CATTAIL CREEK WATERSHED STUDY

HOWARD COUNTY, MARYLAND
CAPITAL PROJECT NO. D-1079

KCI PROJECT NO. 01-90074

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1.0 INTRODUCTION

1.1 Authorization

On January 18, 1990, KCI Technologies, Inc. (KCI), formerly Kidde Consultants, Inc. was invited to submit a proposal to provide engineering and surveying services for the preparation of a technical watershed study for the Cattail Creek watershed in Howard County, Maryland. A proposal was submitted to Howard County to perform a hydrologic and hydraulic analysis, conduct field surveying of the stream, preliminarily assess flood hazard mitigation alternatives, and submit a report summarizing the results of the study. KCI's proposal was selected and a purchase order to begin work was issued by Howard County on April 16, 1990. If there are any questions regarding the study presented herein they should be addressed to the Howard County Department of Public Works, Division of Transportation Projects and Watershed Management at (410) 313-2414.

1.2 Overview

The Cattail Creek watershed study began in April 1990. The first step in the study was the collection of all available data applicable to the study. An initial field reconnaissance was conducted during this time to identify the characteristics of the watershed. Following the data collection effort, the hydrologic analysis was performed to compute the discharges for known return periods. The hydrologic results were then used in hydraulic models to compute the water surface elevations for the 100 year storm event. Floodprone structures were identified from the hydraulic results and potential alternatives to reduce the flood hazards were identified.

This report summarizes the Cattail Creek watershed study. Following the next sections describing the study area, the report summarizes each major step of the analysis including hydrology, hydraulics, and selection of alternatives. The summary at the end of the report briefly describes the major points of the study.

1.3 Project Description

This project is located in western Howard County, Maryland (See Figure 1). The mainstem of Cattail Creek runs north to south with its headwaters northwest of the interchange at Route 94 and I-70 and its outfall at the Triadelphia Reservoir. There are twenty tributaries to the mainstem, each of which has up to thirteen second or third order tributaries. The watershed extends as far west as the intersection of Florence Road and St. Michael Road and as far east as the intersection of Burnt Woods Road and Ivory Road.

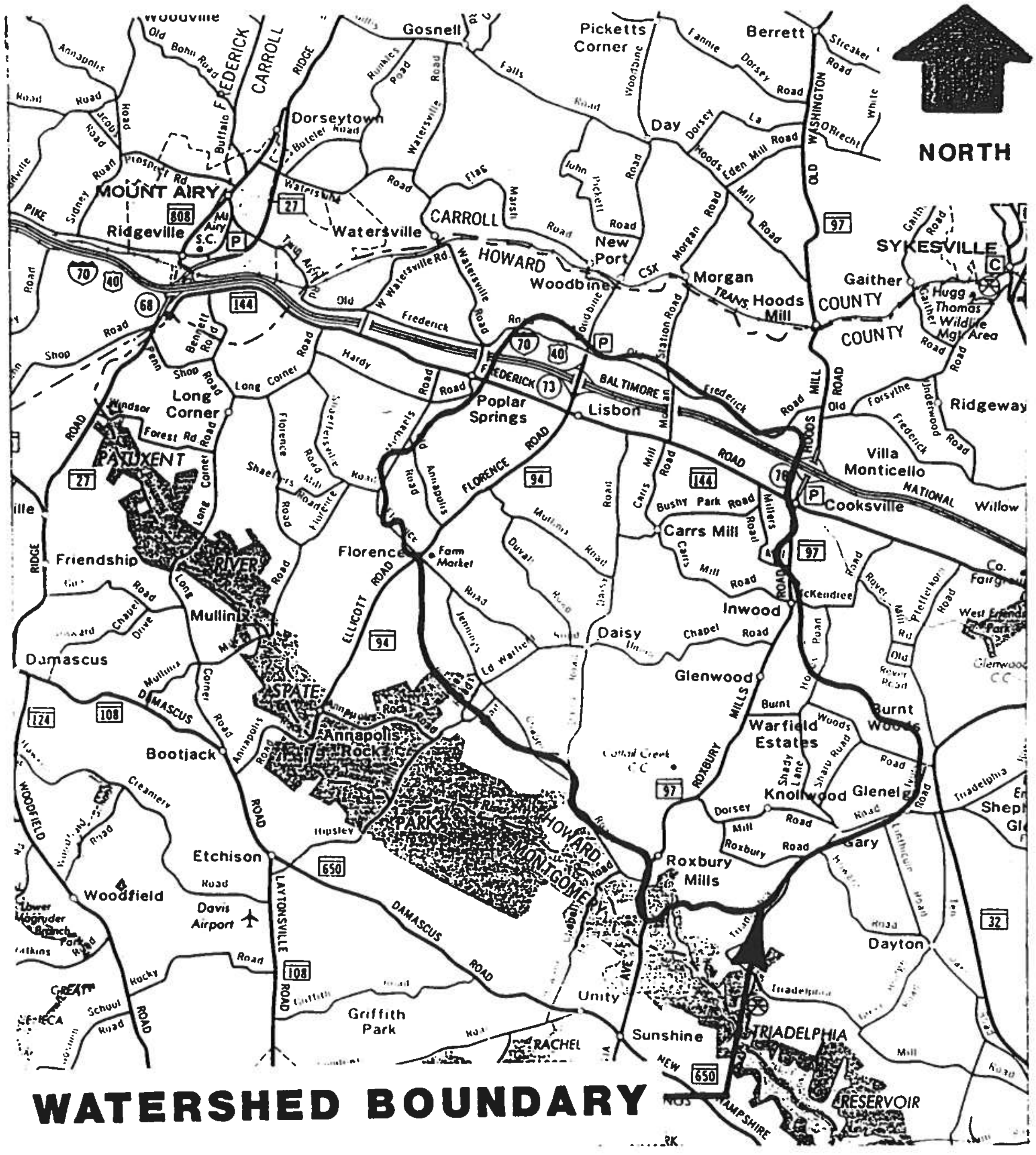


FIGURE NO. 1

Project Location

Scale: 1"=2.2 Miles

1.4 Watershed Description

The Cattail Creek watershed is comprised of approximately 28.3 square miles and has approximately 62 river miles of streams that are part of this study. There are over 80 stream crossings within the watershed ranging from large bridges to small driveway culverts. Cattail Creek is categorized as a Use III, Natural Trout Stream. With the exception of several localized areas of development, the watershed is primarily farmland and pasture with areas of heavy woods interspersed throughout the watershed. A majority of the streams and tributaries are located in areas of heavy underbrush, woods or farmlands. Average channel slope within the watershed is approximately 0.45 percent. The stream channels in this study range from about six feet wide and two feet deep on the smaller tributaries up to about sixty feet wide and ten feet deep where Cattail Creek empties into Triadelphia Reservoir.

As a part of this watershed study, the Maryland Department of Natural Resources (Forest Park and Wildlife Service) and the Maryland Historical Trust were contacted to determine whether any special environmental or cultural resources are located within the area of the Cattail Creek watershed. There are no known Federal or State threatened of endangered plant or wildlife species within the Cattail Creek watershed, however, the State's threatened and endangered species database does show four species of flora and one species of fauna in the general area of the watershed. The State also noted that the forested areas on the project site may be utilized as breeding areas by Forest Interior Dwelling Birds.

The Maryland Historical Trust identified ten known archeological sites in or near the Cattail Creek watershed. Since little archeological work has been done to date in the project area there is good potential that other undocumented sites exist in the study area. There are approximately 35 known historic properties and two known National Register buildings within the Cattail Creek watershed. Some of the 35 sites may qualify for National Register status as well.

The Department of Natural Resources and the Maryland Historical Trust noted that any proposed projects within the Cattail Creek watershed should be sensitive to threatened and endangered species, archeological sites, and historic properties. Both agencies asked to be notified of potential conflicts resulting from any proposed projects in the watershed and expressed their interest in working with the County to solve any problems that may arise.

2.0 HYDROLOGY

2.1 Methodology

The September 1, 1983 version of the U.S.D.A. Soil Conservation Service's (SCS) computer program TR-20 was used to model the hydrologic characteristics of the Cattail Creek watershed. The 2-, 10- and 100-Year return period discharges were computed using the SCS Type II, 24-hour storm distribution with antecedent moisture condition 2. The discharges were computed for two different land use conditions (existing and ultimate) which are described in Sections 2.3.2 and 2.3.3, respectively.

The TR-20 model calculates the summations of runoff hydrographs (plots of flow versus time) computed for subareas of the watershed, including the routing of these hydrographs through reaches and impoundments to account for travel time and storage. Generation of the hydrograph for each subarea requires computations of the drainage area, runoff curve number, and time of concentration for the subarea. Hydrographs, which are assumed to be applicable at the outfall of the subarea, are reach routed through downstream subareas. The runoff hydrograph computed for the downstream subarea is then added to the routed hydrograph to obtain the discharge at the outfall of the downstream subarea. Also, when appropriate, hydrographs are routed through impoundments, such as reservoirs and major road crossings, to account for reservoir routing effects.

In addition to the parameters required to compute, combine, and route hydrographs, the TR-20 model also requires parameters which reflect the rainfall characteristics of the watershed. The SCS Type II, 24-hour rainfall distribution is the standard distribution for watershed studies in the State of Maryland. The rainfall distribution is a dimensionless curve of cumulative rainfall depth versus time which reflects the variation in storm intensity over time. A 24-hour duration is assumed because this is the typical duration of major storms in Maryland. The ordinates of the rainfall distribution are multiplied by the rainfall depth for the given return period to compute the total rainfall which has fallen up to a given point in time. The rainfall depths will be discussed in a later section.

The antecedent moisture condition (AMC) refers to conditions prior to the beginning of the storm and is used to compute the initial abstraction (i.e., the amount of rainfall required before runoff begins). AMC of 1 refers to dry conditions while 3 refers to wet conditions. An AMC of 2 is the average condition when rainfall occurs. For this study, an AMC of 2 was assumed.

The parameters referred to in this section represent input values needed for the TR-20 model. Most of the parameters are discussed in more detail in the following sections. Copies of the hydrologic work maps, the parameter computations, and the TR-20 runs are included in Appendices to this report.

2.2 Drainage Areas

Subareas are delineated such that all runoff leaving the subareas follows a hydrologically similar flowpath (i.e., runoff flows over similar terrain, through similar hydraulic structures, to similar streams). To ensure hydrologically similar flow paths, subareas were delineated at confluences of major stream reaches and at road crossings causing significant impoundments. Subareas were also delineated with consideration of the homogeneity of the land use in the subarea. In addition, subareas were delineated at points at which discharge data will be needed, such as intermediate points along tributaries to be studied in detail, sites of proposed bridge replacements, and areas of known flood hazard.

The subareas were initially delineated using the 1"=2000' scale USGS quadrangle maps for Woodbine, Sandy Spring and Sykesville. Fifty-one subareas were utilized to model the Cattail Creek watershed. Howard County 1"=600' scale topography with 5' contour interval was then used to check the actual drainage boundaries in conjunction with Howard County 1"=200' scale topography with a 5' contour interval. The 1"=200' scale topography was assumed to govern where there were discrepancies with the 1"=600' scale topography. The drainage area size averaged 0.56 square miles with the smallest and largest drainage areas being 0.21 and 0.92 square miles, respectively.

2.3 Runoff Curve Numbers

In the SCS hydrologic methodology, the runoff curve number (RCN) reflects the runoff potential for a subarea. Since runoff potential is primarily dependent on soil type and cover (i.e., land use) characteristics, RCNs have been computed for various combinations of soil type and land use (Table 1). The soils are classified into the four Soil Conservation Service (SCS) hydrologic soils groups which range from Type A (high infiltration rates, low runoff) to Type D (low infiltration rates, high runoff). The land use categories were based on zoning categories with the addition of a few descriptive land uses such as woodland and pasture.

The RCN for each subarea was computed as the area weighted average of the RCNs found in the subarea. The land uses per soil group were hand planimetered and a weighted average was then computed. Table 1 summarizes the RCN for the hydrologic soil groups and land uses that apply to the Cattail Creek watershed.

TABLE 1

Runoff Curve Numbers

Cover Description	Hydrologic Condition	Hydrologic Soil Group A	B	C	D
3 Acre Lot Zoning	----	45	64	76	81
Business Zoning	----	--	92	94	--
Impervious	----	98	98	98	98
Pasture	good	39	61	74	80
Row Crops	good	65	75	82	86
Woodland	good	30	55	70	77

2.3.1 Soils

The hydrologic soil groups were delineated based on the "Soil Survey of Howard County, Maryland", developed by the SCS and dated July 1968. The individual 1"=600' scale sheets in the survey were supplied to KCI by Howard County. The hydrologic soil type boundaries were transferred to the 1"=600' scale base sheets which also show land use and ultimate zoning. The majority of the Cattail Creek watershed is hydrologic soil type B with a minimum amount of type A and D.

2.3.2 Existing Land Use

The existing land use developed for this study was compiled from a number of sources including:

1. 1"=200' scale topographic maps (updated 1985);
2. Howard County Department of Planning and Zoning information on current developments;
3. The Howard County, Maryland ADC Street Map Book;
4. USGS quadrangle maps; and
5. A comprehensive visual reconnaissance conducted during the Spring of 1990.

Several decisions and assumptions were made in order to define existing land use for the RCN computations. The first decision was the best way to account for agricultural land. A majority of the watershed is currently under agricultural use, i.e. row crops or pasture. To precisely delineate which land was in each form based on the information available would have been a major undertaking. From visual observations about half of the agricultural land had row crops and the other half was pasture, it was decided to measure the agricultural lands as one value and then designate half as row crops and half as pasture. The acreage for meadows and lawns was then added to the pasture area and was given the RCN for pasture. It was also assumed that the 50%-50% split between row crops and pasture will remain in the future.

Additional assumptions were used in order to compute existing and ultimate RCN values. An average value of 0.1 Acre was used for the impervious area on each residential homesite while larger buildings were measured individually. Impervious area associated with roadways other than I-70 were assumed to be 15 feet wide on average and I-70 was measured individually. This roadway average accounts for two lane streets, narrow backroads and access drives to farms, as well as driveways. Any area currently designated as a 'preservation' zone was assumed to have the same land use in the existing and ultimate condition.

Another assumption made was that the average buildable lot size for Rural Residential and Rural Conservation zones was three acres.

2.3.3 Ultimate Land Use

The ultimate land use was developed from zoning maps for Howard County and the Howard County 1990 General Plan. The Howard County Zoning Maps, at 1"=600' scale and dated August 2, 1985, were obtained from the Howard County Department of Planning and Zoning.

The 1990 General Plan was approved on July 2, 1990 and made "clustering" mandatory in Rural Conservation areas and optional in Rural Residential areas. Clustering is a planning policy that takes the total dwelling units allowable by a specific zoning and clusters the total dwelling units in a single area of that zoning. This allows for larger, contiguous open areas. Since the average drainage area size used in the Cattail Creek watershed study is about 0.5 square mile and since the specific cluster areas have not been determined and since the average lot size with and without clustering is the same, ultimate land uses did not directly account for clustering.

2.4 Times of Concentration

The time of concentrations (T_c) for existing land use were computed using the overland flow method as presented in Technical Note N-4. The time of concentration is the longest time it takes for rainfall falling on the subarea to reach the subarea outlet. The times of concentration for ultimate land use were assumed to equal the existing T_c as per the direction of Howard County Department of Public Works. The T_c is usually computed by dividing the total flow path into segments and computing the travel time through each segment as the length of the segment divided by the velocity of flow in the segment.

The existing land use flow paths were based on the 1"=200' scale and 1"=600 scale topographic map. Overland flow was generally assumed to occur until the 1"=200' scale contours showed a tendency to swale flow. The maximum overland flow length was assumed to be 100 feet. For shallow concentrated flow the velocity was computed based on Technical Note N-4. Shallow concentrated flow was assumed to extend to the point at which the 1"=200' scale topography showed a well defined concentration of flow.

From shallow concentrated flow, the stream was usually assumed to enter a small tributary. The velocity in the small tributary was estimated from computations using Manning's equation on a typical stream cross section. The smaller streams emptied into larger tributaries. The velocity in these streams was estimated in a similar manner as the small tributaries.

As stipulated by Howard County and WRA, the overland flow component of the T_c was computed differently for the 2, 10, and 100 year storm events. The overland flow equation requires a rainfall amount. In a majority of floodstudies, the 2 year rainfall is used to compute the overland component regardless of the storm event discharge being calculated, however, for this study the 2, 10, and 100 year rainfall was used to compute a 2, 10, and 100 year T_c, respectively. On average, the 2 year T_c is 0.09 hour greater than the 100 year T_c.

2.5 Reach Routing

Reach routing was performed where required to route hydrographs computed for upstream subareas through downstream subareas. The reach routing accounts for the effects of travel time and stream valley storage on the hydrograph. The latest version of the TR-20 program uses the att-kin (attenuation/kinematic wave) routing method for reach routing.

For this study, the routing characteristics for each reach were input into the TR-20 program as an elevation-discharge-end area rating curve (i.e. XSECTN table). The rating curve was computed using the slope area method available in the U.S. Army Corps of Engineers hydraulic computer model HEC-2 which will be discussed in more detail in the hydraulics section of this report. A range of discharges was run for each cross section to compute the water surface elevations and cross sectional areas for the rating curves. The average slope computed for the reach length was used as the slope in the computations. Reach tables were developed for 30 reaches for the Cattail Creek TR-20 models.

The channel cross section used for the rating curve calculations were representative cross sections within each stream reach that were measured in the field by an engineer. If necessary, the field measured section was supplemented with 1"=200' scale aerial topography. Typically, the XSECTN tables are generated from HEC-2 cross sections. The Cattail Creek TR-20 model was run with XSECTN tables generated from both sources. As part of the TR-20 model calibration it was determined that the engineer measured and not the HEC-2 model cross sections produced a more acceptable model. The 100 year discharge at the USGS gaging station for the TR-20 model with HEC-2 generated XSECTN tables was significantly lower than the TR-20 model calibration run. The lower discharge was due to a lag in the travel time of the flood hydrograph as a result of stream valley storage indicated in the XSECTN table. Since the TR-20 model calibration run matched the TR-20 model with the XSECTN tables generated from engineer measured cross sections, the engineer measured sections were utilized for the reach routing.

The reach lengths were computed from the 1"=600' scale topographic maps. The length was computed as the distance the flood flows would have to travel between the upstream and downstream subareas.

The reach routings performed in the Cattail Creek TR-20's attenuated the peak discharge hydrographs as a result of accounting for stream valley storage and travel time through the watershed. The reach lengths were sufficiently long to provide peak flow attenuation in all cases, with many cases exhibiting significant attenuation.

2.6 Structure Routing

In addition to reach routing of flood hydrographs, the TR-20 models also included structure routing. Structure routing is required to account for the time lag and peak attenuation (storage) impacts of ponds and other structures which act as ponds during flood events. Structures which act as ponds include culverts and bridges with relatively small waterway openings and relatively large upstream storage.

While there are no water supply reservoirs in the Cattail Creek watershed, there are a number of ponds. The vast majority of these are small farm ponds or small stormwater management (SWM) ponds which control runoff from small developments. These ponds are too small to have a significant effect on the discharges in Cattail Creek, although the SWM ponds serve a major role in protecting the stream immediately downstream of the small development. As a result, the ponds were not included in the TR-20 model.

A number of road crossings in the watershed were preliminarily identified as causing impoundments. The topographic maps were then checked to determine if the crossings had significant upstream storage. The stage-storage curves for the crossings with significant storage were computed from the 1"=200' scale topographic maps.

HY-8 Version 3.2, November 1990, was used to compute stage-discharge curves for the structures to be modelled in the TR-20. HY-8 is an interactive computer model which automates Federal Highway Administration techniques for analyzing the hydraulic performance of culverts. The model is able to compute hydraulic information for single or multiple pipes of varied shapes, sizes, and materials. Since the four culverts to be modelled vary in size and shape, HY-8 was chosen as the most consistent and accurate means for analyzing the culverts. The stage-storage and stage-discharge curves were combined to compute the structure, i.e. RESVOR, table for the crossing. The structure tables were input into the TR-20 model.

A total of fourteen structures were included in the final TR-20 runs. Not all of these structures provided substantial opportunities for flood attenuation through structure routing. Null structures, i.e. blank structure tables, were included at ten road crossings and/or upcoming Howard County Capital Project locations to allow the model user the convenience of adding the structure table data in the future should the need arise. At this time, only four road crossings were deemed as significant impoundments and were modelled as full structure tables. These structures, along with their identifying number (the subarea number at the dam or the road crossing), and stream name are included in the following list:

Structure 3 - Cattail Creek at MD Route 144

Structure 19 - Tributary L at Carrs Mill Road

Structure 37 - Tributary E-5 at Roxbury Mills Road

Structure 41 - Cattail Creek at Roxbury Mills Road

The structure routing would be expected to provide attenuation of the discharge hydrograph peak in a similar manner as reach routing does. The four modelled structures provided varying degrees of flow attenuation. Structures 3 and 19 provided about a 20% reduction in flow rates. The remaining two structures provided less than a 10% reduction in the discharge rates with Structure 41 having almost no impact on the peak discharge rate.

2.7 Rainfall Depth

The TR-20 program requires the 24-hour rainfall depth for each return period to compute the rainfall occurring over each time increment. The 24-hour rainfall depths have been estimated for Howard County by SCS from the U.S. Department of Commerce - Weather Bureau publication TP-40 (Table 2).

TABLE 2

24-Hour Rainfall Depths

Return Period (years)	Rainfall Depth (inches)
2	3.2
10	5.1
100	7.2

TP-40 notes that for drainage areas greater than several square miles consideration could be given to the area to depth of rainfall relationship. The depth of rainfall can be reduced as the drainage area size increases. Based on the 28.6 square mile drainage area for the Cattail Creek watershed, the rainfall depths could be reduced by approximately 3% as per TP-40. Discharge rates are generated throughout the watershed for use in the HEC-2 model. The subareas have varying drainage areas, with the average drainage area being 0.5 square mile. The individual drainage areas would not have any reduction in the rainfall depth based on TP-40, therefore, the 3% reduction was not applied to the TR-20 model.

2.8 Calibration

An important aspect of preparing a hydrologic model is performing a calibration of the model relative to known data if it is available. For the Cattail Creek watershed there is a U. S. Geologic Survey (U.S.G.S.) gaging station within the watershed at the lower portion of the watershed that was used to provide the known data used to calibrate the TR-20 model. The TR-20 model was run with actual storm rainfall and the results were compared and plotted against the actual recorded storm hydrograph at the gaging station.

The hydrograph plots and rainfall distribution for the storm of May 5-6, 1989 were used for the calibration. The selection of the storm was important because input parameters such as time of concentration and curve numbers should closely match the land use conditions prevailing at the time of the storm. The storm should also have a total 24-hour precipitation greater than 3.2 inches, the rainfall associated with a 2-year storm event, in order to generate meaningful results. After careful review of gage and rainfall records, the May 5-6, 1989 storm was selected. Other storms were investigated but were not considered for model calibration due to insufficient rainfall/runoff data or the lack of other pertinent information.

U.S.G.S. Gage #01591400 has been recording runoff data through an automatic water-stage recorder since June 1978. The total drainage area upstream from this gaging station is 22.9 square miles. The gage is located on the right bank at the downstream side of the MD Route 97 bridge over Cattail Creek which corresponds to the ADDHYD statement at drainage area 41 in the TR-20 model. Runoff data for the storm of May 5-6 was obtained from U.S.G.S. in a standard format and the recorded stage data for the storm was converted into discharge values by using the gage rating curve supplied by U.S.G.S.

The Cattail Creek watershed is surrounded by at least four rainfall gaging stations at which total precipitation is recorded on a daily basis. These rainfall gaging stations are located at Unionville (north), Damascus (west), Brighton Dam (south), and Woodstock (east). There are no rainfall gaging stations within the Cattail Creek watershed. Rainfall data for the May 5-6 storm was obtained from all four gages. By drawing a Thiessen network relative to the four gages it was observed that the total rainfall in the Cattail Creek watershed can be estimated by interpolating the data recorded at the Damascus and Woodstock rain gages. It was also observed that approximately 70% of the watershed is influenced by the Damascus rain gage. For the purpose of the calibration, the rainfall records at Damascus were considered to be representative of the average rainfall for the entire Cattail Creek watershed. The total daily rainfall recorded at Damascus was then converted into hourly precipitation based on the rainfall distribution observed at the BWI Airport gage.

Actual storm events seldom follow the synthetic storm pattern generated by a Type II rainfall distribution which is what the TR-20 model uses. Since hourly precipitation for the selected storm was known, an actual 'S' curve was created instead of using the standard Type II distribution. The advantage of using actual cumulative values was noted when the TR-20 model was tested for this storm.

The TR-20 hydrograph developed a similar shape as the recorded hydrograph at the U.S.G.S. gaging station.

Other input parameters used in the calibration of the TR-20 model were as follows:

1. An antecedent moisture of 2 was used for the model because the 5 day antecedent rainfall was observed to be less than 2.0 inches.

2. The runoff curve numbers for existing conditions land use were used in the calibration model.

3. The time of concentrations based on the 2 year overland flow computations were kept the same as for a 2-year frequency storm.

4. The reach routing XSECTN tables in the TR-20 model were deemed applicable for the calibration run and were not changed. The source of the XSECTN tables will be discussed below.

5. The structure routing data in the TR-20 model were deemed applicable for the calibration run and were not changed.

As previously noted in the Section 2.5 of this report, the XSECTN tables were based on cross sections measured in the field by an engineer prior to the completion of the HEC-2 cross section field survey. When field surveyed HEC-2 cross sections were available, they were used to generate new XSECTN tables. The TR-20 model with the May 5-6 rainfall and the new XSECTN tables was run and two items were noted. The TR-20 model discharge was significantly lower than the actual storm hydrograph and the TR-20 generated hydrograph peaks occurred several hours after the actual storm peaks. This lag time was a function of additional stream valley storage in the cross sections surveyed for the HEC-2 model.

As part of the calibration effort, KCI determined that making arbitrary changes to the RCN values would get the TR-20 discharge rate closer to the actual storm rates, however, there would still be a lag in the hydrograph peaks. The peak time difference was due to the difference in the XSECTN tables. Two options were identified for calibrating the TR-20 model. The first option was to arbitrarily change times of concentration and/or RCN values and the second option was to use the original XSECTN tables. While the XSECTN table is constant for every storm event in both the existing and ultimate condition, times of concentrations and RCN values do change from storm to storm and from existing to ultimate conditions, respectively. Therefore, the factor that is most appropriate for verifying the TR-20 model is the XSECTN tables since they are constant for each TR-20 model.

After discussions with Howard County and WRA, it was agreed that the XSECTN tables was the factor that would be used for the calibration. It was further agreed that the TR-20 model should use the engineer measured cross sections. Even though the XSECTN tables would not have the same cross sections as the HEC-2 model, the XSECTN tables are still based on actual field conditions within the watershed as opposed to modifying RCN or time of concentration values. The TR-20 model with the engineer measured XSECTN tables was used for further comparisons to the gaging records.

The output hydrograph from the TR-20 run with the May 5-6 rainfall was plotted against the recorded hydrograph at the U.S.G.S. gaging station. The runoff hydrograph shape generated by the TR-20 model was found to be in agreement with the recorded hydrograph. The total runoff volume differed slightly which could be a result of the TR-20 model not accounting for base flow. The peak discharge rates also differed slightly, however, the difference is considered within reasonable limits. Based on the comparison between the existing TR-20 model results and the actual storm results the existing TR-20 model was determined to be a reasonable hydrologic model. The ultimate conditions TR-20 model was therefore also deemed to be a reasonable model for generating discharge rates for use in the HEC-2 model.

2.9 Summary of Results

The TR-20 model was executed for the 2-, 10-, and 100-year storms for existing and ultimate land use conditions. The existing and proposed land use TR-20 discharges for the 2-, 10- and 100-year storms are compared at two locations in the watershed in Table 3. The two locations chosen were the confluence of Cattail Creek with the Triadelphia Reservoir and the U.S.G.S. gaging station where Cattail Creek goes under MD Route 97, i.e. TR-20 Sections 151 and 41, respectively. Tables 4 through 6 contain the drainage area, RCN, T_c and discharge rates for the existing and ultimate 2-, 10-, and 100-year storm events, respectively.

The hydrologic models for the different land use scenarios show different degrees of increases in the discharges from existing to proposed conditions. Approximately two-thirds of the individual drainage areas showed little or no increase in discharge, however, the remaining one-third of the drainage areas exhibited greater than a 10% increase in discharge rates. The areas with minimal increases are already mostly if not completely developed to ultimate conditions. The areas with significant increases are those areas that have not yet been developed to ultimate conditions. The increase in discharge rate for the Cattail Creek watershed at its confluence with the Triadelphia Reservoir is approximately

23%, 11%, and 8% for the 2, 10, and 100-year storms, respectively. This increase is due to the buildout of the entire watershed to ultimate conditions.

TABLE 3

Comparison of Discharges At Two Watershed Locations

Comparison Point	Q2 (CFS)	Q10 (CFS)	Q100 (CFS)
Cattail Creek at U.S.G.S. Gaging Station (TR-20 Section 41)			
Existing Conditions	1802	5609	11166
Proposed Conditions	2184	6225	12088
Cattail Creek at Confluence with Triadelphia Reservoir			
Existing Conditions	2131	6423	12969
Proposed Conditions	2612	7106	14071

TABLE 4

2-Year Drainage Area Summary

DRAINAGE AREA NUMBER	ACREAGE (SQ. MI.)	EXISTING RCN	EXISTING Tc (HOURS)	EXISTING DISCHARGE (CFS)	PROPOSED RCN	PROPOSED Tc (HOURS)	PROPOSED DISCHARGE (CFS)
1	0.5385	65	0.61	116	69	0.61	168
2	0.4955	70	0.56	177	70	0.56	177
3	0.9036	70	0.53	336	71	0.53	365
4	0.6612	67	0.70	158	69	0.70	188
5	0.8465	70	0.64	278	70	0.64	278
6	0.9188	66	1.05	616	68	1.05	710
7	0.3723	71	0.74	119	72	0.74	128
8	0.7238	68	0.73	182	70	0.73	215
9	0.3525	68	0.48	119	70	0.48	140
10	0.5643	60	0.39	90	64	0.39	148
11	0.3570	70	0.48	142	71	0.48	153
12	0.3435	68	0.52	111	68	0.52	111
13	0.3622	69	0.48	133	69	0.48	133
14	0.6508	67	0.62	170	70	0.62	219
15	0.3041	71	0.58	116	78	0.58	181
16	0.3803	65	0.53	91	69	0.53	131
17	0.4993	68	0.88	111	70	0.88	131
18	0.5114	66	0.66	115	70	0.66	164
19	0.7167	68	0.60	209	71	0.60	266
20	0.4804	65	0.76	89	69	0.76	128
21	0.6444	59	0.50	75	61	0.50	100
22	0.6993	62	0.51	122	65	0.51	170
23	0.7651	62	0.57	124	65	0.57	174
24	0.5695	63	0.45	123	65	0.45	153
25	0.6289	68	0.66	170	69	0.66	186
26	0.6883	67	0.96	132	70	0.96	170
27	0.5843	67	0.43	194	70	0.43	249
28	0.5047	67	0.74	116	70	0.74	149
29	0.2118	68	0.80	50	70	0.80	59
30	0.2828	66	0.69	62	68	0.69	74
31	0.5350	67	0.80	116	69	0.80	138
32	0.4658	69	0.64	141	69	0.64	141
33	0.4035	59	0.95	31	66	0.95	71
34	0.7509	69	0.65	226	71	0.65	264
35	0.5934	70	0.45	248	70	0.45	248
36	0.5624	68	0.50	118	71	0.50	240
37	0.8865	71	0.64	315	72	0.64	339

TABLE 4
2-Year Drainage Area Summary (continued)

DRAINAGE AREA NUMBER	ACREAGE (SQ. MI.)	EXISTING RCN	EXISTING Tc (HOURS)	EXISTING DISCHARGE (CFS)	PROPOSED RCN	PROPOSED Tc (HOURS)	PROPOSED DISCHARGE (CFS)
38	0.3971	70	0.48	158	71	0.48	170
39	0.7729	67	0.72	181	70	0.72	234
40	0.4765	66	0.69	104	70	0.69	148
41	0.6899	69	0.68	199	73	0.68	270
42	0.5733	71	0.76	180	71	0.76	180
43	0.7503	67	0.69	180	70	0.69	232
44	0.6947	70	0.67	220	71	0.67	238
45	0.3596	70	0.50	142	71	0.50	153
46	0.5575	68	0.62	159	70	0.62	187
47	0.4091	68	0.52	133	70	0.52	156
48	0.4235	65	0.59	94	69	0.59	135
49	0.4713	70	0.55	170	71	0.55	184
50	0.3977	66	0.44	120	69	0.44	156
51	0.5969	67	0.81	128	69	0.81	153

TABLE 5
10-Year Drainage Area Summary

DRAINAGE AREA NUMBER	ACREAGE (SQ. MI.)	EXISTING RCN	EXISTING Tc (HOURS)	EXISTING DISCHARGE (CFS)	PROPOSED RCN	PROPOSED Tc (HOURS)	PROPOSED DISCHARGE (CFS)
1	0.5385	65	0.54	440	69	0.54	534
2	0.4955	70	0.50	549	70	0.50	549
3	0.9036	70	0.47	998	71	0.49	1041
4	0.6612	67	0.67	517	69	0.67	568
5	0.8465	70	0.58	841	70	0.58	841
6	0.9188	66	0.96	535	68	0.96	591
7	0.3723	71	0.68	345	72	0.68	360
8	0.7238	68	0.68	588	70	0.68	644
9	0.3525	68	0.44	380	70	0.44	415
10	0.5643	60	0.36	450	64	0.36	569
11	0.3570	70	0.43	424	71	0.43	442
12	0.3435	68	0.48	350	68	0.48	350
13	0.3622	69	0.42	417	69	0.42	417
14	0.6508	67	0.57	568	70	0.57	654
15	0.3041	71	0.52	342	78	0.52	443
16	0.3803	65	0.48	335	69	0.48	405
17	0.4993	68	0.81	361	70	0.81	395
18	0.5114	66	0.57	425	70	0.57	514
19	0.7167	68	0.53	690	71	0.53	787
20	0.4804	65	0.69	333	69	0.69	405
21	0.6444	59	0.44	422	61	0.44	481
22	0.6993	62	0.46	540	65	0.46	636
23	0.7651	62	0.53	538	65	0.53	636
24	0.5695	63	0.41	493	65	0.41	549
25	0.6289	68	0.60	558	69	0.60	584
26	0.6883	67	0.91	436	70	0.91	502
27	0.5843	67	0.39	645	70	0.39	738
28	0.5047	67	0.65	406	70	0.65	465
29	0.2118	68	0.71	169	70	0.71	185
30	0.2828	66	0.60	228	68	0.60	251
31	0.5350	67	0.72	403	69	0.72	443
32	0.4658	69	0.55	456	69	0.55	456
33	0.4035	59	0.87	165	66	0.87	251
34	0.7509	69	0.58	714	71	0.58	779
35	0.5934	70	0.41	721	70	0.41	721
36	0.5624	68	0.45	599	71	0.45	682
37	0.8865	71	0.56	937	72	0.56	976

TABLE 5
10-Year Drainage Area Summary (continued)

DRAINAGE AREA NUMBER	ACREAGE (SQ. MI.)	EXISTING RCN	EXISTING Tc (HOURS)	EXISTING DISCHARGE (CFS)	PROPOSED RCN	PROPOSED Tc (HOURS)	PROPOSED DISCHARGE (CFS)
38	0.3971	70	0.44	467	71	0.44	487
39	0.7729	67	0.64	627	70	0.64	720
40	0.4765	66	0.62	375	70	0.62	452
41	0.6899	69	0.61	632	73	0.61	748
42	0.5733	71	0.70	525	71	0.70	525
43	0.7503	67	0.63	614	70	0.63	705
44	0.6947	70	0.61	665	71	0.61	694
45	0.3596	70	0.46	413	71	0.46	431
46	0.5575	68	0.54	529	70	0.54	578
47	0.4091	68	0.46	430	70	0.46	470
48	0.4235	65	0.51	359	69	0.51	435
49	0.4713	70	0.48	524	71	0.48	547
50	0.3977	66	0.39	418	69	0.39	481
51	0.5969	67	0.73	439	69	0.73	482

TABLE 6
100-Year Drainage Area Summary

DRAINAGE AREA NUMBER	ACREAGE (SQ. MI.)	EXISTING RCN	EXISTING Tc (HOURS)	EXISTING DISCHARGE (CFS)	PROPOSED RCN	PROPOSED Tc (HOURS)	PROPOSED DISCHARGE (CFS)
1	0.5385	65	0.50	929	69	0.50	1057
2	0.4955	70	0.47	1018	70	0.47	1018
3	0.9036	70	0.47	1856	71	0.47	1910
4	0.6612	67	0.65	1018	69	0.65	1084
5	0.8465	70	0.55	1587	70	0.55	1587
6	0.9188	66	0.91	1084	68	0.91	1159
7	0.3723	71	0.64	654	72	0.64	673
8	0.7238	68	0.65	1150	70	0.65	1223
9	0.3525	68	0.41	739	70	0.41	785
10	0.5643	60	0.34	999	64	0.34	1161
11	0.3570	70	0.39	821	71	0.39	845
12	0.3435	68	0.46	677	68	0.46	677
13	0.3622	69	0.39	809	69	0.39	809
14	0.6508	67	0.54	1125	70	0.54	1234
15	0.3041	71	0.48	635	78	0.48	757
16	0.3803	65	0.46	680	69	0.46	772
17	0.4993	68	0.76	710	70	0.76	756
18	0.5114	66	0.52	888	70	0.52	1006
19	0.7167	68	0.49	1360	71	0.49	1487
20	0.4804	65	0.64	698	69	0.64	796
21	0.6444	59	0.41	968	61	0.41	1051
22	0.6993	62	0.42	1174	65	0.42	1308
23	0.7651	62	0.51	1146	65	0.51	1279
24	0.5695	63	0.38	1063	65	0.38	1141
25	0.6289	68	0.57	1088	69	0.57	1123
26	0.6883	67	0.88	865	70	0.88	951
27	0.5843	67	0.36	1297	70	0.36	1420
28	0.5047	67	0.60	818	70	0.60	898
29	0.2118	68	0.66	332	70	0.66	353
30	0.2828	66	0.54	473	68	0.54	505
31	0.5350	67	0.66	811	69	0.66	864
32	0.4658	69	0.50	915	69	0.50	915
33	0.4035	59	0.83	386	66	0.83	508
34	0.7509	69	0.53	1403	71	0.53	1487
35	0.5934	70	0.39	1365	70	0.39	1365
36	0.5624	68	0.42	1170	71	0.42	1278
37	0.8865	71	0.50	1845	72	0.50	1897

TABLE 6
100-Year Drainage Area Summary (continued)

DRAINAGE AREA NUMBER	ACREAGE (SQ. MI.)	EXISTING			PROPOSED		
		RCN	Tc (HOURS)	DISCHARGE (CFS)	RCN	Tc (HOURS)	DISCHARGE (CFS)
38	0.3971	70	0.41	884	71	0.41	910
39	0.7729	67	0.60	1252	70	0.60	1375
40	0.4765	66	0.57	773	70	0.57	877
41	0.6899	69	0.58	1223	73	0.58	1371
42	0.5733	71	0.66	983	71	0.66	983
43	0.7503	67	0.60	1216	70	0.60	1334
44	0.6947	70	0.58	1269	71	0.58	1306
45	0.3596	70	0.44	770	71	0.44	792
46	0.5575	68	0.50	1062	70	0.50	1128
47	0.4091	68	0.42	850	70	0.42	903
48	0.4235	65	0.47	743	69	0.47	845
49	0.4713	70	0.45	999	71	0.45	1028
50	0.3977	66	0.36	855	69	0.36	939
51	0.5969	67	0.69	879	69	0.69	937

3.0 HYDRAULICS

3.1 Methodology

The floodplain hydraulic model used was the Corps of Engineers' HEC-2 computer program version 4.6.2 updated May 1991. The program is intended for calculating water surface profiles for steady gradually varied flow in natural or man made channels. Both subcritical and supercritical flow profiles can be calculated. The effects of various obstructions such as bridges, culverts, weirs and structures in the floodplain may be considered in the computations. The computational procedure is based on the solution of the one-dimensional energy equation with energy loss due to friction evaluated in Manning's equation. The computational procedure is generally known as the Standard Step Method. The program is also designed for application in floodplain management and flood insurance studies to evaluate floodway encroachments and to designate flood hazard zones. Also, capabilities are available for assessing the effects of channel improvements and levees on water surface profiles. Input and output units may be English or Metric.

As will be discussed in Section 3.4, there was one instance at the I-70/MD Route 94 interchange where it was necessary to compute a headwater elevation at a culvert location on the northwest ramp onto I-70. The methodology utilized for this task was the Bureau of Reclamation (BPR) charts for computing headwater elevations for culverts under inlet and outlet control. Due to the distance between the culvert in question and downstream outfall at the southeast ramp and slope of the existing pipe system, outlet control was judged not to govern since the effects of the tailwater at the downstream end of the pipe network would not be seen at the upstream end of the pipe network. Therefore, inlet control was deemed as the governing hydraulic condition for the 100 year storm event. The BPR charts were used for inlet control to determine a headwater elevation.

3.2 Model Set-Up

Due to the relatively large size of the Cattail Creek watershed and the complexity of its first, second, third and sometimes fourth order tributaries, the watershed was divided up into eight HEC-2 models. The first HEC-2 model is comprised of the Cattail Creek mainstem, starting downstream at Station 0+00 and ending upstream northwest of Maryland Route 94/I-70 interchange at Station 454+60. The HEC-2 continues upstream of the northwest ramp of the interchange at mainstem Station 471+60 with the water surface elevation computed at the culvert inlet by the BPR charts. The HEC-2 run for the mainstem continues westerly parallel to I-70 and ends just short of crossing back under I-70. The mainstem model also included first order tributaries B, C, D, F, G, I, J, M, N, Q, R, and S. The remaining seven tributaries A, E, L, P, O, K and H were independently modelled. Each tributary was further divided into a number of subtributaries which were identified by a letter-number designation, i.e., A-1, A-2, etc. In addition to the mainstem, tributary "A" is comprised of thirteen subtributaries, A-1 through A-13; tributary "E" is comprised of nine subtributaries, E-1 through E-9; tributary "L" is comprised of five subtributaries, L-1 through L-5; tributary "P" is comprised of four subtributaries, P-1 through P-4; tributary "O" is comprised of nine subtributaries, O-1 through O-9; tributaries "K" and "H" are comprised of two subtributaries each, K-1 through K-2 and H-1 through H-2, respectively.

Tributaries A, E, H, K, L, O, and P with their respective subtributaries are each contained in a separate file while the eighth file is comprised of the mainstem of Cattail Creek and the remaining tributaries. The HEC-2 input file names are as follows:

STREAM	FILE NAME
Main and Tribs B,C, D,F,G,I,J, M,N,Q,R,S	CATTRIB.DAT
Trib A	TRIBA.DAT
Trib E	TRIBE.DAT
Trib H	TRIBH.DAT
Trib K	TRIBK.DAT
Trib L	TRIBL.DAT
Trib O	TRIBO.DAT
Trib P	TRIBP.DAT

3.3 Tributaries

The Cattail Creek mainstem HEC-2 model consists of approximately ten miles of mainstem and 6.8 miles of first order tributaries. The tributaries included in the mainstem of Cattail Creek HEC-2 model were B, C, D, F, G, I, J, M, N, Q, R and S. Their starting water surface elevations for the first order tributaries in the mainstem model were derived from the water surface elevations of the cross sections immediately downstream of the tributary's confluence with the Cattail mainstem. This was done according to HEC-2 methodology by starting the tributary run with the mainstem cross section with a negative designation. The negative sign tells the HEC-2 model to start the tributary run with the mainstem water surface elevation. For the seven tributaries that were modelled in separate HEC-2 models, the starting water surface from the appropriate mainstem model cross section was input on the J1 card at the beginning of the HEC-2 model. Where the tributary confluence occurred between two mainstem cross sections, the starting water surface for the tributary was the interpolated water surface between the two mainstem cross sections.

3.4 Model Continuation Through MD-94/I70 Interchange

The flow path for the main stem of Cattail Creek through the MD-94/I70 interchange is an intricate combination of inlets and closed storm drains as well as open channel ditch flow. Cattail Creek enters a single 10'x 8' reinforced concrete box culvert at the upstream end of the interchange. Storm runoff from the interchange area flows through ditches and enters the closed storm drain system through a series of inlets. Enough area drains into the main closed storm drain system that by the time Cattail Creek exits the closed storm drain system, it does so through three culverts (two 60" reinforced concrete pipes and one 96" structural plate metal pipe). The total travel length through the pipe system for Cattail Creek is approximately 500'.

After discussions with the Howard County Department of Public Works, it was decided that the way to treat the entire interchange area was to stop the HEC-2 model at the southeast edge of the interchange and resume the HEC-2 model at the northwest edge of the interchange in lieu of attempting to the model the area within the interchange with a complex hydraulic analysis. The starting water surface for the continuation of the HEC-2 model was computed using BPR charts as previously explained in Section 3.1. The computed 100 year headwater elevation was entered into the HEC-2 model by using an X5 card.

Since no development within the interchange area is anticipated in the future, a floodplain analysis was not performed for Cattail Creek from the upstream ramp to the downstream ramp within the interchange area. A detailed analysis was not necessary since this property belongs to Maryland State Highway Administration and Howard County receives no benefit from a detailed hydraulic analysis.

3.5 Discharges Used in HEC-2 Model

As defined by Howard County and WRA in the RFP for this watershed study, the average drainage area size was to be one-half of a square mile. While this was appropriate for the hydrologic analysis, the TR-20 results were not sufficient for the HEC-2 hydraulic analysis. The need for discharges for each first, second, and third order tributaries as well as the need for changing discharges on the main stem of Cattail Creek necessitated a breakdown of discharges throughout the watershed. A regression analysis was determined to be the most appropriate means for computing intermediate discharges within the watershed.

The regression equation used was taken from Technique for Estimating Magnitude and Frequency of Floods in Maryland which is published by U.S.G.S., 1980 and is as follows:

$$Qu=Qg(Au/Ag)^{x}$$

where Qu = estimated discharge for ungaged drainage area Au
Qg = known discharge for gaged drainage area Ag
x = exponent for the Northern region (x=0.70)

Each of the 51 drainage areas was broken up into numerous smaller subareas and discharges were computed. Table 7 depicts the results of the regression analysis.

As the discharges changed throughout the watershed, they were similarly changed in the HEC-2 model. This was accomplished by using the QT card to introduce a new discharge. The locations where discharges are changed in the model were predetermined after a number of discussions with Howard County and the Water Resources Administration.

The regression analysis gave good results for individual tributary discharges, however, the discharge to use on the main stream reaches between TR-20 sections was not as clear cut. The methodology used to define the discharges for the HEC-2 model are as follows:

1. Where the discharge differed between two successive TR-20 sections by less than 10 percent, the higher of the two discharges was used for the entire reach. This decision essentially ignores the input from the smaller tributaries due to hydrograph timing and assumes minimal stream storage for the reach.

TABLE 7

Regression Analysis Results

TR-20 MODEL WATER-SHED ID NO	SUB WATER-SHED ID NO	STREAM NAME	LOCATION OF SUBWATERSHED DIVIDE	DRAIN AREA (SM.)	USGS CONV. FACTOR FROM EQ.*	DISCHARGE FROM TR-20 MODEL OUTPUT 2-YR (CFS)	10-YR (CFS)	100-YR (CFS)	ESTIMATED DISCHARGE USING USGS EQUATION* 2-YR (CFS)	10-YR (CFS)	100-YR (CFS)
1	1	MAIN	MAIN	0.54		168	534	1057			
	1-1	MAIN	MAIN	0.32	0.69				116	370	733
	1-2	MAIN	MAIN	0.14	0.39				65	208	411
2	2	MAIN	@ CONF/TRIB. S	0.50		177	549	1018			
	2-1	MAIN	U/S CONF/TRIB. S	0.27	0.65				115	357	661
	2-2	TRIB. S	U/S CONF/MAIN	0.23	0.58				103	319	591
3	3	MAIN	MAIN	0.90		365	1041	1910			
	3-1	MAIN	U/S CONF/TRIB. R	0.26	0.42				153	436	801
	3-2	TRIB. R	U/S CONF/MAIN	0.51	0.67				245	699	1283
	3-3	TRIB. R	U/S CONF/TRIB. Q	0.27	0.43				157	448	822
	3-4	TRIB. Q	U/S CONF/TRIB. R	0.23	0.38				140	401	735
	3-5	TRIB. Q	TRIB Q	0.07	0.17				61	174	320
	3-6	TRIB. R	TRIB R	0.14	0.27				99	283	519
4	4	MAIN	@ CONF/TRIB. O	0.66		188	568	1084			
	4-1	MAIN	U/S CONF/TRIB. P	0.50	0.82				155	468	893
5	5	TRIB. P-2	@ CONF/TRIB. P	0.85		278	841	1587			
	5-1	TRIB. P-2	U/S CONF/TRIB. P4	0.37	0.56				155	470	887
	5-2	TRIB. P-4	U/S CONF/TRIB. P-2	0.31	0.49				137	415	783
	5-3	TRIB. P-2	TRIB P-2	0.19	0.35				97	295	556
	5-4	TRIB. P-4	TRIB P-4	0.15	0.30				83	250	471
6	6	MAIN	MAIN	0.92		710	591	1159			
	6-1	TRIB. P	U/S CONF/MAIN	0.89	0.98				694	577	1132
	6-2	TRIB. P-1	U/S CONF/TRIB. P	0.13	0.25				180	150	295
	6-3	TRIB. P-3	U/S CONF/TRIB. P	0.19	0.33				235	196	384
	6-4	TRIB. P	U/S CONF/TRIB. P2	0.67	0.80				569	473	928
	6-5	TRIB. P	U/S CONF/TRIB.P3	0.29	0.45				316	263	517

TABLE 7

Regression Analysis Results (Continued)

7	7	TRIB.O-1	TRIB O-1	0.37		128	360	673			
	7-1	TRIB O-1	TRIB O-1	0.20	0.65				83	234	438
8	8	TRIB. O-2	@ CONF/TRIB.O-1	0.73		215	644	1223			
	8-1	TRIB. O-2	U/S CONF/TRIB O-3	0.53	0.80				172	515	977
	8-2	TRIB. O-3	U/S CONF/TRIB O-2	0.17	0.36				78	232	441
	8-3	TRIB. O-2	TRIB O-2	0.18	0.38				81	242	459
9	9	TRIB.O-1	@ CONF/TRIB.O	0.35		140	415	785			
	9-1	TRIB.O-1	TRIB O-1	0.22	0.72				101	300	567
10	10	TRIB O	TRIB O	0 56		147	569	1161			
	10-1	TRIB. O	TRIB O	0.42	0 82				120	465	949
	10-2	TRIB. O	U/S CONF/TRIB O-9	0.16	0 42				61	237	483
	10-3	TRIB O-9	U/S CONF/TRIB.O	0 10	0 30				44	170	348
11	11	TRIB. O	@ CONF/TRIB.O-6	0.36		153	442	845			
	11-1	TRIB O	U/S CONF/TRIB.O-8	0.18	0.62				94	272	520
	11-2	TRIB. O-8	U/S CONF/TRIB O	0.10	0 41				62	180	345
12	12	TRIB O-6	@ CONF/TRIB O	0 34		111	350	677			
	12-1	TRIB O-6	U/S CONF/TRIB O-7	0 18	0 64				71	224	434
	12-2	TRIB. O-7	U/S CONF/TRIB O-6	0 13	0.51				57	179	345
13	13	TRIB O-5	TRIB O-5	0 36		133	417	809			
	13-1	TRIB O-5	TRIB O-5	0.22	0.71				94	295	573
14	14	TRIB O	@ CONF/TRIB.O-1	0.65		219	654	1234			
	14-1	TRIB. O	U/S CONF/TRIB O-4	0.40	0.71				156	466	878
	14-2	TRIB. O-4	U/S CONF/TRIB. O	0.13	0.32				71	212	400
	14-3	TRIB. O	U/S CONF/TRIB.O-5	0.15	0.36				78	234	442
	14-4	TRIB. O-5	U/S CONF/TRIB. O	0.20	0.44				96	287	541
15	15	TRIB. O	@ CONF/MAIN	0.30		181	443	757			
	15-1	TRIB. O	TRIB O	0.20	0.75				136	334	570
16	16	MAIN	MAIN	0.38		130	405	772			
	16-2	TRIB N	U/S CONF/MAIN	0.19	0.62				80	249	475
17	17	MAIN	@ CONF/TRIB K	0 50		131	395	756			
	17-1	MAIN	U/S CONF/TRIB L	0.40	0.86				112	338	647
	17-2	TRIB. M	U/S CONF/MAIN	0.29	0.68				89	270	516

TABLE 7

Regression Analysis Results (Continued)

	17-3	MAIN	U/S CONF/TRIB M	0.09	0.30				39	119	228
18	18	TRIB. L	@ CONF/TRIB.L-4	0.51		164	514	1006			
	18-1	TRIB. L-4	U/S CONF/TRIB. L	0.22	0.56				91	285	558
	18-2	TRIB. L-3	U/S CONF/TRIB. L	0.08	0.27				45	141	275
	18-3	TRIB. L	U/S CONF/TRIB.L-3	0.20	0.52				85	267	522
19	19	TRIB. L	@ CONF/TRIB L-1	0.72		266	787	1487			
	19-1	TRIB. L-1	U/S CONF/TRIB. L	0.22	0.44				116	343	648
	19-2	TRIB. L	U/S CONF/TRIB.L-1	0.49	0.76				203	601	1136
	19-3	TRIB. L-2	U/S CONF/TRIB. L	0.15	0.33				89	262	496
	19-4	TRIB. L	U/S CONF/TRIB L-2	0.22	0.44				116	343	648
	19-5	TRIB. L	U/S CONF/TRIB L-1	0.10	0.25				67	198	373
20	20	MAIN	@ CONF/TRIB K	0.48		128	405	796			
	20-2	TRIB L	U/S CONF/MAIN	0.31	0.74				94	298	586
21	21	TRIB. K	TRIB K	0.64		100	480	1051			
	21-1	TRIB. K	TRIB K	0.38	0.69				69	333	730
	21-2	TRIB. K	TRIB K	0.25	0.52				52	249	544
22	22	TRIB. K	@ CONF/TRIB.K-2	0.70		170	636	1308			
	22-1	TRIB. K	U/S CONF/TRIB.K-2	0.34	0.60				103	384	789
	22-2	TRIB. K	TRIB K	0.14	0.32				55	206	424
	22-3	TRIB. K-2	U/S CONF/TRIB. K	0.36	0.63				107	399	821
	22-4	TRIB. K-2	TRIB K-2	0.13	0.31				52	196	403
23	23	TRIB. K	TRIB. K	0.77		174	636	1279			
	23-1	TRIB. K	TRIB K	0.38	0.61				106	388	780
	23-2	TRIB. K	TRIB K	0.21	0.40				70	256	515
24	24	TRIB. K	TRIB. K	0.57		153	549	1141			
	24-1	TRIB. K	TRIB K	0.27	0.59				91	325	676
25	25	TRIB. K	@ CONF/MAIN	0.63		186	584	1123			
	25-1	TRIB. K	U/S CONF/TRIB.K-1	0.21	0.46				86	271	520
	25-2	TRIB. K-1	U/S CONF/TRIB. K	0.28	0.57				105	331	637
	25-3	TRIB. K-1	TRIB K-1	0.16	0.38				71	224	430
26	26	MAIN	@ CONF/TRIB. I	0.69		170	502	951			
	26-2	TRIB. J	U/S CONF/MAIN	0.46	0.75				128	378	716
	26-3	TRIB. J	TRIB J	0.23	0.46				79	233	441

TABLE 7

Regression Analysis Results (Continued)

27	27	MAIN	@ CONF/TRIB. I	0.58		249	738	1420			
	27-1	MAIN	U/S CONF/TRIB. I	0.25	0.55				138	409	788
	27-2	MAIN	U/S CONF/TRIB J	0.09	0.27				68	200	385
	27-3	TRIB. I	U/S CONF/MAIN	0.33	0.67				168	497	957
	27-4	TRIB. I	TRIB I	0.17	0.42				105	313	601
28	28	TRIB. H	TRIB H	0.50		149	465	898			
	28-1	TRIB. H	TRIB H	0.40	0.86				127	398	768
	28-2	TRIB. H	TRIB H	0.22	0.56				84	262	505
29	29	TRIB. H	@ CONF/TRIB.H-2	0.21		59	185	353			
30	30	TRIB. H-2	@ CONF/TRIB H	0.28		74	251	505			
31	31	TRIB. H	@ CONF/TRIB.H-1	0.54		138	443	864			
	31-1	TRIB. H	TRIB H	0.34	0.72				100	320	625
32	32	TRIB. H-1	@ CONF/TRIB H	0.47		141	456	915			
	32-1	TRIB H-1	TRIB H-1	0.35	0.81				115	371	744
	32-2	TRIB H-1	TRIB H-1	0.20	0.55				78	251	503
33	33	MAIN	@ CONF/TRIB H	0.40		71	251	508			
	33-1	MAIN	U/S CONF/TRIB. H	0.24	0.70				50	176	355
	33-2	TRIB. H	U/S CONF/MAIN	0.16	0.53				37	132	267
34	34	MAIN	@ CONF/TRIB E	0.75		264	778	1487			
	34-1	MAIN	U/S CONF/TRIB. F	0.39	0.63				167	492	941
	34-2	TRIB. F	U/S CONF/MAIN	0.32	0.55				145	429	819
	34-3	MAIN	U/S CONF/TRIB. G	0.09	0.23				60	176	337
	34-4	TRIB. G	U/S CONF/MAIN	0.19	0.38				101	298	569
	34-5	TRIB. F	TRIB F	0.18	0.37				97	287	548
35	35	TRIB. E-2	@ CONF/TRIB.E-8	0.59		248	721	1365			
	35-1	TRIB. E-2	U/S CONF/TRIB E-9	0.37	0.72				179	520	985
	35-2	TRIB. E-2	TRIB E-2	0.23	0.52				128	373	706
	35-3	TRIB. E-9	U/S CONF/TRIB E-2	0.08	0.25				61	178	337
	35-4	TRIB E-2	TRIB E-2	0.10	0.29				72	208	394
36	36	TRIB E-2	@ CONF/TRIB E	0.56		240	682	1278			
	36-1	TRIB. E-2	TRIB E-2	0.39	0.78				186	529	992
	36-2	TRIB E-8	U/S CONF/TRIB E-2	0.09	0.28				67	190	355

TABLE 7

Regression Analysis Results (Continued)

37	37	TRIB. E-5	@ CONF/TRIB.E-6	0.89		339	976	1897		
	37-1	TRIB. E-5	U/S CONF/TRIB.E-6	0.64	0.79				269	775	1506
	37-2	TRIB. E-6	U/S CONF/TRIB.E-5	0.16	0.30				102	294	571
	37-3	TRIB. E-5	U/S CONF/TRIB.E-7	0.38	0.55				187	538	1046
	37-4	TRIB. E-7	U/S CONF/TRIB. E-5	0.21	0.36				123	355	690
	37-5	TRIB. E-5	TRIB E-5	0.20	0.35				119	343	667
	37-6	TRIB. E-7	TRIB E-7	0.10	0.22				73	211	411
	37-7	TRIB. E-5	TRIB E-5	0.09	0.20				68	196	381
38	38	TRIB.E	@ CONF/TRIB.E-2	0.40		170	487	910			
	38-1	TRIB.E	U/S CONF/TRIB.E-5	0.13	0.46				77	222	414
	38-2	TRIB.E-3	U/S CONF/TRIB. E	0.16	0.53				90	256	479
	38-3	TRIB. E-5	U/S CONF/TRIB. E	0.05	0.23				40	114	212
39	39	TRIB.E	@ CONF/MAIN	0.78		234	720	1375			
	39-1	TRIB.E	U/S CONF/TRIB.E-1	0.55	0.78				183	564	1077
	39-2	TRIB.E-4	U/S CONF/TRIB. E	0.15	0.32				74	227	434
	39-3	TRIB.E	US/ CONF/TRIB.E-4	0.18	0.36				84	258	493
40	40	TRIB. E-1	@ CONF/TRIB E	0.48		148	452	877			
	40-1	TRIB. E-1	TRIB E-1	0.30	0.72				107	325	631
	40-2	TRIB. E-1	TRIB E-1	0.18	0.50				74	227	441
41	41	MAIN	@ CONF/TRIB C	0.69		270	748	1371			
	41-1	MAIN	MAIN	0.49	0.79				212	589	1079
	41-2	TRIB D	U/S CONF/MAIN	0.21	0.43				117	325	596
	41-3	MAIN	U/S CONF/TRIB D	0.04	0.14				37	102	187
42	42	TRIB. A	@ CONF/TRIB.A-12	0.57		180	525	983			
	42-1	TRIB. A	U/S CONF/TRIB.A-12	0.34	0.70				125	366	685
	42-2	TRIB. A-12	U/S CONF/TRIB. A	0.18	0.45				80	234	439
	42-3	TRIB. A	U/S CONF/TRIB.A-10	0.18	0.45				80	234	439
	42-4	TRIB. A-10	U/S CONF/TRIB. A	0.13	0.36				64	187	349
	42-5	TRIB. A-11	U/S CONF/TRIB. A	0.11	0.32				57	166	311
	42-6	TRIB. A	U/S CONF/TRIB.A-11	0.03	0.13				23	67	125
43	43	TRIB. A	@ CONF/TRIB.A-8	0.75		232	705	1334			
	43-1	TRIB. A-9	U/S CONF/TRIB. A	0.69	0.94				219	665	1258
	43-2	TRIB. A-9	TRIB A-9	0.53	0.78				182	553	1046
	43-3	TRIB. A-9	TRIB A-9	0.10	0.24				57	172	326

TABLE 7

Regression Analysis Results (Continued)

44	44	TRIB A	@ CONF/TRIB A-7	0 69		238	694	1306			
	44-1	TRIB A-8	U/S CONF/TRIB. A	0 68	0 99				236	687	1293
	44-2	TRIB. A-8	TRIB A-8	0 58	0 89				211	615	1157
	44-3	TRIB A-8	TRIB A-8	0 31	0 57				136	396	746
	44-4	TRIB A-8	TRIB A-8	0 14	0 33				78	227	428
45	45	TRIB A	@ CONF/TRIB A-6	0 36		153	430	792			
	45-1	TRIB A-7	U/S CONF/TRIB A	0 16	0 57				87	244	449
46	46	TRIB A	@ CONF/TRIB A-5	0 56		187	578	1128			
	46-1	TRIB A-5	U/S CONF/TRIB A	0 36	0 73				137	424	828
	46-2	TRIB A	U/S CONF/TRIB A-5	0 19	0 47				88	271	529
	46-3	TRIB A-6	U/S CONF/TRIB A	0 10	0 30				56	173	338
	46-4	TRIB. A	U/S CONF/TRIB A-6	0 07	0 23				44	135	263
	46-5	TRIB. A-5	TRIB A-5	0.21	0 50				94	291	568
47	47	TRIB A	D/S CONF/TRIB A-2	0.41		156	470	903			
	47-1	TRIB A	U/S CONF/TRIB A-2	0 20	0 61				94	284	546
	47-2	TRIB. A-2	U/S CONF/TRIB A	0 21	0 63				98	294	565
	47-3	TRIB. A-4	U/S CONF/TRIB. A	0 10	0 37				58	175	336
48	48	TRIB A	D/S CONF/TRIB A-2	0.42		135	435	845			
	48-1	TRIB. A	U/S CONF/TRIB A-3	0.08	0.31				42	136	265
	48-2	TRIB. A-3	U/S CONF/TRIB. A	0.28	0.75				102	328	636
	48-3	TRIB. A-3	TRIB A-3	0.10	0.37				49	159	309
49	49	TRIB. A	@ CONF/TRIB A-1	0.47		184	547	1028			
	49-1	TRIB. A-13	U/S CONF/TRIB. A	0.06	0.24				44	129	243
	49-2	TRIB. A-1	U/S CONF/TRIB A	0.31	0.75				137	409	768
	49-3	TRIB. A-1	TRIB A-1	0.24	0.62				115	342	642
	49-4	TRIB. A	U/S CONF/TRIB A-1	0.10	0.34				62	185	348
	49-5	TRIB. A-1	TRIB A-1	0.09	0.31				58	172	323
50	50	TRIB. A	@ CONF/MAIN	0.40		155	481	939			
	50-1	TRIB. A	U/S CONF/TRIB. B	0.16	0.53				82	253	494
	50-2	TRIB. B	U/S CONF/TRIB A	0.24	0.70				108	336	657
	50-3	TRIB. B	TRIB B	0.17	0.55				85	264	516
51	51	MAIN	@ STUDY LIMIT	0.60		153	482	937			
	51-1	MAIN	U/S CONF/TRIB. A	0.23	0.51				78	246	479
	51-2	TRIB. C	U/S CONF/MAIN	0 15	0.38				58	183	355

TABLE 7

Regression Analysis Results (Continued)

NOTE

1. MOST OF THE DISCHARGES LISTED ABOVE WERE USED IN THE HEC-2 MODEL. THE OTHER DISCHARGES HAVE BEEN INCLUDED FOR INFORMATION PURPOSES.

2. DISCHARGES ARE BASED ON ULTIMATE LAND USE CONDITIONS.

* Qu=Qg*(Au/Ag)^x WHERE "Qu" IS THE ESTIMATED DISCHARGE AT UNGAGED DRAINAGE AREA "Au"
"Qg" IS THE GAGED DISCHARGE AT DRAINAGE AREA "Ag"
"x" IS THE EXPONENT FOR THE NORTHERN REGION (x=0.70)

2. Where the discharge differed between two successive TR-20 sections by more than 10 percent the impact from tributaries and stream storage were deemed to be more critical. In most of these cases a discharge-averaging technique was developed to determine the discharges to use along the stream reach. The larger discharge was used for the downstream half of the reach and an average between the larger and smaller discharge was used for the upstream half of the reach. The exact location to change the discharge was determined based on the location of the actual tributaries.

3. There were four or five instances where the discharge differed between two successive TR-20 sections by more than 10 percent and the discharge-averaging technique described above did not apply. These cases were studied on a case by case basis to determine the discharges to use and the location to change the discharge.

In any hydrologic modelling study, certain assumptions have to be made relative to the many factors that can affect the computed discharges. In general, however, small differences in discharges should not cause a significant difference in the 100 year water surface elevations. The differences in discharges would be greater at the downstream end of the tributaries and the main stem of Cattail Creek. Engineering judgement, standard engineering practices, as well as specific requirements stipulated by Howard County in the Scope of Work were used to evaluate the factors and make the needed assumptions. Some of the factors considered for the Cattail Creek hydrologic study are as follows:

1. The 100 year discharge was computed using the 100 year rainfall to calculate the 100 year time of concentration.

2. The Forest Conservation Act which requires reforestation of land will tend to reduce the ultimate development discharge. Since the Act did not go into effect until the hydrology for this study was completed, the lower runoff curve numbers and lower resulting discharges have not been accounted for in this watershed study.

3. The time of concentration for existing land use conditions was used for the ultimate land use conditions.

4. Soil groups A and B were not downgraded to B and C in ultimate conditions to account for compaction during construction as is typically done for site specific stormwater management designs.

5. The storage capacity in all stormwater management and farm ponds was not incorporated into the TR-20 model. Only significant storage areas were included.

3.6 Cross Sectional Data

The Cattail Creek watershed cross section layout was based upon visual inspection and the use of Howard County's 1"=200' scale photogrammetric maps. The location and interval of the cross sections were selected based upon the hydraulic characteristics of the channel and the impact on the backwater computation. The cross section locations were reviewed and approved by Howard County prior to commencing field surveys. The emphasis was on significant changes in the channel slope and geometry, i.e., expansion and contraction. Howard County uses thirty acres as the minimum drainage area for computing and delineating 100 year floodplains. This study similarly used thirty acres as the limit for locating cross sections to be surveyed and modelled. The total length of streams and tributaries within the Cattail Creek watershed is approximately 62 river miles.

Each cross section was field surveyed including the locations of the left and right overbank. When the 100 year water floodplain elevation was greater than the highest point surveyed, the cross sections were extended using the County's photogrammetric maps of 1"=200' scale and 5' contour intervals. In order to extend the cross sections, the surveyed stream centerline was aligned with the stream centerline on the 1"=200' scale maps and the GR points needed to extend the sections were read from the 1"=200' scale maps. Typically, the extended GR points can be distinguished from the surveyed GR points by virtue of the extended points being at even contour elevations.

There were also cross sections that were not field surveyed but were copied or fully interpolated based on the field survey. This situation occurred mostly at road crossings where HEC-2 requires sections upstream and downstream of the culvert. Appendix B lists all those sections that were fully interpolated.

It should be noted that the HEC-2 model is based on the field survey which was started in the spring of 1990 and completed in the first few months of 1991. Any construction that occurred after the survey was done will not be reflected in the HEC-2 model. The Cattail Creek Country Club is one example of construction that is not reflected in the HEC-2 model.

3.7 Manning's Roughness Coefficient

To select a value of Manning's Roughness Coefficient, n, actually means to estimate the resistance to flow in a given channel. Numerous factors influence the value of n. The major factors are the channel's surface irregularities, variations in shape and size of the channel cross sections, obstructions, vegetation and channel meandering.

Roughness coefficients used in the HEC-2 model were assigned based on numerous field investigations and engineering judgement following guidelines established by Chow in his text Open Channel Hydraulics. It should be noted that n values were estimated for the channel conditions least conducive to flow, e.g. n value based on full summer foliage as opposed to barren winter vegetative cover. Table 8 lists the various roughness factors established for the model.

TABLE 8

Manning's Roughness Coefficient

Description	Manning's Roughness, n
Main Channel	0.013 - 0.065
Overbank Areas	0.055 - 0.1

This range reflects the wide variety of vegetation in the study area. The lower channel n values, i.e. 0.013 - 0.020 represent culvert flow and flow over paved roadways.

3.8 Bridge Modelling

Early in the survey portion of this project it became evident that there were a large number of small diameter culverts within the watershed, e.g. 12" diameter driveway culverts. To include every single culvert in the HEC-2 model would have been very time consuming and would not have added significantly to the accuracy of the HEC-2 model. Therefore, after consulting with Howard County, it was mutually decided to only model culverts and bridges larger than 48" in diameter. If, however, the pipe had a diameter smaller than or equal to a 48" and was located in a high embankment that would obviously create a severe backwater condition the culvert less than 48" was included in the model. Another criteria for determining whether to model a stream crossing was whether the crossing would be present during a 100 year storm event. There were several small footbridges used by individual property owners to cross the stream to get to the rest of their property. These small crossings were not modelled in HEC-2 since they were small enough that it was felt they would either be washed out by the 100 year storm or they would pose a negligible impediment to the storm flow.

Only 50 of the many roadway crossings were modelled in the Cattail Creek watershed study. The type, shape, size and material of the structures encountered throughout the watershed were all different. The stream crossings ranged from pipe arches, box culverts, circular and elliptical culverts, and bridges. Culvert materials varied from reinforced concrete to corrugated metal. Road crossings and structures that were considered for this study are listed in Table 9 in conjunction with the modelling technique used in the HEC-2.

The HEC-2 special bridge method was used to initially model all 50 culverts and bridges in the Cattail Creek watershed since it was felt that most pipes would be in pressure flow for the 100 year event. If overtopping does not occur, the model will revert back to the normal bridge method and will calculate losses using Manning's Equation.

For bridges without piers, the coefficient for Class A low flow was left blank. For twin and triple culverts which were generally separated by two to four feet, the pier shape coefficient used was 1.05. These distances between the pipes were considered as pier width distances and coded as such. Since low flow typically is not occurring for the 100 year storm, this coefficient is probably rarely used. For the pressure flow calculations, a typical value was selected for XKOR. The value of 1.6 was chosen since HEC-2 notes that this value for XKOR is applicable to most bridges and short culverts. The weir flow coefficient, COFQ, was assumed to be similar for all of the bridges and culverts. A value of 3.0 was used for all weir flow calculations in keeping with the HEC-2 manual recommendations.

The HEC-2 model was run and the results analyzed to determine if the proper bridge/culvert modelling technique was used. There were only a few instances where the model reverted to normal bridge for computing the 100 year water surface elevation. The remaining cases exhibited a combination of pressure and weir flow over the road. If the road is highly submerged HEC-2 suggests that special bridge may not be the best way to model the bridge or culvert, therefore, an alternate technique was investigated to treat the cases of high submergence. For the purpose of this study KCI defined high submergence as a weir flow depth over the road equal to one half of the culvert/bridge height or greater than one and one half feet of water flowing over the road.

There were fifteen cases of high submergence. It was observed that in the high submergence scenarios, approximately 90% of the flow was going over the road while only about 10% of the flow was passing through the culvert/bridge opening. Since most of water in these cases was overtopping the roadway by weir flow, KCI modelled the top of road as a typical GR (ground) card to define the weir cross section, the roadway profile. The recoding of the highly submerged bridges and culverts was done and the results were compared with the results of the special bridge run. There were differences in computed water surface elevations but the differences were not significant between the two

TABLE 9

Summary of Bridges & Road Crossings

Structure Number	Stream Name	Roadway Name	Type of Structure	Approximate Cross Section #	Modelling Technique Used[1]
1.	Cattail Creek	Roxbury Mills Road	Single Span Bridge	7220	SB
2.		Roxbury Mills Road	Single Span Bridge	8120	SB
3.		Union Chapel Road	Single Span Bridge	23605	SB
4.		Bushy Park Road	22' x 6.5' Box Culvert	32495	SB
5.		Unnamed Road	Twin - 60" & Single 48" RCP	33824	GR
6.		Unnamed Road	Twin - 36" RCP	34268	GR
7.		Carrs Mill Road	Twin - 48" CMP	35395	GR
8.		Carrs Mill Road	Twin - 42" CMP	36225	SB
9.		Maryland Rte 144	Twin-8' x 8' Box Culvert	39950	SB
10.		Unnamed Road	Single - 48" RCP	42372	GR
11.		Madison Street	Single - 5.7' x 3.2' Box Culvert	45160	SB
12.		NW Ramp @ MD 94/I-70 Interchange	Single - 10' RCP	47160	BPR
13.	Tributary A	Roxbury Road	Single Span Bridge	4230	GR
14.	Tributary A	Unnamed Road	Triple - 48" CMP	8375	GR

SB - Special Bridge
GR - Ground Card Used to Model Weir Flow over Roadway
BPR - BPR Chart Calculation

TABLE 9

Summary of Bridges & Road Crossings (continued)

Structure Number	Stream Name	Roadway Name	Type of Structure	Approximate Cross Section #	Modelling Technique Used[1]
15.	Tributary A	Shady Lane	Single Span Bridge	12082	GR
16.	Tributary A-1	Roxbury Mill Road	Single 48" RCP	2195	SB
17.	Tributary A-5	Unnamed Road	Twin - 36" CMP	195	SB
18.	Tributary A-5	Dorsey Mill	Twin - 36" CMP	305	SB
19.	Tributary A-8	Sharp Road	Twin - 60" CMP	1460	SB
20.	Tributary A-8	Kennard Road	Single 60" CMP	6150	SB
21.	Tributary E	Roxbury Mills Road	36" x 24" Elliptical CMP	10435	GR
22.	Tributary E-2	Union Chapel Road	Triple - 36" CMP	5520	GR
23.	Tributary E-3	Roxbury Mills Road	Single 4' x 3' Box Culvert	695	SB
24.	Tributary E-5	Roxbury Mills Road	Twin - 69" x 53" Elliptical Pipe	1550	GR
25.	Tributary E-5	Unnamed Road	Single 4'-10" x 4'-0" Box Culvert	3605	SB
26.	Tributary H	Daisy Road	Single Span Bridge	2925	SB
27.	Tributary H	Ed Warfield Road	Single 6' x 6' Box Culvert	9450	SB
28.	Tributary H-1	Unnamed Road	Single 48" RCP	1000	GR

SB - Special Bridge
GR - Ground Card Used to Model Weir Flow over Roadway
BPR - BPR Chart Calculation

TABLE 9

Summary of Bridges & Road Crossings (continued)

Structure Number	Stream Name	Roadway Name	Type of Structure	Approximate Cross Section #	Modelling Technique Used[1]
29.	Tributary K	Daisy Road	Single Span Bridge	1590	SB
30.	Tributary K	Unnamed Road	Single Span Bridge	2460	GR
31.	Tributary K	Duvall Road	Twin - 48" CMP	6665	SB
32.	Tributary K	Maryland Route 94	Single 6.5' x 3.5' Box Culvert	15760	SB
33.	Tributary L	Carrs Mill Road	Twin - 60" CMP	3650	SB
34.	Tributary L-1	Carrs Mill Road	Single 36" CMP	782	GR
35.	Tributary M	Daisy Road	Single 60" CMP	1715	SB
36.	Tributary O	Daisy Road	Triple 42" x 72" Elliptical CMP	1565	SB
37.	Tributary O	Mullinix Road	Twin-58"x 36"Elliptical Pipe CMP	10500	SB
38.	Tributary O	Maryland Rte. 94	Single 6.2' x 6.0' Box Culvert	12320	SB
39	Tributary O-1	Unnamed Road	Single 42" RCP	3074	GR
40.	Tributary O-1	Maryland Rte. 94	Single 60" CMP	6780	SB
41.	Tributary O-1	Lisbon Fire Station	Single 60" CMP	6875	SB
42.	Tributay O-1	Maryland Rte. 144	Single 6.0' x 4.8' Box Culvert	7745	SB

SB - Special Bridge
GR - Ground Card Used to Model Weir Flow over Roadway
BPR - BPR Chart Calculation

TABLE 9

Summary of Bridges & Road Crossings (continued)

Structure Number	Stream Name	Roadway Name	Type of Structure	Approximate Cross Section #	Modelling Technique Used[1]
43.	Tributary O-2	Maryland Rte. 94	Single 3.3' x 1.3' Box Culvert	3008	GR
44.	Tributary O-5	Maryland Rte. 94	Single 11.5' x 6.25' Box Culvert	3495	SB
45.	Tributary O-6	Maryland Rte. 94	Single 4.3' x 2.5' Box Culvert	2705	SB
46.	Tributary P-2	Maryland Route 144	Single 8'9" x 5'-5" Stone Arch	2565	SB
47.	Tributary P-4	Maryland Route 144	Single 11'0" x 5'-6" Stone Arch	1305	SB
48.	Tributary Q	I-70	Twin - 54" RCP	1080	SB
49.	Tributary R	I-70	Twin-54" RCP	650	SB
50.	Tributary S	I-70	Single 60" RCP	940	SB

SB - Special Bridge
GR - Ground Card Used to Model Weir Flow over Roadway
BPR - BPR Chart Calculation

runs. The model was left with the top of road GR cards since this more realistically reflects flow conditions during a 100 year storm.

It should be noted that all culverts and bridges were modelled with their full hydraulic cross section being available for flow. This HEC-2 model does not account for sediment buildup or scour, and clogging of the culverts. Some of the smaller openings could be subject to debris clogging up the flow opening, however, the possibility of clogging was not investigated as part of this study.

3.9 Expansion and Contraction Coefficients

These coefficients are used to compute energy losses associated with changes in the shape of the stream cross sectional area from one cross section to the next. Typical values for gradual transitions are 0.1 and 0.3 (contraction and expansion, respectively) while typical values for more abrupt transitions are 0.3 and 0.5 (contraction and expansion, respectively). Gradual transition values were used throughout the Cattail Creek watershed model, with the general exception of the areas upstream and downstream from the bridges and culverts that were modelled with special bridge. The contraction and expansion of flow occurs more abruptly at a bridge or culvert, therefore, HEC-2 suggests the higher values for the expansion and contraction coefficients upstream and downstream from the bridge or culvert. In the case where there is a bridge or culvert but weir flow over the road predominates, there is not a sudden contraction and expansion of the flow at the bridge. The contraction and expansion coefficients, therefore, were not increased in these instances.

3.10 Ineffective Flow Areas

HEC-2 assumes all area in a cross section is effective in the hydraulic computations unless the user reduces the flow conveyance by blocking a portion of the cross section geometry or by increasing roughness n-values. Areas within the floodplain of dead storage or ineffective flow areas are treated with this approach.

Ineffective area outside the main channel was modelled by the X3 card. Flow in the left and right overbanks was only modelled after the flow in the channel exceeded the elevations defined at the left and/or right overbank stations. In this study, NH cards were also used to define ineffective flow areas. An artificially high n value of 100 was entered in the NH card to essentially eliminate a portion of the cross section from further hydraulic calculations.

The X3 card was also used to remove ineffective flow in the immediate vicinity of the bridges and culverts. While it is customary in HEC-2 to create ineffective flow areas just upstream and downstream of a bridge or culvert. Where roads were overtopped by the 100 year storm in the Cattail Creek floodstudy, the entire road cross section in addition to the full sections upstream and downstream were generally considered to be effective flow areas and the ineffective flow option was not used.

3.11 Subcritical vs Supercritical

The entire model was initially run as a subcritical model. The results showed that within a given tributary reach several cross sections may exhibit a tendency towards being supercritical. If there were only occasional sections that could be considered as supercritical, the entire stream was not rerun as a supercritical model. Tributaries 'A-5' and 'B', however, exhibited supercritical tendencies for the majority of the cross sections. These two tributaries were also run as supercritical. With the exception of one or two cross sections for each of these two tributaries where the elevations differed by about one foot, the supercritical and subcritical models yielded similar water surface elevations. Therefore, for the consistency of the overall model, the entire HEC-2 analysis was done as subcritical including Tributaries 'A-5' and 'B.

3.12 HEC-2 Model Calibration

Only one U. S. Geologic Survey gaging station exists within the Cattail Creek watershed. This gaging station (No. 01591400) is located at downstream end of MD Route 97 (Roxbury Mills Road) bridge. The gaging station has been being operated at this location since October 1983. This gage location was used to perform a calibration of the HEC-2 model in the area around the gage. High water marks do exist along Cattail Creek, however, no corresponding discharge data are recorded relative to the high water marks. Therefore, the high water marks throughout the watershed can not be used to calibrate the HEC-2 model.

The gaging station is located on Cattail Creek at the downstream section of the study area, about 2100 feet upstream from the confluence of Tributary A (Dorsey Branch) and Cattail Creek. A meaningful HEC-2 calibration run can only cover the segment of Cattail Creek in the vicinity of gaging station, from upstream of Dorsey Branch to the MD Route 97 bridge. It is important to note that the calibration is only valid in the vicinity of the gaging station. For this reason, the HEC-2 model used in the calibration was a segment of Cattail Creek near the gaging station. There is insufficient data throughout the remainder of the watershed to properly calibrate the HEC-2 model elsewhere in the watershed.

The two maximum recorded storms at the gaging station were selected for the calibration run. The two selected storms are:

(1) February 12, 1985
Maximum Gage Height = 8.12'
Peak Discharge = 4040 cfs

(2) May 5-6, 1989
Maximum Gage Height = 7.72'
Peak Discharge = 3520 cfs

A separate HEC-2 model was developed for Cattail Creek in the area upstream and downstream from the gaging station based on field survey data. The purpose of this separate model was to check the calibration of the model in the area of known gaging records. The Mannings roughness coefficients were estimated from field investigation. The "n" value in the stream channel ranges from 0.03 to 0.035, and the "n" value in the overbank area ranges from 0.075 to 0.1. A very high "n" value of 100 was used to account for ineffective flow areas near the bridge (for low flow or pressure flow only). The starting water surface elevation for this separate HEC-2 model was computed by the slope-area method. The discharge used in the HEC-2 calibration model was the peak discharge from the stream gage.

The HEC-2 model noted above was run and the computed depth of flow was compared to the recorded gage height. This was done for February 12, 1985 and May 5, 1989 storms. The comparison between the HEC-2 model results and gaged records are presented in Table 10 below.

TABLE 10

HEC-2 Calibration Results

Storm Event	Peak Discharge	Recorded Gage Height	Calibrated HEC-2 Height	Difference
Feb 12, 1985	4040 cfs	8.12'	8.09'	0.03'
May 5, 1989	3520 cfs	7.72'	7.82'	0.10'

The difference between the HEC-2 computed water surface elevation and the recorded gage water elevation were only 0.03' and 0.10' for the two storms, respectively. This correlation of the modelled and the recorded water surface elevations is within an acceptable range, therefore, the HEC-2 model is considered to be calibrated. The resulting HEC-2 model at the gaging station was incorporated into the larger model for the entire Cattail Creek mainstem.

3.13 Summary of Results and Special Modelling Considerations

Table 11 contains the results of the hydraulic analysis of Cattail Creek and its tributaries. For simplicity, only the stream name, cross section number, 100 year ultimate discharge rate, and the 100 year water surface elevation are given in Table 11.

The records of historic flooding during Agnes and other major storm events were compared to the HEC-2 results and there was a similarity between areas and relative magnitudes of road overtopping. Since we do not know storm event frequencies for the historic storm events it is difficult to compare the HEC-2 modelled 100 year overtopping depths with those recorded during actual storm events.

One area which required special consideration in the HEC-2 modelling is where Cattail Creek flows east under Carrs Mill Road and then back to the west under Carrs Mill Road between HEC-2 cross sections 352+30 and 362+95. The upstream culvert did not fit the definition of the road overtopping with high submergence therefore that culvert was modelled with special bridge. Between the upstream and downstream culverts, Tributary 'P' combines with Cattail Creek. The additional flow in Cattail Creek is enough that the downstream culvert meets the definition of high submergence, therefore, the downstream culvert was modelled as weir flow only with a GR card and no bridge modelling. A review of the delineation shows that during a 100 year storm, Cattail Creek does not actually flow east and west under Carrs Mill Road. The flow runs from north to south down the length of Carrs Mill Road.

The HEC-2 model was run for the 100 year ultimate discharge only. Since this was the only discharge used for the hydraulic modelling, assumptions were made in the HEC-2 modelling that applied to a 100 year storm event. If different frequency storm events are to be run in the HEC-2 model, these assumptions will need to be checked. The most significant assumptions made in the 100 year model are relative to bridges and culverts and are as follows:

1. Culverts less than or equal to 48" in diameter were deemed insignificant for the 100 year storm. The use of the smaller culverts could be considered for smaller magnitude storm events.

2. Roadways with high submergence during the 100 year storm were modelled by weir flow over the road only without using special or normal bridge methodology. Special or normal bridge should be considered for the roadways modelled for weir flow only in the case

TABLE 11
Computed Water Surface Elevations

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Cattail	14,071.00	550	376.39	Cattail	12,088.00	10,530	400.43
Main Stem	"	1,120	379.27	Main Stem	"	11,230	400.87
"	"	1,600	380.72	"	"	12,020	401.73
"	"	2,070	381.35	"	"	12,375	402.25
"	"	2,800	383.00	"	"	12,625	402.67
"	"	3,200	383.54	"	12,073.00	13,055	403.72
"	"	3,830	384.18	"	"	13,430	405.39
"	"	4,230	384.45	"	"	13,840	406.61
"	"	4,750	386.99	"	"	14,385	407.33
"	"	4,960	386.37	"	"	14,840	408.75
"	"	5,400	389.48	"	"	15,130	410.21
"	13,080.00	5,650	389.78	"	"	15,330	411.74
"	"	5,970	389.95	"	"	15,565	414.23
"	"	6,280	390.20	"	"	16,195	414.81
"	"	6,600	390.42	"	10,378.00	16,865	415.68
"	"	7,100	390.38	"	"	17,140	418.79
"	"	7,180	390.93	"	"	17,410	421.12
"	"	7,220	392.19	Cattail	"	17,815	423.87
"	"	7,260	392.20	Main Stem	"	18,075	425.57
"	"	7,490	392.29	"	"	18,385	426.51
"	12,088.00	7,800	392.33	"	"	18,645	427.20
"	"	7,950	392.80	"	"	18,945	428.55
"	"	8,120	391.89	"	"	19,175	430.44
"	"	8,157	392.39	"	"	19,455	432.31
"	"	8,200	394.45	"	"	19,755	434.76
"	"	8,350	395.95	Main Stem	"	20,150	438.69
"	"	8,790	397.39	"	9,731.00	20,520	440.62
"	"	9,295	398.60	"	"	20,940	443.72
"	"	9,560	399.70	"	"	21,470	445.03
"	"	9,860	400.05	"	"	21,940	446.07
"	"	10,165	400.19	"	"	22,510	446.64

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Cattail	9,731.00	22,890	446.98	Cattail	4,136.00	34,595	486.95
Main Stem	"	23,360	447.43	Main Stem	"	34,888	488.00
"	"	23,605	448.74	"	"	35,230	490.16
"	"	23,645	448.94	"	"	35,395	490.49
"	"	23,715	454.80	"	"	35,665	490.58
"	"	23,905	455.81	"	2,061.00	36,145	493.14
"	"	24,315	456.09	"	"	36,225	493.47
"	"	24,690	456.24	"	"	36,275	494.77
"	"	25,300	456.55	"	"	36,295	494.84
"	"	25,795	456.90	"	"	36,675	495.93
"	7,629.00	26,345	457.30	"	"	37,225	500.15
"	"	26,795	457.65	"	"	37,810	502.34
"	"	27,480	462.29	"	"	38,485	505.27
"	"	28,335	426.32	"	"	38,970	507.63
"	"	28,955	466.27	"	"	39,570	509.87
"	"	29,735	471.05	"	"	39,810	510.90
"	"	30,265	473.16	"	"	39,950	512.33
"	"	30,495	474.58	"	"	39,985	517.91
"	7,525.00	31,110	475.74	"	2,656.00	40,020	518.02
"	"	31,775	477.16	"	"	40,360	518.27
"	"	32,407	479.49	"	"	41,110	520.35
"	"	32,495	480.21	"	2,088.00	41,460	522.54
"	"	32,519	480.41	"	"	42,372	530.94
"	"	32,541	482.49	"	"	42,715	533.08
"	"	32,835	482.82	"	"	43,215	536.80
"	"	33,210	483.68	"	"	43,865	542.71
"	"	33,630	485.36	"	1,288.00	44,450	550.50
"	"	33,824	486.44	"	"	44,800	555.00
"	4,136.00	34,120	486.73	"	"	45,040	558.42
"	"	34,268	486.78	"	"	45,160	562.19

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Cattail	1,288.00	45,200	564.33	Tributary A (continued)			
Main Stem	"	45,230	566.30	"	4,683.00	5,815	416.17
"	"	45,460	569.63	"	"	6,100	418.33
"	1,057.00	47,160	606.40	"	"	6,450	420.51
"	"	47,510	606.59	"	"	6,930	422.43
"	"	48,010	615.90	"	"	7,330	424.09
"	733.00	48,460	627.92	"	"	7,960	426.74
"	"	48,960	639.27	"	4,408.00	8,375	429.66
"	"	49,410	651.47	"	3,581.00	8,620	431.47
"	411.00	50,060	665.22	"	"	9,155	450.07
"	"	50,480	677.79	"	"	9,555	458.09
"	"	50,850	682.63	"	"	10,195	468.43
Tributary A				"	"	10,745	475.42
"	5,338.00	200	389.48	"	"	11,210	482.30
"	"	490	"	"	"	11,640	487.04
"	"	800	"	"	3,607.00	11,925	490.07
"	"	1,090	"	"	"	12,082	490.65
"	"	1,385	"	"	2,311.00	12,745	494.82
"	"	1,655	"	"	"	13,205	500.03
"	5,011.00	1,955	"	"	"	13,670	503.01
"	"	2,275	390.59	"	685.00	14,300	505.82
"	"	2,615	393.10	"	"	14,810	511.74
"	"	2,955	396.09	"	"	15,450	518.84
"	"	3,355	399.38	"	"	15,970	524.35
"	"	3,825	404.43	"	"	16,495	530.80
"	4,683.00	4,175	406.07	"	439.00	17,190	537.56
"	"	4,230	406.21	"	125.00	17,820	551.71
"	"	4,400	406.66	Tributary A-1			
"	"	4,990	410.51	"	5,338.00	-1,655	388.25
"	"	5,395	413.74	"	768.00	425	389.15

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary A-1 (continued)			
"	768.00	1,040	399.34
"	642.00	1,425	412.91
"	"	1,880	426.31
"	"	2,055	430.91
"	"	2,195	433.77
"	"	2,285	439.54
"	"	2,320	439.72
"	"	2,600	439.98
"	323.00	3,185	448.09
"	"	3,995	465.38
"	"	4,395	470.66
Tributary A-2			
"	4,683.00	-4,400	406.66
"	565.00	285	414.13
"	"	420	419.65
"	"	590	434.59
"	"	705	446.16
"	"	885	459.51
"	"	1,110	465.73
"	"	1,605	479.54
"	"	2,165	495.54
Tributary A-3			
"	4,683.00	-5,815	416.17
"	636.00	135	416.87
"	"	445	418.55
"	"	845	427.37
"	"	1,225	439.86
"	"	1,460	447.97
"	"	1,810	458.37

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary A-3 (continued)			
"	636.00	2,130	465.22
"	309.00	2,840	475.71
"	"	3,190	482.16
Tributary A-4			
"	4,683.00	-7,330	424.09
"	336.00	170	427.67
"	"	470	451.51
"	"	785	466.42
Tributary A-5			
"	4,683.00	-7,960	426.74
"	828.00	195	427.86
"	"	225	428.49
"	"	305	431.51
"	"	350	433.59
"	"	370	433.61
"	"	610	440.82
"	"	1,110	458.13
"	"	1,760	476.90
"	"	1,800	481.13
"	568.00	2,085	486.60
"	"	2,650	499.97
Tributary A-6			
"	4,408.00	-8,375	429.66
"	338.00	615	443.08
"	"	1,225	455.32
"	"	2,155	488.87
Tributary A-7			
"	3,607.00	-11,925	490.07
"	449.00	255	491.60

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary A-7 (continued)				Tributary A-9			
"	449.00	715	498.86	"	2,311.00	-14,300	505.82
"	"	1,105	507.54	"	1,258.00	640	512.26
"	"	1,365	518.19	"	"	890	515.29
"	"	1,925	524.43	"	1,046.00	1,280	518.56
"	"	2,325	528.75	"	"	1,695	524.49
Tributary A-8				"	"	2,275	535.92
"	3,607.00	-12,082	490.65	"	326.00	3,055	545.60
"	1,293.00	120	491.40	Tributary A-10			
"	"	730	498.22	"	685.00	-16,495	530.80
"	1,157.00	1,300	507.38	"	349.00	555	547.72
"	"	1,460	508.50	"	"	900	556.00
"	"	1,500	509.46	Tributary A-11			
"	"	1,540	509.54	"	439.00	-17,190	537.56
"	"	1,880	512.23	"	311.00	630	549.21
"	"	2,510	519.93	"	"	1,180	560.19
"	"	3,100	525.67	Tributary A-12			
"	746.00	3,450	530.21	"	2,311.00	-13,670	503.01
"	"	3,930	537.51	"	439.00	895	518.52
"	"	4,630	547.34	"	"	1,600	537.27
"	428.00	5,365	555.07	Tributary A-13			
"	"	5,970	562.50	"	5,338.00	-1,655	388.25
"	"	6,150	565.57	"	243.00	305	390.11
"	"	6,165	576.48	Tributary B			
"	"	6,297	576.48	"	14,071.00	-4,960	386.37
"	"	6,400	576.49	"	657.00	400	391.16
"	"	6,620	576.55	"	"	970	416.31
"	"	7,205	584.59	"	516.00	1,205	436.41
"	"	7,400	592.24	"	"	1,680	464.98
				"	"	2,000	474.68

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary B (continued)			
"	516.00	2,580	487.86
"	"	3,030	500.38
Tributary C			
"	13,080.00	-6,600	390.42
"	355.00	400	390.53
"	"	505	390.72
"	"	790	394.56
"	"	1,115	401.19
"	"	1,365	407.34
"	"	1,465	413.52
"	"	1,605	416.54
Tributary D			
"	12,088.00	-11,230	400.87
"	596.00	1,180	405.68
"	"	1,980	419.53
"	"	2,470	432.60
Tributary E			
"	3,214.00	480	402.66
"	"	785	402.66
"	"	1,010	403.45
"	"	1,520	405.14
"	"	2,050	407.99
"	"	2,535	410.55
"	"	2,910	413.19
"	"	3,310	414.58
"	"	3,895	417.82
"	"	4,275	421.19
"	"	4,560	423.51
"	"	5,090	426.98

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary E (continued)			
"	3,214.00	5,430	429.41
"	"	5,670	431.36
"	"	6,070	435.02
"	"	6,475	438.51
"	"	6,730	441.52
"	"	6,940	447.20
"	2,851.00	7,330	454.89
"	"	8,035	464.42
"	"	8,505	470.82
"	"	9,180	481.34
"	"	9,815	486.44
"	414.00	10,135	488.44
"	"	10,435	498.67
"	"	10,580	499.38
"	"	11,080	511.91
"	"	11,580	528.88
Tributary E-1			
"	3,214.00	-3,310	414.58
"	877.00	1,225	417.62
"	"	1,775	422.48
"	"	2,240	428.31
"	"	2,740	433.54
"	631.00	4,190	458.00
"	631.00	5,345	477.66
"	"	5,850	491.32
Tributary E-2			
"	2,851.00	-7,330	454.89
"	1,464.00	300	461.22
"	"	590	464.00

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary E-2 (continued)				Tributary E-4			
"	1,464.00	1,170	467.74	"	3,214.00	-5,670	431.36
"	"	1,910	472.13	"	434.00	650	440.19
"	"	2,565	477.36	"	"	1,235	461.26
"	"	3,155	481.21	Tributary E-5			
"	"	3,785	484.82	"	2,851.00	-9,815	486.44
"	"	4,185	487.50	"	"	810	504.07
"	"	4,685	491.88	"	"	1,270	511.84
"	"	5,110	496.10	"	1,897.00	1,550	516.40
"	"	5,250	498.59	"	1,506.00	2,600	519.81
"	1,365.00	5,520	504.45	"	1,046.00	3,035	521.27
"	"	5,820	507.33	"	"	3,490	523.90
"	"	6,140	514.99	"	"	3,565	524.25
"	985.00	6,705	520.95	"	"	3,605	526.34
"	"	7,260	529.97	"	"	3,635	527.76
"	"	7,780	539.77	"	"	3,645	527.77
"	"	8,600	548.46	"	"	4,225	530.31
"	"	9,085	556.35	"	"	4,620	536.40
"	706.00	9,425	561.21	"	667.00	5,385	544.13
"	"	10,235	575.34	"	381.00	6,035	552.30
"	394.00	10,905	587.54	"	"	6,410	559.82
Tributary E-3				"	"	7,740	585.00
"	2,851.00	-9,180	481.34	Tributary E-6			
"	479.00	340	486.66	"	1,897.00	-1,550	516.48
"	"	675	493.13	"	571.00	525	526.87
"	"	695	494.20	"	"	1,275	537.40
"	"	745	497.48	Tributary E-7			
"	"	750	497.48	"	1,046.00	-3,035	521.27
"	"	905	497.52	"	690.00	640	528.35
"	"	1,735	510.69	"	411.00	1,220	537.33

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary E-8				Tributary H (continued)			
"	1,464.00	-4,185	487.50	"	2,800.00	3,080	470.06
"	355.00	1,000	503.11	"	2,009.00	3,350	470.43
Tributary E-9				"	"	4,160	474.76
"	985.00	-6,705	520.95	"	"	5,060	481.66
"	337.00	520	526.65	"	"	5,450	483.37
Tributary F				"	1,800.00	5,740	486.79
"	12,073.00	-13,430	405.39	"	"	6,180	491.01
"	819.00	905	412.46	"	"	6,540	492.99
"	"	1,395	420.74	"	"	6,995	496.33
"	"	1,810	422.78	"	"	7,175	498.81
"	548.00	2,190	425.63	"	1,154.00	7,515	501.97
"	"	2,320	428.01	"	"	7,765	504.65
Tributary G				"	"	8,280	509.44
"	12,073.00	-15,330	411.74	"	"	9,090	523.49
"	569.00	690	414.66	"	"	9,426	532.52
"	"	1,200	418.76	"	898.00	9,450	533.39
"	"	1,635	430.88	"	"	9,486	533.19
"	"	2,265	447.49	"	"	9,492	535.68
Tributary H				"	"	9,595	535.78
"	2,800.00	555	421.54	"	"	9,950	536.54
"	"	1,195	430.21	"	"	10,125	540.47
"	"	1,715	438.22	"	768.00	10,725	547.68
"	"	2,045	444.70	"	505.00	12,130	571.28
"	"	2,375	456.95	"	"	13,145	586.62
"	"	2,660	463.20	Tributary H-1			
"	"	2,780	464.54	"	2,800.00	-3,080	470.06
"	"	2,925	465.49	"	915.00	190	470.32
"	"	2,950	467.77	"	"	608	474.79
"	"	2,980	469.94	"	"	1,000	480.39

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary H-1 (continued)				Tributary K (continued)			
"	915.00	1,165	482.21	"	2,782.00	1,360	461.23
"	744.00	1,685	490.35	"	"	1,470	461.92
"	"	2,265	500.32	"	"	1,590	462.13
"	503.00	3,465	517.58	"	"	1,615	463.23
"	"	3,875	523.53	"	"	1,645	463.38
Tributary H-2				"	"	1,960	463.76
"	1,800.00	-7,175	498.81	"	2,629.00	2,460	465.50
"	505.00	190	501.54	"	"	2,770	467.84
"	"	755	508.66	"	"	3,035	469.96
"	"	1,275	515.27	"	"	3,425	473.49
"	"	1,825	527.37	"	2,475.00	3,645	475.71
"	"	2,375	542.62	"	"	4,040	477.86
Tributary I				"	"	4,480	481.19
"	10,378.00	-20,150	438.69	"	"	4,955	484.63
"	957.00	210	443.99	"	"	5,565	490.02
"	"	710	456.67	"	"	6,315	495.63
"	"	1,040	461.71	"	2,247.00	6,505	496.56
"	"	1,590	476.03	"	"	6,665	497.65
"	"	2,005	486.36	"	"	6,695	499.25
"	"	2,275	491.89	"	"	6,735	499.62
Tributary J				"	"	7,100	502.91
"	9,731.00	-24,690	456.24	"	"	7,790	509.32
"	716.00	1,355	456.90	"	"	8,470	514.59
"	"	1,855	468.59	"	1,951.00	9,100	518.70
"	441.00	2,315	483.64	"	"	9,590	522.91
"	"	2,935	491.48	"	"	10,275	528.48
Tributary K				"	"	10,900	532.28
"	2,782.00	620	456.90	"	1,655.00	11,795	541.40
"	"	1,010	457.75	"	"	12,495	549.62

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary K (continued)			
"	1,655.00	13,325	562.73
"	1,353.00	13,925	575.00
"	"	14,545	581.44
"	"	15,030	583.67
"	"	15,660	598.94
"	1,051.00	15,760	599.95
"	"	15,800	599.68
"	"	15,840	600.39
"	"	15,975	601.22
"	"	16,525	608.96
"	"	17,125	620.29
"	730.00	17,630	627.83
"	"	18,330	641.27
"	"	18,770	649.38
"	544.00	19,640	668.78
"	"	20,330	691.96
Tributary K-1			
"	2,782.00	-1,960	463.76
"	637.00	965	469.60
"	"	1,465	478.46
"	"	2,145	489.61
"	"	3,395	516.65
"	430.00	3,785	525.49
Tributary K-2			
"	1,951.00	-10,900	532.28
"	821.00	225	535.94
"	"	445	541.54
"	"	1,190	554.69
"	"	1,810	566.10

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary K-2 (continued)			
"	821.00	2,405	576.74
"	403.00	2,855	587.33
"	"	3,690	616.04
Tributary L			
"	1,608.00	640	461.18
"	"	1,240	463.49
"	1,465.00	3,210	473.05
"	"	3,570	477.30
"	"	3,650	478.87
"	"	3,700	482.08
"	"	3,720	482.09
"	1,638.00	4,050	482.49
"	"	4,950	485.18
"	"	5,600	492.14
"	"	6,425	500.78
"	1,322.00	7,055	504.36
"	"	7,705	511.93
"	"	8,280	519.74
"	522.00	9,010	527.64
"	"	9,370	534.57
"	"	9,760	542.53
"	"	10,235	555.34
"	"	11,095	570.46
Tributary L-1			
"	1,638.00	-4,050	482.49
"	648.00	40	486.36
"	"	782	495.90
"	"	1,250	504.99
"	373.00	1,730	512.92

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary L-1 (continued)			
"	373.00	2,415	529.09
Tributary L-2			
"	1,638.00	-6,425	500.78
"	496.00	370	507.97
"	"	1,135	520.71
Tributary L-3			
"	522.00	-9,010	527.64
"	275.00	810	546.29
"	"	1,150	562.75
Tributary L-4			
"	1,322.00	-8,280	519.74
"	558.00	250	522.28
"	"	500	527.01
"	"	940	536.80
Tributary M			
"	7,629.00	-28,335	462.29
"	516.00	450	472.42
"	"	1,175	484.20
"	"	1,655	494.53
"	"	1,715	495.16
"	"	1,755	498.87
"	"	1,770	498.96
"	"	2,145	499.51
"	"	2,765	512.42
Tributary N			
"	7,525.00	-31,775	477.16
"	475.00	480	482.04
"	"	920	493.46

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary O			
"	3,891.00	350	485.81
"	"	985	489.55
"	"	1,365	491.39
"	"	1,565	492.84
"	"	1,610	493.89
"	"	1,655	495.26
"	"	1,730	495.48
"	"	1,930	495.74
"	"	2,620	496.48
"	"	3,200	499.64
"	2,220.00	3,880	502.44
"	"	4,560	506.51
"	"	5,375	511.04
"	"	5,895	514.91
"	"	6,395	518.48
"	1,733.00	6,995	521.61
"	"	7,495	526.10
"	"	7,895	529.86
"	1,246.00	8,345	534.14
"	"	8,820	539.82
"	"	9,590	546.02
"	"	10,040	550.31
"	"	10,420	555.76
"	"	10,500	557.68
"	"	10,540	557.81
"	"	10,560	558.18
"	"	10,860	560.06
"	"	11,270	566.49
"	"	11,870	575.50

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary O (continued)				Tributary O-1 (continued)			
"	"	12,080	582.08	"	"	6,740	573.05
"	1,161.00	12,320	591.04	"	438.00	6,780	573.64
"	"	12,360	591.95	"	"	6,864	573.44
"	"	12,420	592.28	"	"	6,875	579.63
"	"	12,650	595.58	"	"	7,206	580.85
"	"	13,100	605.68	"	"	7,226	580.86
"	"	13,630	620.81	"	"	7,465	584.90
"	949.00	14,010	629.23	"	"	7,685	589.93
"	"	14,460	639.30	"	"	7,745	591.40
"	"	14,735	645.20	"	"	7,810	591.48
"	"	15,310	654.88	"	"	8,525	604.93
"	"	15,820	667.47	"	"	9,205	627.58
"	483.00	16,310	682.77	Tributary O-2			
"	"	17,050	702.64	"	1,896.00	-3,074	521.01
Tributary O-1				"	1,223.00	525	529.20
"	3,891.00	-3,200	499.64	"	"	1,085	533.70
"	1,784.00	565	503.97	"	977.00	1,585	542.55
"	"	1,145	508.10	"	"	2,715	553.86
"	"	1,650	510.91	"	"	3,008	560.00
"	1,896.00	2,100	513.22	"	"	3,235	560.56
"	"	2,690	518.04	"	"	4,135	571.46
"	"	3,074	521.01	"	"	4,835	588.30
"	"	3,190	522.03	"	"	5,525	606.20
"	"	3,450	523.80	Tributary O-3			
"	673.00	4,175	532.47	"	1,223.00	-1,085	533.70
"	"	4,545	537.00	"	441.00	350	537.29
"	"	5,030	541.88	"	"	720	545.33
"	"	5,685	554.26	"	"	1,340	555.97
"	"	6,405	565.60	"	"	1,760	566.30

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary O-4			
"	2,220.00	-5,375	511.04
"	400.00	400	515.09
"	"	900	525.10
Tributary O-5			
"	2,220.00	-6,395	518.48
"	1,135.00	690	525.23
"	"	1,470	534.18
"	"	2,175	541.77
"	"	2,680	548.97
"	"	3,260	563.04
"	"	3,395	564.19
"	809.00	3,495	563.31
"	"	3,535	564.62
"	"	3,560	564.99
"	"	4,430	582.31
"	"	5,130	596.39
"	573.00	5,770	613.55
"	"	6,410	631.23
"	"	7,380	661.78
"	"	7,555	667.48
"	"	7,975	687.09
Tributary O-6			
"	1,733.00	-7,895	529.86
"	677.00	390	532.11
"	"	895	544.48
"	434.00	1,530	558.18
"	"	2,405	571.71
"	"	2,625	582.33
"	"	2,705	583.67

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary O-6 (continued)			
"	434.00	2,755	583.78
"	"	2,775	584.08
"	"	3,010	589.49
Tributary O-7			
"	677.00	-895	544.48
"	345.00	460	557.25
"	"	1,110	571.69
"	"	2,040	594.30
"	"	2,076	594.99
"	"	2,515	601.28
Tributary O-8			
"	1,246.00	-9,590	546.02
"	345.00	285	550.90
"	"	625	555.98
Tributary O-9			
"	949.00	-15,820	667.47
"	348.00	65	677.42
Tributary P			
"	2,313.00	560	493.34
"	"	1,090	497.33
"	"	1,320	498.47
"	"	1,610	499.62
"	928.00	1,805	500.50
"	"	1,985	502.27
"	"	2,760	510.55
"	"	3,520	523.41
"	"	4,190	533.20
"	"	4,790	540.48
"	517.00	5,270	544.75

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary P (continued)				Tributary P-4			
"	517.00	5,685	551.85	"	1,587.00	-1,585	512.88
"	"	6,510	570.01	"	783.00	590	520.15
"	"	6,920	579.65	"	"	1,225	534.89
Tributary P-1				"	"	1,305	535.48
"	2,313.00	-1,320	498.47	"	"	1,340	537.12
"	295.00	520	506.72	"	"	1,360	537.15
"	"	840	516.58	"	"	1,755	537.85
Tributary P-2				"	471.00	2,555	552.03
"	2,313.00	-1,610	499.62	"	"	3,360	575.44
"	1,587.00	170	500.47	"	"	3,875	592.60
"	"	650	502.89	"	"	4,470	616.21
"	"	1,345	509.11	Tributary Q			
"	"	1,585	512.88	"	2,656.00	-41,110	520.35
"	887.00	2,165	515.99	"	1,283.00	620	526.40
"	"	2,485	522.05	"	735.00	815	529.42
"	"	2,565	523.38	"	"	960	531.86
"	"	2,590	525.65	"	320.00	1,080	532.81
"	"	2,610	525.73	"	"	1,280	532.85
"	"	2,930	525.81	"	"	1,310	533.00
"	556.00	3,985	535.85	"	"	1,760	543.12
"	"	4,510	544.72	Tributary R			
"	"	5,035	558.07	"	2,656.00	-41,110	520.35
Tributary P-3				"	822.00	140	522.90
"	928.00	-4,790	540.48	"	"	545	528.39
"	384.00	420	547.35	"	519.00	650	530.67
"	"	1,060	559.57	"	"	900	536.98
"	"	1,660	571.56	"	"	925	537.38
"	"	2,220	593.20	"	"	1,200	537.39
				"	"	1,750	538.46

TABLE 11
Computed Water Surface Elevations (continued)

Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)	Stream Name	Discharge (CFS)	Cross Section #	Water Surface Elev. (Ft.)
Tributary S							
"	2,088.00	-43,856	542.71				
"	591.00	230	547.06				
"	"	620	553.87				
"	"	900	563.52				
"	"	940	563.56				
"	"	1,260	584.57				
"	"	1,270	584.57				
"	"	1,690	584.57				
"	"	2,250	586.16				

of smaller magnitude storm events where there might be little or no roadway overtopping.

3. Siltation in the culverts was assumed to be scoured out during the 100 year storm, making the entire cross sectional area available for conveying flow. For smaller magnitude storm events, the smaller flows might not scour out the culvert which would reduce the cross sectional area available for conveying flow.

A warning message that occurred periodically throughout the model results was CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE. The 'acceptable' range is 0.7 - 1.4. HEC-2 notes that this message can be expected to occur in the vicinity of bridges due the expansion and contraction of the flow. A value outside the range, may indicate the need for closer spacing of cross sections especially where there are significant changes in the width, depth, and roughness in the channel.

The various warning messages generated by the HEC-2 model would suggest that more frequent cross sections would have eliminated many of the warning messages. Field 7 on the J1 card allows the user to direct the model to interpolate cross sections whenever the velocity head exceeds a user defined value. When this option has been used in the past to interpolate additional cross sections, there has not been an appreciable difference in water surface elevations as a result of the interpolation. The interpolated sections were, therefore, not added in the Cattail Creek watershed HEC-2 modelling.

3.14 Floodplain Delineation

Even though the HEC-2 model is based on field survey information, the delineation is done by plotting the computed 100 year water surface on the 1"=200' scale topographic sheets based on the topographic sheet contours. Therefore, there may be some inconsistencies between the HEC-2 computed begin and end station values and the begin and end stations that are plotted in plan for each cross section. There are several instances where plotting the computed water surface with the topo map contours gives an unrealistic delineation at that section. Where this occurs, the delineated floodplain just upstream and downstream were used in conjunction with the water surface elevation of the problem section in order to plot a more realistic floodplain at the problem section. A better source for ascertaining the 100 year water surface elevation will be the HEC-2 model results or the water surface profiles which give the computed water surface elevations relative to a surveyed stream invert.

Where streams flow through existing ponds or immediately adjacent to existing ponds, the HEC-2 cross sections were spaced such that there is one cross section just upstream and one cross section just downstream of the pond. The delineation accounts for the presence of the ponds and if the floodplain elevation is higher than the pond, the entire pond is shown within the 100 year floodplain. In the delineation of the floodplain, if a tributary water surface elevation was lower than the water surface of the stream it was emptying into, the higher water surface was used for the appropriate tributary cross sections.

Two new ponds and several new roads were surveyed that did not appear on the topographic sheets. They have been added and labelled on the plan sheets. The larger of the new ponds is an extension of an existing pond on Tributary K at Larriland, Section 150+30.

The Union Chapel Road bridge over Cattail Creek was modelled as a special bridge application. The results of HEC-2 model indicate a water surface elevation that is not overtopping the road but an energy gradient above the road. There is also a low water crossing situation occurring, i.e. a low point elevation in the approach roadway that is lower than the low chord elevation of the bridge. The HEC-2 results indicate low flow occurring which is a function of the low water crossing situation. For the purposes of the floodplain delineation and the HEC-2 summary tables, the energy gradient elevation at the bridge will be used as the water surface elevation since overtopping is occurring at this location.

Tributary S is a small tributary to Cattail Creek which crosses I-70 near the I-70 and MD Route 94 interchange. The HEC-2 model indicates that I-70 is overtopped by 0.07' or approximately 20 cfs. The construction documents for the culvert on Tributary S should be investigated to determine the criteria for sizing the culvert. The area upstream from the culvert is primarily undeveloped. If the culvert was designed to carry the 100 year storm based on existing land use, the increase in flows in the ultimate conditions may be enough to cause the slight overtopping that the HEC-2 model is indicating. If this is the case, there may be a need for Howard County to require stormwater management to be done when the upstream area is developed.

Tributary O-1 crosses MD Route 144, flows by the Lisbon Fire Station, and then crosses MD Route 94. The modelling of this area was extremely difficult due to two situations. Construction was done to expand the fire station between the time of the 1"=200' scale topography and the KCI field survey, and the culvert under the expanded parking lot outlets extremely close to the culvert under MD Route 94. The model results show the floodplain overtopping the fire station parking lot, however, the flow is then shown as low flow through the MD Route 94 culvert. At MD Route 94 the energy gradient is above the low chord which would suggest pressure flow while the water surface elevation is below the low chord. It is unlikely that the flow would overtop the parking lot and then be concentrated through the 60" culvert under MD Route 94, therefore, this area warrants further investigation. Detailed topography is needed in this area and the culvert analysis should be verified by HY-8 or BPR charts. For the purpose of this watershed study, the water surface elevation for the fire station parking lot is also used for MD Route 94, and the floodplain is shown overtopping both the fire station parking lot and MD Route 94. (This area is discussed further in the Alternatives Selection portion of this study since several buildings may be in the floodplain at this location.)

Where Tributary O-1 crosses MD Route 144 there is a low water crossing similar to that described at Union Chapel Road. The roadway slopes down from west to east such that the area east of the stream crossing allows the flow to overtop the road prior to the water reaching the elevation of the culvert low chord. The delineation of the floodplain has been based on field survey as well as the 1"=200' scale topography. Additional area and/or houses may be in the floodplain near MD Route 144, but detailed survey is needed to determine the limits of the floodplain. The MD Route 144 area should be included in the detailed investigation suggested above at the fire station due the proximity of the two areas.

All of the cross sections used in the HEC-2 model are shown on the 1"=200' scale topographic sheets used for the floodplain delineation. There are also a few cross sections that were field surveyed but not used in the model, specifically around the I-70 and MD Rte 94 interchange. These sections are still shown on the plan but have a slash drawn through them.

It should be noted that the cross sections depicted on the 1"=200' scale plan sheets are meant to show the location of the cross section but are not meant to imply the actual width of the modelled cross section.

4.0 ALTERNATIVE SELECTION

4.1 Problem Identification

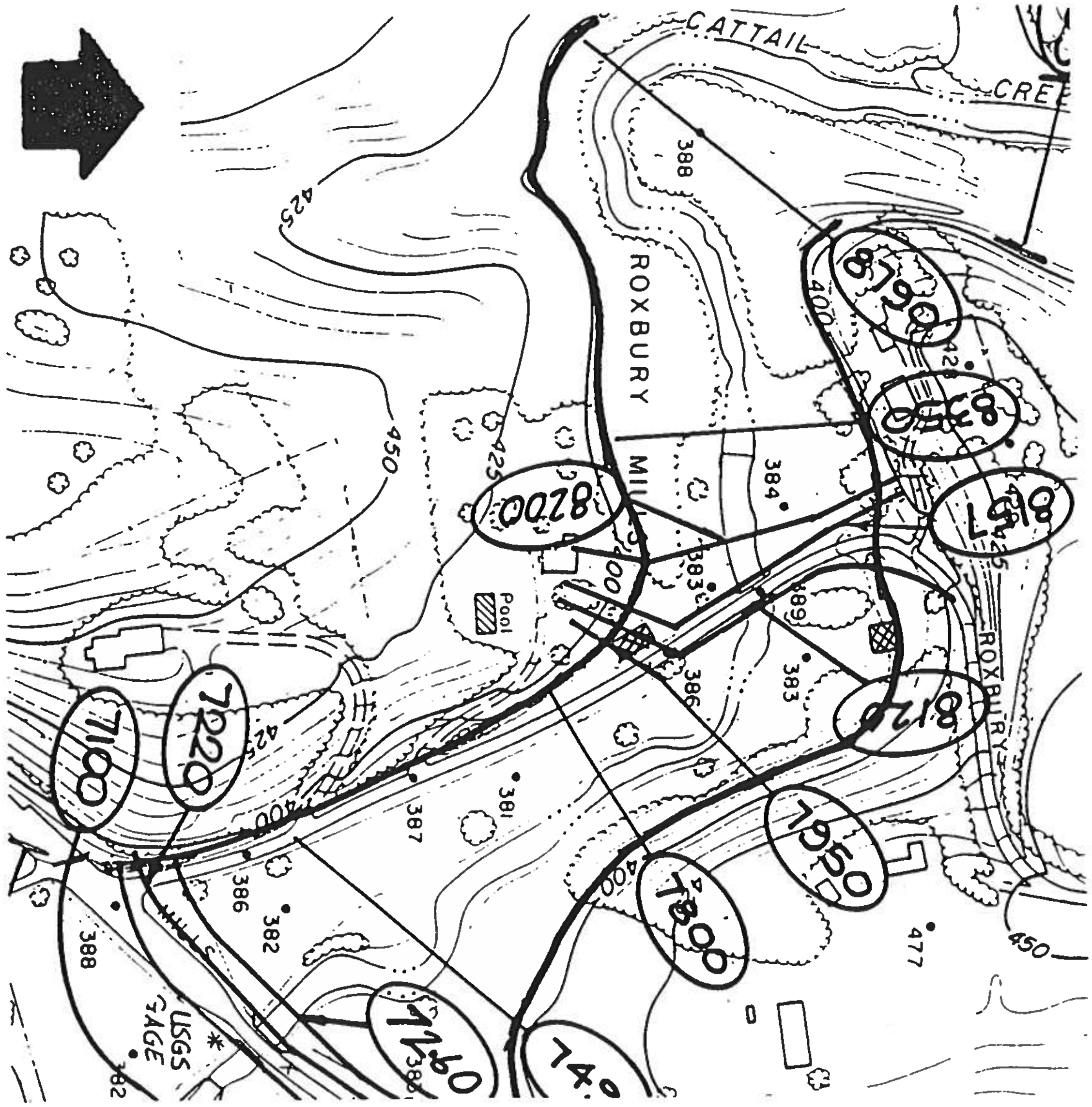
It is not only important to determine the existing and ultimate discharge rates and to compute and delineate the 100 year floodplain, but it is equally important to study the ramifications and effects the floodplain has on the residents of Howard County. The purpose of the alternative selection section of the Cattail Creek watershed study is to identify areas that may be subjected to flooding and categorize the areas relative to the potential impacts. The major distinction that can be made is between roadways that will be overtopped during a storm event and primary residences and significant buildings that could be flooded. For the purpose of this analysis, ancillary structures such as barns, stand alone garages, and storage sheds will not be considered as significant buildings.

Computer modeling and field investigation were used to identify existing or potential flooding problems in the Cattail Creek watershed. In general, the results of this study show that the flooding problems are not very severe. This may be attributed to the relatively low densities of existing development and good agricultural management practices within the watershed.

Flooding problems within the Cattail Creek watershed are limited to roadways and a minimal number of buildings. The instances of roadway overtopping occur throughout the watershed. Figures 2 through 9 show the floodprone buildings. Although the flooding of roadways is typically not as severe a hazard as flooding of buildings, frequent flooding of roadways can build up to a serious problem. The flooding of roadways can present potential hazards that include: the sudden stopping or slowing of traffic; the possible loss of the roadway itself; the threat of automobiles being trapped in flood waters on the bridge or culvert; and even the threat of an automobile or a pedestrian being washed downstream.

The HEC-2 computer model was used to predict the 100-year flood elevations for ultimate conditions. The computed flood elevations were compared to the elevation of roadways and other structures to identify flooding problems. The floodprone roadways and structures are listed in Tables 12 and 13, respectively.

It should be noted that all discussions and recommendations relating to flooding of roadways and buildings within the Alternative Selection section of this study refer to the 100-year ultimate land use conditions.



LEGEND:

FLOOD PLAIN BOUNDARY

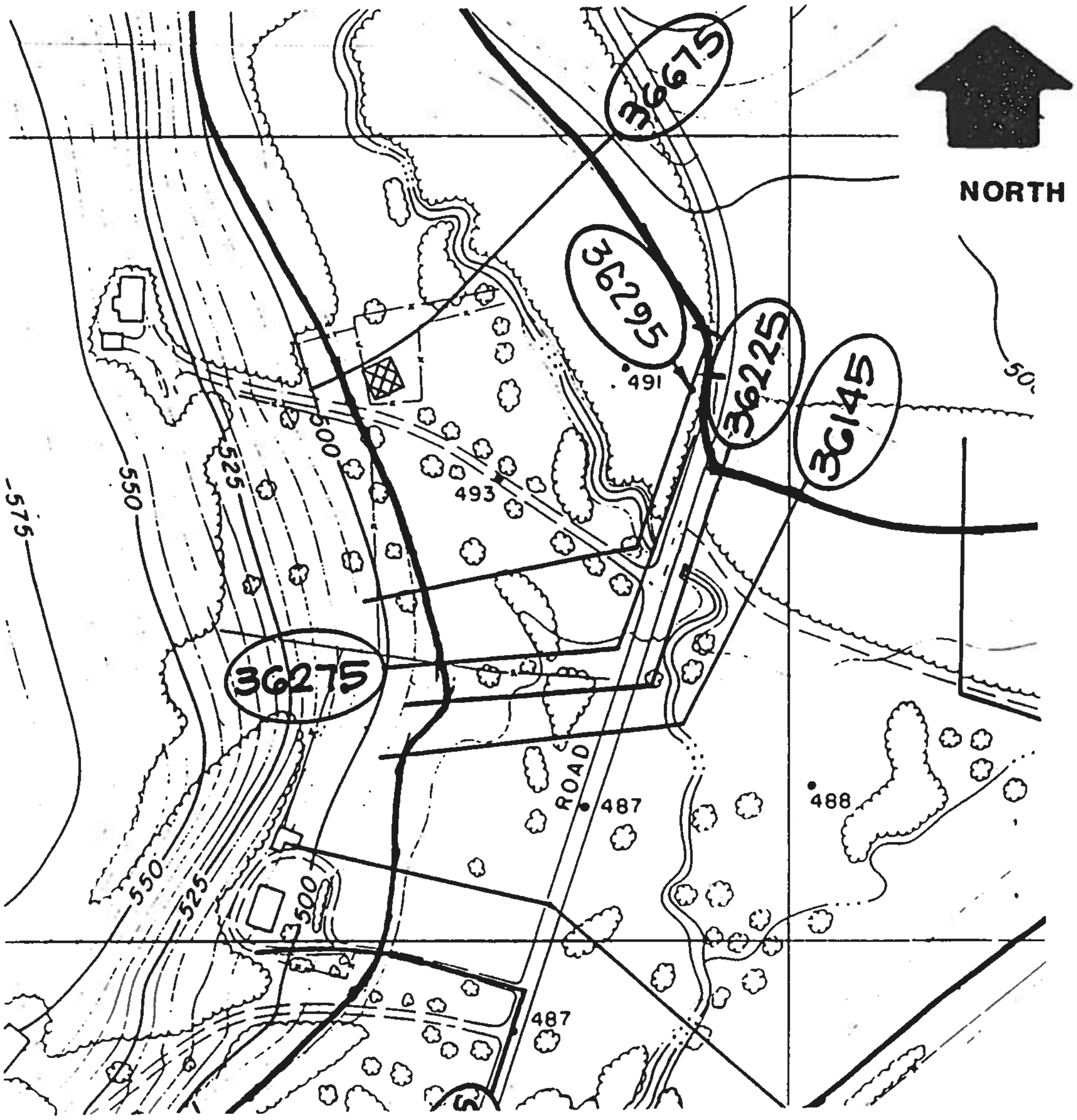
FLOOD-PRONE STRUCTURE

KCI TECHNOLOGIES

FIGURE NO. 2

Location of Floodprone Building-
Part of Map 30-31

Scale: Not to Scale



LEGEND:

FLOOD PLAIN BOUNDARY

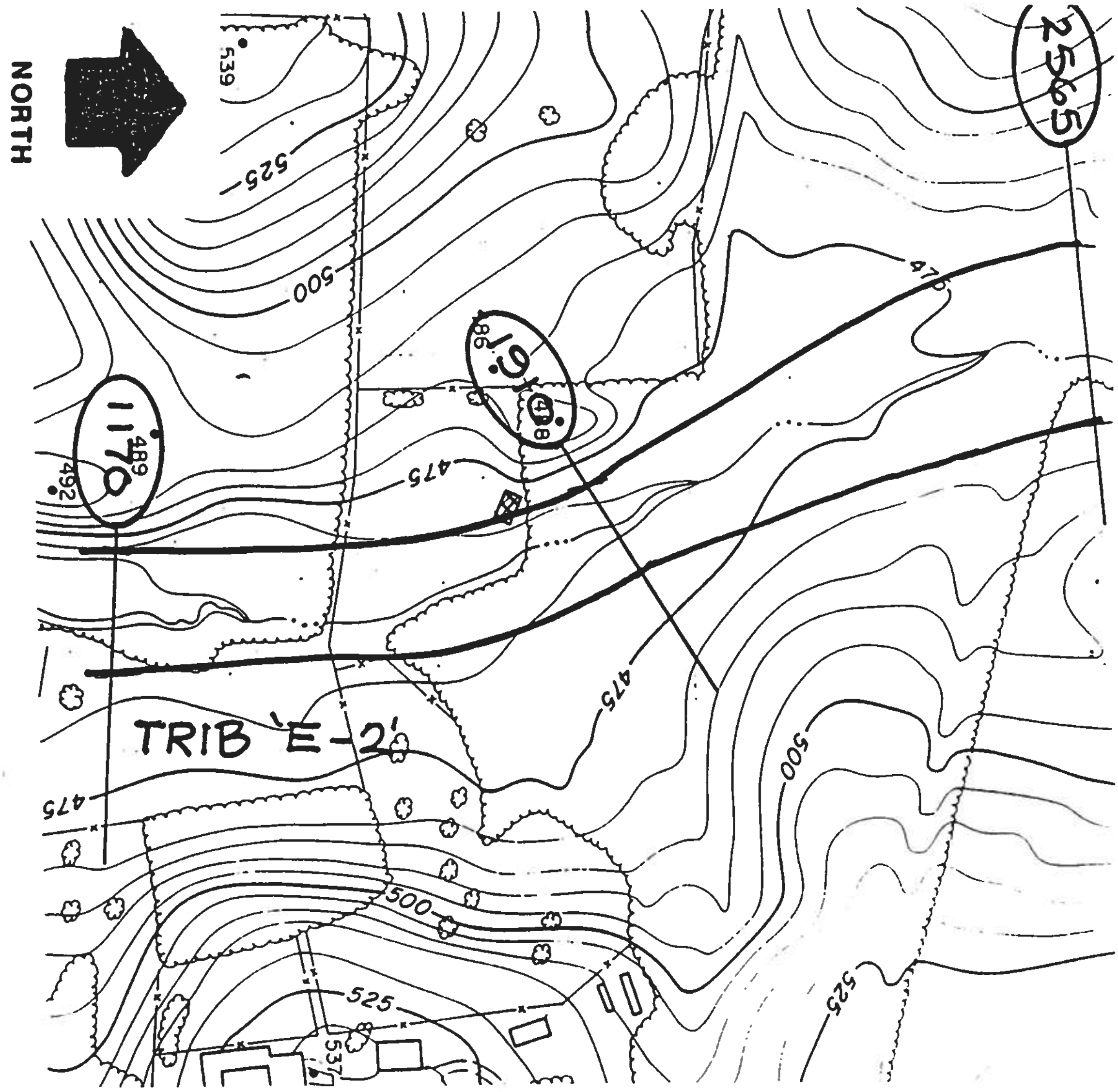
FLOOD-PRONE STRUCTURE

KCI TECHNOLOGIES

FIGURE NO. 3

Location of Floodprone Building-
Part of Map 36-31

Scale: Not to Scale



LEGEND:

FLOOD PLAIN BOUNDARY

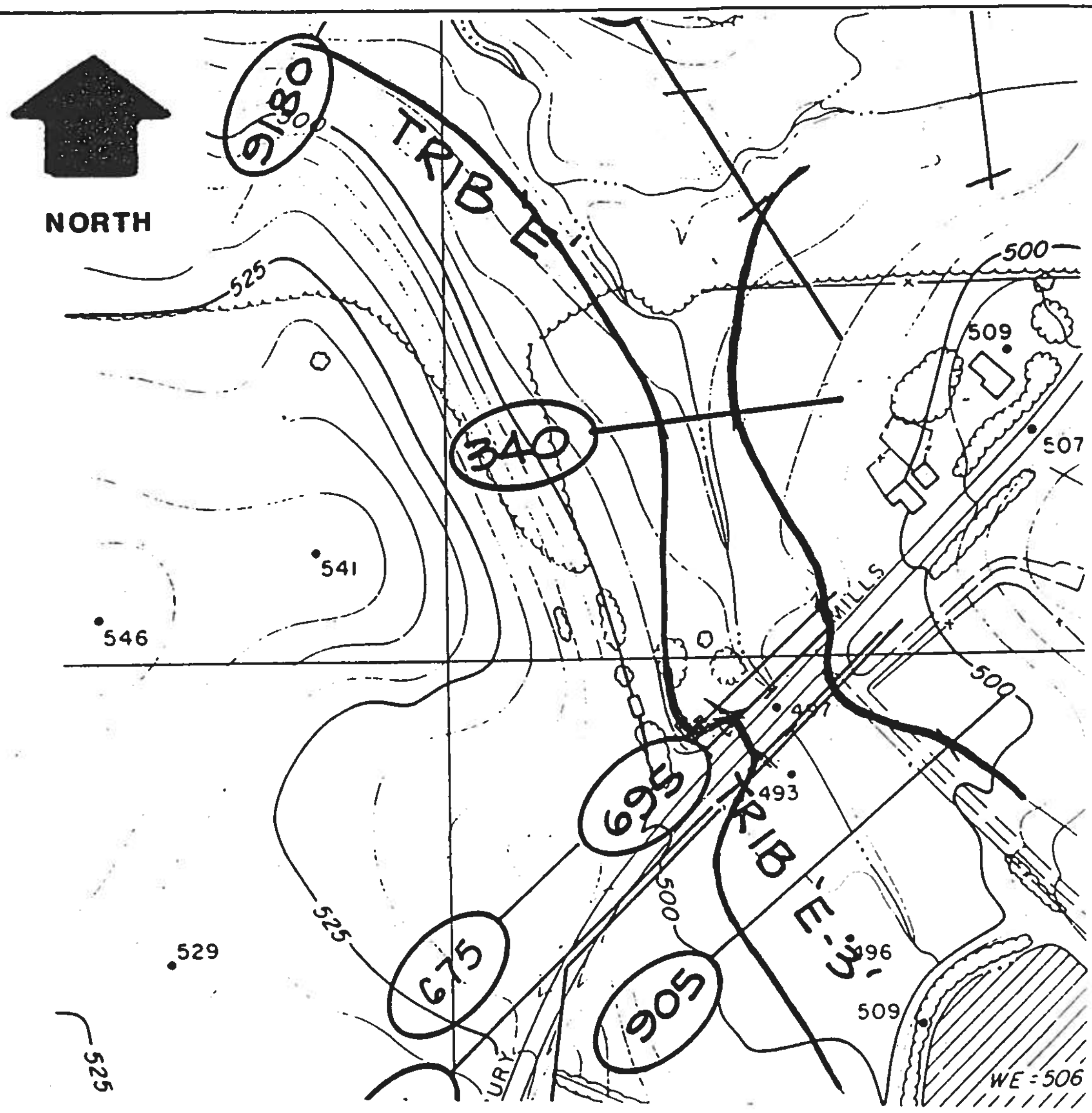
FLOOD-PRONE STRUCTURE

KCI
TECHNOLOGIES

FIGURE NO. 4

Location of Floodprone Building-
Part of Map 33-32

Scale: Not to Scale



LEGEND:

FLOOD PLAIN BOUNDARY

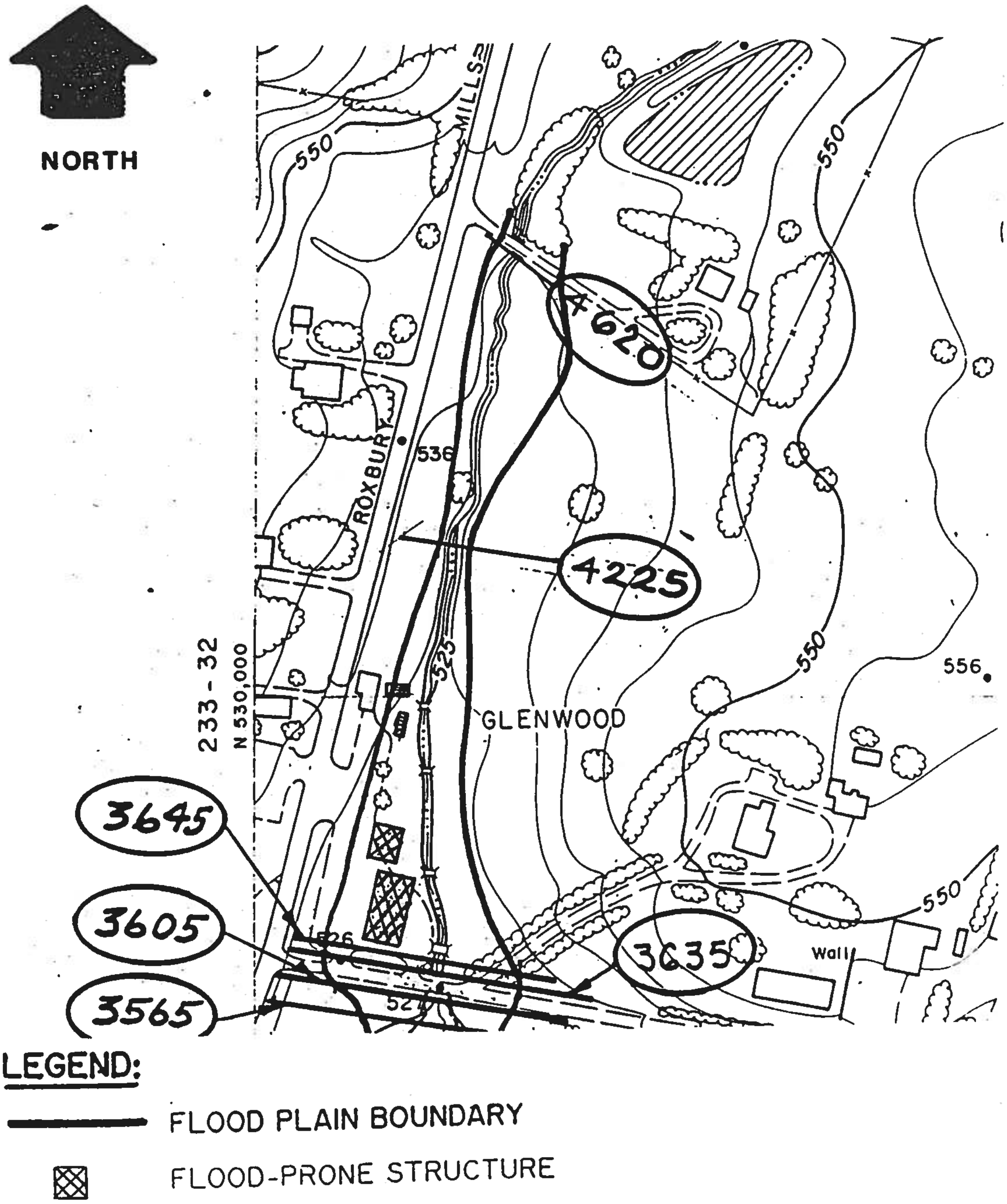
FLOOD-PRONE STRUCTURE

KCI TECHNOLOGIES

FIGURE NO. 5

Location of Floodprone Building-
Part of Map 32-32

Scale: Not to Scale

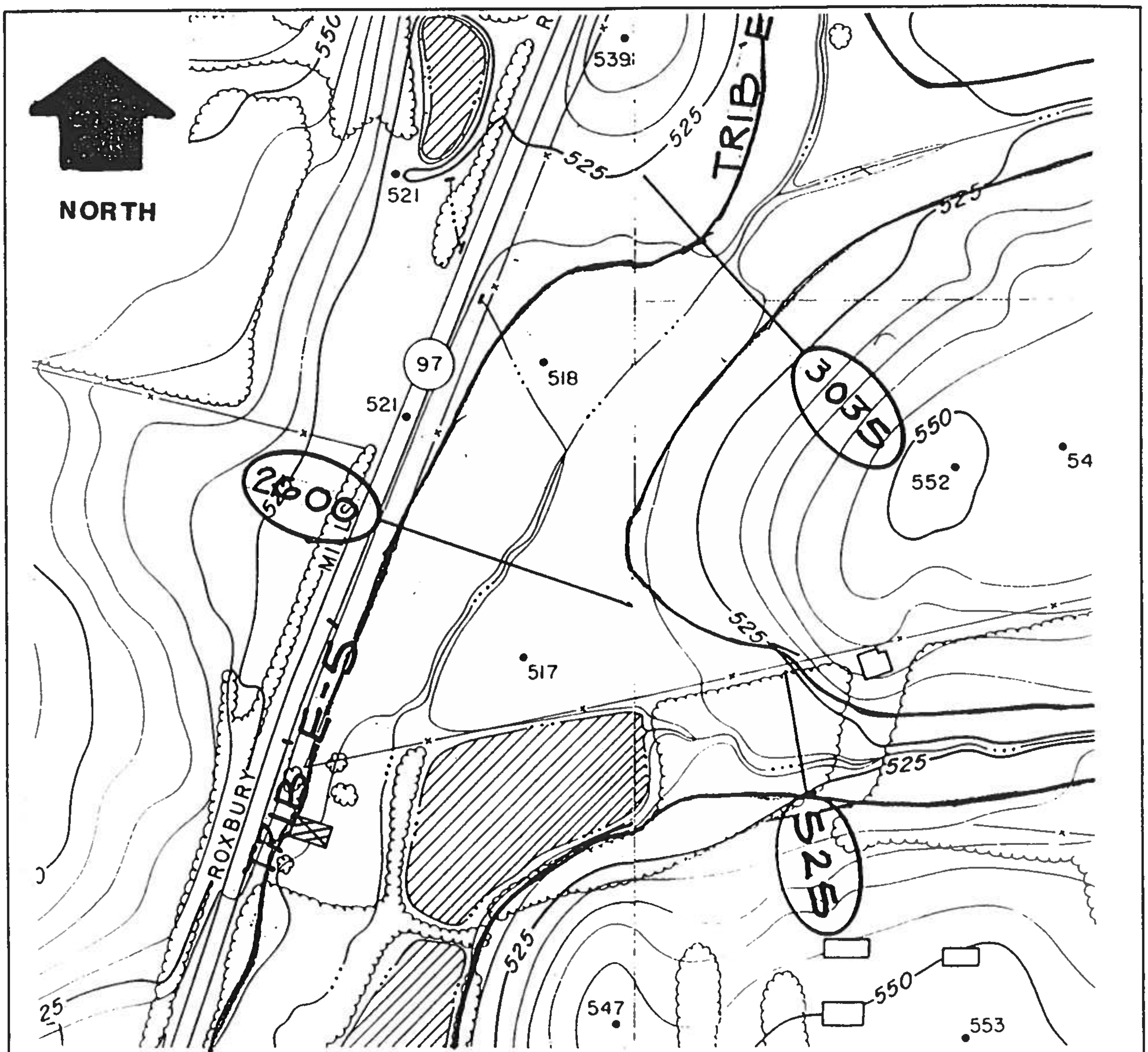


KCI TECHNOLOGIES

FIGURE NO. 6

Location of Floodprone Building- Part of Map 33-33

Scale: Not to Scale



LEGEND:

FLOOD PLAIN BOUNDARY

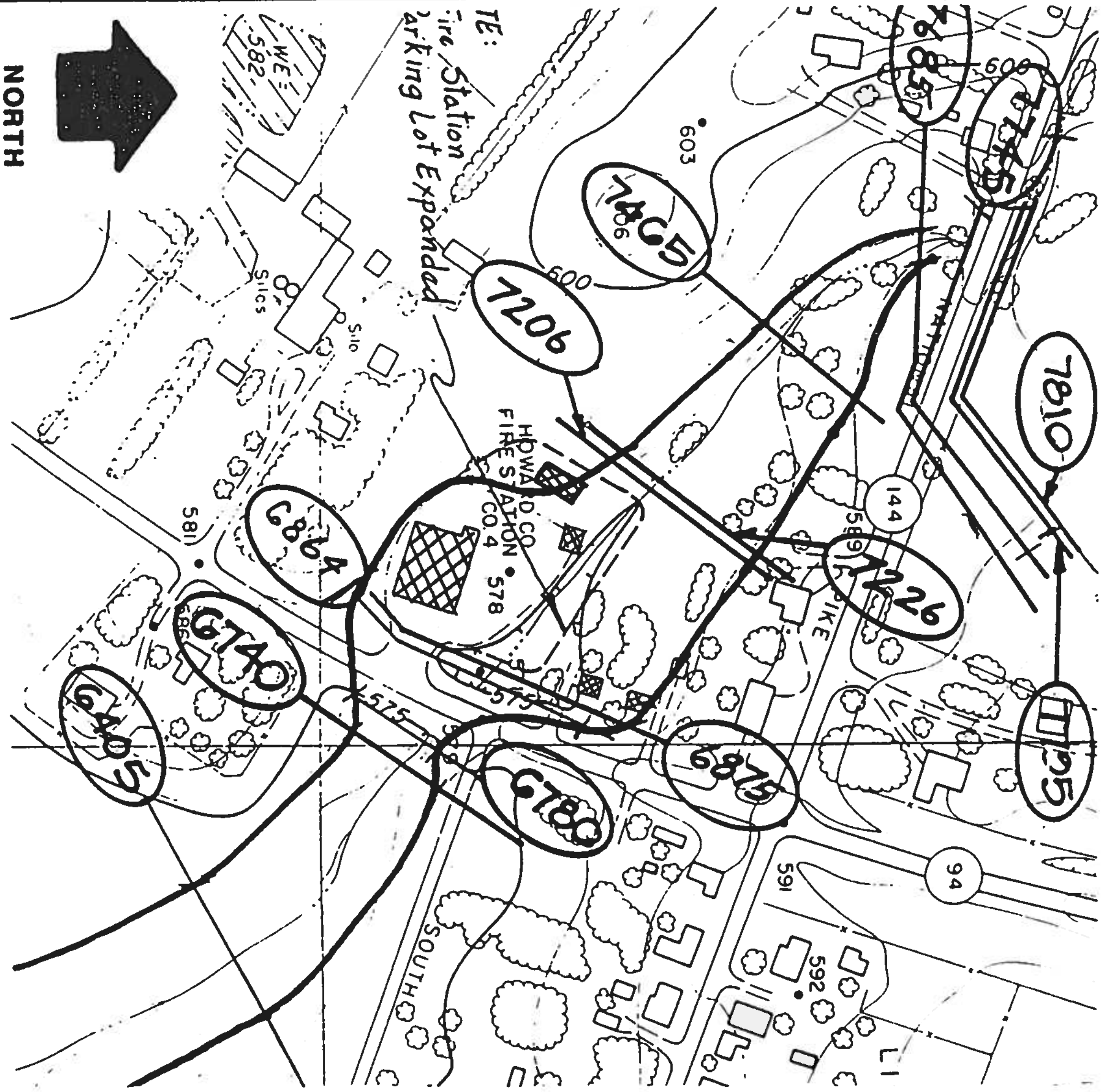
FLOOD-PRONE STRUCTURE

KCI TECHNOLOGIES

FIGURE NO. 7

Location of Floodprone Building-
Part of Map 33-32

Scale: Not to Scale



LEGEND:

FLOOD PLAIN BOUNDARY

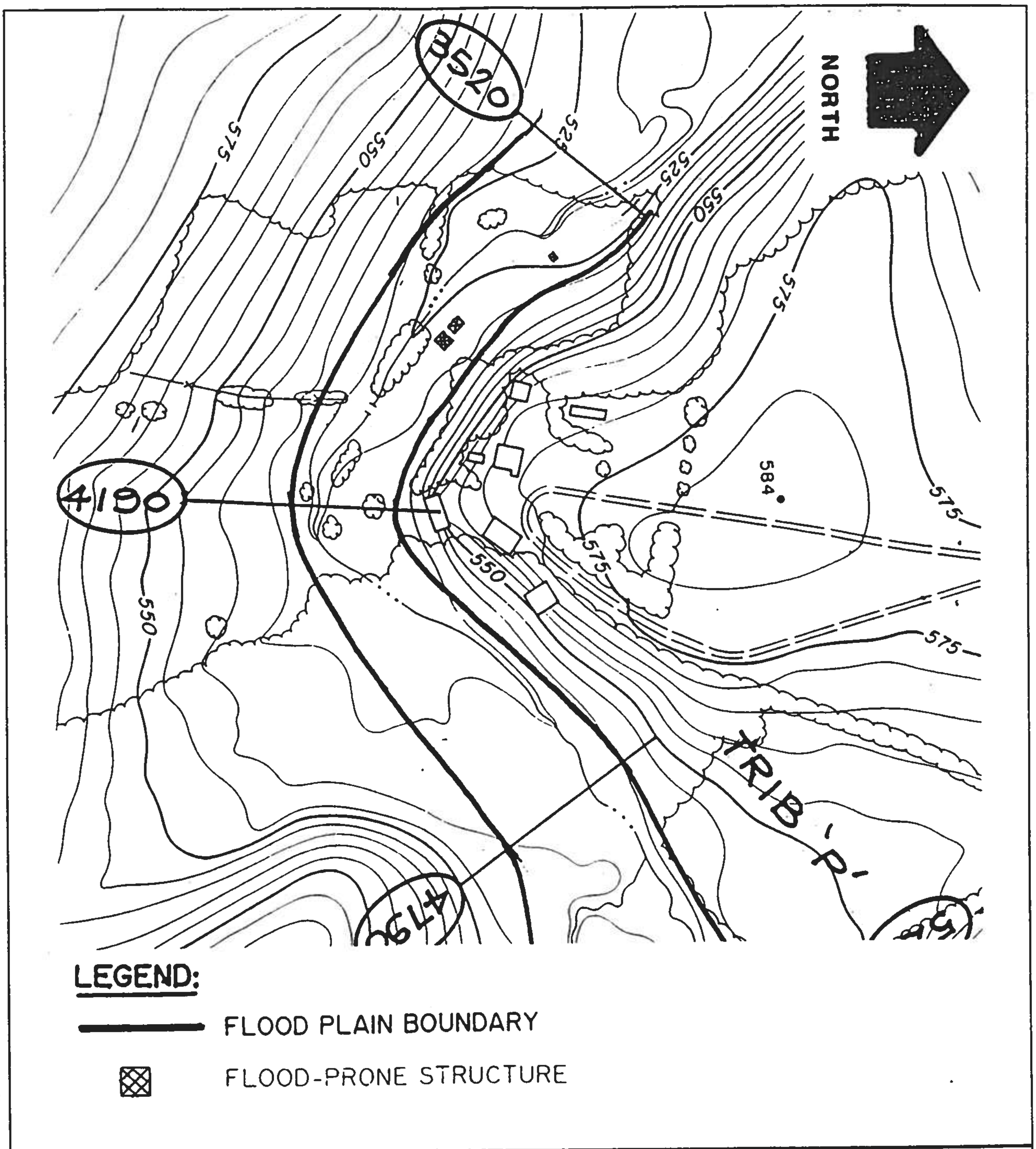
FLOOD-PRONE STRUCTURE

KCI TECHNOLOGIES

FIGURE NO. 8

Location of Floodprone Building-
Part of Map 37-30

Scale: Not to Scale



KCI TECHNOLOGIES

FIGURE NO. 9

Location of Floodprone Building-
Part of Map 36-32

Scale: Not to Scale

TABLE 12

Roadway Flooding Areas

Stream	HEC-2 Struct. #	Road Crossing	Howard County Flood-plain Sheet #	Minimum Roadway Elev. (Feet)	100-Year Flood Elev. (Feet)	Over-Topping Depth (Feet)
Cattail Creek	1	Roxbury Mills Road	30-31	391.70	392.19	0.49
	2	Old Roxbury Mill Road	30-31	388.00	392.39	4.39
	3	Union Chapel Road	33-31	449.00	454.08	5.08
	4	Bushy Park Road	35-31	475.40	480.41	5.01
	5	Unnamed Road	36-31	479.30	486.44	7.14
	6	Unnamed Road	36-31	481.00	486.78	5.78
	7 8	Carrs Mill Road (DS)* Carrs Mill Road (UP)*	36-31 36-31	487.00 493.34	490.49 494.77	3.49 1.43
	9	MD Route 144	37-31	517.37	517.91	0.54
	10	Unnamed Road	37-31	529.00	530.94	1.94
	11	Madison Street	38-31	563.62	564.33	0.71
Tributary A	13 14 15	Roxbury Road Unnamed Road Shady Lane	31-32 31-33 31-33	401.80 426.56 488.40	406.21 429.66 490.65	4.41 3.10 2.25
Tributary A-1	16	Roxbury Mills Road	31-32	438.50	439.54	1.04
Tributary A-5	17 18	Unnamed Road Dorsey Mill Road	33-33 31-33	427.63 432.63	428.49 433.59	0.86 0.96
Tributary A-8	19	Sharp Road	31-33	508.57	509.46	0.89
Tributary E	21	Roxbury Mills Road	32-32	497.50	498.67	1.17
Tributary E-2	22	Union Chapel Road	34-32	502.30	504.45	2.15
Tributary E-3	23	Roxbury Mills Road	32-32	497.00	497.48	0.48
Tributary E-5	24	Roxbury Mills Road	32-32	514.00	516.40	2.40
	25	Unnamed Road	33-33	527.00	527.76	0.76
Tributary H	26 27 28	Daisy Road Ed Warfield Road Unnamed Road	32-30 33-30 32-30	467.25 531.97 479.00	467.77 533.19 480.39	0.52 1.22 1.39

TABLE 12

Roadway Flooding Areas (continued)

Tributary K	29 30 31 32	Daisy Road Unnamed Road Duvall Road MD Route 94	34-31 34-31 34-30 35-29	462.29 464.00 498.06 599.11	463.23 465.50 499.25 599.68	0.94 1.50 1.19 0.57
Tributary L	33	Carrs Mill Road	35-32	481.20	482.08	0.88
Tributary L-1	34	Carrs Mill Road	35-32	495.00	495.90	0.90
Tributary M	35	Daisy Road	35-31	497.00	498.87	1.87
Tributary O	36 37 38	Daisy Road Mullinix Road MD Route 94	35-31 36-30 36-29	492.70 556.79 591.11	493.89 557.81 591.95	1.19 1.02 0.84
Tributary O-1	39 40 41 42	Unnamed Road MD Route 94 Lisbon Fire Sta. MD Route 144	36-31 37-30 37-30 37-30	519.34 579.62 579.80 589.70	521.01 580.85 580.85 591.40	1.67 1.23 1.05 1.70
Tributary O-2	43	MD Route 94	37-30	558.20	560.00	1.80
Tributary O-6	45	MD Route 94	36-30	583.20	583.78	0.58
Tributary P-2	46	MD Route 144	37-32	525.09	525.65	0.56
Tributary P-4	47	MD Route 144	37-32	536.60	537.12	0.52
Tributary S	50	I-70	38-31	584.50	584.57	0.07

* DS — Downstream Crossing UP — Upstream Crossing

TABLE 13

Residential and Commercial Flooding

Stream	Figure Number	Howard County Sheet #	Structure	First Floor Elevation (Feet)	Approx. 100-Year Flood Elevation (Feet)
Cattail Creek	2	30-31	Abandoned house off Old Roxbury Mills Road on the east side	NA*	391.9
	2	30-31	Garage on Old Roxbury Mills Road on the west side	NA*	391.9
	3	36-31	Shed off Carrs Mill road on west side	NA*	495.9
Tributary E-2	4	33-32	Shed	NA*	471.0
Tributary E-3	5	32-32	Residence at 3332 Roxbury Mills Road	NA*	493.1
Tributary E-5	6	33-33	Three buildings at Glenwood Gardens Nursery (office, greenhouse and shed) on east side of Roxbury Mills Road	NA*	527.8 to 530.3
	7	33-32	Residence on east side of Roxbury Mills Road	NA*	518.1
Tributary O-1	8	37-30	Residence at 1306 and 1310 Florence Road, garage, Fire Station and parking lot	NA*	579.4 to 580.8
Tributary P	9	36-32	Two sheds	NA*	523.4 to 533.2

*NA — Not Available

4.2 Recommended Solutions to Flooding Problems

This chapter addresses the flooding problems identified in the Cattail Creek watershed by recommending alternative structural and non-structural management measures. Among the alternative flood hazard mitigation measures that were initially investigated are:

1. Alternative land use pattern
2. County acquisition of flooded areas
3. Channel modification
4. Bridge and culvert improvements
5. Elevating of roadway
6. Flood Insurance
7. Floodproofing
8. Flood Warning signs
9. Floodwall/Levees
10. Stormwater management
11. Combinations of the above

A major goal in flood mitigation is the protection of human life and reduction of property loss from floods. However, constraints such as environmental impact, local responsibilities, legal and financial considerations dictate how this goal is achieved. Therefore, a criteria was developed to screen the potential alternatives. The criteria was based on the following:

1. Public health and safety
2. Physical, legal, and financial constraints
3. Environmental impact, water quality, aesthetics
4. Acceptance to public, local goals, local responsibilities
5. Level of protection or mitigation provided

After the initial investigation, alternative land use patterns, floodwall/levees, acquisition and stormwater management were considered not feasible mitigation measures to the specific flooding problems identified in the Cattail Creek watershed.

Through zoning and land use regulations, ultimate land uses have been established in the master plan. Although, the master plan can be amended, because the ultimate land uses are primarily agricultural,alternative land use patterns are not expected to alleviate the existing and future flooding problems. Generally, where floodwalls/levees were applicable, raising the roadway profile or modifying the stream channel provided a comparable solution. Stormwater management, though not found to be a solution to any of the specific problems identified could be a means for reducing the floodplain elevations in general throughout the watershed.

It could not be determined whether or not floodproofing or acquisition of building structures identified as floodprone are applicable due to insufficient information on the specific structures. All buildings identified as floodprone in this study should receive a site specific evaluation and be studied in more detail prior to implementing the recommended mitigation actions. The following measures were considered as possible mitigation actions:

1. Flood Insurance - Flood insurance is federally subsidized insurance under the National Flood Insurance Program and is designed to provide protection for property owners in floodprone areas. In this study, flood insurance is recommended for buildings identified as being in the floodplain, but for which there is lack of adequate information to make a determination that another mitigation measure is superior.

2. Flood Warning Signs - Flood warning signs are used primarily in areas where flash flooding occurs or where flooding is a minor problem. Signs along the roads calling attention to a flood hazard area are recommended for roads in the Cattail Creek watershed that are inundated.

3. Bridge and Culvert Improvements - If stream flow which is constricted at the roadway crossing due to inadequate hydraulic capacity of the bridge or culvert it can cause flooding of the roadway, the areas upstream of it and even damage the bridge or culvert. An effective solution is to install a new hydraulic structure or to increase the hydraulic capacity of the existing structure. These mitigation measures are recommended at some roadway crossings where alternatives such as raising the elevation of the roadway would cause flooding problems upstream.

4. Elevating of Roadway - A low point on the roadway approach which is not at the stream crossing often is flooded before the bridge or culvert is overtopped. Under such circumstances increasing the hydraulic capacity of the structure may not be adequate. Elevating the roadway becomes the most practical solution. Although raising the elevation of the roadway at stream crossings can cause the backwater to rise upstream, most cases in the Cattail Creek Watershed have no structures that could be impacted by the backwater. Elevating the roadway can provide the additional benefit of reducing downstream flooding and/or minimizing stream channel erosion by creating a stormwater management pondlike facility on the upstream side of the roadway.

5. Channel Modification - Channel modification refers to a natural channel that has been modified in cross-section geometry, alignment, or slope to increase the discharge capacity or to eliminate meanders. Although modification of a channel tends to generate adverse impact on aquatic life, sometimes it is the most cost-effective mitigation measure to alleviate flooding. Channel modification is recommended for a tributary of Cattail Creek which has meanders so close to the a roadway, that not only is the road inundated by the 100-year flood, potential erosion problems in the tributary could impact the roadway.

4.3 Roadway Flooding

General

Occasional roadway flooding is something that must be lived with because it is cost prohibitive to keep every roadway in the County dry for any storm event. The key to addressing potential flooding of roadways is to maintain a viable roadway network in the event of a major storm. A viable roadway network is one where no area, or only a few areas that are relatively unpopulated, are isolated from evacuation and rescue equipment. The recommendations noted in the Alternative Selection section of this study should be reviewed and acted upon in conjunction with a review of the entire Howard County roadway network. The County should prioritize those crossings that need to be upgraded to provide a viable roadway network.

As part of its prioritization process, the County must also consider the design storm for each of the roadways that is overtopped during a 100-year storm event. A driveway or a minor roadway may be designed to overtop for storms more frequent than the 100-year event. For the purposes of this watershed study, all roadways modelled in the HEC-2 have been treated as having a 100-year design storm.

Another consideration for the County is environmental factors involved with addressing flooding issues. Local, state, and federal environmental agencies will take a close look at proposals to reduce or increase levels of inundation as a result of elevating roadways, increasing hydraulic capacity of stream crossings, and channel modification. Reducing flooding may also serve to reduce the existing wetlands, which may not be acceptable from an environmental perspective or may require mitigation be done for the lost wetland resources. Increasing the flooding behind a road crossing to minimize flooding downstream and over the road may also serve to inundate existing wetlands more frequently than they are inundated presently. This scenario may also be unacceptable to the environmental agencies or may require wetland mitigation. This watershed study concentrates on addressing the hydraulic and safety factors of the flooding; environmental considerations will have to be addressed by Howard County on a case by case basis relative to the priority for reducing or eliminating flooding at each road crossing.

As previously noted, the HEC-2 model does not include culverts smaller than 48" diameter. It is possible that a roadway with a culvert smaller than 48" could be overtopped in a 100-year storm. Such a situation will not show up in the HEC-2 model nor will it be noted in the Alternative Selection section of this study. These overtopped roadways include both County and State roadways as well as private driveways. The County should determine which of the private driveways that are overtopped but are not modelled in the HEC-2 warrant consideration for the early flood warning notice.

Cattail Creek Mainstream

Several roadway crossings are overtopped by the 100-year flood as shown in Table 12. Bushy Park Road(#4) is overtopped by a depth of approximately 5 feet. Possible solutions to the flooding problem are; raising the roadway, increasing the capacity of the culvert under the road or both. However, approximately 1400 feet stretch of Carrs Mill Road north of its intersection with Bushy Park Road is inundated by the ultimate 100-year flood from the backwater caused by the culvert under Bushy Park Road. Therefore, raising Bushy Park Road could exacerbate the inundation at Carrs Mill Road. A combination of elevating the roadway and increasing the capacity of the culvert is the most feasible solution. It is recommended that a relief culvert be installed under Bushy Park Road and the road approach elevated accordingly.

Like Bushy Park Road, Old Roxbury Mill Road(#2) is overtopped by a depth of more than 4 feet. The Cattail Creek crossing of Old Roxbury Mill Road is within the stretch of the road between its two intersections with Roxbury Mills Road which is also known as MD Route 97. While this section of Old Roxbury Mill Road is open to local traffic, the bridge has been closed to vehicular traffic. Posting of flood warning signs should be considered but no further action is recommended unless the County plans to reopen the bridge to vehicular traffic.

Union Chapel Road(#3) is overtopped by more than 5 feet. Eliminating the overtopping is a difficult task in this instance for several reasons. There is a house upstream that is already close to the floodplain so raising the roadway might impact the existing house. Increasing the hydraulic capacity of the bridge is possible but this bridge is fairly large and the costs to improve it could be large. This case may be one that simply requires closing the roadway and providing detours during major storm events.

Carrs Mill Road crosses Cattail Creek at two locations(#7&#8), approximately 1000 feet apart. This length of the road is overtopped by the 100-year flood to a maximum depth of 3.5 feet at the downstream crossing. A feasible solution to this flooding problem would be to raise the roadway. Alternatively, Carrs Mill Road between the two crossings could be closed during a significant rain storm. There are also two private driveways(#5&#6) in the vicinity of the two Carrs Mill Road stream crossings that experience severe overtopping. The residents that are served by the driveways should be told of the potential flooding and should be put on a notification list when the County flood warning system notes elevated flows in the area.

MD Route 144(#9) is overtopped by more than six inches. After prioritizing the roadways that overtop, if this case of overtopping is to be remedied, raising the elevation of the roadway is recommended. There is a private driveway(#10) upstream from the MD Route 144 stream crossing that experiences almost 2 feet of overtopping. The residents that are served by the driveway should be told of the potential flooding and should be put on a notification list when the County flood warning system notes elevated flows in the area. The flooding experienced by three other roads (#1,#3&#11) is not severe so no action is recommended at this time.

Tributary A

Tributary A, which is also known as Dorsey Run, crosses Roxbury Road(#13) near the road's intersection with Dorsey Mill Road. The crossing is overtopped to a depth of more than 4 feet. Elevating the roadway or replacing the existing single span bridge with a hydraulically larger capacity structure are feasible solutions. There are no structures immediately upstream from the intersection that could be impacted by the increase in backwater that would result from raising the road if that option was selected in lieu of increasing the bridge area.

Upstream of the Roxbury Road and Dorsey Mill Road intersection, Tributary A approximately parallels Dorsey Mill Road. The stream meanders such that the stream is only a few feet away from the road at three locations. To avoid potential flooding and damage to the roadway from bank erosion in the stream channel, channel modification or bank stabilization may be needed along the meanders.

The Tributary A crossing of Shady Lane(#15) is inundated to a depth of 2 feet. A 1300-foot length of Shady Lane north of the crossing, which is approximately parallel to Tributary A-7, is also flooded. The Shady Lane roadway profile can be elevated to eliminate or at least minimize the flooding at the crossing and along the length of Shady Lane. Raising of the road is therefore recommended.

Roxbury Mills Road(#16) experiences flooding of approximately 1 foot. Although a foot of water does not necessarily stop automobile traffic from trying to drive across the road, this is a highly travelled roadway and the County should consider replacing the existing 48-inch RCP with a larger capacity structure.

There is a private driveway(#14) near the confluence of Tributaries A and A-5 that experiences over 3 feet of overtopping. The residents that are served by the driveways should be told of the potential flooding and should be put on a notification list when the County flood warning system notes elevated flows in the area. The flooding experienced by three other roads (#17,#18&#19) is less than one foot. These crossings do not require immediate action but they should be considered when the overall review of the roadway network is made.

Tributary E

Tributary E-2 overtops Union Chapel Road(#22) by a depth of more than 2 feet. Elevating the roadway or replacing the existing stream crossing with hydraulically larger capacity structure are feasible solutions. There are no structures immediately upstream from the intersection that could be impacted by the increase in backwater that would result from raising the road in this localized low point in Union Chapel Road.

There is an approximately 2000 foot long section of Roxbury Mills Road which is north of Countryside Road that is overtopped by three tributaries. Tributary E(#21) overtops the road by more than one foot, Tributary E-5(#24) overtops the road by more than 2 foot, and Tributary E-3(#23) overtops the road by less than six inches. Elevating the roadway in this area could impact other roadways and possibly some residences so elevating the road is not a viable option. Increasing the hydraulic capacity of the stream crossings for Tributaries E and E-5 is recommended. Increasing the capacity of the crossings would increase the floodplain downstream slightly but would not impact any residences or roadways. In fact, the floodplain decrease upstream from Roxbury Mills Road on Tributary E-5 could also help reduce the floodplain impacts to an existing residence that is in the 100 year floodplain. This residence will be discussed further in Residential and Commercial Flooding.

The flooding experienced by one other road(#25) is not severe so no action is recommended at this time.

Tributaries H and K

Ed Warfield Road(#27) over Tributary H and Duvall Road(#31) over Tributary K are inundated to a depth of over a foot. Possible remedial measures would be to raise the roadway at Tributary H and replace the culvert at Tributary K.

There are two private driveways(#28&#30) on Tributaries H and K, respectively, that experience over 1 foot of overtopping. The residents that are served by the driveways should be told of the potential flooding and should be put on a notification list when the County flood warning system notes elevated flows in the area. Daisy Road experiences flooding where is crosses Tributaries H(#26) and K(#29) and MD Route 94 is inundated by Tributary K(#32). However, the overtopping depths at these latter three crossings are less than a foot and no immediate action is recommended.

Tributaries L and M

Carrs Mill Road is overtopped by Tributaries L(#33) and L-1(#34) to a depth of almost 1 foot. While a combination of elevating the roadways and increasing the hydraulic capacity of the crossings could be considered, this area should be prioritized by the County to determine if immediate action should be taken.

Daisy Road is inundated to a depth of over 1.5 feet at Tributary M(#35). Raising the elevation of Daisy Road at the crossing is recommended in this case since increasing the capacity of the stream crossing could subject a residential property to increased flooding.

Tributary O

Daisy Road is inundated to a depth of approximately 1 foot at Tributary O(#36). Mullinix Road also experiences flooding of approximately 1 foot at the Tributary O(#37) crossing. Raising the elevation of Daisy Road at the crossings and increasing the capacity of the culvert at Mullinix Road are recommended.

Tributary O-2 overtops MD Route 94(#43) by more than 1.5 feet. Raising the road elevations would require substantial reconstruction of the roadway, therefore, increasing the capacity of the crossing would be a more viable recommendation for reducing the overtopping of MD Route 94. Flooding at MD Route 94 is less than 1 foot deep at Tributaries O(#38) and O-6(#45) and no immediate action is recommended. However, due to MD Route 94 being a major north-south roadway, increasing the capacity of the two crossings may be warranted.

MD Route 144 is overtopped by Tributary O-1(#42) by more than 1.5 feet. Elevating the roadway could cause flooding of houses adjacent to MD Route 144, therefore, increasing the capacity of the culvert would be a preferred means for decreasing the overtopping of the road. The Lisbon Fire Station(#41) and MD Route 94(#40) crossings of Tributary O-1 overtop by more than one foot. The action recommended at this time for crossings #40 and #41 is a more detailed analysis which should include crossing #42. A better understanding of the floodplain in this area is needed before recommending any modifications to the culverts or the roadways. There are also several buildings in the floodplain in this area, therefore, a single study could address a number of possible flooding issues.

There is a private driveway(#39) on Tributary O-1 that experience over 1 foot of overtopping. The residents that are served by the driveway should be told of the potential flooding and should be put on a notification list when the County flood warning system notes elevated flows in the area.

Tributaries P and S

Tributary P-2(#46) and P-4(#47) overtop MD Route 144 by approximately 6 inches. Since the depth of flow is small and since I-70 provides an east-west travel route, no immediate action is recommended for these two culverts at this time. Tributary S crosses I-70(#50) and the HEC-2 model has computed an overtopping depth of 0.07 feet. Despite the fact that I-70 is a major travel route, the minimal depth of flow is negligible and should not require any action.

4.4 Residential and Commercial Flooding

Cattail Creek Mainstream

An abandoned house off Old Roxbury Mill Road, a garage on Old Roxbury Mill Road and a shed off Carrs Mill Road are in the ultimate 100-year floodplain. It is recommended that the County should inspect the abandoned house for possible condemnation. No action is recommended for the garage and the shed.

Tributaries E-2, E-3, and E-5

A residence at 3332 Roxbury Mills Road and a shed are just outside or partially within the floodplains of Tributaries E-3 and E-2, respectively. We recommend further site specific topographic survey to determine the extent of potential flooding prior to making a final recommendation. If the buildings are found to be in the 100 year floodplain, the owners could consider acquiring flood insurance for the buildings as needed.

At Glenwood Gardens Nursery, an office building, a greenhouse and a shed are in the floodplain of Tributary E-5. During the initial reconnaissance phase of this watershed study, KCI spoke with the owner of the nursery who said that they had not seen any flooding in the buildings. We do recommend further site specific topographic survey to determine the extent of potential flooding prior to making a final recommendation. If the buildings are found to be in the 100 year floodplain, the owners could consider acquiring flood insurance for the buildings as needed. Since none of the affected buildings are residential dwellings, flood insurance may not be deemed necessary by the owners of the nursery.

TABLE 14

Summary of Roadway Flooding and Recommended Corrective Action

Stream	HEC-2 Structure #	Road Crossing	Recommended Solution
Cattail Creek	1	Roxbury Mills Road	No immediate action.
	2	Old Roxbury Mill Road	No immediate action.
	3	Union Chapel Road	No immediate action.
	4	Bushy Park Road	Increase culvert capacity and elevate roadway.
	5	Unnamed Road	No immediate action.
	6	Unnamed Road	No immediate action.
	7 8	Carrs Mill Road (DS)* Carrs Mill Road (UP)*	Raise roadway or close road during rainstorm. Raise roadway or close road during rainstorm.
	9	MD Route 144	No immediate action.
	10	Unnamed Road	No immediate action.
	11	Madison Street	No immediate action.
Tributary A	13 14 15	Roxbury Road Unnamed Road Shady Lane	Elevate road or increase culvert capacity. No immediate action. Elevate roadway.
Tributary A-1	16	Roxbury Mills Road	No immediate action.
Tributary A-5	17 18	Unnamed Road Dorsey Mill Road	No immediate action. No immediate action.
Tributary A-8	19	Sharp Road	No immediate action.
Tributary E	21	Roxbury Mills Road	Increase capacity of culvert.
Tributary E-2	22	Union Chapel Road	Elevate road or increase culvert capacity.
Tributary E-3	23	Roxbury Mills Road	No immediate action.
Tributary E-5	24	Roxbury Mills Road	Increase capacity of culvert.
	25	Unnamed Road	No immediate action.
Tributary H	26 27 28	Daisy Road Ed Warfield Road Unnamed Road	No immediate action. Increase capacity of culvert. No immediate action.
Tributary K	29 30 31 32	Daisy Road Unnamed Road Duvall Road MD Route 94	No immediate action. No immediate action. Increase capacity of twin culverts.* No immediate action.
Tributary L	33	Carrs Mill Road	No immediate action.

TABLE 14

Summary of Roadway Flooding and Recommended Corrective Action

Tributary L-1	34	Carrs Mill Road	No immediate action.
Tributary M	35	Daisy Road	Increase capacity of culvert.
Tributary O	36 37 38	Daisy Road Mullinix Road MD Route 94	Increase capacity of culvert. No immediate action. No immediate action.
Tributary O-1	39 40 41 42	Unnamed Road MD Route 94 Lisbon Fire Sta. MD Route 144	No immediate action. Further study recommended. Further study recommended. Increase capacity of culvert.
Tributary O-2	43	MD Route 94	Increase capacity of culvert.
Tributary O-6	45	MD Route 94	No immediate action.
Tributary P-2	46	MD Route 144	No immediate action.
Tributary P-4	47	MD Route 144	No immediate action.
Tributary S	50	I-70	No immediate action.

* DS — Downstream Crossing   UP — Upstream Crossing

TABLE 15

Summary of Residential and Commercial Flooding and Recommended Corrective Study

Stream	Howard County Sheet #	Structure	Recommended Solution
Cattail Creek	30-31	Abandoned house off Old Roxbury Mill road on the east side	County to inspect for possible condemnation
	30-31	Garage on Old Roxbury Mill Road on the west side	No action
	36-31	Shed off Carrs Mill road on west side	No action
Tributary E-2	33-32	Shed	No action
Tributary E-3	32-32	Residence at 3332 Roxbury Mill Road	Further site specific investigation
Tributary E-5	33-33	Glenwood Gardens Nursery (office, greenhouse and shed) on east side of Roxbury Mill Road	Further site specific investigation
	33-32	Residence on east side of Roxbury Mills Road	Further site specific investigation
Tributary O-1	37-30	Residence at 1306 and 1310 Florence Road, garage, Fire Station and parking lot	Further site specific investigation
Tributary P	36-32	Two sheds	No action

A residence on Roxbury Mills Road, south of the Glenwood Gardens Nursery and approximately 1200' north of Burnt Woods Road is located within the floodplain of Tributary E-5. There is also an above ground swimming pool adjacent to the house that is also in the floodplain. We recommend that a site specific topographic survey be done to determine grades around the house and point of first entry elevations prior to making a final recommendation. If the house is confirmed to be in the 100 year floodplain, the owners should consider acquiring flood insurance.

Tributaries O-1 and P

Residences at 1306 and 1310 Florence Road, a garage, some of the fire station buildings, and a parking lot may be in the floodplain of Tributary O-1 as noted earlier. Expansion of the fire station occurred after the 200 scale topographic mapping was done and the field survey for HEC-2 cross sections did not pick up all of the new grading at the site. Current site topography should be surveyed, including point of first entry elevations for the houses, and the HEC-2 model checked in this area due to the potential for flooding at the fire station as well as the two residences. If the buildings are found to be in the 100 year floodplain, the respective owners should be contacted regarding the acquisition of flood insurance. Two sheds may also be in the flooplain of Tributary P. No action is recommended relative to the sheds.

4.5 Alternative Selection Summary

This report presents the results of a study to identify floodprone structures in the Cattail Creek watershed. The study methodology included a combination of extensive field investigation, computer modelling, engineering analysis and alternative control evaluation. Flood mitigation techniques recommended for implementation includes:

1. elevating the roadway being flooded
2. increasing the hydraulic capacity of existing culverts
3. closing flooded roadways during major rain storm
4. posting flood warning signs in low, floodprone areas
5. adding a new culvert
6. modifying the existing channel near the roadway

Mitigation technique number 4, the posting of flood warning signs is recommended at all roadway locations where roadway overtopping is anticipated, even is those cases where no immediate action is being recommended. Posting signs is a relatively inexpensive way to alert the public that a roadway area is low and could be subject to flooding.

In addition to the recommended measures, the current Howard County flood warning system should be maintained. Also, periodic inspection and cleaning of bridge openings and culverts is recommended. The HEC-2 model used to predict the flood elevations, assumed that there is no accumulation of debris or trash which would serve to reduce the hydraulic capacity of the bridge or culvert. Water surface elevations at roadway crossings during the ultimate 100-year flood, would be higher than computed if debris and trash accumulate inside the structure under the road.

The County should consider incorporating the recommended measures for the floodprone roadways into regular maintenance activities, and as part of future capital improvement programs. It is recommended that future roadway improvements be designed to address roadway flooding problems.

As expected in basins with predominantly rural land use, flooding of residential and commercial structures is a minor problem in the Cattail Creek watershed. However, four residences, a Fire Station, and an office building appear to lie partially or entirely in the ultimate 100-year floodplain. We recommend further site specific investigation prior to final recommendation. In the interim, flood insurance could be considered.

Among the goals of Howard County's current Stormwater Management Program is to reduce flooding. Where feasible, regional stormwater management facilities could be considered. Regional facilities are superior to on-site facilities in alleviating flooding problems throughout the watershed since regional facilities are designed to control runoff from much larger areas and typically provide a reduction in flows that affect a larger stream reach than those flow reductions from an on-site pond.

Estimating the costs and the benefits resulting from the implementation of the recommended mitigation measures, and the cost of doing nothing were not part of this study. It should be recognized, however, that experience with actual flood damage indicates that it is almost always cost-effective to provide mitigation measures in floodprone areas.

A roadway structure which collapses due to flooding or a roadway approach which is inundated during a major storm can create safety hazards to motorists, as well as creating social impacts and economic losses over a period of time. In addition to the cost to the County or State of replacing/repairing the structure or the roadway approaches there can also be significant costs associated with constructing detours and lost business opportunities. There can also be the intangible costs associated with added travel time, inconvenience, and the piece of mind of the public. Therefore, it is important for the County to consider the recommended measures noted in this section.

5.0 DELIVERABLES

After completing all required computations and modelling it is important that the results be presented to Howard County in a usable form. Howard County has specified what deliverable items should be provided. Many of these items have been discussed or alluded to elsewhere in this report. At this point it is worth listing the deliverables which are as follows:

1. 2 - sets of 1"=600' scale drainage area maps with existing and planned development, hydrologic soil groups, and times of concentration.

2. 2 - sets of 1"=200' scale Howard County mylar topographic base sheets with the HEC-2 cross section locations and the delineation of the 100 year floodplain limits based on ultimate zoning conditions.

3. 3 - sets of blue line maps of 2. above.

4. 1 - set of 2. above reduced to 11" x 17" mylars.

5. 3 - sets of blue line maps of 4. above.

6. 1 - set of 1"=600' scale mylar overlays with the delineation of the 100 year floodplain limits based on ultimate zoning conditions.

7. 1 - set of survey field books containing the field surveyed cross sections and bridges/culverts.

8. 1 - set of calculations, photographs, and other related material used to support the findings of this study.

9. 2 - sets of IBM PC/AT compatible computer disks containing all hydrologic and hydraulic models.

10. 1 - camera ready master copy of this report.

11. 31 - copies of this report.

12. 2 - sets of cross section plots

13. 2 - sets of profile plots

6.0 CONCLUSIONS AND RECOMMENDATIONS

The Cattail Creek watershed study presented herein provides Howard County with its first comprehensive analysis of the watershed's hydrologic and hydraulic characteristics. The study also provides the County with field run survey for the 62 miles of stream that was studied. In addition to defining discharge rates for existing and ultimate conditions for the 2, 10 and 100 year storm events, the study also identifies potential flooding areas. Since the floodplain delineation is done for the 100 year ultimate buildout condition, and since this watershed is experiencing slow growth the study should allow the County to identify critical areas and conduct detailed studies of specific areas of concern. The County can also utilize the study for planning purposes and as a resource for a preliminary review of proposed developments within the Cattail Creek watershed. The intent of this watershed study was to provide a watershed level analysis of Cattail Creek and its tributaries.

In the course of preparing this study and analyzing and summarizing the study's results, several points stood out as recommendations to the County. These recommendations are as follows:

1. While the hydrologic and hydraulic components of this study present a good picture at the watershed level, this study was not detailed enough to make conclusions about specific areas. The purpose of this study was a watershed level analysis which could be used as a planning tool and which would identify specific areas requiring further investigation. The purpose of this study was not to conduct detailed investigations of specific areas. Areas of concern and future development parcels should be looked at in more detail.

2. The hydraulic model requested by Howard County was for the 100 year storm event. Several assumptions were made in the preparation of the HEC-2 model that are applicable to the 100 year storm but may not apply to more frequent storm events. If storm events other than the 100 year event are studied, the HEC-2 assumptions should be investigated.

3. The alternatives selection portion of this study has identified numerous roadways that are subject to flooding during large magnitude storm events. The alternative selection has also identified several significant buildings/primary residences that may also be susceptible to potential flooding. The roadway flooding should continue to be the focus of the County's flood warning system to enable traffic to be rerouted or stopped until the flooding potential has passed. The significant buildings and primary residences should be investigated in more detail since that detailed analysis is beyond the scope of this study.

4. Howard County should continue maintenance of existing as well as future culverts and bridges to insure that the full hydraulic capacity is available to convey flood flows. This study is based on culverts and bridges that have their full cross sectional area available for storm flows.

In conclusion, KCI Technologies, Inc. presents the Cattail Creek watershed study to Howard County as a comprehensive analysis of the hydrology and hydraulics of the streams within the watershed. We believe the models that have been prepared present an accurate depiction of what is occurring and will occur within the watershed based on the planned ultimate buildout of the watershed. We therefore recommend acceptance of the study presented herein by Howard County and Water Resources Administration.

7.0 REFERENCES

1. U.S. Army Corps of Engineers, Hydrologic Engineering Center, "HEC-2 Water Surface Profiles User's Manual", May, 1991

2. FHWA, Microcomputer Software Program HY-8, "FHWA Culvert Analysis", Version 3.2, November, 1990

3. U.S. Department of Agriculture, Soil Conversation Service, "Computer Program for Project Formulation, Hydrology", Technical Release Number 20, May, 1983

4. Ven Te Chow, "Open Channel Hydraulics", McGraw-Hill Book Company, 1959

5. U.S. Department of Commerce, "Rainfall Frequency Atlas of the United States, for Duration from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years", Technical Paper No. 40, May, 1961

8.0 APPENDICES

APPENDIX A

WATERSHED MAP AND KEY TO 1"=200' SCALE PLANS

KCI TECHNOLOGIES, INC.
ENGINEERS PLANNERS SURVEYORS
10 NORTH PARK DRIVE, HUNT VALLEY, MARYLAND 21030
(410) 316-7800

CATTAIL CREEK
DRAINAGE AREA MAP AND KEY TO 200 SCALE PLANS

HOWARD CO. PROJECT NO.	DATE
D - 1079	SCALE 1" = 2000'

APPENDIX B

LIST OF FULLY INTERPOLATED CROSS SECTIONS

List of Fully Interpolated Cross Sections

The following is a list of HEC-2 cross sections that were fully interpolated from the 200' scale topographic maps or were repeat cross sections based on field surveyed cross sections:

Cattail Creek Mainstem	1600, 7180, 7260, 8157, 8200, 15330, 23645, 23715, 23905, 32407, 32541, 34888, 36145, 36275, 36295, 39810, 39985, 40020, 42372, 43215, 45040, 45250, 45230, 48010, 48960
Tributary A	4230, 8375, 12082
Tributary A-1	2055, 2285, 2320
Tributary A-5	225, 350, 370
Tributary A-8	1300, 1500, 1540, 6150, 6400
Tributary A-13	305
Tributary E	5520
Tributary E-3	675, 750
Tributary E-5	1550, 3565, 3605, 3635, 3645
Tributary H	2780, 2950, 2980, 9426, 9486, 9492
Tributary H-1	608, 1000
Tributary K	1615, 1645, 1960, 2460, 6505, 6695, 6735, 15660, 15800, 15840
Tributary K-2	225
Tributary L	3700, 3720
Tributary L-1	1000
Tributary L-4	250

List of Fully Interpolated Cross Sections (Continued)

Tributary M	1655, 1770
Tributary O	1610, 1655, 1730, 10420, 10540, 10560, 12080, 12360, 12420
Tributary O-1	6740, 6875, 7226, 7685, 7795, 7810
Tributary O-5	3395, 3535, 3560
Tributary O-6	2625, 2755, 2775
Tributary O-7	460, 1110
Tributary P-2	2485, 2590, 2610
Tributary P-4	1225, 1360
Tributary Q	960, 1280
Tributary R	925
Tributary S	900, 1260

APPENDIX C

PERTINENT CORRESPONDENCE

MARYLAND HISTORICAL TRUST

William Donald Schaefer
Governor

Jacqueline H. Rogers
Secretary, DHCD

August 14, 1990

Mr. Mark S. Richmond, P.E.
Associate
Kidde Consultants, Inc.
1020 Cromwell Bridge Road
Baltimore, Maryland 21204

Re: Cattail Creek Watershed Model, KCI Job No. 01-90074 Howard County, Maryland

Dear Mr. Richmond:

This office has reviewed the above-referenced project with respect to effects on cultural resources.

With respect to archeology, our files indicated that the Cattail Creek Watershed contains seven known archeological sites; three additional archeological sites are documented in the immediate vicinity of the study parcel (see enclosed map and inventory forms):

<u>Sites Within Study Area</u>

Site No.	Cultural Period	Setting
18HO46	Prehistoric	On rise near stream junction
18HO47	Prehistoric	Near stream junction
18HO48	Prehistoric	Adjacent to stream
18HO75	Prehistoric	500 m from stream
18HO76	Prehistoric	100 m from stream
18HO122	Late Archaic	On knoll overlooking stream

18HO123	Historic (19th c.)	75 m from spring
18HO27	Prehistoric	300 m from stream
18HO98	Prehistoric	At stream junction
Sandy Spring Quad 6 (MO-MM mill)	Historic	Near stream

There is not much information known about these sites, but the settlements are often found adjacent to streams.

In our opinion, there is good potential that other undocumented prehistoric archeological sites exist within the study area in similar environmental settings, especially on high ground near stream junctions. Additionally, historic archeological sites have a high probability of occurrence along the historic roads in the watershed. Because the amount of professional archeological survey coverage of the area is very small (e.g., in scattered areas by investigators Barse and Barse 1985; Brown 1976; Rule and Evans 1985; and Wesler et al. 1981 [see enclosed title pages]), we strongly recommend that the Howard County Department of Public Works and the Water Resources Administration conduct an archeological survey of lands to be impacted by planned developments and undertakings. The survey should be conducted by a qualified professional archeologist, and performed in accordance with the "Guidelines for Archeological Investigations in Maryland" (McNamara 1981). If sites are identified by the survey, they should be sensitively incorporated into the property's future use.

With respect to historic standing structures, the project area contains approximately 35 known historic properties. Additional structures exist adjacent to the project area as well. An evaluation of National Register eligibility for many of these structures has not been conducted. Due to the large number of identified resources, our office has not provided the architectural survey forms. You are more than welcome to review our architectural inventory files in the Trust's library and make appropriate photocopies. Please contact Ms. Mary Louise de Sarran at 301-974-5000 to arrange a library visit.

There are two known National Register buildings with the project area: Hobson's Choice and Union Chapel. National Register forms for each resource are included and the site locations are marked on the enclosed map.

As plans progress for this project, the Water Resource Administration and Howard County will need to consult further with our office in order to formally determine the project's effects to cultural resources and fulfill compliance with Article 83B Section 5-618 of the Annotated Code of Maryland. If you have any questions or require further information, please contact Ms. Lauren Bowlin (for structures) or Dr. Gary Shaffer (for archeology) at (301) 974-5007. Thank you for providing us this opportunity to comment.

Sincerely,

Elizabeth J. Cole

Elizabeth J. Cole
Administrator
Archeological Services
Office of Preservation Services

Enclosures
EJC/GDS/LLB/meh
cc: Ms. Catherine Pieper Stevenson
Mr. James M. Irvin
Mrs. Phillip St. C. Thompson
Ms. Alice Ann Wetzel

KIDDE CONSULTANTS, INC.

PROGRESS REPORT

SUBJECT:	Cattail Creek Watershed Model Howard County Capital Project No. D-1079 Agreement No. CA-90-43 KCI Job No.: 01-90074
REPORT PERIOD:	July 6, 1990 - August 16, 1990
DATE PREPARED:	August 31, 1990
DISTRIBUTION:	Ms. Elizabeth Calia, Howard County, Dept. of Public Works Mr. Steve Sharar, Howard County, Dept. of Public Works Mr. John Smith, Water Resources Administration Mr. Richard Umbarger, Kidde Consultants, Inc. Mr. Anand Terway, Sheladia Associates, Inc.
PREPARED BY:	Mr. Mark Richmond, Kidde Consultants, Inc. MSR

A meeting was held at Howard County on July 19, 1990 with Ms. Calia, Mr. Chuck Boyd and Mr. Dave Holden (Howard County Department of Planning and Zoning) to discuss the cluster development concept recently approved as part of the 1990 General Plan. We discussed clustering as it applies to rural residential and rural conservation zones, agricultural preservation areas, density transfer possibilities, and the existence of previously platted one acre lots which have yet to be built on. Unless there are specific high density areas, assuming 3 acre lots for the remainder of the watershed not in preservation easements should give a conservative ultimate discharge.

On July 20, 1990 we received confirmation from Ms. Calia that Kidde can delay its field surveying of the heavy growth areas along streams and crop fields. A limited amount of field survey work was performed during this progress report period.

Mr. Richmond and Mr. Clay Quinn (Kidde Consultants, Inc.) spent July 24, 1990 in the field to identify row crop fields vs meadow fields and to measure stream cross-sections throughout the watershed for use as TR-20 reach cross sections. Time of concentration and RCN computations were completed as were the cross section and structure tables. The drainage area maps were completed.

We also began inputting the completed field survey information into HEC-2 files.

Our goals for next month include the following:

1. Sheladia to complete TR-20 model calibration.

2. Prepare hydrology submittal package and meet with Howard County and W.R.A. to submit the package.

3. Begin cataloging photographs for final report.

4. Continue inputting field survey information into HEC-2 files.

Maryland Department of Natural Resources
Forest, Park and Wildlife Service
Tawes State Office Building
Annapolis, Maryland 21401

RECEIVED
OCT 1 1990

William Donald Schaefer
Governor

Torrey C. Brown, M.D.
Secretary

Donald E. MacLauchlan
Assistant Secretary

September 26, 1990

Mr. Mark S. Richmond
KIDDIE CONSULTANTS, INC.
1020 Cromwell Bridge Road
Baltimore, MD 21204

Re: Cattail Creek Watershed Model
KCI Job No. 01-90074

Dear Mr. Richmond:

This is in response to your request for information regarding the above referenced project. There are no known Federal or State threatened or endangered plant or wildlife species present at this project site.

However, our threatened and endangered species database has records for the following species in the area of the Cattail Creek Watershed:

Scientific Name	Common Name	Status
FLORA		
Fraxinus profunda	Pumpkin Ash	State Endangered
Lythrum alatum	Winged Lossestrife	Highly State Rare
Stellaria alsine	Trailing Stitchwort	State Endangered
Stenanthium gramineum	Featherbells	State Threatened
FAUNA		
Speyeria idalia	Regal Fritillary	State Endangered

We recommend that appropriate habitats contained within the study area be surveyed for these species prior to disturbance. For additional information contact Aaron Keel at (301) 974-2870.

The forested areas on the project site may be utilized as breeding areas by Forest Interior Dwelling Birds. The habitat of these birds is rapidly disappearing in Maryland. Conservation of this habitat is not mandated outside of the Chesapeake Bay Critical Area, but we will assist those interested in voluntarily protecting this habitat.

If you have any questions regarding this please contact Bill Gates at (301) 827-8612.

Sincerely,

James Burtis, Jr.
Director, Planning and Program Development

JB:dec

cc: Bill Gates
Lynn Davidson
Bill Brumbley
Jeff Horan
ER# 90.05.360

KIDDE CONSULTANTS, INC.

memorandum:

project: name: Cattail Creek

number: 01-90074

date: March 25, 1991

time:

✓ telephone conversation ___ meeting ___ second hand

person: Steve Sharar - Howard Co.

subject: Status

(1) Steve will try to finish up hydrology review next week.

(2) Regarding small driveway and road culverts i.e. less than 48" diameter. If they have a significant impact on flood study, we'll model them with HEC-2 bridge routine. For example, a 36" culvert under a county road with 6' of fill from crown of pipe to top of road would be modelled whereas a 36" culvert under a county road with 1' of fill from the crown to top of road would not be modelled. In the latter case a HEC-2 cross section on the road surface will not be used. This would give a very conservative water surface over the road. Since we are already using a conservative discharge (100 year ultimate) Steve felt that showing an approximate flood delineation over the road for the small culverts would be acceptable as long as we note in the report what we did & why we did it.

KC. Steve Sharar by: Mark Richmond

KCI TECHNOLOGIES

33

→ Steve this seems like a reasonable appro[ach]

file D-7

MEMORANDUM OF MEETING

DATE: March 31, 1992

MEETING DATE: March 27, 1992

TIME: 8:30 am

PLACE: Howard County Office Building

ATTENDEES:
Howard County Department of Public Works
Steve Sharar

Water Resources Administration
John Smith

KCI Technologies, Inc.
Mark Richmond MSR

SUBJECT:
Cattail Creek Watershed Model
Howard County Capital Project No. D-1079
Agreement No. CA-90-43
KCI Job Order No. 01-90074

The purpose of this meeting was to discuss the problem we have encountered with t regression analysis method of computing the intermediate discharges for the HEC-2 model.

The regression analysis gives good results for individual tributary discharges but cann always adequately determine a discharge on the main streams between TR-20 sections. Af looking at several types of problem areas, the following general scenarios were set out:

1. If the discharge differs between two successive TR-20 sections by less than 10 perce we will use the higher of the two discharges for that entire reach length. T essentially ignores the input from the smaller tributaries due to hydrograph timing a assumes minimal stream storage for the reach, and

2. If the discharge differs between two successive TR-20 sections by more than percent, we will not automatically use the higher of the two discharges. In this secc

scenario, tributary discharges and/or stream storage have a more significant impact on the stream discharge. As would be expected, scenario two occurs more often at the top of the watershed than the bottom of the watershed.

A print has been enclosed that shows the first and second scenario occurrences. At least two-thirds of the second scenario conditions can be handled by using a discharge-averaging-technique. The larger discharge would be used for approximately half of the reach and an average between the higher and lower discharge would be used for the other half of the reach length. For example, the discharge changes within a given reach from 1000 cfs upstream to 2000 cfs downstream. By the discharge averaging technique, 2000 cfs would be used for the lower half of the reach while 1500 cfs would be used for the upper half of the reach. Of course, the location of tributary confluences would help determine when to switch from 2000 cfs to 1500 cfs.

The remaining four or five cases that do not fit any of the above scenarios will be analyzed on a case by case basis to determine the appropriate discharges.

If we have not heard back from Mr. Sharar within one week of receipt of this Memorandum of Meeting, KCI will be authorized to proceed with determining the discharges as stated above. KCI will redline a 2000' scale print for Mr. Sharar and Mr. Smith with KCI's proposed HEC-2 discharges. Upon concurrence from both reviewers, KCI will complete its HEC-2 model for submittal to Howard County and WRA.

A copy of the flow schematic has been included for Mr. Sharar's use.

We believe that the above accurately reflects what transpired at this meeting. However, we will appreciate comments involving a difference in understanding of what occurred. Unless we are notified in writing to the contrary within ten (10) days after receipt, we will assume that all in attendance concur in the accuracy of this transcription.

aew

Enclosures

pc: All Attendees
Elizabeth Calia