ABSTRACT

Data visualization is a very active research area, and an important tool that all disciplines of science rely on. By rendering raw data into visually stimulating images scientists can form new hypotheses and discover new trends.

This project used environmental data collected by the Conrad Blucher Institute for Surveying and Science to create several different types of visualizations including two and three-dimensional geo-referenced models and graph models. Within these two types of models still image visualizations and animations were also developed.
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1. BACKGROUND AND RATIONALE

Our bays and estuaries are some of our most precious resources [Allen 2005], and they serve as a home to a host of wildlife including fish, shrimp, blue crabs, and the endangered whooping crane. One of the most challenging issues Corpus Christi and the surrounding Texas Coastal areas face is monitoring freshwater inflows to the bays.

In 1985, with the building of Choke Canyon Reservoir on the Nueces River, it was recognized that the natural flow of freshwater from the Nueces watershed into Nueces Bay would be reduced to the point where some water management action would be necessary. The City of Corpus Christi, in partnership with three state agencies, the Texas Parks and Wildlife Department (TPWD), the Texas Natural Resources Conservation Commission (TNRCC), and the Texas Water Development Board (TWDB), began studying the problem and decided to take action to alleviate potential problems, specifically, ensuring water flows that approximate the natural flows into Nueces Bay. To study the effects of the water flow management, the City of Corpus Christi through the Division of Nearshore Research (DNR) have been monitoring salinity levels in the Nueces Estuary since November 1991 [DNR 2005].

1.1 Background Information on the Nueces Estuary

The Nueces Estuary, as seen in Figure 1.1, is approximately 500 km$^2$ and has an average depth of approximately 2.4 m [Orlando 1991]. Several navigational channels bisect the estuary, including the Corpus Christi Channel, the Encinal Peninsula Channel, and the La Quinta Channel. The two major bays located within the Nueces Estuary are
the Corpus Christi Bay, and the Nueces Bay, with the Oso Bay and the Redfish Bay being secondary bays.

**Figure 1.1:** Nueces Estuary [Orlando 1991]

The estuary’s defined boundaries establish a low-level dam at Calallen to represent the head of tide on the Nueces River to the terminus at Aransas Pass. The northern boundary is located at Redfish Bay, where it joins the Mission-Aransas estuary. The southern boundary is the JFK Causeway that separates the Corpus Christi Bay with the upper Laguna Madre. The outer boundary separating the estuary from the Gulf of Mexico is Mustang Island [Orlando 1991].

Unfortunately, both natural and man-made obstructions impede the freshwater and saltwater exchange within the Nueces Estuary. The main source of the estuary’s freshwater inflow, which accounts for about 99 percent of gauged inflow, is from the Nueces River. Another source of freshwater is from Oso Creek, which only accounts for
less than one percent of gauged inflow. Isolated freshwater pulses, rather than seasonal fluctuations of freshwater inflow, are attributable to the most significant changes in bay-wide salinity distribution [Orlando 1991].

1.2 The Nueces Bay

The Nueces Bay has a surface area of approximately 74.5 square kilometers and depths ranging up to 1.2 meters [Jacksony 1995]. The bay serves as an estuary and nursing grounds to numerous species such as brown and white shrimp, bay anchovy, spotted sea trout, and striped mullet. An important factor influencing the physical make-up of the Nueces Bay is salinity, which is the number of grams of dissolved salts present in 1,000 grams of water [CB 2005]. The salinity of the Nueces Bay ranges from 15-30 parts per thousand (ppt) [Jacksony 1995], and without the proper balance of salt and freshwater inflow into the Bay, countless aquatic species would be unable to survive.

1.3 Research Institutes/Systems at TAMU-CC

The Conrad Blucher Institute for Surveying and Science (CBI) was established at Texas A&M University – Corpus Christi (TAMU-CC), in 1989 with the commencement and installation of a modern state-of-the-art water-level measurement system along the Texas coast to help assist local officials with preparations for incoming hurricanes and tropical storms. In 1991, following a Texas Legislative mandate, the network of water level gauges became known as the Texas Coastal Ocean Observation Network (TCOON), and has since expanded from the initial three stations, located in Corpus Christi, to over forty stations by 1992 [TCOON 2005].
CBI consists of the following four main branches:

- Division of Nearshore Research (DNR)
- Division of GIS, Geomatics, and Mapping
- Division of Environmental Engineering
- Division of Ecotourism and Nature Science Awareness

1.3.1 Division of Nearshore Research

DNR predicts coastal and ocean phenomena, by collecting real-time data using sensors that monitor wind speed and direction, salinity, turbidity, water temperature, and conductivity. This data provides useful information to: commercial shrimp and fishing industries; aquatic recreational hobbyists, such as surfers; and also helps to ensure the safety of water navigation and marine life. Data is collected from the various monitoring stations and is stored in a database management system, accessible through the Internet [DNR 2005b].

1.4 Why Visualize the Data

Taking data and rendering it in a visually intuitive way that easily relates to a person or environment helps the person to gain key insights into understanding the underlying trends and principles embodied in the data. Raw data can be visualized in numerous ways including graphs, maps, animations, and simulations, aiding in the communication of vital information. Humans understand (even complex) images easier than large amounts of numbers. The creation of clear, understandable visualizations of data is of fundamental importance to all branches of science [Egger 2005].
1.4.1 History of Visualizations

In the mid 1800s an outbreak of Cholera was taking many lives in the Parish of St. James’ Westminster, in London. Trying desperately to unearth the source of the Cholera outbreak, Dr. John Snow used numerous statistical graphs to aid in identifying the source of the Cholera. Unfortunately the statistical graphs were not providing Dr. Snow with any information as to why so many people were contracting Cholera and where the Cholera source was located. It was not until 1854 when Dr. Snow began plotting the locations of the dead, seen in Figure 1.2 that the source of the Cholera, a contaminated well located on Broad Street, would be identified and the epidemic would come to an end [Tufte 1997].

![Figure 1.2: Dr. Snow’s Cholera Epidemic Spot Map](image)

Dr. Snow’s map of the Cholera Epidemic is one of the most successful visualizations, and helped him in saving countless lives. Unfortunately, not all scientific data can be visualized using a two-dimensional graph, and therefore the type of visualization to be used depends greatly on the data.
1.4.2 Current Nueces Bay Data Visualization

The past thirteen years of data is being stored in a database, accessible via the Internet at, http://lighthouse.tamucc.edu/Main/HomePage. New data is collected every thirty minutes, but the data represented online is hourly (an average of the two thirty minute intervals), and is displayed in various two-dimensional graphs, as seen in Figure 1.3, which often times does not allow the researcher to see the correlations between all aspects of the data. Thus said, the DNR staff is seeking a way to better represent the environmental data.

![Graph of Salinity in Nueces Bay](image)

**Figure 1.3:** Current Mapping of the Salinity in Nueces Bay [DNR 2005]
1.4.3 Motivation for System Development

In Spring 2005 staff members from DNR came to speak to Dr. Scott King’s Data Visualization class. During this time they expressed their need and desire for a better way to visualize their current and past environmental data.

Following this class discussion a meeting was set up with several people from DNR to determine a more in-depth requirement of their visualization needs. They explained how they would like to be able to visualize salinity data within the Nueces Bay using various visualization techniques such as, a geo-referenced model.

1.5 What Visualizations can Accomplish

Visual aids and graphs are a vital part of research papers that present new scientific data. Presenting data in an objective format that allows other researchers to analyze the data and draw their own conclusions is necessary for all scientific experiments [Egger 2005]. Moreover, visualizations are useful in analyzing large amounts of data, and can uncover trends never seen before.

1.5.1 Future Possibilities

Successful visualizations present data in a way where even the most inexperienced person can understand the data. Visualizing thirteen years of salinity data for the Nueces bay may show trends never seen before, and with an easy to understand visualization in hand, it will help to convey important thoughts and ideas to key investigators. The awareness of different environmental and human factors have, on not only the Nueces Bay, but also on the Nueces Estuary is important to the coastal
community for numerous reasons. These reasons include economic factors, recreational enjoyment, and the future survival of various species calling the estuary home.

This visualization can help attain money needed to complete ongoing studies and future work surrounding the Nueces Estuary, by providing researchers with an easy to understand, versatile tool.
2. VISUALIZATION OF ENVIRONMENTAL DATA IN THE NUECES BAY

The primary goal of this project is to provide key researchers the capability to effectively visualize environmental data, in a way that may reveal relations between the various elements (i.e., water temperature, salinity, currents, etc.) and the Nueces Bay. There are two main visualization models in this project: geo-referenced visualization models and graph models.

2.1 Nueces Bay Visualization Models

Throughout the project several models were used to represent the data collected from the DNR website. The first model constructed was a two-dimensional model in the shape of the Nueces Bay that displays salinity levels. The next model built was very similar to the first, except it is a three-dimensional model displaying the shape and elevation/bathometry data for the bay, as well as salinity levels. Both the two-dimensional and the three-dimensional models have the capability of showing salinity levels simulated over time or at a single point in time. The final models created were conventional graphs, such as line, and scatter point graphs, that rely on the same data that supports the other two models.

2.1.1 Geo-referenced Models

The geo-referenced bay models are comprised of a framework consisting of multiple layers, which are invisible to the user. The first layer provides the visualization with fundamental characteristic information such as shoreline data, which is used in both
models, and elevation/bathymetry data found in the three-dimensional model; examples of these models can be seen in Figure 2.1. For the three-dimensional model to render the elevation and bathometry data, a number proportional to the data value at each point is calculated; then by the use of shading and lines, the surface becomes deformed creating an illusion of highs and lows, as seen below.

![Figure 2.1: Realistic models of the Nueces Bay](image)

Lying on top of the background layer are other layers consisting of information pertaining to the Nueces Bay, such as salinity data or sensor locations. Examples of these overlying layers are seen in Figure 2.2.

![Figure 2.2: Variable Overlaying Layers](image)
With the combination of the background layer and the overlaying layers, a multitude of various visualizations can be created. For example, Figure 2.3 shows a two-dimensional model of the Nueces Bay, and salinity levels throughout the bay at a single point in time. While, Figure 2.4 is an example of how representing elevation data through the use of lines, instead of color, allows for the user to see a specific outline of the Nueces Bay area and the sensor locations. By simply changing the way the data is displayed new information can be derived/shown.

Figure 2.3: Nueces Area Land Elevation and Salinity Levels

Figure 2.4: Contour Lines and Sensor Locations
In addition to still images, variables can be simulated over time, to create animation models.

### 2.1.2 Conventional Graph Models

In certain cases, it is more effective to view the data using graphs, which provide a more quantitative representation. These graphs can easily display large amounts of data over a specified time, and have the ability to represent the data in numerous ways. Within this project two graphs were chosen to represent the data including the line graph which will show univariate data, and the scatter plot graph which visualizes multivariate data.
3. SYSTEM DESIGN OR RESEARCH

This project focuses on the visualization of environmental data for the Nueces Bay however this visualization model could be used to visualize data for any bay. By retrieving data collected by environmental sensors located throughout the Nueces Bay, this project renders the data in a way that is visually stimulating for researchers in hopes that they may find new correlations between different environmental factors and the effect they have on the bay.

For the development and creation of this project, a software package called OpenDX was utilized. Originally introduced in 1991, as Visualization Data Explorer (DX) by IBM Research, this software package allowed for data analysis and visualization. In May 1999, IBM released the source code for DX. The unlicensed, open source software is now known as OpenDX, and can be freely downloaded [ODX 2005].

3.1 OpenDX

OpenDX provides users with the same ability as DX, and allows users to apply advanced visualization analysis techniques to their data to possibly gain new insights about the data. OpenDX is a portable software package, that offers a large variety of processing, realization and rendering capabilities through several different interfaces such as motif widgets, visual programming, script language programming and application programming interface (API). OpenDX supports hardware graphics through OpenGL. If a machine does not have hardware graphics support, images are then rendered with in the software and displayed using 24 bits.
3.1.1 Reason for Employing OpenDX

OpenDX is a very powerful software visualization program, allowing for the creation of volume visualization, isosurfaces, cutting planes, streamlines, image processing, molecular modeling, animation, scalar and vector glyphs and many other kinds/types of visualizations.

OpenDX also provides different programming environments for creating visualizations. The first environment allows the programmer to program using the Data Explorer User Interface. This type of programming was designed as visual programming environment, and an example of this programming environment can be seen in Figure 3.1.

![Figure 3.1: Data Explorer User Interface (Visual Programming)](image-url)
Another programming environment OpenDX provides is the Data Explorer Executive. This environment provides the more experienced C programmer the ability to create and modify modules.

3.2 Utilizing OpenDX for Visualization Rendering

As data is brought into OpenDX, it must be converted into an excepted file format, OpenDX understands. To do this, all data files that are not native to OpenDX, must describe their data structure and type. The supported data structures include: data defined on a regular grid, data on deformed or curvilinear grids, a variety of meshes, and unstructured data with no connection between data samples. Supported data types include: real and complex, scalar, vector and tensor, byte, short, integer (signed and unsigned), and floating point. Once the data structure and types are described the data must be saved as a .general file, for the data to be referenced in the OpenDX visualization network.

This visualization network file consists of various modules the programmer will link together by numerous connectors. There are very specific ways modules must be linked, and an order of execution they must follow, for the visualization to display properly. Different modules allow for the visualization to be rendered in various ways. When the network is completed, it will be saved as a .net file, and will be ready for execution and display.

Table 3.1, gives a brief overview of the visualization flow process through OpenDX, this project utilized.
Table 3.1: Visualization Flow Process Through OpenDX

3.3 Data Formats

For OpenDX to properly visualize data, all data being imported must be described properly. This description must define the data structure, the data samples in relation to space and dimensionality, and the data type. These descriptions of the data module will depend upon the visualization to be created, and the type of data.

3.3.1 Realistic Model Data Configuration

Data used in creating the realistic bay models is contained in a 1652 by 943 grid, or a 30-meter grid size. This particular grid size was chosen because it effectively
describes the underlying surface features of the Nueces Bay and marshy-wet-land, as well as giving surrounding land areas.

As mentioned previously, when using real data sets, there are missing data values within the data. These missing data values within the visualization are noted in the data files as –9999 for integer value data sets and as –9999.9 for float value data sets.

3.3.2 Graph Model Data Configuration

To configure data sets used in the graph model, the number of points or the grid size must be known. When using the number of points, all data values within the data set are represented as a point value. Missing data, from the real data set, can not be represented as NA, and therefore must be represented as a dummy number, such as a smaller number not ever seen within the data set.

3.3.3 Data Reliability and Versatility

For the creation of the visualizations, accurate data or what the data is describing was not important. This is because the main focus of this project is to create the visualizations, which will display the given data in a useful and effective way. Although, the focus of this system was mainly on visualizing salinity data within the Nueces Bay, this is in fact a generic software system, and if the researcher provides the given information the system is capable of visualizing any data across any bay.

3.4 Creating Visualizations

The primary goal of this project was to create visualization models to display the environmental data being collected in the Nueces Bay in a useful and effective manner. This included creating visualizations that would allow for the comparison of multiple
variables, creating a model that could show the differences between actual readings versus predictive readings, animation models that would show the effect of a variable over time, as well as various geo-referenced models to show the salinity levels throughout the bay.

The project can be broken into two major visualization models: geo-referenced models, and graph models. These two categories of models, make-up the system, which has a basic framework of accepting input from the user, processing or rendering the input, and outputting a visualization model.

3.4.1 Input

The input into the models is environmental data that was retrieved from the DNR website. This data was then formatted to meet OpenDX’s specifications of data input, as outlined in section 3.2.

3.4.2 Processing and Rendering

Processing and rendering of the data, is largely dependent on OpenDX and the modules selected for use within OpenDX. These modules all fall within twelve fundamental categories in OpenDX which include: annotation, DXLink, flow control, import and export, interactor, interface control, realization, rendering, special, structuring, transformation, and windows.

3.4.3 Output

The output of the visualizations varied, even though sometimes the data file inputs were the same. This variation was deliberate and occurred within the rendering phase to achieve the visualization goals of the project.
3.5 Geo-referenced Models

An important goal of the geo-referenced models was indicating the salinity levels between the various sensor stations. This information was obtained using math modeling equations which required some preprocessing. However, this preprocessing was an early extension to the project, and is not part of this project scope.

Only after the data was processed and formatted for OpenDX, could rendering occur. Several factors played an important role when rendering this data, such as color, height, and the ability to allow the users to be able to extract, and highlight, important features contained within the data set. To accommodate these factors numerous modules were used, and various models were created.

3.5.1 Colors

The colors within the geo-referenced models play an important role in describing the data. Therefore the ability for the user to be able to access and change the colors was an important feature, within the system. Figure 3.2, is what OpenDX refers to as the Colormap Editor, and it is from this module the user has the ability to modify the colors displayed within the visualization, and then save the colormap for future use within a visualization.
With easy manipulation of the hue, saturation, value, and opacity components, along with the addition of several critical points, a new color scheme can be developed, as seen below in Figure 3.3. This particular color scheme, in Figure 3.3, was useful in creating realistic colors for the two and three-dimensional models of the Nueces Bay.
The colormap module is also preprogrammed for settings that can create a band of colors, or a change in color every user-determined amount.

### 3.5.2 Elevation/Bathometry

To create a three-dimensional model that displays highs and lows, the RubberSheet and Normals modules were implemented. These modules helped to create a more realistic setting of the Nueces Bay and surrounding area by displaying elevation and bathometry levels.

Within the RubberSheet module the user has the ability to set the displacement scaling. While the Normals module computes the points for shading, within the visualization.

### 3.5.3 Legends and Captions

An important role within all visualizations is the ability for users to understand the meaning of the visualization and what is being visualized. To help aid the user in accomplishing the task of understanding what is being visualized, a Caption module is added to the network. Settings that can be set within the Caption module include, the title of the visualization, font information (including size and style), and the position/location of the title within the visualization.

A module called ColorBar can be utilized within the network to create a legend, to help the user determine the meaning of the various colors contained in the visualization. ColorBar determines the colors used within the visualization from the Colormap settings that are defined in the visualization’s network. Within the ColorBar module, settings include min, max, and location of the ColorBar within the visualization.
Figure 3.4 is an example visualization that shows the output from using the Caption and ColorBar modules within the visualization network.

![Figure 3.4: Example Using Legends [OpenDX 2005]](image)

### 3.5.4 Input and Output

Before a network can run, it must be told which .general file to use, and where it is located. To accomplish this, the Import module is used in the network file, and is often times the beginning of a network. Although another module, the FileSelector module can be included in front of the Import module to increase the ease in locating and naming the file.

There are several different options the programmer has to display the output of the network file. Two of the options include using the modules, Display and Image. This system makes use of both output modules, and the choice of when to use which module depends on the type of visualization being created and the purpose of the visualization.
For example when creating a single, still image, the Image module is used. However for the creation of animations and more complex visualizations, the Display module is used.

The difference between these two modules is the functionality capability they provide to the programmer. The Image module easily provides many interactive image-manipulation features such as, resizing the image, pan/zoom, mouse-driven rotation, navigation in the image, and direct user control of Image-window size. Where as, the Display module relies heavily on other modules for these same capabilities. The Display module is required when creating animation files that are going to be exported and used later in another application.

### 3.5.5 Contours

When creating visualizations, such as the one seen below in Figure 3.5, it is useful to sometimes use contour lines to represent variables, or highlight certain regions. In Figure 3.5, magenta contour lines are used to represent salinity levels, while red contour lines highlight the Nueces Bay and river.
Figure 3.5: The Use of Contour Lines

Several of the models within this system rely on the use of contour lines to display and/or highlight data. The Isosurface and ScalarList modules are needed to create these contour lines.

The Isosurface module is the module responsible for computing the isosurfaces and contours within a data set. This module adds a default color to the output however this default color can be changed by adding a Color module to the network, as seen in Figure 3.6.
The ScalarList module allows for the user to interactively change a list of scalar values. The range of these values can either be data driven, determined by the input module, or specified by parameter values set within a dialog box, as seen in Figure 3.7.
3.5.6 Sequencer

The Sequencer module is used within all animation models, and is what animates the models. Below, in Figure 3.8, shows the two control panels, Sequence Control and Frame Control, for the Sequencer module.
Within the Sequence Control Panel, the user has the ability to control the animation, with the given buttons (left to right): loop, reset to beginning of frames, frame-by-frame walk through, frame control, reverse play, play, stop, and pause.

The Frame Control Panel allows the user to describe how to animate the frames, by allowing them to change starting and stopping frames, as well as the number of frames to increment.

3.6 Graph Models

A primary goal of the graph models was to create visualizations that would accurately display data for analysis and comparison. Important features taken into consideration with these data sets included: excluding dummy data numbers within the data sets, plotting the data values on an easy-to-read graph, and allowing the user the
capability to select what data they want visualized. To provide this functionality, the following modules were employed.

3.6.1 Include

As previously discussed, when working with real data sets there is always a possibility for missing data, therefore when importing data into OpenDX a dummy number must be inserted into the data set. These numbers must then be removed from the data set, before rendering and visualizing the data takes place. To accomplish this, the Include module is utilized. This module allows for the programmer to denote which data points are valid by specifying a min and a max number within the data set.

3.6.2 Plot

Whether creating a line graph or a histogram, the Plot module must be used. Plot creates a two-dimensional plot from a line or set of lines. This module was used in the creation of the majority of the graph models.

By using the Options module before the Plot module, as seen below in Figure 3.9, the characteristics of the graph can be set.
3.6.3 Selector

When importing a group of variables that are related, but not to be displayed at the same time, the Selector module is used. This module allows for the user to select one item from the list to be displayed at a time. An example of the control panel for the Selector module can be seen in Figure 3.10.
The Selector module was useful when importing single variable data from all the sensor stations at one time. This allowed for one data file to be generated, but gives the user the ability to graph the data for each station separately.

**Figure 3.10:** Selector Control Panel
4. RESULTS

4.1 Creating Realistic Models

One feature this project provides researchers with is the capability to visualize environmental data using geo-spatial referencing. This allows researchers to view the data throughout the bay. Another aspect this project took into consideration was the creation of a geo-spatial model that used more realistic colors to represent the bay and surrounding areas. For example, people associate the color blue with water, and therefore the marshy areas are represented as a tan color.

4.1.1 Using Basic Color Schemes

Figure 4.1 shows elevation levels of the Nueces Bay area, with a basic color scheme ranging from blue, which represent lower elevation levels, to red which represent higher elevation levels. Basic land elevation can be derived from this model, but the researcher may not get a true feeling for how drastically different the levels of elevation are surrounding the bay, as well as the bathymetry levels within the bay.
To help enhance the bay’s elevation features, and to provide a more realistic view, a third dimension, elevation, was added to the model. This three-dimensional model, as seen in Figure 4.2, allows for the researcher to get a better understanding of the bay’s bathometry and the surrounding area’s elevation.
4.1.2 Realistic Color Scheme

People associate certain colors with particular objects, such as people think of water as being blue, and land as being green. To accommodate these assumptions this project allows for the researchers to change the colors of the Nueces Bay area too more realistic color scheme, while still being able to display elevation data, as seen below. Unlike the previous model, this model uses a bright green color to represent the highest points of elevation, a tan color to show elevation levels between 20-40 feet, various shades of brown to represents elevation levels around 10 feet, black for elevations of 2-5 feet (representing the marsh areas of the bay), and blue for elevations between 0-2 (representing the bay). However, for researchers to get a true sense of heights and lows throughout the region, a three-dimensional model is a better representation.
Figure 4.3: Two-Dimensional, Realistic Color Scheme for the Nueces Estuary

This three-dimensional model, in Figure 4.4, allows researchers to represent the Nueces Bay’s elevation and bathometry data with a realistically colored model.
4.2 Bay Outline and Contours

Another feature of this project, allows for the researchers to extract and visualize the outline and contours of the Nueces Bay.

4.2.1 Nueces Bay Outline

This outline of Nueces Bay, in Figure 4.5, provides the basic features of the Nueces Bay, such as the ship channel, and the Nueces River. This outline, although maybe not useful by itself, can be combined with other techniques to create visualizations that will portray a more powerful message.

Figure 4.4: Three-Dimensional, Realistic Color Scheme for the Nueces Estuary
4.2.2 Nueces Bay Contours

Although very similar to the Nueces Bay Outline, this model allows for the addition of contour lines to be added to the Nueces Bay Outline. This can be useful when looking at various elevation levels within the bay. Figure 4.6 shows the Nueces Bay with a contour level of 5, meaning that all levels from 0 to 5 are represented by a different line.
Figure 4.6: Nueces Bay Outline and Contours
4.3 Bay Outline with Variable Data

Figure 4.7: Nueces Bay with Sensor Locations

Figure 4.8: Nueces Bay Outline with Salinity Levels
4.4 Adding Grids to the Models

By allowing the functionality of being able to add grids to the models gives the researcher the capability to quantitatively document a point of interest. This will allow for others to locate, reference, and recognize the point of interest with a greater accuracy. An example of a model using a grid is seen below in Figure 4.9.

![Figure 4.9: Nueces Bay Outline with Sensor Locations and Grid](image)

4.5 Bay and Data Models Using Various Techniques

Combining various techniques previously discussed, a multitude of models can be generated. These models can be custom designed to display the areas of interest.
4.5.1 Three-Dimensional Bay Model with Salinity Contours and Bay Outline

This particular model, in Figure 4.10, uses a red line to highlight the bay's outline, as well as the Nueces River, and purple lines to represent a change in salinity levels. Elevation data is also displayed using this model, giving the model a three-dimensional effect.

![Three-Dimensional Bay Model with Salinity Contours and Bay Outline](image)

**Figure 4.10:** Three-Dimensional Bay Model with Salinity Contours and Bay Outline

4.5.2 Using Color Bands to Display Salinity Levels

As represented below in Figure 4.11, this model highlights the different levels of salinity within the bay, in one-step increments. Each new increase in salinity level has a new color assigned to it, therefore allowing the researcher to attain a better understanding
for how the salinity is dispersed throughout the bay. This model, also displays a two-dimensional representation of land elevation.

**Figure 4.11:** Two-Dimensional Bay Model with Salinity Color Bands

4.5.3 **Using a Smooth Color Scheme to Show Salinity Levels**

This model in Figure 4.12 was generated, for researchers to gain a more realistic understanding of how salinity levels may be spread through out the bay, as well as the land area elevation surrounding the bay. Using a normal color scheme, this model attempts to show the smooth contrast in salinity levels, where the color blue represents lower levels of salinity, and red represents higher levels of salinity.
4.6  Just Bay Data

Sometimes it is not necessary to show the surrounding features of the bay. Therefore the next two models represent salinity levels within the bay, with out the extra information that may be distracting. The difference between the two models is the background color. Allowing the researcher to have the ability to change the background color, can allow for a broader examination of data.
Figure 4.13: Nueces Bay on White Background

Figure 4.14: Nueces Bay on Black Background
4.7 Animation

A good way to view changes in salinity levels over time is through animation. The following 30 frames show the change in salinity levels within the Nueces Bay, over thirty days. This animation relies on the smooth color change, but due to some of the math modeling required to interpret salinity values between sensor stations and throughout the bay, some very harsh lines can be seen. The only way to get a smooth contrast in changing salinity is for the math model to be revised, which is not within the scope of this particular project.

![Salinity Animation for the Nueces Estuary](image)

**Figure 4.15:** Salinity Animation for the Nueces Estuary
4.8 Graph Models

These models allowed for the research to obtain a more quantitative understanding of the affects of the variable. Several different graphs were created including a basic line graph, seen in Figure 4.16, Figure 4.17, and Figure 4.18, and a scatter plot graph, seen in Figure 4.19.

4.8.1 Line Graph With Color Accent

The line graph seen below in Figure 4.16 is a basic line graph that has used color on data line to help highlight the highs and lows within the data set. In this case, red represents high, while blue represents low.

![Figure 4.16: Simple Line Graph With Color Accent](image)

4.8.2 Line Graph With Line Bar Label

This line graph is useful if the researcher wants to display numerous data lines at once. Figure 4.17 shows how the use of a line bar legend, in the upper right hand corner, helps to determine which line represents what value.
Figure 4.17: Simple Line Graph with Line Bar Label

4.8.3 Single Data Set, Multiple Line Graphs

Figure 4.18, shows the five different line graphs that can be created from one data set that contains five instances of one variable. Although the user interface is not seen, the user selects which graph to view – only one graph can be viewed at a time.
Figure 4.18: Single Data Set, Multiple Line Graphs
4.8.4 Scatter Plot, Multivariate

![Scatter Plot, Multivariate](image)

**Figure 4.19:** Scatter Plot, Multivariate
5. FUTURE WORK

This system contains many different visualization models and provides a good foundation for future additions. One such addition to this project includes the ability to visualize multivariate data in the geo-referenced model. This would allow researchers to see the affects of several different variables and possibly their interaction with one another. However, the equations used within the math modeling portion of the geo-referenced model need improvement and refinement to improve the quality and accuracy of the visualization. Future study could be done to see if it is possible to let the interpolation and extrapolation of the math modeling be computed within OpenDX instead of within a feeder program.

Other future additions include providing the ability for real-time access to visualization models across the Internet or incorporating neural networks into the visualization so future predictions of the bay’s reaction to an ever-changing environment could be made.

All of this future work would help to provide researchers at DNR with an enhanced way of looking at data that could be crucial to better understanding our environment. This would also give the DNR staff a new way to present data in a manner that is still simplistic enough that they layman can understand what is going on, but detailed enough for the researcher to draw new hypotheses.

Additional future work suggestions, made by DNR, can be found in Appendix B.
6. CONCLUSION

Data visualization is a very active area of computer science that is involving all disciplines. Countless researchers and scientists rely on effective visualizations to form hypotheses, conduct experiments, and draw conclusions from. This is because of the benefit visualizations have of representing large data sets in a clear and concise manner.

The goal of this project was to visualize environmental data of the Nueces Bay by using different visualization models. These models fell into one of two categories: geo-referenced models or graph models. Geo-referenced models provide the capability of visualizing a variable across the Nueces Bay, while the graph models show a more quantitative view of the variable involved.

Within these two main categories of visualization models, they allowed for the display of univariate and multivariate data in a couple different visualization formats. These formats included still images for analysis at a specific point in time, animations over an extended period of time, as well as graphs that would allow for a more numerical study of the data.

Although this system has the ability for additions, improvements, and numerous extensions, it has given DNR the capability to visualize salinity data across the entire Nueces Bay, which is something they currently do not possess, as well as several other types of visualizations they may prove to be useful. Finally, this project has also demonstrated that using a visualization model to display large amounts of data is easier to understand and comprehend than studying large sets of numeric values.
ACKNOWLEDGEMENTS

This project required collaborative efforts to take place between several students as well as various departments located on the Texas A&M University – Corpus Christi campus. First, let me thank the Division of Nearshore Research, and various other TAMU-CC departments, for providing me/us with the access to their data and various resources. Without these tools, the visualization would have never even been able to start.

Second, it is to be noted that certain topics within the visualization were intensely focused on by individuals other than myself, and thus said, I would like to thank my fellow partners, Mr. Stan Leja and Mr. Larry Young, for their various individual contributions to this project. Mr. Leja, having adequate knowledge in mathematics was able to provide all of the necessary mathematical formulas and computations required to accurately represent the salinity distribution throughout the Nueces Bay. While Mr. Young created several C++ programs to convert the raw data into the 1652 by 943 grid format needed to feed the visualization, as well as providing Mr. Leja with mathematical support.
BIBLIOGRAPHY AND REFERENCES


APPENDIX A – USER’S MANUAL

VISUALIZATION OF ENVIRONMENTAL DATA IN THE NUECES BAY

USER’S MANUAL
Version 1.0
Fall 2005
Preface

This software user’s manual describes how to use OpenDX with Visualization of Environmental Data in the Nueces Bay software system.

System Overview

OpenDX is a visualization toolkit, which was developed by IBM Research for data analysis and visualization. Using this toolkit, a software system was developed for the visualization of environmental data in the Nueces Bay.

Document Overview

This software user’s manual is organized into the following chapters:

1. OpenDX System Overview
2. Visualization of Environmental Data in the Nueces Bay Software System Summary
3. Using the Software System and OpenDX
4. Data Model Options

Other References

OpenDX Quickstart Guide:
Provides a “hands on” introduction to OpenDX and is designed to help you start working immediately.

OpenDX User’s Guide:
Is a guide for manipulating and controlling data visualizations, importing various kinds of data for visualization, creating and customizing visual programs with the Visual Program Editor, using the OpenDX scripting language to create visual programs.

OpenDX User’s Reference:
This manual contains detailed descriptions of IBM Visualization Data Explorer tools for transforming, realizing, and rendering data. Each description includes the script-language syntax for invoking the tool; input and output specifications; details of module function; and names of sample visual programs that demonstrate the module's function.

OpenDX Programmer’s Guide:
This reference is intended for programmers who: 1. want to write their own modules for use with Data Explorer, or 2. want to write applications which incorporate Data Explorer modules or use the Data Explorer data model, or 3. want to write applications which directly control the Data Explorer executive or user interface. Programmers using this reference should be familiar with Data Explorer (in particular, its data model).
1. OpenDX System Overview

This chapter provides a brief system overview of OpenDX.

OpenDX Framework

OpenDX has a basic framework of accepting input from the user, processing or rendering the input, and outputting a visualization model.

Input

When data is brought into OpenDX, it must be converted into an excepted file format, OpenDX understands. To do this, all data files that are not native to OpenDX, must describe their data structure and type. The supported data structures include: data defined on a regular grid, data on deformed or curvilinear grids, a variety of meshes, and unstructured data with no connection between data samples. Supported data types include: real and complex, scalar, vector and tensor, byte, short, integer (signed and unsigned), and floating point. Once the data structure and types are described the data must be saved as a .general file, for the data to be referenced in the OpenDX visualization network.

Processing and Rendering

Processing and rendering of the data, is largely dependent on OpenDX and the modules selected for use within OpenDX. These modules all fall within twelve fundamental categories in OpenDX which include: annotation, DXLink, flow control, import and export, interactor, interface control, realization, rendering, special, structuring, transformation, and windows.

Output

The output of visualizations can vary from single images to animations and from images to graphs. This variation occurs within the rendering phase of the visualization and is based the modules that have been selected for use in the visualization’s network.
This chapter provides a summary of the Visualization of Environmental Data in the Nueces Bay software system.

The Visualization Models
The software system can be broken into two major visualization models: geo-referenced models, and graph models. Within these two main categories of visualization models, the display of univariate and multivariate data can occur in a couple different visualization formats. These formats included still images for analysis at a specific point in time, animations over an extended period of time, as well as graphs that would allow for a more numerical study of the data.

Geo-referenced Models
The geo-referenced bay models are comprised of a framework consisting of multiple layers, which are invisible to the user. The first layer provides the visualization with fundamental characteristic information such as shoreline data, which is used in both the two and three-dimensional models, and elevation/bathymetry data found in the three-dimensional model. For the three-dimensional model to render the elevation and bathometry data, a number proportional to the data value at each point is calculated; then by the use of shading and lines, the surface becomes deformed creating an illusion of highs and lows.

Lying on top of the background layer are other layers consisting of information pertaining to the Nueces Bay, such as salinity data or sensor locations.

An important goal of the geo-referenced models was indicating the salinity levels between the various sensor stations. This information was obtained using math modeling equations which required some preprocessing. However, this preprocessing was an early extension to the project, and is not part of this project scope.

Only after the data was processed and formatted for OpenDX, could rendering occur. Several factors played an important role when rendering this data, such as color, height, and the ability to allow the users to be able to extract, and highlight, important features contained within the data set. To accommodate these factors numerous modules were used, and various models were created.

Conventional Graph Models
In certain cases, it is more effective to view the data using graphs, which provide a more quantitative representation. These graphs can easily display large amounts of data over a specified time, and have the ability to represent the data in numerous ways. Within this project two graphs were chosen to represent the data including the line graph which will show univariate data, and the scatter plot graph which visualizes multivariate data.

A primary goal of the graph models was to create visualizations that would accurately display data for analysis and comparison. Important features taken into consideration with these data sets included: excluding dummy data numbers within the
data sets, plotting the data values on an easy-to-read graph, and allowing the user the capability to select what data they want visualized.
3. Using the Software System and OpenDX

This chapter provides an overview of how to open, execute, and save a network in the Visualization of Environmental Data in the Nueces Bay software system and OpenDX.

Opening a Network File

After starting OpenDX, a screen like the one seen in Figure 3.1 will be displayed.

![OpenDX Main Menu](image)

Figure 3.1: OpenDX Main Menu

This screen provides access to the basic functionality of OpenDX such as: importing data files, running the visual programs, editing visual programs, creating new visual programs, running the tutorials, and viewing sample programs.

To open an already existing network file, such as one from the Visualization of Environmental Data in the Nucues Bay project, click on the button entitled “Edit Visual Programs…”. This will bring up a new screen called “Net File Selection”, as seen below in Figure 3.2.
Figure 3.2: Net File Selection

From this screen navigate to where the network files are saved by either typing the location of the directory and file name into the Selection field, or by clicking on the files listed under the Directories heading. (To navigate to file folders that are above the current directory double click the directory name ending with \\.)

After successfully opening a network file, a screen similar to the one seen in Figure 3.3 will be displayed.
This main screen provides complete access to the network file, and from here one has the ability to change, manipulate, and/or execute the current network.

**Executing the Network File**

There are several different ways to execute a network. First, assuming a network file is already open navigate to the menu bar, which is highlighted in yellow in Figure 3.4, located at the top of the screen.

Click once on “Execute” and a drop down menu will be displayed, Figure 3.5, and click on “Execute Once”.
Another way to execute a network file is to select “Execute on Change” from the “Execute” drop down menu. This will re-execute the network every time a change has been made within the network, while the network is open.

Finally if a network is not currently open, you can execute a network file from the main menu screen (Figure 3.1). The process for executing a network from this screen is exactly like the process of opening a network, except instead of clicking on “Edit Visual Programs…” click on “Run Visual Programs…”.

Saving the Network File
If changes have occurred to the network file, it is necessary to save them before exiting the program. To do this click on “File” from the menu bar, Figure 3.6.

If you wish to overwrite and loose the current network file, click the “Save Program” option, otherwise click “Save Program As”. A new window will pop-up, as seen in Figure 3.6, which is entitled Save As.
Navigate, as previously explained in the Open Network File section, to the desired directory and type in a new file name under Selection. It is important to note, that the old network file name is in the space where you will type in the new file name, and therefore must be deleted. After the desired directory and file name have been selected, click on “OK”.

If you have chosen a file name that already exists a new window, similar to the one seen in Figure 3.8, will appear asking you if you want to overwrite the other file.

By clicking “Yes”, you will overwrite and lose all information within that other network file. Clicking on “No” will cancel the save, and therefore you must repeat the previous steps, and choose a new name in which to save the file.
4. Data Model Options

This chapter describes several of the different options available within the various data models.

Changing the Colors

Colors play an important role within any data visualization. Therefore the ability to be able to access and change the colors was an important feature, within the system.

Figure 4.1, is what OpenDX refers to as the Colormap Editor, and it is from this module the ability exists to modify the colors displayed within the visualization, and then save the colormap for future use within a visualization.

![Basic Colormap Editor Screen](image)

**Figure 4.1: Basic Colormap Editor Screen**

With easy manipulation of the hue, saturation, value, and opacity components, along with the addition of several critical points, a new color scheme can be developed, as seen below in Figure 4.2. This particular color scheme, in Figure 4.2, was useful in creating realistic colors for the two and three-dimensional models of the Nueces Bay.
The colormap module is also preprogrammed for settings that can create a band of colors, or a change in color every user-determined amount. To access this click on “Edit” in the menu bar, Figure 4.3, and a drop down menu will appear.

Click “Generate Wave Form” and a new window will pop-up, as seen in Figure 4.4. From that window new waveforms or colormap settings can be generated.
To save a new colormap click on “File” in the menu bar, then click save. The colormap saving process is the same process as previously discussed in Chapter 3, Saving the Network.

**Importing New .General Files**

When inside a network file double click on the FileSelector module and a new window will open, Figure 4.5.

If you know the path name and file name of the new .general file, you can simply type it in here, otherwise click on the “…“ button to open a new window for easier navigation to the file.

Once the file is successfully located, and the new file appears in the FileSelector Import Window, re-execute the network for the change to occur. Remember if you wish to always reference this .general file, you must save your network.
Adding/Removing Contour Lines

Several of the models within this system rely on the use of contour lines to display and/or highlight data. To create these contour lines the Isosurface and ScalarList modules are needed within the visualization network.

The Isosurface module is the module responsible for computing the isosurfaces and contours within a data set, and is not normally modified.

The ScalarList module, however, allows for the user to interactively change a list of scalar values. The range of these values can either be data driven, determined by the input module, or specified by parameter values set within a dialog box, as seen in Figure 4.6.

![ScalarList Module Control Dialog Box](image)

**Figure 4.6:** ScalarList Module Control Dialog Box

To add more contour values, a contour value must first be selected. To do this, use the two arrows to increase or decrease the contour value. Once the desired value is selected, click on “Add”.

To remove contour values, you must first highlight the contour value within the list to be removed, then click “Delete”.

Animation Save Toggle

To save an animation frame by frame, double click on the Toggle module, seen in Figure 4.7.
A new window will appear, asking if you want to write the image, Figure 4.8.

Click the gray box once. The color of the box will now be white, Figure 4.9.
Next, choose the format you wish to save the animation frames. To do this, double click the WriteImage module in the network, and the WriteImage window will appear, Figure 4.10.

In the row that is labeled format, highlighted in Figure 4.11, click on the “…” button.
This will bring up a drop down menu of different file formats the animation frames can be saved as, Figure 4.12. Select one of these formats, and then click “OK” in the WriteImage window.

Back in the network double click on the Format module, and a new window will appear, Figure 4.13. In the row labeled template, and in the value column change the ending format of the file name, to the file format previously selected, and click “OK”.

Figure 4.11: WriteImage Window, Selected Row

Figure 4.12: Animation Frame Formats
Re-execute the network, and run the animation. The animation frames will now appear in the same directory where the animation network is located.
APPENDIX B – DIVISION OF NEARSHORE RESEARCH,
FUTURE SUGGESTIONS FOR IMPROVEMENT