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**TWDB R&PF
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Developing a GIS – TxRR Model

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The Overview of TxRR Project

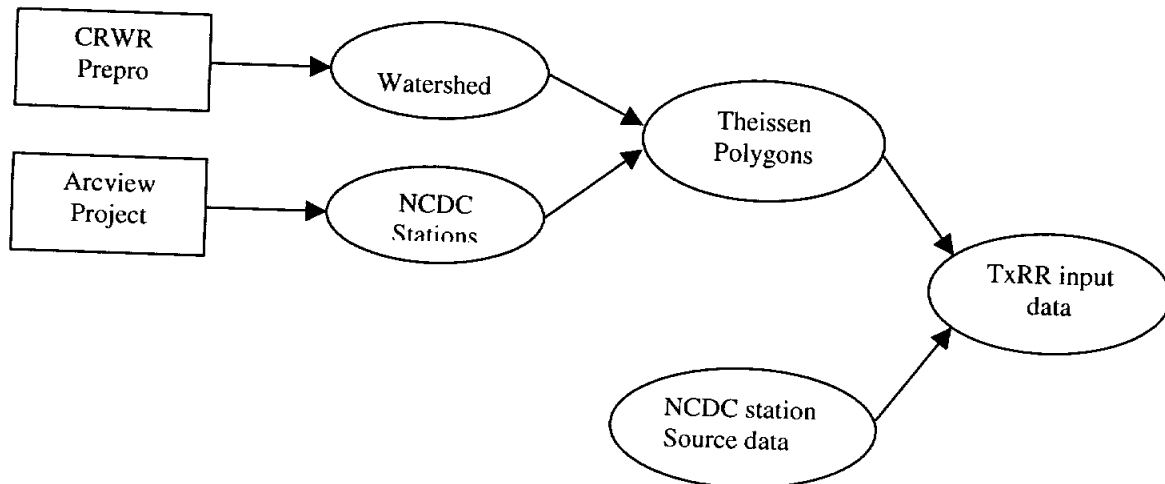
The Texas Water Development Board has a soil water balance model called TxRR (Texas Rainfall-Runoff), which is used to simulate the inflow to Texas bays and estuaries. This program requires input data on geographic definition and connection of the drainage areas of the bays and estuaries, on soil and land use properties of these areas, and on daily precipitation data. The current form of the TxRR model does not have an explicit connection to a geographic information system, nor does it have a formal structure for storing and manipulating the precipitation data from gages to determine precipitation data over drainage areas. This project was formulated to address these deficiencies using the Nueces and Corpus Christi Bay system as a pilot test area.

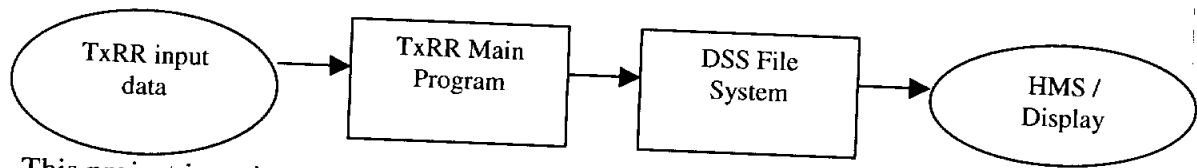
A structure is devised which couples TxRR with the ArcView GIS, the HEC-HMS hydrologic modeling system for routing water through the landscape, and HEC-DSS for storage and manipulation of precipitation time series.

The TxRR model has been developed by TWDB to simulate precipitation-runoff. The main program is written in FORTRAN. This program takes historical daily precipitation data as simulation input. In this project, a GIS pre-processing procedure was developed to create input data for TxRR main program. Also, the connection between the Fortran program and GIS project has been implemented. After the model execution, the data storage tool within the HMS system is used for data management and display.

The source data used in this project are daily precipitation data from NCDC stations. This data has been compiled onto a source data CD.

The whole procedure of this project is straightforward and fairly simple. First, we use CRWR-PrePro in ArcView to develop watersheds for a basin of interest. Second, we create a point coverage of NCDC gage stations over the basin. Next, Thiessen Polygons are added to the basin and an average of the precipitation data is calculated at each NCDC station. After the data has been processed, we go back to ArcView project and call the TxRR Model interface to run the program in Fortran. After the model has run, the output data is stored in the DSS file system and displayed in HMS.





This project is an implementation of a GIS application in hydrologic modeling. The report focuses on a detailed description of building a GIS-TxRR model for the Nueces Estuary with the method that has been developed. The following figure shows the location of the sample area.



Location of the study area

The Structure of TxRR Model Implementation

The model package is implemented in three main parts: GIS pre-processing and post-processing, data storage system, TxRR main program in FORTRAN, and HEC-HMS.

GIS preprocessing

The input file required for the TxRR model includes a list of parameters, and two sets of historical data (precipitation and streamflow values). With the aid of GIS, it is possible to create this input file by associating the source data with geographic definitions (e.g. watersheds). The GIS preprocessing is used to achieve the following goals:

The GIS preprocessing procedure is structured as follows:

- 1) CRWR-PrePro is used to construct an HEC-HMS basin file that contains the watershed properties of the region of interest. This basin file can be geographically displayed by both ArcView and by HEC-HMS.
- 2) CRWR-PrePro is also used to construct Thiessen polygons around the precipitation gages in the region of interest, and to intersect these polygons with the watersheds so as to determine the precipitation gage weight needed in each watershed.

Within ArcView, the extensions CRWR-Raster and CRWR-Vector need to be installed for this project. These extensions provide tools necessary for manipulating shape files and grids. The CRWR-Vector extension is a tool set which includes functions for creating Thiessen Polygons. Also, it contains several useful tools for manipulating shape files. For example, it contains a tool to calculate the area of a newly defined polygon. CRWR-Raster is used to manipulate grids. For example, to focus the study on a particular region, Raster tools are used to extract a portion of a grid from an overall DEM.

Data Storage System

For this project, HEC-DSS is used as the time-series data storage system. This database was developed for storage of large amounts hydrologic data in the US Army Corps of Engineers Hydrologic Engineering Center's models. The DSS file format can be imported directly into HEC-HMS software, which is the main reason this tool was selected as the data storage system.

A DSS database is a collection of time series data elements with default or user defined fields such as the following: station ID, station name, time and date. This database allows users to modify the existing fields and configure the data format. After the database has been built, time series information can be indexed by specifying data search fields.

The DSS package also provides tools for data display and data importing and exporting. With these tools, the data can be prepared as a text file, imported into DSS format and printed out as a report from this DSS file.

This project also uses two tool packages: DSSTUL and DSPLAY. DSSTUL provides a means of performing utility functions on data stored in the DSS system. These functions include tabulating, editing, copying, deleting and converting data. These functions provide a means of converting data between text format and DSS format. DSPLAY is a utility program whose main function is to provide a quick and simple means of graphically displaying data stored in a DSS file. DSPLAY is available on a Unix or a DOS platform but is not Windows compatible. This limitation affects the usability of DSPLAY because ArcView and other GIS software are commonly Windows based.

TxRR Model

The form of the TxRR model used in this project was programmed in FORTRAN. It takes an input file containing user specified parameters, streamflow historical data,

precipitation historical data. The output file of the model is a simulation of the daily streamflow during the user-specified time period.

The TxRR FORTRAN program can be controlled within an ArcView project by using ArcView menu controls.

To run TxRR Model, the following functions are provided in the TxRR ArcView project:

- 1) Edit the input file parameters,
- 2) Retrieve the data from the DSS files and convert it into the TxRR input file format,
- 3) Run the TxRR program,
- 4) Convert the results into DSS format and store the data into DSS files, and
- 5) Display results of model runs in DISPLAY.

HEC-HMS

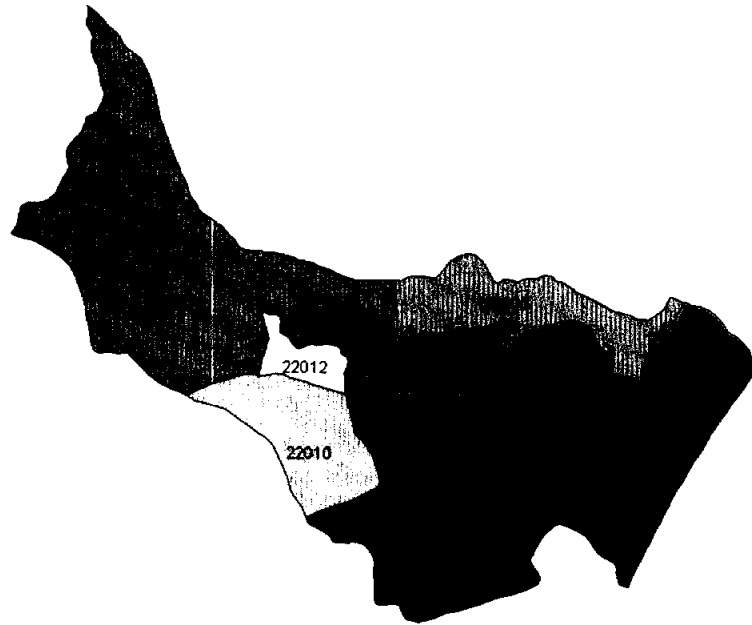
HEC-HMS can be used for display and routing of the streamflow data. At this point, the results of GIS preprocessing and the historical data prepared by the DSS system are combined into a basin file that can be read by the HEC-HMS software. HEC-HMS has the ability to display the hydrological properties of a basin and to perform further simulations.

The final step includes exporting the data (i.e. excess runoff) from the TxRR model into HEC-HMS for the purpose of graphical data display.

Building a GIS – TxRR model for the Nueces Estuary

1. The original TWDB TxRR layout

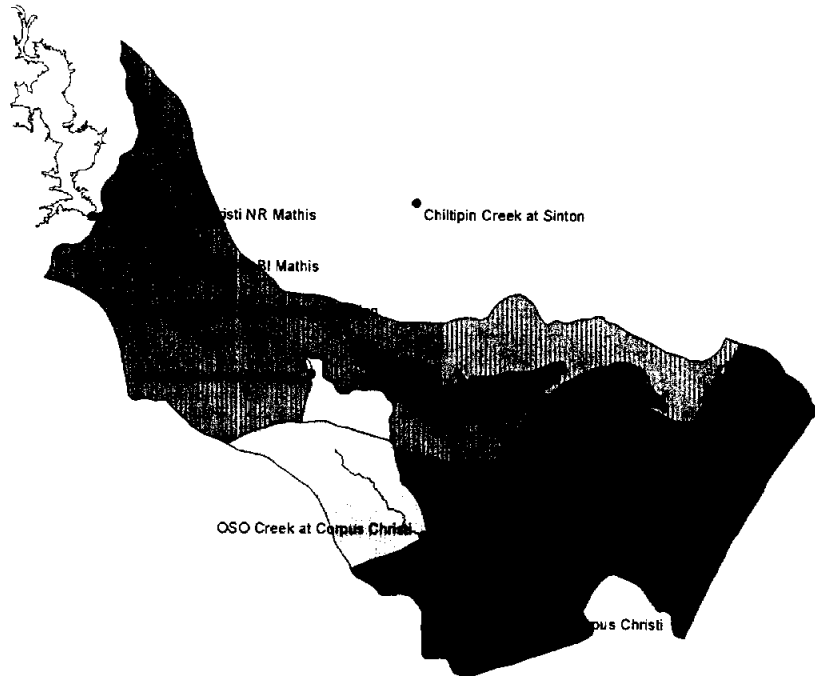
The point of departure for building a GIS-TxRR model for the Nueces estuary is the layout of the drainage areas which had been used by the Texas Water Development Board for the original TxRR model, as shown below:



There are 4 bay systems, labeled as shown: Nueces Bay (24820), Corpus Christi Bay (24810), Redfish Bay (24830) and Oso Bay (1). Draining into these bay systems are 9 land surface areas: Upstream Nueces River (21010), Downstream Nueces River (22012), Nueces River Estuary (22013), Upstream Oso Creek (22010), Downstream Oso Creek (22011), and four areas draining mostly to Corpus Christi Bay (0 – Mustang Island, 14850, 22014, and 20005). It is not clear from the layout how this schematic was defined or which bays some of the downstream areas drain into. We have attempted to refine this layout using digital elevation models in this research.

2. Building a Base Map

In order to get a sense of why the original watershed layout had been done as it was, the EPA river reach files and USGS gaging station locations were placed on the map. The river reach files were edited to isolate the main stem of the Nueces River and of Oso Creek. When these files were overlaid on the TWDB TxRR layout, some reasons for the boundary choices became obvious. First the upstream portion of the boundary is defined by the location of the outlet of Lake Corpus Christi into the Nueces River near Mathis, Tx. Second, the lower subdivisions of the drainage on the Nueces River appear related to the location of the gage at Callalan, and to the point where the Nueces River enters Nueces Bay. Finally, the division between the upper and lower drainage areas on Oso Creek is located at the Oso Creek gaging station.



3. Defining a Digital Elevation Model

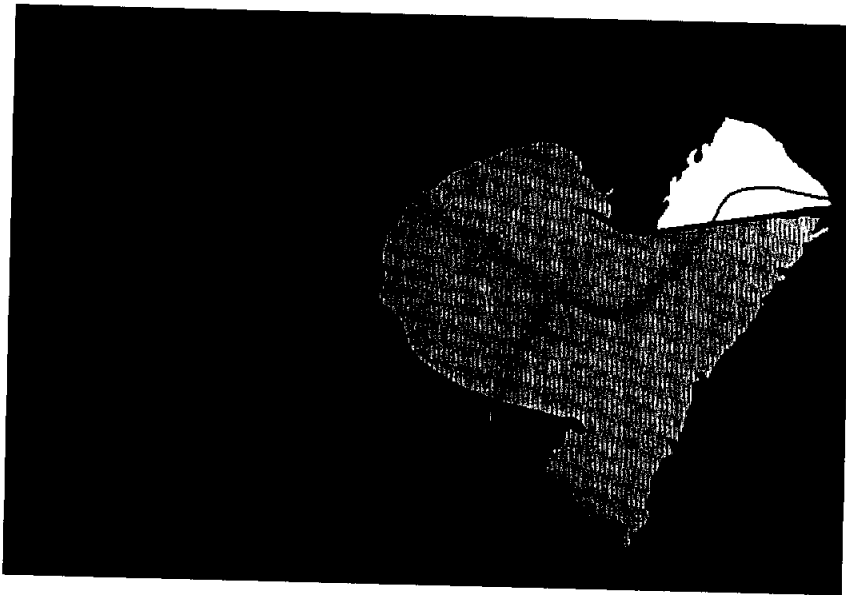
In order to define the drainage areas in a more systematic way, it is useful to employ GIS analysis of a digital elevation model (DEM). In this instance, a 30m DEM was used, derived from the 1 arc-second National Elevation Dataset for Texas.



This elevation model has $2718 \times 3129 = 8.5$ million cells, each 30m by 30m in area, with an elevation value at the center. The elevation data are given in floating point meters, such as 32.1864, which corresponds to 32.1864 m above mean sea level. The elevation

data are not really as precise as this number of decimal places implies. The use of floating point meters as units is to allow a smooth variation of topography near the coast where 1 m change in elevation can take place over a considerable distance.

In order to ensure that drainage follows a correct path from bay to bay out to the Gulf Coast, the DEM was modified, so that Nueces Bay and Oso Bay were everywhere attributed as 4500 m, Corpus Christi Bay was attributed as 4000m, and Redfish Bay with 3500m. All the land surface cells had 5000m added to their elevation.



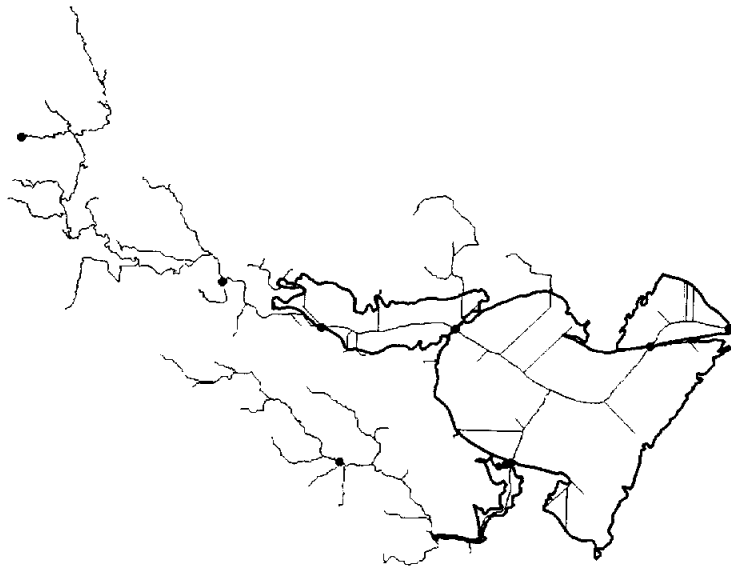
In addition, a series of flow lines were cut into the DEM, shown here in light blue, to direct the flow through the bays in a logical way, and to prevent the Lower Laguna Madre and Aransas Bay from entering the model. The lines crossing these main flow lines at the bay exits were put there to ensure that all the drainage passing through each bay is accounted for at a single location at its outlet. The elevation on these lines was set at 2000m. This, rather artificially modified DEM was used for all subsequent processing steps.

The DEM was processed using CRWR-PrePro as if it was everywhere a land surface. Standard methods were employed as described at:

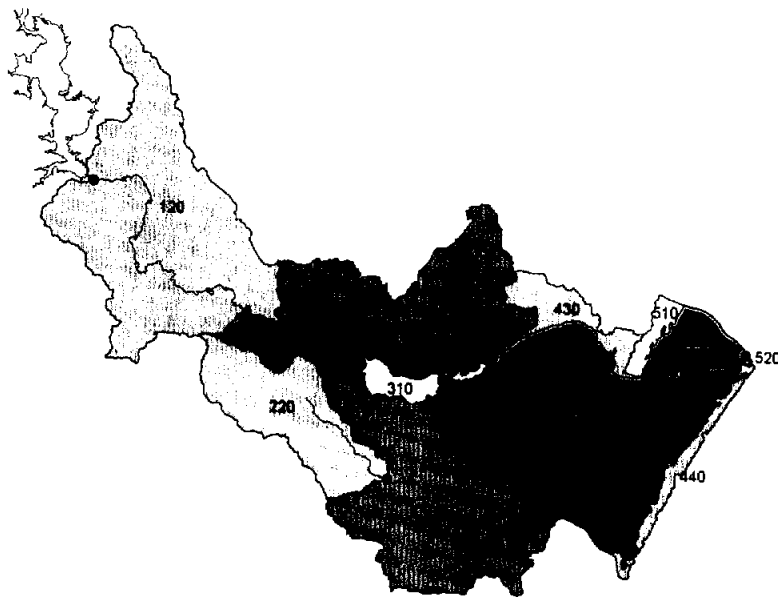
<http://www.ce.utexas.edu/prof/olivera/prepro/prepro.htm>

4. Determining Drainage Areas

Drainage outlets were placed at the same locations on the land surface portion of the DEM-based drainage network as they had existed in the original TxRR layout, and additional drainage outlets were placed at the exits of each of the 4 bays in the model. The curvilinear drainage paths on the land surface in the picture shown below are the result of "burning in" the principal rivers and streams into the DEM. The straighter flow lines within the bays followed paths that were digitized by hand and also burned into the DEM, as previously described.



Watersheds were delineated from each of the red dots on the outlet locations, then the portion of the watershed that is a bay was clipped out from the remainder by using the template of the extent of each bay in the original TxRR layout. The resulting drainage area layout is shown below.



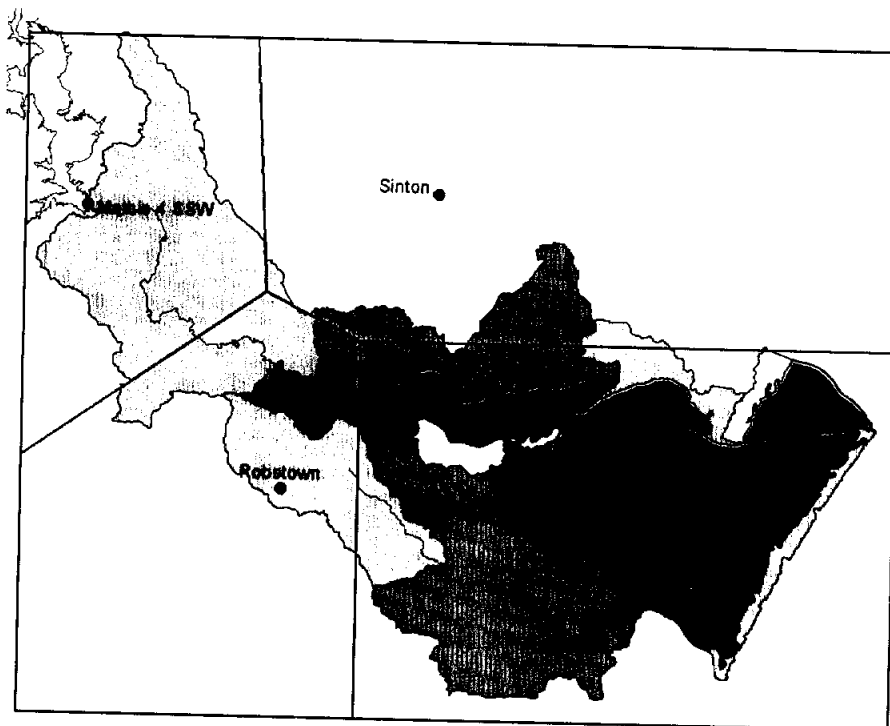
A new numbering system for these drainage areas was evolved. Drainage flowing into the Nueces River is labeled 110 (Lower Nueces below Calallen), and 120 (Upper Nueces between Lake Corpus Christi and Calallen); Oso Bay is labeled 200, and its two watersheds labeled 210 (watershed of Oso Bay below the USGS gage on Oso Creek), and 220, drainage area of Oso Creek above the USGS gage); Nueces bay is labeled 300, and it has two direct contributing areas, 310 on the South Side and 320 on the North side; Corpus Christ Bay is labeled 400, and it has four contributing areas: 410 East of Oso Creek, 420 South of Corpus Bay, 430 North of Corpus Christi Bay, and 440 which is that

portion of Mustang Island that drains inward towards Corpus Christi bay; finally, Redfish Bay is labeled 500 and it has one drainage area on each shore, 510 and 520, respectively.

This watershed scheme follows approximately the same logic as did the original TWDB TxRR model layout, but the individual drainage areas are more precisely defined in terms of which river or water body their drainage enters.

5. Determining the Thiessen Polygons

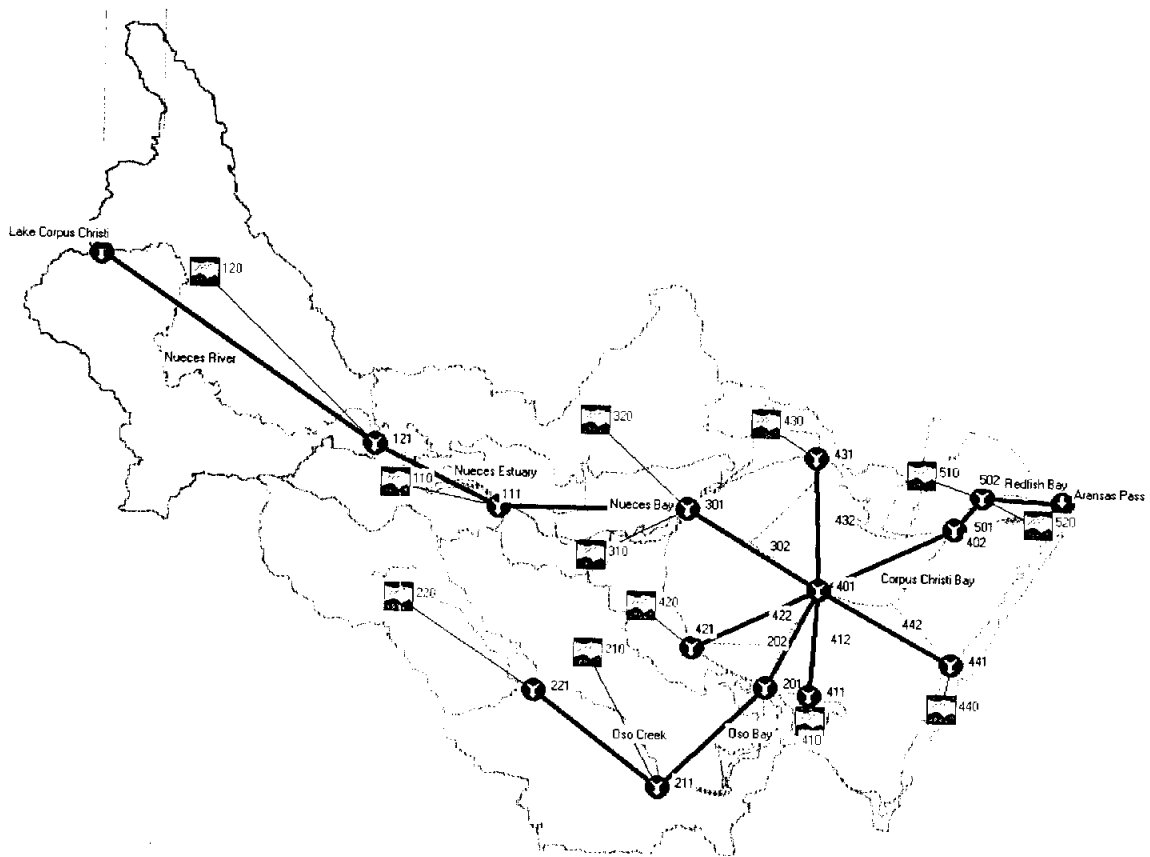
Four NCDC weather stations were used in the TxRR simulations: Corpus Christi, Mathis, Robstown, and Sinton. The Thiessen polygons for these stations were defined using the CRWR-Vector extension of ArcView. These polygons were intersected with the drainage area polygons using the ArcView Geoprocessing Wizard. Then, CRWR-Vector was used to determine the resulting areas of each Thiessen polygon in each watershed. By taking the ratio for each watershed of the Thiessen area for each gage to the total watershed area, the Thiessen gage weights for each watershed were determined. See <http://www.ce.utexas.edu/prof/olivera/header.htm> for more information about CRWR-Vector.



6. Building an HMS Model

The CRWR-PrePro system contains an automated method for building the Basin file and Map file defining the physical attributes of an HEC-HMS model for hydrologic modeling. This model can run for any duration of time, based on time series data storage within the HEC-DSS system attached to HEC-HMS. The physical attributes of the model, such as drainage area, stream length, and the like are determined automatically

from GIS data. The HMS model derived from CRWR-PrePro for the Nueces Estuary appears in the following graphic.



Each of the green rainfall-runoff elements represents a watershed within which the TxRR soil water balance model is run. These watersheds are numbered within HEC-HMS using the same numbering scheme described previously for the GIS. There are no watershed losses in these watersheds because the rainfall-runoff transformation has been separately accounted in the TxRR model.

The blue circles represent inlets, internal junctions and outlets. There is one inlet to this model, the flow into the Nueces River from Lake Corpus Christi. This flow can be included in the model by attaching flow data from the USGS gage on the Nueces River near Mathis. There is one outlet to the model, the discharge into the Gulf of Mexico at Aransas Pass.

The blue lines represent routing reaches between junctions. The internal routing across the bays is artificial because there is really no river in those locations. What is being done is a mass balance calculation to allow an accounting of the additional flow that is added as each bay system is traversed. The placement of the junctions in HEC-HMS allows flows at critical points to be determined, such as at the discharge point of the Nueces River to Nueces Bay, the discharge of Nueces Bay to Corpus Christi Bay, etc

This HMS model serves as the time series repository and as a framework for horizontal routing of water through the landscape, including accounting for upstream inflows, such as from Lake Corpus Christi.

TxRR Model and Display

1. Running the Txrr Model

In order to run the Texas Rainfall Runoff Model, the precipitation data from the area of interest must be extracted from the HYDROSPHERE Climatedata CD. For the basins in this study the *Climatedata Volume 7.3 NCDC Summary of the Day – West 2* was used. The CD includes a subprogram to access the database of gaging stations. For this run, four stations were used, station number 2015, 5661, 7677, and 8354. The graphic below shows the subprogram used to access the data. The user must select the station id and the parameter to be exported. Also, the user must select the format and the years of interest.

ID	Name	Parameter
1	3508	GEORGE WEST 2 SSW PRECIP TOT DAY IN-Sum

Export Options

View:

Format:

Data For Years

1992	▲
1993	▲
1994	▲
1995	▲
1996	▲
1997	▲

Add-> All-> Rem->

Export These

1948	▲
1949	▲
1950	▲
1951	▲
1952	▲
1953	▲

Some data files are not complete and will cause the main program to crash if these files are used to run the Txrr model.

These gage station data files are exported in a time-series text format and must be converted to the data input file of Txrr main program. To do this, a script has been written called **Rain time-to-input** and can be found in the ArcView project **Txrr.apr** under the **Txrr Model** drop down menu. Once this program has been run an input file will be created and this file must be named rain.dat. The Txrr Model must be run

separately for each gage station and the input file used must always be called rain.dat or the program will not run.

The Txrr main program also uses another input file, which must be edited by the user for each run. This file is known as Inputd. If the input parameters need to be changed, the command **Inputd Edit** under the **Txrr model** drop down menu can be used. When the command is executed, the script will open the input control file and allow the user to make any changes to customize the model run.

```

inputd - Notepad
File Edit Search Help
NUECES BASIN 15020
IDRAN, IBEGN, NYEARS, SMMAX, MOIST1, DAREA
8150200, 1964, 34, 3.00, 2.352, 145.
MONTHLY DEPLETION FACTORS
0.0097 0.0132 0.0182 0.0149 0.0640 0.0425
0.0376 0.0696 0.0669 0.0178 0.0247 0.0131
STATD, IYR1, MON1, IYR2, MON2, B, QB1, RECES, WB
0, 1971, 1, 1986, 12, 2.00, 0.0025, 0.97, 0.001
0.2, abst1: initial abstraction
1, ibaseflow: 1 to relate base flow to precip; 2 to infiltrat
1, isimtable: 1 to print complete simulation table; 0 not to
1, 1971, 1, 1986, 12, 2.00, 0.001, 0.97, 0.00000005
0.0099 0.0148 0.0183 0.0179 0.0460 0.0479
0.0403 0.0586 0.0733 0.0185 0.0186 0.0151
0.0083 0.0177 0.0181 0.0186 0.0585 0.0628
0.0652 0.0631 0.0595 0.0198 0.0200 0.0151
.0100, .0158, .0137, .0153, .0374, .0292
.0376, .0356, .0579, .0189, .0217, .0138
0.0085 0.0083 0.0192 0.0152 0.0608 0.0407
0.0348 0.0638 0.0599 0.0214 0.0185 0.0140
0.0183 0.0277 0.0381 0.0386 0.0785 0.0828
0.0852 0.0831 0.0795 0.0398 0.0300 0.0251
Final depletion factors: A(I)
0.0241 0.0131 0.0232 0.0225 0.0913 0.0768
0.0564 0.1491 0.1265 0.0240 0.0600 0.0134
0.008860.010500.018080.013020.061160.03978
0.035920.064600.059240.017520.024010.01294

```

Once the input files have been prepared the Txrr main program can be run from within the ArcView project **Txrr.apr**. By going to the **Txrr Model** drop down menu and

selecting **Txrr Daily Model** the Txrr main program will make a run. The output of the model run can be viewed by clicking the command **Txrr Model/Daily Model Output**.

```

output.D - Notepad
File Edit Format Help

TWDB DAILY RAINFALL-RUNOFF MODEL: RRD3

INPUT PARAMETERS:
TITLE : NUCES BASIN 15020
DRAINAGE AREA ID = 8150200
FIRST YEAR OF PRECIP DATA = 1964
LAST YEAR OF PRECIP DATA = 1997
NUMBER OF YEARS OF DATA = 34
MAX SOIL MOISTURE IN INCHES = 3.00
INITIAL SOIL MOISTURE = 2.35
DRAINAGE AREA IN SQ MI = 145.00
MONTHLY DEPLETION FACTORS, JAN TO DEC:
.0097 .0132 .0182 .0149 .0640 .0425
.0376 .0696 .0669 .0178 .0247 .0131
DAILY STATISTICS WANTED ? = NO
BEGIN YEAR/MONTH OF DAILY SIMULATION = 1971 JAN
END YEAR/MONTH OF DAILY SIMULATION = 1986 DEC
COEFFICIENT FOR LAG TIME EQN = 2.00000
INITIAL BASE FLOW IN INCHES = .00250
RECESSION CONSTANT = .97000
WEIGHT FOR BASEFLOW = .0010000
INITIAL ABSTRACTION COEFFICIENT = .20
BASE FLOW OPTION = 1
COMPLETE SIMULATION TABLE WANTED? = YES

INFORMATION ON UNIT HYDROGRAPH:
LAG TIME IN HOURS = 39.61
TIME TO PEAK IN HOURS = 51.61
BASE TIME IN HOURS = 258.07
BASE TIME IN DAYS = 11

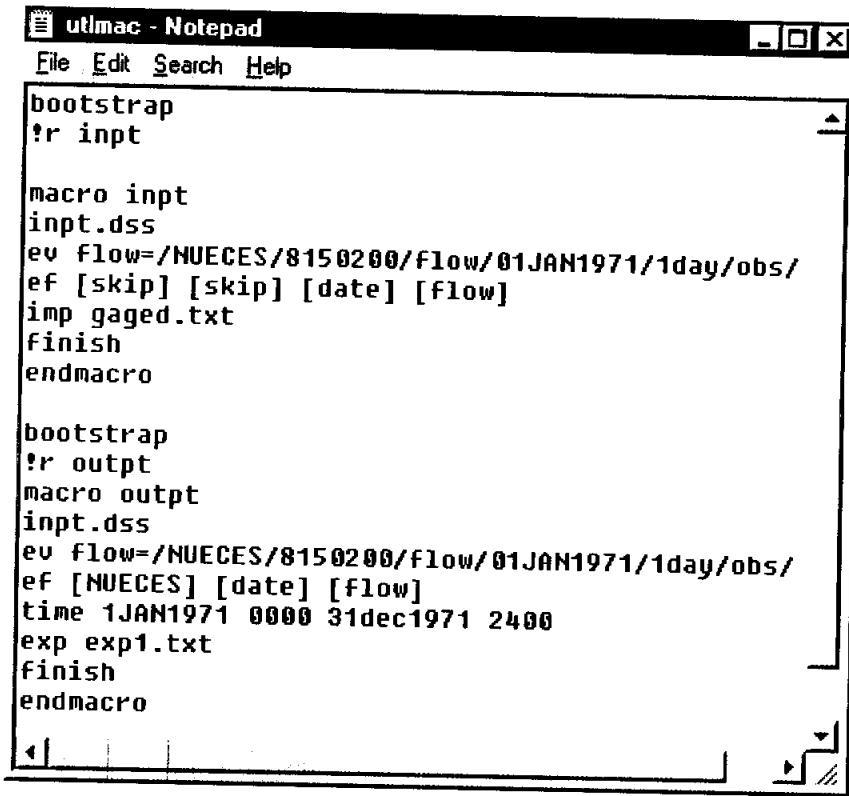
PORTION OF UNIT HYDROGRAPH:
1ST DAY = .0545
2ND DAY = .2680
3RD DAY = .3244
4TH DAY = .1913
5TH DAY = .0861
6TH DAY = .0421
7TH DAY = .0191
8TH DAY = .0088
9TH DAY = .0035
10TH DAY = .0016
11TH DAY = .0007
  
```

In order to view the output data using Hydrologic Engineering Center Data Storage System (HEC-DSS) the file must first be converted into a time series format. A script has been created called **Output Data to Time Series** and can be found in the **Txrr Model** drop down menu. The script will go to the output file and extract the flow data and store them into two files each in a time series format. These two output files created: should be named **gaged.txt** and **simued.txt**. The data file format used in this project is a text file with four columns indicating: station ID, state, date and data.

For a complete reference of HEC-DSS, visit the menu at HEC's web page <http://www.wrc-hec.usace.army.mil/>. Here, related to this project, a connection between the data files and the storage system has been implemented.

2. Formatting DSS files

To use HMS, the input files must first be converted to a format that is readable by the program. In this case, the input file of interest is gage.txt, created in the previous section. By editing the utlmac file, the user can customize the import and export procedures of the DSS system calling the appropriate file and converting it to DSS. A script has been created to edit the utlmac file. This script calls the file and allows the user to change the file format and specify the time period of interest.



```
utlmac - Notepad
File Edit Search Help
bootstrap
!r inpt

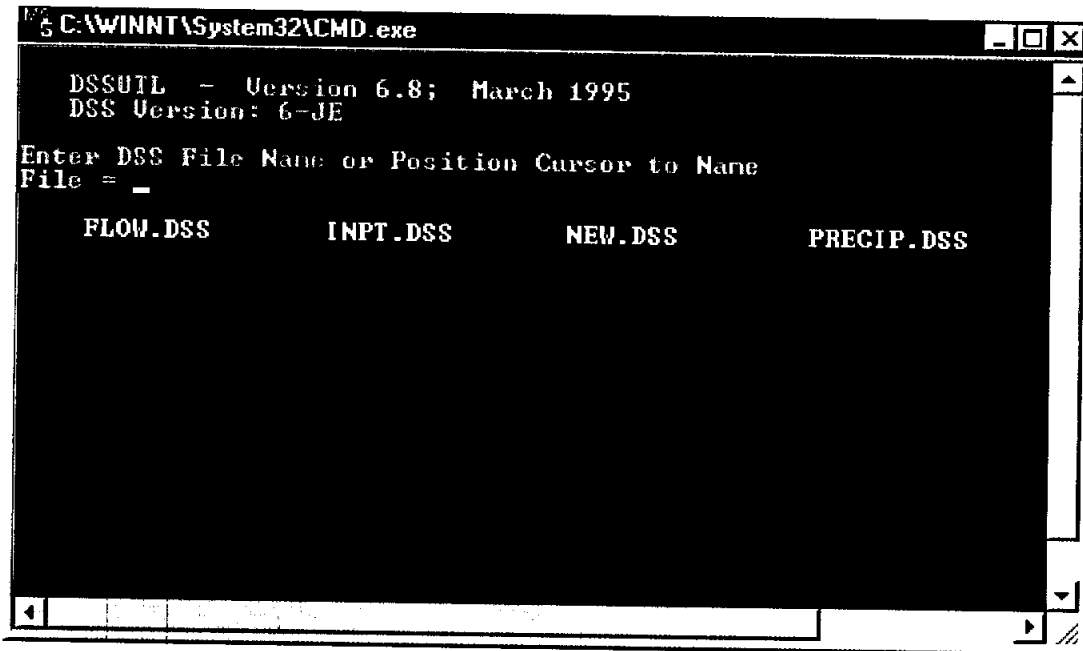
macro inpt
inpt.dss
ev flow=/NUECES/8150200/Flow/01JAN1971/1day/obs/
ef [skip] [skip] [date] [flow]
imp gaged.txt
finish
endmacro

bootstrap
!r outpt
macro outpt
inpt.dss
ev flow=/NUECES/8150200/Flow/01JAN1971/1day/obs/
ef [NUECES] [date] [flow]
time 1JAN1971 0000 31dec1971 2400
exp exp1.txt
finish
endmacro
```

The above control file includes two macros: **inpt** and **outpt**. The first sentence: macro **inpt** declares that the name of this macro is "**inpt**". The next line is a DSS file name, "**inpt.dss**". This file indicates where the data is to be imported. Then command "**ev**" declares the store/search path for data. There are six columns for each path. In this case, we use these six columns to indicate: Basin name, Basin ID, data, date and time interval, etc. The next line starts with the command "**ef**", which tells the software the format of the import file. The columns that are not to be imported are ignored with the command **[skip]**. Notice, the columns indicated in this command line must be consistent with the "**ev**" command specifications. For example, data column **[flow]** must be declared in "**ev**" command line first. The next step, we need to tell the software where the data is stored. The line says: **imp gaged.txt**, which means import the data contained in the file gaged.txt. This line should specify the directory in which to find the file or the file can be located in the same directory as the DSS Utilities executable file. At the end of macro definition, the file must contain the commands **finish** and **endmacro**. This control file can process up to fifteen files at once, however each file must have its own "**ev flow**",

“ef” and “imp” command lines. Furthermore, the user can process many individual input files and build one large DSS file by simply changing one item in the **ev flow** command line such as the date or the Basin ID for each input and processing each file separately.

Now that the file `inpt.dss` has been created the DSS Utilities program can be used finish processing the file. The DSS system can be called from the ArcView environment with the drop down menu **Txrr Model/DSS Utilities**. A DOS window will be prompted and the user must enter a file name, in this case we are using `inpt.dss` created previously.



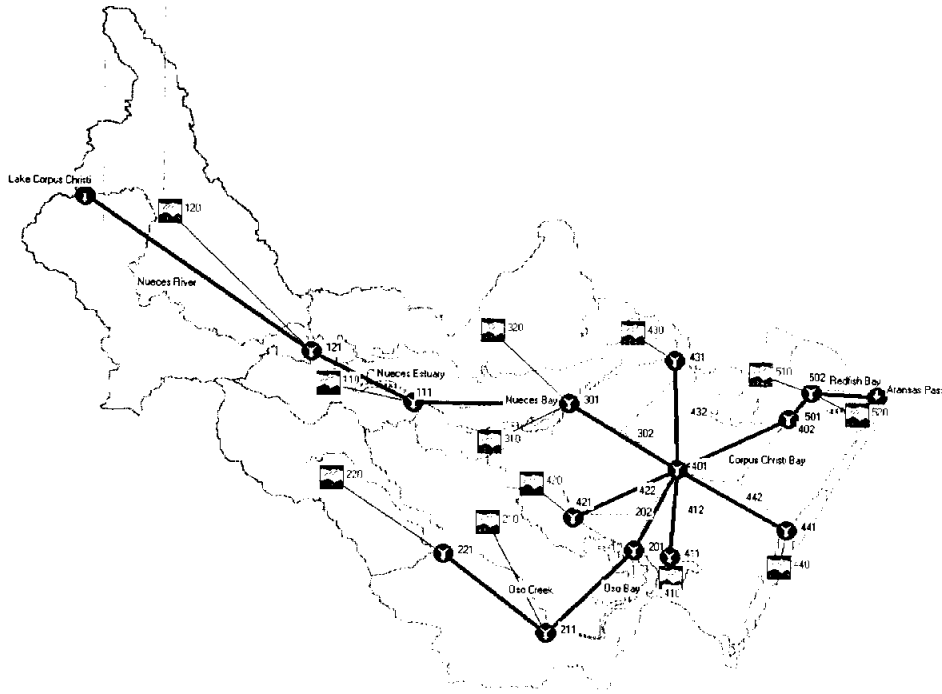
```
C:\WINNT\System32\CMD.exe
DSSUTIL - Version 6.8; March 1995
DSS Version: 6-JE
Enter DSS File Name or Position Cursor to Name
File = _
FLOW.DSS      INPT.DSS      NEW.DSS      PRECIP.DSS
```

A “U>” prompt appears, and the file can be processed by typing “!r inpt”. Now a DSS file “`inpt.dss`” has been completed.

To export this time series data, DSS Utilities was used as well. In order to do this the file of interest must be called, in this case “`inpt.dss`”. The file was exported with the command “!r outpt”. The output data was stored in the file “`imp.txt`” according to the output macro to UTLMAC.

3. Building a TxRR-HMS Model

In order to view the output of the TxRR model along with the basin model and GIS map, it is useful to employ HEC-HMS. With the streamflow values calculated from the precipitation data, it is possible to use HMS to display the data according to subbasin. To do this, the basin file and GIS map created with CRWR-PrePro was imported into HMS as shown below.



After the basin file and map have been imported, a precipitation model must be built. In order to do this, the precipitation gage must be entered. The following dialogue box can be called from the project definition window and the DSS file created previously should be entered.

HMS * Precipitation Gage List

Edit View Help

Gage ID	Time Interval	Description
Gage 1	1DAY	

File:
Pathname:

Close

The data contained in the DSS file are output results from the Txrr model of excess runoff data, not precipitation. In this way, we can use the HMS system to display the results from the Txrr model.

By clicking **Generate Catalog** and selecting the Pathname, the previously created DSS files can be used.

DSS PATHNAME SELECT

DSS File: File Browser...

Pathname:

Generate Catalog

- /NUECES/8150200/PRECIP/01JAN1947/1DAY/OBS/
- /NUECES/8150200/PRECIP/01JAN1948/1DAY/OBS/
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Filters

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D:	<input type="text"/>	E:	<input type="text"/>	F:	<input type="text"/>

Once the DSS files were entered as a precipitation model it was necessary to create another precipitation model with user specified gage weights for each subbasin.

Recall that the Thiessen Polygon method was applied before running the TxRR Model. So the output of TxRR Model is the average of a basin as a whole. Therefore, the gage data input are actually the average data of a basin. So a gage weight of 100% was assigned in HEC-HMS. Here the TxRR Model is run for Subbasin 10 and the data is imported into HMS.

HMS Precipitation Model * USER-SPECIFIED GAGE WEIGHTS

File Edit Help

Precipitation Model: Precip 2

Description: _____

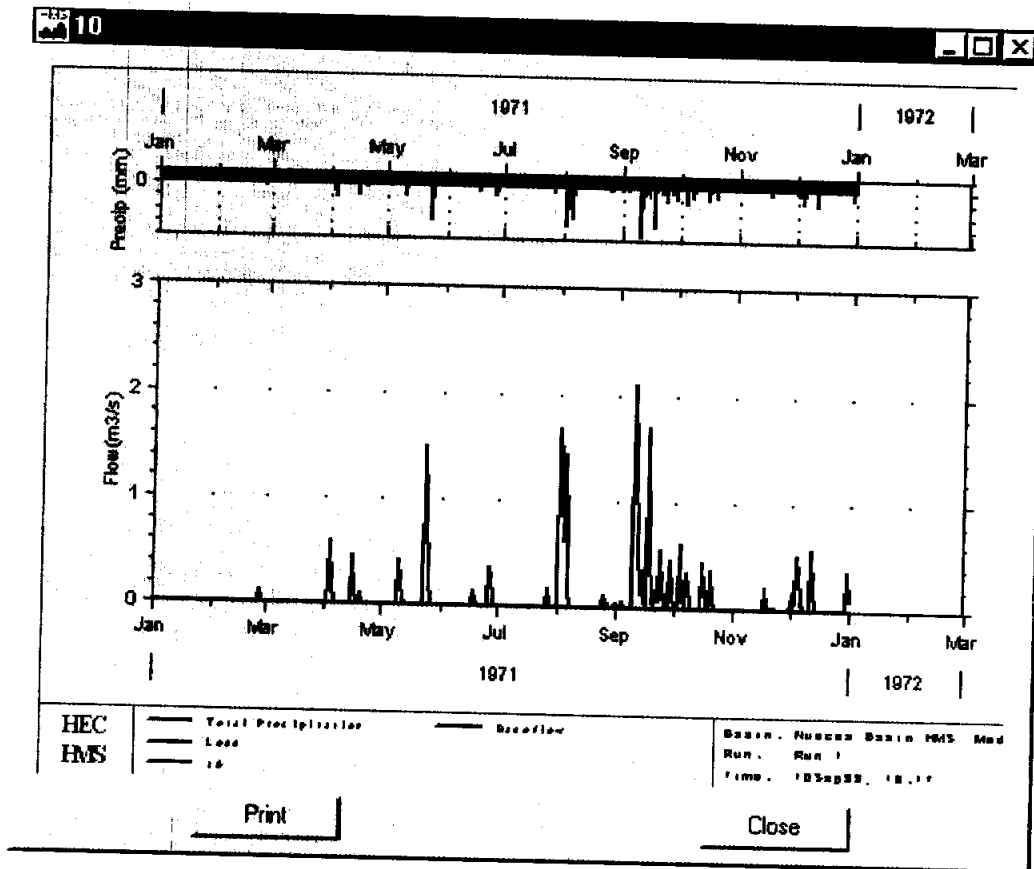
Gages | Subbasins | Weights

Subbasin: 10

Gage ID	Gage Type	Total-storm Gage Weight	Temporal Distr. GageWeight
Gage 1	R	100	100

OK Apply Cancel

Next, a control file was built that contains the precipitation model and basin model that was previously built. This control file simulates the beginning and ending date as well as the time interval between data. Once the basin model, precipitation model and control file were completed HMS was used to run a simulation. The data created in this simulation can be presented in both graphical and spreadsheet formats. The results for each subbasin can be viewed simply right clicking on the basin of interest.



Furthermore, it is also possible to view the flow for each junction and reach with the same method as described above.

Conclusions

This report describes a procedure by which the TxRR model for the vertical water balance between precipitation and runoff is combined with the HEC-HMS and HEC-DSS systems for storing precipitation and runoff time series, and for routing the water through the landscape. GIS processing routines using ArcView are used to create the linkage files needed to synthesize the components. Several conclusions were reached during this research:

- (1) In this application, HEC-HMS and HEC-DSS are being used as hydrologic modeling shells, mainly because the GIS preprocessing routines already existed for them, and no other defined system existed for manipulating time series. The experience of this project suggests that HEC-DSS, at least in the form available to the investigators, which is DOS and not Windows based, is not sufficiently flexible or usable as a time series storage system independent of the HEC models.
- (2) The research leading to the drainage basin definitions for the Nueces-Corpus Christi Bay system was very insightful. This study showed that defining drainage areas for coastal systems is quite different than defining them for regular river basin systems.

Those insights have been subsequently used by CRWR investigators in designing the new ArcGIS Hydro Data Model, which has special structures for dealing with coastal drainage. Many of the automated functions of CRWR-PrePro, which are appropriate when dealing with river basins, were redundant when dealing with coastal basins. In effect, the GIS processing routines for defining the coastal drainage areas, especially those to the bay system, were all worked out as new procedures for this project.

(3) The use of HEC-HMS a routing shell for moving the water from the near coastal environment to the bays and estuaries does not really perform a critical function. The time of travel is small when compared to the long duration of the model simulations. A new procedure now being developed at CRWR for the ArcGIS Hydro Data Model for linking each drainage area with the next area downstream seems like a more reasonable way of moving the runoff generated from TxRR to the bays and estuaries.

The research described here is being continued by a subsequent project involving study of runoff into East Matagorda Bay. In this project, the ArcGIS Hydro Data Model structures are being used and the result will be implemented in Visual Basic employing the ArcView 8.1 GIS linked to a Visual Basic representation of the TxRR model developed by the Texas Water Development Board.

Appendix

The TxRR model contains the following components:

Soil Moisture

The depletion process of the soil moisture can be described as follows:

$$SM_{2_i} = SM_{1_{i-1}} \times e^{(-\alpha_m \times t_i)}$$

where:

- SM_{2_i}: soil moisture right before the i-th precipitation
- SM_{1_{i-1}}: soil moisture right after the i-1th precipitation
- α_m: monthly depletion factor for the m-th month
- t_i: arrival time in days of the i-th precipitation

Soil moisture is renewed by infiltration caused by new precipitation. The renewal process is described by:

$$SM_{1_i} = SM_{2_i} \times F_i$$
$$F_i = P_i - Ia_i - Qd_i$$

where:

- Qd_i: direct runoff
- SM_{1_i}: new soil moisture right after ith precipitation
- F_i: infiltration

Soil Retention

The moisture retained in the soil can be described by:

$$S_i = SM_{\max} - SM_{2_i}$$

where:

- S_i: soil retention
- SM_{max}: maximum soil moisture

Direct Runoff

The direct runoff can be computed using the expressions:

$$Qd_i = \frac{2Pe_i}{(Pe_i + S_i)}$$

$$Pe_i = P_i - Ia_i$$

$$Ia_i = abst1 \times S_i$$

where:

Pe_i : effective precipitation
 $abst1$: initial abstraction coefficient

Base Flow

The baseflow of the stream can be calculated with expression:

$$Q_{B2} = Q_{B1} \times K^{(t_2 - t_1)}$$

where:

K : recession constant
 Q_{B2}, Q_{B1} : base flow at time t_2, t_1
 $t_2 - t_1$: the elapse time

Daily Streamflow Simulation

The streamflow is simulated with the expressions:

$$NDAYS = INT\left(\frac{T_b}{24}\right) + 1$$

$$T_b = 5T_p$$

$$T_p = 12 + T_l$$

$$T_l = T_b \times 0.6A$$

where:

$NDAYS$: base time in days
 T_b : base time
 T_p : time to peak
 T_l : lag time
 A : drainage area

The daily runoff volume is computed by linearly interpolating the Mass Curve Ratios by the SCS method.

Monthly Depletion Factor & Parameter Optimization

The most important variable of TxRR model is the soil moisture. Therefore, in order to improve the accuracy of the model a depletion factor must be used. This parameter optimization process is based on historical data and can be described as follows:

$$f(\alpha_{m,k}) = SimuQ_{m,k} - GageQ_{m,k}$$

$$\Delta f(\alpha_{m,k}) = f(\alpha_{m,k}) - f(\alpha_{m,k-1})$$

$$\Delta \alpha_{m,k} = \alpha_{m,k} - \alpha_{m,k-1}$$

and the new depletion factor is computed by:

$$\alpha_{m,k+1} = \frac{\alpha_{m,k} - f(\alpha_{m,k})}{\left\{ \frac{\Delta f(\alpha_{m,k})}{\Delta \alpha_{m,k}} \right\}}$$

The iteration can be stopped when the error reaches a pre-specified tolerance. Also considered in the optimization are the parameters SM_{\max} and the initial abstraction factor (abst1).