REAL-TIME ENVIRONMENTAL VISUALIZATION FOR DIVERSE USER COMMUNITIES

BY

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THESIS

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ABSTRACT

Modern day scientific visualizations are often focused on a domain-specific audience. As environmental research begins to intersect further with public policy, a diverse community of both technical and non-technical users is becoming engaged in the process of scientific analysis. In order to ease this transition and allow more open data access, visualizations must move from a paper medium to a virtual medium. These new visualizations address the varied requirements of this broadened research community, specifically by showing diverse changes in environmental systems through the use of real-time data. This paper considers the general design requirements necessary to create these visualizations. The primary requirement is to introduce simplified key indicators of environmental status, updated in real time, with the ability for the user to delve into those indicators more deeply if desired. Another key requirement is to make any visualization easily accessible. One particularly accessible delivery platform for the visualization is the Web browser. From these requirements, three visualization interfaces are developed: (1) a dashboard providing at-a-glance views, (2) a map-based exploration system for more detailed observations and (3) a hybrid mode combining elements of both a dashboard and map-based interface. A case study on the efficacy of these three implementations was performed, using Corpus Christi Bay, Texas as a test location. The results of the case study revealed that the majority of stakeholders was able to determine, in full or part, the state of Corpus Christi Bay from the visualization interfaces.

DEDICATION

To Stuart, Kelley, Ryan, and Chris

ACKNOWLEDGEMENTS

Without the aid and advice of a large number of faculty, students, friends, and family, this thesis would not have come to fruition. First, I would like to thank my advisor, Dr. Barbara Minsker, who sought out a number of original research ideas for my thesis and allowed me the unique opportunity to blend civil engineering with computer science. For the doors she opened and the advice she gave, I am deeply grateful. I would also like to give my thanks to Luigi Marini for the inspiration and contributions he provided during the course of my research. Furthermore, Mr. Marini created the programming which simultaneously displays the two visualizations I develop in this thesis. Without his programming, gathering meaningful survey results would have proven challenging. I would also like to offer my thanks to Rob Kooper, a colleague of Luigi Marini who provided software design advising, and Dr. Karrie Karahalios, who introduced me to many software interface design tools and concepts. The support I received on software design was furthered by discussions with the Corpus Christi Bay Testbed Team, which also provided access to data sources and logistical support. From that group, I would especially like to thank Dr. Paul Montagna for providing access to a community of stakeholders for the case study and survey. Ernest To also deserves thanks, as he provided a great deal of support when I ran into issues using the CUAHSI Web services. I would also like to acknowledge and thank the National Science Foundation, which provided financial support during my time in graduate school through grant CBET – 0609545. Lastly, I would be remiss if I did not thank Evan Coopersmith, ostensibly for providing the impetus to develop the Web services library, but mostly for securing my sanity during these past two years and for being a true friend.

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1. Introduction

Environmental data are of keen interest to the diverse communities which inhabit and govern environmental systems (Monmonier 1990). These communities of stakeholders include technical users such as researchers and engineers who are accustomed to working with environmental data. However, the majority of these communities are comprised of less technical users such as governmental regulators, concerned members of the public, industry groups, and students. Opening environmental data access to both technical and nontechnical users alike will allow more informed participation in research and decision-making for environmental systems (Bakkes 1994, Smeets 1999, Ehler 2003).

Differing approaches to opening access to environmental data exist. Enabling access to multiple tabular datasets, for instance, might constitute open access to environmental data. However, only a limited subset of the text could be viewed and understood at any given time—a shortcoming caused by constraints on physical screen space as well as human perception (Keim 2002). This difficulty in perceiving tabular data suggests that a simpler and more nuanced approach may be needed. Instead of focusing on an entire dataset at once, perhaps a subset could be utilized and transformed to show the status of a particular aspect of an environmental system. If enough of these simple data subsets could be utilized, a presentation of the overall state of an environmental system, dependent on key subsets, could emerge.

How can a subset of data from an environmental system be chosen to represent the overall state? Moreover, what is meant by the state of an environmental system? The answer to these two questions can be discerned by observing the actions undertaken by stakeholders in response to changes in an environmental system. For instance, if temperatures in shallow areas of a bay are approaching critically low levels, shipping could be stopped through deeper areas of the bay in an attempt to allow marine migration to these deeper and warmer areas. Such responses can be guided by information about changes in an environmental system, which represents the state of the system for each stakeholder. While this definition of state may vary somewhat among individuals, the stakeholder community will often have some common information requirements. These common requirements can be used to establish a generalized set of environmental data necessary to describe the state.

One way to represent information about changes in an environmental system consists of combining current observations of parameter values along with an explanation of the context of those values – an explanation of the effects of the values on the environment. This context is chiefly gleaned by understanding how the current data compare to past values and how these data are expected to compare to future values. Moreover, meaning can also be intuited from real-time values by characterizing their effects on the environment, specifically for conditions which are harmful to life or violate established standards.

Some methods of conveying such a contextual-based state of an environmental system to a large and diverse community of stakeholders have been developed. Oftentimes, however, a major impediment is that environmental data are typically quite complex (Ahlberg 1995, Carr 2002). While there are existing visualization methods to access these data (Chernoff 1973), oftentimes the data are best pared and reformulated in order to provide an end product palatable to a diverse user community.

One tool which aims to reduce complexity in environmental data is Hydroseek (Beran 2007), a search engine for hydrological data which provides an easy to understand yet powerful interface for accessing hydrological data. Hydroseek, however, only delivers the data and does not attempt to provide context. The Chesapeake Bay Program does provide such context through static visualizations showing the overall health of the bay, shown in Figure 1. The relation between the current and goal quality indices for various indicators in the bay is displayed in a simple and clear image (Chesapeake Bay Program Office 2008).

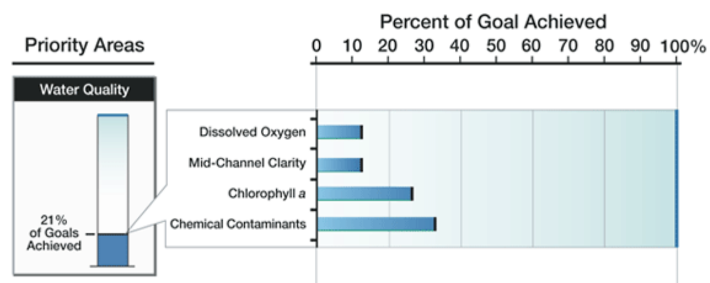

Figure 1: Health Indicator for the Chesapeake Bay (Chesapeake Bay Program Office 2008)

The data used in developing the Chesapeake Bay Program visualization are statically updated. However, standards compliant Web services, such as the CUAHSI HIS Web services (Maidment 2005, Valentine 2006, 2007) have recently been developed, allowing for automatic real-time updating of system-state information. These Web services, which utilize a client-server model, can be integrated into many programs and programming languages, such as Excel, Matlab, and Java.

Standards compliant access methods to environmental data, such as the kind offered by the CUAHSI HIS Web services, have greatly increased the ease and speed with which environmental data can be made accessible to a broader and more diverse community of stakeholders. The skill set required to implement these data access methods, however, still remains beyond the ability of many stakeholders. Steep learning curves to facilitate access to these Web services are very real impediments to improving access to environmental data.

Even in the event that stakeholders possess the requisite skills, a disproportionate amount of time may still be spent enabling access to these data for continued use. A generalized, reusable software package, commonly known as a software library, can be used to remove the need for constant reimplementation of data access methods. This simple library, known as the CUAHSI Web services library, which itself relies on the CUAHSI HIS Web services (CUAHSI 2008, Valentine 2007), will allow the more technical members of the stakeholder community to quickly and easily make data available to others. The Web services library allows for metrics, such as aggregations, combinations, and comparisons, to be calculated from the data as defined in Section 3.1.

Even if the returned data can be pared down through the use of these metrics, humans may still have difficulty interpreting the dense data sets which can result. The Health Indicator for the Chesapeake Bay in Figure 1 illustrates that one of the simplest ways to provide accessibility to environmental data is in the form of Web visualizations. These Web visualizations can display real-time data returned by the Web services library to provide a more coherent picture of the current state of an environmental system.

As a case study for such real-time Web visualizations, the environmental system of Corpus Christi Bay, Texas, is introduced in section 1.2.1. Two web visualization systems are implemented for Corpus Christi, though they can be easily generalized by changing the RSS (Really Simple Syndication) input to other locations. The first visualization, an at-a-glance dashboard with support for closer inspection of particular sampling locations, is described in section 1.2.2. The second visualization, a map-based visualization which allows the viewing of the most critical real-time data at particular locations in an environmental system, is described in section 3.2.1. Each visualization interface shares a separate code base but common inputs – the technical details of which are developed in section 3.2.2. In order to evaluate the efficacy of the visualization development, in section 3.2.3 these visualizations are joined in a combined interface and a survey introduced to evaluate stakeholder response. The results of this survey are presented in section 3, followed by an analysis of these results in section 4.

2. Methodology

In order to demonstrate use with a real-world environmental system, all visualization interfaces developed in this paper are supplied with data from Corpus Christi Bay, Texas. Further, two visualization interfaces, usable inside a standard Web browser, are developed in this section. The first visualization interface, the dashboard (Figure 2), is comprised of a number of linked views which allow for at-a-glance data summaries of key indicators across the entire environmental system, such as oxygen, water temperature, and salinity. On demand location summaries, showing both real-time and historical data for a chosen location, are also available through the dashboard interface. The second visualization interface, the map (Figure 3), consists of a single view, an interactive map with icons marking each sampling location. Selecting each icon will cause a pop-up window to appear containing a data summary for the chosen location. The map can be placed alongside the dashboard, resulting in a combined interface which allows for interaction and shared control between the map and dashboard. Case study metrics are also developed in this section to evaluate if the real-time state of an estuarine system can be adequately conveyed by the map or dashboard interfaces.

The case study metrics rely on sensor data from Corpus Christi Bay. During the summer months, Corpus Christi Bay typically experiences hypoxia, and recent studies have confirmed that the long-term oxygen levels are in decline (Applebaum 2005). Due to concerns of low oxygen levels, several networks of sensors have been deployed in and around Corpus Christi Bay. Data from these sensors, accessible through the CUAHSI HIS Web services, is of interest to a diverse community of stakeholders, including fishermen, regulators, and residents of Corpus Christi. In order to adequately convey sensor data to these stakeholder communities, the map interface and the dashboard interface are utilized.

A real-time comparison of minimum and maximum values is the first view shown when loading the dashboard interface, as shown in Figure 3. This comparison is over all sensors in the environmental system and shows the value, the sample time, and the sample location. The comparison also includes a collection of colored zones which indicate critical zones for each variable.

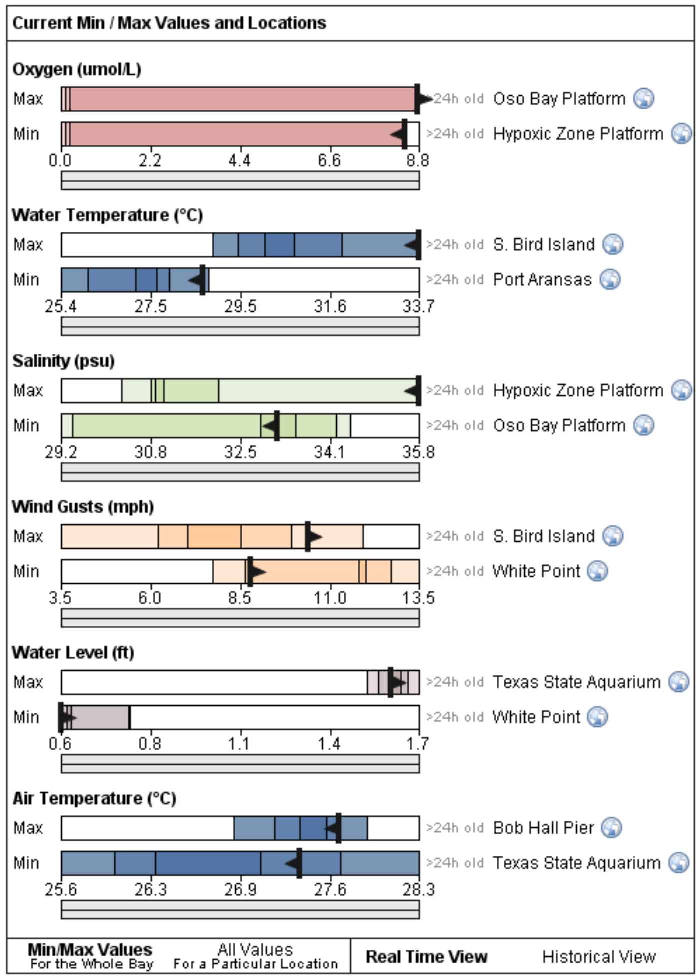

Figure 2: Dashboard interface, with a comparison of the minimum and maximum values of key indicators across all sensors

The minimum and maximum comparison view is only one component of the dashboard—historical views and location summary views are also available, which will be defined further below. These other views allow greater data detail than is available either in the default dashboard view or the map interface.

Though providing increased data detail, the dashboard interface lacks a spatial context. The map interface given in Figure 3 provides this missing spatial context through the use of dynamically updating location icons. By clicking on different location icons, in-window pop ups will appear that show the current location name, value, update time, and trend.

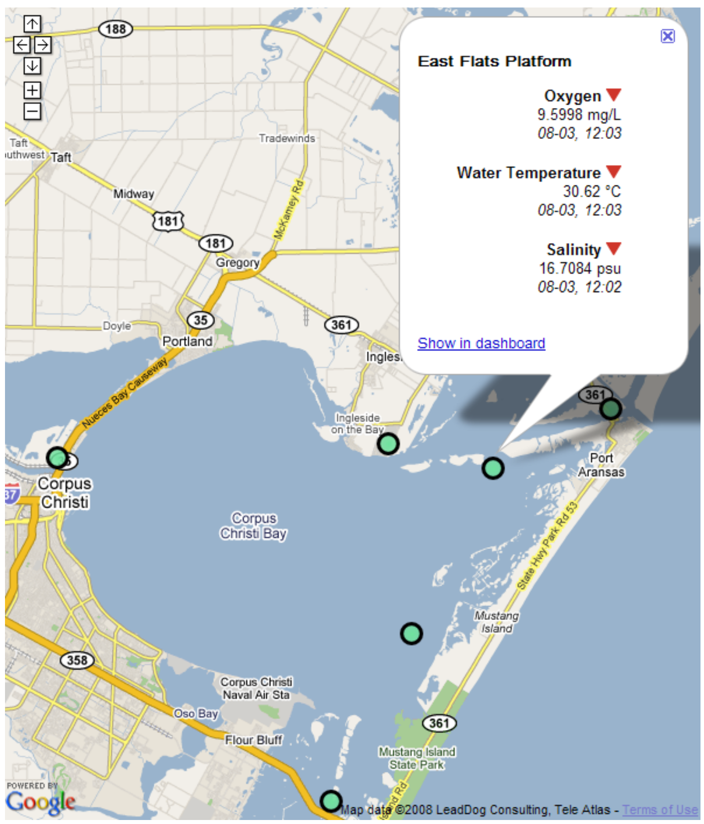

Figure 3: Map interface, with status-based location icons

Both the dashboard and map-based interfaces have weaknesses that can be ameliorated by combining the two interfaces in one window. This combination of the dashboard, providing value comparisons, and the map-based display, providing spatial reference, may yield a more effective data exploration tool. Such a hybrid interface will be evaluated in the Corpus Christi case study to determine whether or not it adequately conveys the real-time state of an estuarine system.

In order to illustrate the ideas used to develop the visualizations, the case study of Corpus Christi Bay will first be considered in section 1.2.1. After this introduction to a real-world environmental system, the generalized design of the dashboard interface will next be developed in section 1.2.2, followed by the map-based interface in section 3.2.1. Directly following the discussion of the individual interfaces, the combined interface will be introduced in section 3.2.2. Lastly, section 3.2.3 presents an overview of the survey methodology.

2.1 Case Study: Corpus Christi Bay

The needs of stakeholders in Corpus Christi Bay provided the impetus for the creation of real-time data visualization tools for environmental systems. As an environmental system, Corpus Christi Bay experiences seasonal hypoxia with an unknown, but suspected, cause (Applebaum 2005). A number of sensors have been deployed in the bay to directly observe hypoxia in real time. Additionally, these sensors can aid in better understanding the causes of hypoxia through adaptive sampling and by acting as inputs into predictive models (Coopersmith 2007, Nelson 2007; Kulis 2006a, 2006b; Islam 2006a, 2006b). These sensors can also be queried by the Web services library and converted by generalized scripts into the RSS inputs for the dashboard and map interfaces.

Figure 4: Corpus Christi Bay with Real-Time Sample Locations

Three primary sensor networks form the core of the Web-accessible real-time data sources for Corpus Christi Bay (see Figure 4): the Texas Coastal Ocean Observation Network (TCOON), the Shoreline Environmental Research Facility (SERF), and the National Water Information System (NWIS). TCOON is an extensive operational sensor network with observation points throughout Texas, including Corpus Christi Bay and the surrounding area (Tissot 2005, DNR 2008). SERF consists of a network of research sensors dedicated to monitoring the health of the Corpus Christi estuary system and supporting the development of predictive models (SERF 2008). The SERF sensors provide the only real-time oxygen sources for Corpus Christi Bay. Lastly, the NWIS network, which measures key characteristics of rivers throughout the United States, is operated by the United States Geological Survey (USGS). Three real-time NWIS sensor stations are located near Corpus Christi Bay, as shown in Figure 4.

These three sensor networks sample a large number of parameters, listed in Appendix G. Through discussions with Corpus Christi Bay researchers, a number of key parameters were selected as indicators of the health of the bay, as listed in Figure 5.

Oxygen (mg/L)
Multiple oxygen values were seen as important, including the predicted minimum value of oxygen and the real-time extremes.

Salinity Stratification (psu)
Salinity stratification has been associated with hypoxia, particularly when highly saline water is layered over less saline water.

Temperature Stratification (°C)
Similar to salinity stratification, temperature is thought to play a part in the occurrence of hypoxia when warm water is layered over cold water.

Water Density (g/L)
Water density captures both the temperature and salinity stratification in the bay in one indicator.

Other Key Indicators
Water Temperature, Salinity, Maximum Wind Speed, Average Hourly Wind Speed, Air Pressure

Figure 5: Key Parameters for Environmental Status of Corpus Christi Bay

In addition to accessing real-time values of parameters, knowledge of predicted future values could also prove useful. For the Corpus Christi Bay visualization, we incorporated forecasts from Coopersmith (2008) into the dashboard as an example of this type of capability (shown below in Figure 6). Coopersmith utilized historical values of oxygen, salinity, temperature, to find the future probability of hypoxia in Corpus Christi Bay, which consists of a matrix of predicted oxygen values across a gridded representation of Corpus Christi Bay.

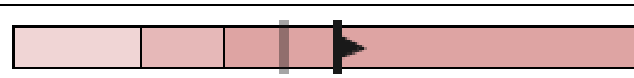

Figure 6: Sliderbar showing the currently observed value (solid black) and the predicted value (semitransparent black)

As stated before, the data sources which power these predictions and allow recording of current parameter values (the TCOON, SERF, and NWIS services) all are accessible through standards-compliant Web services. One caveat with these Web services is that while the access methods are standardized, the output formats are not identical, necessitating conversion of the data into a common intermediary format. In order to provide both uniform data access as well as analytics, an intermediary layer of reusable code, the Web services library, was created. This library allows for simple acquisition and analysis from online data sources. Additionally, while being designed to work with the CUAHSI HIS Web services, the library can be extended to work with other Web data providers. This generalization provides the dual benefits of uniform data access and analytics – saving others the time and expense of reimplementation.

One of the key analytic functions in the Web services library is the division calculator, which establishes zones of criticality for each value at a location. While many divisions are calculated on the basis of historical data, some values have set divisions which do not vary based on historical data. For instance, the oxygen divisions are established with respect to the effects of hypoxia on marine life. The threshold for the true occurrence of hypoxia has been established at 3 $^{mg}/_{L}$ for Corpus Christi Bay (Ritter 1999). Limited hypoxic effects, which are also of concern, occur between 3 $^{mg}/_{L}$ and 5 $^{mg}/_{L}$ (Ritter 1999). Combining these values results in the following set of three division groups for the case study:

1. 0 $^{mg}/_{L}$ – 3 $^{mg}/_{L}$
2. 3 $^{mg}/_{L}$ – 5 $^{mg}/_{L}$
3. 5 $^{mg}/_{L}$ – Maximum Observed Value Over the Past Year ($^{mg}/_{L}$).

Scripts have been developed which utilize both the real-time values, divisions, and other associated metadata along with model forecasts to produce outputs usable by the dashboard and map interfaces. These scripts are linked through a scientific workflow manager, Cyberintegrator (Marini 2006). Any location for which data have been sampled in the last 48 hours is processed, with the Web services library analytic tools used for querying and generation of the necessary metadata. The output from these scripts consists of an RSS feed as well as a set of historical data files for each sampled value.

2.2 Dashboard Interface

From the script outputs, a visualization must use an appropriate data subset in order for the target community to quickly assimilate and gain an understanding of the real-time state of an environmental system. The dashboard is the prototypical at-a-glance visualization system, taking key data subsets and reorganizing them into an easily understood, informative context. The primary visualization used to convey these data subsets is the sliderbar, a horizontal bar delineated by historical bins, with a marker showing the real-time value. For example, the sliderbar for oxygen in Figure 9 gives the current value, an arrow indicates the trend of the data (increasing or decreasing), and the magnitude of the value relative to the historical data bins. The secondary visualization of data subsets is the time history graph (Figure 7). These two visualizations, along with a control interface of view selection buttons, comprise the dashboard interface.

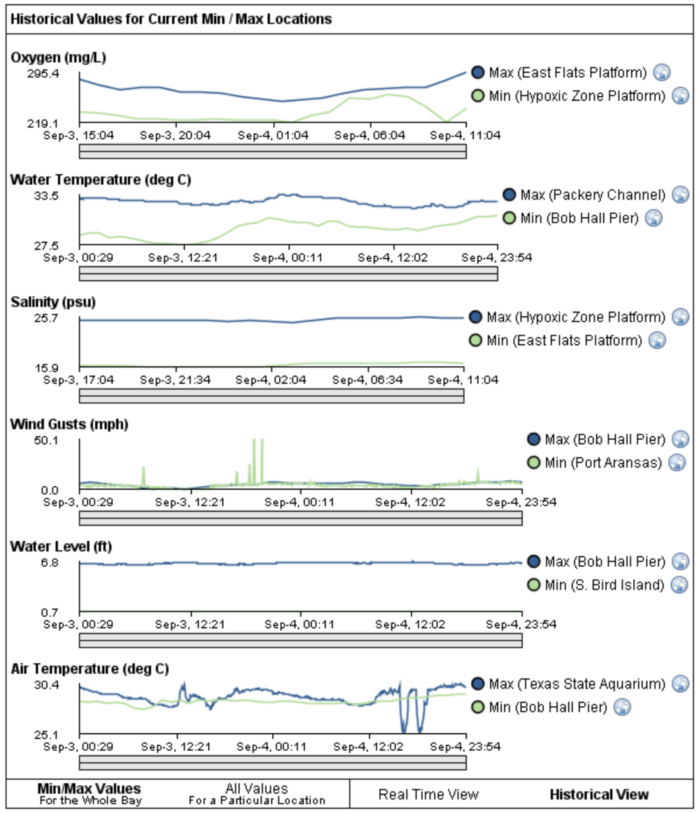

Figure 7: Time History Graph

The selection of the appropriate data subset for a particular view is critical to the utility of the dashboard interface. Given that many data sets will be too large to allow complete inclusion, some data must be excluded from the current view. Deciding which data to present is not a trivial problem, but does have simple solutions in certain cases. For instance, when attempting to discern the state of a system, looking at real-time extremes may aid the stakeholder in narrowing the possible set of environmental system states. This is the approach taken for the Corpus Christi case study to address stakeholder input, but alternative indicators can easily be accommodated (e.g., showing sets of the data that are particularly sensitive to an aquatic organism of interest). These types of indicators allow the user to focus on evaluating a key subset of possible system states.

A simple indicator such as a real-time extreme has its own limitations. For instance, users may wish to exclude certain locations from a search for real-time extremes, suggesting that some level of pre-selection on the part of the user is important. For example, consider a point which contains vertically sampled data, such as oxygen data at multiple depths in Corpus Christi Bay. Should all values be considered in the comparison of extremes? Perhaps only the bottom-most sample is important, which is usually most likely to be hypoxic (Galkovskaya and Minyanina, 2005). The answer to such questions should be considered on a location by location basis. Ideally the software interface should allow users to easily customize and adopt data views that address their own indicators of interest, a feature that will be explored in future generations of this work.

After data have been selected, the data subsets must be effectively visualized. Many schemes have been proposed, such as the radial gauge shown in Figure 8 below. Such a radial gauge borrows a reliable real-world indicator and transforms it for use in a virtual medium.

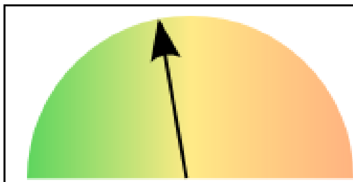

Figure 8: Radial Gauge

Despite its familiarity, the radial gauge is ill suited to make the transition from automobile dashboard to virtual system. In some cases, such as representing parameters often measured with gauges, a radial gauge visualization is suitable. In most situations, however, the radial gauge consumes a large amount of screen space while conveying a relatively small amount of information (Few 2006).

In order to lessen the problems associated with radial gauges, an alternate indicator is proposed: the sliderbar. A sliderbar, shown below in Figure 9, is in essence a horizontal gauge with support for multiple bins, often statistical quantiles. Much of the dashboard design was inspired by the design concepts of Tufte (1983, 1990, 2000, 2006)—especially the idea of conveying greater information with fewer graphics. The primary advantage in using a sliderbar over a radial gauge is a much lower areal requirement, allowing a greater number of indicators to be shown on screen at once (as can be seen with the excess space in the previously shown Figure 2). The benefits of a sliderbar are particularly important when noting that the smallest dimension on modern computing displays is frequently vertical, allowing more sliderbars than radial gauges to be shown at once on a display.

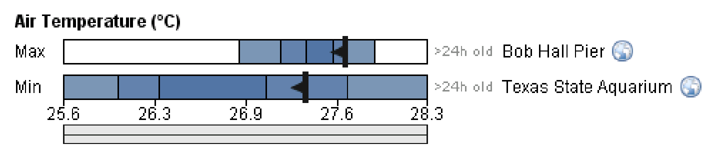

Figure 9: Example of a Sliderbar

The title to the left of the slider bars in Figure 9 is a description indicating the reason for inclusion of the sliderbar in the set of other sliderbars for each variable. In the default view, the title is either Min or Max, but depth values can also be used for the title. In some situations, such as when only one value is suitable for display, the title is left entirely blank. Adjacent to the title, the colored delineations on the bar represent either environmentally critical thresholds or the historical distribution of values (typically statistical quantiles) at a particular location. The marker on the colored delineations indicates the position of the real-time value within the historical data range. Each marker also contains an arrow which points in the direction of the prevailing trend, as determined by a Mann-Kendall trend test (Mann 1945, Kendall 1938). To the right of the bar is the update time, which shows when the data were sampled. Adjacent to the update time is the location description, if any. Lastly, an optional map-link icon is used to control the map interface, when available. In the absence of the map interface, this icon is not shown.

The divisions on the sliderbar utilize varying colors to convey key division zones in the data. In any design paradigm, a color budget is an essential concept – color may be most efficiently used where it will enhance the utility of a visualization. When creating division zones, differing intensities of the same color can often do the job of different shades of color (Few 2006), while allowing differing colors to denote various sampled values such as Oxygen, Water Temperature, and Salinity, as seen in Figure 2.

Division boundaries themselves can be created through a number of methods, the most common of which is a quantile bin distribution for the data set. Other meanings for the divisions are possible, such as definitively established boundaries (e.g., healthy, impacted, and dangerous conditions). In the case study of Corpus Christi Bay, most division values were established on the basis of the one-year history for samples at a particular location, divided into twenty-percent increments. The exception was for oxygen, whose divisions indicated varying degrees of harm to aquatic life (Ritter 1999). Enabling an interested user to determine the meaning of the divisions in a dashboard is critical for comprehension. In this paper, context sensitive tooltips are used within the dashboard in order to convey the division meanings, as shown in Figure 10.

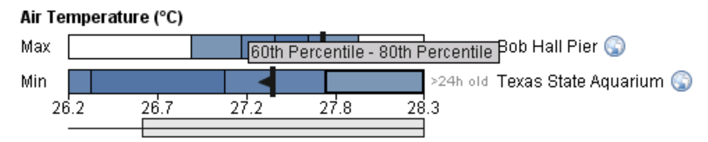

Figure 10: Context sensitive tooltip for divisions

Often the divisions will be irregularly distributed over the range of values for a sample location, resulting in very close spacing in some areas of the sliderbar. In such situations, the range selector shown in Figure 11 can be used to zoom in on desired segments of the sliderbar. This zooming allows for unencumbered viewing of the division segments, markers, and predictions which make up the sliderbar.

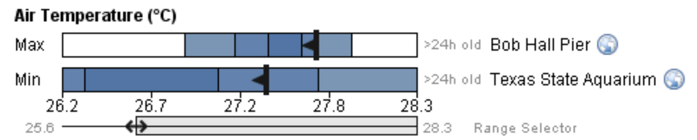

Figure 11: Range Selector

In addition to the divisions, a marker and trend arrow are placed on each sliderbar as shown in Figure 12. For this case study, the marker value shows the most recent value available from a sample location. As noted earlier, the trend arrow is generated via a simple Mann-Kendall trend test (Mann 1945, Kendall 1938).

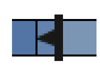
Figure 12: Note the marker and trend direction indicator

Hirsch (1982, 1984) proposed an alternative to the Mann-Kendall test that detrends natural fluctuations from a dataset in order to determine longer-term trends. In the Corpus Christi case study, stakeholders were most interested in assessing short-term trends from the real-time data, hence detrending was not necessary. Such detrending may prove useful in other environmental situations, however, such as analyzing the long-term health of the bay.

While the most recently available data are placed as markers on the sliderbar, these data are not necessarily considered real time. The true determination of real-time status is the decision of the end user. For this reason, the time since the data have been sampled is listed directly to the right of a sliderbar.

The sliderbar-based view, while important for understanding the real-time state of an environmental system, lacks detailed historical information. While this lack of detail is ideal for an at-a-glance view, some stakeholders will need more detailed historical information.   Indeed, humans in general perform data analysis in a three step process (Shneiderman 1996):

1. Look for a general summary of the data and pick out points of interest
2. "Zoom and filter" (Keim 2002) each section of interest for increased granularity. Zooming allows for focusing on particular data subsets; filtering allows selecting certain elements from these subsets.
3. Extract and analyze data subsets from the true areas of interest

While the initial dashboard view provides a general data summary, other views are better suited for zooming, filtering, extracting, and analyzing data subsets. To this end, the dashboard control interface, located at the bottom of the dashboard, incorporates toggle buttons allowing the user to select either a real-time or historical view.

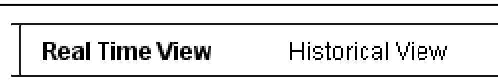

Figure 13: Real Time and Historical View Toggle Switch

While the real-time view utilizes sliderbars for data display, the historical view uses line graphs, as shown in Figure 14. This allows for greater control over the time history shown, as well as a greater understanding of the temporal patterns in the data history at a particular sample location.

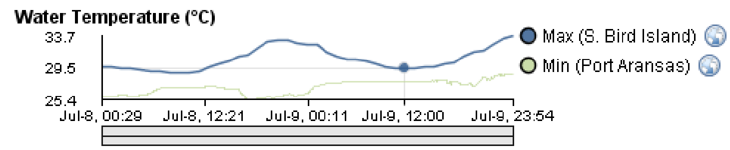

Figure 14: Time History Graph

The historical view incorporates the same range selector used with the sliderbar, allowing for zooming in or out of detailed data sets. Hovering over a point on the time history graph will highlight that data point and show the sample value and time on each respective axis, as shown in Figure 14.

Zooming and filtering data consists of more than switching between a real-time and historical viewing context. The option to access all real-time data in a dataset, not just the minimum and maximum values, must also be included. Due to this need, the option of exploring data by location has been included in the dashboard through the "All Values for a Particular Location" button.

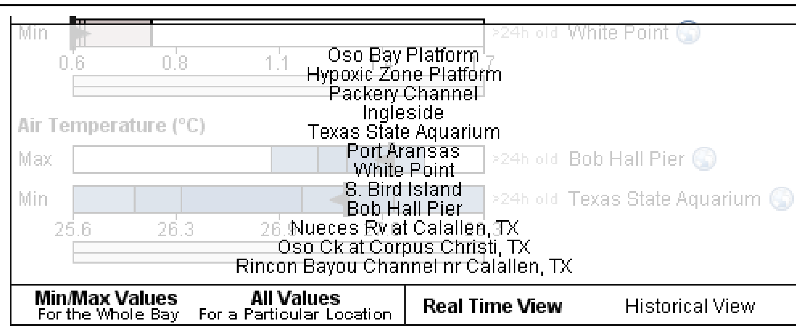

Figure 15: All Values for a Particular Location

When clicking on this button, a menu appears allowing the selection of a particular location, as shown in Figure 15. Upon clicking on a location name, the dashboard will display all available data sources for each location. The real-time and historical views can be utilized in the same manner as when using "Min/Max Values for the Whole Bay."

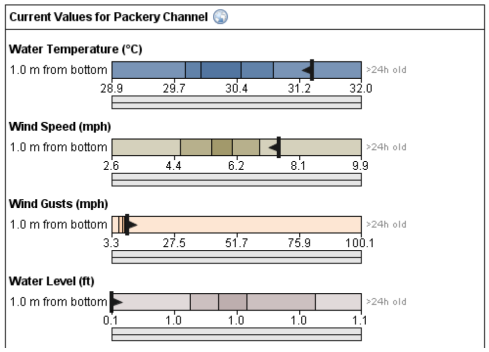

Figure 16: Sampled Location Values, Real Time View

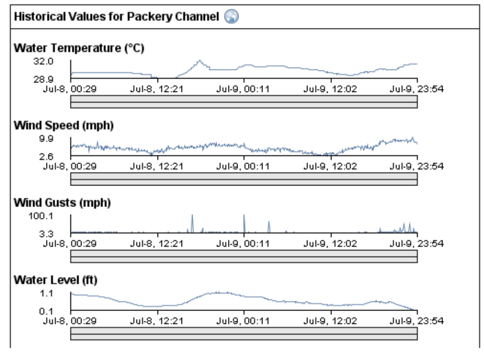

Figure 17: Sampled Location Values, Historical View

2.1 Map-Based Interface

As with the dashboard view, the focus of the map-based interface is aggregating environmental data and deciding the proper grouping of data subsets. Unlike the dashboard interface, however, the use of a spatial context automatically determines how the data are aggregated and grouped – by location. Each sample location on the dashboard is referenced by an indicator icon, which changes to either red (critical) or green (noncritical) depending on the values at the sample location. Zooming and filtering of data is available by clicking on the location icon, which produces a summary popup showing the most important values for each location, as shown below in Figure 18. This concept of importance, necessitated by the large number of sensors which can be deployed at a particular location, can be decided on any number of bases. In the case of Corpus Christi Bay, the lowest (bottom-most) values were deemed the most critical by researchers who are studying hypoxia in the bay and assisted in designing the dashboard and map interfaces. Below the list of the most important values is a linkage back into the dashboard interface, the "Show in dashboard" link.

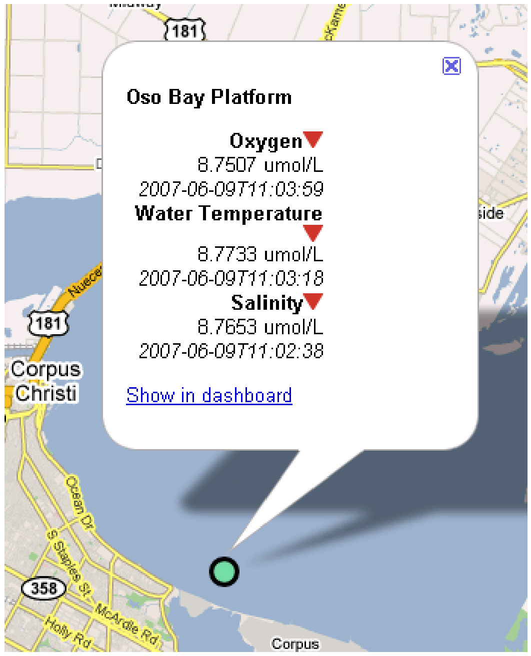

Figure 18: Map Location Icon and Pop Up

Beyond the “Show in dashboard” link, there are a number of design paradigms which are shared between the dashboard and map interface. In particular, the map location icon borrows the concept of critical divisions from the sliderbar. The same quantile calculations discussed in Section 1.2.2 are used to determine a set of bins for a particular location and value. If any value for a particular location falls into the most critical bin, the location icon will change from green to red, indicating that greater analysis may be warranted at a particular location. For the Corpus Christi case, oxygen levels were used to determine the color of the location icon.

While the status icons in the map interface display general information about each sample location, the ability to filter and zoom would allow for a much more thorough exploration of the data. A logical method of providing the ability to filter and zoom is via location pop ups, as illustrated below in Figure 19.

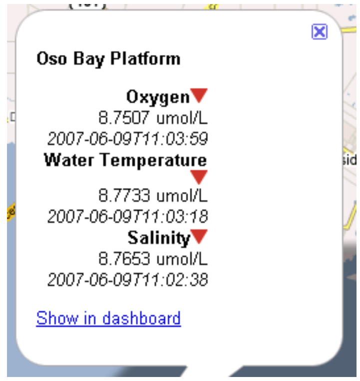

Figure 19: Location Pop Ups

Due to the limited amount of screen space available to a pop-up, efficient layout will allow the display of greater amounts of applicable data. If too little information is included, the popup may lose effectiveness as an information discovery tool. If too much information is included, however, the user could quickly become overwhelmed. Four key subcomponents were chosen for representation in the popup:

1. The variable name
2. The trend
3. The variable value
4. The sample time

The variable name is displayed most prominently in the popup, much as it is in the dashboard. This highlighting of the variable name is intended to allow for easier location of a desired variable – important in a text-rich popup.

Adjacent to the variable name is the trend icon, which can reduce the need to reference time history graphs and may reduce the need for evaluating the actual value.

An upward pointing green trend arrow indicates that a value is increasing; a downward pointing red arrow, the converse. There exists some question as to whether or not green and red are appropriate indicator colors, as green generally means a beneficial change while red means the opposite. When used as trend arrows, these color meanings do not correspond to an actual beneficial or detrimental change in the state of the bay, but simply to the direction of change. One potential remedy to this problem would be to remove the coloring from the trend arrows entirely. Doing so, however, could modify the trend arrows from a form which is quite familiar (due to the ubiquity of color-based trend arrows in other realms of visualization, such as television) to one which is slightly more unfamiliar. Furthermore, if color was left on the trend arrow, it could be used to indicate whether the observed variable is presently in a critical zone. The use of trend arrows in this manner, however, would involve encoding multiple meanings into one visual element, increasing the complexity and learning curve for the dashboard. After consideration of the potential issues caused by these two alternate scenarios, color was left on the trend icons, with green indicating a numerically positive change for a variable and red indicating a numerically negative change.

Below the variable trend arrow and title lies the currently sampled value. Some locations sample particular variable values at multiple vertical positions. Showing each sample value would result in a crowded popup. In order to ameliorate this problem, only the most important value (in the case of Corpus Christi Bay, determined programmatically on a per-variable and per-location basis), is shown. This programmatic determination is established beforehand on the advice of stakeholders as well as by designers aware of the unique informational needs of each environmental location. In the case of Corpus Christi Bay, sample values at the bottom of the water column were chosen for inclusion, as this zone is where environmentally deleterious effects are typically observed.

Though the map interface provides a spatial context for the displayed value, a temporal context can aid users in establishing the importance of a particular sample value. The update time, located below the currently sampled value, provides this context.

With the components described above, a map-based popup can provide a substantial amount of information about an environmental system. However, spatial constraints dictate that a map-based popup cannot fully represent all data available in an environmental system. Furthermore, certain actions, such as extreme comparisons, are simple to perform with the dashboard but become laborious with the map interface. For these reasons, a link back to the dashboard is provided at the bottom of every map popup, as shown in Figure 20.

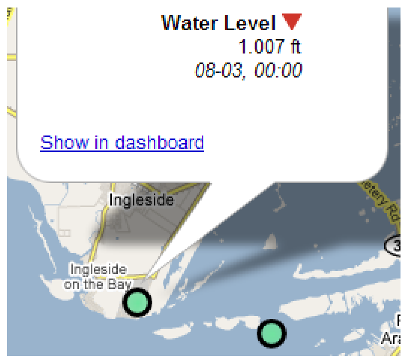

Figure 20: Dashboard interface link, shown as a blue hyperlink

2.2 Implementation of Interfaces

The dashboard interface is written entirely in Processing, a Java-based language, while the map interface is written in Java. Each interface utilizes the same input, a file based on the RSS standard. This RSS file, more commonly called an RSS feed, contains real-time values for all locations in an environmental system, along with any requisite metadata, such as a list of critical divisions, current trend values and update times. The dashboard utilizes an additional set of inputs – historical data sets for sample locations.

Creating the dashboard required largely graphical programming. In order to reduce development time, this programming was performed in a specialized programming language for visualization – Processing (Reas 2003, 2007). While the same interface could have been created using other major programming languages, such as C++ or Java, the utilization of a specialized programming language reduced implementation time and complexity due to the greater simplicity of the language and focus on built-in graphical functions. The Processing language itself was chosen because it is based on the Java programming language, which allows for direct use of the software as an in-browser applet, a Java program called from and included within a web page.

The data sources for the dashboard consist of a real-time input for the entire environmental system and an historical input for each sampled location. The real-time input is based on the RSS standard, which is itself based on XML, a self-describing format. Specifically, the XML format utilizes standard encodings and human-readable tags. These features allow the format to be more easily interpreted and re-used by others, providing a more open data format.

Owing to its basis in XML and generalized design, RSS feeds allow for simple sharing of datasets that update over time. Some metadata elements, however, are not easily represented using RSS. For instance, each sample location has an associated latitude and longitude. While this information can be represented in the same section as the real-time observations, the feed would become less comprehensible by both humans and programs. Another choice is to store these data in separate sections of the file through the use of modules, extensions of the RSS format. These modules can be utilized to allow the inclusion of georeferenced data and any other extra elements inside RSS feeds.

One module, used to establish a map icon for each location, is the Yahoo! Media Module (Yahoo! 2008). While this module provides a visual display of a location on a map, it does not determine the location. In order to adequately establish the georeferenced location of each sample point, another module, the GeoRSS module is used (Reed 2006, Turner 2008). GeoRSS itself is an open standard which can be written in two ways: GeoRSS Simple and GeoRSS GML (Cox 2004). As suggested by the names, GeoRSS simple provides a basic way to add georeferenced points and shapes to RSS feeds, while GeoRSS GML allows for a much larger selection of georeferencing options. Because the dashboard interface is configured to display point data, at this time only GeoRSS Simple is supported in the input RSS feed.

The Yahoo! Media and GeoRSS modules, however, provides only partial support for the data which needs to be stored in an RSS feed. Critically, the values and associated metadata, such as trend, sample time, and historical divisions, need to be contained within an RSS feed. Due to the specificity of these requirements, no currently available RSS modules support the necessary elements. In order to satisfy these data representation requirements, another custom extension is included in the RSS feed. This custom extension involves the creation of new tags, or elements, within the RSS feed. Each tag can contain a current observation for a parameter value, as well as any associated metadata not provided for in other formats. The format for this custom extension of the RSS format is defined in Appendix B.

After inclusion of the necessary elements described above, the RSS feed contains a complete set of real time data for an environmental system. The dashboard, however, supports viewing both real-time and historical data for a sample location. While no technical impediment exists to prevent inclusion of historical data within the RSS input feed, such inclusion would result in an order of magnitude increase in file size. Instead, the historical values for each sample location are included in separate files, the format of which is defined in Appendix E. The path to the Web address containing these historical data files is an input parameter to the dashboard.

The map interface supports the RSS input feed through the Google Maps Application Programming Interface (API) along with custom Java code. Utilizing the Google Maps API provides native support for RSS and the GeoRSS module, reducing development time for the map interface. Other modules included in the RSS feed, however, contain extra elements not supported by Google Maps. For instance, the icons for each location utilize the Media RSS

Module (Yahoo! 2008), which is not directly supported by the Google Maps API. In order to provide full support for these features in the map-based interface, some additional custom Java programming was performed. This custom Java programming only needed to be implemented once in order to enable full support for any location with a compliant RSS feed.

2.3 Survey

The map and dashboard interfaces, though comprised of different codebases, were designed to function together when presented on the same Web page, titled the Corpus Christi Bay Explorer. This combined interface, shares a unified data feed and was evaluated in a survey of Corpus Christi Bay stakeholders.

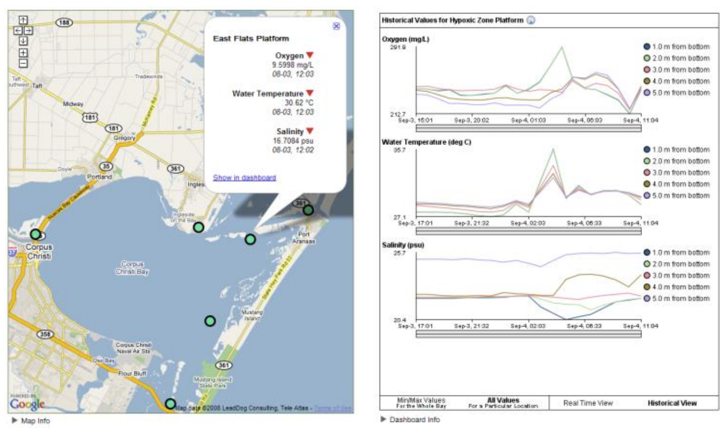

Figure 21: The Corpus Christi Explorer, a combined display of the map interface and dashboard interface

The survey requested that users compare the combined interface developed in this paper to DASH, a data download interface developed explicitly for the CUAHSI HIS server (Whitenack 2007). The complete questionnaire, available in Appendix H, establishes four primary evaluation metrics:

1. Ease in Accessing Real-Time Data
2. Ease in Comparing Real-Time Data Values

3. Ease in Inferring Trends
4. Speed and Responsiveness

User responses to these areas of interest are intended to determine whether a real-time visualization system, such as that offered by the combined interface, is truly needed to understand the state of an environmental system. DASH enables access to the same datasets as are available through the dashboard and map interfaces but provides a different interface, as its primary purpose is to facilitate downloading of environmental data. The survey seeks to evaluate whether the dashboard and map interface can convey the state of Corpus Christi Bay, and if they are more effective at conveying the state of Corpus Christi Bay as compared to the general purpose DASH interface.

3. Results

The survey was distributed online to a broad set of researchers, regulators, and community members. Seventeen responses were received, of which 70% self identified as researchers. Most respondents reported a high degree of technical competency, with 87% having either moderate or a good deal of experience with computers and Web browsing. When this community was asked to correctly identify elements of the Corpus Christi Bay Explorer in the absence of instructions, responses were mixed, indicating that instructions are needed to use the system effectively. After receiving such instructions and using both the DASH and Corpus Christi Bay Explorer interfaces, 69% of respondents concluded that viewing and comparing real time data was easier using the dashboard and map interfaces. Additionally, the map and dashboard interfaces were able to convey the state of Corpus Christi Bay fully to 40% of respondents and partially to the remaining 60%. More details on these overall findings are given below.

Before evaluating the Corpus Christi Bay Explorer and its ability to convey the environmental state, two questions were asked (numbers 8 and 10, available with all other questions in Appendix I) about the meanings of different elements in the dashboard interface.

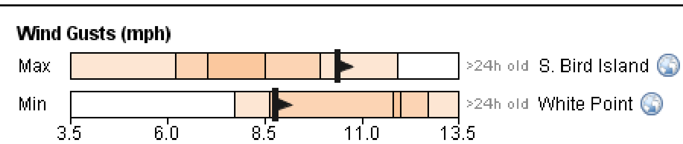

Figure 22: The Example 1 figure from the survey, showing differentially colored ranges from the sliderbar

The first question, survey question 8, asked what the differentially colored ranges of the sliderbar (shown in Figure 22 above) represented.

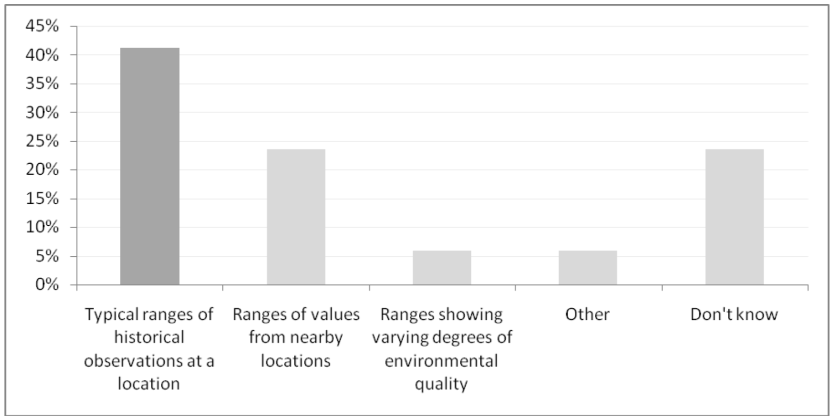

Figure 23: What do the differentially colored ranges in the Example 1 figure represent to you? (Survey Question 8)

A large minority (41%) of respondents answered correctly, indicating that the colored ranges represented “typical ranges of historical observations at a location” (Figure 23). The second largest minority (24% of respondents) was tied between “ranges of values from nearby locations” and “don’t know.”

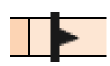

Figure 24: The Example 2 Figure from the survey, showing the triangular protrusion

The next evaluation question, survey question 10, asked the meaning of the triangular protrusion on the current value indicator on the sliderbar (shown in Figure 24 above).

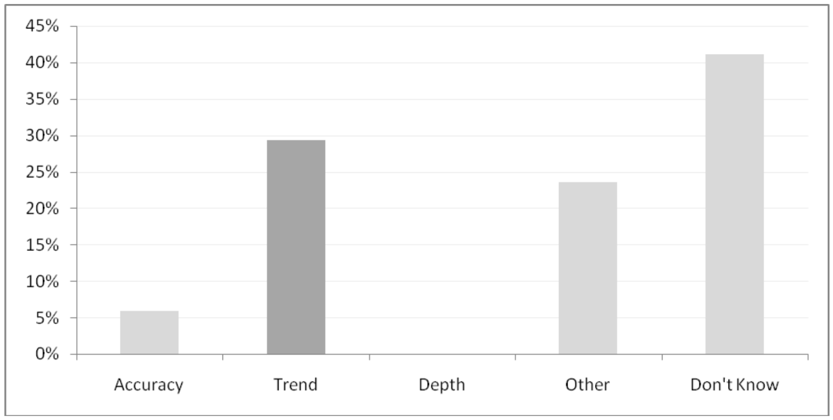

Figure 25: What does the triangular protrusion on the vertical black bar in the Example 2 figure represent to you? (Survey Question 10)

Responses collected from this group were varied, with some comments even suggesting that it marked an historical observation. The actual meaning of the triangular protrusion, which is to show the recent trend of a value at a location, garnered the second largest number of responses, 30%. The largest response group for this question was in the "don't know" group.

After the preliminary evaluation questions, which determined initial impressions with the dashboard without instructions, a series of instructions were provided for operating both the combined map-dashboard interfaces and DASH. Coupled with these instructions were a series of individual tasks, which were intended to extract largely the same information from both interfaces. After finishing these tasks, a series of comparative questions were asked about ease of use and general impressions when using the Corpus Christi Bay Explorer.

Overall, viewing real-time data, extreme values (outliers), and per-location values (from questions 12, 15, and 18, respectively) were all considered easer to perform in the Corpus Christi Bay Dashboard by the majority (70 – 80%) of respondents, with 20 – 30% experiencing no change in ease of use. Inferring trends (questions 13) was also considered easier by the majority (77%) of respondents, while the rest (23%) reported no change.

Although the majority of comparative questions indicated the Corpus Christi Bay Explorer was easier to use than DASH, questions on accessing and comparing data illuminated somewhat mixed impressions. For instance, in question 14, while 62% of users felt they were able to view more information at once with the Corpus Christi Bay Dashboard, 23% reported being able to view less data. Additionally, some users also reported slight glitches with information access when using the Corpus Christi Bay Explorer. Similarly, in question 19, 69% found making real-time comparisons was easier with the Corpus Christi Bay Explorer but 8% found these comparisons easier to make with DASH

Questions centering on the responsiveness of the Corpus Christi Bay Explorer also elicited mixed responses. When evaluating map responsiveness in question 16, 42% reported a faster experience, but 8% reported a slower experience (with 50% reporting no change between the Corpus Christi Bay Explorer and DASH). The overall responsiveness of the map and dashboard interfaces combined (question 17), however, received higher marks, with 67% reporting a faster experience and only 8% still reporting a slower experience. Though a minority of users did experience speed issues with the map, when asked to cite the most useful element of the Corpus Christi Bay Explorer, a number of the write-in responses cited the increased speed and ease of use of the Corpus Christi Explorer.

In order to evaluate the overall usability of the Corpus Christi Bay Dashboard, the effectiveness of each visualization system at conveying the state of the Corpus Christi Bay was asked of respondents in questions 23 and 25.

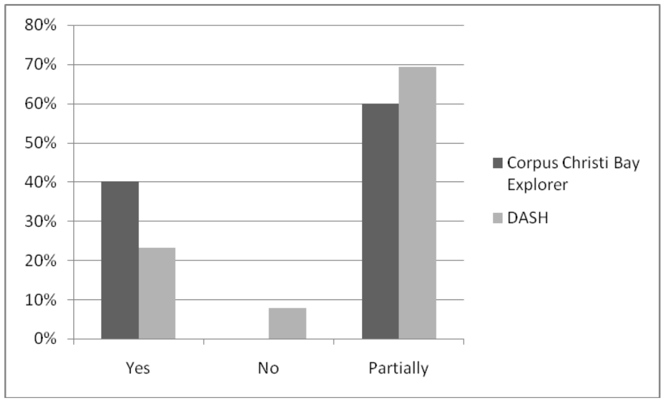

Figure 26: Response to the survey questions 23 and 25, "Does the Corpus Christi Bay Explorer / DASH fulfill your needs in determining the state of Corpus Christi Bay?"

The respondents reported that the Corpus Christi Bay Explorer was better able to convey state of the bay as compared to DASH. Neither interface, however, gained a majority approval in determining the state of Corpus Christi Bay, instead receving a significant number of responses with partial approval. The reasons cited for partial approval varied between DASH and the combined map and dashboard interfaces. For DASH, respondent reservations focused on the amount of work necessary to extract data, while for the Corpus Christi Bay Explorer, a myriad of reasons were given, such as Java plug-in issues and unfamiliar controls.

4. Discussion and Conclusions

As public policy and scientific research increasingly reach a confluence in the realm of environmental management, new data visualizations will allow the participation of diverse communities of stakeholders in the decision making process. In order to facilitate this transition, two visualizations, the dashboard and map interfaces, were developed in this paper, both with the goal of enabling ease of use and rapid access to data by a broad set of users. The first interface, the dashboard, was designed to facilitate logical comparisons between different sampling locations. By contrast, the intention of the second interface, the map interface, was to allow spatially-based comparisons. The data sources for the dashboard and map interfaces were unified in the form of an RSS feed. In addition to sharing data sources, the map and dashboard interfaces can also share the same presentation canvas, in the form of a combined interface on a Web page called the Corpus Christi Bay Explorer.

This combined interface was evaluated via a case study on Corpus Christi Bay, an estuarine system which experiences seasonal hypoxia during the summer months. To provide a baseline comparative reference for this survey, the Corpus Christi Bay Explorer was compared with DASH, a real-time and historical data downloader. The survey was distributed to a broad range of researchers, regulators, and community members in Corpus Christi Bay.

Before providing baseline instructions on the use of the Corpus Christi Bay Explorer, respondents were asked their initial impressions on two visual elements with mixed results. These ambiguous responses were not wholly unexpected since users had no instructions on which to rely other than their own intuition. The results underscore the need for proper instructions for any visualization, no matter how simple it may seem to the developing organization.

The next section of the survey included instructions for both the DASH and combined interfaces of the Corpus Christi Bay Explorer. After following these instructions and performing the associated tasks, respondents to the survey generally found the Corpus Christi Bay Explorer was easier to use and more readily enabled access to data, as compared to DASH. In particular, accessing real-time data and properly inferring trends received high marks from respondents. These user conclusions appear consistent with the intended design differences between the Corpus Christi Bay Explorer and DASH. The Explorer presents real-time value and trend information on the initial start screen, while DASH, in keeping with its intended purpose as a data downloader, requires zooming and selection before real-time and trend data can be accessed.

Nearly all survey respondents (90 - 100%) concluded that both visualizations were able to partially convey the state of Corpus Christi Bay, but neither was able to fully convey this state of to a majority of users. The Corpus Christi Bay Explorer approached this majority threshold, with 40% of respondents reporting that it was able to convey the state of the bay, compared with 23% for DASH. The results for DASH are not surprising, as DASH is intended to facilitate data downloading and not necessarily ease of data access. Concerns about DASH centered on the number and complexity of steps required to access data. The Corpus Christi Bay Explorer, by contrast, is explicitly designed to facilitate data access, and through that simplicity convey the state of the bay. Feedback for the Corpus Christi Bay Explorer indicated that a different set of evaluation criteria were being used by respondents, with most critiques not discussing the more basic issue of ease of data access. Instead the respondents primarily cited more complicated issues, such a need for greater amounts of environmental data to be included in the Corpus Christi Bay Explorer. A minority also focused on the wait time necessary for the Java plug-in to load.

Indeed, wait or load times, be it for the Corpus Christi Bay Explorer or DASH, were often cited as problematic. While the majority of respondents found that while the Corpus Christi Bay Explorer was more responsive than DASH (42 – 67%), a minority (8%) found the opposite. One potential explanation to the speed issue experienced by a minority of respondents may lie in the Java browser plug-in, which can sometimes take as long as 60 seconds to load. A new release of the Java Virtual Machine (JVM) may be able to correct the issue in the future. Alternately, numerous fixes need be applied to correct minor glitches in both the map and dashboard interfaces, some of which may improve plug-in load speed. The most promising solution to this problem, however, is a set of recent developments (Resig 2008) which may allow the dashboard source code to be ported to the much more browser-friendly JavaScript programming language.

In addition to visualization responsiveness issues, the meaning of certain elements of the sliderbar in the Corpus Christi Bay Explorer was ambiguous to some of the respondents even after instruction. For instance, questions were raised by respondents about the calculation methods for the differentially colored zones in the sliderbar, specifically whether calculations of historical values were performed on a per-site or whole-bay basis. To remedy these issues, more descriptive context-sensitive help text and instructions may be added to aid visualization users in understanding the dashboard.

Other enhancements for future versions of the visualization system are also possible. Sensors may occasionally read erroneous values, skewing historical data representations and calculations. Applying a quality filter to these data and highlighting potentially erroneous data (see, e.g., Hill 2007) could improve the data exploration features of visualizations.

Furthermore, as real-time environmental data sources begin to increase, there exists a very real possibility that information overload will become an issue on the map interface. In order to cut down a cluttered display and allow users to focus only on the data they wish to explore, map layers could be employed. Each map layer, representing a different element of a dense data set, could be displayed or hidden by the user, allowing far greater data granularity than is presently available in the current Corpus Christi Bay Dashboard.

These enhancements for the dashboard and map interfaces could increase the utility of the visualizations for the target community of stakeholders, particularly those who are not as technically adept as the survey respondents. However, the implementation of the map and dashboard, as described in this paper, provides an interface which is usable and considered by many to be easier to use than currently available data download services, such as DASH. With further enhancements through hands-on usability studies using different types of environmental systems, the Explorer shows strong promise for providing the ability to visualize and explore real-time data and establish the state of environmental systems.

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Appendix A: Data Available in the RSS Input

The following is a list of data which can be represented by the RSS input to the dashboard and map interfaces. If the visualizations expect a particular format for an input, it is defined as well.

- Location Name: The exact name of the location to be displayed in the end-interface
- Variable Name: The name of the observed parameter value
- Units: The units of measure associated with the observed parameter value

  SI units are the preferred form of the units of measure, though there are no restrictions on the string representation of the units above those enforced by the XML parsing library, proXML (Riekoff 2006).
- Value: The sample reading of a parameter at a particular location
- Trend: The prevailing increase or decrease in a parameter value

  A value of "1" indicates a positive trend, while a value of "-1" indicates the opposite. Other values are not ascribed a meaning.
- Divisions: A set of values which define various parameter ranges

  The collection of divisions created by the acquisition and analysis component is represented by this attribute, with single spaces separating each individual division.
- Offset: The distance from an observation to a universally defined datum

  This datum must be the same for all observed parameter values in the GeoRSS feed.
- Spatial Reference (Lat, Lon): A spatial reference for the observed values.

  All spatial references should be in decimal form and adhere to the WGS84 standard (NIMA 2004).
- Timestamp: A record of when a parameter value was observed

  Note that the time zone also needs to be specified. For use with custom scripts and the Dashboard interface, the required timestamp format is “yyyy:mm:ddThh:mm:ss.” For example, July 25th, 2007 at 12:45 PM and 10 seconds would be represented as “2007:07:25T12:45:10.”
- Comparison Value: Comparisons with other values in the Min/Max View of the dashboard interface are allowed when this attribute is "1." Any other attribute value, or an omission of this

attribute, will result in the parameter value not being compared with other parameter values within the dashboard interface.

- Display Value: Display of the value in specified interface (e.g., the map interface) is only allowed when this element is set to “1”. Any other code results in display only in the dashboard detail views.

Appendix B: Custom RSS Extensions

This section defines custom changes to the RSS format that allow for support of the some of the attributes defined in Appendix A. These custom extensions were created in order to properly isolate and store each data element not supported in either the basic RSS module or the GeoRSS or Yahoo! Media Modules. These extensions consist of three modifications made to the RSS format – (1) the addition of an unformatted title element, (2) the addition of an element for value data and metadata, and (3) a variable summary element.

The first modification, that of an unformatted title element, <dse:unformattedTitle>, is a result of the use of HTML and CSS formatting attributes in the RSS title element. The dashboard visualization requires a non-formatted string for display purposes, and this element fulfills that need. An example of the use of the element is provided below.

```
<dse:unformattedTitle>Oso Bay Platform</dse:unformattedTitle>
```

Figure 27: The dse:value Element

The second, and by far the most major, modification is the inclusion of the value element, <dse:value>. This element contains many of the attributes defined Appendix A. An example of the element can be found in Figure 28 below, followed by a brief description of the attributes.

```
<dse:value varname="Oxygen" bottomDistance="5" trend="1" time="2007-06-
09T11:03:59" divisions="195.7767 230.20 250 287.65"
comparisonValue="1">273.46</dse:value>
```

Figure 28: The dse:value Element

- varname: The “Variable Name” item from the “Acquisition and Analysis” section

- The varname attribute must have an identically matching entry in the <dse:variables> element noted below.
- bottomDistance: The “Offset” item from the “Acquisition and Analysis” section
- trend: The “Trend” item from the “Acquisition and Analysis” section
- time: A combination of the Year, Month, Day, Hour, Minute, Second
- divisions: The “Divisions” item from the “Acquisition and Analysis” section
- comparisonValue: The “Comparison Value” item from the “Acquisition and Analysis” section

The last modification to the RSS format is the inclusion of a variables element, <dse:variables>, which contain a list of entries for all variables (Oxygen, Salinity, etc.) used in a visualization (see Figure 29 below for an example).

```
<dse:variables>
   <dse:variable units="umol/L">Oxygen</dse:variable>
</dse:variables>
```

Figure 29: The dse:variables Element

Each variable entry in the <dse:variable**s**> list is contained in the <dse:variable> element, and is intended to store any variable-specific metadata for the RSS feed. In particular, any data attributes which are intended to share the same values across multiple "<dse:value>" elements instead belong in the "dse:variable" element. The child of the "<dse:variable>" element is the corresponding variable name, which must exactly match the variable name used in a "<dse:value>" element in order for that value element to appear anywhere on the dashboard. Only one attribute is used with the "<dse:variable>" element, "units," which contains the data from the “Units” item defined in section 0.

Appendix C: RSS Generator Script Input Format

In order to allow ease in the creation of an RSS feed with the custom extensions defined in section 0, an RSS Feed Generator script, written in Java, can be utilized. This feed generator script uses a tab separated text input, with one entry per line. Each line should contain the following elements: Location Name, Variable Name, Units, Value, Trend, Divisions, Offset, Lat, Lon, Year, Month, Day, Hour, Minute, Second, Time Zone, Comparison Value, Display Value. Any data which are unavailable can be left blank and replaced with a double tab.

```
Hypoxic Zone Platform 1     Oxygen      umol/L      7.7965      -1      0 3 5 14.889
Hypoxic Zone Platform 2     Oxygen      umol/L      7.8047      -1      0 3 5 12.894
Hypoxic Zone Platform 3     Oxygen      umol/L      7.9834      -1      0 3 5 12.440
Hypoxic Zone Platform 4     Oxygen      umol/L      8.0308      -1      0 3 5 12.428
Hypoxic Zone Platform 5     Oxygen      umol/L      7.9868      -1      0 3 5 12.441
Hypoxic Zone Platform 1     Water Temperature       °C      29.46 1     4.2967 16.31
Hypoxic Zone Platform 2     Water Temperature       °C      29.4633     1       4.8267
Hypoxic Zone Platform 3     Water Temperature       °C      29.8867     1       4.8267
Hypoxic Zone Platform 4     Water Temperature       °C      30.18 1     4.8267 16.19
Hypoxic Zone Platform 5     Water Temperature       °C      30.3367     1       4.8233
Hypoxic Zone Platform 1     Salinity    psu     22.1509     -1      3.0623 20.0406 28
```

Figure 30: Sample from the RSS generator script input file

Appendix D: RSS Feed Format

The RSS format follows the standard RSS format, with the addition of three extra modules, the Yahoo! Media Module, the GeoRSS Module, and the custom module developed in section 0. A simplified example of this feed, along with explanations where needed, is provided below.

RSS Base   Yahoo! Media Module   GeoRSS Module   Custom Module

<?xml version="1.0" encoding="UTF-8"?>	
<rss version="2.0" ... >	Defines the RSS version and establishes the namespaces used for each module
<channel>	
<title>Station Updates</title>	
<item>	
<title> ... /title>	HTML Formatted Title, formatted with HTML and CSS, for display in the title of the pop-up in the map interface
<dse:unformattedTitle> Packery Channel </dse:unformattedTitle>	For use in displaying titles in the dashboard interface -- see section 0 for further definition details
<pubDate> Sat Sep 06 16:59:08 EDT 2008 </pubDate>	
<geo:Point>	GeoRSS element set, which defines the latitude and longitude
<geo:lat>27.6346</geo:lat>	
<geo:long>-97.237</geo:long>	
</geo:Point>	
<dse:value varname= ... > 5.6 </dse:value>	Contains the observed value and associated metadata for a particular sample location -- see section 0 for further definition details
<dse:value varname= ... > 7.7 </dse:value>	
<description> ... </description>	Description, for Display in the Body of the Pop-up in the Map Interface
<media:thumbnail ... />	Yahoo! Media Thumbnail Image, for the Location Icon in the Map Interface
</item>	
</channel>	
<dse:variables>	For use in establishing a list of variables to evaluate in the dashboard -- see section 0 for further definition details
<dse:variable units="°C"> Temperature </dse:variable>	
<dse:variable units="psu"> Salinity </dse:variable>	
</dse:variables>	
</rss>	

Figure 31: Simplified Example RSS Feed

Appendix E: Historical Data Format

In addition to using the RSS input, the dashboard also utilizes an historical input, which consists of a two column row-based format. The first column specifies the time, in “yyyy-mm-ddThh:mm:ss” format. The second column contains the observed value at the time specified in the first column. The two columns are tab separated with a newline ending each line of data.

```
2008-09-05T0:30:00	28.1
2008-09-05T0:36:00	28
2008-09-05T0:42:00	28
2008-09-05T0:48:00	28
2008-09-05T0:54:00	28
2008-09-05T1:00:00	28
2008-09-05T1:06:00	28.1
2008-09-05T1:12:00	28
2008-09-05T1:18:00	28
2008-09-05T1:24:00	28.1
2008-09-05T1:30:00	28
2008-09-05T1:36:00	28.1
```

Figure 32: Sample Historical Data Output

For use with the dashboard, the file name must also follow a naming convention. The dashboard will search in its default repository location (see Appendix F) for a file name of the following format: “Location Name”_ “Variable Name”_ “Offset Value (Optional).

For instance, if the location name is “Oso Bay Station,” the variable name is “Oxygen,” and the offset value is “5.0” (assumed meters), then the file name would be as follows:

Oso Bay Station_Oxygen_5.0

In the event now offset is used, the file name would change to:

Oso Bay Station_Oxygen

The three elements of the file name, the location, variable, and offset values are defined in the input RSS feed to the dashboard. The dashboard will look for an exact match for these files, and if unavailable, will skip visualization of that particular variable.

Appendix F: Dashboard Runtime Options

The dashboard supports several runtime options which can alter the default appearance and data search locations. When in run as an applet, these options can be passed as parameters encoded in the web page HTML:

- xmlSource – Specifies the path to the RSS input. If no path is specified, the dashboard next looks for "http://localhost/currentData.xml." If no file is found in this location, the dashboard then tries to find "currentData.xml" in the platform-specific source directory of the dashboard. Changing this parameter will have no effect once the dashboard is loaded.
- historicalDataSource – Setting this option will specify the folder or resource which contains the historical data files. If not set, this value will default to "http://localhost/". Changing this parameter will have no an effect once the dashboard has been loaded.
- option –Allows the default dashboard view show either an overview of the entire environmental system ("maximums") or a list of real-time values available at a particular location ("location"). Note that if the *option* value is set to "location," the *optionLocation* value must also be defined. Changing this parameter will continue to have an effect after initial loading of the dashboard.
- optionLocation – If setting option to "location," this parameter must specify a location name. This location name must match a location on the RSS input, otherwise no location will be displayed. Changing this parameter will continue to have an effect after initial loading of the dashboard.
- view – Controls whether or not the initial dashboard view shows real-time data (which utilizes the RSS feed) or historical data, which utilizes multiple historical input files defined in section 0. In order to set to show real time data, set this option to "real time". In order to show historical data, set this option to "historical". As with *option* and *optionLocation*, this value can be modified after the dashboard has loaded in order to change the view.

Appendix G: Corpus Christi Bay Data Sources

There are three primary data sources for Corpus Christi Bay, the Texas Coastal Ocean Observation Network (TCOON), the Shoreline Environmental Research Facility (SERF), and the National Water Information System (NWIS). Each of these sensor networks samples a large amount of data, not all of which are utilized as inputs into the visualization interfaces. For completeness, tables of all available real-time parameters for each location are provided below. Note that the TCOON and NWIS networks are geographically extensive – only those locations near Corpus Christi Bay are included within the tables.

	Packery Channel (005)	**Inglesid e (006)**	**Texas State Aquariu**	**Port Aransas (009)**	**White Point (011)**	**S. Bird Island (013)**	**Bob Hall Pier (014)**
	27.6346, -97.2370	27.8217, -97.2033	27.8143 -97.3984	27.8398 -97.0727	27.8608 -97.4828	27.4847 -97.3181	27.5811 -97.2164
Primary Water Level (m)	●	●	●	●			●
Harmonic Predicted Water Level (m)	●	●	●	●			●
Water Level Std Dev (m)		●		●		●	●
Water Level Outliers (m)	●	●		●	●	●	
Water Temperature (˚C)		●		●		●	●
Air Temperature (˚C)			●				●
Wind Speed (m/s)	●	●		●	●	●	●
Wind Gusts (m/s)	●	●		●	●	●	●
Wind Direction (˚ from N)	●	●		●		●	●
Barometric Pressure (kPa)		●				●	●
Salinity Lower Bounds (psu)				●	●	●	
Salinity Upper Bounds (psu)				●	●	●	

Figure 33: TCOON Locations and Values, Updated March 2008

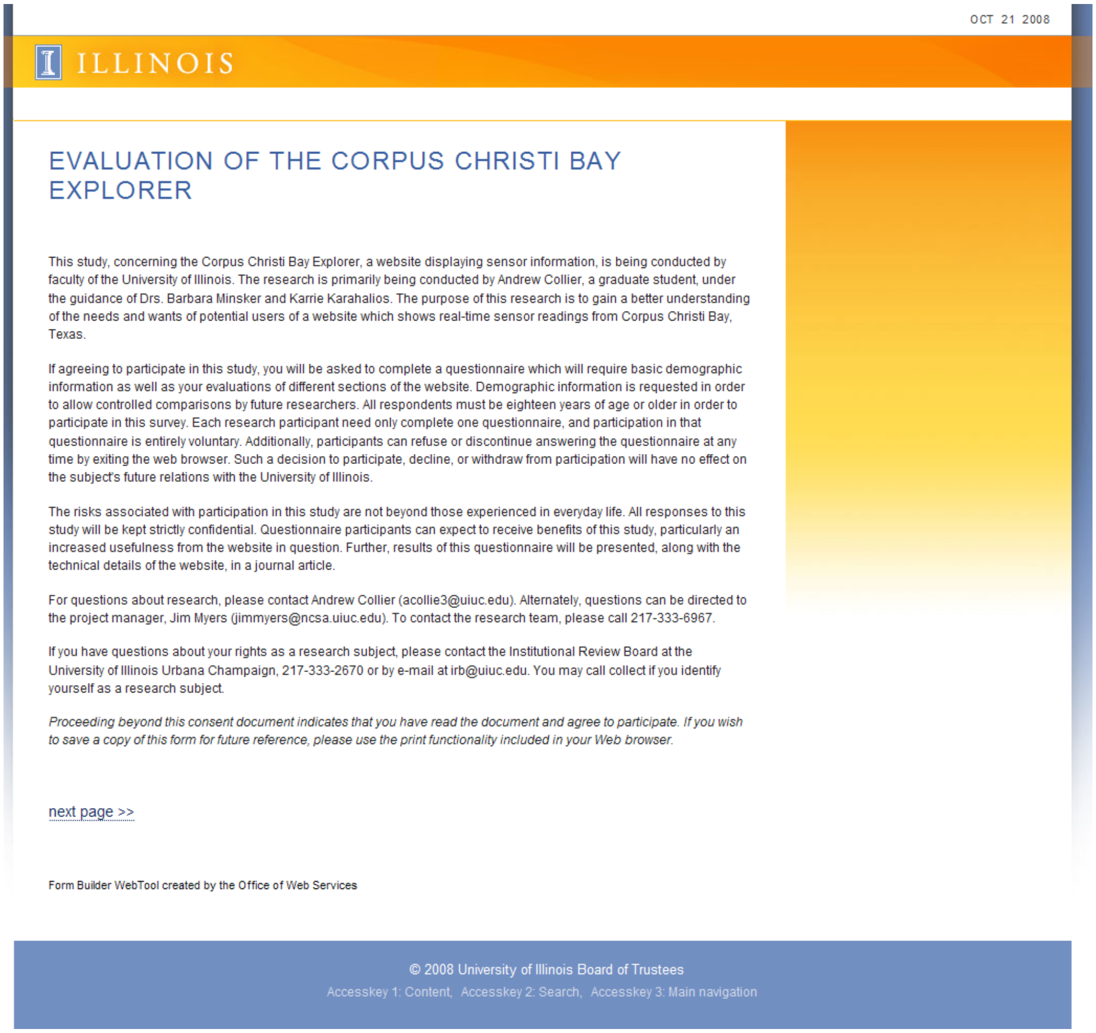
	Hypoxic Platform (009)	East Flats
	27.7227 -97.1898	27.8088, -97.1419
Dissolved Oxygen (mg/L)	●	●
Water Temperature (˚C)	●	●
Salinity (psu)	●	●
Fluorosine	●	●
CDOM	●	●
Chlorophyll	●	●

Figure 34: SERF Locations and Values, Updated March 2008

	Nueces River at Calallen,	Oso Creek at Corpus	Rincon Bayou Channel
	27.8831 -97.6253	27.7114 -97.5019	27.8970 -97.6256
Discharge (cfs)	●	●	●
Gage Height (ft)			●
Stream Velocity (fps)			●
Specific Conductance, Unfiltered			●
Water Temperature (˚C)			●
Salinity, Unfiltered (psu)			●

Figure 35: NWIS Locations and Values, Updated March 2008

Appendix H: Survey Questionnaire



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EVALUATION OF THE CORPUS CHRISTI BAY EXPLORER

This study, concerning the Corpus Christi Bay Explorer, a website displaying sensor information, is being conducted by faculty of the University of Illinois. The research is primarily being conducted by Andrew Collier, a graduate student, under the guidance of Drs. Barbara Minsker and Karrie Karahalios. The purpose of this research is to gain a better understanding of the needs and wants of potential users of a website which shows real-time sensor readings from Corpus Christi Bay, Texas.

If agreeing to participate in this study, you will be asked to complete a questionnaire which will require basic demographic information as well as your evaluations of different sections of the website. Demographic information is requested in order to allow controlled comparisons by future researchers. All respondents must be eighteen years of age or older in order to participate in this survey. Each research participant need only complete one questionnaire, and participation in that questionnaire is entirely voluntary. Additionally, participants can refuse or discontinue answering the questionnaire at any time by exiting the web browser. Such a decision to participate, decline, or withdraw from participation will have no effect on the subject's future relations with the University of Illinois.

The risks associated with participation in this study are not beyond those experienced in everyday life. All responses to this study will be kept strictly confidential. Questionnaire participants can expect to receive benefits of this study, particularly an increased usefulness from the website in question. Further, results of this questionnaire will be presented, along with the technical details of the website, in a journal article.

For questions about research, please contact Andrew Collier (acollie3@uiuc.edu). Alternately, questions can be directed to the project manager, Jim Myers (jimmyers@ncsa.uiuc.edu). To contact the research team, please call 217-333-6967.

If you have questions about your rights as a research subject, please contact the Institutional Review Board at the University of Illinois Urbana Champaign, 217-333-2670 or by e-mail at irb@uiuc.edu. You may call collect if you identify yourself as a research subject.

Proceeding beyond this consent document indicates that you have read the document and agree to participate. If you wish to save a copy of this form for future reference, please use the print functionality included in your Web browser.

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Accesskey 1: Content, Accesskey 2: Search, Accesskey 3: Main navigation

Figure 36: Survey Questionnaire, Page 1

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EVALUATION OF THE CORPUS CHRISTI BAY EXPLORER

Section 1: Initial Questions (1/6)

Please begin by answering some basic questions about yourself

	No Experience	A Little Experience	Moderate Experience	A Good Deal of Experience
1. Please rate your experience with computers	○	○	○	○

	Inexperienced	Somewhat Experienced	Moderately Experienced	Experienced
2. Please rate your experience with web browsing	○	○	○	○

	Opera	Internet Explorer	Firefox	Other	Don't Know
3. Which web browser are you using to complete this questionnaire?	○	○	○	○	○

	Researcher	Stakeholder	Member of the Public	Other	Don't Know
4. Which of these roles best describes you?	○	○	○	○	○

5. Is knowing the current environmental state of Corpus Christi Bay important to you?

○ Yes
○ No
○ Somewhat

6. If needed, please explain your answer to the above question

7. If knowing the current environmental state of Corpus Christi Bay is important to you, what information aids you in determining this overall environmental state?

If you do not know what information would be important, or if knowing the environmental state of Corpus Christi Bay is not important to you, skip this question.

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Figure 37: Survey Questionnaire, Page 2

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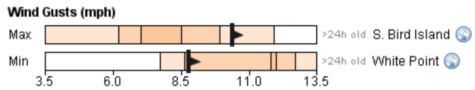
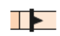
EVALUATION OF THE CORPUS CHRISTI BAY EXPLORER

Section 2: Interpreting Visualizations (2/6)

The next two questions ask for your initial impressions to the Example 1 and Example 2 figures.



Example 1, a sample variable indicator



Example 2, a subsection of a sample variable indicator

	Typical ranges of historical observations at a location	Ranges of values from nearby locations	Ranges showing varying degrees of environmental quality	Other	Don't know
8. What do the differentially colored ranges in the Example 1 figure represent to you?	○	○	○	○	○

9. If needed, please explain your answer to the above question

	Accuracy	Trend	Depth	Other	Don't Know
10. What does the triangular protrusion on the vertical black bar in the Example 2 figure represent to you?	○	○	○	○	○

11. If needed, please explain your answer to the above question

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Accesskey 1: Content, Accesskey 2: Search, Accesskey 3: Main navigation

Figure 38: Survey Questionnaire, Page 3

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EVALUATION OF THE CORPUS CHRISTI BAY EXPLORER

Section 3: Evaluating the DASH system (3/6)

*Internet Explorer is required for this section. If you do not have Internet Explorer, skip this section, and **Section 5: Comparisons**. Additionally, in **Section 6: Final Questions**, some questions will reference the DASH system -- skip these questions.*

Begin by evaluating the DASH visualization system for Corpus Christi Bay, which can be accessed by opening Internet Explorer and navigating to http://river.sdsc.edu/DASH/.

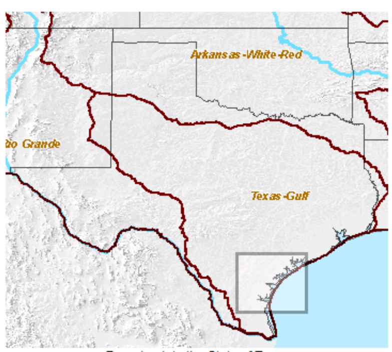
The Default View for DASH

After navigating to the web page, locate and observe real-time data at one location in Corpus Christi Bay. **Note that for the purposes of this survey, today's date (the day you take this survey) is assumed to be August 4th, 2007 and should be used for all real-time data.** This unchanging assumption for today's date is made due to the dynamic environment in Corpus Christi Bay as well as sensor maintenance schedules, which can cause an occasional lack of availability for true real-time data.

To observe real-time data with DASH, follow the instructions below. Alternately, a video showing the execution of each step is provided after the instructions, at the bottom of this page.

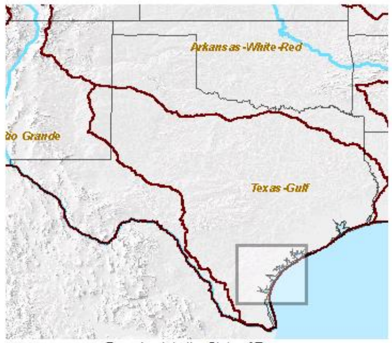
1. Zoom into Corpus Christi Bay area by clicking on the **Zoom In** icon.

   The icon resembles a magnifying glass with a plus sign. Zooming can be accomplished by clicking and dragging the cursor in order to make a rectangle. This rectangle represents the area to be enlarged. Note that you may need to zoom more than once in order to see Corpus Christi and the surrounding area. Take care to zoom in no closer than the view shown at the end of this entry, "View of Corpus Christi Bay After Zooming."

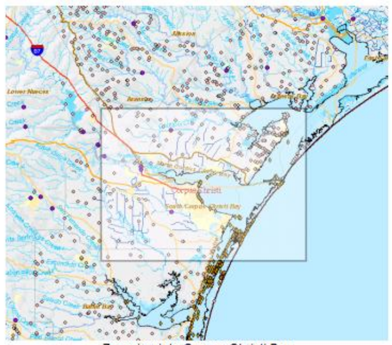


Zooming into the State of Texas

Figure 39: Survey Questionnaire, Page 4 (Part 1)



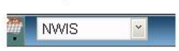
Zooming into the State of Texas


Zooming into Corpus Christi Bay


View of Corpus Christi Bay After Zooming

2. View real-time data at one location. To view these data, first click on the **HIS Network Identify** icon.

Next, select **NWIS** from the **drop down menu** to the right of the HIS Network Identify icon and the Shopping Cart icon.



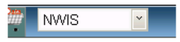
Now, click on one of the purple circles on the map to select an NWIS location.


An NWIS location

Figure 40: Survey Questionnaire, Page 4 (Part 2)

2. View real-time data at one location. To view these data, first click on the **HIS Network Identify** icon.

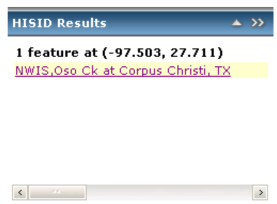
Next, select **NWIS** from the **drop down menu** to the right of the HIS Network Identify icon and the Shopping Cart icon.



Now, click on one of the purple circles on the map to select an NWIS location.

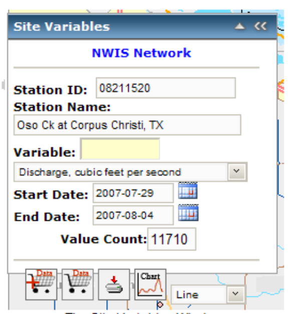
An NWIS location

3. The **HISID Results** pane on the left hand side of the browser will appear with the text "1 feature at ..."



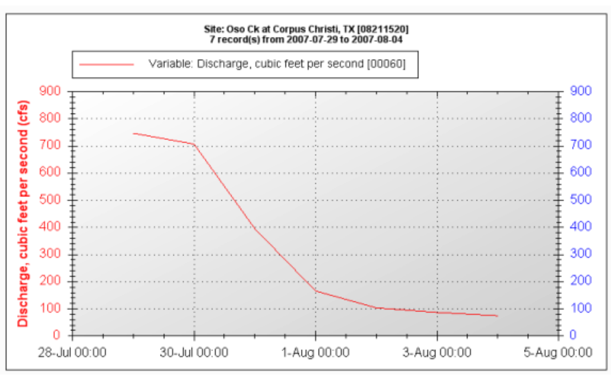
The HSID Results Pane

4. Click on the hyperlink just below this text, which will pop up the **Site Variables** window. In the **Site Variables** window, select a variable name of "Discharge, cubic feet per second." Enter a start date of "2007-07-29" and an end date of "2007-08-04." Note that you may need to manually type this number into the date boxes instead of clicking on the adjacent calendar icons, depending on your browser settings.



The Site Variables Window

5. After establishing the date range, click on the **Chart** icon at the bottom of the **Site Variables** window. A chart should appear on the screen.



The Discharge Rate Chart for Oso Creek

6. Using this chart, determine the most recent value at this location and the general trend of the values (increasing or decreasing).

7. By selecting other stations and viewing the chart, determine the maximum and minimum values in the bay for "Discharge, cubic feet per second."

Figure 41: Survey Questionnaire, Page 4 (Part 3)

7. By selecting other stations and viewing the chart, determine the maximum and minimum values in the bay for "Discharge, cubic feet per second."

A video which demonstrates the process of following the instructions is provided below:

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Figure 42: Survey Questionnaire, Page 4 (Part 4)

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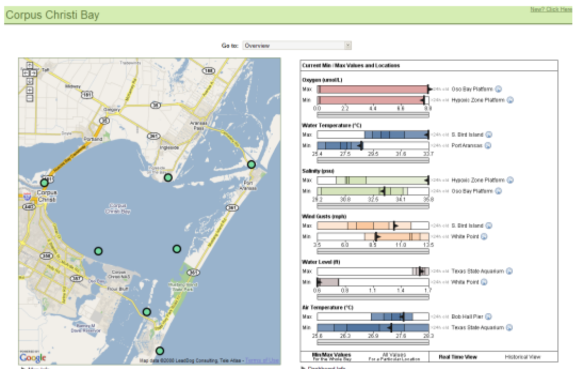
EVALUATION OF THE CORPUS CHRISTI BAY EXPLORER

Section 4: Evaluating the Corpus Christi Bay Explorer (4/6)

Continue by evaluating another visualization system for Corpus Christi Bay. This visualization system, known as the Corpus Christi Bay Explorer, can be accessed by navigating to http://isda.ncsa.uiuc.edu/ccbay/CCBayExplorer.html.



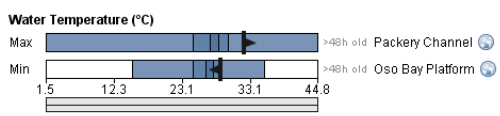
The default view for the Corpus Christi Bay Explorer, with the map in the left pane and the dashboard in the right pane.

After navigating to the Corpus Christi Bay Explorer, locate and observe real-time data at one location in Corpus Christi Bay. **Note that throughout this survey, today (the date you take this survey) continues to be assumed to be August 4th, 2007 for real-time data purposes.** This unchanging assumption for today's date is made due to the dynamic environment in Corpus Christi Bay as well as sensor maintenance schedules, which can cause an occasional lack of availability for true real-time data.

In order to locate and observe the data, follow the instructions below.

1. First, if you have clicked on or interacted with any element of the web page, please reload http://isda.ncsa.uiuc.edu /ccbay/CCBayExplorer.html to ensure you are presented with the default view.

2. Without clicking on or interacting with any element of web page, locate and observe the "Temperature (° C)" section, on the dashboard (the right side, or pane, of the web page).



The Temperature Section, or Indicator, on the Dashboard, Showing Two Sliderbars

This section, or indicator, forms the basis of the dashboard component of the Corpus Christi Explorer. Each indicator represents a certain variable, in this case temperature. Depending on the configuration options, set at the bottom of the dashboard, multiple combinations of variables and indicators can be displayed.

The Sliderbar
In the default view, the indicator shows the minimum and maximum values in the entire bay for a particular variable (temperature in the figure above). This value is represented as a vertical black marker along a long horizontal bar, known as a sliderbar. The differentially colored ranges on the sliderbar typically represent the historical distribution of sampled values at a location. Additionally, for some variables, such as oxygen, these ranges represent critical zones for environmental quality. Hovering your cursor over each range will display a pop-up providing further information on the range's meaning.

The Sliderbar

Trend
The arrow, or triangular protrusion, on the vertical black marker indicates the trend of the variable at each location. A right pointing arrow indicates an increasing trend; a left pointing arrow, a decreasing trend.

The Trend Icon

Figure 43: Survey Questionnaire, Page 5 (Part 1)

Trend
The arrow, or triangular protrusion, on the vertical black marker indicates the trend of the variable at each location. A right pointing arrow indicates an increasing trend; a left pointing arrow, a decreasing trend.

The Trend Icon

The Range Selector
The range selector, the last component of the indicator, is located below sets of sliderbars. The purpose of the range selector is to allow narrowing of the data range shown by the sliderbar via mousing over, clicking, and dragging. The use of the range selector is not only limited to the sliderbars, but also can be used with historical plots, which are introduced below in step 5.

The Range Selector

Text Captions
Three text caption areas are located around the sliderbar: the left label, the update time, and the right label. Typically, the left label is used to show either the min / max status of a value or its depth. The right value either shows the location name or is left empty. The update time shows the amount of time passed since the variable value was sampled. **Note that due to the unique date usage for this survey (the assumption that today's date is August 4th, 2007), all update times should be disregarded and any sampled value considered "real-time."**

3. Determine, for one entry in the "Temperature (° C)" section (a) the most recently sampled temperature value and (b) the trend (whether the temperature level is increase or decreasing).

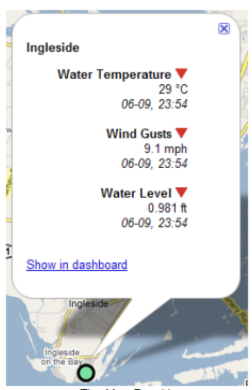
4. Again, by viewing the "Temperature (° C)" indicator on the dashboard (the right pane), determine the minimum and maximum temperatures in the entire bay.

5. Using the dashboard (the right pane), switch to the historical view by clicking the **Historical View** button, located at the bottom right of the dashboard.

Historical View

The Historical View Button

6. Using the map (the left side, or pane, of the webpage), click on a location icon in the bay and observe the values displayed in the pop-up. In order to conserve screen space, some locations have only a subset of available values displayed. For instance, at locations which have the same variable sampled at multiple depths, only the bottom-most value is shown in the pop-up.



The Map Pop-Up

7. Utilizing the same pop-up in the map, click on the **Show in dashboard** link at the bottom of the pop-up. The complete data set for the chosen location can then be viewed in the dashboard (the right pane).

8. At the bottom of the dashboard (the right pane), hover your mouse over the **The All Values for a Particular Location** button and click on a location from the list which appears.

All Values
For a Particular Location

The All Values Button

9. Observe both the real-time and historical data for this location by clicking on the **Historical View** and **Real Time View** buttons at the bottom of the dashboard.

Real Time View Historical View

The Real Time and Historical View toggles

Figure 44: Survey Questionnaire, Page 5 (Part 2)

Appendix I: Survey Results

1. Please rate your experience with computers

No Experience	A Little Experience	Moderate Experience	A Good Deal of Experience
0.0%	12.5%	37.5%	50.0%

2. Please rate your experience with web browsing

Inexperienced	Somewhat Experienced	Moderately Experienced	Experienced
6%	6%	38%	50%

3. Which web browser are you using to complete this questionnaire?

Opera	Internet Explorer	Firefox	Other	Don't Know
0%	63%	38%	0%	0%

4. Which of these roles best describes you?

Researcher	Stakeholder	Member of the Public	Other	Don't Know
69%	19%	6%	0%	6%

5. Is knowing the current environmental state of Corpus Christi Bay important to you?

Yes	No	Somewhat
75%	6%	19%

6. If needed, please explain your answer to the above question

Most were concerned about degradation of environmental quality, with a minority interested in this degradation along the broader Texas coastline.

7. If knowing the current environmental state of Corpus Christi Bay is important to you, what information aids you in determining this overall environmental state?

Knowledge of key indicators was foremost in the need to establish real-time indicators. In a related thread, knowledge of the water quality implications of these indicators was also deemed important. Of lesser importance was public safety information, information on algae blooms, harm to aquatic life, and direct observation accounts from researchers

8. What do the differentially colored ranges in the Example 1 figure represent to you?

Typical ranges of historical observations at a location	Ranges of values from nearby locations	Ranges showing varying degrees of environmental quality	Other	Don't know
41%	24%	6%	6%	24%

9. If needed, please explain your answer to the above question

Respondents were generally unsure of what each value meant. Of particular interest was confusion about the meaning of 'max' and 'min' as the default view displays only two locations. Providing some context that more than two locations are being compared could prove useful.

10. What does the triangular protrusion on the vertical black bar in the Example 2 figure represent to you?

Accuracy	Trend	Depth	Other	Don't Know
6%	29%	0%	24%	41%

11. If needed, please explain your answer to the above question

Respondents were generally confused as to the meaning of the protrusion

12. Viewing real-time data was

Much Easier	Somewhat Easier	About the Same	Somewhat Harder	Much Harder
38%	31%	31%	0%	0%

13. Inferring data trends was

Much Easier	Somewhat Easier	About the Same	Somewhat Harder	Much Harder
38%	38%	23%	0%	0%

14. The amount of information I was able to view at once was

Much Less	Somewhat Less	About the Same	Somewhat Greater	Much Greater
8%	15%	15%	46%	15%

15. Viewing the extreme values (outliers) in Corpus Christi Bay was

Much Easier	Somewhat Easier	About the Same	Somewhat Harder	Much Harder
38%	31%	31%	0%	0%

16. Map responsiveness was

Much Faster	Somewhat Faster	About the Same	Somewhat Slower	Much Slower
25%	17%	50%	8%	0%

17. The overall responsiveness of the interface was

Much Faster	Somewhat Faster	About the Same	Somewhat Slower	Much Slower
25%	42%	25%	8%	0%

18. Viewing the observed values at a particular location was

Much Easier	Somewhat Easier	About the Same	Somewhat Harder	Much Harder
36%	45%	18%	0%	0%

19. Making rough comparisons between real-time data and historical data was

Much Easier	Somewhat Easier	About the Same	Somewhat Harder	Much Harder
38%	31%	23%	8%	0%

20. The use of colored dividers to represent historical data ranges in the figure above is

Very Ineffective	Somewhat Ineffective	Somewhat Effective	Very Effective
7%	40%	33%	20%

21. In the Corpus Christi Bay Explorer, the visualizations (sliderbars, map pop-ups, etc.) used to show sampled values were generally

Very Confusing	Somewhat Confusing	Somewhat Clear	Very Clear
0%	29%	50%	21%

22. I typically access real-time environmental data through

The DASH system	Other scientific websites	I don't typically access real-time environmental data
0%	47%	53%

23. Does the Corpus Christi Bay Explorer fulfill your needs in determining the state of Corpus Christi Bay?

Yes	No	Partially
40%	0%	60%

24. If needed, please explain your response to the previous question

Users generally wanted a wider selection of parameter values available inside the Corpus Christi Bay Explorer. Some reported problems with being confused by the visualization options in the Corpus Christi Bay Explorer, while others noted issues with the required Java plug-in.

25. Does the DASH system fulfill your needs in determining the state of Corpus Christi Bay?

Yes	No	Partially
23%	8%	69%

26. If needed, please explain your response to the previous question

Most users reported that the DASH system required more work to access data.

27. Do visualizations which show both real-time and historical data aid in understanding the state of environmental systems?

Yes	No	Partially	Don't Know
67%	0%	27%	7%

28. If needed, please explain your response to the previous question

No Responses

29. What was the most useful aspect of the Corpus Christi Bay Explorer?

The ease of use in the Corpus Christi Bay Explorer, coupled with its faster speed, was often cited as the most useful aspect of the Corpus Christi Bay Explorer. The visualization of historical data was another aspect which was also considered another useful aspect.

30. What would you change in Corpus Christi Bay Explorer? Why?

Greater clarity was requested with regards to using the colored dividers, coupled with suggestions to increase the use of the historical plots. Other suggestions included re-ordering parameters, adding map layers, and sizing visualizations dynamically for users with smaller displays.

31. What other comments or suggestions would you like to provide? If you experienced technical difficulties, please include them in response to this question.

Downloading data was considered to be a very important feature. One other interesting comment centered on showing how often a particular location provided the minimum or maximum value for the bay.