

Chapter 5

Results and Discussion

5.1 RAINFALL/RUNOFF AND RAINFALL/FLOW CORRELATION

Newell, et al. (1992) stated that the development of a rainfall/runoff relationship in the Houston area was difficult due to the watershed's high amount of urbanization. Instead, their 1992 study produced design hydrographs from flow and precipitation data. In the present research, however, flow and precipitation data was used directly to result in the graphs shown in [Figures 4-16 and 4-23](#). These figures show relationships for runoff and flow, with precipitation and land use. Although both equations calculated have a rather low R^2 values, the results obtained from these correlations compare relatively well to the measured values. Since these relationships were developed from data over 30 years, the equations are meant to represent long-term steady state conditions. In addition, the "relative runoff coefficient" introduced in this process only represents a relative measure of the urbanization of a given watershed and is not being used in an absolute sense.

To verify the calculated runoff values, flow data from a station (USGS Gauge 8075900), which was not used in the development of the runoff/precipitation/land use equation, was downloaded from Texas USGS (Texas USGS, 1996). This station, located on Greens Bayou, is further described in [Table 3-6](#). After the flow data from this station was downloaded, the baseflow was subtracted from the total flow, using the same FORTRAN program discussed in [Section 4.3](#). The average runoff depth for the available period of record was then calculated. To compare this measured runoff value with its corresponding calculated runoff, [Figures 5-1 and 5-2](#) were created. [Figure 5-1](#) shows the calculated runoff depth routed down the delineated streams, and the USGS gauge stations attributed with their measured average runoff depths. The runoff in the streams represents the average depth of runoff from any given point over all land upstream of that point. As a result, a direct comparison of the colors shown in [Figure 5-1](#), between the point coverage and the arc coverage, can be made. [Figure 5-2](#) displays a graph of

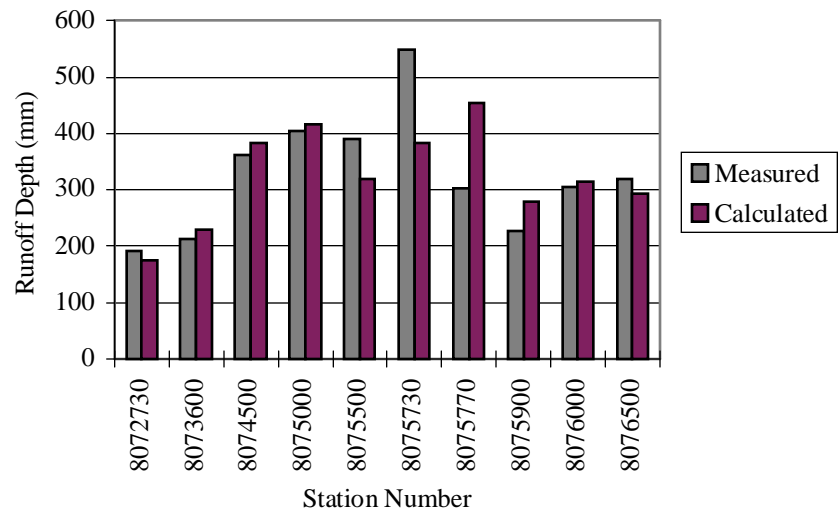


Figure 5-2 Direct comparison of calculated runoff depths at same location as measured depths for each USGS gauge. Most calculated values compare reasonably well with the measured depths. Stations with smaller watershed areas seem to have more of discrepancy.

the same stations, comparing the measured values to the calculated runoff depths for each station.

As shown in [Figures 5-1](#) and [5-2](#), the measured runoff depths compare reasonably well to the calculated depths represented by the streams. Those stations that had larger drainage areas, such as 8073600 and 8075000, seemed to result in more accurate results. The station which was not used in the correlation development (8075900) also indicates that the calculated value for that area is representative of the actual measurement. Whether the calculated values over or under estimated the actual measured values is not consistent from station to station. Errors may have been introduced by the assumption that the watershed had a uniform response to the rainfall. In addition, one station in particular seemed to be an outlying data point on [Figures 4-16](#) and [4-23](#) (8075730) This station had the smallest drainage area (8.3 mi²) and was the closest station to the coast. Since the watershed area is small and the station's precipitation is possibly influenced by the coastal environment, inaccuracies may have occurred when it was included in the regional precipitation/runoff relationship.

For the flow correlation, [Table 5-1](#) gives some selected flow measurements from various sources, compared to the calculated flow values at approximately the same location. These calculated flow values correspond to the main segment flows determined for the WASP5 model. Although the calculated numbers primarily represent the main tributaries entering into given model segment on the Houston Ship Channel, they also encompass any diffuse runoff or smaller tributaries entering into that main segment. In spite of the fact that the calculated flow values are meant to represent long-term averages, some are similar to the measurements from past years. While some of this measured flow data is decades old, this coherence is not surprising, as a large percentage of Houston has been urbanized for more than 20 years. Because of this history, the flow patterns in the metropolitan area have probably not changed significantly. In particular, the calculated flows for the Buffalo, Brays, and Carpenters Bayous correspond well to the historical data. On the other hand, the Sims/Berry, Hunting, and Greens/Hall Bayous have considerably higher calculated flows

than the measured flows. Besides errors the introduced by using one equation to represent the flow over the entire area, some other possible explanations for these differences include:

- The main segment downstream of the respective bayou may receive additional flow from diffuse runoff or smaller tributaries, resulting in a higher total calculated flow for that segment.
- Urbanization or recent land use changes may have caused the flow to increase from earlier measured values.
- The average measured flows presented in **Table 5-1** do not encompass the same years used in the correlation development (Armstrong and Ward, 1994 and Espey, *et al.*, 1971).

Table 5-1 Comparison of Calculated to Measured Flow for Various Tributaries at Different Years

Bayou Name	Calculated Flow (m ³ /sec)	Downstream Main Segment	1971 Flow* (m ³ /sec)	1994 Flow** (m ³ /sec)
Buffalo	14.23	1	15.83	12.41
Brays	5.70	2	4.67	6.55
Sims/Berry	3.54	3	1.25	3.31
Vince	1.00	4	2.38	
Hunting	2.06	5	0.99	0.70
Greens/Hall	7.59	6	3.37	2.67
Carpenters	1.20	8	0.99	

Sources: * Espey, *et al.*, 1971

** Armstrong and Ward, 1994

5.2 WATERSHED DELINEATION

In the past, watershed delineation was performed using contour maps and possibly, ground surveying techniques. Once the boundaries were drawn on maps, they could be digitized into GIS as polygons. This was the method used for the development of the watershed in Newell, *et al.*, (1992). However, for this study, the watershed delineation method used in Saunders (1996) was employed. This process, which uses a grid-based terrain analysis to determine the direction of water flow, has proved to accurate in digitally representing a given drainage basin (Maidment, 1993 and Saunders, 1996). The final watershed boundary used in this study is compared to the USGS digitized boundary in **Figure**

3-3. The USGS watersheds shown in the figure are digitized basins for each major bayou draining into the Houston Ship Channel (Newell, *et al.*, 1992). It is difficult to perform a direct quantitative comparison on the total area encompassed by the eight USGS watersheds and the grid delineated boundary, since the USGS watersheds also include an small area which lies downstream of the final outlet set for this current project. Nevertheless, the accuracy of the digital representation of the terrain can be investigated by looking at the USGS gauge station watershed areas in comparison to those delineated with Arc/Info. Table 4-4 presents the USGS watersheds as compared to the delineated areas. For most gauges, the error in the delineated basins with the given USGS area is less than 10%. Two of those higher than 10% (Stations 8072730 and 8075770) have relatively small areas, which makes it difficult to accurately represent them. It is unclear why station 8073600 has such a large difference, except that errors may have also occurred in the area given by USGS.

The primary source of these errors lies in the highly developed characteristic of the watershed. This urban development makes it difficult to accurately represent man-made flow paths such as canals and reservoirs. In addition, the flat coastal regions have proved to be problematic when trying to digitally delineate stream networks (Saunders, 1996). Although most of these errors were avoided by “burning” in a DLG of the stream network (see Section 4.3), inaccuracies still exist. In addition, complete confidence in the USGS areas should not be taken. These areas were read from contour lines on a USGS quad sheet and cannot be considered 100% accurate.

5.3 NON-POINT AND POINT SOURCE LOADINGS

Non-point Source Loading

Non-point source loading has recently become a primary area of concern related to water quality of rivers, lakes, and bays. Significant amounts of harmful materials accumulated from the land surface have been found to be carried by stormwater runoff which eventually enters the water bodies. Of particular concern in urbanized areas is BOD, oil and grease, and heavy metals. For this present modeling effort, only BOD loading was a concern

(Figure 4-19). As expected, the areas which produce higher runoffs and have more urbanization, result in higher NPS loading. The values presented in Figure 4-19 represent steady state yearly averages, but, since rainfall does not actually occur in a steady state fashion, it may be more insightful to calculate the loading from just one storm event on a time varying basis. In addition, the investigation of time varying EMCs within a storm event could also be beneficial.

For this study, though, steady state values were acceptable since the model connection is initially being developed for steady state conditions. A similar non-point source loading assessment was performed on the entire Galveston Bay system in 1992 (Newell, *et al.*, 1992). Table 5-2 presents the results from the 1992 study as compared to this present research (see Figure 3-3 for USGS subwatershed locations). Since slight differences existed in the watershed areas for both studies, care should be taken when directly comparing the two average areal loading values. In particular, a downstream portion of the Ship Channel watershed from the Newell, *et al.* (1992) study was not included in this research since it was downstream of the ultimate outlet point established in this study. For this reason, a direct comparison of those BOD loading values is not completely accurate.

Table 5-2 Comparison of BOD Non-Point Source Loading Results by USGS Watershed

Watershed	Newell, <i>et al.</i> (1992) Loadings (kg/yr/hect)	Calculated Loadings from this Study (kg/yr/hect)
Addicks Reservoir	20.2	16.1
Barker Reservoir	19.0	13.7
Brays Bayou	51.7	40.9
Buffalo Bayou	51.5	40.5
Greens Bayou	38.8	26.3
Ship Channel	46.5	40.0
Sims Bayou	41.5	30.3
Whiteoak Bayou	52.7	38.7
Total	312.9	246.5

As shown in Table 5-2, the values from both studies compare relatively well. Since both method used the same EMCs (Table 4-7) and land use coverage (Figure 3-6), the differences are probably due to the runoff volumes used in each study. As mentioned in Section 5-1, Newell, *et al.* (1992) developed design storms, using a model and previous

runoff data, while this research established a rainfall/runoff/urbanization curve. [Table 5-2](#) indicates that the runoff volumes used in this study are less than those used for an "Average Year" in the Newell, *et al.* (1992) report. However, since considerably different methods were used to obtain runoff volumes, disagreements between the two results are expected. On the whole, though, the differences in the trend in the loading from watershed to watershed is the same for both studies.

Point Source Loadings

The final point source loadings from municipalities and industry along the Upper HSC are shown in [Table 4-9](#). As discussed in [Section 4.4](#), these loadings are not truly representative of the entire system, since only half of those dischargers located along the 25 km stretch had reported BOD measurements. Although these loadings were obtained from self-reporting data or estimated with standard concentrations multiplied by flow data, these values are probably more accurate than those that could be obtained directly from the industry's discharge permit. Since dischargers sometimes gain permits for effluent concentrations and flows they do not always reach, the self-reported data is more representative of the actual flow. Because more data from the missing point source dischargers could not be obtained, the loadings given in [Table 4-9](#) were used in the model. A more refined modeling effort could consider the point source effluents entering the tributaries (segments 10 through 16), instead of assigning a concentration value to the tributary's upstream boundary, as was done in this research.

Direct comparison of these point source loadings to other reports proved to be difficult. The major stumbling block was that earlier waste loading estimations for the Channel grouped all the permitted dischargers and estimated runoff loads into one category (Espey, *et al.*, 1971 and TDWR, 1984). However, for this modeling effort, those industries not directly discharging into the Upper HSC were considered in the tributary boundary conditions. In addition, the segmentation in the earlier studies used to report total loadings did not match the segmentation used here.

Also worth mentioning is the Combined Sewer Overflows (CSOs) located in the city of Houston. In recent years, these old sewer systems have become a concern as a potential source of BOD and other harmful pollutants, during runoff events (EH&A, 1994). But, since the city has over 80 overflow locations, time constraints did not permit the consideration of these inputs into the model. Further research could be conducted to develop special boundary conditions or loadings which account for the CSOs during heavy rainfall conditions.

5.4 MODEL CALIBRATION

Salinity, which is considered an excellent conservative tracer, was used to calibrate the calculated flows, dispersive coefficients, and other parameters used in the Houston Ship Channel model. Two segments were set at their long-term salinity values, while the other segments were input at zero or minimal salinities. The model was executed to quasi-steady state and the calculated concentrations compared to measured values. The results of this model calibration are shown in [Figures 5-3](#) and [5-4](#). [Figure 5-3](#) compares the model results (smooth line) to the long-term averages from Ward and Armstrong (1992). The approximate midpoint of each hydrographic segment shown in [Figure 4-4](#), was used as the kilometer marker for the measurement. The turning basin was assumed to be the starting point and distances were positive, downstream from this datum. In addition, the same relative comparison is shown in [Figure 5-4](#), with the use of ArcView. The hydrographic segments are shaded to their corresponding concentrations, and the segments are also color-ramped in a similar fashion. Both figures show relatively good agreement of the model with the averages, with the downstream values being slightly better. Differences are probably most due to the fact that these point measurements are actually averages taken over as many as 50 or 60 years. As a result, these averages may not be truly representative of the system for flows and exchange coefficients from data for 1960 to 1990. To more accurately compare measurements to the model results, data from just those years should be averaged and used.

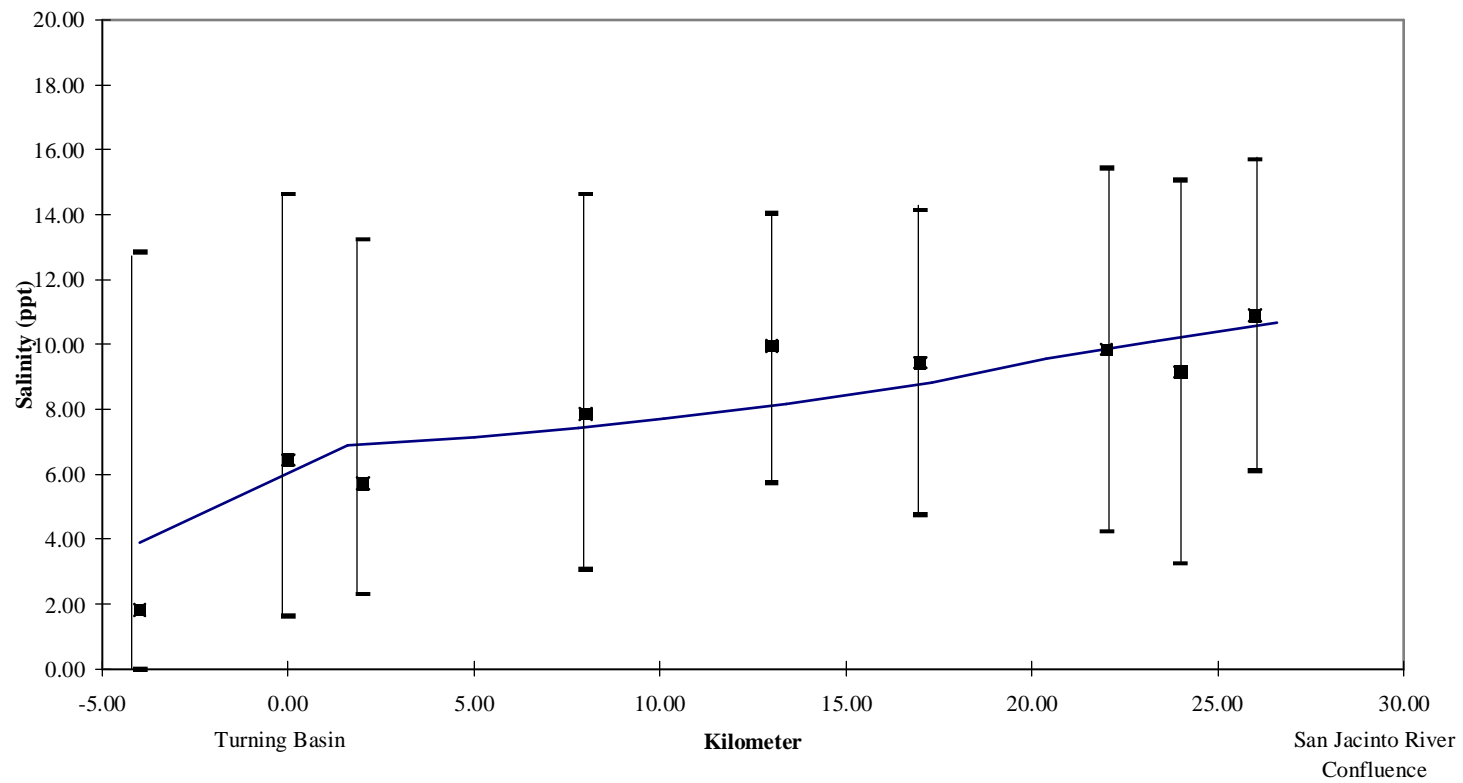


Figure 5-3 Model calibration results. Smooth line is model concentrations, while the points are averaged measurements from Ward and Armstrong (1992). The averages also have their corresponding ranges shown.

5.5 BOD/DO MODEL RESULTS

Previous modeling efforts on the Houston Ship Channel resulted in varying DO profiles over distance. In 1971, the modeled DO in the Upper HSC was near or equal to zero for all segments. The 1971 study also projected the DO in the Upper Channel equal to 1.8 mg/L if secondary treatment of wastewater was to be implemented and about 3.4 mg/L if advanced treatment was used (Espey, *et al.*, 1971). Since their modeling project was performed before secondary or advanced treatment processes were actually implemented, it is more accurate to investigate a study performed after the 1970's. In 1984, the TDWR predicted the DO in the Upper HSC would vary from just under 1 mg/L at the Turning Basin to 4.5 mg/L at the San Jacinto Monument (TDWR, 1984). However, it is unclear what reaeration coefficient was used in the 1984 model.

Figure 5-5 illustrates the BOD/DO results for the initial cases modeled in this research (Case I and II: Table 4-15). In this model run, k_2 and k_d were both set to 0.1 /day. For the average year results (runoff and NPS loads included) the DO varied from 2.5 mg/L to about 3.3 mg/L, while the BOD only had a 1 mg/L gradient from 5.5 mg/L to 6.5 mg/L. For the dry weather conditions (no runoff or NPS loads) the DO in the upper end of the modeled reach changed considerably to 0.5 mg/L, but then improved to 2.5 mg/L by the time the downstream segment was reached. The BOD in the dry weather scenario also decreased, but to a much lesser degree than the DO. The modeled BOD started at 4.5 mg/L in the Turning Basin to about 6.5 mg/L at the downstream end. Figures 5-6 and 5-7 also show a GIS representation of the DO and BOD modeling results.

The differences between the average year and dry weather conditions reflect a change in concentration due to loading and flow modifications. Since the dry weather flows did not include NPS loads or runoff, this case represents baseflow only with point source loads, or a worst case scenario for flow conditions. Because of this low flow condition, the DO concentrations decline, since the Upper HSC does not receive as much DO from the tributaries. The BOD concentrations also decline, although not as sharply as the DO, since

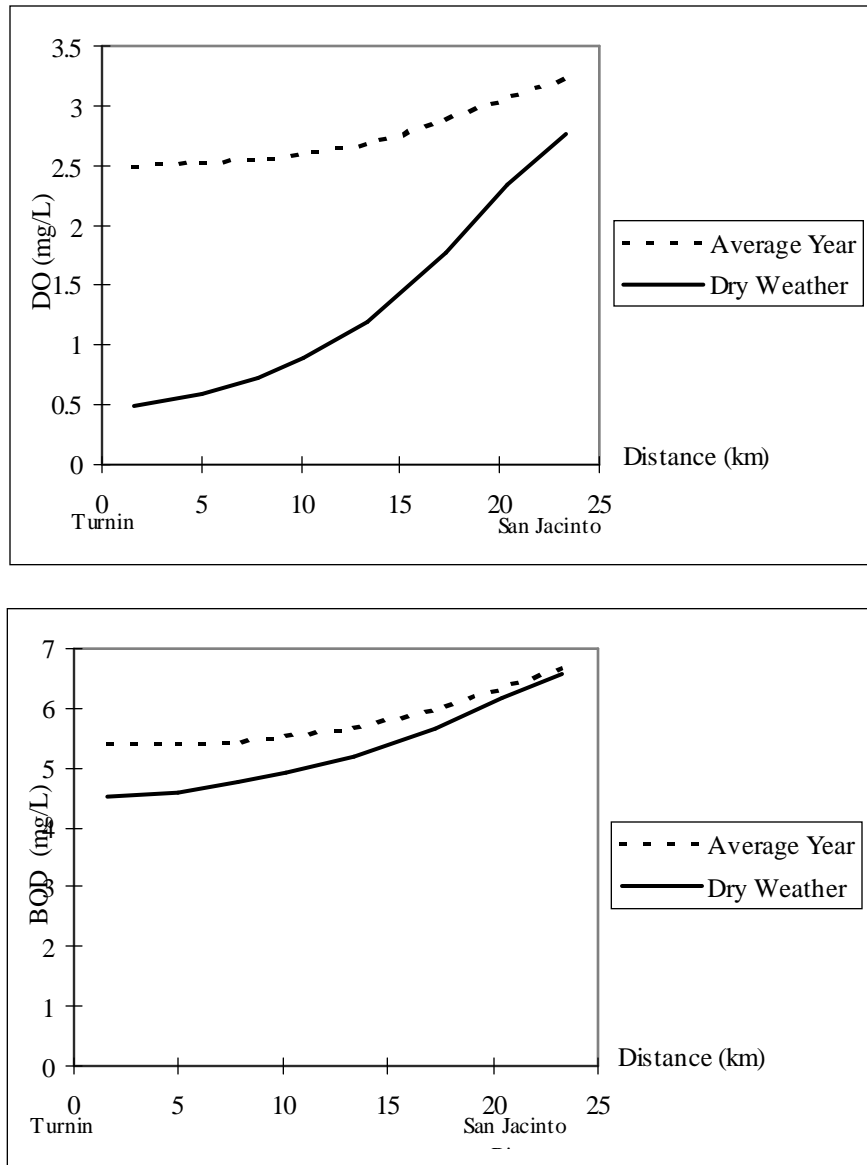


Figure 5-5 BOD and DO modeling results for average year and dry weather conditions. Graphs show a decrease in both DO and BOD concentrations from the average year (Case I) to the dry weather conditions (Case II) .

the segments are still receiving the point source effluents from the industries, but not the NPS loads. For a comparison of the daily loading to each segment from point and non-point sources, refer to [Table 4-14](#). For both cases, the upstream result in segment 8 is somewhat controlled by the boundary condition set at segment 17 (see [Figures 4-6 and 4-7](#)). This boundary condition (3.64 mg/L DO and 7.42 mg/L BOD) accounts for the large inflow of the San Jacinto River entering that segment. To avoid this forced boundary, the entire channel could be modeled, from the Turning Basin to Morgan's Point (the confluence of the channel with main Galveston Bay -- see [Figure 1-1](#)). As a result, Galveston Bay could be set as the downstream boundary condition instead of a portion of the channel, resulting in a more representative model of the entire system.

In comparison to the 1984 modeling effort, the overall averages of DO in the Upper HSC are about the same (around 2 to 2.5 mg/L). The current model shows a higher concentration in Turning Basin than the 1984 model. This result may be accurate, since the loadings to the Houston Ship Channel are said to have declined in the past decade (Shipley and Kiesling, 1994). The downstream result for the 1984 model, though, is higher than the result from this study's model (TDWR, 1984). This difference may be due to the boundary condition mentioned in the previous paragraph. In addition, it is unclear exactly what reaeration coefficient was used in the 1984 study for this 25 km reach. As a result, the differences in the two models' results could be attributed to a change in the reaeration coefficient.

5.6 MODEL SENSITIVITY

To investigate the model's sensitivity to the constants used in the input, two additional cases were run on the average year conditions (see [Table 4-15](#)). The cases either increased reaeration coefficient, k_2 or deoxygenation rate, k_d , while keeping all other parameters, loadings, and flows the same. [Figures 5-8 and 5-9](#) show the results of this effort. [Figure 5-8](#), which illustrates Cases I and III from [Table 4-15](#), indicates that that DO concentration is dependent on the value of k_2 . The results show an increase of anywhere

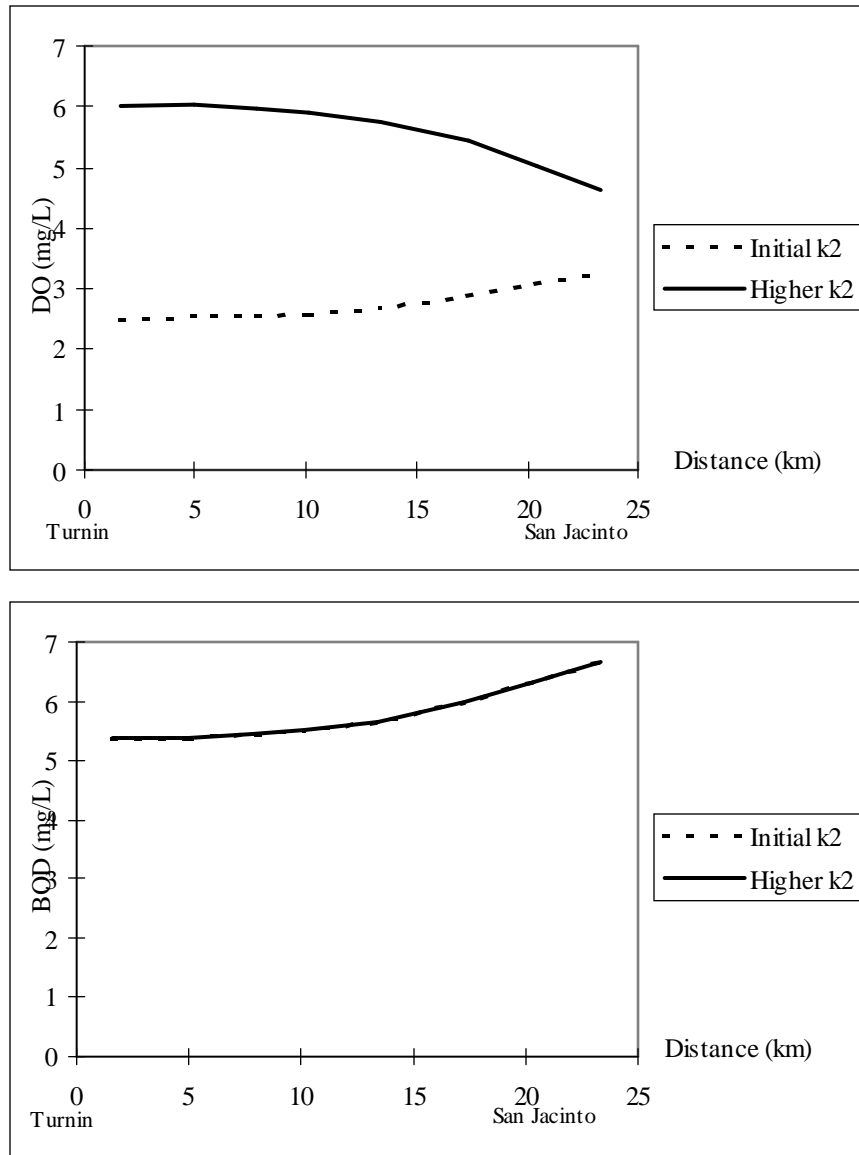


Figure 5-8 Comparison of Case I and Case III for BOD/DO model. Both used average year conditions, Case I: $k_2 = 0.1$ /day, Case III: $k_2 = 0.5$ /day. The BOD concentrations in both Cases are the same.

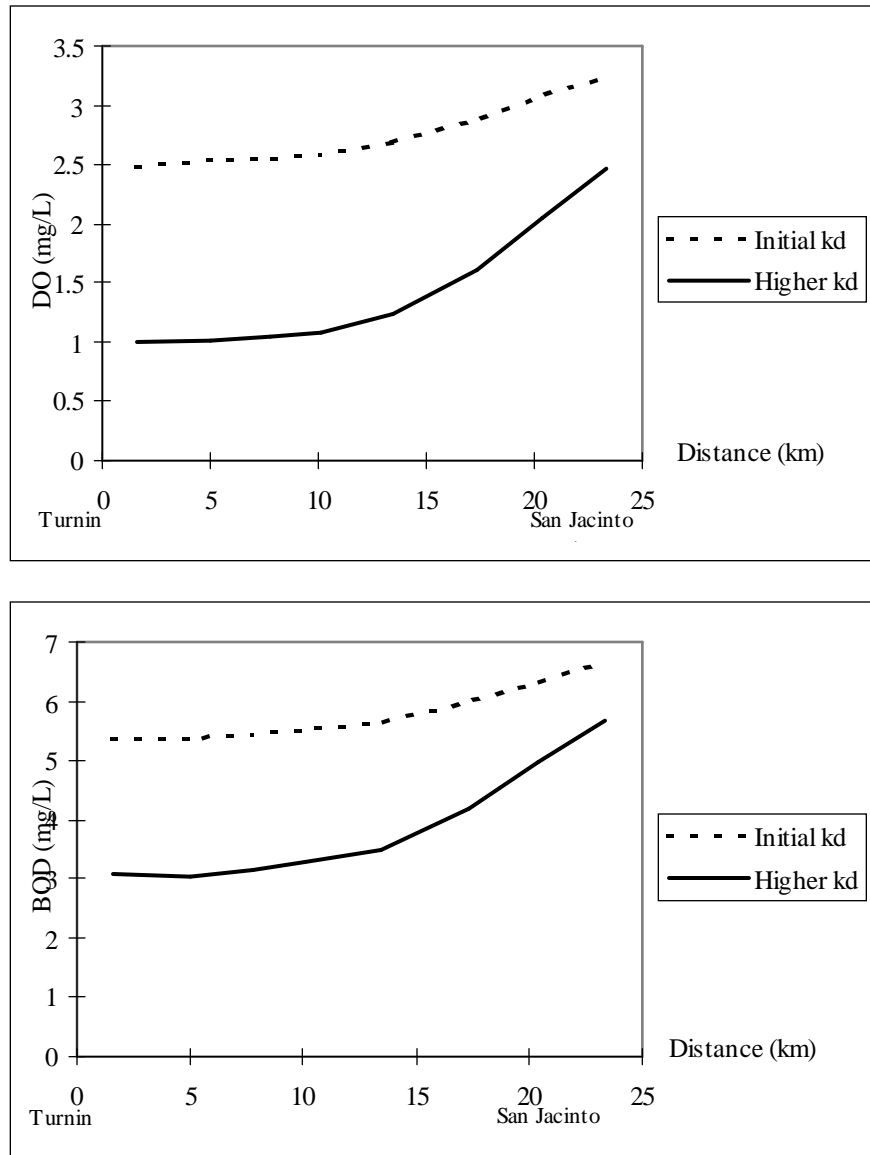


Figure 5-9 Comparison of Case I and Case IV for BOD/DO model. Both used average year conditions, Case I: $k_d = 0.1$ /day, Case IV: $k_d = 0.3$ /day.

from 1.5 to 3.5 mg/L of DO over the modeled water body. The concentration of BOD, though, stays exactly the same for both cases. **Figure 5-9**, which represents a comparison between Cases I and IV, shows decreases in both BOD and DO concentration for an increased k_d .

The increase in DO due to an increase in k_2 (Case III: **Figure 5-8**) is expected; a higher reaeration coefficient indicates that oxygen is being introduced into the water at a faster rate. The influence of this change is shown especially in the upstream portion of the HSC. However, the modeled concentrations seem more dependent on the aforementioned boundary concentration in segment 17 for the downstream segments. The fact that the BOD did not change for a higher in k_2 indicates that its concentration is dependent on the loadings to the system and the value of k_d , rather than the concentration on DO in the water. However, it should be noted that more sophisticated model of the system would result in the BOD concentration depending on the DO concentration. For an increased k_d (Case IV: **Figure 5-9**) the changes in DO concentration from the initial case (Case I) are not as pronounced as for Case III. The dissolved oxygen follows the same profile in both Cases I and IV, but the overall difference only varies from about 1 to 1.5 mg/L. This decrease in DO is understandable, since the BOD is being oxidized at a faster rate. The overall result is that more BOD is used, causing lower DO concentrations. Likewise, the higher k_d also reduces the final BOD concentration. Similar modeling results were observed in the TDWR model when investigating sensitivity. A 50% change in the reaeration coefficient resulted in a significant difference in the final DO concentrations. However, the same percentage change to the oxidation coefficient did not effect the modeled DO much (TDWR, 1984).

5.7 WASP5/GIS CONNECTION

Introduction

The overall connection illustrated in **Figure 4-24** is accomplished in GIS through scripts written in Avenue, the programming language for ArcView. The connection allows the user to perform a number of modeling scenarios, including model calibration, average

year BOD/DO modeling, and dry weather BOD/DO modeling. At the present time, the connection set up for a Simple Streeter-Phelps model through EUTRO5 or a model calibration using level one TOXI5. In addition, this initial link only considers steady state processes.

For the connection to work, all of the tables and coverages described in [Section 4.6](#) must be opened in the ArcView project. In addition, the field names for each table have to correspond to the names described in [Appendix A](#). Presently, the GIS/WASP5 connection can be termed a "loose link", since a FORTRAN program actually formats the data exported from ArcView into the input file for WASP5 and another FORTRAN program reads the WASP5 output file to write a readable text file for ArcView. Even so, the connection can be considered quite unique in that it utilizes Avenue and provides a link into and out of the GIS software, ArcView. Most other examples of connections to models with GIS have been using Arc/Info, which is command-line based and primarily utilized in coverage creation. ArcView, on the other hand, is a user friendly Windows-based program which lends itself to customized menus, multiple display of coverages, and easy output presentation.

It is important to note that a basic knowledge of WASP5, specifically EUTRO5, and a general understanding of ArcView is necessary to use this connection to its fullest extent. The help file provided with the connection ([Section 4.6.9](#) and [Appendix G](#)) is meant to assist the user with the general concept and processes in the GIS/WASP5 link. It is not, however, intended as a stand alone document for ArcView and WASP5 methodologies or concepts. When creating this connection, it was assumed that the user understands the parameters needed for a WASP5 input file and also knows how to produce this input in the necessary GIS format. Information on WASP5 can be obtained from the USEPA Homepage (<http://www.epa.gov/>) and the WASP5 User's Manual (Ambrose *et al.*, 1993). In addition, some knowledge of ArcView is an advantage when the final output presentation stage is reached. Although the interface does create new charts and themes, the final formatting of these objects has to be performed by the user ([Section 5.8](#)).

Scripts

As mentioned in [Section 4.6](#), there are 33 Avenue scripts which run the GIS/WASP5 connection. The choices on the customized menus shown in [Figure 4-25](#) control each of these scripts. In most instances, the order in which the menu items are invoked is not important, excluding the following cases:

1. *Input Block A: Model Options* is run before executing any other scripts. This input block sets the working directory which tells Avenue where to find the FORTRAN programs and model executables. This input block also sets some initial model parameters for the rest of the input block generation and allows the user to name the WASP5 input file. Note that for model calibration, Input Block A is automatically run if "Write Input Information" is chosen ([Figure 4-25](#)).
2. *Check Model Parameters* is always run before processing and viewing output data from WASP5. This script double checks the print options set for the output file and retrieves the name of the output file to process.

A beneficial characteristic of the menu structure is the ability to perform the steps that produce model output at different times. Multiple input files can be generated one day, the model runs performed later, and then any output file processed at any time. Any table resulting from the output processing can be used to create new themes and charts in the *View Output* command during any project session.

The first customized menu *BOD/DO Input Blocks* has the option of creating all 10 WASP5 input blocks at once, or executing just one script that generates the related text file for one particular block. This feature is an advantage if only one or two model characteristics need to be changed after the initial creation of an input file. For example, after an input file for a given model with the initial conditions is made, the user can create input files for the same system while changing just the model constants or boundary conditions.

Input Message Boxes

The interface used to input and choose information is the Avenue input message box. These message boxes (see [Figure 4-32](#)) allow the user to choose from a list of available variables, or input required parameters by keyboard. One limitation to these message boxes is size; the size of the box is preset in Avenue. As a result, it is sometimes difficult to reduce the amount of text in a string so that all the information is displayed in the choices. This problem, shown in [Figure 4-35](#) (b) is only resolved when the string is chosen, causing the rest of the text to appear in the top selection box.

Limitations

One limitation to the interface is its extreme sensitivity to the table, coverage, and field naming conventions. If a table or coverage outlined in [Sections 4.6.4](#) and [4.6.5](#) is not included, named differently, or its fields named incorrectly, the scripts are not able to read the table information to print to the text file. This error occurs because each script searches for the tables by its name or alias. In addition, the units outlined in [Appendix A](#) for the table fields have to be adhered to, since the scripts contain unit conversions to write the input information for WASP5 in the proper dimensions.

Limitations are also present in the output processing, table/chart relationships, and multiple new theme creation. The maximum length of the output file to be processed is dependent on the amount of available memory of the computer running the connection. For EUTRO5, 18 lines of text are written for each segment at every time step. In the same way, 7 lines of text are written for each segment at each time step in the TOXI5 output file. If an "out of memory" or "stack overflow" error occurs when trying to process the output data file, the number of times steps written to the output file can be reduced to decrease the number of lines in the WASP5 output files. Concerning the table/chart limitation, a chart is always related to its data table. If one or a number of records are chosen in a table, the chart will display all selected records. Once the table selection changes, the chart modifies its display, accordingly. This restriction becomes a problem when two records from the same chart want to be viewed separately. To get around this relational limitation, two identical tables are

added to the same project. A different chart is then linked to each table. Finally, the ArcView constraint related to the new theme creation has to do with joining new fields to a table. When a new theme is created by the output viewing step, the aat of the "main segmentation" coverage is actually joined with the values of concentration at a chosen time step. This field then becomes the attributed field for the theme legend. However, although multiple copies of this theme can be added to a view, only one aat truly exists for this coverage. Because of this concept, once a project is exited, ArcView only "remembers" the field for the last theme created and the concentration values from that time step control all "main segmentation" themes attributed with concentration. One way to avoid this problem is to manually create a dbf table with a field for each concentration value to be displayed. This table is joined to the "main segmentation" table and multiple themes are attributed with the desired field, instead of using the same field with different concentration values depending on the theme.

The final limitation to the connection is related to the speed of the model run through ArcView. Since WASP5 is a DOS-based model, ArcView must execute a DOS prompt to execute the model. However, when this process occurs, the graphics entailed in displaying the DOS prompt and running the model cause the program to run at a slower speed than if the model were run directly through DOS (Plover, 1996). In addition, when ArcView runs either EUTRO5 or TOXI5, ArcView is suspended and control is passed to the DOS prompt. Any further ArcView scripts are delayed with a message box display (see [Figure 4-32](#)). When the model is completely finished running, control is returned to ArcView by pressing "OK" in the message box.

Comparison to Previous Connections

As mentioned in Chapter 2, the majority of the previous connections of GIS to existing models have used the software programs, Arc/Info and GRASS. This research, on the other hand, utilized the ArcView software with the object-oriented programming language, Avenue. Specifically in relation to the WASP model, the only other connection that was found in the literature used Arc/Info and its corresponding macro language to

establish a link between EUTRO4 and GIS (DePinto, *et al.*, 1993 and DePinto, *et al.*, 1994). Although both this current connection and the EUTRO4 connection, called GEO-WAMS, would be considered "partial integrations" as described by Tim and Jolly (1994) (see [Figure 2-1](#)), the Arc/Info interface is more advanced than this current ArcView link. The connection for this present research is still in its initial stages and there is much room for modeling advancements in the interface. However, it seems that the current trend in GIS modeling incorporates ArcView and Avenue more frequently, since ArcView is more visual and user-friendly than Arc/Info. As a result, the possibility exists to further develop this connection to the level that GEO-WAMS has attained.

Future Possibilities

Now that the initial connection to the WASP5 model is established, the possibility for further refinement and advancements in the link is completely possible. As newer versions of ArcView are released, updates to Avenue may make it easier to format the data directly from Avenue to a WASP5 input file, instead of using FORTRAN to format the files. Another possibility to investigate would be to further utilize GIS's topological concepts by having the scripts determine direction of flow and neighboring segments and possibly develop the option for more complex modeling (i.e., overlying water segments, etc.). In the future, the connection can be updated to run all levels of complexity of WASP5, along with time varying parameters. A final goal could be to develop the pollutant loading model within ArcView so that impacts on land use or engineering practices to the receiving waters could be observed directly through ArcView, without having to perform the NPS loading analysis in Arc/Info.

5.8 OUTPUT PRESENTATION

One of the powers of ArcView lies in its output presentation capabilities. Once a general knowledge of the software is gained, the possibilities for communicating information to engineers, city planners, or the general public are limitless. With the output data processed, different tables and charts can be related, along with various new themes, to display the model results. [Figures 5-10](#) through [5-13](#) illustrate just a few examples of the

output formats possible through ArcView. **Figure 5-10** shows the relational capabilities of GIS through a one-to-one relate. The table shown on the bottom of the page is related to the segmentation coverage in that each arc in the coverage has one corresponding record in the table. This ability is an advantage if the user wants to see the given information about one segment, quickly and easily. By highlighting the segment on the coverage, the corresponding record highlights in the table; the opposite occurs if the table record is first highlighted. In addition, multiple tables can be linked together to allow even more information to be displayed. For example, if concentration measurements for the segments at different times are known, a table containing this information can be made in ArcView and a one-to-many relational link established between the present table and this new table. The user can then view all measurements taken in a particular segment by just clicking on that segment.

Figure 5-11 illustrates the charting capabilities of ArcView for output presentation. This figure shows BOD and DO concentrations versus time for two segments in the main reach. By formatting the charts and themes in an ArcView layout, the user can depict the different concentration changes in different segments over time, with one picture. Unfortunately, the chart formatting options in ArcView are limited which makes it difficult to obtain consistent graphs in **Figure 5-11**. **Figure 5-12** depicts the output from a "movie"; one of the output viewing options for the GIS/WASP5 link. With this figure, one can see the change in concentration of DO over time. Although, for steady state model runs, these views only illustrate the model reaching quasi-steady state, this option lends itself well to output viewing if time-variant modeling is attempted. Finally, **Figure 5-13** is meant to show the multiple display ability of ArcView. The number of objects which can be displayed on layout is only limited by style and space. In **Figure 5-12**, a table, chart, and view, all portraying dissolved oxygen results, are placed on the layout. The chart allows the user to see the final concentration in all model segments, while the table and view permit representation of the concentration in just the main modeled reach.

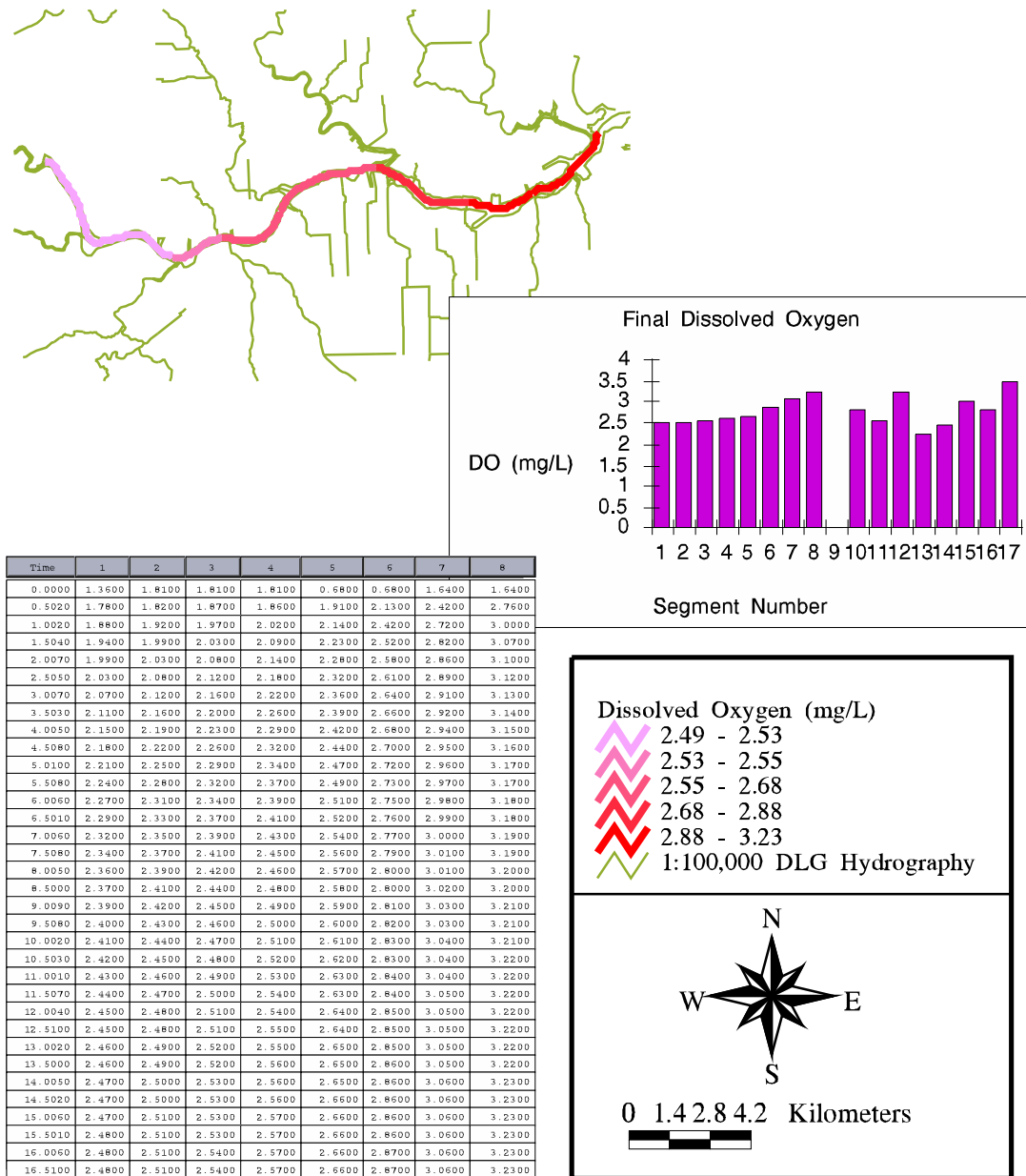


Figure 5-13 Layout illustrating the multiple display capabilities of ArcView. A view of the segmentation with the final DO concentration gradient is shown, along with the table from where the final data was obtained. The chart shows the final concentration of DO in every model segment, including the boundary ones.