DEEP RUN WATERSHED STUDY

HOWARD COUNTY, MARYLAND
CAPITAL PROJECT NO. D-1094

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1.0 INTRODUCTION

1.1 Authorization

On December 23, 1991, KCI Technologies, Inc. (KCI), was invited to submit a proposal to provide engineering and surveying services for the preparation of a technical watershed study for the Deep Run watershed in Howard County, Maryland. A proposal was submitted to Howard County to perform a hydrologic and hydraulic analysis, conduct field surveys 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 notice to proceed was issued by Howard County on April 10, 1992.

The enclosed study hydraulically models close to twenty three miles of stream and more than thirty bridges or culverts. Hydrology was performed for the entire watershed. The mainstem of Deep Run is included in its entirety as well as a bulk of Tributary D and its numerous subtributaries. Several other small tributaries are included but a large number of tributaries to Deep Run were not surveyed and are not included in the HEC-2 model.

1.2 Project Overview

The Deep Run watershed study began in April 1992. 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. Field surveys were begun at the same time as the data collection was taking place. 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. Flood prone structures were identified from the hydraulic results.

The next step in the development of a comprehensive flood management plan for the Deep Run watershed is for Howard County to authorize an evaluation of potential alternatives to reduce the flood hazards to be followed by detailed study of the proposed alternatives. These tasks are not part of the study contained herein.

This report summarizes the Deep Run watershed study. Following the next sections describing the study area, the report summarizes each major step of the analysis including hydrology and hydraulics. 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 southeastern Howard County, Maryland (See Figure 1). The mainstem of Deep Run initially runs from the northwest corner of the watershed in a southeasterly direction. It then flows to the east and eventually to the northeast where it discharges into the Patapsco River. There are twenty three tributaries to the mainstem, each of which has up to thirteen second or third order tributaries. The watershed is generally bordered on the west by MD Route 175, on the north by MD Route 103, and on the southeast by MD Route 713 in Anne Arundel County.

1.4 Watershed Description

The Deep Run watershed is comprised of approximately 19.8 square miles and has approximately 37 river miles of streams within it. The watershed encompasses portions of both Howard and Anne Arundel Counties. See Figure 1. There are over 30 stream crossings within the watershed ranging from large bridges to small driveway culverts. Deep Run is categorized as a Use I waterway. Deep Run is a fairly well developed watershed with a mixture of residential and industrial land uses. Three major roadways traverse the watershed in a southwest to northeast direction. They are Interstate 95, MD Route 1 and Interstate 295. The extension of MD Route 100 also crosses the watershed in a northwest to southeast direction. A majority of the streams and tributaries are located in areas of heavy underbrush, woods or through developed subdivisions.

1.5 Existing Studies

Kidde Consultants, Inc. performed a hydrologic and hydraulic analysis of the Deep Run watershed that was completed in 1984. This study included hydrologic and hydraulic analysis for most of the study area.

In 1991, a detailed hydrologic and hydraulic model for Deep Run in the vicinity of MD Route 100 was prepared by KCI for Maryland State Highway Administration. The TR-20 analysis for the MD Route 100 study stopped at MD Route 100 and did not incorporate the portion of the Deep Run watershed downstream of the project limits. Several of the structure tables from the MD Route 100 study were used in the study presented herein. The HEC-2 model generated for the MD Route 100 study, including discharge rates, is incorporated in its entirety into the overall HEC-2 model for the current hydraulic analysis.

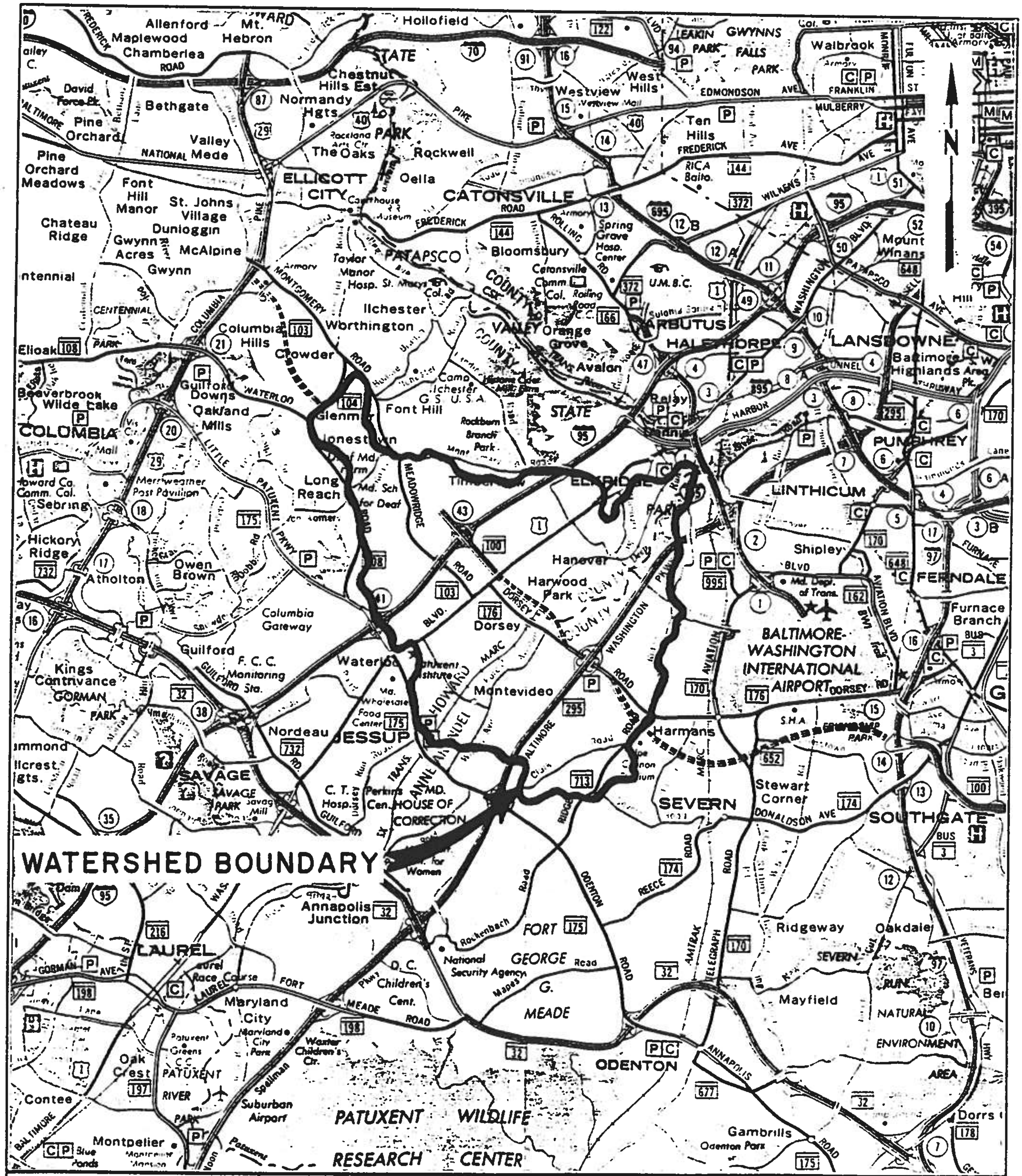

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FIGURE NO. 1

Project Location

Scale: 1" = 2.2 Miles

In 1996, a detailed hydrologic and hydraulic model for Deep Run adjacent to a different segment of MD Route 100 than previously studied was prepared by URS Greiner and Constellation Design Group for Maryland State Highway Administration. The TR-20 analysis for the Greiner study broke the watershed into smaller drainage areas than in the hydrologic analysis performed for the Howard County study described herein. The HEC-2 model generated for the MD Route 100 study, including discharge rates, is incorporated in its entirety into the overall HEC-2 model for the current hydraulic analysis.

1.6 Natural Resource Inventory

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 Deep Run watershed. The Natural Heritage Program's data base contains two records for State Endangered species within the Deep Run watershed, an historic record for Gentiana villosa, striped gentian and a recent record for Solidago speciosa, Showy goldenrod. 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 over 90 known resources including archeological sites and historic standing structures within the study area. 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.

The Department of Natural Resources and the Maryland Historical Trust noted that any proposed projects within the Deep Run 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 Deep Run 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 proposed for the year 2010). The land use conditions are described further in Sections 2.3.2 and 2.3.3, respectively. In addition, the 50- and 500- Year discharges were computed for proposed land use.

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' USGS quadrangles for Savage and Relay. Thirty-seven subareas were utilized to model the Deep Run watershed. Howard County 1"=600' topography with 5' contour interval was then used to check the actual drainage boundaries in conjunction with Howard County 1"=200' topography with a 5' contour interval. The 200' scale topography was assumed to govern where there were discrepancies with the 600' scale topography. The drainage area size averaged 0.53 square miles with the smallest and largest drainage areas being 0.29 and 0.76 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 and cover (i.e., land use) characteristics, RCNs have been computed for various combinations of soil type and land use. 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 utilized for the Deep Run watershed model are listed in Table 1 along with each land use's RCN value for each hydrologic soil group.

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. Individual soil maps were scanned into digital format as part of the MD Route 100 wetland assessment project prepared for MSHA. Accuracy of the scanned information is as good as the original soil survey mapping.

Soils attribute tables were developed in the GIS using information from the Soil Survey. These tables include the soil classification and hydrologic soil group code for each soil polygon. The digital files were then loaded into KCI's SPANS GIS system and overlaid onto existing and proposed land use to develop composite runoff curve numbers for each sub watershed. The runoff curve numbers were computed using a matrix overlay model developed with the GIS modeling language.

TABLE 1
Runoff Curve Numbers

Cover Description	Condition	Hydrologic Soil Group A	B	C	D
Rural Residential	N/A	46	65	77	81
Low Density Resid	N/A	51	68	79	84
Med Density Resid	N/A	54	70	80	85
Townhouses	N/A	77	85	90	92
Garden Apts	N/A	77	85	90	92
Light Commercial	N/A	81	88	91	93
Industrial	N/A	81	88	91	93
Heavy Commercial	N/A	89	92	94	95
Airport	N/A	96	96	96	96
Impervious	N/A	98	98	98	98
Row Crops	good	65	75	82	86
Open Space(Lawn)	good	30	58	71	78
Woods	good	30	55	70	77

2.3.2 Existing Land Use

The existing land use information was also developed as part of the MD Route 100 wetland assessment project. A multispectral SPOT satellite image of the region was classified to Anderson Level I Land Use/Land Cover classifications. This digital land use/land cover data was then further refined using low-altitude black and white and high-altitude infrared aerial photography. Through several meetings with the Howard County and Anne Arundel County Departments of Planning and Zoning, this information was further refined to more accurately reflect the County conditions. As with the soils data, attribute tables were developed containing a record for each land use polygon. These records contain such items as the area, perimeter, and land use class of each polygon. This final existing land use product was loaded into KCI's SPANS GIS system.

2.3.3 Proposed Land Use

The proposed land use was the third piece of information taken from the MD Route 100 study. Starting with the existing land use information, KCI met with the Planning and Zoning Departments of Howard and Anne Arundel Counties to update the existing information and incorporate the 1990 General Plan of both Counties into the Proposed land use document. The proposed land use was loaded into KCI's SPANS GIS system and reflects build out to year 2010.

While Year 2010 build out is not the same as ultimate build out based on current zoning, there is a minimal difference between the two build out scenarios. Discussions with Howard County Departments of Planning and Zoning and Public Works prior to generating the TR-20 models indicated that Year 2010 build out could be considered as ultimate build out for the purpose of the watershed study presented herein.

Ultimate conditions is based on build out to the extent allowed by current zoning. However, Year 2010 build out makes certain assumptions based on current growth rates in the County. At this time, residential build out is predicted to occur around 2014 or beyond and commercial and business build out is never expected to reach full build out.

2.3.4 The GIS System

The GIS system for the Deep Run Watershed consisted of areal (polygon) files, point files, and matrix tables. The areal files consist of the subwatersheds, hydrologic soils, existing land use, and proposed land use. The point files link the polygons to the attributes, or physical descriptions of what each of the polygons within the areal files represent, e.g. soil group A or medium density residential land use. The matrix tables enable the GIS software to determine the attributes for each polygon in the areal file.

By defining an attribute(s) for each polygon and a matrix table for each type of areal file, computations such as determining composite runoff curve numbers can be readily performed. For example, the GIS system "overlays" drainage area, soil groups, and land use to calculate the area of each type of land use within a sub watershed for a given hydrologic soil group. These individual areas are then assigned runoff curve numbers, e.g medium density residential with soil group A has a RCN value of 54. The GIS then calculates a weighted RCN for each subwatershed.

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 majority of 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 (overland, shallow concentrated, and concentrated flow) 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' and 1"=600 topographic map. Overland flow was generally assumed to occur until the 1"=200' 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' 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 flood studies, 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. The T_c for the 100 year rainfall was also used for the 50, and 500 year TR-20 models. On average, the 2 year T_c is 0.08 hour greater than the 100 year T_c.

2.5 Reach Routing

Reach routing was performed 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.

The reach routings performed in the Deep Run TR-20 models attenuated the peak discharge hydrographs by 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.

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 Mannings Equation. A spreadsheet was developed to perform the repetitive calculation of Mannings Equation for a range of discharges at each reach cross section. A representative cross section for each reach was selected from the field surveyed cross sections or based on field measurements if field survey was not available. A series of discharges was then run for the cross section in order to compute the water surface elevation and cross sectional area. The average slope computed for the reach length was used in the computations. Reach tables were developed for 26 reaches for the Deep Run TR-20 models.

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

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 Deep Run watershed, there are a number of ponds. The vast majority of these are small farm ponds or small storm water management (SWM) ponds which control runoff from small developments. These ponds are too small to have a significant effect on the overall discharges in Deep Run, although the SWM ponds serve a major role in protecting the stream immediately downstream of the small development. The individual ponds were not include in the TR-20 model.

A number of road crossings in the watershed were preliminarily identified as causing impoundments during significant storm events. The topographic maps were 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' topographic maps.

HY-8 Version 3.2 was used to compute stage-discharge curves. HY-8 is an interactive computer model which automates Federal Highway Administration techniques for analyzing the hydraulic performance of culverts (HDS-5). The model is able to perform hydraulic analyses for single or multiple pipes of varied shapes, sizes, and materials. Since the Deep Run watershed culverts to be modeled 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 18 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 nine 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 nine road crossings were deemed as significant impoundments and were modeled as full structure tables. These nine structures, along with their identifying number i.e. the subarea number at the road crossing, and stream name are included in the list below. Structures 6, 9, and 14 are taken from the approved MD Route 100 study and structure 8 was taken from the Brookdale Industrial Park, (Baltimore-Washington Auto Exchange, Inc.) hydrologic and hydraulic study which was prepared by Purdum & Jeschke, Inc. in 1992.

Structure 6 - Deep Run at I-95
Structure 7 - Deep Run at US Route 1
Structure 8 - Deep Run at Brookdale Industrial Park
Structure 9 - Deep Run at B&O Railroad Bridge
Structure 14 - Deep Run at B&O Railroad Bridge
Structure 23 - Piny Run at I-95
Structure 26 - Tributary D-10 at MD Route 100
Structure 30 - Tributary D at B&O Railroad Bridge
Structure 32 - Tributary D-1 at Loudon Avenue

The MD Route 100 study was performed for the Maryland State Highway Administration to determine the hydrologic and hydraulic effects of the proposed roadway alignment on Deep Run. Structure numbers 6 and 9 were included in the MD Route 100 study as upstream improvements. Reservoir routing for these two structures is straight forward.

The MD Route 100 crossing of Deep Run, structure number 14, is a complex site. MD Route 100 has an interchange with relocated Dorsey Road just upstream of a 14 foot diameter structural plate pipe which conveys Deep Run under the B&O railroad spur. This pipe generates a severe tailwater condition, approximately 23 feet deep, which extends upstream through both the relocated Race Road and MD Route 100 crossings of Deep Run.

To model the site, an iterative TR-20/HEC-2 approach was undertaken. TR-20 components consisted of multiple reach/reservoir routings. The HEC-2 model consisted of bridge modeling, weir flow (over the B&O railroad spur), and flow balancing (between the weir flow over the rail spur and the flow through the relocated Race Road structure). Figures 2, 3, and 4, which have been taken from the MD Route 100 study, have been included in this report to help illustrate the flow distribution situation for the 2 year, 10 year, and 100 year events, respectively.

The MD Route 100 crossing of Deep Run was submitted to WRA on MSHA's behalf in June, 1990. After extensive review, WRA approval was granted for the MD Route 100 crossing of Deep Run that was prepared by KCI.

The MD Route 100/Deep Run hydrologic study prepared by URS Greiner in 1996 was submitted to MDE and approval was granted.

The structure routing would be expected to provide attenuation of the discharge hydrograph peak in a similar manner as reach routing does. The nine modeled structures provided varying degrees of flow attenuation. Structures 7, 8, 9, and 23 provided less than a 10% reduction in flow rates. The remaining five structures had a substantial effect on the discharge rates being released from the structures. Structures 6, 14, 26, 30, and 32 reduced peak discharge rates by approximately one-third. It should be noted that structure 9 is a stone arch, but for computational purposes it was considered as a rectangular opening.

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).

The 500 year rainfall depth was computed by extrapolation using the rainfall values for the 1, 2, 5, 10, 25, 50, and 100 year storm events. The extrapolation was done using a log-normal plot which can be found in Appendix C.

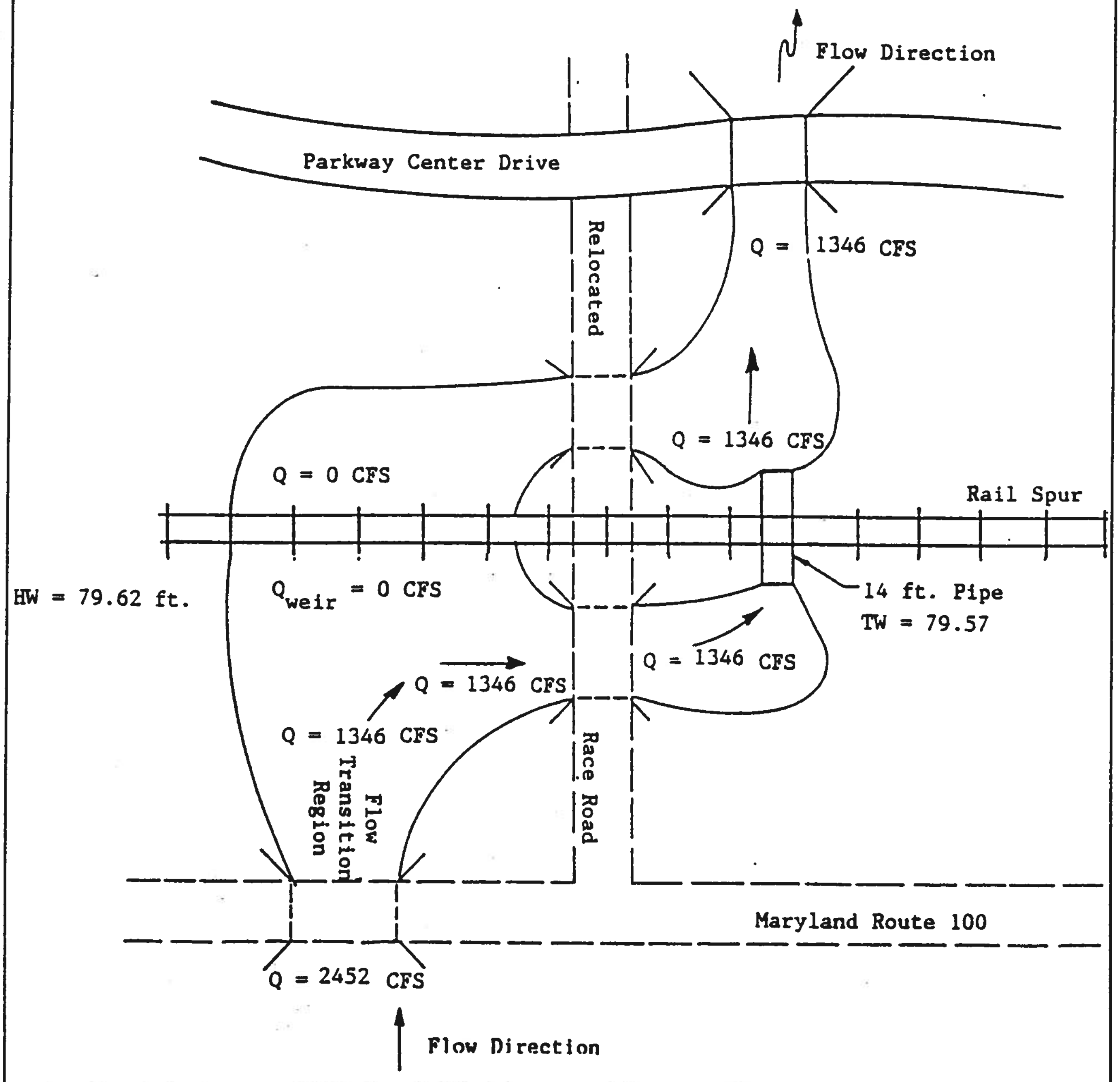

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FIGURE NO. 2

MD Route 100
Flow Split Schematic - 2 Year

Scale: Not to Scale

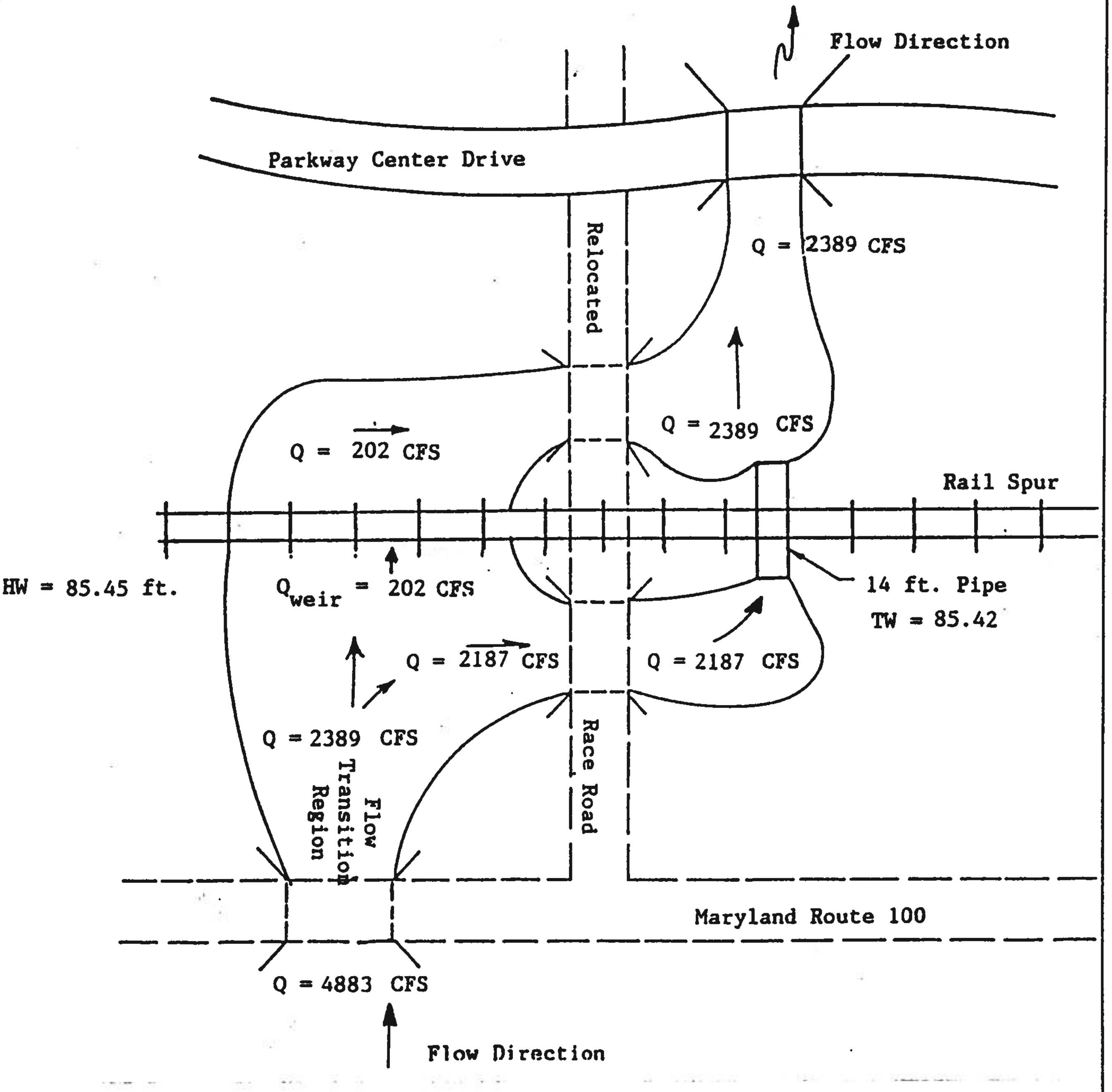

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FIGURE NO. 3

MD Route 100
Flow Split Schematic - 10 Year

Scale: Not to Scale

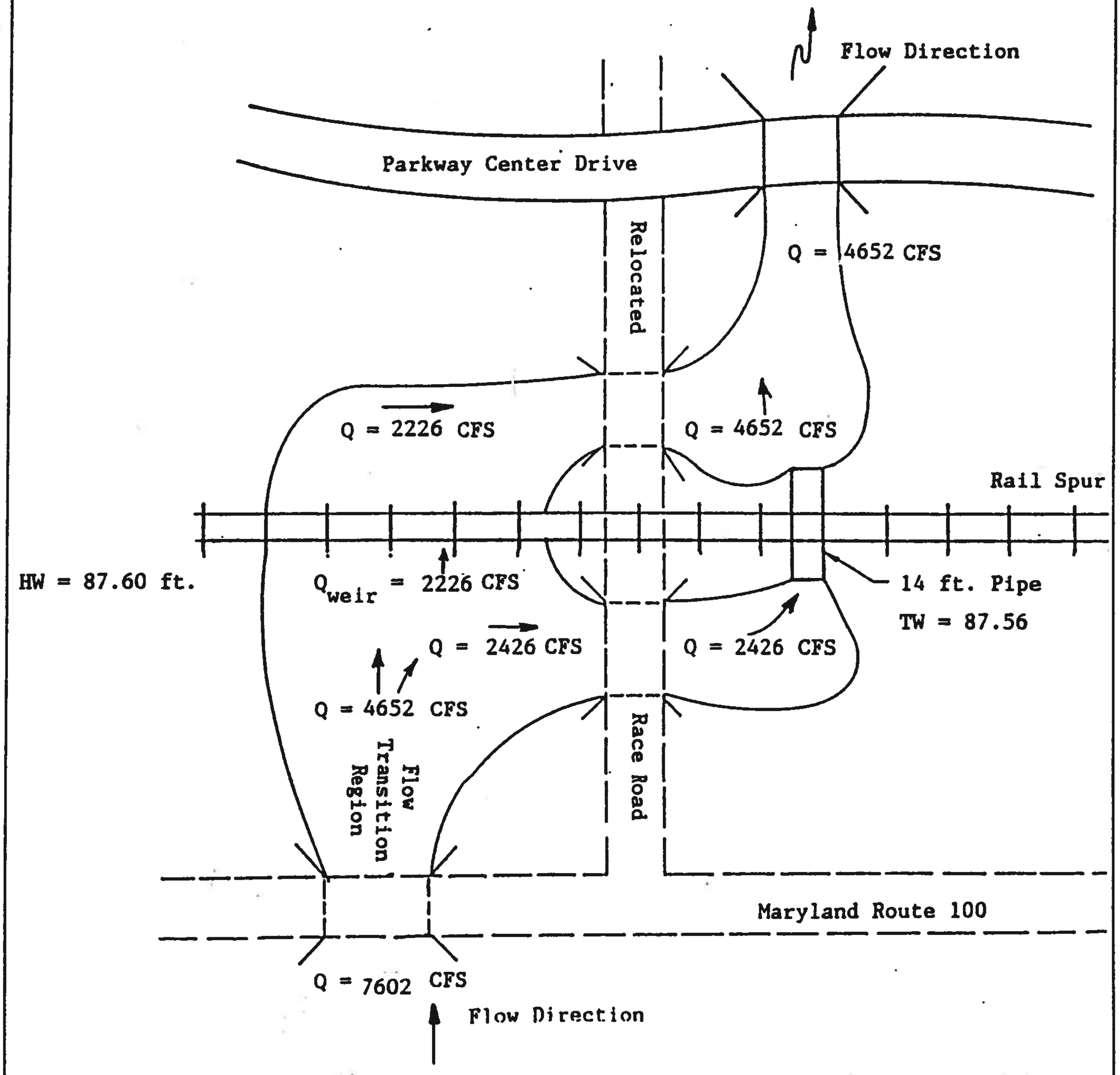

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FIGURE NO. 4

MD Route 100
Flow Split Schematic - 100 Year

Scale: Not to Scale

TABLE 2
24-Hour Rainfall Depths

Return Period (years)	Rainfall Depth (inches)
2	3.2
10	5.1
50	6.3
100	7.2
500	9.6

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 19.8 square mile drainage area for the Deep Run watershed, the rainfall depths could be reduced by approximately 2% 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 2% reduction was not applied to the TR-20 model.

2.8 Calibration

One method for calibrating the TR-20 model is to acquire USGS gage records for a stream gage within the watershed being studied. The gage would likely be located on the main stream reach at the downstream end of the watershed. There are no stream gages located within the Deep Run watershed which would allow for calibrating the TR-20 model by this method so an alternate method for calibrating the peak flows was pursued. There are adjacent watersheds of varying size that do have USGS gages and which have a significant period of record. KCI acquired data from the Maryland Geological Survey for comparison to the Deep Run flow rates which is shown below in Table 3.

TABLE 3
Comparison of Existing Gage Records

Gage Name (Number)	Drainage Area (Sq Mi)	Q100 (cfs)	Q100/Sq Mi (cfs)
Patapsco River at Hollofield, MD (#5890)	285	95,300	334
East Branch Herbert Run at Arbutus, MD (#5891)	2.47	2,520	1020
Little Patuxent River at Guilford, MD (#5935)	38	10,100	266
Little Patuxent River at Savage, MD (#5940)	98.4	17,900	182

The above information is provided for comparison, however, the gage records noted in Table 3 above cannot be used to calibrate the Deep Run TR-20 model. Lacking a gage in the Deep Run watershed, KCI feels that the TR-20 modeled discharge rates are reasonable and the model should be accepted.

2.9 Summary of Results

The TR-20 model was executed for the 2-, 10-, and 100-year storms for existing land use conditions and for the 2-, 10-, 50-, 100-, and 500-year storms for the proposed land use conditions.

Tables 4 through 8 contain the drainage area, RCN, T_c and discharge rates for the 2-, 10-, 50-, 100-, and 500-year storm events, respectively. 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 9 below. The two locations chosen were the confluence of Deep Run with the Patapsco River and the downstream end of Deep Run where it discharges through the B&O Railroad at TR-20 Structure 9. TR-20 Structure 9 is the B&O Railroad crossing located approximately 200 feet upstream from O'Connor Road.

TABLE 4
2-Year Drainage Area Summary

DRAINAGE AREA NUMBER	ACREAGE (ACRES)	EXISTING			PROPOSED		
		RCN	Tc (HOURS)	DISCHARGE (CFS)	RCN	Tc (HOURS)	DISCHARGE (CFS)
1	312	67	0.56	135	67	0.56	135
2	386	67	0.65	153	69	0.65	181
3	303	68	0.69	124	69	0.69	136
4	269	77	0.59	237	77	0.59	237
5	245	69	0.80	99	73	0.80	135
6	476	76	0.86	308	76	0.86	308
7	272	74	0.74	170	78	0.74	216
8	488	80	0.80	414	80	0.80	414
9	379	81	0.50	460	81	0.50	460
10	563	71	0.74	284	70	0.74	263
11	471	70	0.64	242	70	0.64	242
12	388	69	0.54	207	71	0.54	245
13	411	72	0.79	211	72	0.79	211
14	378	82	0.58	443	83	0.58	464
15	369	81	1.19	256	84	1.19	297
16	458	65	0.57	161	66	0.57	178
17	187	65	0.43	80	74	0.43	166
18	340	45	0.52	2	48	0.52	4
19	303	62	0.62	71	72	0.62	185
20	228	69	0.54	122	76	0.54	200
21	351	67	0.60	146	78	0.60	324
22	324	71	0.56	197	87	0.56	489
23	342	70	0.47	217	79	0.47	392
24	400	68	0.63	175	77	0.63	337
25	310	73	0.50	235	87	0.50	498
26	385	82	0.47	510	82	0.47	510
27	298	64	0.62	89	71	0.62	169
28	291	74	0.65	196	75	0.65	209
29	198	76	1.38	117	76	1.38	117
30	287	79	0.49	319	79	0.49	319
31	282	75	0.48	250	75	0.48	250
32	337	76	0.46	329	76	0.46	329
33	321	72	1.00	144	82	1.00	264
34	368	70	0.64	189	71	0.64	206
35	223	74	0.42	201	75	0.42	213
36	304	70	0.50	185	70	0.50	185
37	344	68	1.08	106	68	1.08	106
Total	12591						
Weighted Average		71.3			74.7		

TABLE 5
10-Year Drainage Area Summary

DRAINAGE AREA NUMBER	ACREAGE (ACRES)	EXISTING			PROPOSED		
		RCN	Tc (HOURS)	DISCHARGE (CFS)	RCN	Tc (HOURS)	DISCHARGE (CFS)
1	312	67	0.51	463	67	0.51	463
2	386	67	0.61	509	69	0.61	560
3	303	68	0.61	420	69	0.61	438
4	269	77	0.54	586	77	0.54	586
5	245	69	0.73	314	73	0.73	377
6	476	76	0.76	783	76	0.76	783
7	272	74	0.68	454	78	0.68	527
8	488	80	0.77	918	80	0.77	918
9	379	81	0.47	1014	81	0.47	1014
10	563	71	0.70	819	70	0.70	783
11	471	70	0.61	717	70	0.61	717
12	388	69	0.49	649	71	0.49	712
13	411	72	0.75	602	72	0.75	602
14	378	82	0.52	990	83	0.52	1009
15	369	81	1.15	556	84	1.15	610
16	458	65	0.51	614	66	0.51	646
17	187	65	0.38	300	74	0.38	453
18	340	45	0.49	63	48	0.49	106
19	303	62	0.58	314	72	0.58	521
20	228	69	0.51	373	76	0.51	494
21	351	67	0.56	495	78	0.56	775
22	324	71	0.52	569	87	0.52	967
23	342	70	0.44	636	79	0.44	895
24	400	68	0.57	584	77	0.57	842
25	310	73	0.47	629	87	0.47	976
26	385	82	0.43	1125	82	0.43	1125
27	298	64	0.57	352	71	0.57	497
28	291	74	0.59	528	75	0.59	547
29	198	76	1.30	293	76	1.30	293
30	287	79	0.44	752	79	0.44	752
31	282	75	0.43	651	75	0.43	651
32	337	76	0.42	820	76	0.42	820
33	321	72	0.95	398	82	0.95	569
34	368	70	0.58	582	71	0.58	606
35	223	74	0.37	549	75	0.37	572
36	304	70	0.44	566	70	0.44	566
37	344	68	1.05	333	68	1.05	333
Total	12591						
Weighted Average		71.3			74.7		

TABLE 6
50-Year Drainage Area Summary

DRAINAGE	ACREAGE	EXISTING			PROPOSED		
AREA NUMBER	(ACRES)	RCN	Tc (HOURS)	DISCHARGE (CFS)	RCN	Tc (HOURS)	DISCHARGE (CFS)
1	312	67			67	0.48	731
2	386	67			69	0.59	854
3	303	68			69	0.57	686
4	269	77			77	0.51	845
5	245	69			73	0.70	555
6	476	76			76	0.70	1169
7	272	74			78	0.64	756
8	488	80			80	0.75	1303
9	379	81			81	0.46	1383
10	563	71			70	0.68	1168
11	471	70			70	0.59	1079
12	388	69			71	0.47	1053
13	411	72			72	0.73	879
14	378	82			83	0.49	1393
15	369	81			84	1.12	820
16	458	65			66	0.47	1048
17	187	65			74	0.36	653
18	340	45			48	0.47	255
19	303	62			72	0.56	770
20	228	69			76	0.49	705
21	351	67			78	0.54	1086
22	324	71			87	0.49	1308
23	342	70			79	0.42	1258
24	400	68			77	0.53	1226
25	310	73			87	0.45	1312
26	385	82			82	0.40	1566
27	298	64			71	0.54	751
28	291	74			75	0.55	812
29	198	76			76	1.24	424
30	287	79			79	0.41	1081
31	282	75			75	0.41	948
32	337	76			76	0.39	1204
33	321	72			82	0.92	778
34	368	70			71	0.54	930
35	223	74			75	0.33	842
36	304	70			70	0.40	884
37	344	68			68	1.03	508
Total	12591						
Weighted Average		71.3			74.7		

TABLE 7
100-Year Drainage Area Summary

DRAINAGE	ACREAGE	EXISTING			PROPOSED		
AREA NUMBER	(ACRES)	RCN	Tc (HOURS)	DISCHARGE (CFS)	RCN	Tc (HOURS)	DISCHARGE (CFS)
1	312	67	0.48	928	67	0.48	928
2	386	67	0.59	1008	69	0.59	1076
3	303	68	0.57	839	69	0.57	863
4	269	77	0.51	1016	77	0.51	1016
5	245	69	0.70	609	73	0.70	679
6	476	76	0.70	1438	76	0.70	1438
7	272	74	0.64	826	78	0.64	917
8	488	80	0.75	1565	80	0.75	1565
9	379	81	0.46	1652	81	0.46	1652
10	563	71	0.68	1507	70	0.68	1460
11	471	70	0.59	1350	70	0.59	1350
12	388	69	0.47	1237	71	0.47	1312
13	411	72	0.73	1078	72	0.73	1078
14	378	82	0.49	1628	83	0.49	1656
15	369	81	1.12	917	84	1.12	973
16	458	65	0.47	1291	66	0.47	1332
17	187	65	0.36	611	74	0.36	803
18	340	45	0.47	301	48	0.47	396
19	303	62	0.56	680	72	0.56	948
20	228	69	0.49	714	76	0.49	861
21	351	67	0.54	979	78	0.54	1309
22	324	71	0.49	1067	87	0.49	1527
23	342	70	0.42	1215	79	0.42	1524
24	400	68	0.53	1159	77	0.53	1472
25	310	73	0.45	1141	87	0.45	1535
26	385	82	0.40	1879	82	0.40	1879
27	298	64	0.54	741	71	0.54	935
28	291	74	0.55	960	75	0.55	985
29	198	76	1.24	518	76	1.24	518
30	287	79	0.41	1300	79	0.41	1300
31	282	75	0.41	1152	75	0.41	1152
32	337	76	0.39	1455	76	0.39	1455
33	321	72	0.92	731	82	0.92	928
34	368	70	0.54	1121	71	0.54	1159
35	223	74	0.33	1001	75	0.33	1030
36	304	70	0.40	1106	70	0.40	1106
37	344	68	1.03	646	68	1.03	646
Total	12591						
Weighted Average		71.3			74.7		

TABLE 8
500-Year Drainage Area Summary

DRAINAGE	ACREAGE	EXISTING			PROPOSED		
AREA NUMBER	(ACRES)	RCN	Tc (HOURS)	DISCHARGE (CFS)	RCN	Tc (HOURS)	DISCHARGE (CFS)
1	312	67			67	0.48	1469
2	386	67			69	0.59	1692
3	303	68			69	0.57	1347
4	269	77			77	0.51	1498
5	245	69			73	0.70	1032
6	476	76			76	0.70	2142
7	272	74			78	0.64	1344
8	488	80			80	0.75	2270
9	379	81			81	0.46	2396
10	563	71			70	0.68	2292
11	471	70			70	0.59	2100
12	388	69			71	0.47	2019
13	411	72			72	0.73	1650
14	378	82			83	0.49	2349
15	369	81			84	1.12	1391
16	458	65			66	0.47	2131
17	187	65			74	0.36	1203
18	340	45			48	0.47	834
19	303	62			72	0.56	1464
20	228	69			76	0.49	1277
21	351	67			78	0.54	1927
22	324	71			87	0.49	2108
23	342	70			79	0.42	2208
24	400	68			77	0.53	2174
25	310	73			87	0.45	2138
26	385	82			82	0.40	2663
27	298	64			71	0.54	1428
28	291	74			75	0.55	1485
29	198	76			76	1.24	774
30	287	79			79	0.41	1894
31	282	75			75	0.41	1721
32	337	76			76	0.39	2158
33	321	72			82	0.92	1329
34	368	70			71	0.54	1769
35	223	74			75	0.33	1519
36	304	70			70	0.40	1729
37	344	68			68	1.03	1024
Total	12591						
Weighted Average		71.3			74.7		

TABLE 9
Comparison of Discharges At Two Watershed Locations

Comparison Point	Q2 (CFS)	Q10 (CFS)	Q100 (CFS)
Deep Run at Outfall from Structure 9 at the B&O Railroad			
Existing Conditions	790	1737	2778
Proposed Conditions	843	1805	2839
Deep Run at Confluence with Patapsco River			
Existing Conditions	1588	4492	8243
Proposed Conditions	2114	5430	9262

The hydrologic models for the different land use scenarios show different degrees of increases in the discharges from existing to proposed conditions. While more than half of the individual drainage areas showed little if any increase, the remaining drainage areas exhibited up to a 30% increase in discharge rates. The areas with minimal increases are already mostly if not completely developed to Year 2010 limits. The areas with significant increases are those areas that have not yet been developed to Year 2010 limits. The increase in discharge rate for Deep Run at its confluence with the Patapsco River is approximately 12% as a result of build out of the entire watershed to Year 2010 limits.

Table 10 is a summary of discharge rates for the existing 2-, 10-, and 100-year storm events and the Year 2010 100-year storm event used for the HEC-2 model. The table incorporates the TR-20 cross section number and drainage area associated with the discharge rates and/or the appropriate HEC-2 cross section number where the discharge rate is used. Where the aerial reduction technique was used to derive intermediate discharge rates, the TR-20 cross section and drainage areas were not included in the table.

TABLE 10
SUMMARY OF DISCHARGES USED IN THE HEC-2 MODEL

Stream ID	TR-20 Model Cross Section	HEC-2 Model Cross Section	Drainage Area (sq.mi.)		Drainage (cfs)			
			Local	Cumulative	Existing			Ultimate
					2 yr.	10 yr.	100 yr.	100 yr.
DEEP RUN	36	1+00	0.47	19.21	1670	4686	8420	9447
DEEP RUN	34	101+50	0.58	18.39	2205	5474	9222	10174
DEEP RUN	15	145+00	0.58	12.88	1055	2718	5123	5723
DEEP RUN	*	203+56	N/A	N/A	-	-	-	4652[1]
DEEP RUN	*	223+22	N/A	N/A	-	-	-	2426[1]
DEEP RUN	*	228+86	N/A	N/A	-	-	-	4652[1]
DEEP RUN	9	252+50	N/A	N/A	-	-	-	4586
DEEP RUN	9	257+34	0.59	4.89	795	1767	2890	2950
DEEP RUN	8	289+40	0.76	4.30	753	1701	2818	2885
DEEP RUN	7	380+62	0.43	3.54	671	1574	2649	2702
DEEP RUN	6	423+20	0.74	3.11	726	2208	3999	4122
DEEP RUN	4	457+65	0.42	2.37	497	1673	3082	3208
DEEP RUN	3	496+50	0.47	1.57	345	1239	2321	2390
DEEP RUN	2	509+50	0.60	1.09	260	927	1863	1925
DEEP RUN	*	543+50	N/A	N/A	-	-	-	1589[2]
DEEP RUN	*	543+90	N/A	N/A	-	-	-	1480[2]
DEEP RUN	*	556+70	N/A	N/A	-	-	-	1036[2]
DEEP RUN	1	572+00	0.49	0.49	135	463	928	928
TRIB 'D'	33	4+78	0.50	4.93	1307	2841	4195	4525
TRIB 'D'	30	69+12	0.45	3.47	1084	2630	4444	5031
TRIB 'D'	*	86+00	N/A	N/A	-	-	-	4618
TRIB 'D'	*	98+00	N/A	N/A	-	-	-	4214
TRIB 'D'	25	112+20	0.49	1.71	746	1750	2823	3334
TRIB 'D'	*	122+80	N/A	N/A	-	-	-	2646
TRIB 'D'	24	151+00	0.63	0.63	175	584	1159	1472
TRIB 'D-1'	*	4+20	N/A	N/A	-	-	-	1577
TRIB 'D-1'	31	62+10	0.44	0.44	250	651	1152	1152
TRIB 'D-2'	*	0+70	N/A	N/A	-	-	-	471

TABLE 10
SUMMARY OF DISCHARGES USED IN THE HEC-2 MODEL

Stream ID	TR-20 Model Cross Section	HEC-2 Model Cross Section	Drainage Area (sq.mi.)		Drainage (cfs)			
			Local	Cumulative	Existing			Ultimate
					2 yr.	10 yr.	100 yr.	100 yr.
TRIB 'D-3'	*	1+10	N/A	N/A	-	-	-	160
TRIB 'D-4'	*	4+40	N/A	N/A	-	-	-	298
TRIB 'D-5'	*	2+60	N/A	N/A	-	-	-	763
TRIB 'D-5'	29	21+40	0.39	0.39	117	293	518	518
TRIB 'D-6'	28	2+00	0.45	0.91	268	849	1642	1870
TRIB 'D-6'	*	36+00	N/A	N/A	-	-	-	1453
TRIB 'D-7'	*	1+05	N/A	N/A	-	-	-	406
TRIB 'D-8'	*	1+30	N/A	N/A	-	-	-	217
TRIB 'D-10'	*	0+90	N/A	N/A	-	-	-	2250
TRIB 'K'	*	4+00	N/A	N/A	-	-	-	109
TRIB 'O'	*	2+40	N/A	N/A	-	-	-	529
TRIB 'P'	5	3+30	0.38	0.38	99	314	609	679
TRIB 'R'	*	3+00	N/A	N/A	-	-	-	202
TRIB 'S'	*	1+60	N/A	N/A	-	-	-	325

[1] These flow rates are taken directly from the MSHA MD Route 100 Over Deep Run Hydrologic Study prepared by KCI Technologies, Inc. (1991).

[2] These flow rates are taken directly from the MSHA Hydrologic Report for Deep Run prepared by URS Greiner, Inc. (1996).

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.

3.2 Model Set-Up

The Deep Run Watershed HEC-2 model is comprised primarily of the Deep Run mainstem, starting downstream at the confluence with the Patapsco River, Station 0+00 and ending upstream near the intersection of MD Route 103 and MD Route 104, Station 595+00. The model also included first order tributaries D, K, O, P, R, and S. Tributary D was further divided into nine subtributaries which were identified by a letter-number designation, i.e., D-1 through D-8 and D-10.

3.3 Tributaries

The Deep Run mainstem HEC-2 model consists of approximately 11.3 miles of mainstem and 11.5 miles of tributaries. The tributaries included in the mainstem of Deep Run HEC-2 model were D-1 through D-8 and D-10, K, O, P, R and S. The starting water surface elevations for the tributaries were derived from the water surface elevations of the cross sections immediately downstream of the tributary's confluence with the 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.

3.4 MD Route 100 Modeling

There are two segments of Deep Run that were modeled separately in conjunction with MSHA's design of MD Route 100. The first segment is approximately one mile of Deep Run which is located in the vicinity of the MD Route 100 crossing of Deep Run and was modeled in great depth as part of the MD Route 100 project. That study included addressing Race Road and the B&O railroad spur in conjunction with the MD Route 100 crossing. A detailed description of that study is beyond the scope of the report presented herein. Additional information regarding the MD Route 100 study can be found in the Pre- and Post-Construction conditions Hydrologic and Hydraulic Reports which were prepared for MSHA and are noted in the References section of this report.

The hydraulic model prepared for the MD Route 100 study was copied in its entirety and inserted into the Deep Run HEC-2 model prepared as part of the study presented herein. All cross sections taken from the MD Route 100 study were not resurveyed or regenerated as part of the current hydraulic analysis. HEC-2 cross sections 203+56 through 249+20 are the cross sections taken from the MD Route 100 study. The location of the cross sections are shown schematically on the 1"=200' scale topographic base maps. The new roadways have been schematically shown for information. For exact locations of roadways and new grading, the MD Route 100 hydraulic study or the MD Route 100 construction drawings should be referred to. The floodplain delineation in this area will be discussed further in Section 3.15 of the report presented herein.

The second segment is approximately one half mile of Deep Run which is located in the vicinity of the MD Route 100 baseline Stations 163+00 - 165+00. A detailed description of that study is beyond the scope of the report presented herein. Additional information regarding the MD Route 100 study can be found in the Deep Run Encroachment Analysis Study which was prepared for MSHA by Constellation Design Group, Inc. and is noted in the References section of this report.

The hydraulic model prepared for the Constellation MD Route 100 study was copied in its entirety and inserted into the Deep Run HEC-2 model prepared as part of the study presented herein. All cross sections taken from the MD Route 100 study were not resurveyed or regenerated as part of the current hydraulic analysis. HEC-2 cross sections 543+50 through 566+60 are the cross sections taken from the Constellation study. The location of the cross sections are shown schematically on the 1"=200' scale topographic base maps. The new roadway has been schematically shown for information. For exact locations of roadways and new grading, the MD Route 100 construction drawings should be referred to. The floodplain delineation in this area will be discussed further in Section 3.15 of the report presented herein.

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 tributary as well as the need for changing discharges on the main stem of Deep Run necessitated a breakdown of discharges throughout the watershed. An aerial reduction technique was used to determine intermediate discharges using the following equation:

$$Q_u=Q_k(A_u/A_k)$$

where Q_k = discharge for a known drainage area A_k
Q_u = unknown discharge for a part of the known drainage area A_u

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.

There are two segments of Deep Run where discharges were used that were not developed through TR-20 and aerial reduction as part of the study presented herein. The first segment of stream is the portion of Deep Run modeled by KCI for MSHA in conjunction with the MD Route 100 crossing of Deep Run as described in Section 3.4 above. In order to maintain the integrity of the existing MD Route 100 hydraulic model, discharges from the KCI MD Route 100 study were used in the hydraulic analysis presented herein.

The second segment of stream is the portion of Deep Run modeled by URS Greiner for MSHA in conjunction with the MD Route 100 adjacent to Deep Run as described in Section 3.4 above. In order to maintain the integrity of the existing MD Route 100 hydraulic model, discharges from the URS Greiner MD Route 100 study were used in the hydraulic analysis presented herein.

In any hydrologic modeling 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 Deep Run. 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 Deep Run 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 storm water management designs.

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

3.6 Cross Sectional Data

The Deep Run 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 modeled. The total length of streams and tributaries within the Deep Run watershed that meet Howard County's definition of a floodplain is approximately 36 river miles. The floodplain analysis presented herein covers approximately 22.8 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. All cross section are coded in the HEC-2 model and plotted on the cross sections oriented left to right looking downstream.

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 1992 and completed in the first few months of 1993. Any construction that occurred after the survey was done will not be reflected in the HEC-2 model.

3.7 Starting Water Surface Elevation

Deep Run flows into the Patapsco River near the lower end of the Patapsco River basin. During a 100 year storm event, the Patapsco River creates approximately 24' of backwater on the Deep Run confluence. The 100 year backwater condition, therefore, should be incorporated into the Deep Run floodplain analysis to provide a more representative depiction of the 100 year flood levels in Deep Run. Kidde Consultants, Inc. prepared the Hydrologic and Hydraulic Report for the I-195 crossing of the Patapsco River in 1987. Based on this study, the 100 year post-construction, ultimate conditions flood elevation on the Patapsco River is 30.32' at the confluence of Deep Run and the Patapsco River.

The Deep Run HEC-2 model was run using the Patapsco River backwater elevation of 30.32' as the starting water surface elevation. There are very small elevation increases from the confluence until approximately cross section 81+80 at which point the normal flow depths in Deep Run begin to govern. The backwater effect on Deep Run from the Patapsco River flood elevation ends at cross section 86+80, approximately 1.5 miles upstream from the confluence of Deep Run and the Patapsco River.

3.8 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 11 lists the various roughness factors established for the model.

TABLE 11

Manning's Roughness Coefficient

Description	Manning's Roughness, n
Main Channel	0.015 - 0.07
Overbank Areas	0.045 - 0.15

This range reflects the wide variety of vegetation in the study area. The lower channel n values, i.e. 0.015 - 0.020 represent culvert flow and flow over paved roadways.

3.9 Bridge Modeling

There are 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.

Only 42 of the many roadway crossings were modeled in the Deep Run watershed study. The type, shape, size and material of the structures encountered throughout the watershed were all different. The stream crossings included pipe arches, box culverts, circular 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 12 in conjunction with the modeling technique used in the HEC-2.

The HEC-2 special bridge or special culvert methods were used to initially model all bridges and culverts, respectively, in the Deep Run watershed since it was felt that most stream crossings would be in pressure flow for the 100 year event. If overtopping does not occur, the special bridge method will revert back to the normal bridge method and will calculate losses using Manning's Equation. Special culvert treats pressure and non-pressure flow scenarios. The special culvert method is similar to the special bridge method except the Federal Highway Administration's (FHWA) standard equations for culvert hydraulics are used to compute losses through the structure.

For the special bridge method bridges without piers, the coefficient for Class A low flow was left blank. Also for the special bridge method, a typical value was selected for XKOR for performing the pressure flow calculations,. The value of 1.56 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 special bridge applications. A value of 2.65 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 modeling 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 when approximately 90% of the flow was going over the road while only about 10% of the flow was passing through the culvert/bridge opening. There were six cases of high submergence. Since most of the water in these cases was overtopping the roadway by weir flow, KCI modeled the top of road as a typical GR (ground) card to define the weir cross section.

Another situation that occurred several times throughout the hydraulic analysis was the presence of in stream storm water management ponds. Construction drawings and computations were reviewed for these ponds and the 100 year water surface elevation from the pond computations was inserted into the HEC-2 model by using an X5 card to input a known water surface elevation.

It should be noted that all culverts and bridges were modeled 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.

3.10 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 Deep Run watershed model, with the general exception of the areas upstream and downstream from the bridges and culverts that were modeled with special bridge. The

TABLE 12

Summary of Bridges & Road Crossings

Structure Number	Stream Name	Roadway Name	Type of Structure	Approximate Cross Section #	Modelling Technique Used[1]
1	Deep Run	Furnace Avenue	Single Span Bridge	2554	SB
2	Deep Run	Hanover Road	Single Span Bridge	14390	NB
3	Deep Run	Parkway Center Drive	Single Span Bridge	21665	NB
4	Deep Run	B&O Railroad	Single - 14' SPP	22507	X5
5	Deep Run	Race Road	Double Span Bridge	22660	SB
6	Deep Run	MD Route 100	Multiple Span Bridge	24233	NB
7	Deep Run	O'Connor Road	Single Span Bridge	25360	GR
8	Deep Run	B&O Railroad	Stone Arch Bridge	25720	X5
9	Deep Run	Dorsey Road	Single Span Bridge	27220	GR
10	Deep Run	Baltimore Washington Auto Exchange	In-Stream SWM Pond	31010	X5
11	Deep Run	US Route 1	Concrete Arch Bridge	38040	X5
12	Deep Run	I-95 (Northbound)	Single - 20'x9' Box Culvert	41750	SC
13	Deep Run	I-95 (Southbound)	Single - 16'x8' Box Culvert	42320	X5

[1] ***LEGEND:***

SB	-	*Special Bridge*
NB	-	*Normal Bridge*
SC	-	*Special Culvert*
GR	-	*Ground Card Used to Model Weir Flow over Roadway*
X5	-	*Water Surface From SWM Pond Design, HY-8 Model, or TR-20 Model*

TABLE 12

Summary of Bridges & Road Crossings

Structure Number	Stream Name	Roadway Name	Type of Structure	Approximate Cross Section #	Modelling Technique Used[1]
14	Deep Run	Mayfield Avenue	Single Span Bridge	45745	SB
15	Deep Run	Stockbridge Road	Twin - 15' CMP	48845	SC
16	Deep Run	Old Montgomery Road	Single Span Bridge	52837	SB
17	Deep Run	N/A	In-Stream SWM Pond	56780	X5
18	Tributary D	Unnamed Road	Single Span Bridge	475	GR
19	Tributary D	B&O Railroad	Stone Arch Bridge	6912	X5
20	Tributary D	Athol Avenue	Single Span Bridge	7443	GR
21	Tributary D	Unnamed Road	Single Span Bridge with Multiple Pipes	9422	X5
22	Tributary D	Unnamed Road	Triple - 6' RCP	10280	SC
23	Tributary D	US Route 1	Single Span Bridge	11170	SB
24	Tributary D	Troy Hill Park Access Road	Single Span Bridge	13427	GR
25	Tributary D	I-95	Single - 9' CMP	16630	SC
26	Tributary D1	Unnamed Road	Triple - 4.5' RCP	639	GR

[1] *LEGEND:*
SB - Special Bridge
NB - Normal Bridge
SC - Special Culvert
GR - Ground Card Used to Model Weir Flow over Roadway
X5 - Water Surface From SWM Pond Design, HY-8 Model, or TR-20 Model

TABLE 12

Summary of Bridges & Road Crossings

Structure Number	Stream Name	Roadway Name	Type of Structure	Approximate Cross Section #	Modelling Technique Used[1]
27	Tributary D1	B&O Railroad	Twin - 9' CMP	1800	X5
28	Tributary D1	Louden Avenue	Single - 14'x5.5' Box Culvert	1860	GR
29	Tributary D1	South Hanover Road	Twin - 5' CMP	3440	SC
30	Tributary D1	US Route 1	Single Span Bridge	5860	SB
31	Tributary D2	Macaw Court	Single - 6' CMP	1062	X5
32	Tributary D5	Glenmore Avenue	Single - 5' RCP	295	SC
33	Tributary D5	US Route 1	Single - 6' RCP	2130	SC
34	Tributary D5	Trailer Park Access Road	Single - 8' RCP	3180	SC
35	Tributary D6	US Route 1	Triple - 5' RCP	630	SC
36	Tributary D7	N/A	In-Stream SWM Pond	105	X5
37	Tributary D7	Kara's Walk	Twin - 5' CMP	401	X5
38	Tributary D10	Unnamed Road	Twin - 4' CMP	360	GR
39	Tributary K	US Route 1	Single - 2.25' CMP	920	SC

[1] ***LEGEND:***

SB - Special Bridge
NB - Normal Bridge
SC - Special Culvert
GR - Ground Card Used to Model Weir Flow over Roadway
X5 - Water Surface From SWM Pond Design, HY-8 Model, or TR-20 Model

TABLE 12

Summary of Bridges & Road Crossings

Structure Number	Stream Name	Roadway Name	Type of Structure	Approximate Cross Section #	Modelling Technique Used[1]
40	Tributary P	Meadowridge Road	Single - 5' RCP	965	GR
41	Tributary P	Wesley Lane	Four - 5.5' CMP	1615	SC
42	Tributary S	Brightfield Road	In-Stream SWM Pond	2080	X5

[1] ***LEGEND:***

SB - Special Bridge
NB - Normal Bridge
SC - Special Culvert
GR - Ground Card Used to Model Weir Flow over Roadway
X5 - Water Surface From SWM Pond Design, HY-8 Model, or TR-20 Model

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.

3.11 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 modeled by the X3 card. This was accomplished by defining the horizontal and vertical limits of the effective flow on the X3 cards. The X3 card was also used to remove ineffective flow in the immediate vicinity of the bridges and culverts. 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 Deep Run flood study, 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.

3.12 Subcritical vs Supercritical

The entire model was initially run as a subcritical model. The results showed that within a given tributary reach or within Deep Run 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. Therefore, for the consistency of the overall model, the entire HEC-2 analysis was done as subcritical. All mapping and plotting reflects the subcritical flow regime. The following list includes stream reaches that exhibit supercritical flow tendencies as indicated by more than 1/2 of the cross sections having critical depth messages:

1. Deep Run Mainstem - Several segments above Section 441+90.
2. Tributary D - Top one half of tributary.
3. Tributary D-2
4. Tributary D-3
5. Tributary D-5 - Top one third of the tributary.
6. Tributary P - Top one half of tributary.

3.13 HEC-2 Model Calibration

There are no U. S. Geologic Survey gaging station within the study limits of the Deep Run watershed. High water marks do exist along Deep Run, 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. A meaningful HEC-2 calibration run would require known high water marks associated with discharge rates. There is insufficient data in the Deep Run watershed to properly calibrate the HEC-2 model.

3.14 Summary of Results and Special Modeling Considerations

Table 13 contains the results of the hydraulic analysis of Deep Run and the tributaries that were studied. 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 13.

The HEC-2 model was run for the 100 year ultimate discharge only. Since this was the only discharge used for the hydraulic modeling, assumptions were made in the HEC-2 modeling that applied to a 100 year 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 generally 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 modeled by weir flow over the road only without using special bridge, normal bridge, or special culvert methodology. Special bridge, normal bridge, or special culvert should be considered for the roadways modeled for weir flow only in the case 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.

TABLE 13
COMPUTED 100-YEAR WATER SURFACE ELEVATIONS

STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)	STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)
Deep Run	9441	100	30.32	Deep Run (cont.)	10167	14357	48.56
""	9441	700	30.59	""	10167	14358	47.49
""	9441	1400	30.63	""	10167	14390	52.26
""	9441	1700	30.66	""	10167	14391	52.24
""	9441	2000	30.72	""	10167	14440	52.14
""	9441	2400	30.74	""	5451	14500	52.44
""	9441	2520	30.77	""	5451	14830	52.72
""	9441	2554	30.79	""	5451	15180	52.74
""	9441	2584	30.79	""	5451	15500	52.75
""	9441	2640	30.82	""	5451	15850	52.70
""	9441	2920	30.83	""	5451	16200	52.93
""	9441	3190	30.84	""	5451	16580	53.19
""	9441	3500	30.84	""	5451	16910	54.29
""	9441	3880	30.85	""	5451	17200	54.79
""	9441	4230	30.85	""	5451	17550	56.75
""	9441	4530	30.87	""	5451	17900	56.96
""	9441	4880	30.89	""	5451	18290	57.50
""	9441	5200	30.90	""	5451	18670	62.20
""	9441	5500	30.92	""	5451	18970	64.32
""	9441	5750	30.92	""	5451	19300	64.62
""	9441	6150	30.94	""	5451	19660	65.31
""	9441	6470	31.01	""	5451	20000	65.54
""	9441	6850	31.08	""	4652	20356	67.59
""	9441	7150	31.14	""	4652	20456	69.00
""	9441	7500	31.26	""	4652	20556	69.83
""	9441	7800	31.36	""	4652	20656	70.59
""	9441	8180	31.62	""	4652	20713	70.98
""	9441	8600	32.10	""	4652	20788	71.94
""	9441	9000	32.37	""	4652	20863	72.04
""	9441	9450	32.91	""	4652	20954	72.07
""	9441	9800	33.37	""	4652	21048	72.10
""	10167	10150	34.19	""	4652	21193	72.12
""	10167	10480	34.54	""	4652	21311	72.14
""	10167	10830	35.42	""	4652	21405	72.15
""	10167	11000	36.53	""	4652	21514	72.18
""	10167	11300	37.25	""	4652	21589	72.18
""	10167	11630	37.73	""	4652	21665	71.65
""	10167	11900	38.10	""	4652	21675	71.99
""	10167	12200	39.81	""	4652	21812	72.95
""	10167	12500	40.18	""	4652	21822	73.11
""	10167	12800	40.61	""	4652	21882	75.00
""	10167	13100	41.58	""	4652	21977	75.01
""	10167	13450	44.67	""	4652	22054	75.04
""	10167	13700	48.89	""	4652	22126	75.06
""	10167	14020	49.10	""	4652	22186	75.06
""	10167	14340	49.16	""	2426	22322	75.90

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TABLE 13
COMPUTED 100-YEAR WATER SURFACE ELEVATIONS

STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)
Deep Run (cont.)	2426	22507	87.00
""	2426	22545	87.00
""	2426	22659	87.00
""	2426	22738	87.01
""	2426	22739	87.01
""	4652	22886	87.02
""	4652	22960	87.02
""	4652	23090	87.02
""	4652	23205	87.02
""	4652	23350	87.02
""	4652	23429	87.03
""	4652	23517	87.03
""	4652	23562	87.03
""	4652	23680	87.04
""	4652	23754	87.04
""	4652	23852	87.04
""	4652	24027	87.04
""	4652	24077	87.04
""	4652	24130	87.04
""	4652	24180	87.00
""	4652	24233	86.95
""	4652	24290	86.80
""	4652	24340	87.21
""	4652	24390	87.41
""	4652	24440	87.51
""	4652	24490	87.42
""	4652	24645	89.95
""	4652	24820	90.44
""	4652	24970	90.58
""	4586	25250	90.97
""	4586	25340	91.18
""	4586	25360	92.06
""	4586	25394	93.00
""	4586	25544	94.94
""	4586	25600	102.41
""	4586	25720	104.28
""	2950	25734	104.22
""	2950	26060	104.65
""	2950	26380	104.69
""	2950	26680	104.69
""	2950	27000	104.85
""	2950	27150	105.30
""	2950	27220	112.42
""	2950	27247	113.41
""	2950	27600	113.46
""	2950	27860	113.50
Deep Run (cont.)	2950	28220	113.94
""	2950	28520	115.34
""	2885	28940	118.49
""	2885	29240	120.44
""	2885	29600	122.26
""	2885	29920	126.13
""	2885	30220	126.99
""	2885	30550	128.00
""	2885	30920	129.95
""	2885	31010	135.09
""	2885	31123	135.01
""	2885	31230	135.29
""	2885	31630	135.42
""	2885	31950	135.74
""	2885	32380	137.49
""	2885	32700	139.39
""	2885	32990	140.61
""	2885	33280	143.24
""	2885	33830	145.22
""	2885	34180	147.33
""	2885	34500	150.26
""	2885	34830	151.21
""	2885	35170	153.52
""	2885	35500	154.33
""	2885	35820	155.42
""	2885	36300	158.89
""	2885	36600	161.25
""	2885	36900	164.33
""	2885	37180	167.57
""	2811	37300	168.07
""	2811	37560	171.21
""	2811	37880	175.37
""	2811	37960	175.85
""	2811	37985	175.87
""	2811	38040	183.81
""	2702	38062	185.35
""	2702	38200	186.05
""	2702	38470	186.07
""	2702	38800	186.17
""	2702	39100	187.04
""	2702	39400	189.69
""	2702	39700	190.25
""	2702	39980	192.38
""	2702	40280	192.77
""	2702	40630	194.58
""	2702	40900	195.99

TABLE 13
COMPUTED 100-YEAR WATER SURFACE ELEVATIONS

STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)	STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)
Deep Run (cont.)	2702	41200	198.41	Deep Run (cont.)	1925	50950	313.82
""	2702	41420	201.94	""	1925	51200	316.80
""	2702	41500	202.33	""	1925	51510	321.14
""	2702	41750	208.93	""	1925	51900	325.02
""	2702	41770	210.88	""	1925	52200	331.14
""	2702	42000	210.95	""	1925	52500	338.13
""	2702	42050	210.96	""	1925	52749	343.70
""	2702	42120	210.77	""	1925	52809	345.92
""	4122	42320	216.68	""	1925	52837	347.16
""	4122	42340	216.57	""	1925	52854	348.61
""	4122	42500	217.66	""	1925	53100	349.32
""	4122	42840	217.72	""	1925	53400	350.17
""	4122	42940	217.75	""	1925	53730	352.14
""	4122	43220	217.80	""	1925	54040	354.49
""	4122	43560	218.07	""	1589	54350	357.59
""	4122	43900	219.03	""	1480	54390	358.28
""	4122	44190	225.75	""	1480	54430	358.89
""	4122	44480	229.65	""	1480	54470	359.60
""	4122	44800	235.08	""	1480	54510	360.04
""	4122	45100	239.60	""	1480	54550	360.42
""	4122	45450	240.69	""	1480	54590	360.78
""	4122	45620	241.33	""	1480	54630	361.13
""	4122	45700	245.50	""	1480	54670	361.45
""	4122	45745	245.53	""	1480	54710	361.88
""	3208	45765	247.15	""	1480	54750	362.48
""	3208	45920	247.59	""	1480	54790	362.94
""	3208	46180	247.73	""	1480	54830	363.39
""	3208	46400	249.11	""	1480	54870	363.82
""	3208	46750	250.33	""	1480	54910	364.21
""	3208	47100	252.12	""	1480	54950	364.50
""	3208	47470	255.61	""	1480	54990	364.88
""	3208	47800	258.97	""	1480	55030	365.32
""	3208	48100	266.98	""	1480	55070	365.77
""	3208	48400	273.07	""	1480	55110	366.24
""	3208	48650	276.78	""	1480	55150	366.89
""	3208	48713	276.88	""	1480	55190	367.25
""	3208	48845	284.61	""	1480	55230	367.36
""	3208	48870	285.80	""	1480	55270	367.54
""	3208	49000	285.42	""	1480	55310	368.06
""	3208	49300	288.68	""	1480	55350	369.52
""	3208	49350	289.66	""	1480	55390	369.63
""	2390	49650	295.32	""	1480	55430	369.74
""	2390	49970	303.05	""	1480	55470	369.86
""	2390	50300	308.44	""	1480	55510	370.31
""	2390	50600	310.01	""	1480	55550	370.57
""	2390	50730	311.95	""	1480	55590	370.95

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TABLE 13
COMPUTED 100-YEAR WATER SURFACE ELEVATIONS

STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)	STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)
Deep Run (cont.)	1480	55630	371.59	Tributary 'D' (cont.)	4525	2850	63.67
""	1036	55670	372.79	""	4525	3170	64.60
""	1036	55710	372.83	""	4525	3820	65.27
""	1036	55750	372.95	""	4525	4200	66.11
""	1036	55790	373.22	""	4525	4535	70.54
""	1036	55830	374.13	""	4525	4870	75.15
""	1036	55870	374.06	""	4525	5070	75.20
""	1036	55910	374.70	""	4525	5400	75.39
""	1036	55950	374.78	""	4525	5700	75.89
""	1036	55990	375.80	""	4525	6000	76.45
""	1036	56030	376.73	""	4525	6240	77.69
""	1036	56070	376.84	""	4525	6580	79.83
""	1036	56110	376.94	""	4525	6770	81.10
""	1036	56150	377.89	""	4525	6850	84.38
""	1036	56190	378.59	""	5031	6912	96.14
""	1036	56230	378.92	""	5031	7200	101.80
""	1036	56270	379.27	""	5031	7420	101.80
""	1036	56310	379.66	""	5031	7443	101.81
""	1036	56350	379.97	""	5031	7640	101.81
""	1036	56390	380.18	""	5031	7970	101.85
""	1036	56430	380.84	""	5031	8200	101.87
""	1036	56470	381.50	""	5031	8260	101.89
""	1036	56510	382.16	""	4618	8600	101.95
""	1036	56550	382.83	""	4618	8900	102.85
""	1036	56590	383.49	""	4618	9200	104.27
""	1036	56630	384.10	""	4618	9214	104.35
""	1036	56660	384.79	""	4618	9410	105.51
""	1036	56700	385.07	""	4618	9422	106.43
""	1036	56780	394.05	""	4618	9465	106.47
""	928	57200	394.07	""	4618	9500	106.12
""	928	57600	395.83	""	4618	9580	106.53
""	928	58060	403.29	""	4214	9800	108.39
""	928	58350	408.11	""	4214	10100	113.44
""	928	58800	414.04	""	4214	10190	115.79
""	928	59170	421.92	""	4214	10260	116.67
""	928	59500	427.65	""	4214	10280	116.76
Tributary 'D'	10167	-14440	52.14	""	4214	10320	116.93
""	4525	460	53.58	""	4214	10390	117.51
""	4525	475	53.67	""	4214	10650	119.67
""	4525	800	53.74	""	4214	10870	122.36
""	4525	1130	53.80	""	4214	10940	122.59
""	4525	1460	54.00	""	4214	11100	122.57
""	4525	1800	54.17	""	4214	11170	124.61
""	4525	1970	54.99	""	3334	11220	125.32
""	4525	2280	57.10	""	3334	11290	125.29
""	4525	2550	58.53	""	3334	11550	126.02

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TABLE 13
COMPUTED 100-YEAR WATER SURFACE ELEVATIONS

STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)	STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)
Tributary 'D' (cont.)	3334	11900	129.65	Tributary 'D1' (cont.)	1577	1760	71.19
""	2646	12280	134.05	""	1577	1800	84.98
""	2646	12600	137.38	""	1577	1860	85.04
""	2646	12900	145.02	""	1577	2200	85.22
""	2646	13200	152.90	""	1577	2650	89.22
""	2646	13412	157.33	""	1577	2940	95.41
""	2646	13427	159.22	""	1577	3220	100.87
""	2646	13620	159.85	""	1577	3330	100.91
""	2646	13920	167.61	""	1577	3370	102.67
""	2646	14200	171.46	""	1577	3440	109.20
""	2646	14440	176.21	""	1577	3455	109.44
""	2646	14780	181.83	""	1577	3800	109.89
""	1472	15100	188.32	""	1577	3880	110.02
""	1472	15450	193.62	""	1577	4100	110.44
""	1472	15740	196.07	""	1577	4540	111.74
""	1472	15890	206.14	""	1577	4760	112.63
""	1472	15930	206.90	""	1577	4900	113.67
""	1472	16630	224.05	""	1577	5220	119.28
""	1472	16690	225.85	""	1577	5520	121.44
""	1472	16900	225.85	""	1577	5740	126.87
""	1472	17120	225.85	""	1577	5800	129.13
""	1472	17400	226.04	""	1577	5860	129.18
""	1472	17700	230.94	""	1577	5875	133.01
""	1472	18000	237.57	""	1152	6210	133.98
""	1472	18300	244.85	""	1152	6550	134.77
""	1472	18600	250.68	""	1152	6880	140.10
""	1472	18900	257.27	""	1152	7180	146.15
""	1472	19175	262.98	""	1152	7490	151.45
""	1472	19500	268.93	""	1152	7790	155.47
""	1472	19800	275.48	""	1152	8090	160.50
""	1472	20100	283.92	""	1152	8400	168.55
""	1472	20400	293.30	""	1152	8700	176.51
""	1472	20700	299.12	""	1152	9030	185.37
""	1472	20900	302.76	""	1152	9400	198.14
""	1472	21100	306.42	Tributary 'D-2'	1577	-3880	110.02
""	1472	21380	313.03	""	471	70	110.35
Tributary 'D-1'	4525	-1970	54.99	""	471	370	111.47
""	1577	420	57.91	""	471	690	119.52
""	1577	564	58.19	""	471	876	123.97
""	1577	620	58.34	""	471	900	124.67
""	1577	639	61.32	""	471	1062	129.07
""	1577	659	62.02	""	471	1068	129.43
""	1577	700	62.12	""	471	1359	132.80
""	1577	1000	63.04	""	471	1550	136.50
""	1577	1300	66.54	""	471	1820	140.99
""	1577	1600	69.84	""	471	1995	147.94

TABLE 13
COMPUTED 100-YEAR WATER SURFACE ELEVATIONS

STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)	STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)
Tributary 'D-2' (cont.)	471	2170	154.21	Tributary 'D-6' (cont.)	1870	630	144.15
Tributary 'D-3'	1577	-4760	112.63	""	1870	650	144.16
""	160	110	113.30	""	1870	950	144.15
""	160	400	122.38	""	1870	1250	144.16
	160	760	135.35	""	1870	1500	144.16
Tributary 'D-4'	1152	-5875	133.01	""	1870	1800	144.19
""	298	440	133.36	""	1870	2100	144.38
""	298	740	136.37	""	1870	2400	146.37
""	298	1040	142.03	""	1870	2700	151.04
""	298	1340	147.95	""	1870	2960	155.74
""	298	1580	152.61	""	1870	3260	162.57
Tributary 'D-5'	5031	-8260	101.89	""	1870	3400	166.99
""	763	260	102.00	""	1870	3490	168.86
""	763	280	102.00	""	1453	3600	170.58
""	763	295	102.00	""	1453	3850	177.56
""	763	305	102.01	""	1453	4150	185.13
""	763	630	102.57	""	1453	4470	191.39
""	763	900	105.35	""	1453	4750	196.13
""	763	1230	111.47	""	1453	4970	198.60
""	763	1500	116.16	Tributary 'D-7'	1870	-3490	168.86
""	763	1650	121.33	""	406	105	174.80
""	763	1800	127.24	""	406	401	182.40
""	763	1970	133.22	""	406	700	188.06
""	763	2010	133.09	""	406	850	191.66
""	763	2130	154.28	""	406	940	193.60
""	518	2140	154.28	Tributary 'D-8'	406	-850	191.66
""	518	2350	154.28	""	217	130	192.50
""	518	2660	154.28	""	217	530	199.04
""	518	3000	154.28	Tributary 'D-10'	3334	-11900	129.71
""	518	3100	154.24	""	2250	90	132.36
""	518	3140	154.19	""	2250	310	133.44
""	518	3180	156.25	""	2250	360	135.59
""	518	3190	157.07	""	2250	390	136.86
""	518	3440	157.12	""	2250	750	138.03
""	518	3750	157.17	""	2250	1040	139.03
""	518	4050	158.62	""	2250	1330	140.59
""	518	4360	163.01	""	2250	1530	144.10
""	518	4670	168.18	Tributary 'K'	2885	-37180	167.57
""	518	4970	173.94	""	109	400	172.27
""	518	5280	180.31	""	109	600	177.76
""	518	5600	185.58	""	109	840	180.61
""	518	5800	192.10	""	109	852	183.41
Tributary 'D-6'	4214	-9580	106.53	""	109	920	192.35
""	1870	200	108.86	""	109	930	192.35
""	1870	280	110.21	Tributary 'O'	4122	-42940	217.75
""	1870	360	111.48	""	529	240	217.81

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TABLE 13
COMPUTED 100-YEAR WATER SURFACE ELEVATIONS

STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)	STREAM NAME	DISCHARGE (CFS)	CROSS SECTION #	WATER SURFACE ELEVATION (FT)
Tributary 'O' (cont.)	529	510	219.35				
Tributary 'P'	3208	-46400	249.11				
""	679	330	253.73				
""	679	620	262.16				
	679	720	266.06				
""	679	820	267.71				
""	679	920.1	269.72				
""	679	965	274.99				
""	679	1000	275.96				
""	679	1300	276.76				
""	679	1416	277.62				
""	679	1516	278.55				
""	679	1615	282.17				
""	679	1640	282.27				
""	679	1950	284.78				
""	679	2270	289.51				
""	679	2620	294.12				
""	679	2950	300.94				
""	679	3270	306.70				
""	679	3500	310.99				
""	679	3880	320.22				
""	679	4200	323.67				
""	679	4550	326.01				
""	679	4950	333.47				
""	679	5320	338.67				
""	679	5750	345.77				
Tributary 'R'	2390	-49350	289.66				
""	202	300	293.49				
""	202	600	299.27				
""	202	920	310.96				
""	202	1200	316.86				
""	202	1500	321.56				
""	202	1770	332.74				
""	202	1950	338.18				
Tributary 'S'	2390	-50730	311.95				
""	325	160	313.72				
""	325	450	317.29				
""	325	750	325.23				
""	325	1230	335.12				
""	325	1660	344.19				
""	325	1920	351.93				
""	325	2080	363.45				

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 Deep Run watershed HEC-2 modeling.

3.15 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 topographic map contours gives an unrealistic delineation at that section. The primary locations where this occurs is in the area of MD Route 100, and the several new road crossings and in-stream storm water management ponds.

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.

Several new ponds and roads were surveyed that did not appear on the current County topographic sheets. A significant area where the topographic base sheets do not reflect actual field conditions is the MD Route 100 crossing of Deep Run. In these areas in particular it is important to refer to the HEC-2 model output and more accurate topography to determine the true extent of the floodplain. It should also 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 modeled cross section.

4.0 DELIVERABLES

After completing all required computations and modeling 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. 27 - copies of this report.
12. 1 - sets of cross section plots
13. 2 - sets of profile plots

5.0 CONCLUSIONS AND RECOMMENDATIONS

The Deep Run watershed study presented herein provides Howard County with an updated analysis of the watershed's hydrologic and the hydraulic characteristics of its major streams and tributaries. The study also provides the County with field run survey for approximately 23 of the 36 miles of stream in the Deep Run watershed. 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 storm for Year 2010 build out condition this 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 Deep Run watershed. The intent of this watershed study was to provide a watershed level analysis of Deep Run 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. A review of the floodplain delineation indicates numerous roadways that are subject to flooding during large magnitude storm events. The delineation has also identified numerous 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. A portion of the Harwood Park area located on Tributary 'D' between MD Route 1 and the B&O Railroad is located within the delineated 100 year floodplain. While field survey was performed for the HEC-2 cross sections,

detailed survey was not done to define point of first entry for any dwellings or general topography between cross sections. It is recommended that the County confirm the plotted floodplain delineation on the plan sheet based on a detailed field survey in the area in question.

5. 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 Deep Run watershed study to Howard County as an 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 build out of the watershed. We therefore recommend acceptance of the study presented herein by Howard County and Water Resources Administration.

6.0 REFERENCES

1. Constellation Design Group, Inc., "Deep Run Encroachment Analysis Study", Contract MSHA No. HO 661-502-770, October, 1996

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

3. KCI Technologies, Inc., "Hydrologic and Hydraulic Report, Pre- and Post-Construction Conditions, MD Route 100 Over Deep Run", Contract MSHA No. AW 890-201-070, Revised November, 1991

4. Kidde Consultants, Inc., "Interstate Route 195 From I95 to BWI Airport - Supplement to Hydrologic and Hydraulic Report, Patapsco River Crossing", MSHA No. AA 220-201-572, FAP No. I-195-1(1), October, 1987

5. URS Greiner, Inc., "Hydrologic Report for Deep Run", Contract MSHA No. HO 661-540-770, July, 1996

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

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

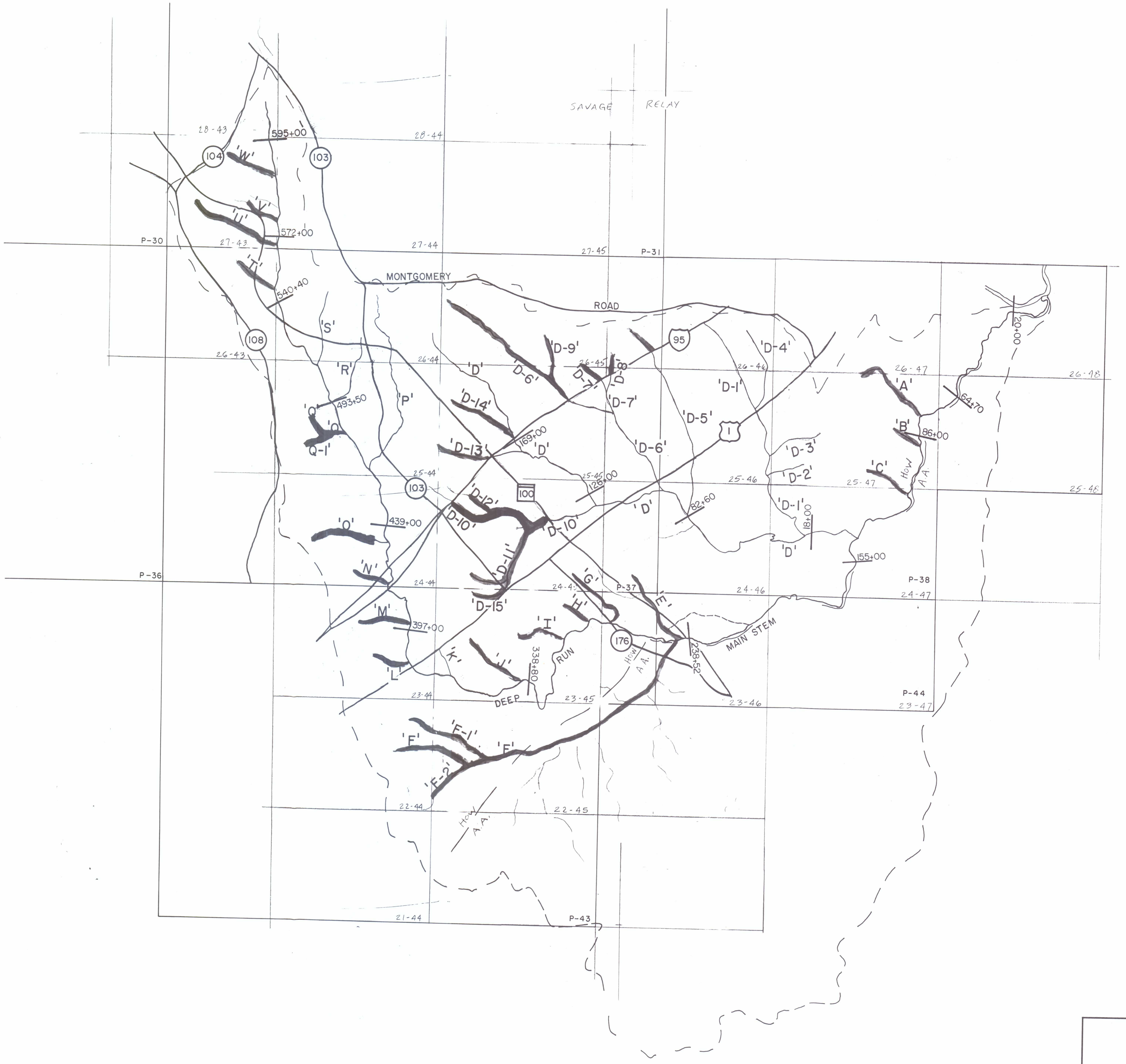
8. U.S. Department of Commerce, "Rainfall Frequency Atlas of the United States, for Duration from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years", Technical Paper No. 40, May, 1961

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

7.0 APPENDICES

APPENDIX A

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



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DATE	REVISIONS

L & ESSER B-5985

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

DEEP RUN
WATERSHED MAP AND
KEY TO 200 SCALE PLANS

SHEET	DATE	JOB NUMBER
1 OF 1	FEB. 1996 SCALE 1"=2000'	D-1094

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:

Deep Run Mainstem	2400, 2584, 14357, 14358, 14390, 14391, 14440, 14500, 25544, 25720, 25734, 37880, 38062, 41420, 41770, 42050, 42340, 45620, 45765, 48713, 48870, 52749
Tributary D	6770, 9214, 10190, 10320, 10940, 11220, 15890, 16690
Tributary D-1	564, 700, 1860, 3455, 5875
Tributary D-2	876, 1068, 1995
Tributary D-5	280, 305, 1650, 1970, 2140, 3100, 3190
Tributary D-6	280, 650
Tributary K	930
Tributary P	1416, 1640

APPENDIX C

MISCELLANEOUS COMPUTATIONS

Howard County Rainfall