Chapter 4

Methodology

This chapter is divided into six main sections, with each section discussing a particular step taken in the methodology. The first five sections are dedicated to developing the data needed to perform four BOD/DO modeling runs in the Upper HSC, while the final section describes the procedure used to establish the GIS/WASP5 model connection. The first section introduces the study area by describing the Upper Houston Ship Channel and its contributing watershed. The second section provides a brief overview of water quality segmentation, previous segmentations of the HSC, and the segments used for the water quality modeling performed in this study. In addition, this section introduces the terminology of *main segment* and *boundary segment* in relation to their use in this research.

Section 4.3 gives a procedure for the calculation of the non-point source loadings entering the Upper HSC. This procedure uses land use-based estimated mean concentrations, with spatially distributed runoff volumes to result in a areal loading of BOD to the Channel from the watershed. This section also presents a method of estimating baseflow, given a daily flow record and spatially distributing that runoff, using existing data and land use characteristics. It is important to note that the loading calculation performed in this section assumes that the non-point source load is only transported by the runoff volume. The following section (Section 4.4) discusses the point source loadings to the modeled reach. Only those dischargers located along the Upper HSC shoreline were considered in the point source loading determination. In contrast to the non-point source loads, the point source loads were assumed to be transported by the channel baseflow, which is discussed further in Section 4.5.

Section 4.5 presents the WASP5 model development, including determination of model constants, estimation of water quality segment parameters, and execution of the model calibration and model runs. Within the section, the channel flow, which is needed for the

WASP5 model, is discussed. This flow is spatially distributed in the same way as the runoff was in Section 4.3. The final flow values for each segment, along with the corresponding runoff values from Section 4.3, are used to determine the baseflow in each water quality segment. This baseflow is necessary when looking at dry weather conditions, where just point source loads are entering the system (i.e., no runoff or non-point source loadings). The four modeling cases are also presented in this section: an average year case, a dry weather condition, and two cases to test model sensitivity.

Finally, Section 4.6 discusses the WASP5/GIS model connection through the software ArcView, while using Avenue and FORTRAN programming. The discussion presents the menus created in ArcView to execute the Avenue scripts which read and write the model input information from tables and coverages. This section also gives a step-by-step procedure, along with an outline of the necessary tables and coverages, which is used to run the model connection. This section also contains an overview of the WASP5 input blocks as they relate to the interface, including assumptions and defaults set in the creation of the input file.

4.1 STUDY AREA

The model developed incorporated the Upper Houston Ship Channel and all land draining into this section of the channel (Figure 4-1). Figure 4-1 also shows the major highway systems in the Houston area for reference. The western boundary for the Upper HSC, the Turning Basin, receives the majority of its input from Buffalo Bayou, whose watershed is primarily covered by the greater metropolitan area of Houston. This water reach then travels east, receiving water and loadings from the Brays, Sims, Berry, Green, Hall, Carpenter, and Vince Bayous, and draining about 2600 km^2 of land. The San Jacinto Monument creates the eastern boundary of the 25 km section studied and is located just west of the confluence of the San Jacinto River. For digital representation, the channel was depicted in GIS two ways: 1) USGS Digital Line Graph (DLG); and 2) a segmented line drawn down the centerline of the channel.

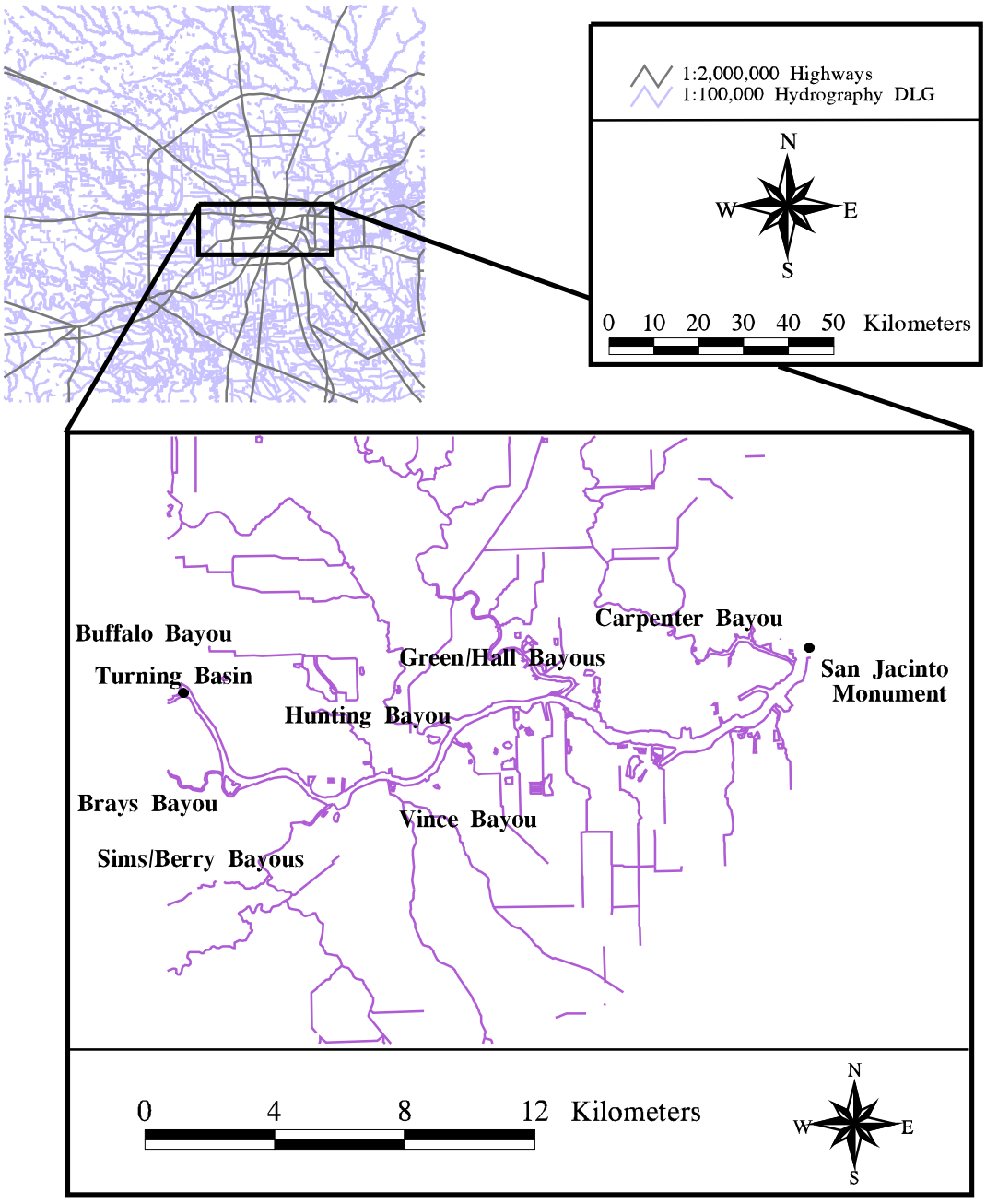


Figure 4-1 Study area, which includes the Upper Houston Ship Channel from the Turning Basin to the San Jacinto Monument and all land draining into the reach. Streams and channel are represented here by 1:100,000 DLG (USGS, 1993). Highways are also shown.

The DLG (Figure 4-1) depicts the Channel as a double-lined water reach; however, for digital representation in GIS and modeling purposes, the channel is depicted as a single flow line. Since the channel width averages only about 1000 meters at its widest point in that area, it could be modeled in just two dimensions (length and depth). Because of this detail, a single line could accurately be used to represent the channel in GIS. Therefore, a centerline was manually-drawn onto the DLG and the shoreline of the Upper HSC deleted in the Arc/Info subprogram, ArcEdit. Figure 4-2 shows the final result of this process. Section 4.2 further discusses the centerline representation of the Channel in GIS.

4.2 CHANNEL SEGMENTATION

In order to model the channel in WASP5, it is necessary to divide the reach into water quality segments. A segment is assumed to have uniform modeling parameters, such as depth, cross sectional area, dispersion coefficients, etc. Each segment is considered to be a completely mixed reactor. After the point and non-point loadings into each segment are determined; these loads, along with the necessary physical and chemical parameters, are read into WASP5 to produce a dissolved oxygen profile.

4.2.1 Previous Segmentation in the Houston Ship Channel

The Texas Water Commission (TWC -- now Texas Natural Resource Conservation Commission -- TNRCC) divided the entire Galveston Bay System into 40 segments (Ward and Armstrong, 1992). However, since the determination of these segments was controlled by regulatory reasons, homogeneous hydrography within a TWC segment could not be assumed. In addition, the reach considered for this study made up only two of the TWC segments (Figure 4-3). This resolution was not fine enough for an accurate modeling effort. Ward and Armstrong (1992) further divided the Bay and Channel into smaller, hydrographic segments (Figure 4-4). But, a full modeling effort, concerning DO had not been performed with this finer segmentation. In another earlier study (Espey et al., 1971), the entire channel was divided into 28 segments (Figure 4-5), from the Turning Basin to Morgan's Point (located at the mouth of the Channel flowing into the main bay). The 1971 effort, performed by Tracor, Inc., modeled the entire HSC for DO and BOD.

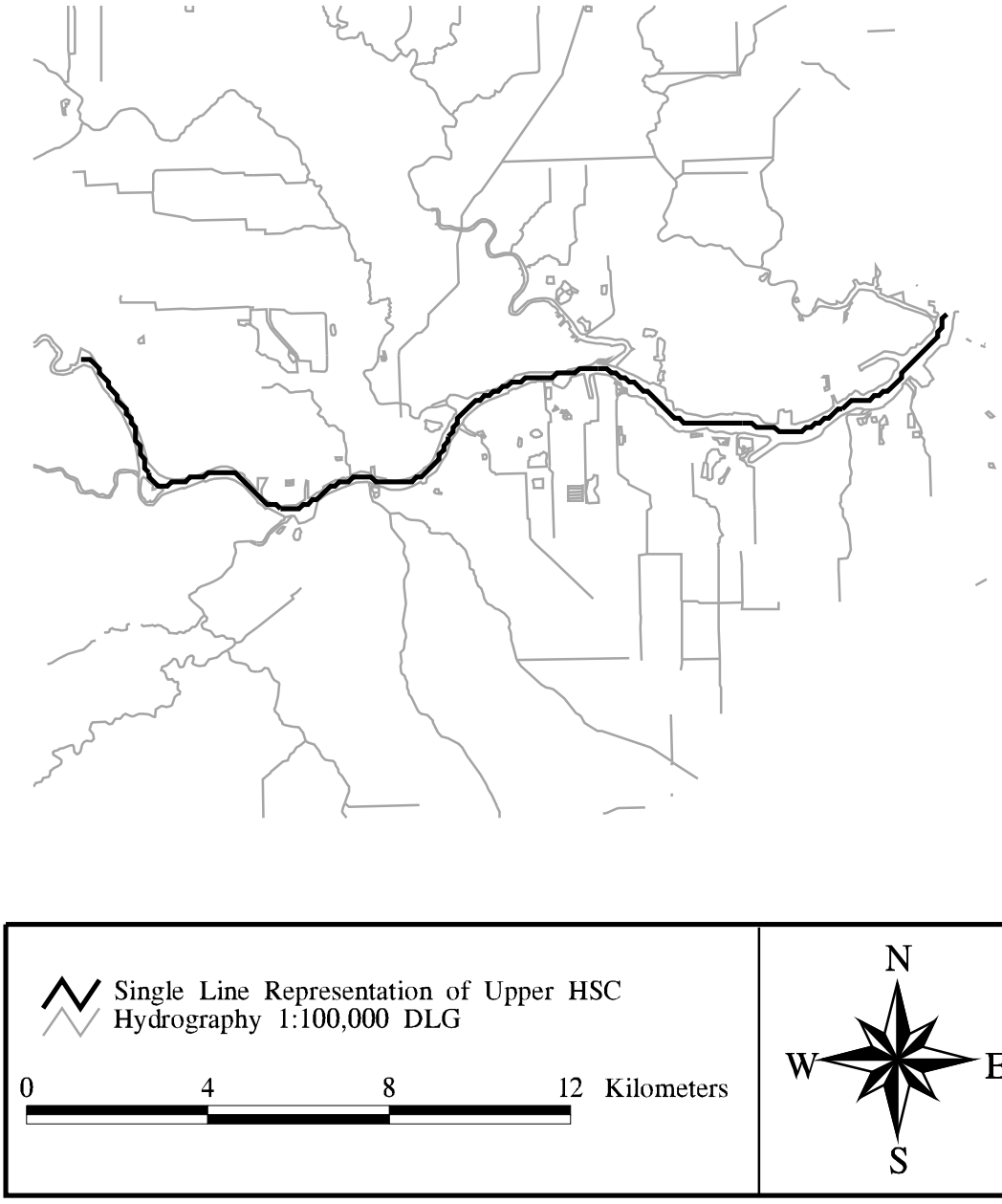


Figure 4-2 Single line representation of the Upper Houston Ship Channel used in GIS.

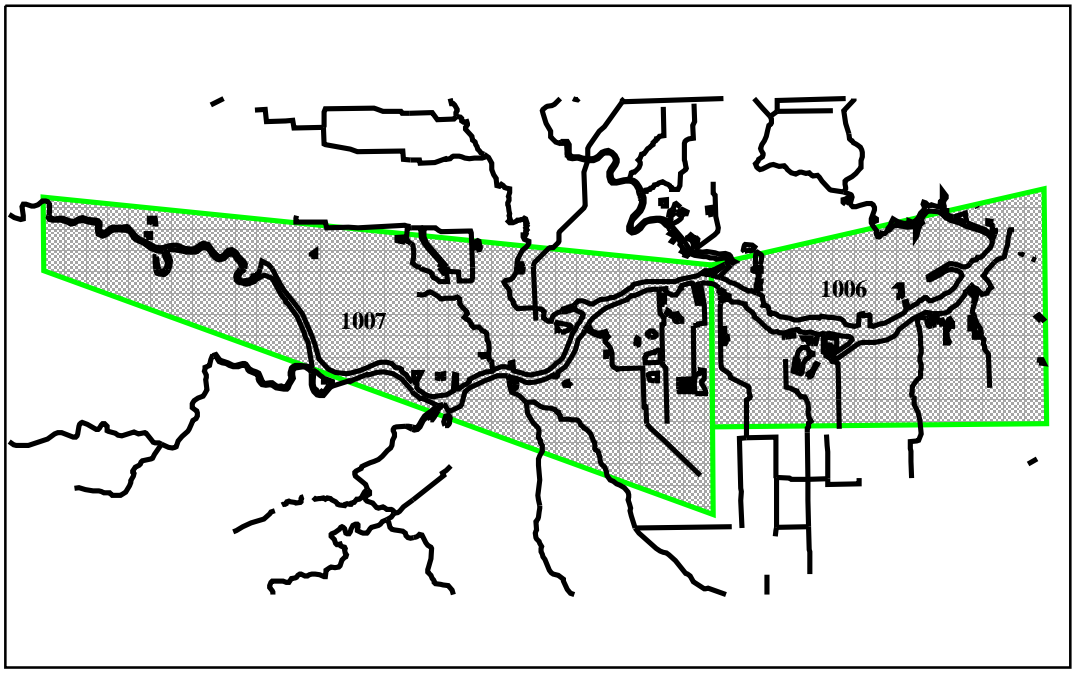
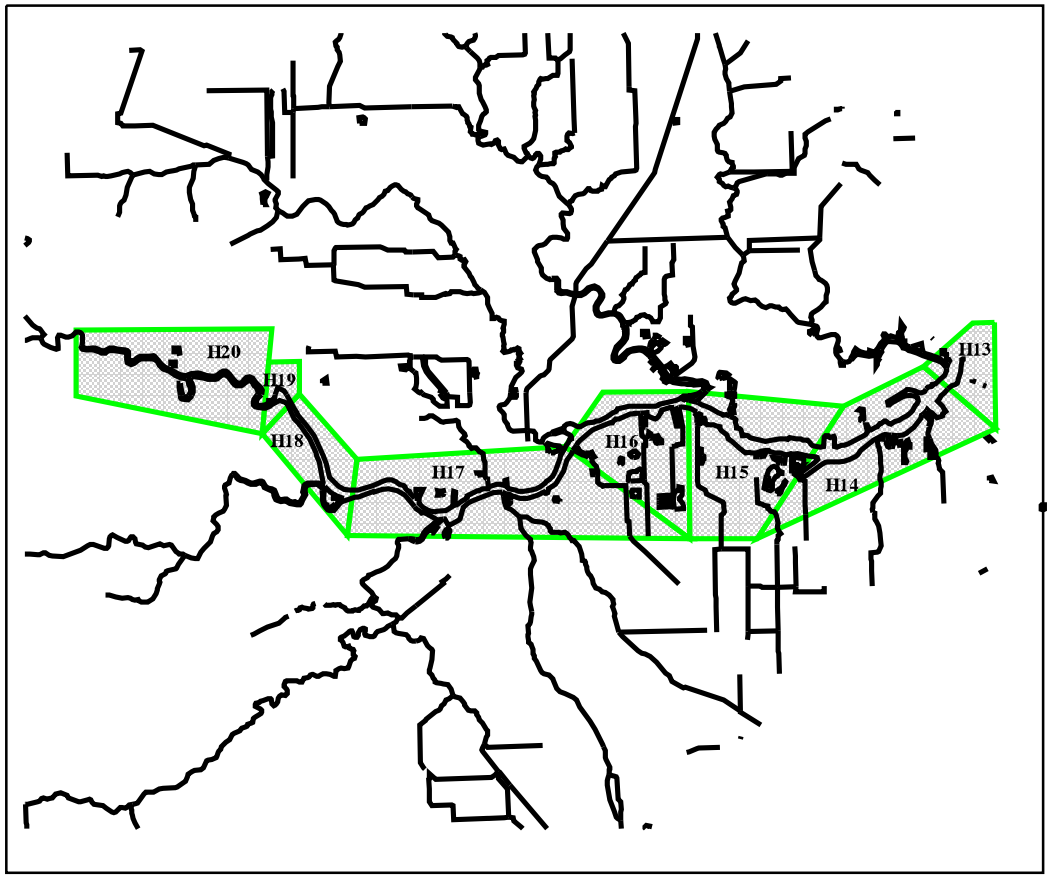


Figure 4-3 Upper Houston Ship Channel showing related TWC (now TNRCC) segments.



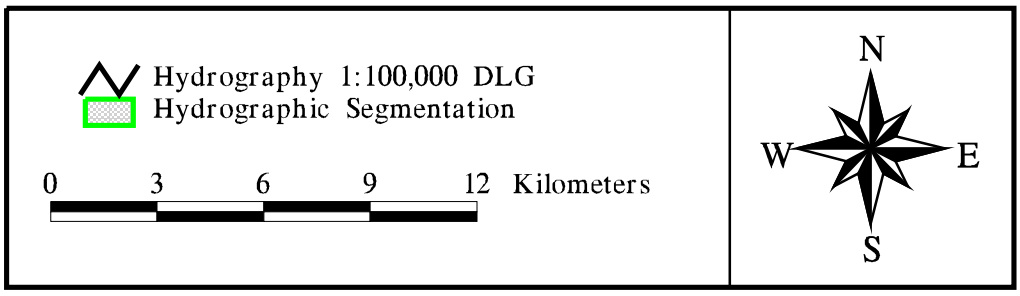


Figure 4-4 Ward and Armstrong (1992) hydrographic segmentation over the study area.

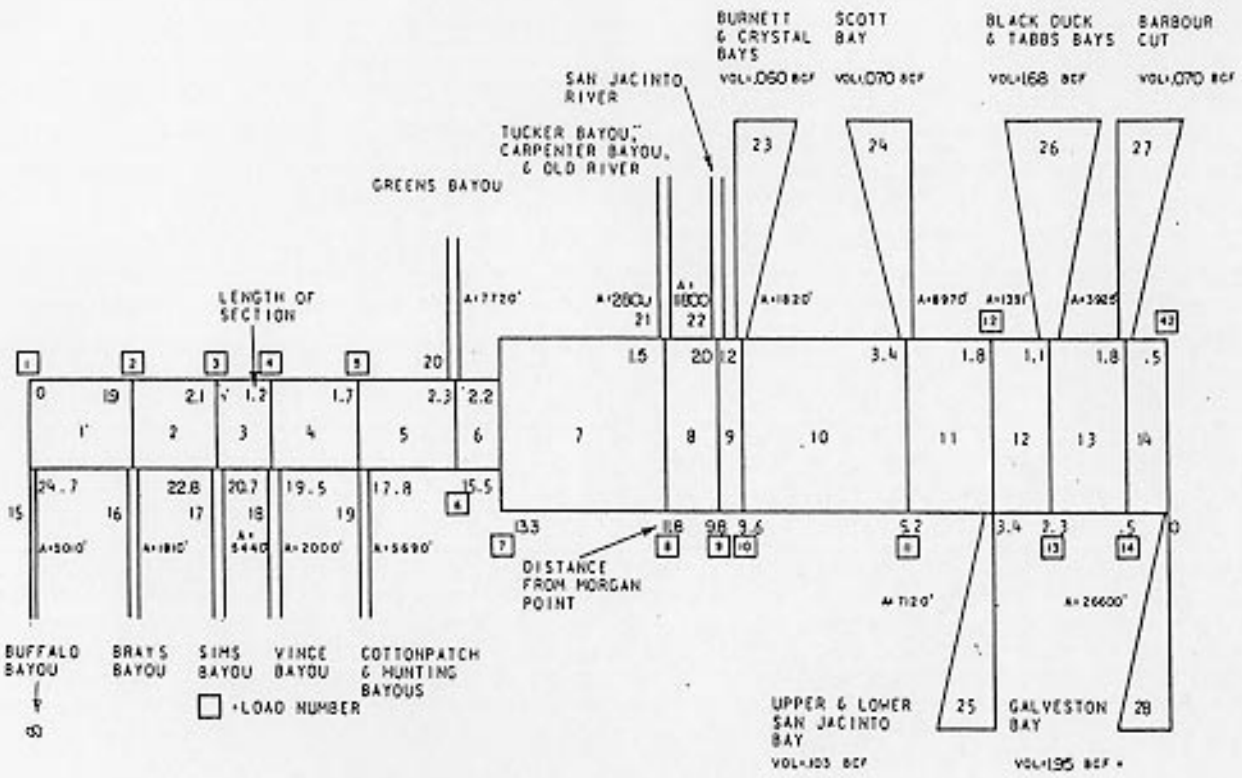


Figure 4-5 Original segmentation used by 1971 Tracor modeling effort (Espey *et al.*, 1971).

4.2.2 Segmentation Chosen

For this study, the Upper HSC reach was divided into eight of the hydrographic segments developed in the Tracor Inc. modeling effort of the HSC (Espey, *et al*., 1971). By using this segmentation, the results of the modeling from this present study could be compared to the results of the 1971 study. Since this research considered just the Upper Houston Ship Channel, only the first eight segments of the 1971 report were used as the main segments for the modeling effort. Figure 4-6 shows the final segmentation used, while Table 4-1 gives some general characteristics of each main segment. In addition, some of the information provided in the 1971 report, concerning the incoming tributaries was used to develop the model boundary conditions (see Sections 4.2.3 and 4.5).

Table 4-1 General Characteristics of the Main Segments used for the Modeling Effort

Segment Number	Length (km)	Cross-sectional Area (m^2)	Depth (m)	% Total Length
1	3.1	1625.8	9.1	12.8
2	3.4	1625.8	9.1	14.1
3	1.9	1625.8	9.1	8.1
4	2.7	1625.8	6.1	11.4
5	3.7	1625.8	9.1	15.4
6	3.5	1625.8	6.1	14.8
7	2.4	2471.3	7.9	10.1
8	3.2	2471.3	7.9	13.4
Total	24.0			

Source: Espey,, et al., 1971

4.2.3 Segment Terminology in this Research

In this report, a *main segment* is a term used in reference to the eight water quality segments described in the previous section and used to represent the 25 km of the Upper HSC modeled in this study. In addition, nine *boundary segments* are defined in this research. Model boundaries are those segments which import, export, or exchange water with the locations outside the main network. A boundary segment represents either a tributary inflow, a downstream outflow, a sediment layer, or an open water end of the model network across which dispersive mixing can occur. Within GIS, arcs were defined to represent the Buffalo,

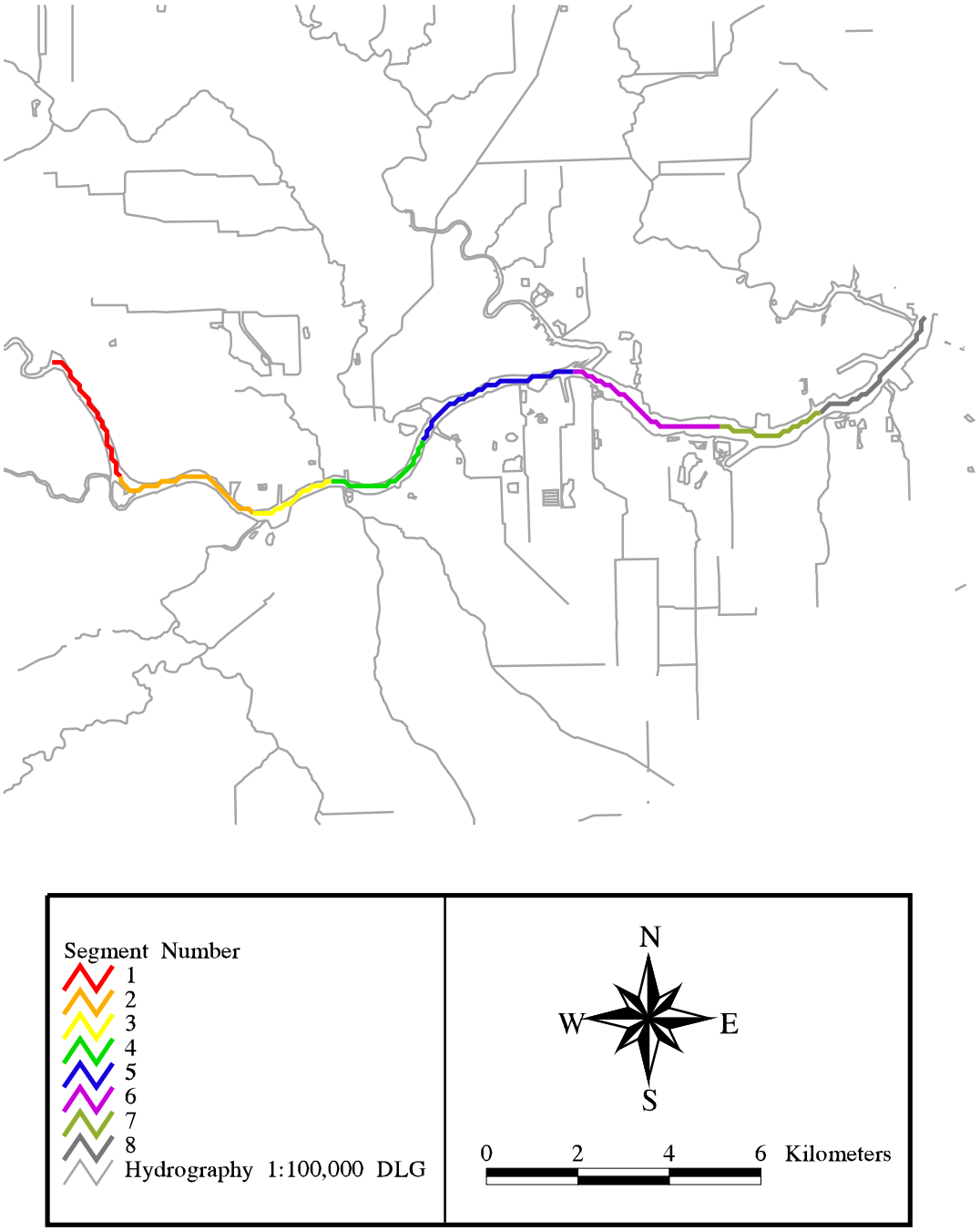


Figure 4-6 Final segmentation used as depicted in GIS (Espey et al., 1971).

Brays, Sims/Berry, Hunting, Vince, Green/Hall, and Carpenter Bayous (see Figures 4-1 and 4-7) to account for the tributaries entering the Upper HSC. The eighth boundary segment is the most downstream segment, which includes an input from the San Jacinto River (segment #17). The length of these arcs is arbitrary, but the lengths of the segments in the model are set at 3.2 km for all but the Buffalo Bayou, which is set at 8 km. These actual lengths, which are defined in a GIS table related to the arc coverage, are meant to depict infinite boundary conditions. Finally, the ninth boundary segment (segment #9), represents the underlying sediment layer. Further discussion on the main and boundary segments, their parameters, and their use in the model is provided in Section 4.5.

4.2.4 Segmentation in GIS

Since the objective of this research was to connect WASP5 to GIS, the channel segmentation needed to be digitally represented in Arc/Info and ArcView. As mentioned earlier, the most efficient way to depict the channel was as a single line in GIS. As a result, the channel was viewed in GIS as a stream, into which numerous other streams (i.e., bayous) drained (Figure 4-6).

However, it was necessary to get GIS to recognize the channel as eight different segments, instead of one long stream. The desired result was eight arcs, each carrying their respective segment number as an attribute. To accomplish this task, a process called "flowlength" in Arc/Info's subprogram, Grid, was executed on the flow direction grid of the DEM (see Section 4.3 for further explanation of the flow direction grid). The flowlength command produced a grid in which each cell value corresponded to the distance, in meters, from that respective cell to the ultimate outlet of the grid. The flowlength values for just the single line representation of the Upper HSC were isolated with a Grid Boolean query (see Procedure 4-1). The result of this effort was a "single-lined" grid of the Upper Houston Ship Channel, with each 100m x 100m cell containing its respective flowlength value.

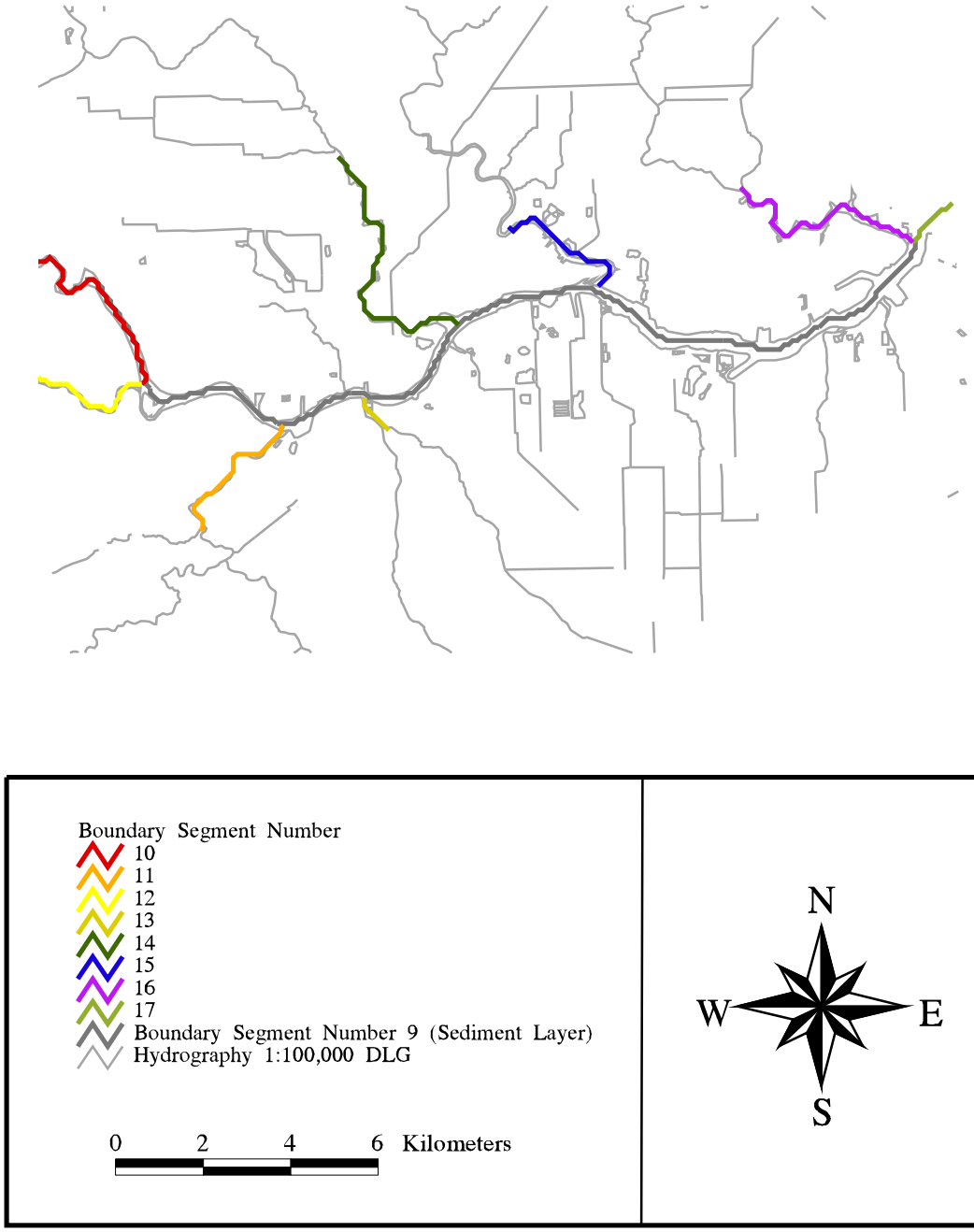


Figure 4-7 Arcs representing boundary segments for the water quality modeling.

Grid: **hscgrid = linegrid (hscalone)**
creates a grid, called hscgrid, of the single-line representation of the Houston Ship Channel
Grid: **hscgrid1 = con (hscgrid > 0, 1)**
puts the value of "1" in each cell of hscgrid which lies on the channel
Grid: **hscfl = flowlength (hscfdr)**
performs the flowlength command on the flow direction grid of the watershed; the result is hscfl, in which each cell carries the value of the length from the ultimate watershed outlet to that respective cell
Grid: **channelfl = con (hscgrid1 == 1, hscfl)**
a Boolean query that produces a grid, channelfl, which holds just the flowlength values for the hscgrid
Grid: **display 9999**
brings up Grid's display window
Grid: **mape hscgrid1**
Grid: **gridpaint bound**
displays the grid of the start and end points of the modeling segmentation; this grid was produced by creating a point coverage of the two boundary points, projecting it into USGS-Albers, and gridding the coverage
Grid: **cellvalue channelfl ***
allows the user to query the cellvalue of the two boundary points by clicking on them within the display window

Procedure 4-1 Process used to determine flowlength values for the start and end points of the segmentation.

In order to determine the actual extent of the modeled reach in GIS, the locations of the start and end points for the channel segmentation were read from a 1:24,000 USGS quad sheet (Table 4-2). A point coverage of these two locations was created in Arc/Info and projected into USGS-Albers Projection. The point coverage was overlaid onto a grid of the single line representation of the Houston Ship Channel (Figure 4-8). The two grid points which corresponded to the start and end points were isolated using ArcEdit. Afterwards, their flowlength values from the isolated flowlength grid were determined with the "cellvalue" command in Grid (Procedure 4-1). The result of this entire process was the start and end flowlength values for the segmentation. By subtracting these two values, the total length of the segmented reach as represented in GIS was determined (Table 4-2). This length (25.1 km) only differed from the length given in the 1971 report (24 km) by 4.6% (Espey, *et al.*, 1971).

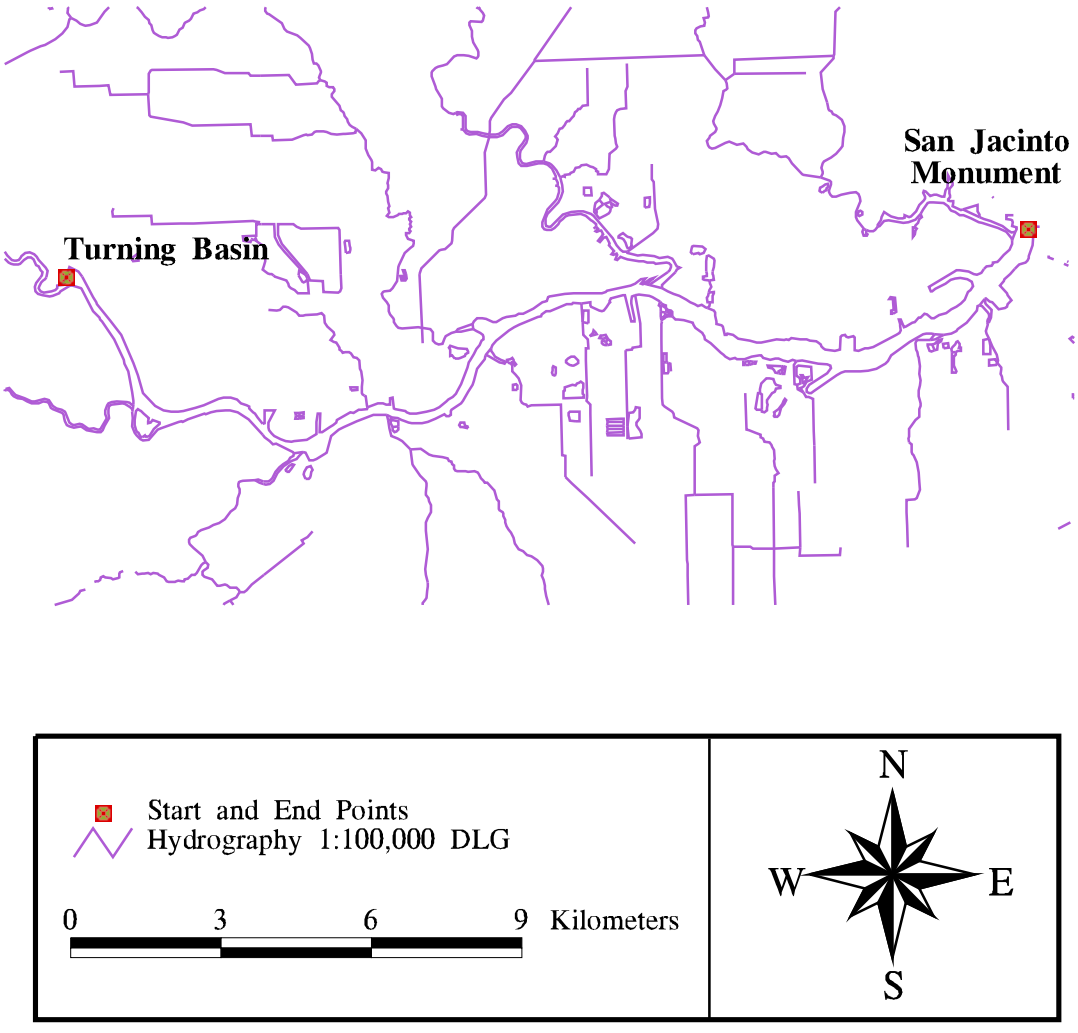


Figure 4-8 Upper Houston Ship Channel showing start and end points used for the modeled reach.

Table 4-2 Start and End Points for Model Segmentation. Table also shows the flowlength values for each point and the resulting reach length in GIS

Point	Location (From 1:24,000 USGS Quad Sheet)	Flowlength Value (m)	
Turning Basin	29° 44' 58.4" N 95° 17' 25.4" W	38654.648	
San Jacinto Monument	29° 45' 24.5" N 95° 5' 20.0" W	13502.429	
	Difference:	25152.219	
	Length of reach in GIS	25.1	km
	% Difference from Espey, *et al*. (1971):	4.6	

Since the scale of the DLG may not have been on the exact same scale as the map used to determine the 1971 segmentation, proportional segmentation was used. To accomplish this task, the percent of the total reach length for each segment was calculated from the lengths given in the 1971 report. Those percentages, as shown in Table 4-1, were then applied to the total stream length of the arc within GIS, as determined from the procedure above. A detailed description of this process is outlined in Procedure 4-2. The final result, as illustrated in Figure 4-6, was an eight-arc coverage of the segmentation, with each arc carrying an attribute corresponding to its segment number.

Grid: **seg_1 = con (channelfl le 38654.648, 0) + con (channelfl gt 35447.318, 1)**
puts a value of "1"(1 + 0) in each cell that has a flowlength value (see Procedure 4-1) less than or equal to 36854.648 (the upper bound for segment one) and greater than 35447.318 (the lower bound); the total length of this segment is 12.8 % of the total segment length (see Table 4-1)
Grid: **seg_2 = con (channelfl le 35447.318, 1) + con (channelfl gt 31902.374, 1)**
Grid: **seg_3 = con (channelfl le 31902.374, 1) + con (channelfl gt 29876.692, 2)**
Grid: **seg_4 = con (channelfl le 29876.692, 2) + con (channelfl gt 27006.975, 2)**
Grid: **seg_5 = con (channelfl le 27006.975, 2) + con (channelfl gt 23124.418, 3)**
Grid: **seg_6 = con (channelfl le 23124.418, 3) + con (channelfl gt 19410.668, 3)**
Grid: **seg_7 = con (channelfl le 19410.668, 3) + con (channelfl gt 16878.562, 4)**
Grid: **seg_8 = con (channelfl le 16878.562, 4) + con (channelfl gt 13502.425, 4)**
the above statements perform the same function as the first, only for each respective segment, the flowlength values change to encompass the necessary segment length and location
Grid: **hsc_seg = merge (seg_1, seg_2, seg_3, seg_4, seg_5, seg_6, seg_7, seg_8)**
merges each individual grid, corresponding to each segment, into one grid
Grid: **segarc = gridline (hsc_seg, #, #, #, #, grid-code)**
creates an arc coverage of the grid and stores the segment number in the aat under "grid-code"

Procedure 4-2 Commands used to segment the single line representation of the HSC into eight arcs.

Once the segmentation was recognized in GIS, the parameters of each segment were attached to the attribute table of the eight-arc segmentation coverage. It was then possible for GIS to read the necessary input parameters for the model run. This concept is further discussed in Section 4.6.

4.3 NON-POINT SOURCE LOADS

Introduction

A non-point source (NPS) load is defined as any input into the HSC waters that is a result of runoff, which flowed over the land and picked up constituents from the land surface. Although the flow may have been channelized into a tributary by the time it reached the Houston Ship Channel, if the constituents originated from the land surface, as opposed to an outfall pipe, the load was considered to be a non-point source load. Determining the actual loading of constituents caused by overland flow has been a subject of numerous reports (Newell, *et al*., 1992; Saunders, 1996). The method used in this report is similar to procedures described in Saunders (1996) and Newell, *et al*. (1992). The process utilized GIS to assist in the non-point source loading calculations. The basic concept of the method incorporated the following general equation:

Concentration (mass/volume) * Volume of Water (volume) = Load (mass) (4-1)

The method developed, discussed in more detail below, was a grid-based model that calculated the non-point source load for each 100m x 100m cell of the watershed. The process used values called Estimated Mean Concentrations (EMCs), which, when associated with land use areas, provided the contribution of a given constituent to the runoff flowing over that area. Actual runoff and precipitation measurements were compiled and correlated to help spatially distribute the runoff over the entire 2600 km^2 area. This distributed runoff, combined with the land use based EMCs, established the NPS loadings into the Upper HSC.

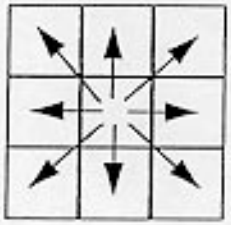
The processed specifically incorporated the following steps:

- Delineate watershed area (total and area draining into each segment)
- Spatially distribute the runoff
- Determine land use and concentration (EMC) from each cell
- Use Equation (4-1) to determine loading from each cell
- Determine the NPS load into each water quality segment

These steps are discussed in more detail in the following paragraphs.

Watershed Delineation

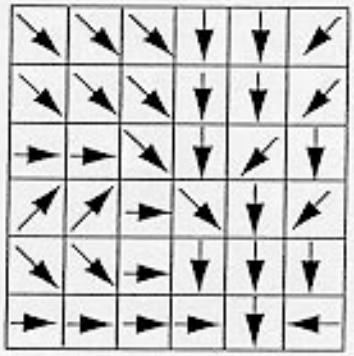
The grid-based watershed delineation has been used in other projects to produce a digital representation of all land draining into a body of water (Saunders, 1996). The concept in the watershed delineation is the use of the 3″ DEM (see Section 3.2.3) to determine the direction of flow over the surface terrain. The basis of this concept is the application of the "eight direction pour point model" (Maidment, 1993). As shown in Figure 4-9, the eight direction pour point model employs the theory that, if a drop of water falls onto a given cell, it can flow in eight different directions. The direction chosen is that of the steepest slope. Once the direction of the water flow is determined (termed the flow direction grid), Arc/Info's subprogram, Grid, accumulates the flow down to a given outlet (or the ultimate outlet of the grid) by counting the number of cells upstream that flow into that particular cell. A stream network is then delineated from a certain threshold value. In other words, a cell with a certain minimum number of cells draining into it was considered part of the stream network. Procedure 4-3 shows a detailed description of this entire process in Grid. It is important to note that the DEM used is one that has been projected into USGS-Albers and a 100m x 100m cell size resolution. In addition, the point which represents the San Jacinto Monument was considered the ultimate outlet of the study area; therefore, a grid containing one cell, corresponding to this ultimate outlet point, was created through ArcEdit.



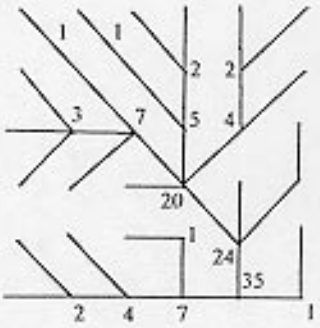
8-Direction Pour Point Model

78	72	69	71	58	49
74	67	56	49	46	50
69	53	44	37	38	48
64	58	55	22	31	24
68	61	47	21	16	19
74	53	34	12	11	12

Grid of Elevation Values



Flow Direction Grid



Flow Accumulation Grid

Figure 4-9 Eight direction pour-point model used in Grid for watershed delineation (Maidment, 1993).

Grid: **fill hscdem hscfil SINK**
fills any "pits" or large differences in elevations between neighboring cells that may cause delineation errors. The "SINK" at the end of the statement tells Grid to look for cells which are lower than its surrounding cells.
Grid: **hscfdr = flowdirection (hscdem)**
creates a flowdirection grid of the dem; each cell carries a value which indicates the direction of flow from that cell
Grid: **hscfac = flowaccumulation (hscfdr)**
creates a flowaccumulation grid of the flowdirection grid; each cell carries a value which corresponds to the number of cells that drain into it
Grid: **str_500 = con (hscfac > 500, 1)**
creates a grid of a stream network on the 500 level threshold; all cells that contain a flow-accumulation value of 500 or higher is considered part of the stream network and given a value of 1
Grid: **totalshed = watershed (hscfdr, outlet)**
delineates the watershed from a given outlet point, in this case a grid containing one cell which is located nearest to the San Jacinto Monument. The outlet grid was developed by creating a point coverage of the location of the San Jacinto Monument (Table 4-2) and then creating a grid which has just one cell, corresponding to the point location through ArcEdit.
Grid: **covstr_500 = streamline (str_500)**
Grid: **covtotsd = gridpoly (totalshd)**
converts the stream network grid and the watershed grid into line and polygon coverages, respectively

Procedure 4-3 Procedure used to delineate a watershed from a DEM for a given outlet.

The procedure above was determined using pure elevation data from the DEM. However, the final product of this attempt produced a poor digital representation of the stream network and watershed boundary (Figure 4-10). This erroneous result was mostly due to the relatively flat terrain in the area. Therefore, it was necessary to "burn in" the streams, using a cleaned 1:100,000 DLG. In this process, which is also employed in Saunders (1996), the original DLG was edited in ArcEdit to eliminate any circular arcs (i.e., lakes, reservoirs, etc.) and connect any dangling streams that are meant to be continuous. In addition, during the edit process, instream lakes and double-lined rivers or channels were replaced with representative streamlines. The streams were then gridded at the same resolution as the DEM (100m x 100m) and the elevations in the DEM, except for the cells which corresponded to the DLG stream cells were raised five meters. A new watershed could then be delineated, producing a more accurate digital representation of the ridgeline (see Procedure 4-4). As done previously, the ultimate outlet for this watershed was chosen to be a cell which was located nearest to the San Jacinto Monument (i.e. the last cell found in

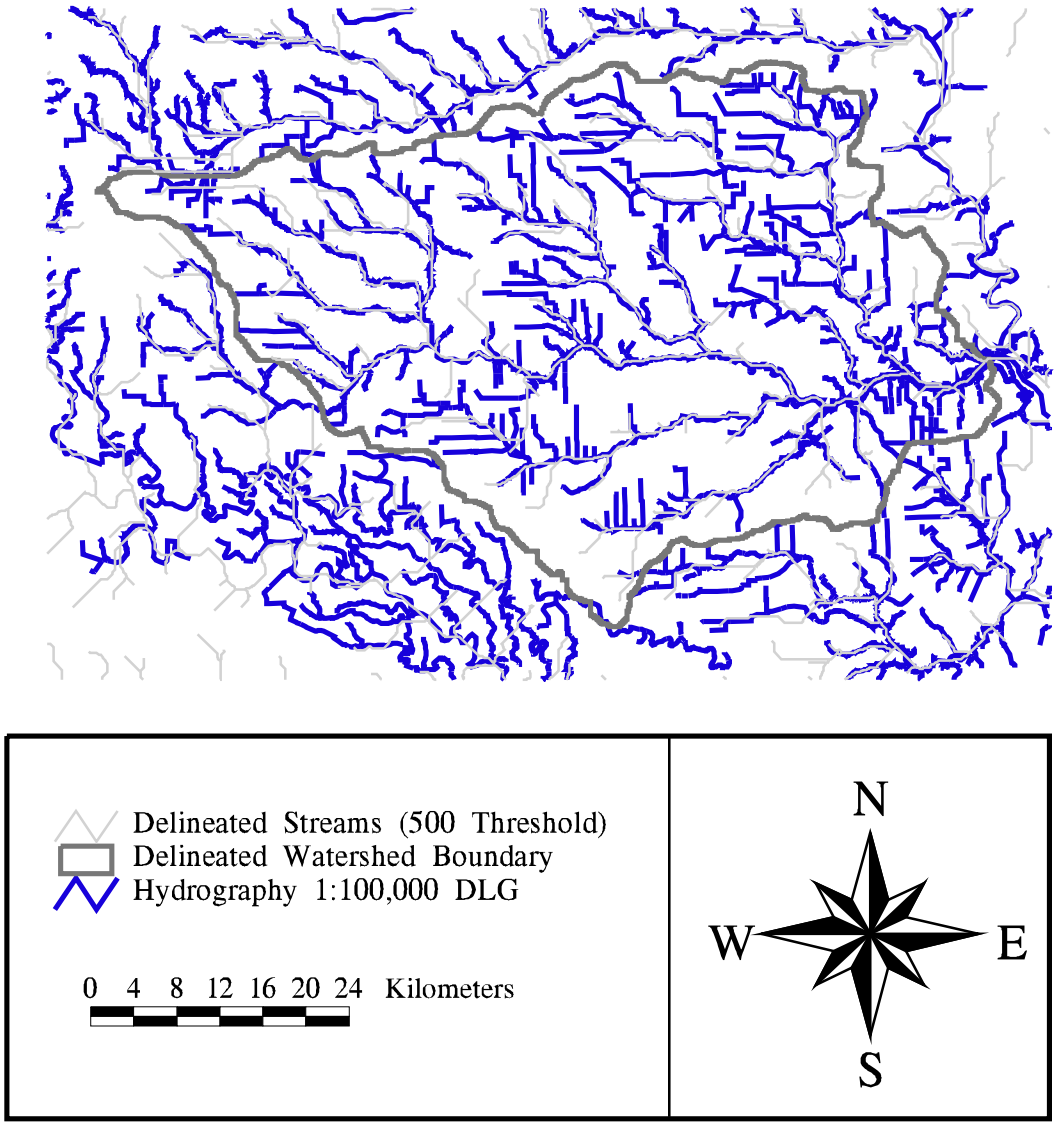


Figure 4-10 Delineated watershed and streams from orginal DEM. Errors exist between the DLG streams and the delineated ones; the watershed boundary is also inaccurate.

water quality segment eight). Figure 4-11 depicts the final watershed and stream network resulting from this procedure.

Grid: **dlggrid = linegrid (dlgedit, #, #, #, 100, 0)**
grids the edited DLG into 100m x 100m cells and places the value of zero in those cells not corresponding to the streams
Grid: **hscburn = con (dlggrid > 0, 0, hscdem + 5)**
increases the elevation values of the DEM grid by five meters and places the value of zero in any cell which corresponds to the stream network
Grid: **fill hscburn hscfil SINK**
fills any "pits" or large differences in elevations between neighboring cells that may cause delineation errors
Grid: **hscfdr = flowdirection (hscdem)**
creates a flowdirection grid of the dem; each cell carries a value which indicates the direction of flow from that cell
Grid: **hscfac = flowaccumulation (hscfdr)**
creates a flowaccumulation grid of the flowdirection grid; each cell carries a value which corresponds to the number of cells that drain into it
Grid: **str_500 = con (hscfac > 500, 1)**
creates a grid of a stream network on the 500 level threshold; all cells that contain a flowaccumulation value of 500 or higher is considered part of the stream network and given a value of 1
Grid: **totalshed = watershed (hscfdr, outlet)**
delineates the watershed from a given outlet point, in this case a grid containing one cell which is located nearest to the San Jacinto Monument
Grid: **covstr_500 = gridline (str_500)**
Grid: **covtotsd = gridpoly (totalshd)**
converts the stream network grid and the watershed grid into line and polygon coverages, respectively

Procedure 4-4 Procedure for "burning in" the DLG streams and delineating the corresponding watershed.

The above procedures produced the total watershed (approximately 2600 km^2). However, the area draining into the segments described in Section 4.2 was of more importance when determining the NPS loading into each of the eight reaches. As a result, an outlet was defined at the downstream point of the segment, for each reach by locating the maximum flowaccumulation value in each zone (i.e. water quality segment) of the segmentation grid (see Procedure 4-5). The result was a grid of eight outlets, from which eight subwatersheds were delineated. Figure 4-12 illustrates the final coverage of the areas draining into each segment, while Table 4-3 gives the delineated areas for each subwatershed. Procedure 4-5 describe the commands used in Grid to produce this result.

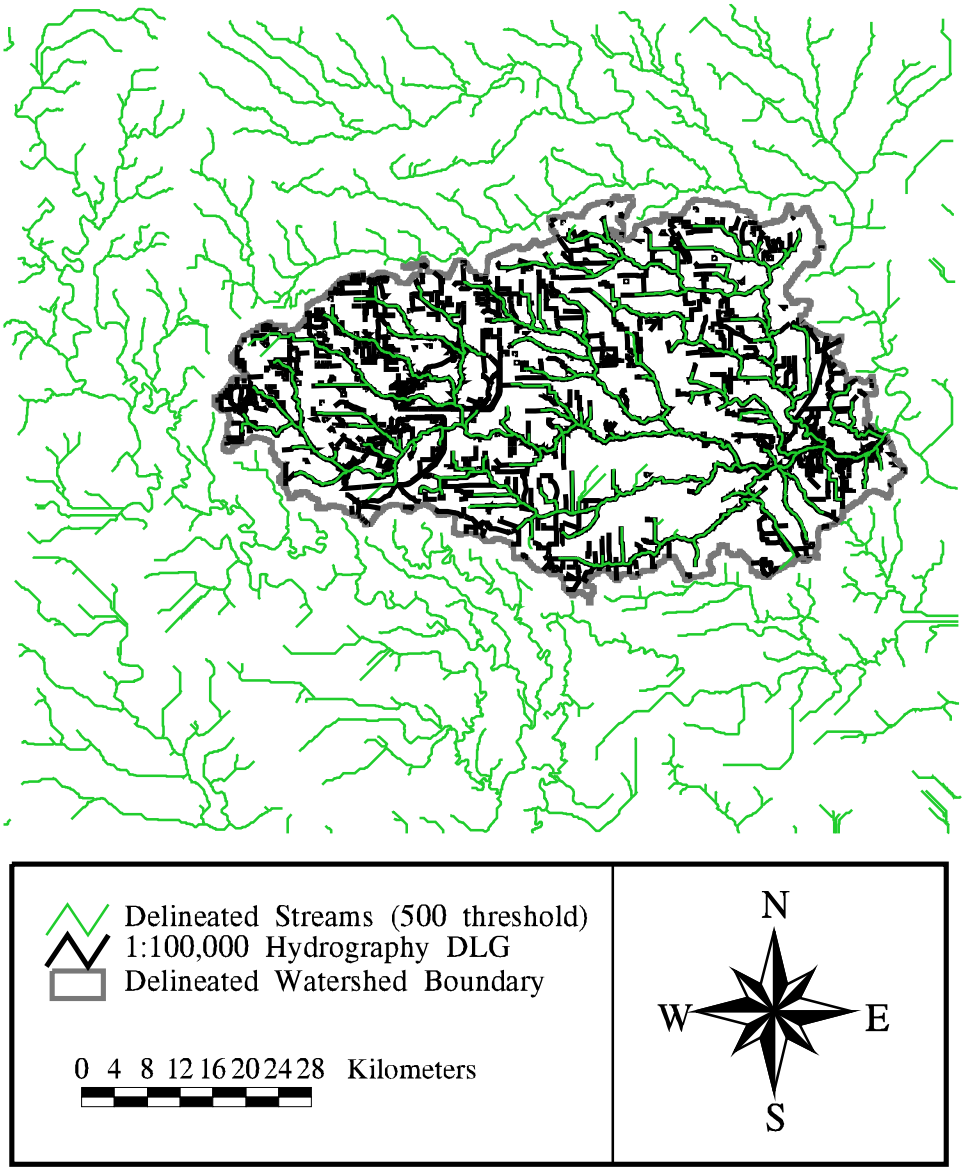


Figure 4-11 Comparison of streams delineated from "burned" DEM grid and 1:100,000 DLG of hydrography. Delineated streams correspond well to the DLG.

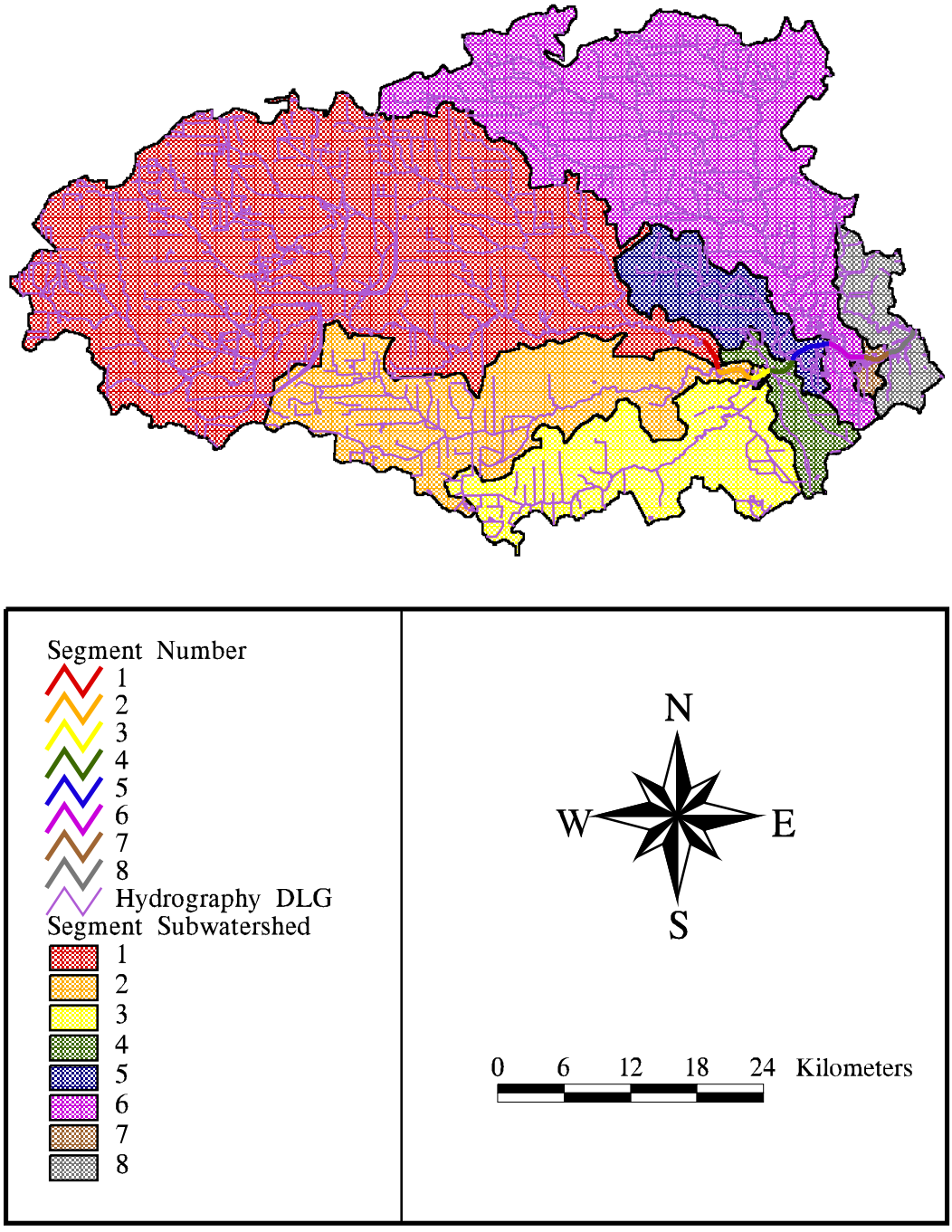


Figure 4-12 Segmentation with corresponding watersheds.

Table 4-3 Delineated Areas of Segment Subwatersheds

Segment Number	Area (km^2)
1	1143.98
2	330.59
3	241.43
4	58.21
5	111.73
6	635.76
7	10.04
8	74.69
Total	2606.43

Grid: **acc_seg = zonalmax (hsc_seg, hscfac)**
locates the maximum flowaccumulation value in each zone; in this case hsc_seg is a grid consisting of eight zones -- one for each segment
Grid: **out_seg = con (acc_seg == hscfac, hsc_seg)**
places the values of the segment number in the cell which corresponds to the maximum flowaccumulation value; the result of this is the outlet grid
Grid: **seg_shd = watershed (hscfdr, out_seg)**
delineates the watersheds for the eight given outlets

Procedure 4-5 Commands used to develop segment subwatersheds.

Spatial Distribution of Runoff

After the watershed was delineated, it was necessary to obtain an average runoff volume generated from each cell. As mentioned in Section 3.2.6, 37 USGS streamflow gauges were located in the study area (Figure 4-13). Of these 37 gauges, nine were chosen for their long period of records to determine a spatial distribution of runoff for the entire watershed (Table 3-6). For each of the nine gauges, the watershed areas were delineated from the flowdirection grid by selecting an outlet point at every gauge location. This selection was performed by choosing the cell, through ArcEdit, which was located on the delineated stream network and was nearest to the point representing the actual gauge location. Table 4-4 shows the watershed areas determined from this process and a comparison of these delineated areas to the areas given by USGS (see Figure 3-8). Most areas delineated by Arc/Info fall within about 10% of the USGS area. Differences are

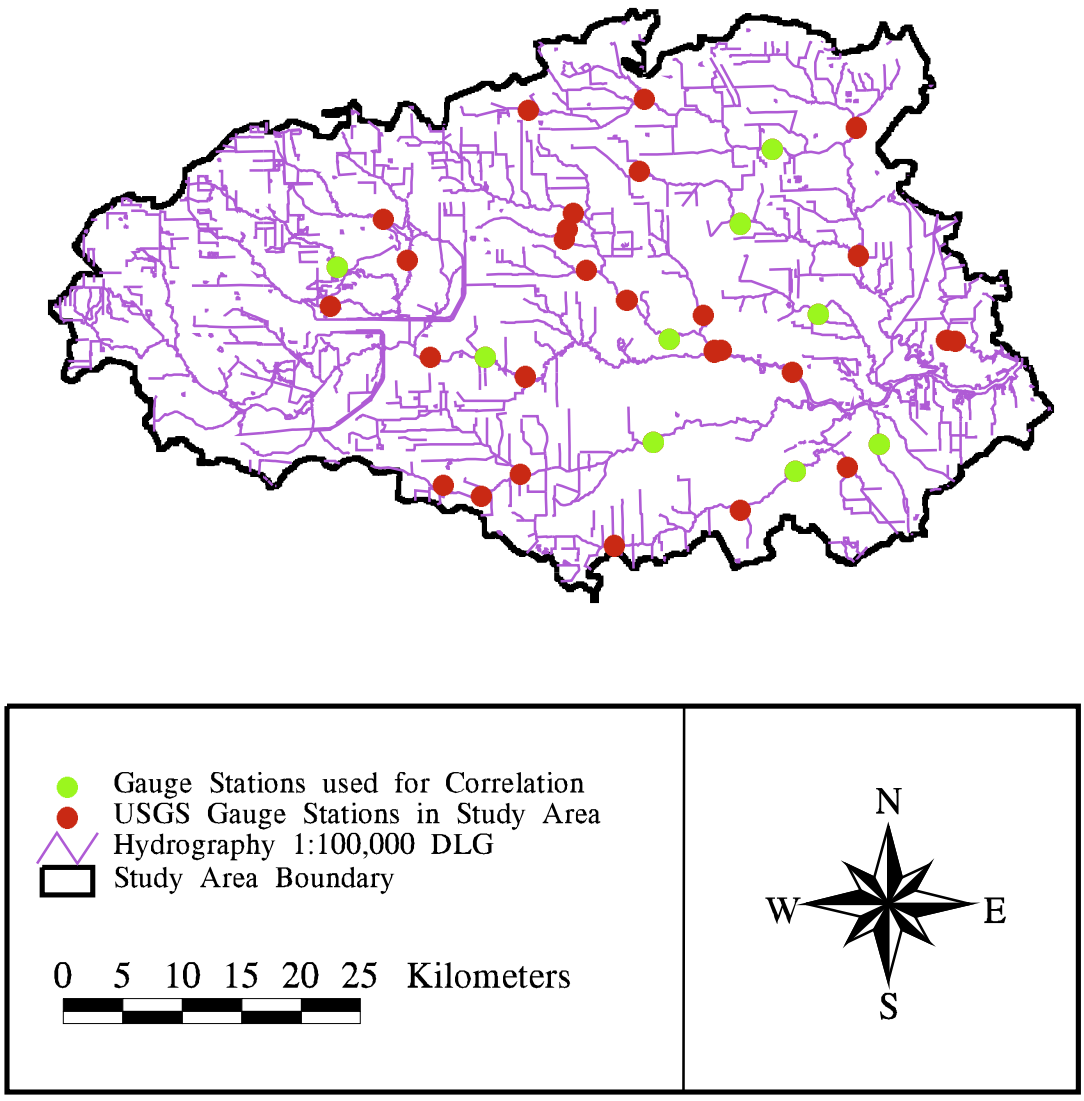


Figure 4-13 Study area showing USGS streamflow gauges.

probably due to small inaccuracies in the DEM or possible errors in the given USGS areas. Since these nine stations only encompassed about 50% of the entire watershed area (see Figure 3-8), it was necessary to "redistribute" this flow data over the total watershed to obtain a runoff value from every cell in the study area.

Table 4-4 USGS Watershed Areas Compared to Delineated Watershed Areas

USGS Station	USGS Drainage Area (mi^2)	Delineated Drainage Area (mi^2)	%Error
8072730	21.5	25.78	19.92
8073600	307.0	273.18	-11.02
8074500	86.3	79.16	-8.28
8075000	94.9	97.94	3.20
8075500	63.0	61.12	-2.98
8075730	8.3	7.82	-5.33
8075770	16.1	20.06	24.61
8076000	68.7	69.04	0.50
8076500	28.7	27.82	3.08

Source: Texas USGS, 1996

Flow records formatted as average daily values are available for every gauge from the Texas USGS via internet (Texas USGS, 1996). Since the data available are in total streamflow, but the EMCs are meant to be applied to surface runoff, baseflow is subtracted out of the flow using a FORTRAN program (Olivera, 1996). This program, shown in Appendix C-3, uses a concept of minimum slopes to estimate the daily baseflow. For the very first day in the period (Day 1), the streamflow value is assumes to be the baseflow. The program then calculates the slopes between the baseflow value to the streamflow values of the next 12 days (Days 2 through 13). The minimum slope found is assumed to be the baseflow slope; the baseflow for Day 2 is calculated using this minimum slope. The program then moves to Day 2 and calculates the slopes between the determined baseflow at Day 2 and the streamflow values of Days 3 through 14; hence the entire process is repeated. This method continues until an estimated baseflow value is obtained for each day in the period of record. Figure 4-14 shows an example of one year of streamflow data, with the estimated baseflow. Since the program assumes that the value on the first day of the record is the

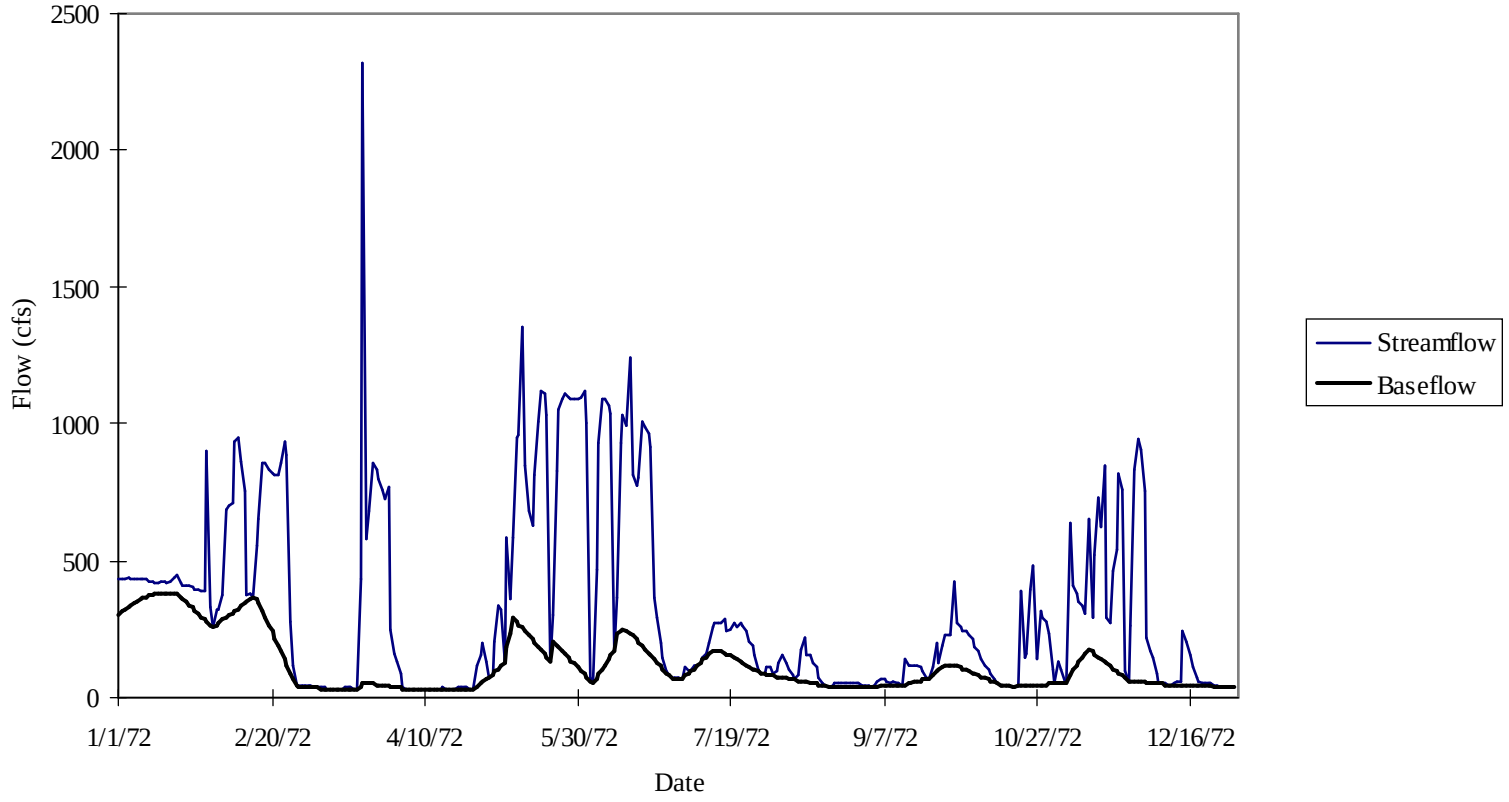


Figure 4-14 Flow record for gauge 8073600, shows the estimated baseflow along with the measured streamflow (Texas USGS, 1996).

baseflow, streamflow values for a few days preceding and following the desired record are included in the baseflow estimation. In this way, any errors involved with this assumption are avoided with the ability to disregard the first and last few baseflow values.

The percentage of the total flow which accounts for the baseflow varied from station to station, with the average being 22%. Stations 8072730 and 8075730, which had small drainage areas, both had a baseflow/total flow percentage of 7%. In contrast, the two larger drainage areas from stations 8073600 and 8075000 resulted in 36% of the total flow being composed of baseflow. The other five stations all had baseflow/total flow ratios of about 21 to 30 %. The calculated baseflow is discussed later in this chapter in relation to the water quality modeling parameters (see Section 4.5.5).

When possible, the average daily flow data was downloaded for the 30 year period of 1961 - 1990 so that an accurate comparison could be performed with the precipitation data for the same period. As shown in Table 3-4, various periods of record existed for each gauge. Once the baseflow was subtracted from the flow, any station containing an incomplete record between 1961 and 1990 was adjusted to fit the studied period of record by using the following equation:

$$(Rx)_{1961-1990} = \left[\frac{(Ry)_{avaiable}}{(Ry)_{1961-1990}}\right](Rx)_{available} \qquad (4\text{-}2)$$

where:

$(R\ x)_{1961\text{-}1990}$ = average yearly runoff depth for a given gauge, x, adjusted to represent the entire period, 1961 to 1990 (mm/yr)

$(R\ y)_{available}$ = average yearly runoff depth of four gauged stations with complete records, averaged over the record available for gauge x (mm/yr)

$(R\ y)_{1961\text{-}1990}$ = average yearly runoff depth of for gauged stations with complete records, averaged over the record, 1961 - 1990 (mm/yr)

$(R\ x)_{available}$ = average yearly runoff depth for partially gauged station, averaged over the record available (mm/yr).

Gauges 8073600, 8074500, 8076000, 8076500, which combined, cover about 44% of the total watershed area, all have 30 years of data available. Although Table 3-6 shows that station 8075500 had a full period of record, some errors existed in the earlier data, resulting in an incomplete record for 1961 (Figure 4-15). To apply Equation (4-2), it is necessary to assume that the response of the entire watershed is similar to the response shown for those four stations. Figure 4-15 indicates that the overall response of the watershed to rainfall events is relatively consistent for gauge to gauge. Therefore, the use of Equation 4-2 is accurate. In addition, since the runoff data was calculated as average daily data, a macro was written in Excel which added the data to obtain yearly data. The final annual flow was divided by the delineated station subwatershed area to obtain depth of runoff per year. Figure 4-15 illustrates the annual flow depths for each station and how they varied over time. In addition, the final adjusted runoff values for each station are shown in Table 4-5. The relative runoff coefficient shown in Table 4-5 is discussed in the following paragraphs, while further discussion on the use of the baseflow in this study is found in Section 4.5.5, in relation to the water quality modeling parameters.

Table 4-5 Streamflow Gauges with Runoff, Precipitation, and Relative Runoff Coefficient

Gage	Average Runoff (mm)	Adjusted Avg Runoff (mm)	Precipitation (mm)	Runoff/ Precipitation	Relative Runoff Coefficient
8072730	219.84	190.89	1111.92	0.17	0.28
8073600	248.68	211.95	1235.21	0.17	0.39
8074500	361.16	361.16	1187.18	0.30	0.56
8075000	404.85	404.85	1180.70	0.34	0.44
8075500	380.55	389.18	1220.16	0.32	0.49
8075730	643.50	548.46	1262.08	0.43	0.59
8075770	314.14	301.93	1223.32	0.25	0.43
8076000	304.32	304.32	1182.56	0.26	0.41
8076500	317.92	317.92	1199.45	0.27	0.52
8075900	241.01	226.56	1180.73	0.43	0.19

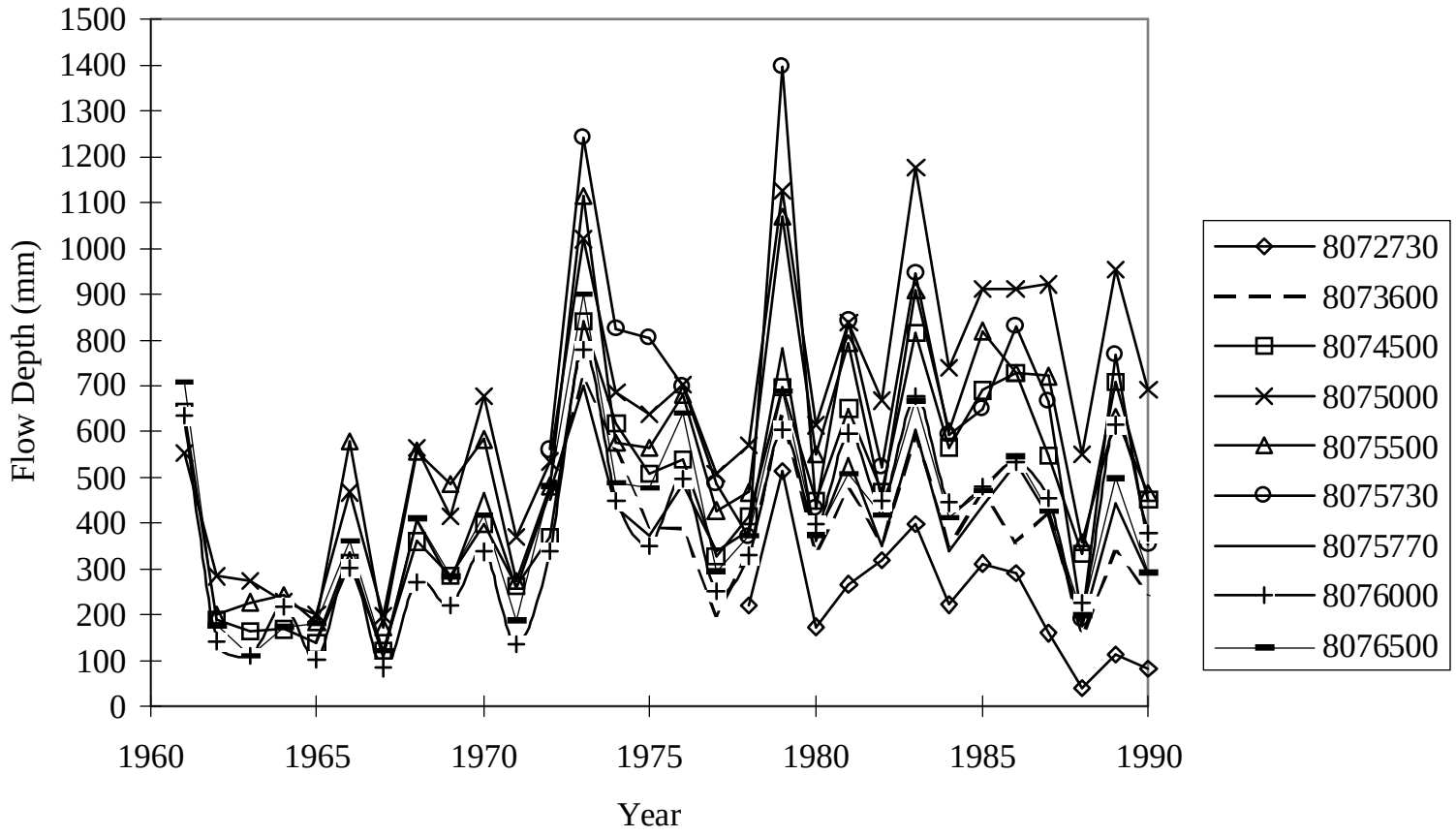


Figure 4-15 Streamflow records for nine gauges used in rainfall/runoff correlation. Graph shows the similar response of the watershed to precipitation.

Once the runoff was determined, the annual precipitation data had to be considered. By using the annual precipitation grid described in Section 3.2.5, an average annual depth was found by performing a weighted flow accumulation on the flow direction grid with the precipitation grid (see Procedure 4-6). The flow accumulation value at each station was then determined by using the "cellvalue" command. This value, which was actually in units of depth x total number of cells upstream from the given cell, was divided by the number of cells in the station subwatershed to obtain an average precipitation depth. The results of this process are shown in Table 4-5. The average runoff depth was divided by the average precipitation depth at each gauge to obtain an estimate for the average yearly percentage of precipitation which becomes runoff.

grid: **pannalb = project (p_ann, geoalb.prj, #, 100)**
projects the annual precipitation grid over the study area from geographic coordinates into USGS-Albers with a 100 m x 100 m cell size
grid: **pannfac = flowaccumulation (hscfdr, pannalb**)
performs a weighted flow accumulation on the flow direction grid by adding up the precipitation cells that flow into a given cell; the final grid contains cells with the total amount of rainfall multiplied by the number of cells flowing into a given cell
grid: **pannvalues = con (gage > 0, pannfac)**
puts the value of the flow accumulation grid cell in to corresponding cell that represents the USGS gauge location
grid: **mape gage**
grid: **gridpaint gage**
grid: **cellvalue pannvalues ***
allows one to query the gauge grid and obtain weighted flow accumulation values at each station

Procedure 4-6 Procedure used to determine the flow accumulation values of precipitation at each gauge station (i.e. subwatershed outlet).

The highly urbanized quality of the watershed provides support to a correlation between this runoff/precipitation ratio and land use. To do this correlation, a value was assigned to each land use cell to characterize the amount of runoff that cell would produce. In classical urban hydrology, it is common to use runoff coefficients to help characterize the amount of runoff produced from a given storm event for a given area. In a similar way, runoff coefficients can provide a relative measure of the urbanization of an area, by assigning high values to paved areas and low values to open, grassy land. This latter concept was employed to get a "relative measure of urbanization" for the Upper HSC watershed. Values

of runoff coefficients vary depending on the source (Chow, *et al.*, 1988; Browne, 1990; Pilgrim and Cordery, 1993). The coefficients found in Table 4-6 were chosen from the researched literature and assigned to each land use (Browne, 1990). The coverage of land use was then gridded and the value of the runoff coefficient was retained as the measurement in each 100m x 100m cell. In a manner similar to the steps followed to obtain average precipitation depth (Procedure 4-6), the average "runoff coefficient" over each station subwatershed was determined (see Table 4-5). It is important to note that this value gives only a relative measure of the urbanization for the watershed; it can not be used in an absolute manner. A small coefficient value indicates less urbanization over a watershed area, as compared to an area with a higher coefficient value.

Table 4-6 Runoff Coefficients Used for Relative Measure of Watershed Urbanization *

Land Use	Runoff Coefficient
Urban[+]	0.89
Open	0.22
Agriculture	0.24
Barren	0.22 (estimated)
Wetlands	0.8
Residential[++]	0.34
Water	1
Forest	0.15

Source: Browne, 1990 (Table 7.6)

* Assumptions: Soil Type D, Design Storm 25 + yrs, Flat Slopes

[+] Assumed Commercial

[++] Assumed 1/2 acre lots

The runoff/precipitation ratios were plotted against these relative runoff coefficients to obtain a relationship between percentage of precipitation which becomes runoff and extent of urbanization over the land surface. Figure 4-16 displays the final correlation graph with a linear regression best fit to the points. The 1:1 line on the graph illustrates the relationship which exists if the relative runoff coefficient represented the percentage of precipitation which eventually becomes runoff. The actual values which resulted from the procedure described in the previous paragraphs, are about 60% of the values on the 1:1 line. This

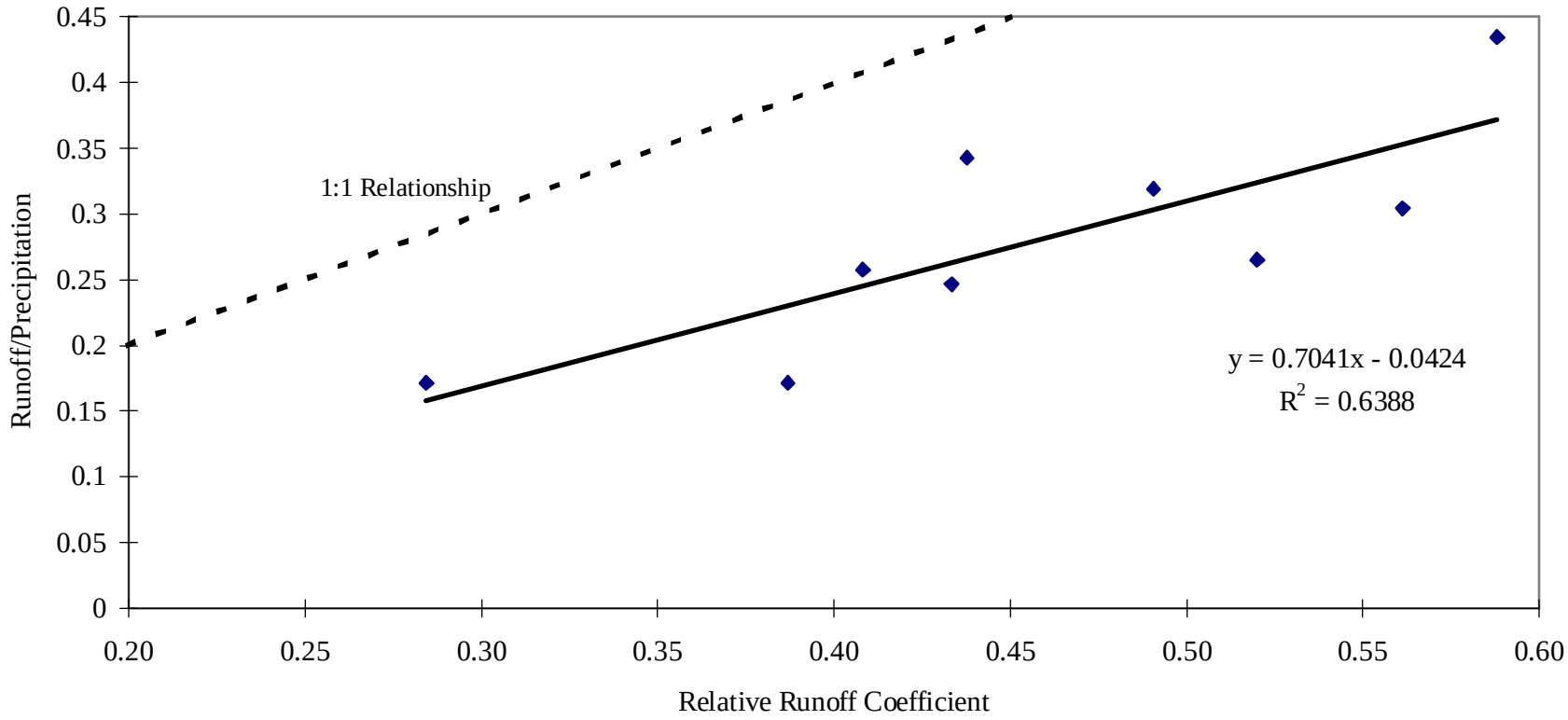


Figure 4-16 Relation between ratio of mean annual surface runoff divided by mean annual precipitation to runoff coefficients for the same area, based on land use and standardized runoff coefficient table. 1:1 line illustrates the relationship that would exist if the runoff coefficient was an absolute measure of the percentage of precipitation which becomes runoff.

equation was then used to redistribute the runoff over the entire watershed area. This process was accomplished by taking the runoff coefficient grid and using it as "input" to the equation to produce a runoff/precipitation grid (Procedure 4-7). The ratio grid, which contained a value of runoff/precipitation for every 100m x 100m cell, was multiplied by the precipitation grid discussed in Section 3.2.5. The final result was a grid of estimated annual runoff (Figure 4-17) in dimensions of depth.

grid: **hsccoeff = polygrid (hsclu, runoff_coeff, #, #, 100)**
grids the land use coverage to a 100 m x 100 m cell size and retains the runoff coefficient attached to the particular land use, as the value in each cell
grid: **r_pann = hsccoef * 0.704 - 0.0424**
uses the correlation shown in Figure 4-16 to calculate a runoff/precipitation value for every cell
grid: **r_ann = r_pann * pannalb**
creates a grid of runoff by multiplying the calculated runoff/precipitation grid by the measured precipitation grid

Procedure 4-7 Procedure used to distribute average annual runoff over the entire watershed area.

Estimated Mean Concentrations

An event mean concentration is the average concentration of water quality constituents over the course of a storm event from a defined drainage are with a given land use. Since this study examines steady-state responses, instead of just one particular storm event, a more accurate name for this factor is Estimated Mean Concentration (EMCs). Numerous studies have been undertaken to determine accurate EMCs for various areas (Newell, *et al*., 1992). Research has shown that most EMCs are site-specific; therefore, it is best to use values that have been determined for either a particular area of study, or for an area with similar land usage. Newell, *et al*., (1992) performed an extensive investigation to obtain accurate Estimated Mean Concentrations values for the Houston area. Most of the EMCs determined from this 1992 study were derived from the analysis of point and non-point source water quality data for the Houston area and previous water quality reports dealing with NPS loading. Although the modeling effort for this current study required only BOD, Table 4-7 shows some other typical values used in the Newell, *et al*., (1992) study. In addition, Figure 4-18 shows the distribution of the BOD EMC values over the watershed area.

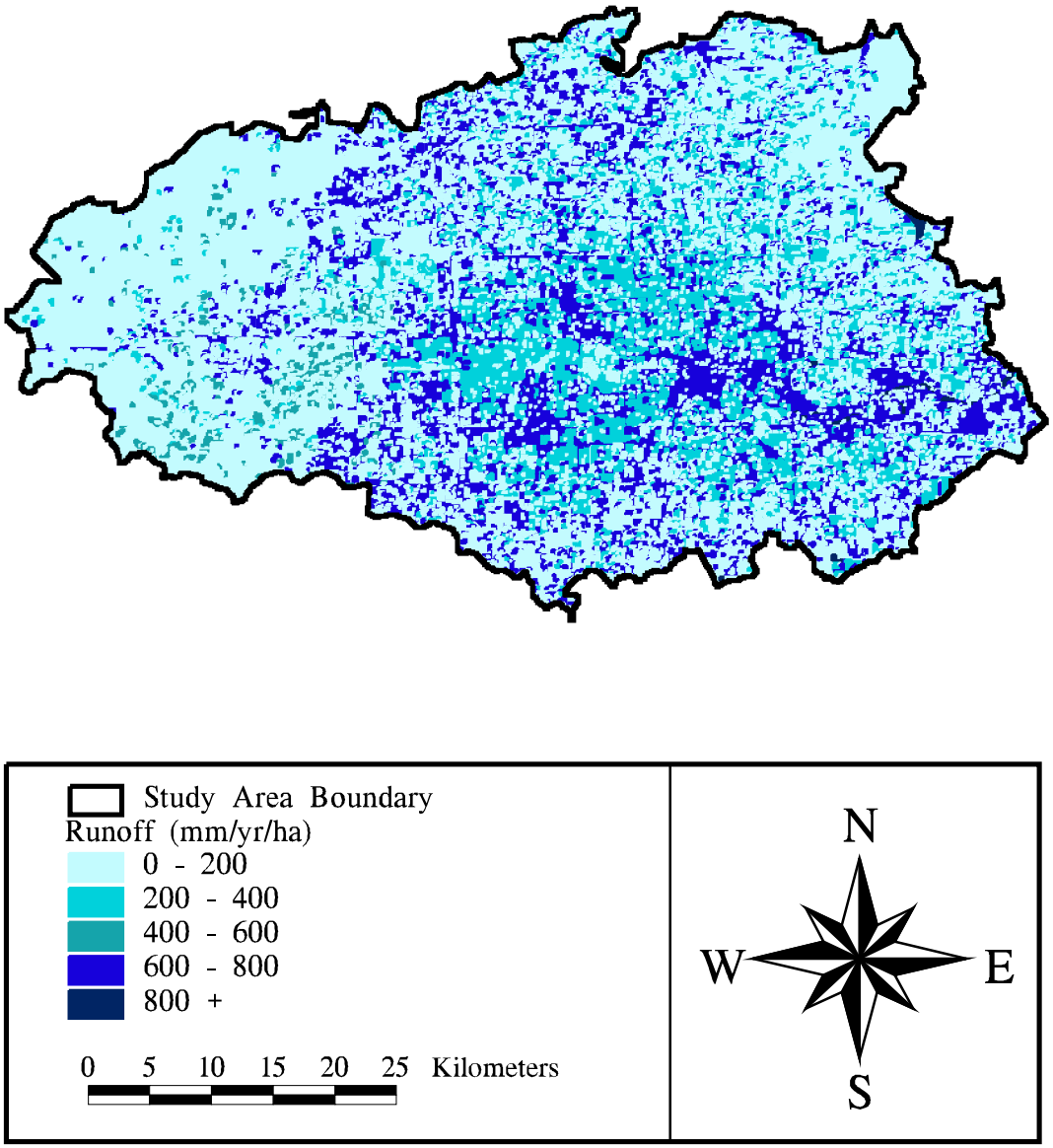


Figure 4-17 Final runoff distribution over watershed area.

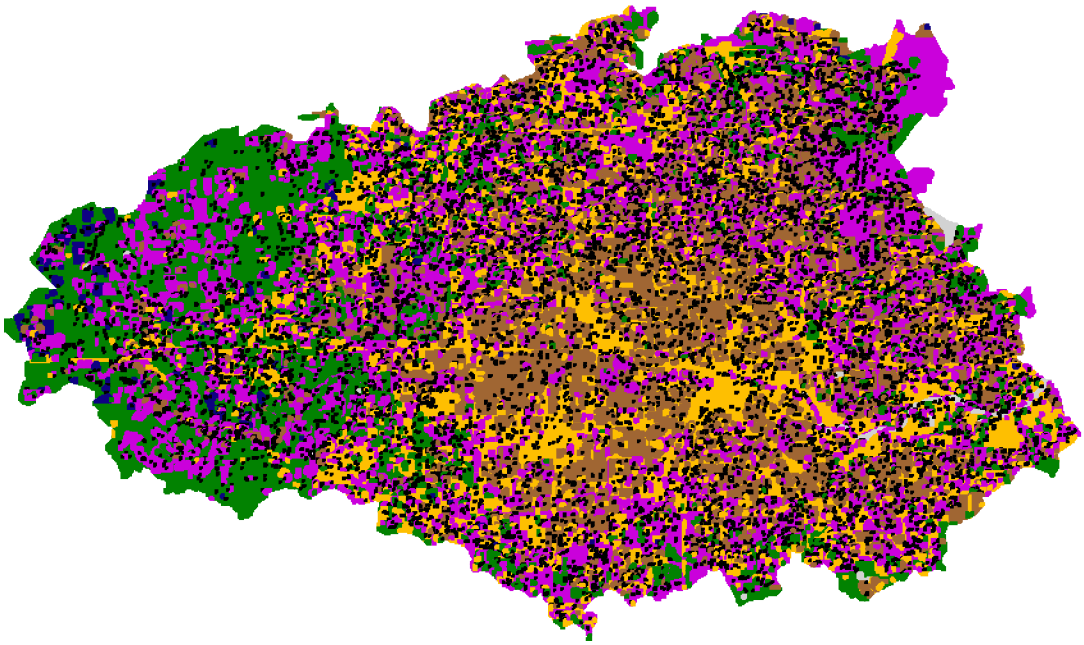


Figure 4-18 Estimated Mean Concentrations for BOD distributed over the watershed area.

Table 4-7 Estimated Mean Concentration Values Used for Non-Point Source Loading

Land Use Category	Total Suspended Solids (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Biochemical Oxygen Demand (mg/L)
High Density Urban	166	2.10	0.37	9
Residential	100	3.41	0.79	15
Agricultural	201	1.56	0.36	4
Open/Pasture	70	1.51	0.12	6
Forest	39	0.83	0.06	6
Wetlands	3	0.83	0.06	6
Water		0.00	0.00	0
Barren	2200	5.20	0.59	13

Source: Newell, et al., 1992

Final Loading Calculations

Equation (4-1) required a runoff volume multiplied by a constituent concentration to obtain a final NPS load. As discussed at the beginning of this chapter, the baseflow, which is presented in Section 4.5.5, carries only the point source loadings, while the runoff transports the non-point source loadings. With the runoff distribution determined above and the BOD concentration from the EMC values, the BOD loading due to non-point sources could be calculated. This procedure was accomplished by multiplying the EMC grid with the runoff grid and correcting for unit conversions (Procedure 4-8). The final result was a grid containing the BOD loading in kg/yr, for each cell. This grid was converted into a coverage and shown in Figure 4-19.

As mentioned earlier, the NPS loading into each water quality segment was the value of interest for this project. These inputs were determined by running a weighted flow accumulation of the BOD loading grid and obtaining the flow accumulated value at each segment "outlet" (Procedure 4-8). Since these values were accumulated, they had to be subtracted, successively. For example, the actual loading to segment two is the flow accumulation value at the outlet to two, minus the flow accumulated value at segment one's outlet. The results of this process are shown in Table 4-8.

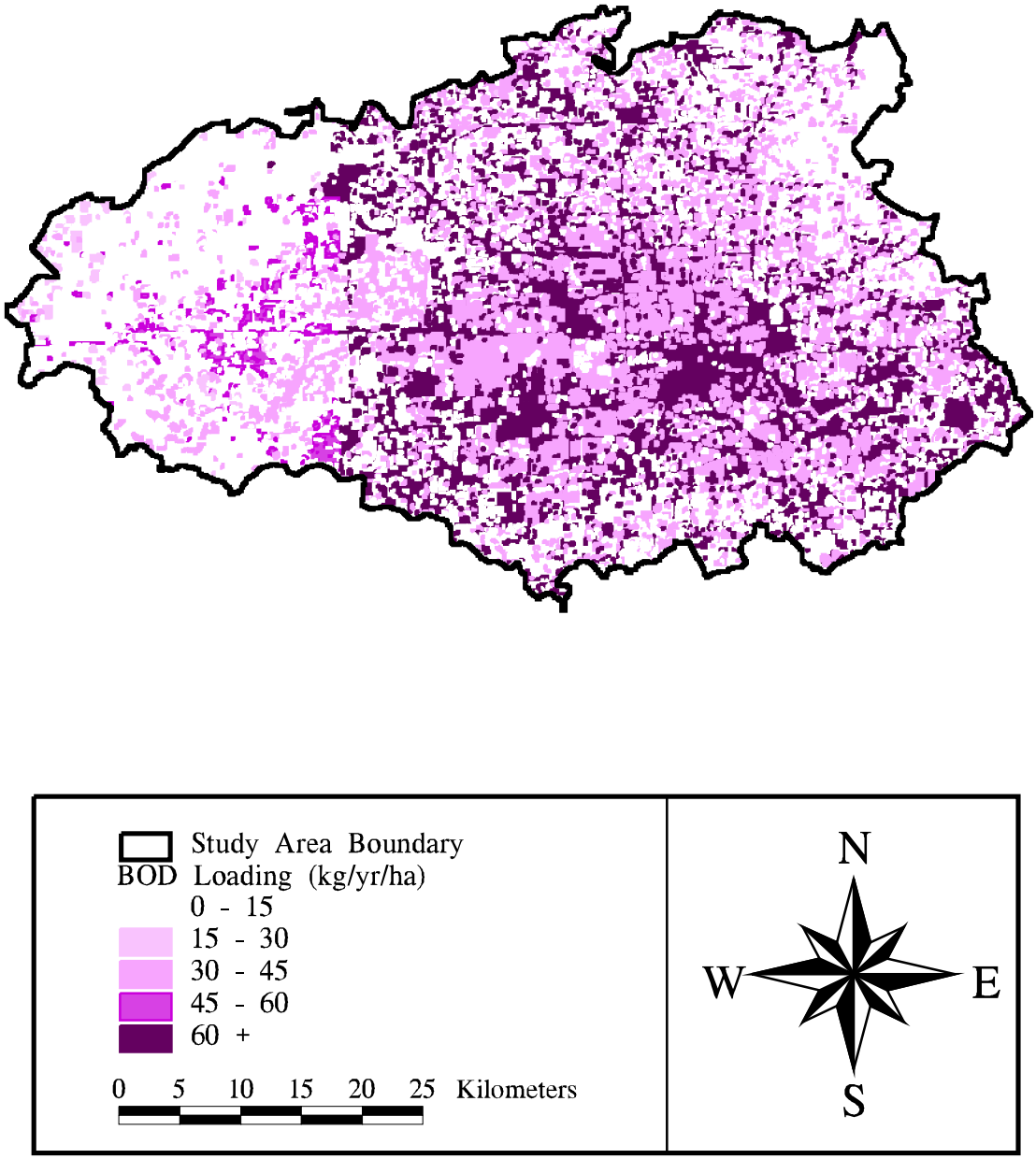


Figure 4-19 Final biochemical oxygen demand (BOD) non-point source loading distribution.

grid: **emcbodgr = polygrid (hsclu, emc_bod, # , #, 100)**
grids the land use coverage into 100m x 100m cells and retains the biochemical oxygen demand EMC as the value in each cell
grid: **bodann = (emcbodgr * r_ann) / 100**
multiplies the emc grid (mg/L) by the runoff grid (mm/yr) and corrects for units to obtain the BOD loading in kg/yr
grid: **bodfac = flowaccumulation (hscfdr, bodann)**
performs a weighted flow accumulation on the flow direction grid with the BOD loading grid
grid: **bodseg = con (out_seg > 0, bodfac)**
puts the flow accumulation value for each segment outlet into a grid called bodseg
grid: **bodsegin = int (bodseg)**
truncates the bodseg grid to have just integer values so that it can be combined with the outlet grid
grid: **bod_out = combine (out_seg, bodsegin)**
combines the segment outlet grid and the BOD loading grid to obtain a value attribute table of the segment number with the corresponding accumulated load value

Procedure 4-8 Steps taken to establish BOD NPS loading over watershed area and into each segment.

Table 4-8 Non-Point Source BOD Loading into Each Segment

Segment Number	Flow Accumulation Value (kg/yr)	Incremental Loading (kg/yr)
1	2,922,613	2,922,613
2	4,267,839	1,345,226
3	5,027,275	759,436
4	5,263,575	236,300
5	5,760,916	497,341
6	7,376,897	1,615,981
7	7,419,253	42,356
8	7,671,837	252,584

4.4 POINT SOURCE LOADS

A point source, for this study, is defined as any permitted municipality or industry which discharges directly into the Upper Houston Ship Channel, through an outfall pipe. The point source loadings are assumed to be carried by the baseflow in the system. In addition, point sources do not include dischargers along the bayous, since their inputs are taken into consideration as boundary concentrations in the tributary baseflow within the water quality model. Although a 1994 point source report exists which specifies each

discharger in the Houston area, the report only indicates the TWC segment to which the industry discharged (Armstrong and Ward, 1994). As mentioned in Section 4.2, the TWC segments were on a much larger resolution than the segmentation used for the modeling. Since it was necessary to know the how much point loading was going into each water quality modeling segment, this spatial resolution is unacceptable.

The locations for each point source were obtained from TNRCC (Visnovski, 1996). Of the approximately 1800 point sources in Houston for which the locations were known, about 70 discharge directly into the Upper Houston Ship Channel shoreline. However, only half of these point dischargers have reported BOD measurements from the 1994 report. Figure 4-20 shows just the dischargers along the Upper HSC and those which have BOD measurement attached to them. Once a point coverage of the 1800 dischargers was created in Arc/Info, the 70 shoreline dischargers were isolated, a new point coverage was created, and the available measurement data was joined to the point attribute table (pat) through ArcView. Table 4-9 gives a summary of the total amount of BOD entering into each segment from the point sources. These numbers, although accurate for the reported dischargers, are not representative of the system. In reality, there are about 35 other point dischargers for which the BOD loading is not known. In addition, the locations of Combined Sewer Overflows (CSOs) are not known. CSOs are typically a large source of BOD during heavy rainfall periods (EH&A, 1994). The shortcomings of the point source data are discussed in more detail in Chapter 5.

Table 4-9 Summary of BOD Discharged into Each Segment, from the Available Point Source Data

Segment	Number of Point Sources	BOD Loading (kg/day)
1	1	2.62
2	6	19.44
3	1	0.00
4	2	1470.06
5	7	56.39
6	6	234.31
7	1	24.79
8	8	226.71

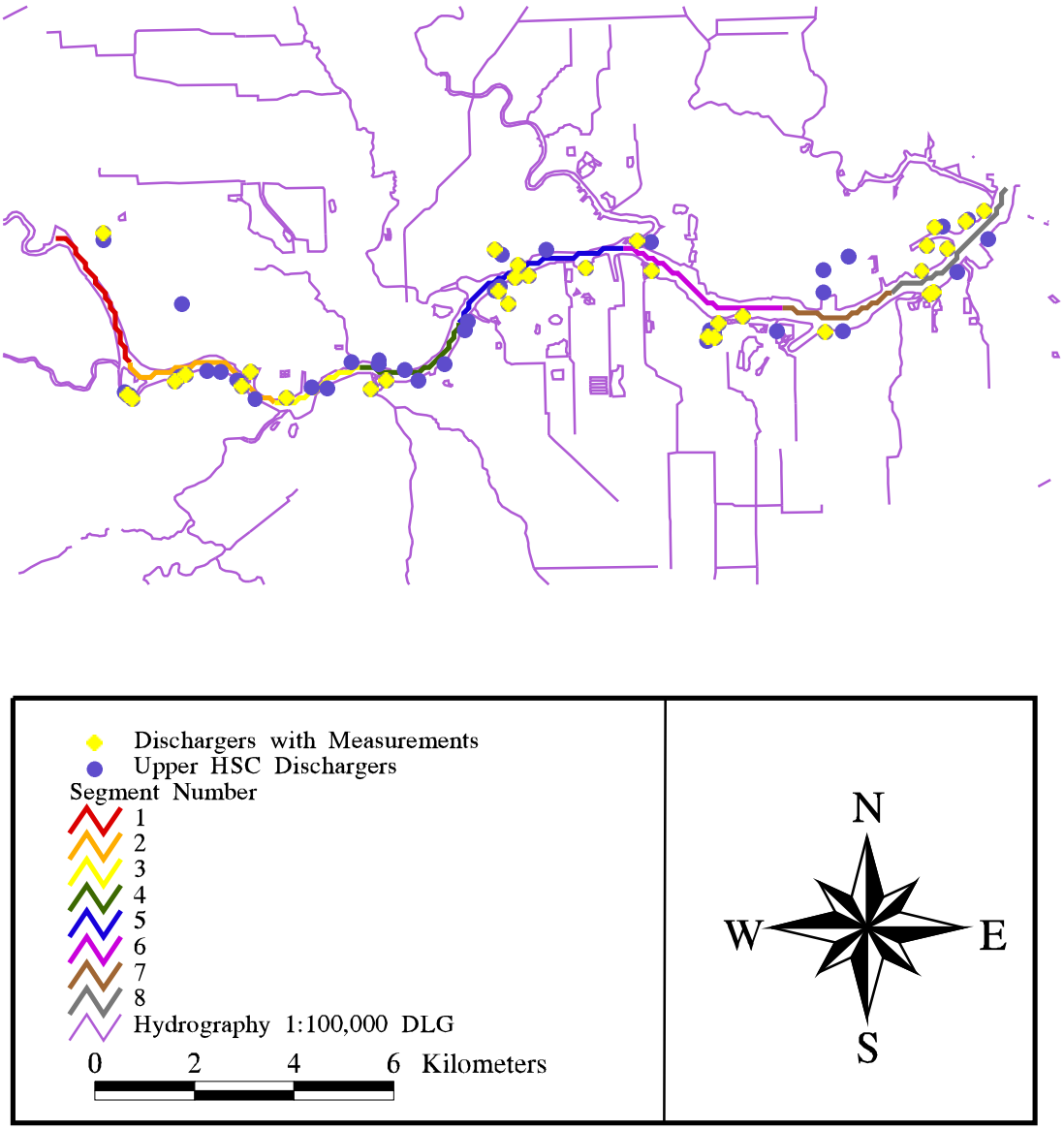


Figure 4-20 Point source dischrgers along the Upper Houston Ship Channel. Lighter points are those dischargers for which BOD measurements are available.

4.5 WASP5 MODEL DEVELOPMENT

4.5.1 Introduction

The Water Quality Analysis Simulation Program (WASP5) is distributed by the USEPA at the Center for Exposure Assessment Modeling (CEAM) in Athens, Georgia. The program consists of a main program, WASP5, and three subprograms: EUTRO5, TOXI5, and DYNHYD5. EUTRO5 is used to model BOD/DO and eutrophication, TOXI5 is used for toxic chemicals and model calibration, and DYNHYD5 for system hydrodynamics. The current version of WASP5, version 5.10, is available as shareware from the USEPA Homepage on the World Wide Web (ftp://ftp.epa.gov/epa_ceam/wwwhtml/wasp.htm). Although the current version has a user interface entitled WISP (WASP Interactive Support Program), the ArcView connection discussed in this project does not utilize this interface. Due to present memory constraints, it is not possible to run WISP, while running the Windows environment necessary for ArcView. As a result, only the EUTRO5 and TOXI5 executables (with their related error and message files) are needed for the ArcView connection.

The WASP5 model, which helps interpret water quality responses of a natural system given man-made pollution or natural events, is written and compiled in Lahey FORTRAN. The program is capable of one, two, or three dimensional modeling; steady-state or time-varying conditions; and model parameter customization. Although the hydrodynamics of a system can be modeled with a separate program or with DYNHYD5, simple hydrodynamics can be simulated directly in EUTRO5 or TOXI5. The basic principle of both the hydrodynamics and the water quality program is the conservation of mass. In other words, the water volumes and water quality constituents are tracked over time and space using a series of mass balancing equations, which are solved with a basin finite differencing method (Ambrose, *et al.*, 1993).

This project concentrated primarily on the BOD/DO model, EUTRO5. Within EUTRO5, there are eight state variables and six levels of complexity. The eight state

variables are ammonia nitrogen, nitrate nitrogen, inorganic phosphorus, phytoplankton carbon, carbonaceous BOD (CBOD), dissolved oxygen (DO), organic nitrogen, and organic phosphorus. As the level of complexity increases, the number of state variables modeled also increases. The complexity levels in EUTRO5 are:

1. Simple Streeter-Phelps BOD/DO with sediment oxygen demand (SOD)
2. Modified Streeter-Phelps with nitrogenous BOD
3. Linear DO balance with nitrification
4. Simple eutrophication
5. Intermediate eutrophication
6. Intermediate eutrophication with benthos

For this study, the first level of complexity was investigated. Level one only considers the state variables, BOD and DO, and incorporates SOD in the mass balances. The equations used in the constituent mass balance for Level one are shown below. Equation 4-3 explains the change in BOD concentration over time, while Equation 4-4 defines the change in DO concentration over time (Ambrose, *et al.*, 1993).

$$\frac{\partial C_5}{\partial t} = -k_D \Theta_D^{(T-20)} \left(\frac{C_6}{K_{BOD} + C_5} \right) C_5 - \frac{v_{s3}(1 - f_{DS})}{D} C_5 \qquad (4\text{-}3)$$

$$\frac{\partial C_6}{\partial t} = k_2 (C_s - C_6) - k_D \Theta_D^{(T-20)} \left(\frac{C_6}{K_{BOD} + C_5} \right) C_5 - \frac{SOD}{D} \Theta_S^{(T-20)} \qquad (4\text{-}4)$$

where;

C_5	=	concentration of carbonaceous biochemical oxygen demand (mg/L) (interpreted as total BOD for level one),
C_6	=	concentration of dissolved oxygen (mg/L),
k_D	=	deoxygenation rate @ 20 °C (/day),
Θ_D	=	deoxygenation temperature coefficient (--),

T	=	temperature (°C),
K_{BOD}	=	half saturation constant for oxygen limitation (mg O_2/L),
v_{s3}	=	organic matter settling velocity (m/day),
f_{DS}	=	fraction of dissolved CBOD,
D	=	depth of the overlying water column (m),
k_2	=	reaeration rate (/day),
C_s	=	dissolved oxygen saturation (mg/L),
SOD	=	sediment oxygen demand @ 20 °C (g/m2-day),
Θ_S	=	temperature coefficient (--).

As discussed earlier, EUTRO5 uses a finite differencing method to solve the above equations to explain the change in concentration over time. For spatial distribution, both advective and dispersive flows affect the concentration. Equation 4-5 describes the change in mass in a given segment due to dispersive exchange.

$$\frac{\partial M_{ik}}{\partial t} = \frac{E_{ij}(t)A_{ij}}{L_{cij}}(C_{ik} - C_{jk}) \qquad (4\text{-}5)$$

where

M_{ik}	=	mass of chemical "k" in segment I (g),
C_{ik}, C_{jk}	=	concentration of chemical "k" in segments "i" and "j" (mg/L),
$E_{ij}(t)$	=	dispersion coefficient time function for exchange "ij" (m^2/day),
A_{ij}	=	interfacial area shared by segments "i" and j" (m^2), and
L_{cij}	=	characteristic mixing length between segments "i" and "j" (m).

4.5.2 Model Constants

For EUTRO5, level one complexity, only two constants had to be set in the model: the reaeration rate and the deoxygenation rate. The reaeration rate (k_2 in Eqn. 4-4) helps determine the rate of gas transfer of oxygen from the overlying atmosphere into the surface

water. The deoxygenation rate (k_d in Eqns. 4-3 and 4-4) explains the rate of oxygenation of the BOD in the water column.

Reaeration Rate

The three main sources of oxygen to water are DO from incoming streams, gas transfer, and photosynthesis from marine plants. Typically, the primary source of oxygen for most natural systems is gas transfer by mixing induced from wind and high flow conditions (Thomann and Mueller, 1987). Within EUTRO5, there are three options on the model's approach to reaeration rate. These options include:

1. A single reaeration constant can be specified, with an internal temperature coefficient of 1.028.
2. Spatially varying reaeration constants can be input and varied through time.
3. EUTRO5 calculates a reaeration rate from water velocity, depth, wind velocity (default set to 0.6 m/sec), water temperature, and air temperature (defaulted to 15°C).

Historically, defining reaeration rates in the Upper HSC has proven to be difficult (Bales and Holley, 1992; Holley, 1996). Since relatively low flow conditions exist in the channel, Option 3 would not produce representative results for the system. In addition, past studies have shown that the reaeration rates are extremely dependent on the mechanical mixing resulting from heavy ship traffic in the area. This mechanical mixing and the lack of hydrodynamic mixing from low flow conditions make it difficult to measure reaeration rates for different areas in the channel (Bales and Holley, 1992). As a result, a spatial variation of the reaeration rate would be hard to establish, since accurate measurements are unlikely to exist. For these reasons, a constant reaeration rate (Option 1) was set initially set at 0.1 /day. This value corresponds to the same number established by Espey, *et al.* (1971) for the Upper HSC.

Deoxygenation Rate

In typical BOD/DO analysis, the total rate of BOD removal is considered. This overall loss rate, termed k_r, considers the effects of settling and oxidation on BOD. However, in EUTRO5, the effects of settling are taken into account with the second term of Equation (4-3). Consequently, it is only necessary to set the rate at which BOD employs oxygen to stabilize the pollutant material present, k_d. Since the estimation of k_d cannot easily be determined from laboratory incubation tests, many studies have attempted to link physical channel characteristics to the deoxygenation rate (Thomann and Mueller, 1987). In addition, as the level of treatment in wastewater treatment plants increases, the BOD which reaches the receiving waters represents the less easily oxidizable portion of the pollutant. Typical values of k_d range from 0.1 to 0.5 /day for bodies of water deeper than five feet (Thomann and Mueller, 1987). Since the treatment of wastewater discharging to the HSC waters has improved in past years, it would be conservative to choose a deoxygenation rate at the lower end of the scale. In the earlier modeling efforts of the Upper HSC, two different values for k_d were employed. Espey, *et al.* (1971) and Hydroscience (1968) used spatially and time constant numbers of 0.10 /day and 0.15 /day, respectively. For this research, a value of 0.10 /day for the entire 25 km modeled reach was assumed.

4.5.3 Main Segment Characteristics

Table 4-10 summarizes the physical characteristics of the main segmentation for the Upper HSC. The table also shows additional model parameters needed for EUTRO5, such as sediment oxygen demand, water temperature, and salinity. The physical attributes of the Channel were obtained from the 1971 modeling study (Espey, *et al.*, 1971). A majority of the other parameters were extracted from the 1992 water quality study performed for the Galveston Bay National Estuary Program (GBNEP) (Ward and Armstrong, 1992).

The segment length was originally obtained from Espey, *et al.* (1971). However, due to scaling differences and the method in which the segmentation was imported into GIS (Section 4.2), the actual lengths used in this research varied slightly from those given in the 1971 report (see Table 4-1). The segment depth and area, however, are the same as those

Table 4-10 Physical Characteristics and Model Parameters for Upper HSC Main Segmentation

Seg #	Length (m)	Area (m^2)	Depth (m)	Exchange Coefficient (m^2/sec)	Temp. (°C)	Salinity (ppt)	SOD ($g/m^2/d$)	Θ_s	Initial DO (mg/L)	Initial BOD (mg/L)	Hydraulic Coefficients* a	b	c	d
1	3238.5	1625.8	9.14	704.5	28.0	5.82	1.5	1.068	1.36	7.18	0.004	0.4	1.2	0.6
2	3538.5	1625.8	9.14	704.5	23.8	7.87	1.5	1.068	1.81	5.04	0.004	0.4	1.2	0.6
3	1990.0	1625.8	9.14	704.5	23.8	7.87	1.5	1.068	1.81	5.04	0.004	0.4	1.2	0.6
4	2631.4	1625.8	6.10	704.5	23.8	7.87	1.5	1.068	1.81	5.04	0.004	0.4	1.2	0.6
5	4038.5	1625.8	9.14	704.5	26.4	9.96	1.5	1.068	0.68	6.25	0.004	0.4	1.2	0.6
6	3697.1	1625.8	6.10	704.5	24.2	9.45	1.5	1.068	2.25	3.53	0.004	0.4	1.2	0.6
7	2490.0	2471.2	7.92	704.5	24.0	9.85	1.5	1.068	1.64	5.06	0.004	0.4	1.2	0.6
8	3404.2	2471.2	7.92	704.5	24.0	9.85	1.5	1.068	1.64	5.06	0.004	0.4	1.2	0.6

Sources: Espey, et al., 1971 and Ward and Armstrong, 1992

* *a,b,c, and d are empirical coefficients as per Equations 4-6 and 4-7*

given in the earlier report (Espey, *et al*., 1971). The exchange coefficients were also obtained from the Tracor modeling effort. In this 1971 study, it was concluded that the dispersion (or exchange) coefficient varied with the magnitude of the net advective flow in the Houston Ship Channel. The study plotted dispersion coefficient versus net flow on a log-log plot and obtained a linear relationship (Figure 4-21). Given the flow values for the Upper HSC, the resulting dispersion coefficient only varies from about 15 to 25 mi^2/day. Since this range is rather small, the 1971 study assumed an average flow for all segments upstream up the San Jacinto River and chose one exchange coefficient of 809 m^2/sec (27 mi^2/day) for the entire 25 km reach. However, the constant value chosen in 1971 seemed high given the graph and average flow. The actual data for this graph was not given in the report and the scale of the chart was relatively large. As a result, it was difficult to reproduce this function accurately. As a result, the same graph was used to obtain a new dispersion coefficient which seemed more representative. The average flow for the eight segments was recalculated at about 900 ft^3/sec, resulting in an exchange coefficient of 704.5 m^2/sec (24.5 mi^2/day).

The temperature, salinity, initial (in time and space) DO, and initial BOD measurements were all obtained from average measurements provided in Ward and Armstrong (1992). Five of the hydrographic segments discussed in Section 4.2 (see Figure 4-4) encompassed the eight main segments of this present modeling effort. Table 4-11 shows the correspondence of the main segmentation to this hydrographic segmentation.

Table 4-11 Hydrographic Segments Corresponding to Main Segmentation

Hydrographic Segments	Corresponding Main Segment (s)
H12	17 *
H14	7,8
H15	6
H16	5
H17	2,3,4
H18	1
H20	10 *

Source: Ward and Armstrong, 1992
* Boundary Segments

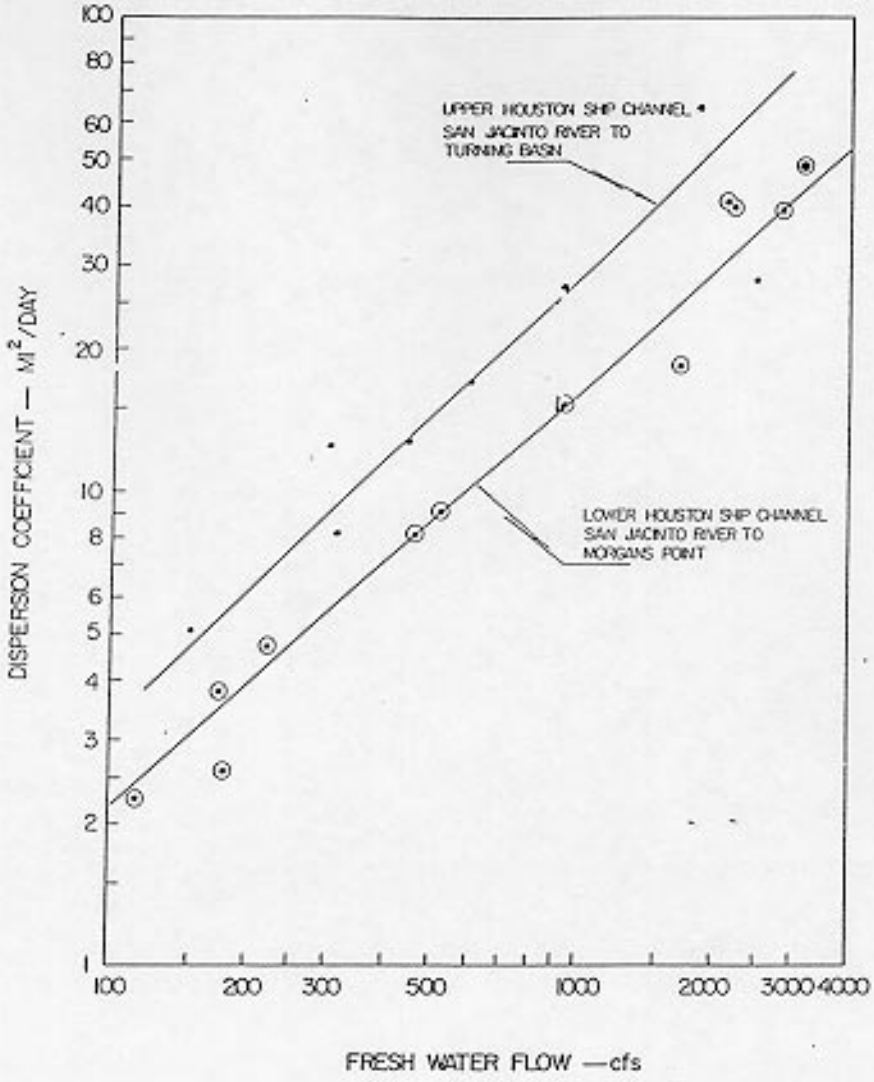


Figure 4-21 Original graph from Espey, *et al.* (1971) showing dispersion (i.e. exchange) coefficient versus net freshwater flow. For the Upper HSC, an average flow value of 900 cfs was assumed and an overall exchange coefficient of 24.5 mi^2/day was chosen.

The surface layer of the sediment layer directly under the water column usually undergoes aerobic decomposition and, in the process, removes oxygen from the overlying water. This effect is usually measured in sediment oxygen demand (SOD). Since actual measurements of SOD for the Upper HSC could not be located, a constant value of 1.5 $g/m^2/day$ was assumed for the entire reach. This number corresponds to the approximate average of the range for estuarine mud given in Thomann and Mueller (1987). In addition, the SOD Θ used to correct for temperatures varying from 20°C was set at the typical value of 1.068 (Thomann and Mueller, 1987).

Finally, the hydraulic coefficients are those coefficients and exponents related to the following equations:

$$V = aQ^b \quad (4\text{-}6)$$

$$D = cQ^d \quad (4\text{-}7)$$

where:

V	=	channel velocity (m/sec),
Q	=	channel flow (m^3/sec),
D	=	channel depth (m), and
a,b,c,and d	=	empirical coefficients or exponents.

For rectangular channels, values of 0.4 and 0.6 can be assumed for b and d, respectively (Ambrose, *et al.*, 1993). Although the Upper HSC is not exactly rectangular, it is similar enough to assume these values without considerable error. Then, since the flow, depth, and velocity (flow/area) are known for each segment, average values of a and c are calculated to be 0.004 and 1.2, respectively. Since EUTRO5 only uses these numbers for reaeration and volatilization calculations and not transport functions, these coefficients do not effect the present model established for the Channel (Ambrose, *et al.*, 1993).

4.5.4 Boundary Segment Characteristics

Model boundaries consist of those segments that import, export, or exchange water with locations outside the main network. A boundary segment is either a tributary inflow, a downstream outflow, or an open water end of the model network across which dispersive mixing can occur. In the Upper HSC, each main segment was assigned a boundary condition to incorporate the main tributaries flowing into the Channel. Table 4-12 gives the characteristics and necessary model parameters for these boundary conditions established for the Upper HSC, while Figure 4-22 shows the conceptual segmentation for the system. Also in Table 4-12 is the name of each bayou assigned to the boundary condition.

The exchange coefficients, cross-sectional areas and depths were all obtained from Espey, *et al.* (1971). Figure 4-21 was again utilized to obtain the exchange coefficient for segment 17, while a small dispersion coefficient of 119 m^2/sec (4 mi^2/day) was assumed for all tributaries. All boundaries, excluding the Buffalo Bayou (segment 10), had lengths set at 3.2 km (2 miles) to emulate a somewhat "infinite" condition. The Buffalo Bayou was set at 8 km (5 miles).

For the boundary BOD concentration in these segments, a number of sources were consulted. For segments 10 and 17, Ward and Armstrong (1992) provided average BOD measurements from the hydrographic segmentation established in that report (see Table 4-11). For the remaining boundary segments, two sources were compared and values for BOD were assumed from the measurements taken for these studies (Armstrong and Ward, 1994; TDWR, 1984). In relation to DO values, a conservative value of 5 mg/L was assumed for all boundaries; except segments 10 and 17, where averages from Ward and Armstrong (1992) were employed. The value of 5 mg/L is the widely accepted minimum needed to maintain marine life (Thomann and Mueller, 1987). Some DO measurements, which ranged from 6 - 7 mg/L, exist for some tributaries (EH&A, 1994). However, since these measurements were taken only during storm events, they were probably not representative of the baseflow conditions because high flow conditions during storms usually result in higher DO

Table 4-12 Physical Characteristics and Model Parameters for Upper HSC Boundary Segmentation

Seg #	Length (m)	Area (m^2)	Depth (m)	Exchange Coefficient (m^2/sec)	Temp. (°C)	Salinity (ppt)	SOD ($g/m^2/d$)	Θ_s	Initial DO (mg/L)	Initial BOD (mg/L)	Down-stream Segment	Name
9	2500.3	0.10	0.10	0.001	20.0	0.00	1.5	1.068	0.00	0.00	0	Sediment Layer
10	8046.9	465.4	9.14	119.9	23.6	1.82	1.5	1.068	3.03	8.14	1	Buffalo Bayou
11	3218.7	505.4	4.88	119.9	20.0	0.20	1.5	1.068	5.00	8.40	3	Sims/Berry Bayous
12	3218.7	168.2	3.05	119.9	20.0	0.20	1.5	1.068	5.00	6.90	2	Brays Bayou
13	3218.7	185.8	1.83	119.9	20.0	0.20	1.5	1.068	5.00	8.00	4	Vince Bayou
14	3218.7	528.6	3.35	119.9	20.0	0.20	1.5	1.068	5.00	8.60	5	Hunting Bayou
15	3218.7	717.2	10.06	119.9	20.0	0.20	1.5	1.068	5.00	5.90	6	Greens/Hall Bayou
16	3218.7	260.1	3.96	119.9	20.0	0.20	1.5	1.068	5.00	6.00	8	Carpenters Bayou
17	3218.7	2471.2	4.88	119.9	25.3	10.90	1.5	1.068	3.64	7.42	0	Dwnstr. Boundary

Sources: Espey, et al., 1971 and Ward and Armstrong, 1992.

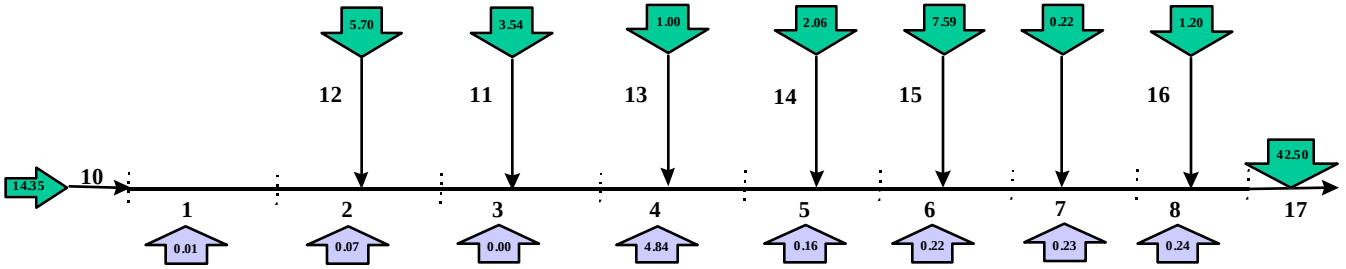


Figure 4-22 Schematic of final segmentation used in Upper HSC model. Numbers next to lines indicate segment numbers. Outline also shows total flows entering each segment (in m^3/sec). Downward pointing arrows are tributary flows, while the upward arrows are point source inflows from Armstrong and Ward (1994). Figure is not to scale.

concentrations. Finally, the SOD for each boundary segment and its corresponding Θ were set at the same values as for the main segmentation (Thomann and Mueller, 1987).

Temperature and salinity values for most boundary segments were set at 20 °C and 0.2 parts per thousand (ppt), respectively. The only exceptions were the concentrations and temperatures in segments 10 and 17. Since these two segments were located along the main channel, the average measurements determined in Ward and Armstrong (1992) could be used. Since the remaining boundaries were relatively freshwater inflows, 0.2 ppt was an reasonable assumption for salinity.

One final boundary segment that needs to be established is a benthic sediment layer (segment #9). This layer, which to acts as a sink for particulate BOD due to settling, is established along the entire length of the main network (segments 1 through 8). The depth of this segment was set at 10 cm to represent the active layer of the sediment. In addition, a vertical exchange rate of 10^{-4} m^2/sec was established between the water column and sediment pore water to simulate a possible sink or source of DO.

4.5.5 Flow and Baseflow

As mentioned earlier, each main segment has an established amount of steady state total flow and baseflow. The total flow, which consists of runoff plus baseflow, is used to represent average year conditions. For this case the runoff is assumed to carry the non-point source loadings, while the baseflow carries both point source loadings. In contrast, the dry weather conditions, only considers the baseflow as flow into the system. This condition is meant to represent a worst case scenario, where no runoff enters the channel. For this situation, only the point source loadings are input to the model, since there is no runoff to carry any non-point source pollution.

Flow

To determine the total flow, a rainfall/flow/urbanization relationship was defined. This relationship is very similar to the rainfall/runoff equation developed in Section 4.3. Following the same reasoning used to distribute the runoff over the watershed area, the flow (i.e. baseflow not subtracted) was also distributed over the land surface. Figure 4-23 illustrates the final relationship between percentage of precipitation which become flow versus relative urbanization of a given USGS subwatershed. The 1:1 line on the graph illustrates the relationship which exists if the relative runoff coefficient represented the percentage of precipitation which eventually becomes flow. The actual values that result in the equation are about 80 % of the values on the 1:1 line. Using the steps outlined in Procedure 4-7 and substituting the new equation from Figure 4-23, grids of flow/precipitation and flow over the entire watershed area were calculated. Once this flow grid was determined, a weighted flow accumulation was performed on the flow direction grid (see Procedure 4-9). The accumulated flow values at each segment outlet were found and converted from mm/yr/ha to m^3/sec. These final numbers are shown in Table 4-13, along with the flow measurement for the San Jacinto River entering segment 17. Although some of this flow enters the segment by way of diffuse runoff, for modeling purposes, it was all assumed to enter the segment at the boundary segment (Figure 4-22).

grid: **flfac = flowaccumulation (hscfdr, flcalc)**
performs a weighted flow accumulation on the flow direction grid, weighted with the grid of flow
grid: **flfacint = int(flfac)**
truncates the weighted flow accumulation values so they can be combined with the outlet grid
grid: **flout = combine (out_seg, flfacint)**
combines the segment outlet gird and the flow accumulation grid to obtain a value attribute table of the segment number with the corresponding accumulated flow value

Procedure 4-9 Steps taken to determine total flow (mm/yr/ha) into each main segment. Flow grid was established using method outline in Procedure 4-7 and relationship shown in Figure 4-23

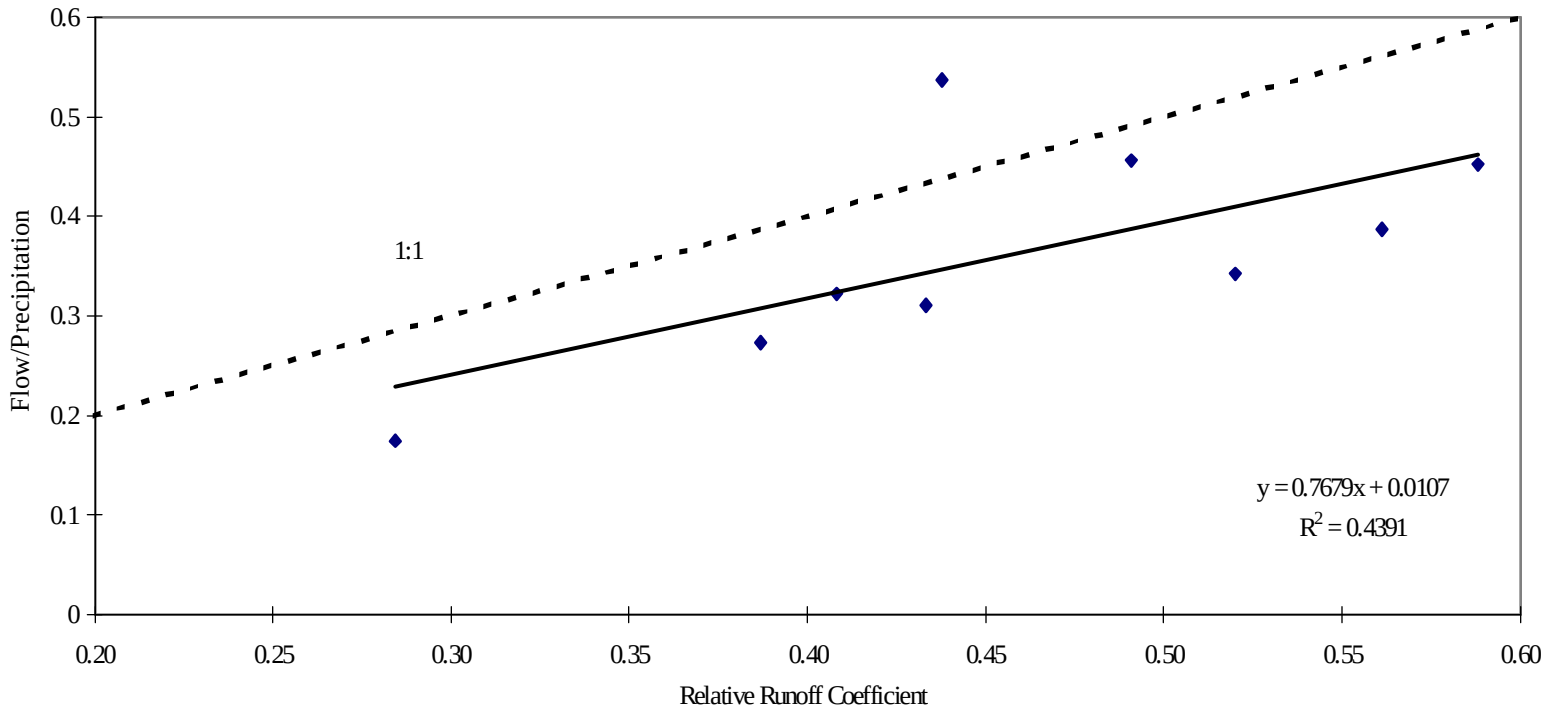


Figure 4-23 Relation between ratio of mean annual surface flow divided by mean annual precipitation to runoff coefficients for the same area, based on land use and standardized runoff coefficient table. 1:1 line illustrates the relationship that would exist if the runoff coefficient was an absolute measure of the percentage of precipitation which becomes flow.

Table 4-13 Final Flow, Runoff and Baseflow Values for Main Segment

Segment	Incremental Total Flow (m^3/sec)	Point Source Flow* (m^3/sec)	Incremental Runoff (m^3/sec)	Incremental Baseflow (m^3/sec)	Baseflow: % of Total Flow
1	14.35	0.01	10.96	3.39	24
2	5.70	0.07	4.57	1.13	20
3	3.54	0.00	2.75	0.79	22
4	1.00	4.84**	0.79	0.21	21
5	2.06	0.16	1.66	0.40	19
6	7.59	0.22	5.68	1.91	25
7	0.22	0.23	0.18	0.04	18
8	1.20	0.24	0.93	0.27	23
17	42.5***	n/a	n/a	n/a	n/a

* *Source: Ward and Armstrong (1992)*
** *3.05 cms is power plant outflow*
*** *From Espey, et al., 1971 San Jacinto River flow*

Baseflow

The final steady state baseflow for the water quality model was calculated by subtracting the runoff determined in Section 4-3 from the flow determined above. The accumulated runoff into each segment was established in the same way the flow to each segment was calculated in Procedure 4-9, but the flow accumulation was weighted with the runoff grid instead of the flow grid. The total flow, runoff, and final baseflow to each segment is shown in Table 4-13. The last column of Table 4-13 shows the percentage of total flow which is composed of baseflow. These values are relatively consistent from segment to segment, ranging from 18% for segment 7 to 25% for segment 6, with the average being 22%. This average compares well to the average percentage discussed in Section 4.3 for the calculated baseflow at each USGS gauge station (also 22%). As mentioned earlier, the baseflow is meant to transport the point source loadings and represent dry weather conditions when input to the model without the runoff.

Point Source Flows

Also shown in Table 4-13 are the point source flows into each segment (Armstrong and Ward, 1994). As mentioned in Section 4.4, these flows only account for about half of the point source dischargers along the channel. Therefore, the entire system cannot be represented accurately until more data is obtained on the other dischargers. In addition, the part of the point source flow entering segment 4 (3.05 m^3/sec), although very large, is a

power plant. Since power plants recycle a majority of their intake, this measurement is ignored. For the final input to the model, only the steady state flow conditions from the tributaries were considered. The point source flows were ignored since they represented only about 2.5% of the total flow shown above. Finally, since there was no major tributary entering segment 7 and the calculated flow was minimal, this flow value was ignored in the final input to the model.

4.5.6 Constituent Loading

As discussed in Sections 4.3 and 4.4, the NPS and point source BOD loading was determined for each segment. These steady state values are summarized in Table 4-14. The point source data did not have flows "attached" to them. But, since these flows are relatively small, the error introduced by their omission is minimal. The non-point source, however, were obtained using the steady state runoff results discussed in Section 4.3. This aspect does affect the model input and is discussed further in Section 4.5.8.

Table 4-14 Final Steady State Loading Values for BOD

Segment Number	NPS BOD Loading (kg/day)	Point Source BOD Loading* (kg/day)
1	8007.16	3.26
2	3685.55	24.16
3	2080.65	0.00
4	647.40	1827.28
5	1362.58	70.09
6	4427.35	291.25
7	116.04	30.81
8	692.01	281.80
Total	**21,018.74**	**2,528.65**

* *Source: Ward and Armstrong (1992)*

4.5.7 Model Calibration

The final model was calibrated to ensure that it accurately represented the Upper HSC. Salinity was chosen as the chemical to calibrate WASP5 because it is considered a conservative material and it is an excellent water mass tracer. The objective of the calibration was to produce results similar to those reported in Ward and Armstrong (1992).

To accomplish this objective, boundary segments 10 and 17 were set to their long-term average values of 1.82 and 10.9 ppt, respectively (Ward and Armstrong, 1992), while all other main segments were set to 0 ppt and boundary segments to 0.2 ppt. WASP5's subprogram, TOXI5, was then run at a level one complexity until quasi-steady state was reached in the Upper HSC. The input file for this calibration is shown in Appendix D-1 and the results are discussed in Chapter 5.

4.5.8 Model Runs

The input file for the BOD/DO model run representing average year conditions is in Appendix D-2. Since this study was centered on connecting the water quality model to GIS, time constraints resulted in fewer model runs than originally desired. However, the model was successfully executed with loadings, flows, and parameters developed in this section, representing long term, steady state conditions. In addition, the sensitivity of the model to the constants (k_2 and k_d) was also investigated. Further research could provide a method for studying the sensitivity of the model to the segmentation, to changes of the water quality due to land use changes or engineering practices; and to time-varying inputs; all using GIS as the interface to implement these changes.

An overview of the four cases investigated in this research is shown in Table 4-15. For cases 1, 3, and 4, the point source and NPS loadings along with the steady state flows were applied to the Upper HSC. Case 2 was established to model "dry weather" conditions, resulting in just steady state baseflow (Table 4-13) being used with the point source loadings.

Table 4-15 Cases Applied for BOD/DO Model in the Upper Houston Ship Channel

Case	Flow Conditions	NPS Loads?	Point Source Loads?	k_2 (/day)	k_d (/day)
I	Average Year	Y	Y	0.1	0.1
II	Dry Year	N	Y	0.1	0.1
III	Average Year	Y	Y	0.5	0.1
IV	Average Year	Y	Y	0.1	0.3

Special attention was given to the boundary concentration since WASP5 accounts for loadings into the main reach from boundaries. The model applies the following equation to determine the loading entering a downstream segment from an upstream boundary:

$$V_i S_{bik} = Q_{0i}(t) C_{bik} \qquad (4\text{-}8)$$

where:

V_i = volume of segment i (m^3),

S_{bik} = boundary loading rate response of chemical "k" in segment, "i" (g/m^3-day),

Q_{0i} = upstream inflow into boundary segment, "i" (m^3/day), and

C_{bik} = concentration in boundary segment, "i" (mg/L).

The way the model input is set, this boundary concentration is applied to the total flow; however, the loading from the runoff has already been considered with the non-point source calculation. As a result, if this calculation does occur with the total flow, it could be viewed as a somewhat "double load" to the system. As a result, the boundary concentrations were adjusted so that the loading calculated in Equation. 4-8 was equal to that of the boundary concentration multiplied by just the steady state baseflow. To accomplish this adjustment, the following equations were employed:

$$V_i S_{bik} = Q_{bf}(t) C_{bik} \qquad (4\text{-}9)$$

$$C'_{bik} = \frac{V_i S_{bik}}{Q_{tot}} \qquad (4\text{-}10)$$

where:

Q_{bf} = steady state baseflow upstream of segment "i" (m^3/day),

C'_{bik} = adjusted concentration for boundary segment "i" (mg/L),

Q_{tot} = total flow upstream of segment "i", and

other variables are previously defined.

4.6 GIS/WASP5 CONNECTION

4.6.1 Introduction

The concept behind this GIS/model connection, shown in Figure 4-24, allows programs within GIS to produce the necessary information for the exterior model's input files. The GIS software then executes formatting programs in order to obtain a properly spaced input file and executes the model. Finally, the model output is processed, imported back into GIS, and viewed as charts, tables, and coverages.

Specifically for this research, the model input is read by the ArcView programming language Avenue (see Section 4.6.2) from tables and coverages within a customized project. The Avenue programs, consisting of compiled scripts, are executed through the ArcView interface by way of menu choices. This information is written into 13 "free form" text files (Appendix E): one for each WASP5 input block and three character files holding filenames, and the model description. These text files become the input for a FORTRAN program which formats all of the data into WASP5's space sensitive input file. After WASP5 is executed, the model's output file is processed by another FORTRAN program to read the necessary results. These results are printed to a new text file in the form of an array and imported back into ArcView, using Avenue. After importing, the output is viewed in the form of tables, charts, and newly created coverages.

4.6.2 Programming Involved

Avenue

Avenue is an object-oriented programming language which is used to create customized ArcView projects. The language works by creating "objects" of project documents, such as views, coverages, and tables and processing, reading, or manipulating information from these objects to create additional objects within the project. As with any typical programming language, loops, input statements, and print statements are possible using Avenue. Once an Avenue script is written and compiled, it is "attached" to a menu

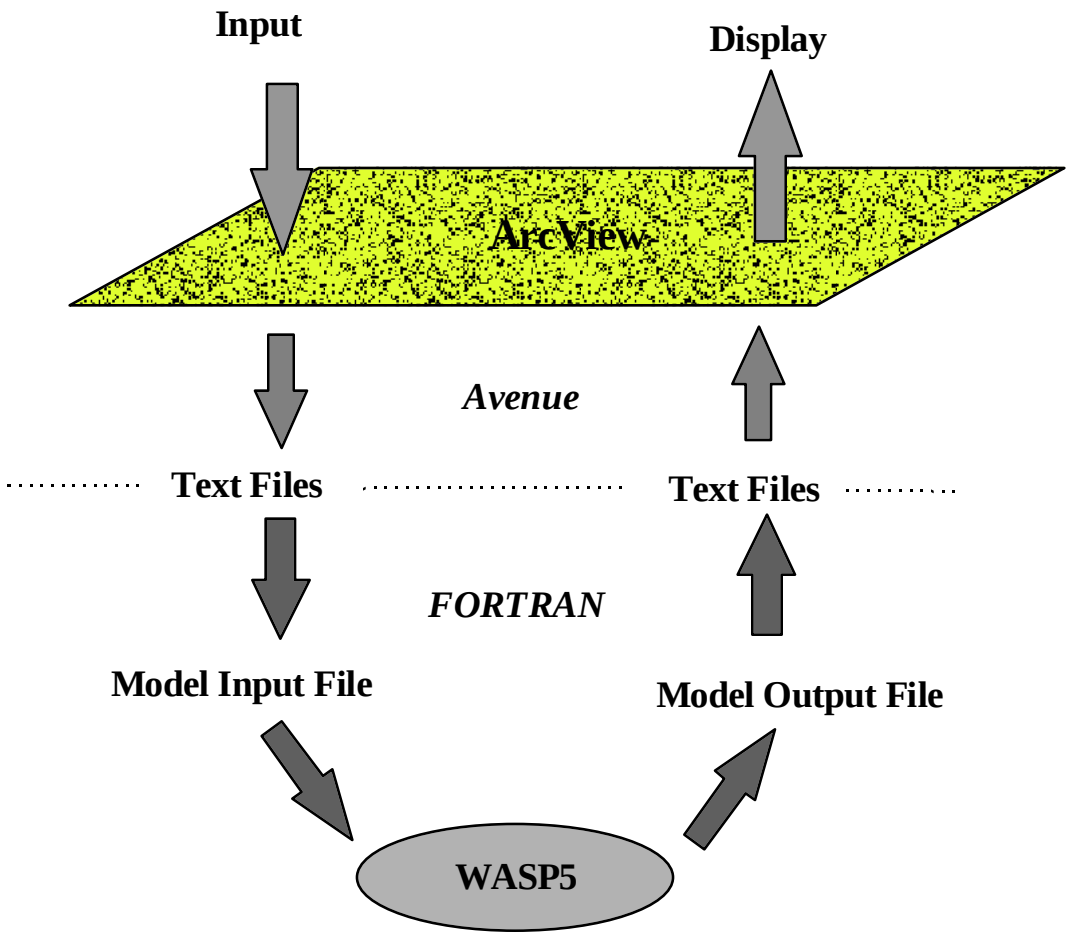


Figure 4-24 Concept behind GIS/WASP5 model connection. Avenue, the programming language in ArcView, creates text files of the necessary model information. FORTRAN formatting programs then read this information and write the WASP5 input file. After the model is run, the output file is read by another FORTRAN program and imported back into ArcView, via Avenue.

selection or tool bar button and executed numerous times. It is important to remember that the scripts in Avenue are based on a particular customized project. For this reason, to re-execute a script, the original objects, such as a given table or view, must always be present in the project.

For this research, 33 Avenue scripts (see Appendix F) were written to create the model connection shown in Figure 4-24. An overview of each of these scripts is outlined in Table 4-16. These scripts wrote the free form text files for each model input block, executed the FORTRAN programs from the ArcView interface, and created charts and coverages to present the output. All of these scripts, except one, are invoked through menu choices in the customized project (Figure 4-25).

FORTRAN

Also included in the connection are four FORTRAN programs used to format the input and read the output (see Appendices C-4 and C-5). These programs, also outlined in Table 4-16, were written and compiled in Microsoft FORTRAN. Since the final connection performed BOD/DO modeling, along with model calibration, different programs were needed to deal with both TOXI5 (calibration model) and EUTRO5 (BOD/DO model) input and output files. Consequently, separate input formatting programs and output reading programs were written for each model, resulting in four compiled FORTRAN codes.

4.6.3 Menu Overview

There are three primary choices on the menu bar related to the model connection (Figure 4-25): *BOD/DO Input Blocks*, *BOD/DO Model*, and *Calibration Model*. Under the first choice, the user may write the necessary information for a EUTRO5, level one complexity, steady-state model run. There are options to either create the all 13 of the text files with the input file information (*All Input Blocks*), or to change just one input block and its related text file by selecting it off of the menu. The second choice, *BOD/DO Model*, is executed after all of the input block information has been written to text files. The first step under this option is *Generate Input File*. By invoking this command, the FORTRAN

Table 4-16 Scripts and Programs Created for ArcView/WASP5 Connection

Program or Script Name	Type	Function
all	Avenue	Runs all scripts to create texts file for EUTRO5 input file
bttn	Avenue	Controls the "bug" icon on the "Segmentation" view to plot a chart
calgen.exe	FORTRAN	Formats the 13 text files into a TOXI5 calibration input file
calinputa	Avenue	Writes the text files for Input Block A in the model calibration
calinputall	Avenue	Runs scripts which create text files for TOXI5 input file
calout.exe	FORTRAN	Processes the "tdf" file to produce an array of salinity at each segment vs. time
cal_parchk	Avenue	Checks the parameters on the output file to process for the calibration model
eutrorun	Avenue	Runs the EUTRO5 model from ArcView
frame1 - frame4	Avenue	Produces a new theme on the "Segmentation" to observe the change in concentration over time; each script is time delayed
gen_file_eutro	Avenue	Executes outgen.exe from ArcView
gen_file_toxi	Avenue	Executes calgen.exe from ArcView
help	Avenue	Executes the help file for the ArcView/WASP5 connection
inputa	Avenue	Writes the text files for Input Block A for the BOD/DO model input file
inputb	Avenue	Writes the text files for Input Block B for the BOD/DO or calibration model input file
inputc	Avenue	Writes the text files for Input Block C for the BOD/DO or calibration model input file
inputcale	Avenue	Writes the text files for Input Block E for the calibration input file
inputcalf	Avenue	Writes the text files for Input Block F for the calibration input file
inputcalg	Avenue	Writes the text files for Input Block G for the calibration input file
inputcalh	Avenue	Writes the text files for Input Block H for the calibration input file
inputcalj	Avenue	Writes the text files for Input Block J for the calibration input file
inputd	Avenue	Writes the text files for Input Block D for the BOD/DO or calibration input file
inpute	Avenue	Writes the text files for Input Block E for the BOD/DO input file
inputf	Avenue	Writes the text files for Input Block F for the BOD/DO input file
inputg	Avenue	Writes the text files for Input Block G for the BOD/DO input file
inputh	Avenue	Writes the text files for Input Block H for the BOD/DO input file
inputi	Avenue	Writes the text files for Input Block I for the BOD/DO or calibration input file
inputj	Avenue	Writes the text files for Input Block J for the BOD/DO input file
mod_parchk	Avenue	Checks the parameters on the output file to process for the BOD/DO model
modout.exe	FORTRAN	Processes the "edf" file to produce arrays of DO and BOD at each segment vs. time
outgen.exe	FORTRAN	Formats the 13 calibration text files into a EUTRO5 input file
run_calout	Avenue	Executes calout.exe and creates a dbf table for salinity at each segment over time
run_modout	Avenue	Executes modout.exe and creates dbf tables for DO and BOD at each segment over time
toxirun	Avenue	Executes TOXI5 from ArcView
vwout	Avenue	Controls the output presentation processes -- all five options

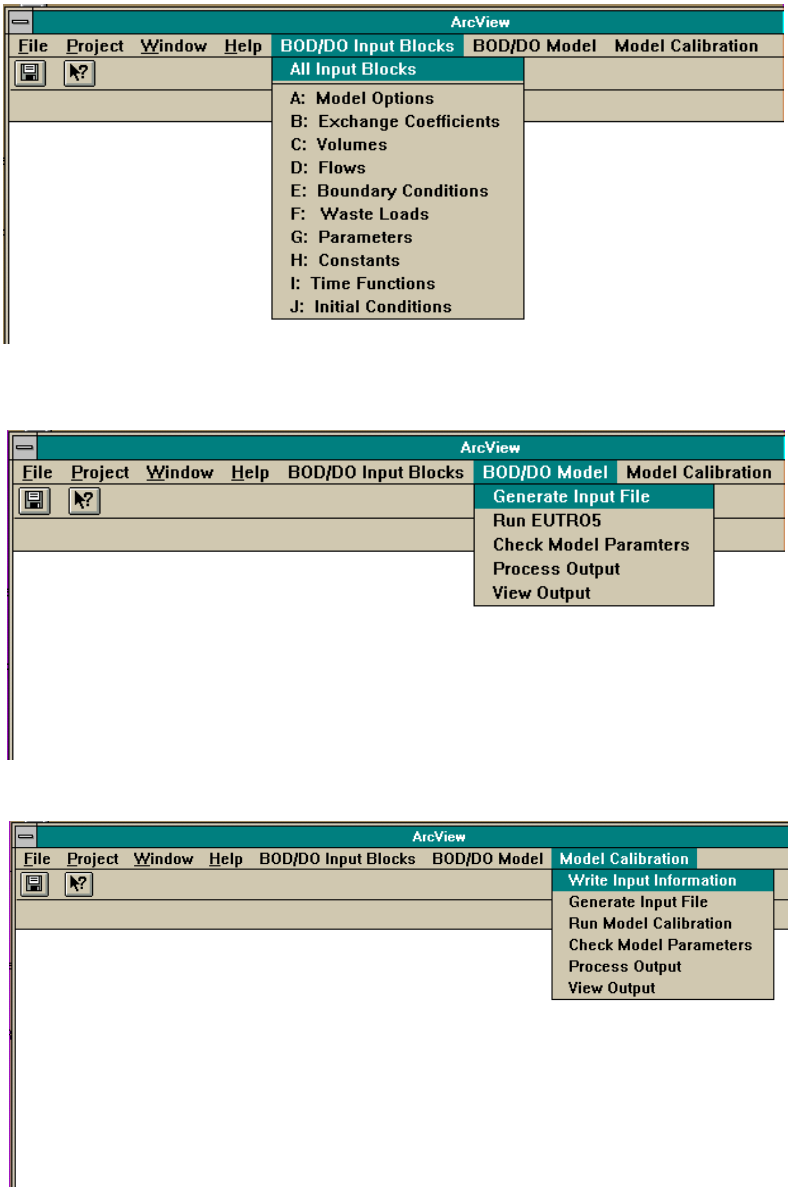


Figure 4-25 Customized menus created to run Avenue scripts. *BOD/DO Input Blocks* creates the text files needed for the EUTRO5 model run. *BOD/DO Model* formats this information and runs the EUTRO5 model. *Model Calibration* assists the user in running TOXI5 to calibrate the model with salinity.

program outgen.for (Appendix C-4) is invoked and the properly formatted WASP5 input file is created from the 13 text files (Appendix E). Once complete, EUTRO5 may be executed with the second option under this menu choice, *Run EUTRO5*. After the model run, the output is processed and viewed by choosing the last three menu options: *Check Model Parameters*, *Process Output*, and *View Output*, in succession (see Section 4.6.8). The last choice on the menu bar is *Model Calibration*. The options located under this choice are similar to those options found under *BOD/DO Model*. However, with the model calibration, all of the input blocks are always created with the first menu option: *Write Input Information*. In other words, the ability to change just one input block of the entire input file is not possible; primarily because the calibration input file is typically much simpler to create than the BOD/DO model input file. In addition, WASP5's subprogram, TOXI5 is executed to perform the model calibration, using salinity as the conservative tracer (*Run Model Calibration*). The options related to the output processing and viewing are identical to the output commands found under *BOD/DO Model*.

Table 4-17 presents a more detailed description of the processes which occur during the *BOD/DO Input Blocks* menu choices. Specifically, Table 4-17 gives the menu option, the tables read during its execution, and the text files produced for each option. For a detailed description of the tables in the connection, refer to Appendix A and the following section.

4.6.4 Tables Needed for Connection

Presently, eight tables within ArcView are needed to run the model connection. These various tables, outlined below, are read by Avenue as objects and the information written to text files. It is extremely important that all tables listed here are included and opened in the project, before the model input file is created. It is also important that all tables are named (either by alias or real name) as they are written below. In addition, since the Avenue scripts contain unit conversions which are performed on values within the tables, the field names, field units, and field order for each table have to adhere to those outlined in

Table 4-17 Detailed Description of *BOD/DO Input Blocks* Menu Options

Menu Option	Tables Read from Project	Fields Read from Table	Text File(s) Produced	Tables Produced
A: Model Options	Boundary Segments	grid-code	a.txt	none
	Main Segment Parameters	grid-code	title.txt	
	Main Segmentation	grid-code	inptnme.txt	
B: Exchange Coefficients	Boundary Segments	act_length	b.txt	none
		dwnstr_seg		
		ex_coeff		
		grid-code		
		perpin		
		type		
		upstr_seg		
		width		
		x_area		
	Main Segment Parameters	dwnstr_seg		
		ex_coeff		
		grid-code		
		length		
		x_area		
C: Volumes	Boundary Segments	act_length	c.txt	none
		bttm_seg		
		grid-code		
		type		
		x_area		
	Main Segment Parameters	bttm_seg		
		grid-code		
		length		
		type		
		x_area		
D: Flows	Boundary Segments	dwnstr_seg	d.txt	flow.dbf
		grid-code	dynhyd.txt	
		type		
		upstr_seg		
	Flow Accumulation Values	flow accumulation		
		grid-code		
	Main Segment Parameters	dwnstr_seg		
		grid-code		
		upstr_seg		
	Runoff Accumulation Values	grid-code		
		rfac		
E: Boundary Conditions	Boundary Segments	grid-code	e.txt	none
		type		
		int_do		
		int_bod		

Table 4-17 (cont) Detailed Description of *BOD/DO Input Blocks* Menu Options

Menu Option	Tables Read from Project	Fields Read from Table	Text File(s) Produced	Tables Produced
F: Waste Loads	BOD Loading Values	accumulated bod loading	f.txt	load.dbf
	Point Source BOD	segment		
		bod		
G: Parameters	Boundary Segments	grid-code	g.txt	none
		sal		
		temp		
		sod		
	Main Segment Parameters	grid-code		
		sal		
		temp		
		sod		
H: Constants	none	none	h.txt	none
I: Time Functions	none	none	i.txt	none
J: Initial Conditions	Boundary Segments	grid-code	j.txt	none
		int_do		
		int_bod		
	Main Segment Parameters	grid-code		
		int_do		
		int_bod		

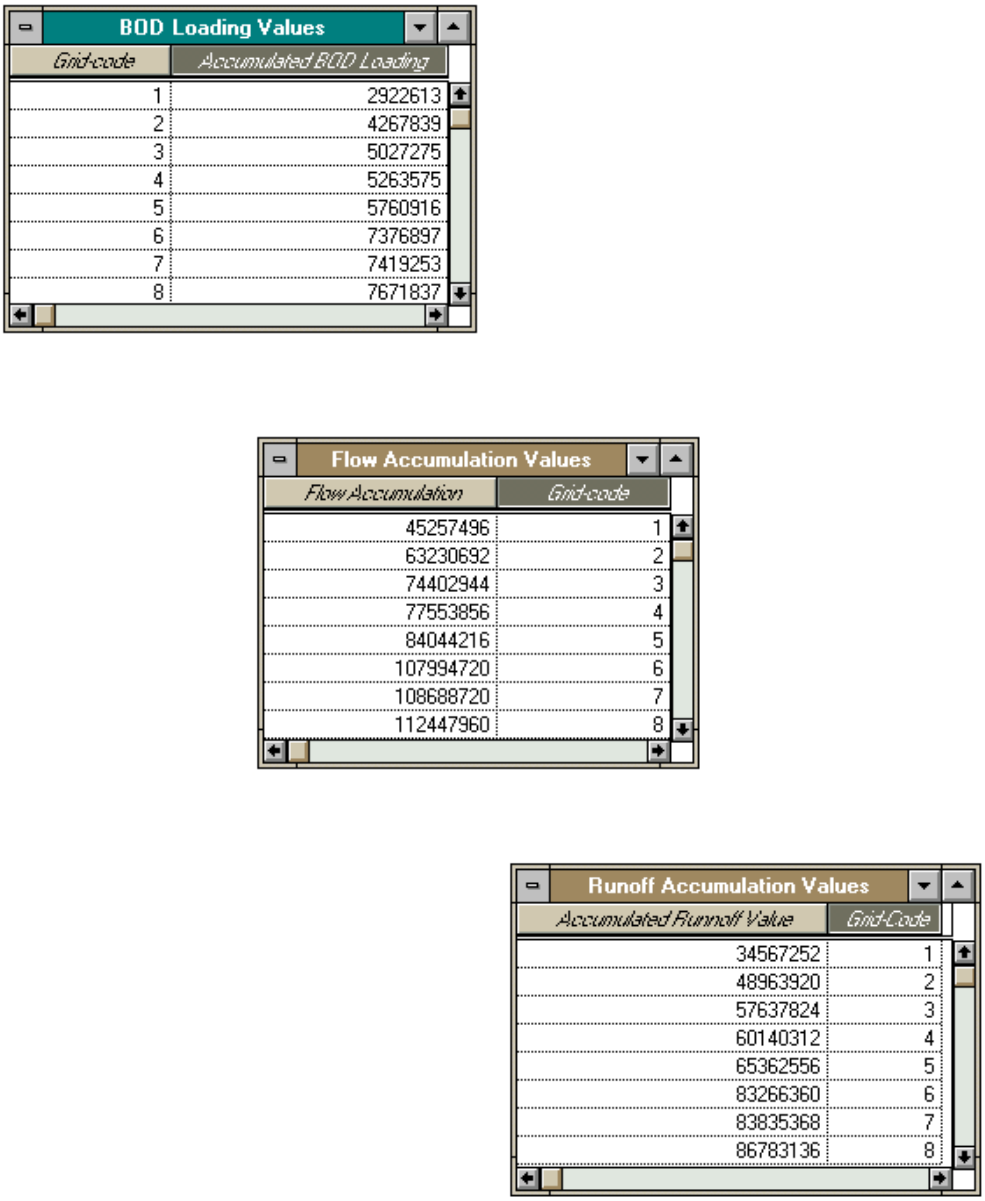
Appendix A. Below is an alphabetical list of the tables and a small description of each; the specific attributes for each table and its corresponding units are found in Appendix A.

BOD Loading Values

A table (value attribute table -- INFO format) of the BOD flow accumulation values for each "outlet" (i.e., its most downstream point) of the main water segments (see Procedure 4-8). These values are usually obtained by running a flow accumulation over the watershed area, weighted by a grid of BOD load, in Arc/Info's subprogram, Grid. This weighted flow accumulation is then "combined" with a grid of the outlet points to obtain this table (see Figure 4-26). This table accounts for the NPS loading from the watershed land surface.

Boundary Segments

A dBase file (dbf) table which contains all boundary segments (water and sediment), and their corresponding parameters. This file can be created in directly in dBase, or in Arc/Info and exported out of ArcView to a dBase format. If the table is not a dBase format,



BOD Loading Values

Grid-code	Accumulated BOD Loading
1	2922613
2	4267839
3	5027275
4	5263575
5	5760916
6	7376897
7	7419253
8	7671837

Flow Accumulation Values

Flow Accumulation	Grid-code
45257496	1
63230692	2
74402944	3
77553856	4
84044216	5
107994720	6
108688720	7
112447960	8

Runoff Accumulation Values

Accumulated Runoff Value	Grid-Code
34567252	1
48963920	2
57637824	3
60140312	4
65362556	5
83266360	6
83835368	7
86783136	8

Figure 4-26 Flow accumulation tables needed in model connection. All of these tables are value attribute tables (vat's) which were formed by performing a combine with the respective weighted flow accumulation grid and a grid of the outlet points to each segment. The order of the fields is not important in these tables; however the accumulation units are important (see Appendix A).

it is not be possible to edit and change parameters in the table. The numbering of the boundary segments starts with the next number after the last main segment. A portion of this table is shown in Figure 4-27.

Flow Accumulation Values

A table (a value attribute table -- INFO format) of the flow accumulation values for each "outlet" (i.e., its most downstream point) of the main water segments (Procedure 4-9). These values are usually obtained by running a flow accumulation over the watershed area, weighted by a grid of flow depth, in Arc/Info's subprogram, Grid. This weighted flow accumulation is then "combined" with a grid of the outlets to obtain this table (Figure 4-26).

Main Segment Parameters

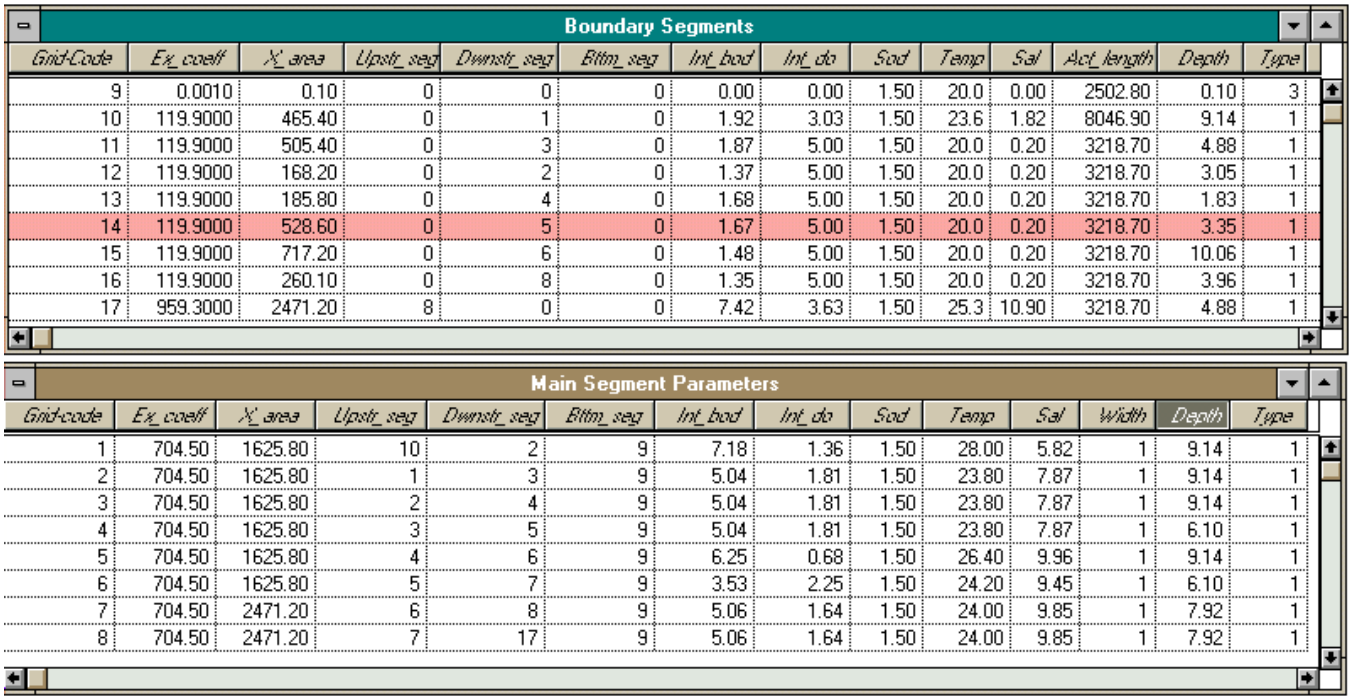
A dbf file which contains the attributes of the main segments for the water quality model. This file can be created in directly in dBase, or in Arc/Info and exported out of ArcView to a dBase format. If the table is not a dBase format, it is not be possible to edit and change parameters in the table. This table is joined, during the generation of Input Block A, to the "Main Segmentation" table below. A portion of this joined table is shown in Figure 4-27.

Main Segmentation

The arc attribute table (aat) of the main segmentation coverage. The numbering of the main segments starts with "1" and continues, in order, until the last main segment is numbered.

Point Source BOD

A dbf file which contains the annual BOD loading into each segment from point sources (Figure 4-28). This file can be created in directly in dBase, or in Arc/Info and exported out of ArcView to a dBase format. If the table is not a dBase format, it is not possible to edit and change parameters in the table..



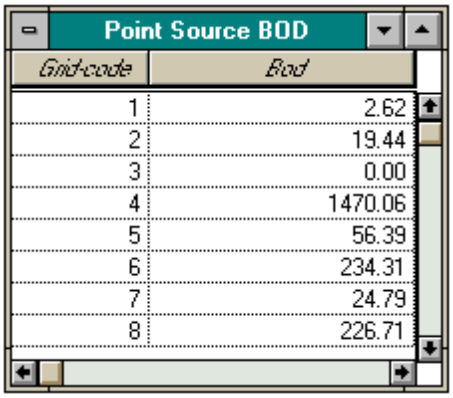
Boundary Segments

Grid-Code	Ex_coeff	X_area	Upstr_seg	Dwnstr_seg	Bttm_seg	Int_bod	Int_do	Sod	Temp	Sal	Act_length	Depth	Type
9	0.0010	0.10	0	0	0	0.00	0.00	1.50	20.0	0.00	2502.80	0.10	3
10	119.9000	465.40	0	1	0	1.92	3.03	1.50	23.6	1.82	8046.90	9.14	1
11	119.9000	505.40	0	3	0	1.87	5.00	1.50	20.0	0.20	3218.70	4.88	1
12	119.9000	168.20	0	2	0	1.37	5.00	1.50	20.0	0.20	3218.70	3.05	1
13	119.9000	185.80	0	4	0	1.68	5.00	1.50	20.0	0.20	3218.70	1.83	1
14	119.9000	528.60	0	5	0	1.67	5.00	1.50	20.0	0.20	3218.70	3.35	1
15	119.9000	717.20	0	6	0	1.48	5.00	1.50	20.0	0.20	3218.70	10.06	1
16	119.9000	260.10	0	8	0	1.35	5.00	1.50	20.0	0.20	3218.70	3.96	1
17	959.3000	2471.20	8	0	0	7.42	3.63	1.50	25.3	10.90	3218.70	4.88	1

Main Segment Parameters

Grid-code	Ex_coeff	X_area	Upstr_seg	Dwnstr_seg	Bttm_seg	Int_bod	Int_do	Sod	Temp	Sal	Width	Depth	Type
1	704.50	1625.80	10	2	9	7.18	1.36	1.50	28.00	5.82	1	9.14	1
2	704.50	1625.80	1	3	9	5.04	1.81	1.50	23.80	7.87	1	9.14	1
3	704.50	1625.80	2	4	9	5.04	1.81	1.50	23.80	7.87	1	9.14	1
4	704.50	1625.80	3	5	9	5.04	1.81	1.50	23.80	7.87	1	6.10	1
5	704.50	1625.80	4	6	9	6.25	0.68	1.50	26.40	9.96	1	9.14	1
6	704.50	1625.80	5	7	9	3.53	2.25	1.50	24.20	9.45	1	6.10	1
7	704.50	2471.20	6	8	9	5.06	1.64	1.50	24.00	9.85	1	7.92	1
8	704.50	2471.20	7	17	9	5.06	1.64	1.50	24.00	9.85	1	7.92	1

Figure 4-27 *Boundary Segments* and *Main Segment Parameters* .tables as they appear in ArcView. These tables hold the segment parameters and data necessary for the WASP5 model. The last column of the *Boundary Segments* table is not shown due to space constraints.



Point Source BOD

Grid-code	Bod
1	2.62
2	19.44
3	0.00
4	1470.06
5	56.39
6	234.31
7	24.79
8	226.71

Figure 4-28 *BOD Point Source Loading* table used for model connection. The point source loads are in units of 10^3 lbs/yr.

Runoff Accumulation Values

A table (a value attribute table -- INFO format) of the runoff accumulation values for each "outlet" (i.e. its most downstream point) of the main water segments. These values are usually obtained by running a flow accumulation over the watershed area, weighted by a grid of runoff depth, in Arc/Info's subprogram, Grid. This weighted flow accumulation is then "combined" with a grid of the outlet points to obtain this table (see Figure 4-26).

Water Boundary Segmentation

The aat of the water boundary segment reaches. It is important not to join this table with the "Boundary Segments" table, since the boundary segments table may have segments which are not Type 1 (i.e., water column). If joined, segments shown on the Boundary Segments table which are not represented in the coverage as water reaches are "lost". The numbering of the boundary segments starts with the next number after the last main segment.

4.6.5 Coverages Needed for Connection

Although other coverages may be added for informational or display purposes, there are only two arc coverages needed in ArcView to run this model connection. Both are located within the same view, "Segmentation" (see Figure 4-29). The necessary coverages are described below:

Boundary Segmentation

An arc coverage of the water boundary segments. The aat attached to this theme is named "Water Boundary Segmentation".

Main Segmentation

An arc coverage of the main segmentation being modeled by WASP5. The aat to this theme is named "Main Segmentation". This coverage is named "segarc" within Arc/Info and aliased as "Main Segmentation" on the view.

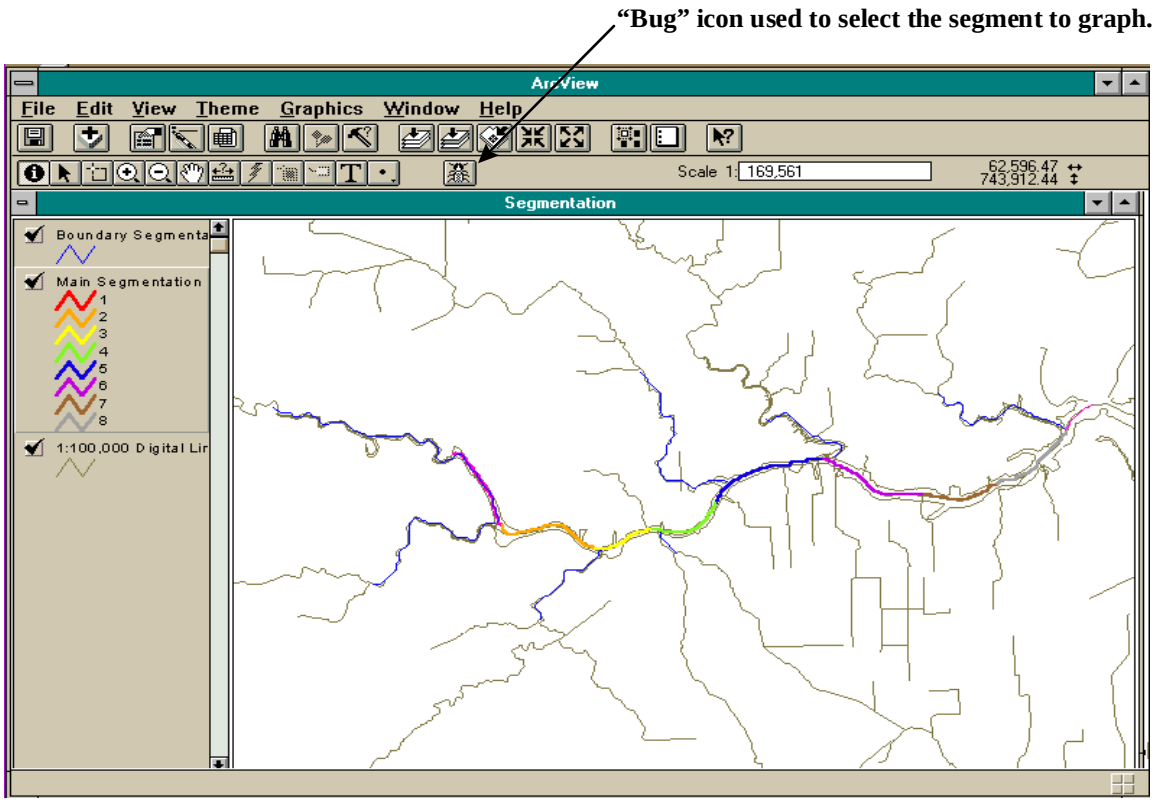


Figure 4-29 ArcView view, entitled "Segmentation". This view holds the two necessary themes (see view legend) to run the connection: "Main Segmentation" and "Boundary Segmentation." The "bug" icon, discussed in Section 4.6.8 is shown on the lower tool bar.

4.6.6 Input File Creation and Modification

Input File Initial Creation

The way this connection works is by reading necessary tabular information and querying the user for needed model options, during the input file generation. WASP5 has ten input blocks (A through J) and a "free form" text file is created by Avenue for each block (Appendix E). In addition, three text files containing the model run description, DYNHYD5 file name, and the input filename are created. Once the input file generation is performed, these text files (see Table 4-17) are in the working directory as a.txt, b.txt, etc. It is then possible to change just one input block (i.e., just the model constants -- Input Block H), while the rest of the parameters stay as they were originally generated.

Avenue executes all of the FORTRAN programs and writes all of the text files to what is termed the "working directory." The working directory, which also contains the WASP5 model executables and FORTRAN formatting programs, is established in running the script for Input Block A. Input Block A is always run before generating a new input file and running the model.

Creating the first input file for the system incorporates the following steps:

1. Checking that all the executables needed for the connection, EUTRO5, and TOXI5 and their related files (see Table 4-16) are in one directory (i.e. the working directory).
2. Referencing the correct coverage in the *vwout* script for the *Main Segmentati*on coverage (see Section 4.6.10).
3. Having all of the necessary tables and view open. They can be minimized to icon views, but they must be open (Figure 4-30).
4. Having the "Project" window active so that the model connection menu items are shown on the main menu bar. They are: *BOD/DO Input Blocks*, *BOD/DO Model*, and *Model Calibration.*
5. Choosing *BOD/DO Input Blocks: All Input Blocks* (Figure 4-30) and allowing the project to run. The entire process takes about 2-3 minutes. The scripts query

the user for some information relating to certain input blocks (Figure 4-31), while other blocks do not require any user input. The project prints a message box to the screen (Figure 4-32) each time it is done writing a particular input block.

6. Once all ten blocks are written, selecting *BOD/DO Model: Generate Input File* executes the FORTRAN program which formats the 13 text files into the WASP5 input file.

Input Block Modification

Once the input file and related text files have initially been established, it is possible to change just one block of the main input file. This ability is an advantage to either correct a possible mistake or to observe the changes that may occur in the results, if a constant or a parameter changes (i.e., to investigate model sensitivity). Before accomplishing this task, the entire input file process explained above has been executed previously. It is not necessary to have run this process during the active project session; if it was run in an earlier session the free form text files created by Avenue (a.txt, b.txt, etc. -- see Table 4-17) are still be present in the working directory. It is then only necessary to rerun those blocks in which related information has been changed. Some important considerations before modifying tables and coverages are:

- Input Block A is always executed at the beginning of a session. This input block establishes the working directory, which is linked to the other subroutines that create Input Blocks B through J.
- The text files which are created and used by the formatting FORTRAN program are always named a.txt, b.txt, c.txt, etc. In order to change information in an input file but preserve the original input file created, the new input file must be named differently during the Input Block A generation. However, changing parameters on a project table results in the old information being overwritten. To avoid this problem, an entirely new table with the new information is created in Arc/Info or dBase, imported into ArcView, and aliased with the correct name.

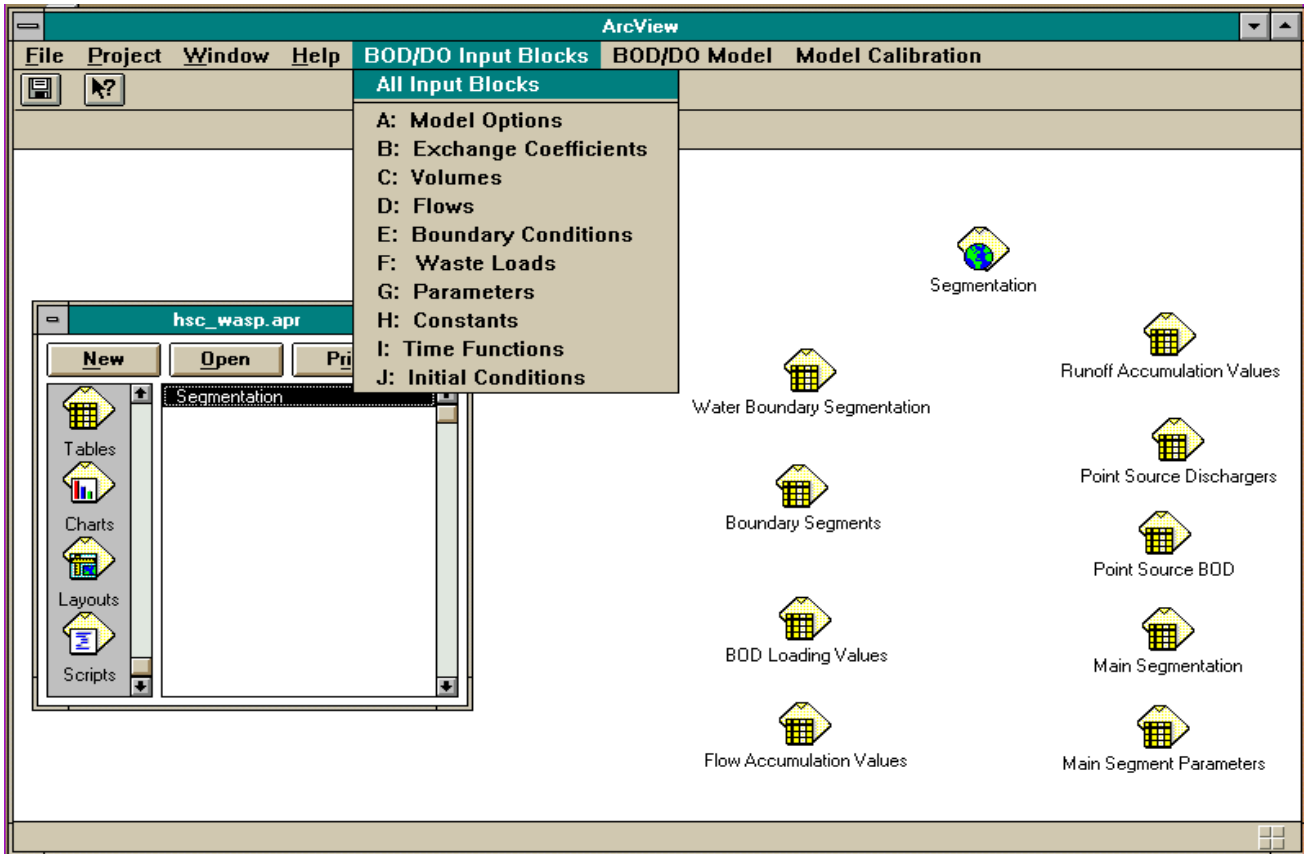


Figure 4-30 ArcView setup for model connection. This figure shows necessary views and tables opened, but minimized. The main project window (hsc_wasp.apr) is active and the customized menus are shown. The menu choice is for All Input Blocks". This choice writes all 13 text files necessary for the input file to WASP5.

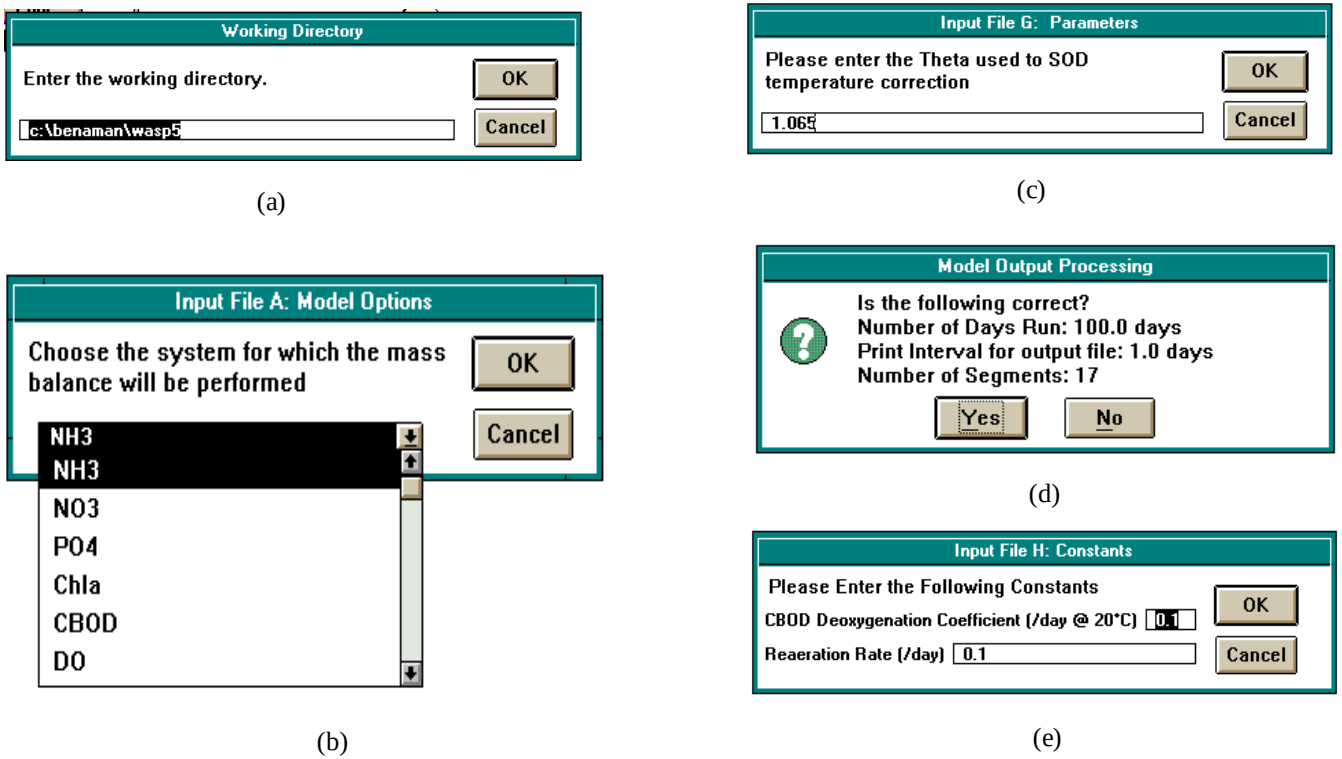


Figure 4-31 Examples of query boxes created by Avenue and shown during input file creation through ArcView. (a) asks the user to input the working directory during Input Block A; (b) displays a list of the state variables in EUTRO5 for the user to choose; (c) shows an input of a parameter for Input Block H; (d) queries the user during output processing; and (e) allows the user to enter the two constants needed for level one EUTRO5 BOD/DO modelling.

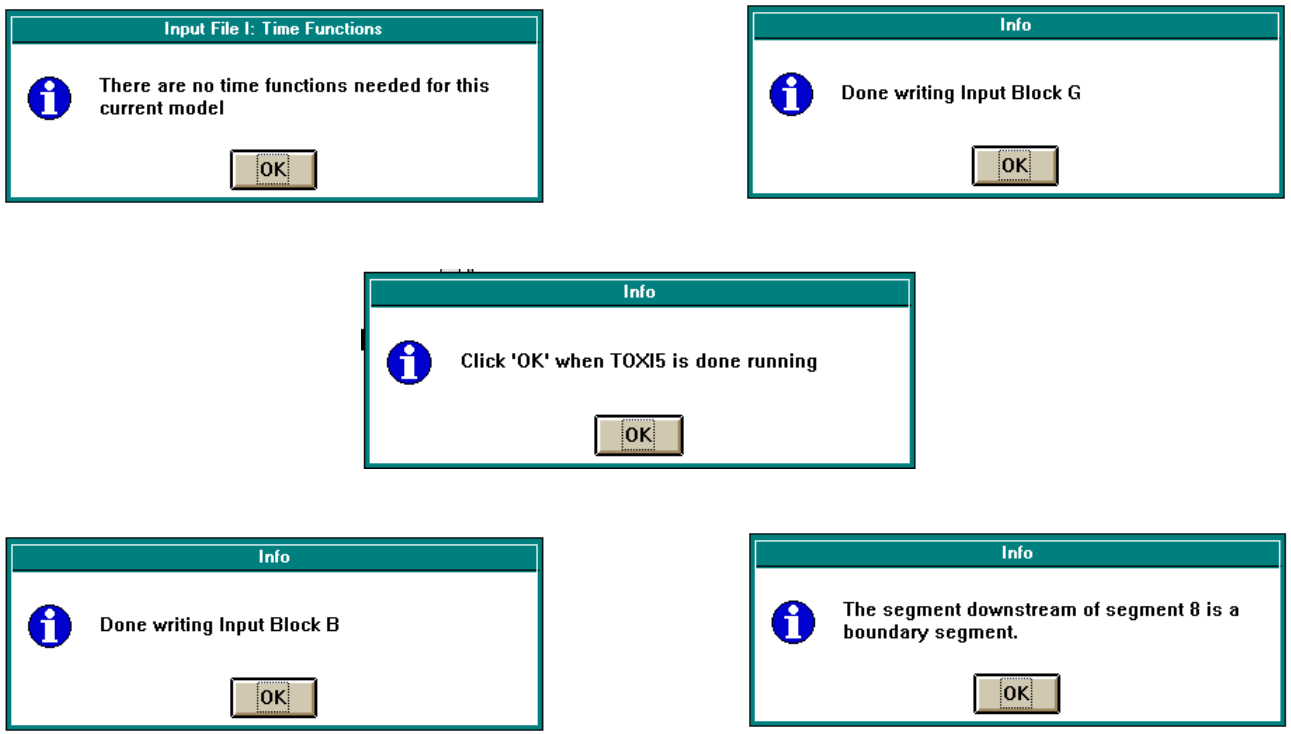


Figure 4-32 Examples of various message boxes created by Avenue. Message boxes are used to inform the user a process is done, give the user information about an input block, or asks the user to click "OK" when a DOS process is finished so ArcView regains "control" of the project.

- If parameters are changed in the tables, all input blocks which are affected by those characteristics that have been modified are rerun. For example, if cross sectional areas are changed , it is necessary to rerun both Input Block B: Exchanges, and Input Block C: Volumes, since the cross sectional area is used in both of these blocks.

Most of the input block creation process reads information from the tables outlined in Section 4.6.4. To change information in a within a table in ArcView, the table must be in a dbf format. Since ArcView only allows one to modify dbf tables, if an INFO file needs to be changed, it is first exported out of ArcView as a dbf file, reopened into the project, and renamed to the correct name. Once the table is a dbf file, it is changed by following the steps below:

1. To edit the table, make it active and choose *Table: Start Editing* on the menu bar (see Figure 4-33). Then, choose the editing icon from the tool bar and change the values. When complete, select *Table: Stop Editing* from the menu.
2. Set the project window active and select *BOD/DO Model* from the menu bar. A menu appears, displaying all ten input blocks (Figure 4-30). Choose the input block to recreate and Avenue regenerates the necessary text files.
3. Rerun Input Block A in order to rename the WASP5 input file and preserve the previous input file (if desired).
4. When complete, choose *BOD/DO Model: Generate Input File*, to recreate the input file with the new information.

Dry Weather Conditions

For the BOD/DO model input file, the user has the option to simulate "dry weather" conditions. During the generation of Input Blocks D and F, Avenue prompts the user to simulate average or dry weather flows. If "dry weather conditions" is chosen, the input file will have just baseflow conditions and point source loads only. It is important that the answer to the query at each input block is consistent; otherwise, an inaccurate input file which either discludes runoff flows or non-point source loads is created.

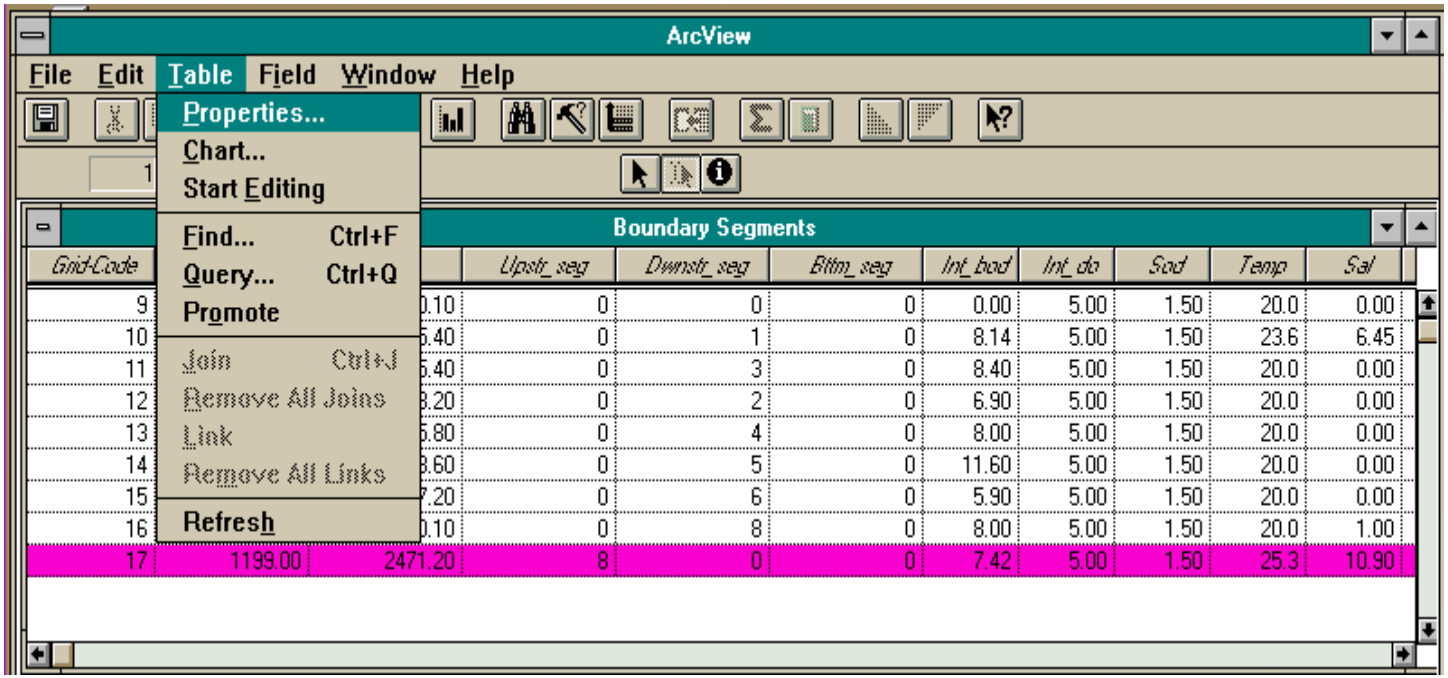


Table edit icon located on lower tool bar

Figure 4-33 ArcView menu showing option to *Start Editing*. Once chosen, the table edit icon (above) is highlighted and the selected table (in this case, "Boundary Segments") is changed. Only dBase tables can be edited.

Calibration Input File

Before running the BOD/DO model in EUTRO5, the system being modeled must first be calibrated. The user can perform this calibration without the help of the ArcView connection, or utilize the ArcView to assist in the model calibration. For calibration, the TOXI5 is used to model a conservative substance in the system. Typically, at least two boundary conditions are set to a known concentration value of the substance; the rest of the segments are set to initial conditions of 0. The model is run and once equilibrium in the system is reached, the calculated values of the conservative substance are compared to known values.

For the calibration in this connection, the method employed is a steady state model using TOXI5, level one complexity and salinity as the conservative substance. When the menu choice *Write Input Information* under *Model Calibration* is chosen (see Figure 4-25), Avenue reads the data from the tables. In addition, the model constants and the desired segment numbers set as the boundary conditions are input by the user. As in the regular input file generation, the Avenue program creates 13 text files. A number of these files are identical to the blocks needed for a BOD/DO model run; specifically, input blocks B,C,D, and I. For this reason, the same free form text files (b.txt,c.txt,d.txt, and i.txt) are written to the working directory. For all other input blocks, the free form text files have the prefix "cal" (i.e. cala.txt).

An Overview of Each Input Block

As mentioned earlier, WASP5 requires 10 input blocks for a completely formatted input file. Most of the information for each one of these input blocks is read by Avenue, using the corresponding choices on the menu bar (see Figure 4-25). However, some defaults to each input block were set within the input block creation in order to make writing the formatted input file more efficient and easier. The following is a short description of each information read from ArcView for each input block and the defaults that were set in its generation.

Input Block A: Model Identification and Simulation Control

This input block contains basic simulation information and model preferences. The script reads how many segments are present and queries the user to choose model preferences such as length of model run, preferred time step, and print intervals. This script also asks for a model title, which is printed on the first line of the input file, and the input file name (*.inp). This file name uses the standard DOS 8.3 file naming convention and always has the extension ".inp".

The following defaults are set in the generation of this input block:

- Presently, the connection is set to handle just EUTRO5 for Simple Street-Phelps modeling and level one complexity TOXI5 for calibration.
- Backward differencing is always used.
- A transport file is always generated.
- The first six segments' solutions are those which are displayed on the screen, during a model run.
- The same maximum time step is used throughout the model run.
- The same print interval is used throughout the model run.

Input Block B: Exchange Coefficients

This input block describes the exchange coefficients for surface water (pore water exchanges are not set in the connection). The script reads the lengths of the segments to calculate the characteristic length between segments. It also determines if the boundary segments are perpendicular to the main segmentation and compensates for that attribute in the characteristic length. Finally, it reads the exchange coefficients and cross-sectional areas for two neighboring segments and chooses the smaller area and the exchange coefficient for printing to the text file. It also established the exchange between the benthic sediment and the water column to emulate a possible sink or source for DO.

The following defaults are set:

- Exchange coefficients are steady-state.
- Exchange coefficients are written to the text file in m^2/sec and lengths are in m.

Input Block C: Volumes

This input block describes the segment volumes for the system. It also sets the hydraulic geometry parameters for calculating segment depth and velocity. These geometry parameters are used to calculate reaeration (if necessary) or volatilization from the segments; they are not used in transport calculations (Ambrose, *et al.*, 1993). For this connection, a constant (in time and space) reaeration coefficient has been assumed; therefore, these geometry parameters are not used to calculate reaeration in this particular set up. The script reads the cross-sectional areas (m^2) and multiplies it by that segment's length (m) to obtain the volume. The script also asks the user to choose the following: 1) water column volume option, 2) benthic volume option, and 3) benthic time step.

The following defaults are set:

- Volumes are written to the text file in m^3.
- Geometry parameters do not spatially vary.
- Only the first benthic volume option is possible.

Input Block D: Flows

This input block provides the advective transport flows that are used in the model. Presently, only flows for WASP5 Flow Field 1 (water column) are used in the connection. First, the script asks the user to choose a flow option. These options are described below (Ambrose, *et al*., 1993):

1. Field one flows are specified directly by the user. Individual flows at each segment interface are summed by the model, and the net flow us applied across the interface.
2. Field one flows are specified directly by the user. Individual flows at each segment interface are applied directly by the model.

3. Flows are read from a formatted file created by DYNHYD5 or another hydrodynamic model. If this option is chosen, the user is asked to enter the file name of the text file which hold this information.

The table, "flow.dbf" (Figure 4-34) is created during this input block determination, by doing a units conversion on the "Flow Accumulation Values" and the Runoff Accumulation Values tables (Figure 4-26) (mm/yr/ha to m^3/sec). This table gives the total cumulative flow, incremental flow, runoff, and baseflow into each main segment in m^3/sec. The baseflow is found by subtracting the incremental runoff from the incremental flow.

The script in ArcView assumes that each boundary segment given has an associated flow and each main segment has just one flow input. The script tracks each flow input from its upper-most boundary to the most downstream segment (see Figure 4-22). To do this process, each boundary segment and its corresponding upstream and downstream segments are read from the "Boundary Segments" table. The main segment, which is downstream of a given boundary, is then found in the "Main Segmentation" table, and its corresponding downstream segment is obtained. The script continues to look for the successive downstream segments, until the most downstream main segment is reached. This flow route is printed to the text file and, at the end of the flow path, the actual flow from the original boundary segment is printed. If dry weather conditions are chosen, Avenue replaces the total flow in this text file with just the baseflow.

The following defaults are set:

- All flows are in m^3/sec. The percentages of the total flow are written to the text file, along with the total flow value.
- The flow is steady state.
- The number of flow fields is set to 1: water column only (no pore water flows).

load.dbf

grid-code	bod_ps	bod_nps	do_nps
1	3.26	8007.16	4735.24
2	24.16	3685.55	1972.15
3	0.00	2080.65	1188.21
4	1827.28	647.40	342.81
5	70.09	1362.58	715.38
6	291.25	4427.35	2452.58
7	30.81	116.04	77.95
8	281.80	692.01	403.80

flow.dbf

grid-code	cumm_flow	int_flow	runoff	baseflow
8	35.66	1.20	0.93	0.27
5	26.65	2.06	1.66	0.40
7	34.46	0.22	0.18	0.04
6	34.24	7.59	5.68	1.91
4	24.59	1.00	0.79	0.21
1	14.35	14.35	10.96	3.39
3	23.59	3.54	2.75	0.79
2	20.05	5.70	4.57	1.13

Figure 4-34 The two dbf files which are created during the BOD/DO input block execution. Flow.dbf gives the cumulative flow, incremental flow, runoff, and baseflow for each segment in m^3/sec, while load.dbf shows the point source BOD loading and NPS BOD and DO loading into each segment in kg/day.

Input Block E: Boundaries

This input block describes the boundary segments and their concentrations. Model boundaries consist of those segments that import, export, or exchange water with locations outside the main network. A boundary is either a tributary inflow, a downstream outflow, or an open water end of the model network across which dispersive mixing can occur. The boundary concentrations are read from the "Boundary Segments" table.

The following defaults are set:

- Since the EUTRO5 model is set just for the Simple Streeter-Phelps Model, only BOD and DO are considered in the boundary concentrations.
- For the calibration model, those boundary segments chosen by the user are set to their respective salinity values, while all other boundaries are set to 0.
- All concentrations are read and written in units of mg/L.
- The boundary conditions are steady state.

Input Block F: Waste Loads

This Input Block writes the BOD and DO loads into each main network segment. The script does two things:

1. Reads the point source BOD loads into each segment (in 10^3 lbs/yr) from the "Point Source BOD" table and converts the value to kg/day.
2. Calculates the non-point source BOD from the "BOD Loading Values" table (Figure 4-26) in kg/day by taking each load value and subtracting the previous segment's load value to get the incremental loading to each segment.

Since the model is set for steady state, the non-point BOD loads are added to the point source BOD loads to get a total load to the segment. This input block also generates a table called "load.dbf" (Figure 4-34), which gives the non-point source loads in kg/day for BOD and DO. This table also gives the total point source BOD loading in kg/day for each main segment. If dry weather conditions is selected during this input block creation, only the

point source loads are written to the input file, since there is no runoff to carry the NPS loads.

The following defaults are set:

- All loads are steady state.
- Only BOD and DO are considered.

Input Block G: Parameters

This input block reads the necessary parameters for the level one EUTRO5 or level one TOXI5 models. As the complexity level increases, the number of parameters needed also increases. Presently, no parameters are needed for the level one TOXI5 model and only four parameters are required for EUTRO5 level one:

1. Temperature, read from the segment tables in °C; temperature is used to correct for deviations from the standard (20°C) and DO saturation.
2. Sediment oxygen demand (SOD), read from the tables in $g/m^2/day$.
3. SOD theta correction, input by user; used to correct SOD for temperatures deviating from 20°C.
4. Salinity, read from the tables; used to calculated DO saturation.

The following defaults are set:

- Temperature does not vary in time.
- SOD theta does not vary in time or space.

Input Block H: Constants

This Input Block queries the user for the necessary constants needed to run the Simple Streeter-Phelps or the calibration models. The definition of the constants varies, depending upon the structure and kinetics of the systems comprising each model. For the present BOD/DO model, only two constants are needed:

1. CBOD deoxygenation rate at 20°C, per day.
2. Reaeration rate constant at 20°C for entire water body, per day.

For the calibration model, three constants are necessary:

1. Molecular weight of the substance being modeled in g/mol.
2. Constant partition coefficient for sorption to solids in L/kg.
3. Water column biodegradation.

The following default is set:

- The constants do not vary in time or space.

Input Block I: Time Functions

If the model were non-steady state for any parameter, this input block would use time functions to vary the specific parameter. Presently, none of the parameters are set to vary in time, so the default for this block is set to 0.

Input Block J: Initial Conditions

This input block describes the initial conditions for each system in the model. For the EUTRO5 model, only DO and BOD are considered in this script. The initial conditions are read from the segment tables. The TOXI5 model only needs to set the boundary segments that are chosen by the user to their respective salinities, while all other initial conditions (i.e., salinities) are equal to zero.

The following defaults are set:

- The dissolved fraction of BOD is set at 0.5.
- The dissolved fraction of DO is always 1.0.
- The dissolved fraction for salinity is 1.0.
- The maximum value for all systems in EUTRO5 is 1.0e8.
- The maximum value for salinity is 35,000 mg/L (sea water).
- Solids Field 3 transports BOD is its particulate form.
- Solids Field 5 transports DO.
- Solids Field 3 transports NaCl.

- All densities are set to 1.0 (EUTRO does not use those values).
- All initial conditions are in mg/L.

4.6.7 Running the Model from ArcView

As mentioned before, the input file which is created has some limitations. This initial connection, although quite simplified for WASP5 capabilities, can be enhanced to eliminate some of the preset defaults presently in the code. However, at this time, this model connection has the following limitations:

- Only steady state input files are run.
- The connection is best set up for a river system, or a tidally influenced river system
- The Simple Streeter-Phelps Model is the complexity level -- the connection considers just Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO)
- Only the water column flow is considered in this connection. The connection is not presently set up for two-layer water systems or for sediment transport.

Once an input file is created in ArcView, a model run can be executed by simply choosing *BOD/DO Model: Run EUTRO5*. Be sure that the input file has been generated before performing this step. When the model is executed, a DOS window appears and the EUTRO5 interface is shown. When a list of input files is displayed, the input file to run is executed. Do not press the "OK" button on the message box (Figure 4-32) until the model has completed executing. Pressing "OK" informs ArcView that the model is completely done running and Avenue can now exit from DOS and return to the ArcView interface. In addition, the EUTRO5 or TOXI5 models do not have to be executed through ArcView. It is possible to get ArcView to write several input files for these models and then run the model separately, through DOS, for each file. The final output can then be processed and viewed through ArcView.

4.6.8 Output File Processing

There are three main steps that need to be executed in succession in order to process and view the output from a model run:

1. Checking the model parameters
2. Processing the output file
3. Viewing the output

All of these steps can be executed from either the *BOD/DO Model* menu or the *Calibration Model* menu. Be sure to choose the correct menu, corresponding to the model that is being processed (see Figure 4-25).

Step 1: Checking the model parameters

This item just reinitializes the model options and file information for ArcView to process the output. With this option, it is possible to create a number of output files with numerous model runs and then process them, one at a time, without having to go back and rerun the model. The correct output file name for the desired model run is input during this step. If an output file from the calibration model is being processed, the output file is named the same as its assigned input file name, with a ".tdf" extension. The BOD/DO model follows the same convention, with an ".edf" extension. This step is always executed before processing and viewing an output file.

Step 2: Processing the output file

This option executes a FORTRAN program which writes a text file with either salinity, or BOD and DO measurements, for every segment at each time step. The text file is then imported into ArcView as a dBase table. Avenue prompts the user to name each table, as it is processed. If a number of output files are being processed at once, their related tables are given descriptive names so that they can be differentiated in the project.

Step 3: Viewing the output

The first step that the user must do, after executing this command is to choose a table to which Avenue links the newly created charts and coverages. Although the table choice

box displays a list of all available tables (Figure 4-35), only those that were created by the above process step can be viewed using this menu option. If a table is chosen that does not have the proper format, ArcView exits out of the view output script. The table selected has to correspond to the parameters set in Step 1, above. If it does not, the user must go back and reset the parameters correctly. This need is because the output viewing steps (such as coverage creation) use some of these parameters in order to execute various Avenue script commands.

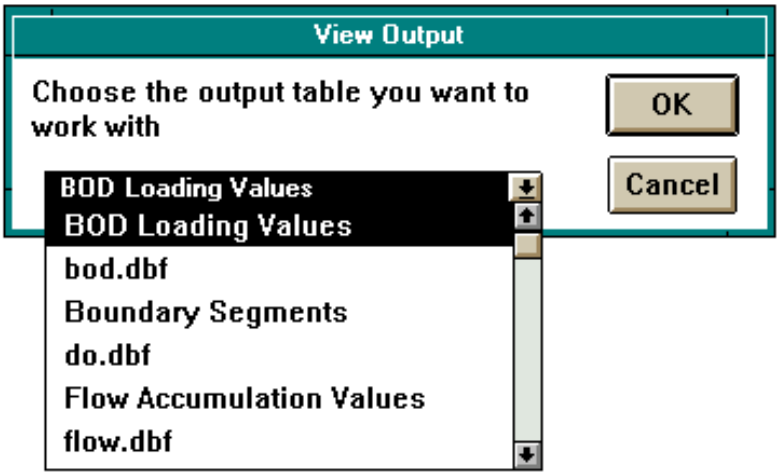
Within this step, there are five options. They are as follows:

1. View the table
2. Create a chart of concentration vs. time for a chosen segment
3. Create a chart of concentration vs. segment number for a chosen time
4. Create a coverage of the concentration at the last time step in the table
5. Create a "movie" of four coverages which display concentration at four chosen times

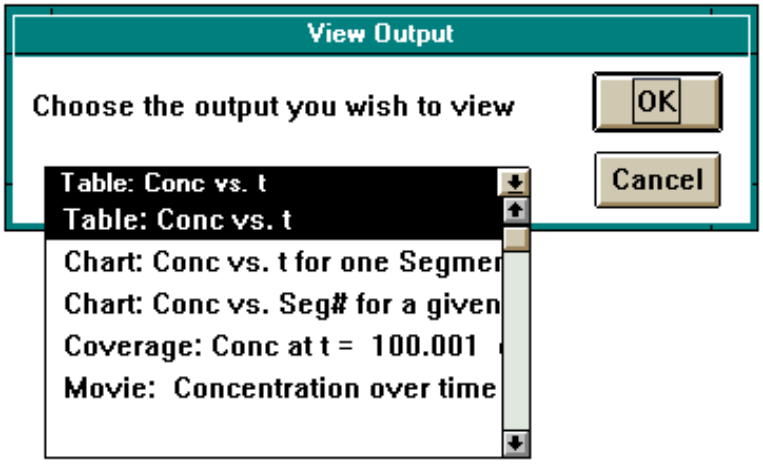
All charts which are created are always "linked" to a given table. If changes are made to that table or to the selections within the table, the chart changes accordingly. For example, if a chart of concentration vs. segment at time = 10 days has been created and another chart of concentration vs. segment at time = 19 days is created and linked to the same table, the first chart changes to reflect the new time. To avoid this problem, the user can create or add multiple copies of the same table to the project and link a chart to each table. This process is accomplished by either adding the dbf file numerous times and renaming the table so that it is more descriptive or processing the same output a number of times and changing the table name when prompted for a name. Then, only one chart is linked to each table and the charts remains independent of one another.

Option 1: Viewing the Table (Figure 4-36)

By choosing this option, the selected table opens and become the active view. The user can then view the output or create charts manually from this table, if desired.

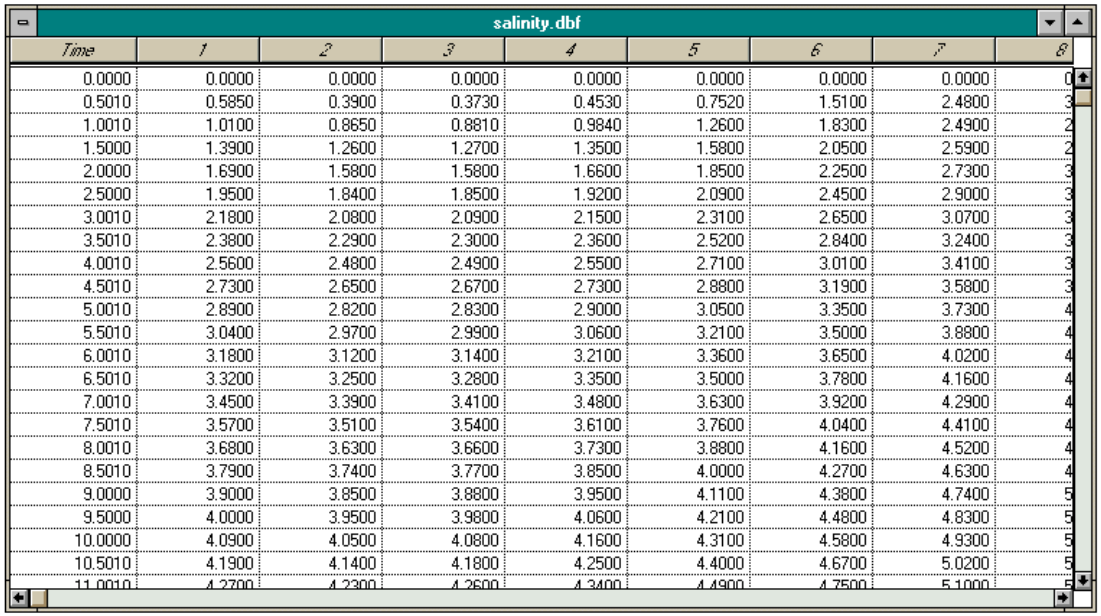


(a)



(b)

Figure 4-35 Query boxes: (a) shows the list of tables to choose from which new charts and themes are created and (b) displays the output options available to the user. Only those tables with a "Time" field are able to be processed.



salinity.dbf

Time	1	2	3	4	5	6	7	8
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0
0.5010	0.5850	0.3900	0.3730	0.4530	0.7520	1.5100	2.4800	3
1.0010	1.0100	0.8650	0.8810	0.9840	1.2600	1.8300	2.4900	2
1.5000	1.3900	1.2600	1.2700	1.3500	1.5800	2.0500	2.5900	2
2.0000	1.6900	1.5800	1.5800	1.6600	1.8500	2.2500	2.7300	3
2.5000	1.9500	1.8400	1.8500	1.9200	2.0900	2.4500	2.9000	3
3.0010	2.1800	2.0800	2.0900	2.1500	2.3100	2.6500	3.0700	3
3.5010	2.3800	2.2900	2.3000	2.3600	2.5200	2.8400	3.2400	3
4.0010	2.5600	2.4800	2.4900	2.5500	2.7100	3.0100	3.4100	3
4.5010	2.7300	2.6500	2.6700	2.7300	2.8800	3.1900	3.5800	3
5.0010	2.8900	2.8200	2.8300	2.9000	3.0500	3.3500	3.7300	4
5.5010	3.0400	2.9700	2.9900	3.0600	3.2100	3.5000	3.8800	4
6.0010	3.1800	3.1200	3.1400	3.2100	3.3600	3.6500	4.0200	4
6.5010	3.3200	3.2500	3.2800	3.3500	3.5000	3.7800	4.1600	4
7.0010	3.4500	3.3900	3.4100	3.4800	3.6300	3.9200	4.2900	4
7.5010	3.5700	3.5100	3.5400	3.6100	3.7600	4.0400	4.4100	4
8.0010	3.6800	3.6300	3.6600	3.7300	3.8800	4.1600	4.5200	4
8.5010	3.7900	3.7400	3.7700	3.8500	4.0000	4.2700	4.6300	4
9.0000	3.9000	3.8500	3.8800	3.9500	4.1100	4.3800	4.7400	5
9.5000	4.0000	3.9500	3.9800	4.0600	4.2100	4.4800	4.8300	5
10.0000	4.0900	4.0500	4.0800	4.1600	4.3100	4.5800	4.9300	5
10.5010	4.1900	4.1400	4.1800	4.2500	4.4000	4.6700	5.0200	5
11.0010	4.2700	4.2300	4.2600	4.3400	4.4900	4.7500	5.1000	5

Figure 4-36 Table (dbf format) which is created during the output file processing of the WASP5 output. This table shows values of salinity (in ppt) and is opened when the first choice for the output presentation is chosen.

Option 2: Concentration vs. Time (Figure 4-37)

This option opens the view, "Segmentation" (Figure 4-29) and prompt the user to activate the "bug" icon and choose a segment. Once the "bug" icon located on the far right bottom tool bar is active, the proper theme (either Main Segmentation or Boundary Segmentation) is highlighted. The chart is created by clicking on the segment to graph. The user is asked a few chart options, including color and the name of the y-axis. Afterwards, a chart, showing concentration vs time (for all time steps) appears.

Option 3: Concentration vs. Segment Number (Figure 4-38)

This option prompts the user for the time at which to display the concentration values. A bar chart showing the concentration for each segment (main and boundary) is then created. If a different time is desired, the new time is selected on the linked table and the chart changes to reflect the new selection.

Option 4: Coverage at Final Time (Figure 4-39)

This option creates an ArcView coverage of the concentration at the final time in the model run. The script automatically brings the coverage up on the view, "Segmentation", and shows the concentration values for that time, in a ramped arc coverage (from blue to red).

Option 5: Movie of Four Chosen Times (Figure 4-40)

This option allows the user to choose four given times from all possible times in a chosen table. The script then opens the view, "Segmentation", and creates a coverage, at a chosen time delay. The script determines the minimum and maximum values within the selected times and ramp the coverage from gray to blue in eight intervals. These intervals stays constant for all four times, so that changes in concentrations can be viewed consistently. After the script is complete, the user has four new coverages of concentration at each time step.

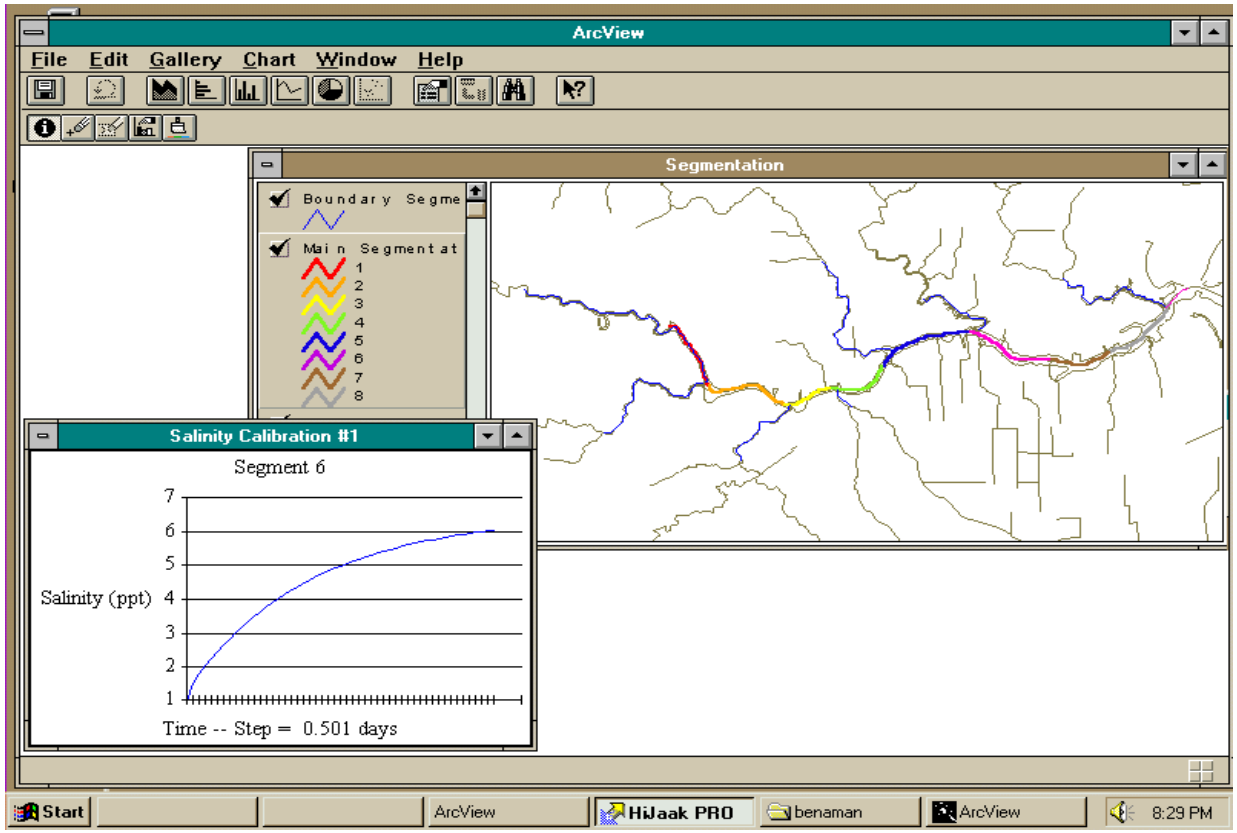
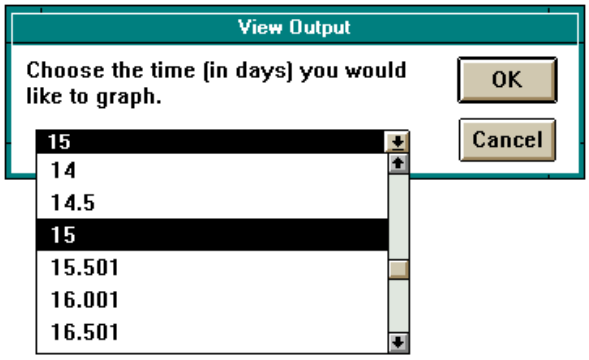


Figure 4-37 Result of second choice in output file presentation options: chart of concentration vs. time for a given segment and chosen table. The chart is created by choosing the bug icon from the view toolbar (see Figure 4-26) and choosing the segment off of the view to chart.



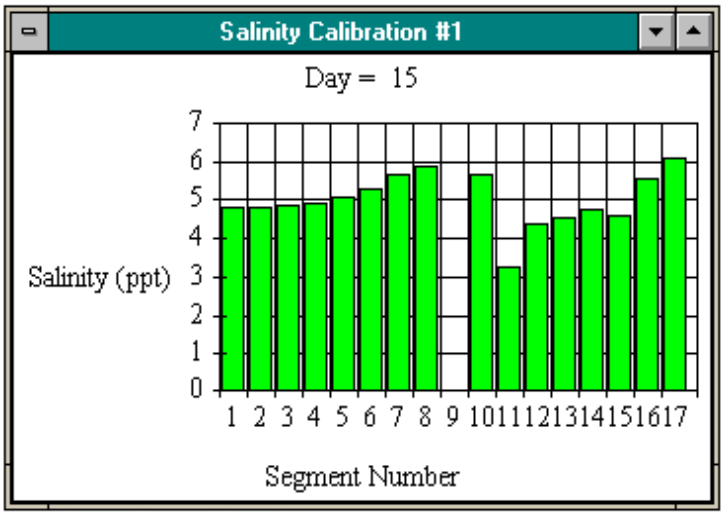


Figure 4-38 Query box and chart for third output presentation option: concentration vs. segment number at a chosen time. The query box allows the user to pick the time at which to chart the concentrations. Segment #9 is the benthic sediment layer; no salinity is modeled in that segment.

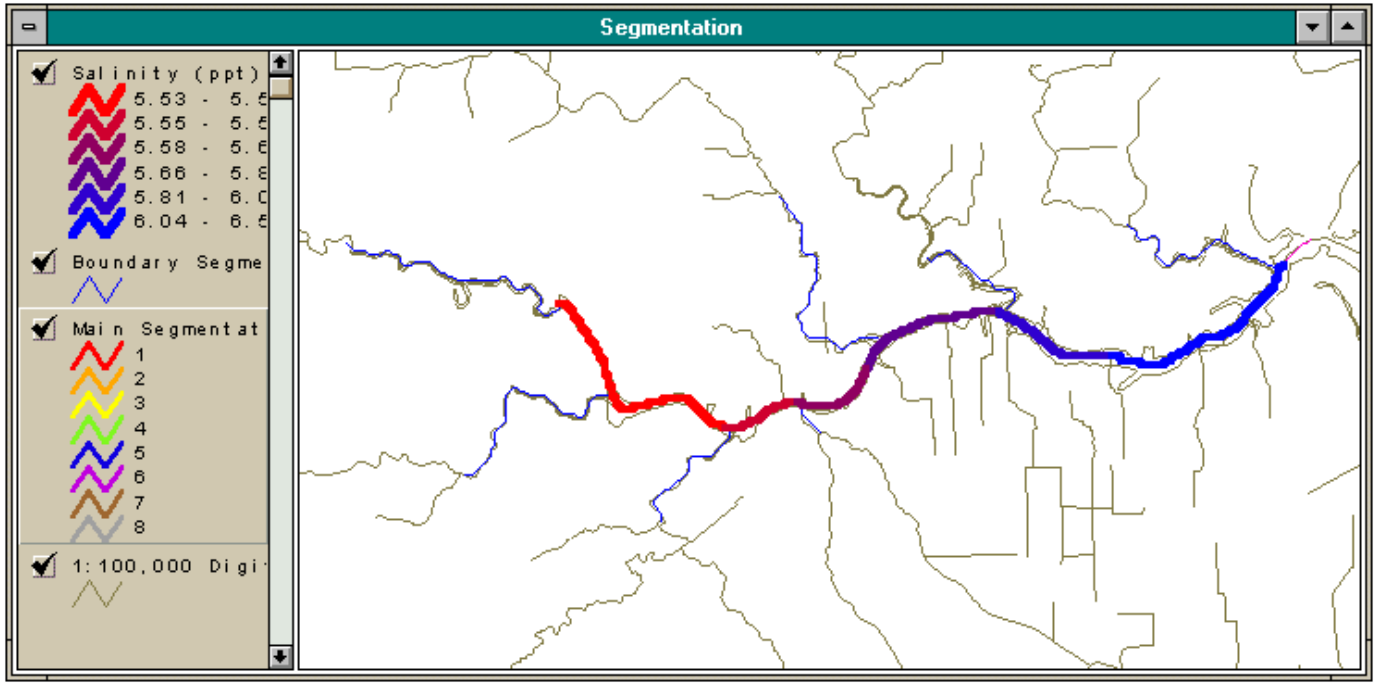


Figure 4-39 New theme created by fourth output presentation option. This new theme shows concentration at the last time in the model run. The arcs are ramped from blue to red.

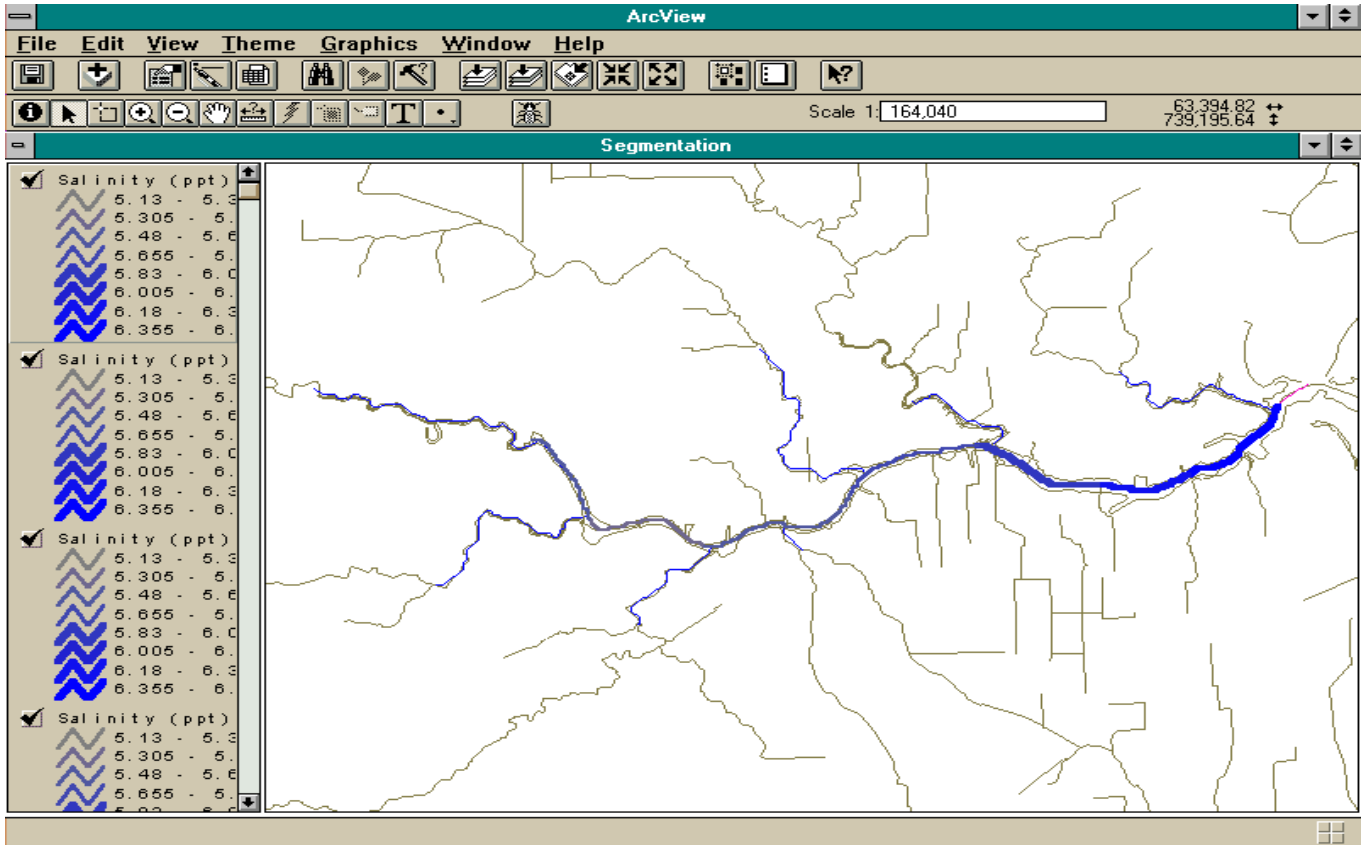


Figure 4-40 Themes created by the fifth output viewing option. The themes, all of concentration at different times selected by the user, are shown on the screen at a set time delay. When complete, four new themes (as shown here) are present on the view. The interval for the ramped arcs is determined by finding the maximum and minimum concentration values of all times chosen and dividing by eight.

4.6.9 Help File Creation

Located within this customized project is a "help" document to assist a user in the use of this model connection. To activate this help document, the option *Help on WASP5/ArcView Connection* under *Help* on the menu bar is chosen (Figure 4-41). This file is a hypertext document, compiled in rich text format and executed under Windows's help file (winhelp.exe). This help document, shown in Appendix G, gives information on the model, the connection, the input blocks, troubleshooting, limitations, and references. In addition, it outlines how to create an initial input file, to change an input block, to run the model, and to perform a model calibration.

4.6.10 Setting up the WASP5/ArcView Connection

The ArcView/WASP5 model connection and a demo which shows the Houston Ship Channel study discussed in this report can be set up on any computer which has ArcView 2.1 or higher installed on the machine. In order to set up the demonstration on a personal computer, the following steps are taken:

- Install WASP5 onto the computer. WASP5 is available from the USEPA Homepage (ftp://ftp.epa.gov/epa_ceam/wwwhtml/wasp.htm).

- Download the demonstration files, in zipped format, from the University of Texas, Center for Research in Water Resources Homepage for the ArcView/WASP5 connection demo (http://www.ce.utexas.edu/prof/maidment /GISHydro/) and unzip them into the directory that the WASP5 executables are located.

- Open the project hsc_wasp.apr in ArcView version 2.1 or higher. ArcView may initially ask the user to location of some coverages and tables. All necessary coverages and tables should be located with in the directory in which the downloaded file was unzipped. Most tables are in dbf format, while the coverages are in a folder entitled *cover*.

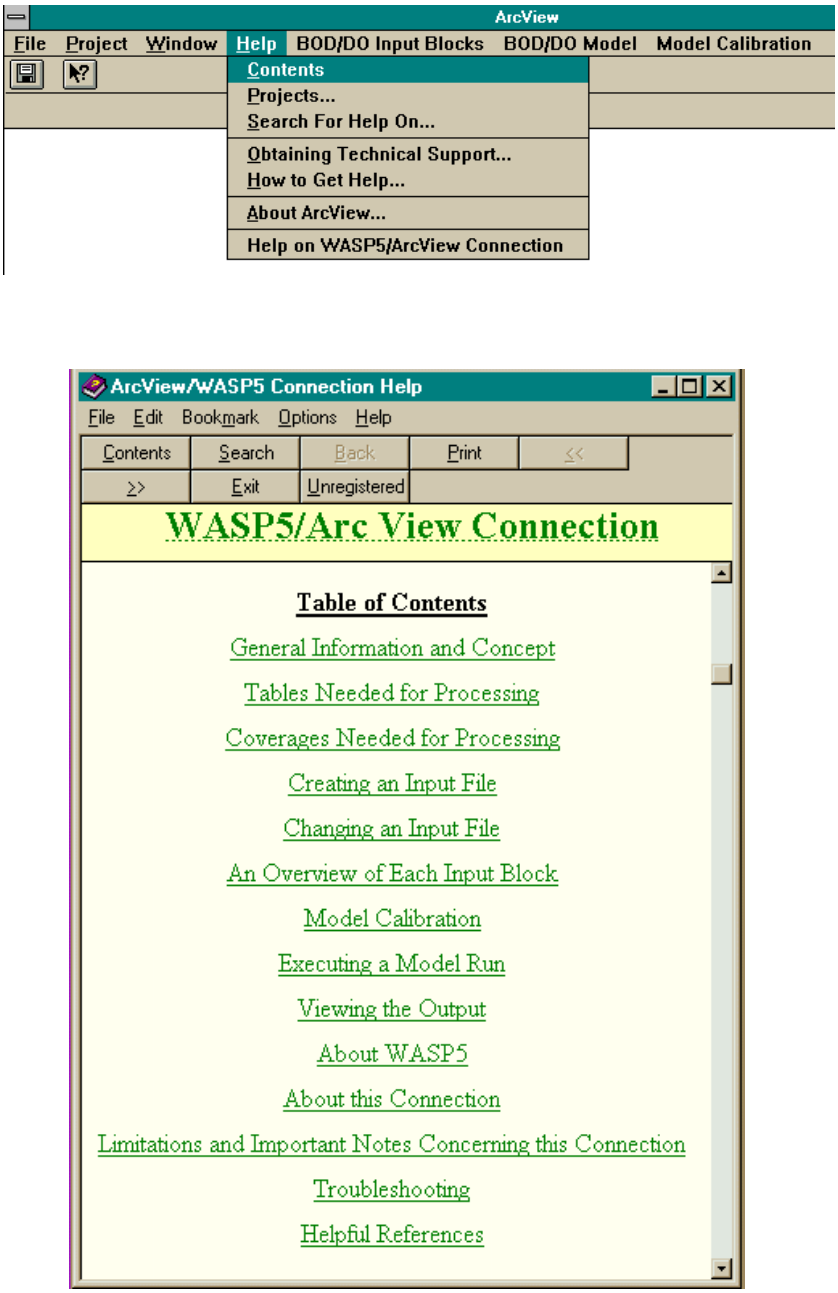


Figure 4-41 Windows help document run by winhelp.exe and created to assist a user in the execution of the WASP5/ArcView connection.

- Open the script *vwout* and locate the two references to the arc coverage *segarc*. Both of the lines in the script read:

  segSrcName = SrcName.Make("c:\wasp\cover\segarc arc")

  This line informs Avenue on where to locate the main segmentation coverage. Be sure that the drive and directory name in this line is correct. Also, if this script is being recompiled for a new system, this line should reference the correct location and name for the main segmentation coverage in the new system that has been developed.
- If the *vwout* script was changed, in any way, recompile it, by clicking on the checkmark icon on the bottom toolbar of the ArcView script tools.
- Model input file creation, model runs, and output viewing can then be performed as described previously in this section.