F	E	R	F	E	R	F	E	R	F	E	R	F	E	R	F	E	R
DS7 Spring #1	NA	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DS7 KW #1	NA	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DS7 KW #2	NA	NA	NA	-	-	+2	-	-	+2	+1	-	+1	-	-	+2	-	-	+2
DS7 KW #3	NA	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB2	NA	NA	NA	-	-	-	+1	-	-	+	-	-	-	-	-	-	-	-
CB4	NA	NA	NA	-	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+2	+1
CB8	NA	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CB1	NA	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fox Lake Apts Spring #3	NA	NA	NA	-	+1	-	-	+2	-	+2	+2	+2	+3	+2	+2	+2	+2	+2
Eagle Brook Apts Seep	NA	NA	NA	-	-	-	+1	+2	-	+2	+2	+1	+2	+2	+2	+2	+2	+2
Pwrline Spring #4	NA	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lowes Spring #5	NA	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Abandon Barn Spring #6	NA	NA	NA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ten Mile Creek Sump	-	-	-	-	-	-	-	+1	-	+1	+1	-	+2	+2	+2	+1	+2	+1
Ebenezer Spring #7	-	-	-	-	-	-	-	-	-	-	+1	-	+2	+2	+2	+2	+2	+2

- Not Detected.
NA Not Analyzed.
+1 Positive Dye Detection
+2 Strong Positive Dye Detection
+3 Very Strong Positive Dye Detection

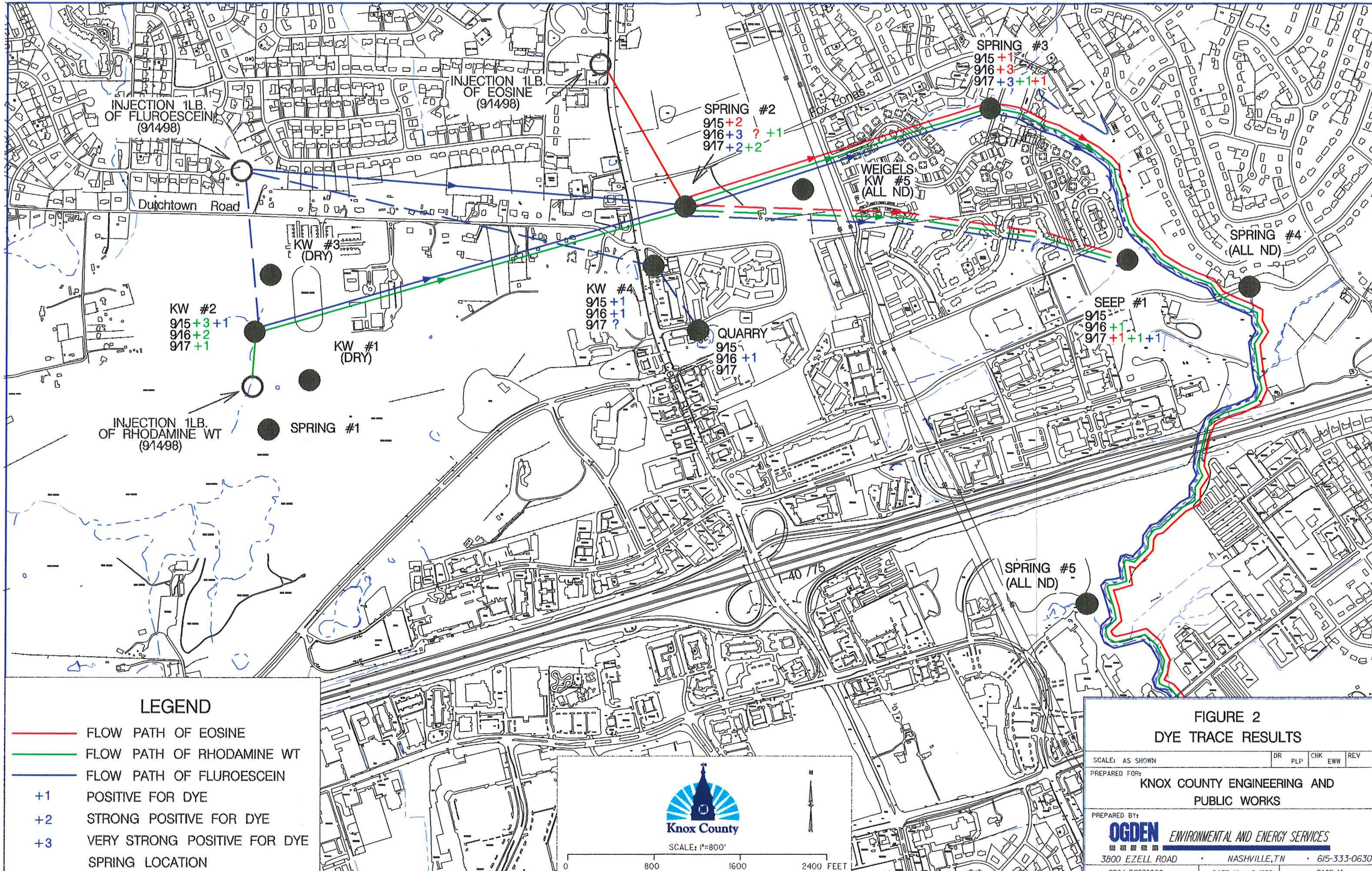


FIGURE 2
DYE TRACE RESULTS

A connection was also determined between the series of sinkholes north of Dutchtown Road and the main Sinkhole (DS7). Fluorescein was detected in a karst window in DS7 on September 17, 1998 thus indicating that the area north of Dutchtown Road drains to DS7. Analysis of the receptors also determined one connection that was not anticipated. Based on review of the dye, there appears to be a connection between CB4 and the seep located at the Eagle Brooks Apartment. Each of the three dyes was detected at the seep within 72-hours of injection. Analysis of receptors collected on September 21 and 25, 1998 continued to detect the three dyes, but these detections are likely the residual dyes that remained within the system.

Finally, the dyes were traced the entire length of Ten Mile Creek from Fox Lake Apartments to the Ten Mile Creek Sump south of Interstate 40/75. At this location, Ten Mile Creek sinks into a series of small sinkholes and then travels entirely underground. Analyses of the receptors collected from the Ebenezer Spring location then concluded that Ten Mile Creek resurfaces and discharges directly into the Fort Loudoun Reservoir. Thus, there is a link from the drainage system of the Dutchtown Road Study Area with the surface waters of Fort Loudoun.

Dye Trace Study Conclusions

Based on the dye trace results, direct flow paths can be interpreted from the three points of injection (Sinkholes DS7, DN2 and CB8) and the spring at CB4. Water from CB4 was then traced to the Fox Lake Apartments Spring #3, which discharges directly into Ten Mile Creek (the base level stream of the area). Ten Mile Creek then flows on the surface along the remainder of its length before sinking into a series of small sinkholes near the intersection of Ebenezer and Peters Roads. The surface water then resurfaces at the Ebenezer Spring #7 to feed directly into Fort Loudoun Reservoir.

Because the dyes were detected within relatively short time of injection, it appears that the subsurface conduits are transmitting the water in a fast (turbulent) flow environment. Therefore, it is likely that obstructions in the subsurface are not the major contributing factor to the surface flooding. Based on observations during the project, it is likely that the flooding was more a result of urbanization and poor erosion controls. Much of the area is covered with impervious materials that promote surface run-off during storm events. Because the sinkholes have a limited storage capacity, an unusually intense storm event may exceed this capacity, causing flooding to occur. This is magnified when the rate of discharge from the sinkhole is impeded or slowed due to debris or silt within the "throat" of the sinkhole. Furthermore, because the entire Cedar Bluff Road area is experiencing significant urbanization, much of the area that once allowed infiltration is covered and therefore, the result is increased stormwater run-off. Unfortunately, more run-off is directly related to the increased demands on the sinkholes storage capacity.

THE APRIL 1998 STORM EVENT

The Dutchtown Road Study Area experienced significant rainfall between April 16 and April 19. According to a rainfall gage operated by the City of Knoxville on Wellington Drive, 7.4 inches of rain fell between noon, April 16 and 1:00 PM April 19. The Wellington Drive recording gage is located approximately 2 miles from the study area. Local accounts of 10 inches in the Dutchtown Road area were common as reported in the local paper.

The antecedent or conditions contributed to the flooding in the Dutchtown Road. The Knoxville area experienced a very wet period in April of this year. March rainfall was near the monthly average according to data from the McGhee Tyson Airport Station. However, the April monthly rainfall total was the highest recorded at that station, 11.07 inches (normal rainfall is 3.8 inches). According to airport data, normal rainfall for the month of April had occurred prior to the April 16 event.

Figure A-1 (in Appendix A) shows the high water marks from the April event. These high water marks were either surveyed or field estimated based on 2-foot KGIS topographical mapping. Table 2 summarizes the high water marks from the April storm in the Dutchtown Road Area.

Table 2. April 1998 High Water Elevations

Sinkhole #	Location	HW Elev.	Comment
CB2/CB3	Walgreen's	935.70	Surveyed
CB4	Cedar Bluff/Fox Lonas	929	Estimated from survey and photographs
CB6/CB7	Cedar Bluff/Knoxville Catholic	931.82	Surveyed
CB9	North of Knoxville Catholic	949.64	Surveyed
DN1	South of Gulf Park Sub	940	Estimated from Survey/HWM
DN2		944	Estimated from HWM
DN3		960	Estimated from HWM
DS5		940	Estimated from Survey/HWM
DS6	Adjacent to Dutchtown Villas	940	Estimated from Survey/HWM
DS7	Adjacent to Dutchtown Harbor	940.47	Surveyed
DS9	Manis Road	944	Estimated from HWM
DH2	Dead Horse Lake	939.5	Estimated

Dutchtown Road Sinkhole Area Flooding

The most severe flooding resulting from the April 1998 storm event occurred where Dutchtown Road crosses the Sinkhole DS7. Sinks DS7, DN1, and DN2 were filled to capacity (approximately 940.0 ft in elevation) after the storm. Flooding of Dutchtown Road and the entrance drive to the Dutchtown Harbor Condominiums began on April 19 and slowly rose to a high water mark elevation of 940.47 on April 21. Floodwaters did not recede quickly, and the road remained impassable until late May. Many backyards and small storage buildings at houses on Sarasota Road were flooded and sandbag dams were constructed around several condominiums bordering the DS7 Sink at the Dutchtown Harbor community (Figure 3).

Figure 3. Dutchtown Harbor on Thursday, April 23, 1998.

Cedar Bluff Sinkhole Area Flooding

Figure A-1 shows flooding at two locations in the Cedar Bluff Road Area. Cedar Bluff Road, Fox Lonas Road and Pensacola Road were all closed for several days when floodwater rose to an elevation of 931.8 ft in that area. Resident interviews and field observations during the storm indicate that the stormwater drainage system for Cedar Bluff Road was overwhelmed during the storm causing inlets along Cedar Bluff to surcharge (Figure 4). In addition, depression CB9 flooded to an elevation of 949.6 ft. These factors resulted in runoff flowing south on Cedar Bluff Road flooding Sinkholes CB6, CB7 and ultimately CB4.

Figure 4. Looking South on Cedar Bluff Road near Fox Lonas Road, Sunday, April 19, 1998.

Sinkholes CB2 and CB3 also flooded during the event to an elevation of 935.7 ft. This caused the closure of Cedar Bluff Road and some flood damage in the Walgreens Drug Store located in the strip mall next to the CB2 Sink (Figure 5). Floodwaters in this area receded within several days of the event.

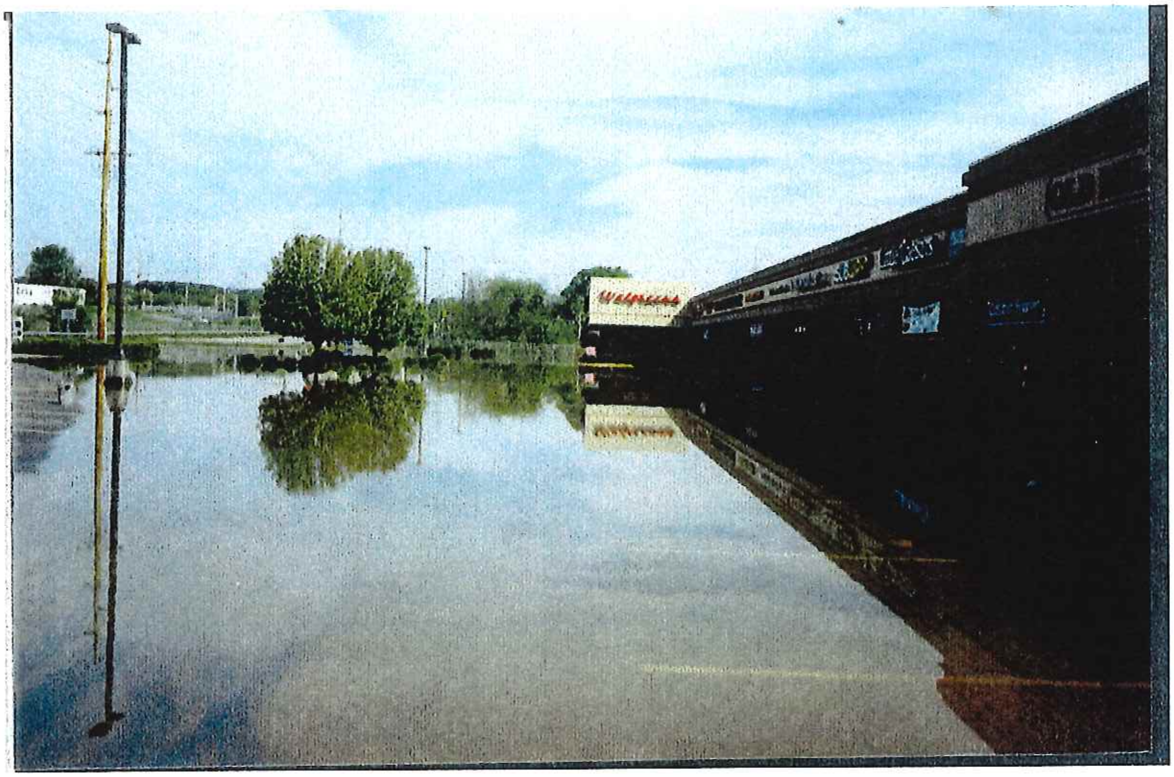


Figure 5. Walgreen's Parking Lot on Cedar Bluff Road, Sunday, April 19, 1998.

Dead Horse Lake Area Flooding

While no survey was performed, the high water mark in Dead Horse Lake was estimated at approximately 939.5 ft. The pipe draining the lake to Sink DS7 was closed at the time of the storm. There was no known flooding of structures or roads in this area.

HYDROLOGIC ANALYSIS

24-Hour Design Storms

A hydrologic analysis was performed to determine preliminary floodplain elevations for the 24-hour, 2-year (50% annual chance), 25-year (4% annual chance) and 100-year (1% annual chance) rainfall events at each karst feature (sinkhole, spring, depression or lake) for existing and future conditions. Table 3 shows rainfall amounts for each storm event.

Table 3. 24-Hour Rainfall Depths

Rainfall Event Frequency	24-Hour Rainfall Depth (in)
2-year	3.3
25-year	5.5
100-year	6.6

Elevation-area relationships were determined for each feature using 1-inch = 200 feet topographic maps of the area provided by KGIS. Elevation-storage relationships were calculated using the Conic Method for Reservoir Volumes (HEC, 1990). Floodplain elevations were determined by linear interpolation of the runoff volume of a feature's drainage area with its elevation-storage relationship. Water surface elevations in features known to impound water during dry periods estimated from spot elevations given on KGIS topographic maps or site plans. The loss of storage due to impounded water was considered in this analysis.

Due to the lack of data on discharge capacity of the sinkhole throats, the analysis was performed assuming zero discharge to the subsurface environment. If the storage capacity of the sinkhole was exceeded (i.e., the sinkhole was flooded), the excess volume of runoff was added to next downstream sinkhole. Surface drainage pathways were established based upon topographic maps and field observations during the April 1998 storm event.

Runoff volumes were determined using the SCS curve number procedures as outlined in TR-55. Drainage areas for each feature were delineated using 200-scale topographic mapping. Mapping of the hydrologic soil groups in the study area by NRCS was in progress, but was not complete at the time of this analysis. Hydrologic soil groups vary from A for sandy, well-drained soils to D for clayey, poorly drained soils. NRCS personnel familiar with the study area estimated that 50% of the soils in the study area were Type B, 20% Type C, and 30% Type D. Based on this information, a Type C soil was assumed for the study area. Average antecedent soil moisture conditions (AMC II) were assumed. Existing landuse data was determined from existing KGIS topographic maps and was field verified. Future landuse for existing undeveloped areas was determined using the 15-year Development Plan for the Northwest Sector developed by MPC. Drainage basin areas, and existing and future curve numbers are given in Table 4.

The 100-year floodplain elevations for existing and future conditions for the 24-hour storm are listed in Table 5.

Table 4. Drainage Basin Areas and Curve Numbers

Basin/Sink ID	Area (acres)	Existing Condition CN	Future Condition CN
CB1	6.7	93	93
CB2	16.1	87	92
CB3	25.1	82	86
CB4	15.1	77	88
CB5	16.9	77	88
CB6	17.9	76	89
CB7	53.1	81	82
CB8	55.0	90	90
CB9	452.8	81	83
CB10	23.2	Not analyzed	89
CB11	97.4	72	Not analyzed
CB12	14.8	85	Not analyzed
DS1	33.3	75	80
DS2	1.6	70	70
DS3	4.0	70	81
DS4	20.5	80	80
DS5	3.8	79	79
DS6	6.7	84	85
DS7	301.4	81	81
DS8	4.8	79	79
DS9	136.6	82	84
DS10	20.3	75	89
DS11	4.1	70	88
DS12	6.5	85	91
DS13	2.6	70	91
DS14	17.9	79	79
DS15	15.9	77	81
DS16	7.2	76	83
DS17	25.7	72	79
DS18	3.8	74	80
DS19	16.6	79	79
DS20	44.7	73	89
DS21	11.8	79	79
DN1	229.6	80	81
DN2	50.9	81	81
DN3	9.4	81	81
DN4	7.0	81	81
DN5	10.0	75	86
DN6	6.5	79	79
DH1	15.9	74	91
DH2	213.3	79	84
DH3	25.7	96	96
DH4	17.2	76	94
DH5	14.9	70	93
DH6	22.6	72	92
DH7	26.3	71	93
DH8	3.9	70	92
DH9	47.8	78	90
DH10	10.4	75	91
DH11	11.6	78	Not analyzed

Hydrologic Analysis of the April 1998 Flood

Rainfall totals, existing condition runoff curve numbers, and surveyed HWMs were used to perform hydrologic analysis of the April storm event. This analysis was performed to gain some insight into the rainfall runoff process and the surface to subsurface drainage characteristics of the study area during extreme events.

Existing condition curve numbers determined for the design storm analysis were adjusted for AMC III (wet) conditions to account for the saturated soil conditions that existing prior to the April rainfall event. The analysis was performed assuming zero discharge to the subsurface environment, however, surface overflow (i.e., flooding) from one sinkhole to another was considered as appropriate. Therefore, the analysis was volume based and did not consider hydrograph timing.

A total rainfall depth of 8 inches was used in the analysis. This rainfall depth was determined by examining rainfall records for the period, NEXRAD radar imagery, and local resident accounts of the storm. When a highwater elevation was known, the upstream area was analyzed by converting rainfall to runoff using SCS procedures. The resulting runoff volume was compared to the storage volume provided at the high water elevation and the difference was considered loss either through overflow or flow through the sinkhole. If a highwater elevation was not known, the analysis proceeded in the same manner as the design storm.

Table 5 shows a comparison of floodplain elevations from the existing and future 100-year events with elevations surveyed and/or calculated for the April, 1998 event. Table 5 also presents additional information, such as drainage area, lip elevation (i.e., the highest elevation defining the sinkhole based on existing mapping), and upstream/downstream karst features.

Table 5. Sinkhole Analysis Summary

Sink	D.A. Size (acres)	Lip Elev (ft)	Runoff volume to spill (inches)	Existing 100-yr WSEL (ft)	Future 100-yr WSEL (ft)	April 1998 WSEL (ft)	Upstream Basins	Spills to
CB1	6.7	940.0	9.0	936.4	936.4	938.8[3]	--	--
CB2	16.1	934.0	1.3	934.5	934.5	935.7[1]	--	CB3
CB3	25.1	934.0	4.5	934.5	934.5	935.7[1]	CB2	--
CB4	15.1	930.0	48.2	930.5	930.5	929.0[2]	CB6	CB5
CB5	16.9	924.0	15.6	924.5	924.5	924.5[3,4]	CB4	--
CB6	17.9	932.0	5.3	932.5	932.5	931.8[1]	CB9,CB8	CB4,CB7
CB7	53.1	932.0	4.9	932.5	932.5	931.8[1]	CB6	--
CB8	55.0	950.0	0.2	950.5	950.5	950.5[3,4]	--	CB6
CB9	452.8	949.0	1.7	949.5	949.5	949.6[1]	--	CB6
CB10	23.2	930.0	10.2	Not Analyzed	928.0	Not Analyzed	--	--
CB11	97.1	Not Analyzed					--	--
CB11	14.8	Not Analyzed					--	--
DS1	33.3	942.0	11.6	938.5	939.3	941.7[3]	DS3, DS4	--
DS2	1.6	1012.0	16.2	996.6	996.6	999.5[3]	--	--
DS3	4.0	950.0	1.7	950.5	950.5	950.5[3,4]	DS4	DS1
DS4	20.5	942.0	0.2	942.5	942.5	942.5[3]	--	DS3
DS5	3.8	940.0	2.0	940.5	940.5	940.5[2]	--	DS6
DS6	6.7	940.0	5.7	940.5	940.5	940.5[2]	DS5	DN1
DS7	301.4	940.0	10.4	936.4	936.6	940.1[1]	DS5, DS6, DS8, DS9, DS14, DS15, DS16, DN1, DN2	--
DS8	4.8	944.0	3.7	944.5	944.5	944.5[3,4]	DS9, DS14, DS15, DS16	DS7
DS9	136.6	944.0	4.3	944.5	944.5	944.0[2]	DS14, DS15, DS16	DS8
DS10	20.3	960.0	11.9	955.0	956.3	957.4[3]	--	--
DS11	4.1	978.0	16.1	971.3	972.8	976.3[3]	DS12	--
DS12	6.5	974.0	5.5	973.5	974.5	974.5[3,4]	--	DS11
DS13	2.6	976.0	10.9	970.8	972.9	973.6[3]	--	--
DS14	17.9	964.0	3.4	964.5	964.5	964.5[3,4]	DS15, DS16	DS9
DS15	15.9	970.0	4.7	969.6	970.5	970.5[3,4]	DS16	DS14
DS16	7.2	976.0	3.3	976.5	976.5	976.5[3,4]	--	DS15
DS17	25.7	984.0	30.6	974.4	974.9	977.3[3]	DS18, DS19	--
DS18	3.8	990.0	2.5	990.5	990.5	990.5[3,4]	--	DS17
DS19	16.6	984.0	1.1	984.5	984.5	984.5[3,4]	--	DS17
DS20	44.7	996.0	12.0	989.7	991.1	992.2[3]	--	--
DS21	11.8	1040.0	19.3	1032.0	1032.0	1034.2[3]	--	--
DN1	229.6	940.0	2.1	940.5	940.5	940.5[2]	DS5, DS6	DS7
DN2	50.9	944.0	1.3	944.5	944.5	944.0[2]	--	DN2
DN3	9.4	964.0	14.3	954.8	952.2	960.0[2]	--	--
DN4	7.0	988.0	15.3	980.9	980.9	983.3[3]	--	--
DN5	10.0	1024.0	14.2	1015.2	1016.7	1018.7[3]	--	--
DN6	6.5	1034.0	14.7	1027.3	1027.3	1029.8[3]	--	--
DH1	15.9	962.0	8.1	959.5	960.7	961.3[3]	--	--
DH2	213.3	944.0	16.1	938.8	939.7	939.5[2]	DH3, DH4, DH5, DH6, DH8, DH9	--
DH3	25.7	956.0	7.4	955.3	955.3	956.5[3,4]	--	DH2

Sink	D.A. Size (acres)	Lip Elev (ft)	Runoff volume to spill (inches)	Existing 100-yr WSEL (ft)	Future 100-yr WSEL (ft)	April 1998 WSEL (ft)	Upstream Basins	Spills to
DH4	17.2	956.0	2.1	956.5	956.5	956.5	--	DH2
DH5	14.9	952.0	2.5	952.5	952.5	952.5[3,4]	--	DH2
DH6	22.6	952.0	1.5	952.5	952.5	952.5[3,4]	--	DH2
DH7	26.3	976.0	5.7	972.3	976.5	976.5[3,4]	--	--
DH8	3.9	970.0	3.0	970.5	970.5	970.5[3,4]	--	DH9
DH9	47.8	962.0	2.1	962.5	962.5	962.5[3,4]	DH8	DH2
DH10	10.4	976.0	6.9	973.7	975.0	976.5[3]	--	--
DH11	11.6	Not Analyzed					--	--

Notes:

Runoff volume to spill is based on direct contributing drainage area and does not include potential overflow from other sinkholes or resurgence. Existing and Future WSELs are based on 24-hour storms.

1 Surveyed Elevation
2 Estimated from Field Information
3 Calculated
4 Calculated to Spill (Elevation assumed equal to 6 inches above lip elevation)

Summary of Analysis

The preliminary analysis indicates the April 1998 water surface elevations were equal to or exceeded the existing and future 100-year WSELs for the majority of the sinks. This can be attributed to the volume of rainfall. The April 1998 rainfall volume was significantly more than the 24-hour 100-year event and the strict volume of runoff was used to calculate high water elevations. Therefore, a storm duration of 24 hours may not be appropriate for sinkhole analysis in this area.

Factors other than direct runoff should also be considered based on observations of the April storm. Resurgence was observed at several sinkholes, noticeably at DS7, CB2/CB3 and DN3. Therefore, additional water contributed to these highwater elevations other than direct runoff. In some cases, especially DS7, the high water from the April storm was probably a reflection of the groundwater table. The length of time required for water to recede also indicates a significant groundwater influence on flood elevations.

Because of the difficulty in assigning an appropriate frequency and duration to the design storm to predict flooding in the Dutchtown Road area, the April storm will be used to evaluate flood solution alternatives.

ALTERNATIVE ANALYSIS

In meetings with Ogden personnel, Knox County officials identified three goals for the study area:

1. Provide alternatives to reduce the flood potential for roads and structures flooded or threatened during recent events;
2. Find ways to reduce overall flood elevations in sinks that tend to flood, and;
3. Find ways to increase the rate at which water drains in Sink DS7.

A number of potential remedial alternatives for flooding in the study area were considered in response to these goals. The alternatives, listed according to the objective they would achieve, are:

Objective 1 (Protect Buildings and Roads):

- Raise road elevations;
- On-site protection of buildings, and;
- Buy flooded property.

Objective 2 (Modify Runoff or Storage Volume):

- Pump and store off-site (i.e., in other sinks or depressions that may have available storage area);
- Improve/increase onsite storage capacity;
- Detain runoff upstream of sink, and;
- Divert flow overland to off-site storage area.

Objective 3 (Increase Discharge Efficiency):

- Find and improve sinkhole throat(s).

One alternative that should be considered for all study areas is the "No Action" option. This alternative simply means that the County and public choose to accept occasional flooding in certain areas. A no action alternative may be appropriate for areas where the flood relief benefits of other alternatives are greatly diminished by other factors, such as cost, maintenance requirements, public unpopularity, or inconvenience.

Alternatives for flood relief were considered for each area known to have experienced flooding during past storm events. These areas are:

- Pensacola Road;
- the Cedar Bluff Road/Walgreens area;
- the Cedar Bluff Road/Fox Lonas Road area; and,
- the Dutchtown Road study area.

All of the potential alternatives listed on the previous page were considered at each location. While each alternative was analyzed as if it were the sole alternative chosen, it should be noted that in some cases the most desirable action to relieve flooding could consist of a combination of two or more alternatives. The alternatives determined to be feasible were analyzed further and are discussed in detail.

Alternative analyses were performed using rainfall data collected at the Gallaher View rainfall gage and surveyed high water marks from the April 1998 storm event. Area, volume, and elevation data were obtained from 1" = 200' topographic maps having 2 ft contours. An appropriate Factor of Safety (FS) was utilized for the analysis and preliminary design of each alternative. An appropriate FS is used to allow for increased flows or runoff volumes that may result from larger storm events, future development, etc. For design of culverts, channels or pumps, an additional 25% was added to the peak flow used for design. For alternatives in which volume and water surface elevation were important (e.g., for excavation volumes, flood protection structure elevations), an additional 1 ft. was added to the design elevation.

Pensacola Road Alternatives

Pensacola Road, shown in Figure 6, is located at the eastern end of the Gulf Park subdivision, and runs through the western end of the CB7 sinkhole. The road provides access to the Gulf Park's tennis and pool facilities and a five-house subdivision currently under construction at the end of the road. Topographic maps show an elevation of 926.4 ft at the lowest point on Pensacola Road. The peak flood elevation in the area during the April 1998 flood event was surveyed at 931.82 ft. The road remained flooded for approximately one week after the storm event occurred. Two alternatives for flood relief were considered on Pensacola Road:

- *Raise Pensacola Road* **(Alternative A)**
- *Pump water from CB7 to CB4* **(Alternative B)**

Alternative A – Raise Pensacola Road

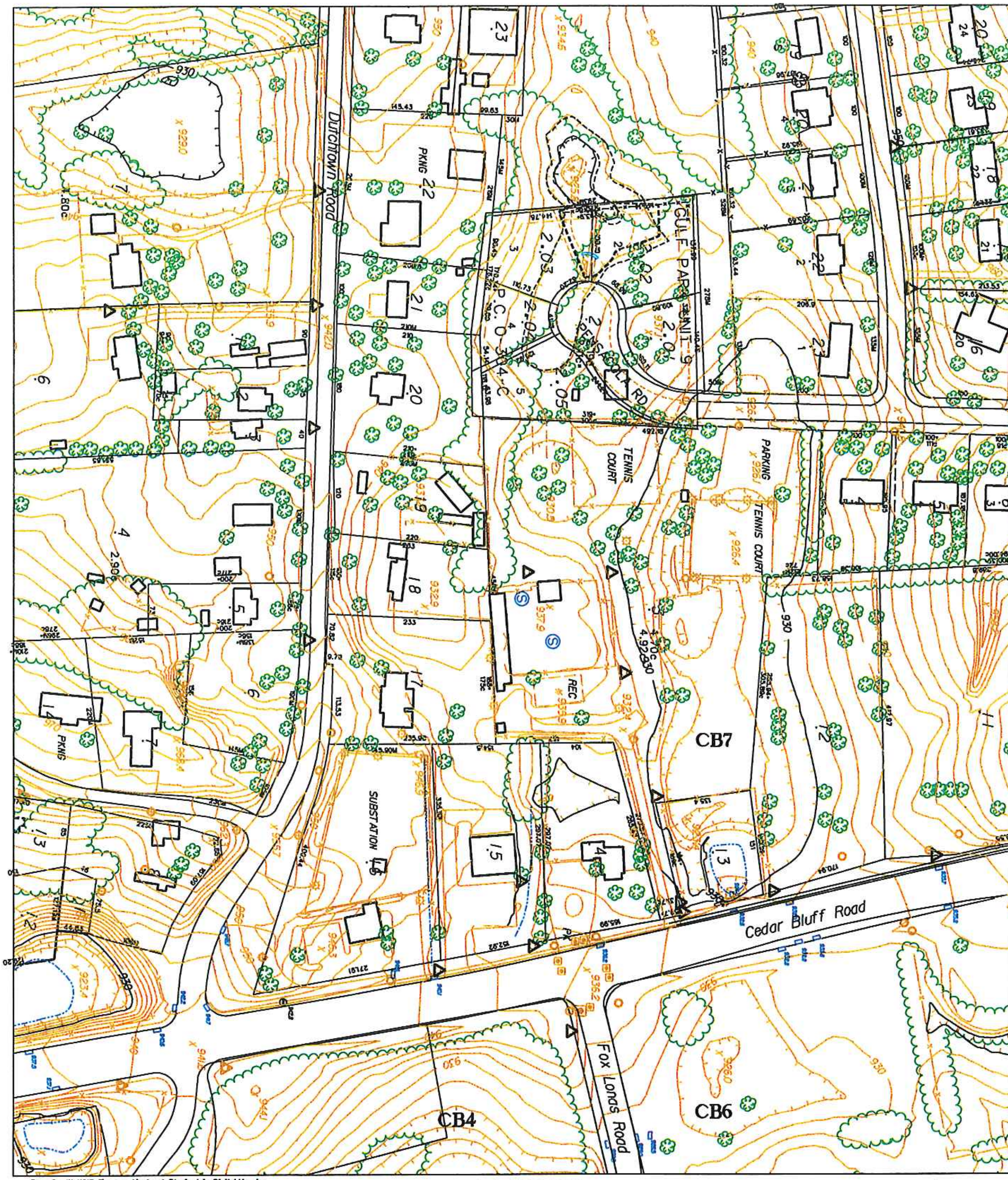
Alternative A requires raising the top-of-road elevation 1-foot above the peak flood elevation. If no other alternative to lower peak flood elevations is used in combination with raising the road, the design top-of-road elevation is 932.8 ft, which is 1 foot above the high water elevation experienced in April 1998. Alternatives that affect the highwater elevation in CB6 will also affect highwater elevations at Pensacola Road because flooding was caused by backwater from CB6. In addition to removal and replacement of utilities in the portion of the raised road, this alternative will require installation of a culvert to allow drainage under the new road and redesign and construction of a new entrance drive to the Gulf Park subdivision pool and tennis facilities.

The advantage(s) of Alternative A are:

- Flooding of the road will be eliminated.

The disadvantage(s) of Alternative A are:

- Raising the road alone will not reduce peak flood elevations.



Base Credit: KGIS Topographical and Planimetric Digital Mapping

Scale :1"=200 FEET

200 0 200 FEET

Figure 6. Location of Pensacola Road.

Alternative B - Pump Excess Water from CB7 to CB4

Alternative B proposes pumping excess runoff from sinkhole CB7 under Cedar Bluff Road and under Fox Lonas Road to sinkhole CB4. A pump station will potentially eliminate flooding on the road and lower the flood stage in sinkhole CB7. A 9,000 GPM pump will be required to lower flood elevations below Pensacola Road. Stormwater would be pumped via approximately 400 ft. of pipe to CB4.

The advantage(s) of Alternative B are:

- Flooding of the road will be eliminated.
- Flood stage would be reduced in CB7.

The disadvantage(s) of Alternative B are:

- The installation of a pump station and force main line will be expensive.
- This alternative requires operation and maintenance of a pump station. There will be some maintenance cost even after construction and installation.

Cedar Bluff Road/Walgreens Area Alternatives

During the April storm flood waters overtopped the sinkholes lips at CB2 and CB3. Two alternatives were considered in detail to lower flood stages within the sinkhole area:

- *Excavate CB3 and CB2 to provide additional storage* **(Alternative A)**
- *Pipe excess water from CB2 and CB3 to CB4* **(Alternative B)**

Alternative A – Excavate CB2 and CB3 to Provide Additional Storage

The objective of Alternative A is to excavate enough volume in within County-owned ROW to provide the storage needed to reduce flood elevations in CB2 and CB3 to 933.0 ft, which is 1 ft. below the lip elevation of both sinkholes. The proposed excavation areas are shown in Figure 7. Volumetric analyses show that it is possible to reduce flood elevations in the area by excavating primarily County ROW located on both sides of Cedar Bluff. There will be a need to acquire a small slope or drainage easement from the Church of the Good Samaritan located on the west side of Cedar Bluff.

The advantage(s) of Alternative A are:

- Peak flood elevations will be decreased due to increased storage volumes in both CB2 and CB3.
- The required excavation is in County ROW.

The disadvantage(s) of Alternative A are:

- Cost of excavation that will likely include substantial rock.

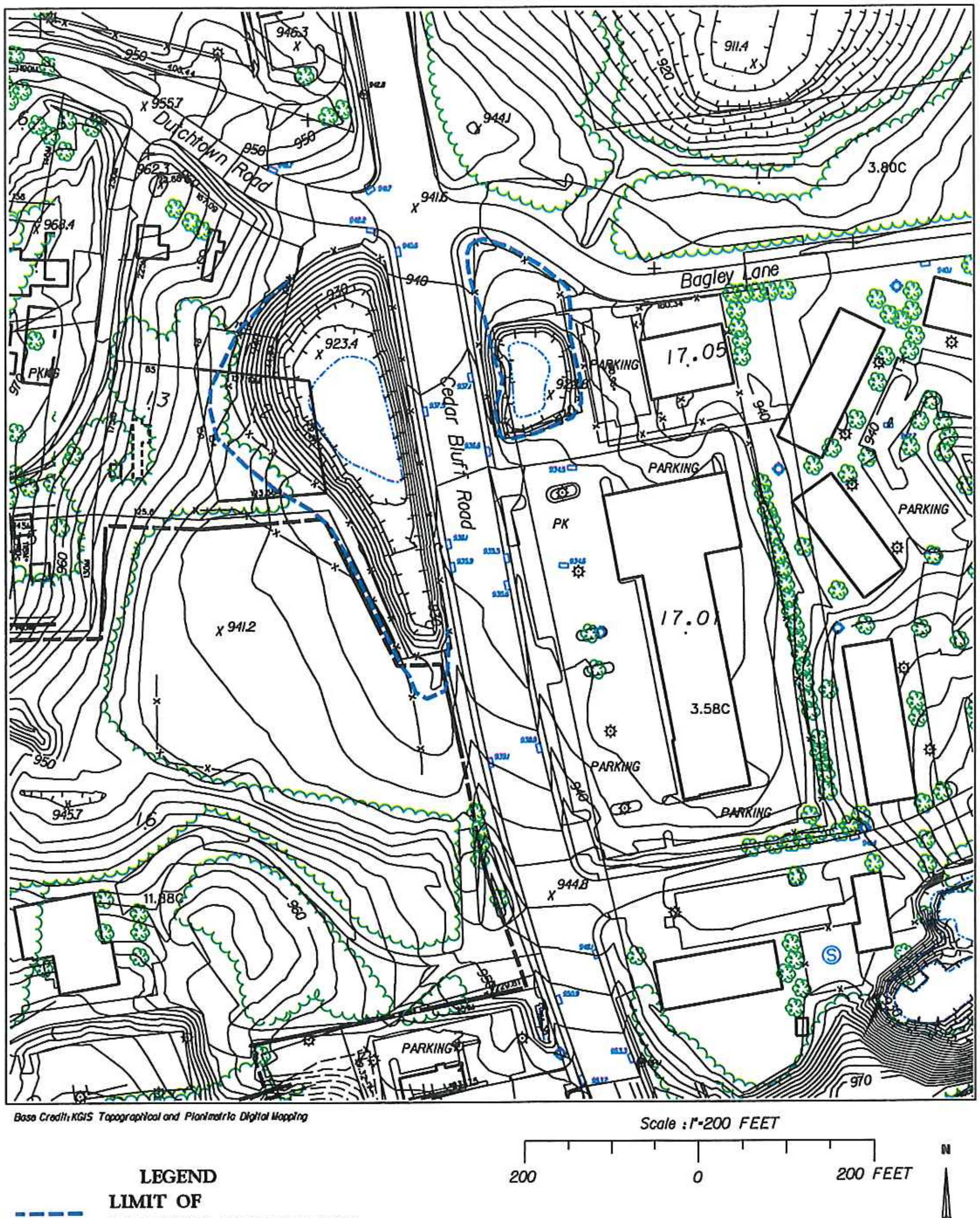


Figure 7. Proposed Excavation Locations in CB2 and CB3 - Alternative A.

Alternative B – Pipe CB2 and CB3 Runoff to CB4

Alternative C involves installing a culvert under Bagley Lane to allow drainage of excess runoff in Sinkholes CB2 and CB3 to Sinkhole CB4. The proposed culvert is a 24-inch RCP with an upstream invert elevation of 932.0 at the north side of CB2 and a downstream invert elevation of 931.25 north of Bagley Lane (See Figure 8). Approximately 4 ac.-ft. of water would be redirected to CB4 under design storm conditions.

The existing street drainage system in the vicinity of the new culvert will need to be reconfigured, and some minor grading and excavation will be required at the downstream end of the culvert to facilitate drainage to CB4.

The advantage(s) of Alternative B are:

- Peak flood elevations are reduced in both sinkholes.
- The County would not be required to purchase land for excavation.
- Construction of the culvert could be performed using County maintenance crews.

The disadvantage(s) of Alternative B are:

- The additional volume of water diverted to Sinkhole CB4 must be considered in alternatives for the Cedar Bluff/Fox Lonas Study area.

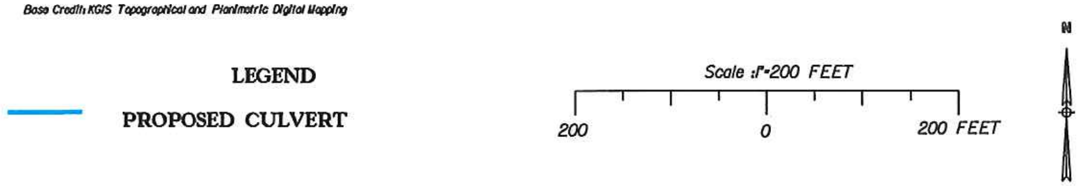


Figure 8. Proposed Culvert from CB2 to CB4 - Alternative B.

Cedar Bluff / Fox Lonas Road Area Alternatives

The area around the intersection of Cedar Bluff and Fox Lonas experienced flooding during the April storms. During that flood event, stormwater in this area was directed to Sinkhole CB4. It was assumed for the purpose of this analysis that CB4 drained at a given rate which reproduced the surveyed high water elevation. Therefore, the preservation of the sinkhole at CB4 as a drainage feature is required for all alternatives. Four alternatives to this flooding were considered in detail for this study:

- *Divert runoff to Sinking Creek, via CB4 and CB5 sinkholes* **(Alternative A).**
- *Divert runoff to Sinkholes CB4 and CB5, and berm CB5 property* **(Alternative B).**
- *Divert runoff to CB4 and CB5 sinkholes and excavate to provide additional storage* **(Alternative C).**
- *Raise Cedar Bluff Road and/or Fox Lonas Road* **(Alternative D).**

Alternative A – Divert Runoff to Sinking Creek, via CB4 and CB5 Sinkholes

Alternative A requires the construction of a channel and pipe system, from CB9 to Sinking Creek. The proposed system was designed to receive excess runoff from Sinkholes CB9, CB8, CB7, CB6, CB2, CB3, CB4 and CB5. It was assumed that runoff from the CB10 drainage basin would be contained in the large detention pond currently under construction for the Knoxville Catholic High School. Excess runoff that would be delivered to the proposed channel if additional alternatives were utilized at other locations (i.e., Pensacola Road – Alternative B, Cedar Bluff/Walgreens – Alternative B) was also considered in the preliminary design. The costs of these alternatives were considered separately.

Figure 9 shows the proposed path of the system, and includes any culverts, channels, and other structures that may be included in the path, both existing and proposed. Table 6 lists, from upstream to downstream, the pipes, culverts, channels and other structures that would require installation or modification.

Table 6. Overflow Channel Structures (Sinkhole CB9 to Sinking Creek)

Item	Existing Configuration	Design Flow or Elevation	Design Configuration
CB9 Spillway	Grass spillway, 4 ft wide	CB9 elevation 949.8 ft	No action
Culvert 1	12-inch CMP	70 cfs	Two 30" RCP's
Channel A	Wide grass swale	70 cfs	No action
CB6 detention pond	South berm elev 932.0 ft	CB6 elevation 929.2	Lower berm to 928.7 ft
Culvert 2	None	90 cfs	42" RCP or box culvert
Channel B	None	60 cfs	Trapezoidal ditch, 6 ft width
Culvert 3	18" to 24" CMP	50 cfs	36" RCP, extend under Condo entrance
Channel C	Trap channel, 3 ft width	50 cfs	Fill
Culvert 4	24" CMP	N/A	Remove, see Culvert 3
Channel D	Trap channel, Approx 2' depth in some places	50 cfs	Regrade as needed to protect condominiums
Culvert 5	1 24" CMP and 2 12" PVC pipes	N/A	Remove culvert
Culvert 6	2 24" CMPs	100 cfs	Two 36" RCP's
Channel E	Trap channel, Approx 0.5' depth		Will not be utilized
Fox Lake	Pool elevation 902 to 903 ft	125 cfs	Rework outlet structure to lower pool elevation

The preliminary design of the system was performed using HEC-1 and HEC-RAS models. A HEC-1 model was created for Sinkholes CB9, CB8, CB7, CB6 and CB4. The model was calibrated using rainfall data and high water elevations collected during the April 1998 storm events. The calibrated model was then used to design the channel and pipe system from CB9 to CB5. A HEC-RAS model was then created to carry the peak flow from CB5, and additional flows from surrounding drainage areas, through the Fox Lake Condominiums and to Sinking Creek.

Flooding on Cedar Bluff Road during the April 1998 storm event was due to overflow from Sinkholes CB9, CB8 and CB7 to the CB6 sinkhole, which is the main detention pond for the All Saints Catholic Church. CB6 does not have the capacity to contain the excess flow from upstream drainage areas, so water backed-up behind the south berm of CB6 and flooded Cedar

Bluff Road. The key element in Alternative A to flood relief on Cedar Bluff is the lowering of the south berm in the CB6 detention pond and allowing runoff to drain to the CB4 / CB5 sinkhole area.

The major complication associated with Alternative A is adding additional stormwater runoff to the Fox Lake Condominium drainage system. Alternative A would require the channels and pipes in the drainage system to be increased in size or replaced. In addition, the normal pool elevation in Fox Lake will need to be lowered approximately three feet to prevent potential flooding at units adjacent to the Lake.

The advantage(s) of Alternative A are:

- The proposed channel system relieves flooding on Cedar Bluff and Fox Lonas Roads, and on Cedar Bluff near Walgreens (i.e., Sinkholes CB2 and CB3). See Cedar Bluff/Walgreens Study Area, Alternative B – page 32.
- The excess runoff is transported off-site via surface drainage features.
- The system takes advantage of available storage in Sinkholes CB6, CB4 and CB5 but does not increase flood elevations. The only excavation of these areas will be grading to facilitate drainage from one sinkhole to another.

The disadvantage(s) of Alternative A are:

- The owners of the Fox Lake Condominiums will have to agree to the changes in the drainage system and this would appear unlikely without compensation.
- There are also potential litigation problems associated with redirecting flood waters through a populated area. If flooding occurs after the project is completed, the flooding will be attributed to the additional water regardless of the cause of the problem.

Alternative B - Divert Runoff to CB4 and CB5 Sinkholes, and Berm CB5 Property

Alternative B requires construction of a pipe and channel system to Sinkhole CB5, and the construction of a berm along Fox Lonas Road to contain the excess runoff delivered to CB5. From Sinkholes CB9 to CB4, the system proposed in Alternative B is identical to that proposed in Alternative A (from the CB9 spillway to Channel B in Table 6), and would receive excess runoff from Sinkholes CB9, CB8, CB7, CB6, CB2 and CB3.

Figure 10 shows the proposed location of the berm constructed along Fox Lonas Road, and the area predicted to flood during a storm event identical to the on that occurred in April 1998. A flood elevation of approximately 925.0 ft would be expected in CB5. The minimum proposed berm elevation is 926.0 ft, and the length is approximately 800 ft. In addition to construction of the channel system and berm, the stormwater drainage system at the corner of Fox Lonas and Park Village Drive will need to be reconstructed. Currently, stormwater is discharged to CB5 via an 18" RCP located near the intersection of the two roads. The estimated invert of this pipe at CB5 was estimated to be approximately 921.0 ft based on field investigation. To avoid flooding the street due to backwater in this pipe, this drainage should be re-directed to drain to Sinking Creek via the ditch in front of the Fox Lake Condominiums.

The advantage(s) of Alternative B are:

- The proposed alternative takes advantage of available storage in Sinkholes CB6, CB4 and CB5. The only excavation of these areas will be channels to facilitate drainage from one sinkhole to another.
- The proposed channel and berm relieves flooding on Cedar Bluff and Fox Lonas Roads, and on Cedar Bluff near Walgreens (i.e., Sinkholes CB2 and CB3).
- Flood problems are not "shifted downstream" to Sinking Creek.

The disadvantage(s) of Alternative B are:

- The County will need to secure an easement for the flooded property in Sinkhole CB5
- Roadway drainage at the corner of Fox Lonas Road and Park Village Drive will need to redirected.

Base Credit: KGIS Topographical and Planimetric Digital Mapping

LEGEND

PROPOSED BERM

PREDICTED FLOODED AREA

PROPOSED HIGH FLOW CHANNEL

Scale :1"=200 FEET

200 0 200 FEET

Figure 10. Predicted Flooded Area for Proposed CB5 Berm - Alternative B

Alternative C - Divert Runoff to CB4 and CB5 and Excavate to Provide Additional Storage

Alternative C requires the construction of a channel and pipe system to Sinkhole CB4 and the excavation of the CB4/CB5 area to provide the additional storage required to contain excess runoff below elevation 922.0. From Sinkholes CB9 to CB4, the system proposed in Alternative C is identical to that proposed in Alternative A (from the CB9 spillway to Channel B in Table 6), and would receive excess runoff from Sinkholes CB9, CB8, CB7, CB6, CB2 and CB3.

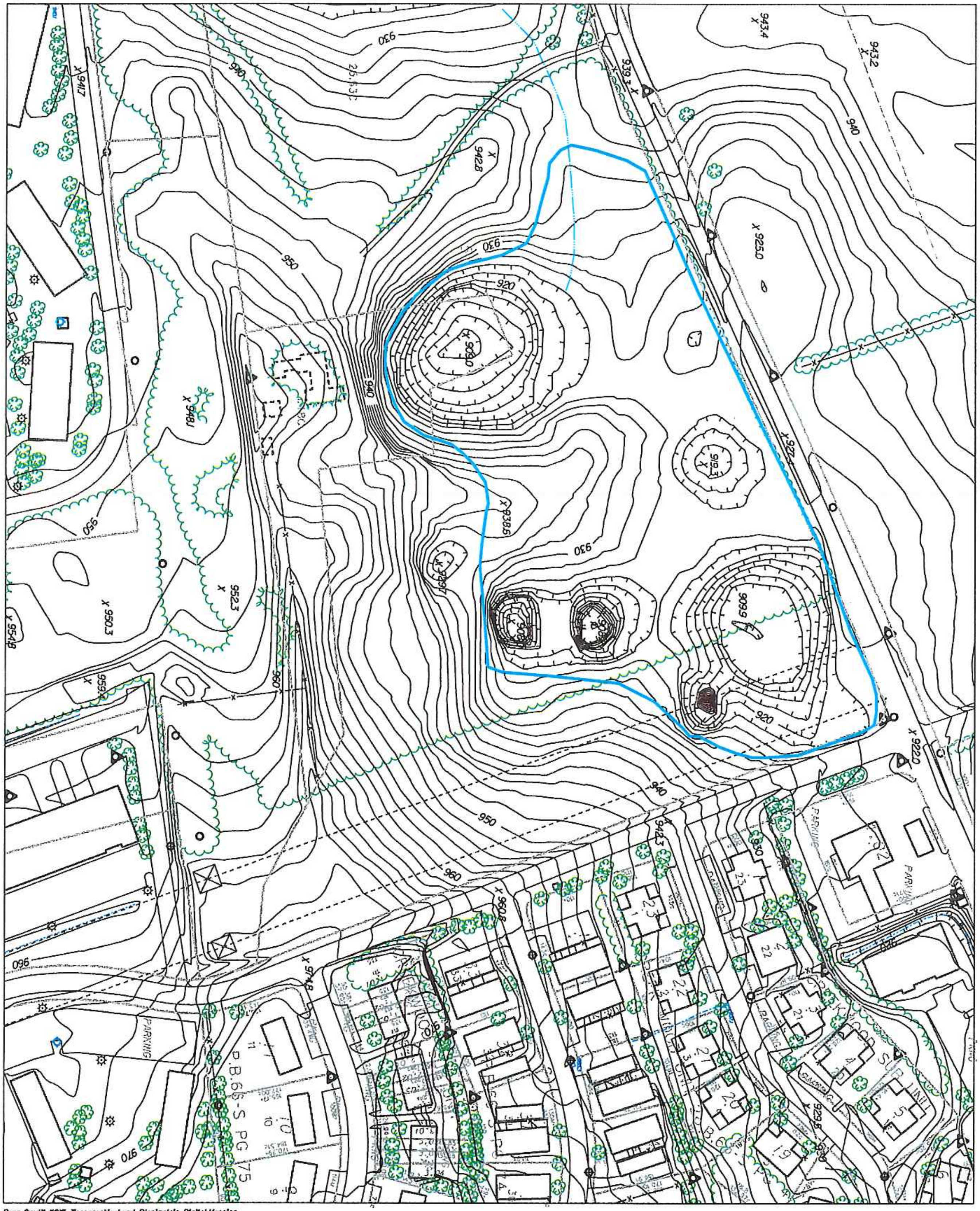
The proposed excavation is located in CB5. Figure 11 shows the proposed area of excavation used for preliminary analysis to determine the feasibility of this alternative. An excavation of approximately 30,000 cu. yd. of material would be required to lower flood stages below Fox Lonas Road. A peak flood elevation of 921.0 ft was calculated for the excavated area using rainfall from the April 1998 storm event.

The advantage(s) of Alternative C are:

- The proposed channel system and excavation relieves flooding on Cedar Bluff and Fox Lonas Roads, and on Cedar Bluff near Walgreens (i.e., Sinkholes CB2 and CB3).
- Flood problems are not "shifted downstream" to Sinking Creek or Ten Mile Creek.

The disadvantage(s) of Alternative C are:

- High cost of excavation.
- The County will need to secure a drainage easement or purchase the property for excavation.



Base Credit: KGIS Topographical and Planimetric Digital Mapping

LEGEND

LIMITS OF PROPOSED EXCAVATION

PROPOSED HIGH FLOW CHANNEL

Scale :1"=200 FEET

200 0 200 FEET

Figure 11. Limits of Proposed Excavation in Sinkhole CB5-Alternative C.

Alternative D – Raise Cedar Bluff Road and Fox Lonas Road

Because flooding in this area was primarily inundation of roads, an alternative to raise the roads above the design flood stage was considered. If no other alternative to lower flood elevations were used in combination with Alternative D, Cedar Bluff Road should be raised to a minimum of 932.8 ft, which is 1 ft. above the peak flood elevation on Cedar Bluff Road after the April 1998 storm event. Fox Lonas Road should be raised to a minimum elevation of 931.5 ft. Removal and replacement of utilities, including reconnection of new storm drains to the existing roadway stormwater drainage system now in place on both roads, will be required in the portion of the raised road.

The advantage(s) to Alternative D are:

- Flooding of roads in this area is relieved.

The disadvantage(s) to Alternative D are:

- Peak flood elevations are not reduced.
- There is a potential to raise flood stages if this alternative is not used in combination with another alternative.
- The cost of roadway construction would be high relative to the benefit.
- Cedar Bluff Road, and to a lesser degree Fox Lonas Road, is a major roadway in west Knoxville. The impact of road closures and detours would be significant on traffic flow in this and surrounding areas.

Dutchtown Road Area Alternatives

The goal of the flood solution alternatives in this area is to keep flood water off of Dutchtown Road and out of existing residential structures. Four alternatives were considered at this location:

- *Raise flooded roads and protect flooded structures* **(Alternative A)**
- *Excavate Sinkhole DS7 to provide additional storage* **(Alternative B)**
- *Buy potentially flooded property* **(Alternative C)**
- *Pump flood water from Sinkhole DS7 to another location* **(Alternative D)**

<u>Alternative A – Raise Flooded Roads and Protect Flooded Buildings</u>

Alternative A encompasses options that provide protection for threatened roads and buildings, but do not decrease the volume of runoff or peak flood elevations. The flood protection options for the Dutchtown Road study area are as follows:

1. Dutchtown Road can be raised above the expected peak flood elevation.
2. Flood protection structures (i.e., floodwalls) can be constructed around threatened residences in the Dutchtown Harbor Community.

<u>Alternative A Part 1 – Raising Dutchtown Road</u>

If no other alternative to lower flood elevations is used in combination with raising the road, the design top-of-road elevation on Dutchtown Road should be 941.5 ft. This elevation is 1 foot above the high water elevation experienced in April 1998. In addition to removal and replacement of utilities in the portion of the raised road, this alternative will require installation of a culvert to allow drainage under the new road to Sinkhole DS7 and the entrance to the Dutchtown Harbor community is relocated to the existing emergency access road. The existing entrance, which floods during extreme events, can be removed and excavated to pre-developed conditions.

Alternative A Part 2 - Floodwalls

Floodwalls can be used to protect structures in the Dutchtown Harbor Community from rising water in the adjacent sinkholes. If no other alternative to reduce peak flood elevations is used in combination with Alternative A, the design top-of-structure elevation for both proposed flood protection structures should be 941.5 ft. Figure 12 shows the footprint of the flood protection structures required to protect the residences. In Dutchtown Harbor, adjacent to the main sinkhole, the proposed floodwall will be 420 ft. in length.

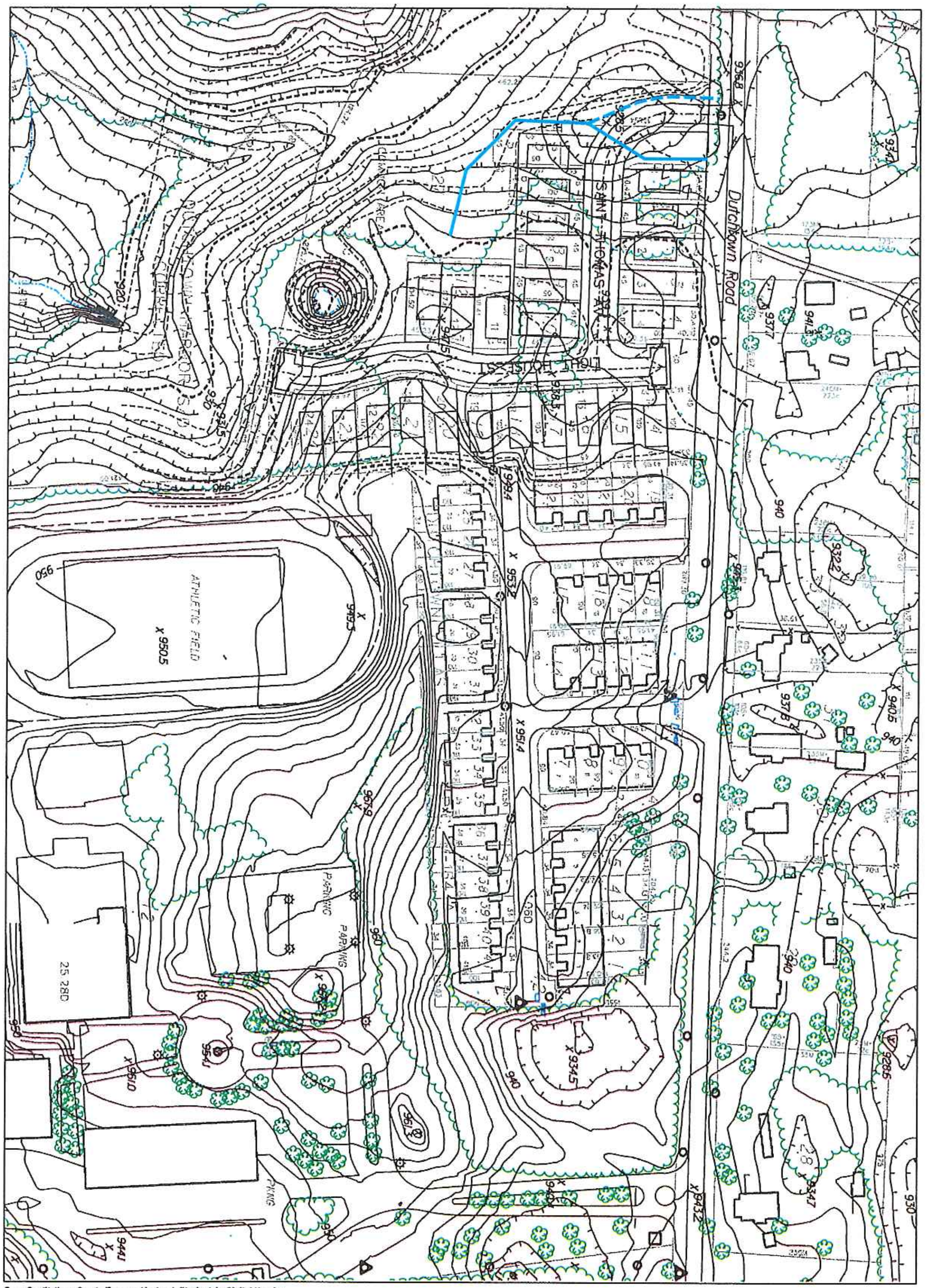
Figure 13 presents a general detail for floodwall design. The design of the wall must not encroach on the existing available storage area and must allow for drainage of runoff from behind the structure (i.e., from the non-flooded side of the structure). Typically, sump pumps are installed to facilitate drainage from behind the wall.

The advantage(s) of Alternative A are:

- Dutchtown Road would not be flooded.
- Potentially flooded structures are protected.
- Knox County has plans to widen Dutchtown Road in the future. Raising the road can be done as part of that project.

The disadvantage(s) of Alternative A are:

- Alternative A does not decrease flood volume or peak elevations.



Base Credit: Knox County Topographical and Planimetric Digital Mapping

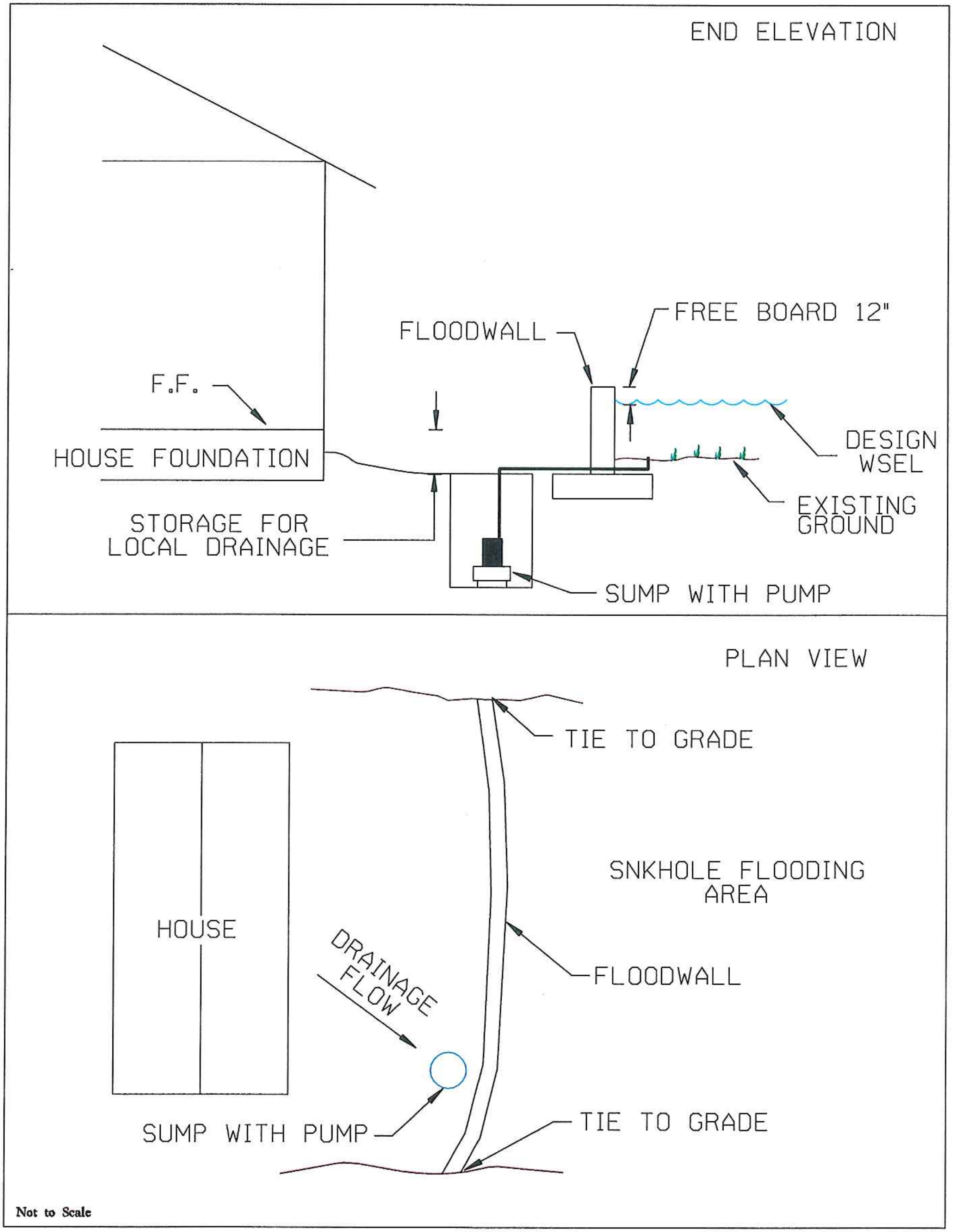
LEGEND

FLOODWALL

ALTERNATIVE LOCATION

200 0 200 FEET

Figure 12. Floodwall Location at Dutchtown Harbor - Alternative A.



Not to Scale

Figure 13. Typical Floodwall Schematic.

Alternative B – Excavate Sinkhole DS7 to Provide Additional Storage

Dutchtown Road floods if peak water surface elevations in Sinkhole DS7 exceed approximately 935.0 ft. The amount of existing undeveloped land that could be utilized for excavation is limited. Undeveloped land exists on both the west and southeast end of DS7. The proposed area of excavation used for the alternative analysis is shown in Figure 14. The amount of excavation and resulting flood elevations are shown in Table 7.

Table 7. Excavation Volumes for Sinkhole DS7, Alternative B

Flood Elevation (ft.)	Required Excavation Volume (cu.-yd.)	Approx. Depth on Dutchtown Road (ft.)
940.5	0.0	5.5
938.0	112,000	3.0
936.0	185,000	1.0
935.0	215,000	0.0

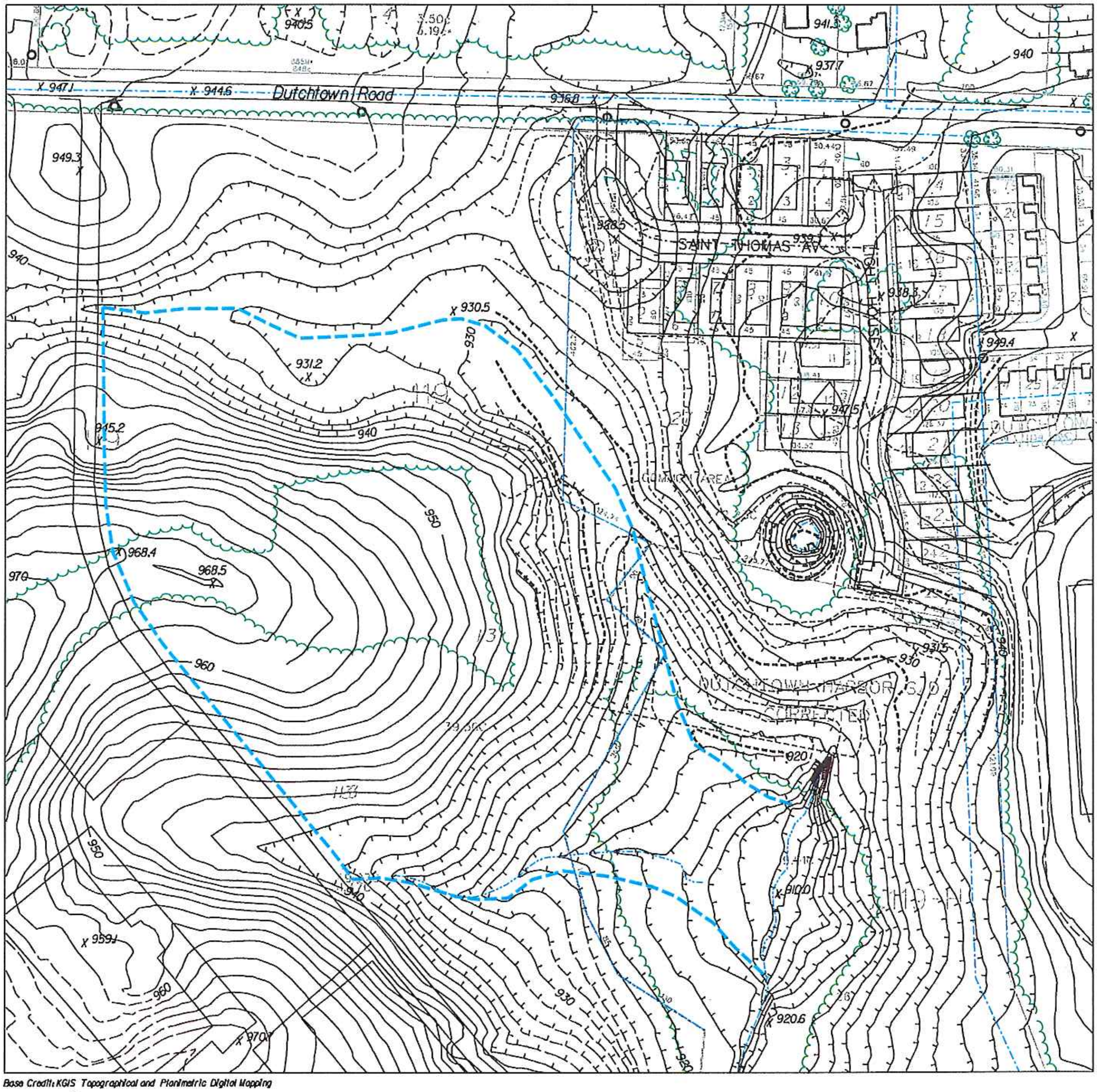
This option could be used in combination with Alternative A (i.e., raising Dutchtown Road). For example, reducing flood elevations to 938.0 ft. would eliminate the potential for flooding at the Dutchtown Harbor condominiums, eliminating the need for a floodwall, and would reduce the design top-of-road elevation for Dutchtown Road to 939.0 ft.

The advantage(s) of Alternative B are:

- Flood elevations are reduced due to the increased storage volume.
- A lower volume excavation could be performed in combination with Alternative A in an effort to reduce flood elevations around residences and eliminate flooding on Dutchtown Road.

The disadvantage(s) of Alternative B are:

- High cost of excavation and property easement or purchase.



LEGEND

LIMITS OF ANALYZED EXCAVATION

Scale : 1"=200 FEET

200 0 200 FEET

N

Figure 14. Analyzed Excavation area in sinkhole DS7-Alternative B.

Alternative C - Buy Potentially Flooded Property

This alternative addresses the option of purchasing property threatened by flooding during the April 1998 event. The County would need to purchase the property located on the parcels J.119-H 5 and J.119-H 6 in Dutchtown Harbor. Figure 15 shows the locations of these properties.

The advantage(s) of Alternative C are:

- Flooded structures are no longer residences.

The disadvantage(s) of Alternative C are:

- Alternative C does not decrease flood volume or peak elevations.
- Flooding on Dutchtown Road has not been addressed.

Alternative D - Pump Floodwater From Sinkhole DS7 to Another Location

Pumping water from DS7 would lower peak flood stages. The size of pump to remove water from the sinkhole at an efficient rate is very large. To lower the peak flood stage at a rate of one-half foot per hour a 30,000 GPM pump would be required.

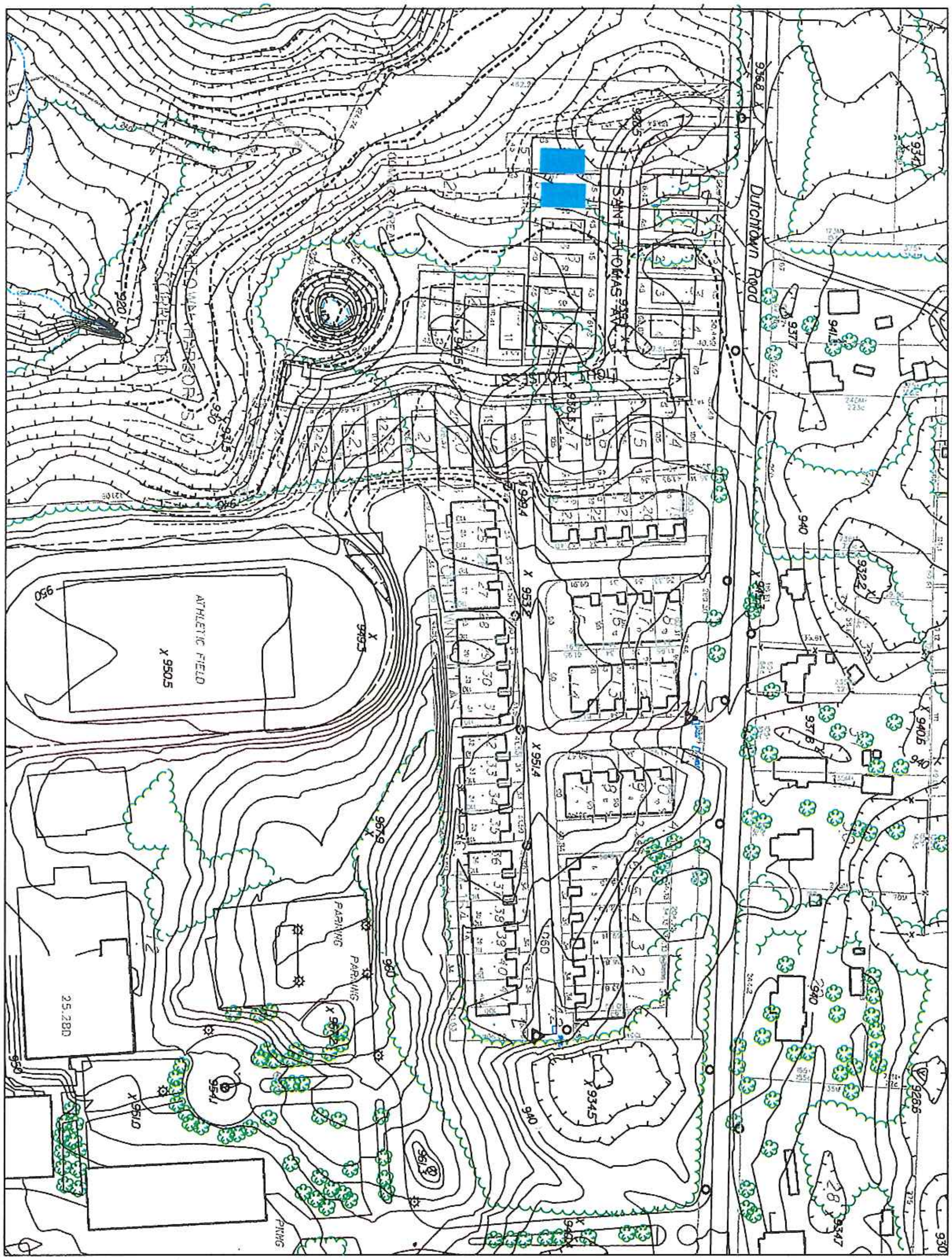
The required pump would be a high volume low head axial pump. The destination of the pumped stormwater is also a concern. To pump water to the nearest surface drainage feature, Sinking Creek, would require over two miles of force main pipe and five pump stations to overcome friction losses. Because of the size of pump, number of pump stations, and length of pipe this alternative will be very expensive.

The advantage(s) of Alternative D are:

- Lower flood elevations.

The disadvantage(s) of Alternative D are:

- High cost and maintenance.



Base Credit: KGIS Topographical and Planimetric Digital Mapping

Scale :1"=200 FEET

200 0 200 FEET

LEGEND

PROPOSED PROPERTY FOR PURCHASE

Figure 15. Proposed Property for Purchase at Dutchtown Harbor - Alternative C

COST ESTIMATE

Cost estimates for each alternative were developed and are presented. Costs are in present day (1998 dollars) and include all projected construction and engineering costs. Engineering costs were estimated as eight percent (8%) of construction costs. The estimates are based on the design concept plans and should be used for planning purposes only. Table 8 provides a summary of costs for each alternative at each location. Detailed cost estimate information is provided in Appendix B.

Table 8. Alternative Cost Estimate Summary

Pensacola Road Area	
Alternative	Estimated Cost
A. Raise Road	$83,025
B. Pump to CB4	$194,400
Cedar Bluff Walgreens Area	
Alternative	Estimated Cost
A. Excavate CB3 and CB2	$246,430
B. Pipe to CB4	$25,380
Cedar Bluff/Fox Lonas Area	
Alternative	Estimated Cost
A. Divert Runoff to Sinking Creek	$254,610 [a]
B. Divert Runoff and Berm CB5 property	$157,730 [b]
C. Excavate CB5 property	$1,062,230 [c]
D. Raise Cedar Bluff Road and Fox Lonas Road	$503,820
Dutchtown Road Area	
Alternative	Estimated Cost
A1. Raise Road	$290,795
A2. Construct Floodwalls	$54,000
B. Excavate	$3,606,770 [c]
C. Buy Flooded Property	$259,200
D. Pump Floodwater	$2,808,000

[a] Costs do not include potential compensation to Fox Lake for easements.

[b] Costs do not include drainage easement.

[c] Costs do not include property purchase or easement acquisition.

RECOMMENDATIONS

The recommended site specific alternatives in the Dutchtown Road Study Area are summarized in Table 9.

Table 9. Recommended Alternatives

Location	Recommended Alternative	Estimated Cost
Pensacola Road	A. Raise Road	$83,025
Cedar Bluff and Walgreens	B. Pipe to CB4	$25,380
Cedar Bluff and Fox Lonas	B. Divert Runoff and Berm CB5 property	$157,730
Dutchtown Road	A1 Raise Road & A2 Construct Floodwalls	$344,795
	Total Cost	$610,930

In general, the lowest cost alternative was chosen at a location if it provided a benefit equal to or greater than other alternatives. Excavation and pump stations were not recommended primarily because of the high cost associated with these alternatives. The primary objective of eliminating roadway flooding for the design event was accomplished with the selected alternatives. Because of the geologic and topographic restrictions in the Dutchtown Study Area reducing flood stages by diverting stormwater to a surface drainage feature would require pumping or channeling through highly populated areas. These options were found to be very expensive and have a low feasibility for implementation.

Establishing Floodplain Elevations

Given the extremely wet antecedent conditions and the historic rainfall amounts associated with the April 1998 event, this event should be considered the historic flood for the area and associated floodplain elevations should be used as the "FEMA 100-Year" base flood elevations. In areas where flood elevations were not surveyed or estimated, floodplain elevations should be estimated using an equivalent rainfall event of 8 inches and no outflow from the sinkhole. The 8-inch rainfall is equivalent to a 2-day 100-year rainfall event for Knox County according to TP-49. Off site drainage from upstream sinkholes that would flood for the 8-inch event should also be considered. In general, one foot of freeboard should be used for any capital improvements in the sinkhole areas and an additional 1 foot (total of 2 feet) is recommended for establishing minimum finished floor elevations for habitable structures.

Sinkhole protection

Protecting the available storage volume provided by sinkholes should be standard practice in the Dutchtown Road area. Where sinkholes are the primary outlet for stormwater runoff, it is recommended that the established floodplain elevations be regulated in a similar manner to floodways. Fill operations inside the floodplain elevations should be restricted; blasting in and around sinkholes should be tightly regulated; and filling of any sinkhole throats should be prohibited.

Sinkhole Throat Maintenance

Several key drainage sinkhole throats in the area were found to be filled with sediment and debris. These locations include:

- The sinkhole throat in DS7 west of the new CAK entrance;
- The main sinkhole throat in DS7 south of Dutchtown Harbor; and
- The sinkhole throat behind the Cedar Bluff Catholic Church rectory on Cedar Bluff.

These sinkhole throats should be cleared and cleaned as soon as possible. A routine maintenance program and inspection after significant runoff events is also recommended for these sinkholes. Throat maintenance can then be performed through regular site visits by the County to remove accumulated sediment and debris.

Erosion Control Measures

In areas that drain to sinkholes, sediment and erosion control should have a high priority. High sediment loads can block sinkhole throats, but they can also block underground passages that are not visible from the surface. Conservative design and strict enforcement is recommended for erosion control measures in the Dutchtown Road Study Area. Every ton of sediment that is released to the drainage system is a ton of sediment potentially blocking the underground conduit.

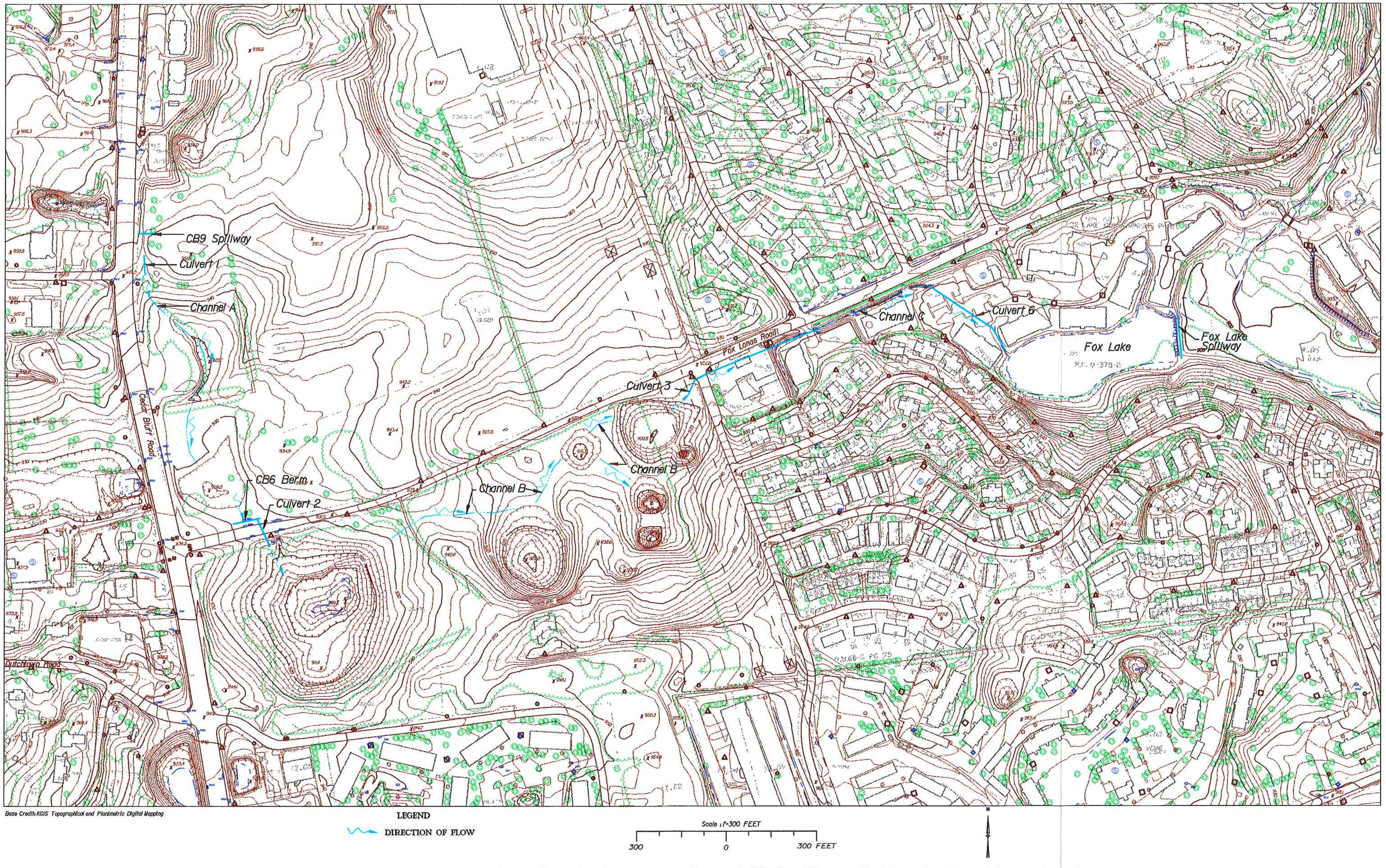
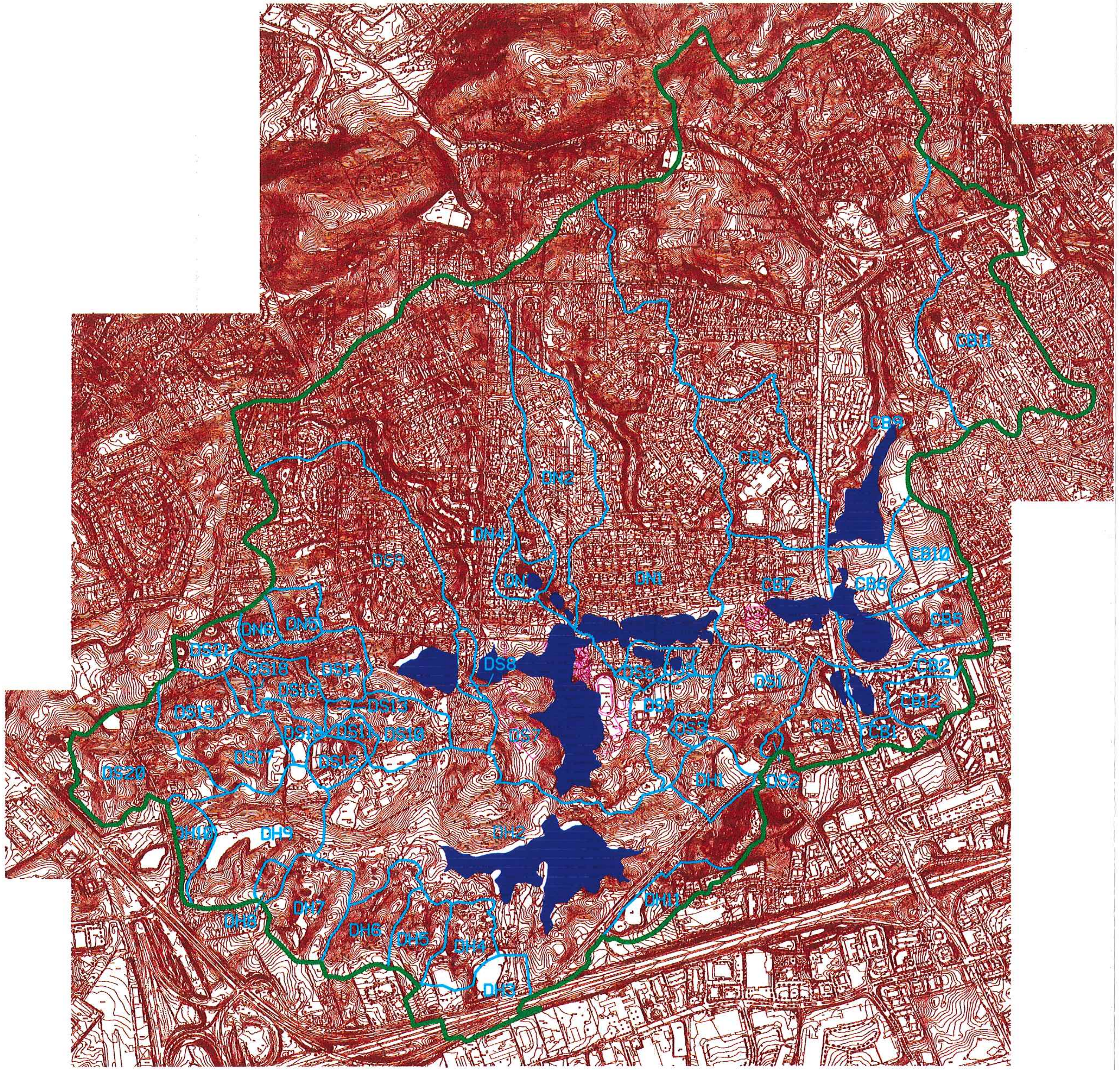


Figure 9. Channel and Pipe System from Sinkhole CB9 to Sinking Creek - Alternative A.

Appendix A



DUTCHTOWN ROAD STUDY AREA

LEGEND

N

DS1 SINKHOLE IDENTIFIER

SINKHOLE DRAINAGE BOUNDARY

STUDY AREA BOUNDARY

FLOOD OF 4-98

SCALE IS GRAPHICAL

0 600 1200 1800 FEET

PREPARED FOR.

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Knox County

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OGDEN ENVIRONMENTAL AND ENERGY SERVICES

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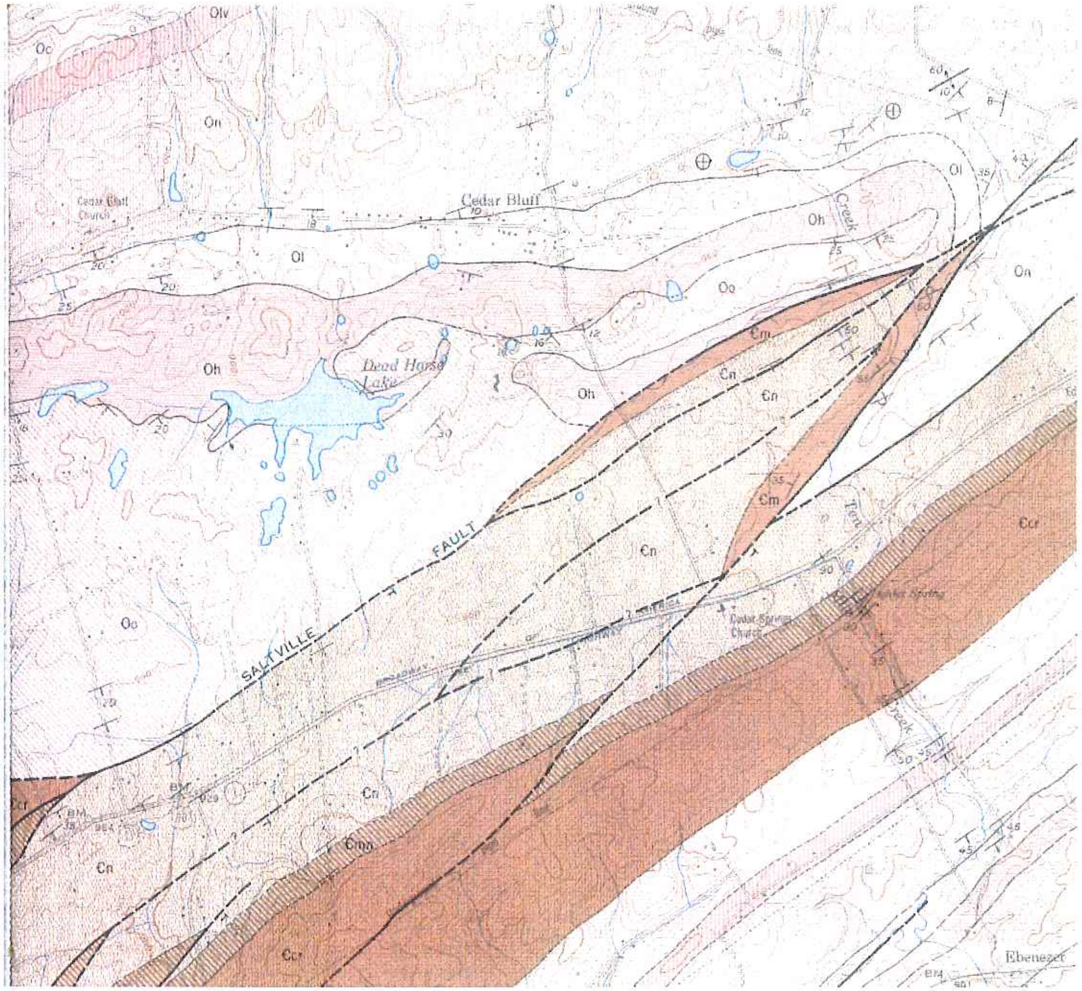
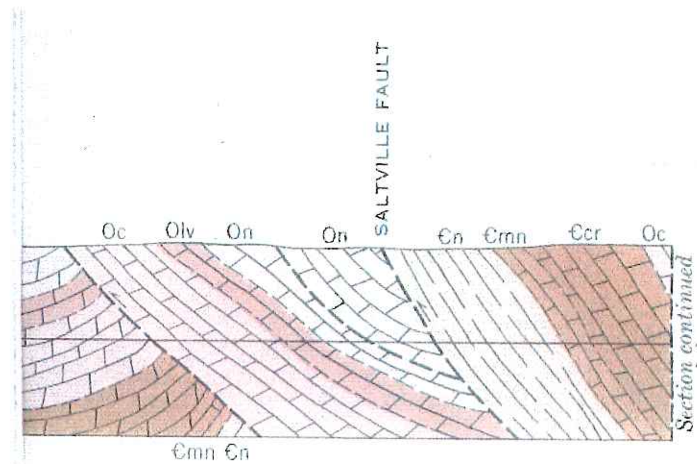
FIGURE A-2. GEOLOGIC MAP OF THE DUTCHTOWN AREA



Cross Section View



Source: USGS Geologic Map of the Bearden Quadrangle, 1960

Appendix B

Pensacola Road - Alternative A - Raise Road

Utilities

Item	Amount	Quantity	Cost per	Cost	
Miscellaneous				$10,000	
				Sub Total	$10,000

Roadway Construction

Item	Amount	Quantity	Cost per	Cost	
Fill	1400	cu.yd	$30	$42,000	
Roadway	800	sq.yd	$25	$20,000	
Culvert (24" RCP)	65	lf	$75	$4,875	
				Sub Total	$66,875

Engineering Costs				**Sub Total**	$6,150
				Total Cost	**$83,025**

Pensacola Road - Alternative B - Pump station

Construction & Materials

Item	Amount	Quantity	Cost per	Cost	
Pump station	1	each	$100,000	$100,000	
Pipe	400	ft	$200	$80,000	
				Sub Total	$180,000
Engineering Costs				**Sub Total**	$14,400
				Total Cost	**$194,400**

Cedar Bluff Road / Walgreens - Alternative A - Excavate					
Excavation					
Item	**Amount**	**Quantity**	**Cost per**	**Cost**	
Cut	5700	cu.yd	$30	$171,000	
Rip-rap	2812	cu.yd	$15	$42,180	
Chain link fence	750	ft	$20	$15,000	
				Sub Total	$228,180
Engineering Costs				**Sub Total**	$18,254
				Total Cost	**$246,434**

Cedar Bluff Road / Walgreens - Alternative B - Pipe to CB4

Construction & Materials

Item	Amount	Quantity	Cost per	Cost	
Culvert (36" RCP)	150	ft	$100	$15,000	
Roadway	50	sq.yd	$50	$2,500	
Curb & gutter	10	ft	$100	$1,000	
Miscellaneous grading				$5,000	
				Sub Total	$23,500
Engineering Costs				**Sub Total**	$1,880
				Total Cost	**$25,380**

Cedar Bluff Rd & Fox Lonas Rd - Alternative A - Channel to Sinking Crk

Culverts & spillways

Item	Amount	Quantity	Cost per	Cost	
Culvert 1 (2 30" RCP, 30 ft)	2	each	$2,250	$4,500	
Culvert 1 grading				$2,500	
CB6 detention berm	100	cu.yd	$30	$3,000	
Rip-rap	85	cu.yd	$30	$2,550	
Culvert 2 upstream grading				$3,500	
Culvert 2 upstream structure				$3,500	
Culvert 2 (42" RCP)	40	lf	$75	$3,000	
Culvert 3 cut				$1,500	
Culvert 3 (36" RCP)	100	lf	$450	$45,000	
Culvert 3 concrete repair	85	cu.yd	$100	$8,500	
Culvert 3 stormdrain rework				$7,500	
Culvert 6 (2 36" RCP, 350 ft)	350	lf	$175	$61,250	
Parking lot replacement	400	sq.yd	$15	$6,000	
Fox Lake berm excavation	420	cu.yd	$30	$12,500	
Berm path replacement	100	sq.yd	$20	$2,000	
				Sub Total	$166,800

Channel Construction

Item	Amount	Quantity	Cost per	Cost	
Channel B excavation	1000	cu.yd	$50.00	$50,000	
Channel B misc. grading				$5,000	
Channel B sod	900	sq.yd	$5.00	$4,500	
Channel D regrade	225	cu.yd.	$30.00	$6,750	
Channel D sod	540	sq.yd	$5.00	$2,700	
				Sub Total	$68,950

Engineering Costs				**Sub Total**	$18,860
				Total Cost	**$254,610**

Cedar Bluff Rd & Fox Lonas Rd - Alternative B - Channel to CB5 Berm

Culverts & spillways

Item	Amount	Quantity	Cost per	Cost	
Culvert 1 (2 30" RCP, 30 ft)	2	each	$2,250	$4,500	
Culvert 1 grading				$2,500	
CB6 detention berm	100	cu.yd	$30	$3,000	
Rip-rap	85	cu.yd	$30	$2,550	
Culvert 2 upstream grading				$3,500	
Culvert 2 upstream structure				$3,500	
Culvert 2 (42" RCP)	40	lf	$75	$3,000	
Miscellaneous excavation				$1,500	
				Sub Total	$24,050

Channel Construction

Item	Amount	Quantity	Cost per	Cost	
Channel B excavation	1000	cu.yd	$50.00	$50,000	
Channel B misc. grading				$5,000	
Channel B sod	900	sq.yd	$5.00	$4,500	
				Sub Total	$59,500

Berm Construction

Item	Amount	Quantity	Cost per	Cost	
Berm	2000	cu.yd	$20.00	$40,000	
Re-route existing stormwater	300	lf	$75.00	$22,500	
				Sub Total	$62,500

Engineering Costs				**Sub Total**	$11,684
				Total Cost	**$157,734**

Cedar Bluff Rd & Fox Lonas Rd - Alternative C - Channel to CB5 excavated

Culverts & spillways

Item	Amount	Quantity	Cost per	Cost	
Culvert 1 (2 30" RCP, 30 ft)	2	each	$2,250	$4,500	
Culvert 1 grading				$2,500	
CB6 detention berm	100	cu.yd	$30	$3,000	
Rip-rap	85	cu.yd	$30	$2,550	
Culvert 2 upstream grading				$3,500	
Culvert 2 upstream structure				$3,500	
Culvert 2 (42" RCP)	40	lf	$75	$3,000	
Miscellaneous excavation				$1,500	
				Sub Total	$24,050

Channel Construction

Item	Amount	Quantity	Cost per	Cost	
Channel B excavation	1000	cu.yd	$50.00	$50,000	
Channel B misc. grading				$5,000	
Channel B sod	900	sq.yd	$5.00	$4,500	
				Sub Total	$59,500

CB5 Excavation

Item	Amount	Quantity	Cost per	Cost	
Excavation	30000	cu.yd	$30.00	$900,000	
				Sub Total	$900,000

Engineering Costs				**Sub Total**	$78,684
				Total Cost	**$1,062,234**

Cedar Bluff Rd & Fox Lonas Rd - Alternative D - Raise Roads

Utilities-- Cedar Bluff Road

Item	Amount	Quantity	Cost per	Cost	
Utilities reloc. Extensive				$50,000	
				Sub Total	$50,000

Roadway Construction - Cedar Bluff Road

Item	Amount	Quantity	Cost per	Cost	
Cut and Fill	4700	cu.yd	$30	$141,000	
Roadway / curb & gutter	3000	sq.yd	$30	$90,000	
				Sub Total	$231,000
Engineering Costs				**Sub Total**	$22,480
			Cedar Bluff Sub Total		**$303,480**

Utilities- - Fox Lonas Road

Item	Amount	Quantity	Cost per	Cost	
Utilities relocation				$40,000	
				Sub Total	$40,000

Roadway Construction - Fox Lonas Road

Item	Amount	Quantity	Cost per	Cost	
Cut and Fill	2350	cu.yd	$30	$70,500	
Roadway	1800	sq.yd	$25	$45,000	
Curb & gutter	2000	lf	$15	$30,000	
				Sub Total	$145,500
Engineering Costs				**Sub Total**	$14,840
			Fox Lonas Sub Total		**$200,340**
				Total Cost	**$503,820**

Dutchtown Road - Alternative A - Raise Road & Floodwall					
A1 Roadway Construction					
Item	**Amount**	**Quantity**	**Cost per**	**Cost**	
Fill	3025	cu.yd	$30	$90,750	
Excavate	3025	cu.yd	$30	$90,750	
Roadway	2850	sq.yd	$25	$71,250	
Condo entrance fill	80	cu.yd	$30	$2,400	
Condo entrance road	225	sq.yd	$25	$5,625	
Condo entrance misc.				$2,400	
Culvert (36" RCP)	50	lf	$100	$5,000	
Culvert (18" RCP)	36	lf	$30	$1,080	
				Sub Total	$269,255
Engineering Costs				**Sub Total**	$21,540
A2 Floodwall Construction					
Item	**Amount**	**Quantity**	**Cost per**	**Cost**	
Floodwall	420	lf	$100	$42,000	
Sumps	4	each	$2,000	$8,000	
Landscaping	4.2	lf/100	$3,000	$12,600	
				Sub Total	$50,000
Engineering Costs				**Sub Total**	$4,000
				Total Cost	**$344,795**

Dutchtown Road - Alternative B - Excavate

Excavation					
Item	**Amount**	**Quantity**	**Cost per**	**Cost**	
Cut	111320	cu.yd	$30	$3,339,600	
				Sub Total	$3,339,600
Engineering Costs				**Sub Total**	$267,168
				Total Cost	**$3,606,768**

Dutchtown Road - Alternative C - Acquire Property

Acquisition Costs					
Item	**Amount**	**Quantity**	**Cost per**	**Cost**	
Dutchtown Harbor #1	1	each	$120,000	$120,000	
Dutchtown Harbor #2	1	each	$120,000	$120,000	
				Sub Total	$240,000
Engineering Costs				**Sub Total**	$19,200
				Total Cost	**$259,200**

Dutchtown Road - Alternative D - Pump station

Construction & Materials

Item	Amount	Quantity	Cost per	Cost	
Pump station	5	each	$200,000	$1,000,000	
Pipe	8000	ft	$200	$1,600,000	
				Sub Total	$2,600,000
Engineering Costs					$208,000
				Total Cost	**$2,808,000**