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Research Article

A Task-Based Approach to User Interface Design for a Web-Based Hydrologic Information Systems

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Abstract
Hydroinformatics is a new and rapidly developing field that integrates knowledge and understanding of water resources with the latest developments in information technology to improve decision-making in many critical applications. It encompasses methods for data capture, storage, processing, analysis and visualization, and the use of advanced modeling, simulation, optimization and knowledge-based tools and systems infrastructure. Three types of hydrological data are most commonly used: flow rate in major rivers and streams, height of water in wells, and precipitation. To get a complete view of the state of water at a given point in space and time, one must analyze many different types of hydrological data together to derive information using an online GIS tool. To help use these disparate data sources more effectively and efficiently, we have built an online interface called the IJEDI WebCenter for Hydroinformatics using a task-based approach. In this design, we first identify the tasks that users perform to study water-related issues, then organize data for each task, and build task-specific tools to present and analyze data and information. In a study involving both novices and experts in hydrology, we found that the both groups performed water-related studies more effectively and efficiently than they would have without the WebCenter.

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1 Introduction

As the Internet and advances in user-centric platforms become ubiquitous in today's world, online interfaces have become increasingly important in supporting scientific research and computing. Infrastructures such as multimedia flash, scripting languages, data availability in digital forms, and corresponding convenient backend database support empower online interfaces in usefulness and user-friendliness. Collections such as measurements, experimental results, and technical documentation are often assembled and provided at a central location for easy access. Visualization tools using animation, graphing and map-making mechanisms extend mere data repositories to information providers. As a result, more and more geographic information systems (GISs) are now available online for better accessibility and wider applications. Most of these online GIS interfaces, however, only provide mechanisms to view different sources of geographic data and suffer from several weaknesses: (1) disparate data sources without proper linkage make search and visualization difficult; (2) data sources organized without task-specific contexts make the navigation and use of data difficult; and (3) lack of task-specific tools make the analysis of data inefficient.

In this paper, we outline a task-based approach to an online interface for hydrological information systems. Our system is called the IJEDI WebCenter for Hydroinformatics. Hydroinformatics is a new field that integrates data, information, knowledge and understanding of hydrological processes. To study water-related issues, data such as stream and well measurements and precipitation are often analyzed together to understand the relationships among the different components of a water cycle. In this design, we first identify the tasks that users perform to study water-related issues, then organize data for each task, and build task-specific tools to present and analyze data and information. Further, the online help menu is both function-centric and task-centric.

To validate the usefulness of our design, we conducted a pilot study involving novices and experts in hydrology. First, we interviewed the experts for their estimation of times and steps required to accomplish a set of tasks. Second, both experts and novices were given a set of tasks to accomplish using the WebCenter individually. For each task, each subject was required to answer specific questions that allow us to make sure that the objectives of each task were achieved. Finally, all subjects were asked to respond to a questionnaire to evaluate the WebCenter along three dimensions: *interfaces*, *functionality*, and *online help*.

In the following, we first provide a brief background for our IJEDI WebCenter for Hydroinformatics in Section 2. In Section 3, we discuss some related work in human-computer interactions. We provide a framework for our task-based approach in Section 4. Section 5 describes our WebCenter. Then, we present our pilot study and our evaluation results in Section 6. Finally, we conclude with a discussion on future work.

2 Background

Of the many natural hazards in the world, drought still remains the most difficult to quantify, delineate, visualize, and quickly interpret in maps. Drought boundaries are diffuse and the episodes emerge, evolve, and migrate across the landscape, often ignoring major physiographic breaks in the landscape, and/or impacting farmers many hundreds of miles away from the actual drought event. Droughts can be classified as meteorologic, agricultural, hydrologic, or socioeconomic (Wilhite and Glantz 1987, Heim 2002), and each type of drought is different in its geospatial and temporal contexts. To illustrate, in Nebraska, drought has a significant impact on individual farmers and their communities. From the policy database of the USDA Risk Management Agency, drought events in 2000, 2002, and 2003 had a significant impact on the economy as could be discerned from the indemnities paid in those years: about \$191 million, \$373 million and \$181 million, respectively. Crop losses across 2002 and 2003 eclipsed \$500 million in Nebraska alone, and these numbers do not reflect or capture associated impacts on animal production, food processing, tourism and recreation, and local community water supplies.

2.1 Web-based GIS Tools

Researchers and practitioners typically analyze different components of the water cycle to understand the scope, magnitude and extent of hydrological drought. The components of the water cycle are viewed through different datasets that store the measurements at different points in space and time. Three such datasets include: (1) streamflow datasets (that measure the flow in the streams at different locations daily); (2) precipitation data (that store the daily precipitation at different locations); and (3) the groundwater data (that store the depth to water level at different wells at irregular time intervals). In addition, many other datasets provide the practitioners a more complete view and context of the hydrologic processes. They include the location of all streams, the geographic boundaries (watershed, ecoregions, etc.), location and extent of other water bodies (lake and reservoirs), cropland, forests, etc. Analyzing these disparate datasets together is a tedious task and hence is often performed inefficiently resulting in incomplete and inaccurate results. New web-based geographic information system (GIS) tools are needed to capture and integrate the many types and characteristics of drought across multiple data sources. In mapping droughts, we are often just mapping the flow and history of water on the landscape. As Internet-based water information resources grow dramatically, integrating, customizing, accessing, and analyzing multiple environmental monitoring networks and synthesizing the daily measurements in new visualizations and interpretations of drought events is essential. These tasks would form a critical component of emergency response systems for many agencies including the United States Department of Agriculture (USDA), National Weather Service (NWS), and United States Geological Survey (USGS). However, each federal or state agency often maintains independent geospatial databases for environmental monitoring, forcing the public to interactively query and process information (streamflow gauges, weather stations, and groundwater wells) from multiple websites. As a consequence, users cannot conveniently integrate these parallel drought parameters and monitoring network data into information for mitigation and emergency response. Here we briefly discuss and compare two such web-based GIS tools against our IJEDI WebCenter.

The USGS provides online, web-based access to data (see http://waterdata.usgs.gov/nwis/ for *NWISWeb* and http://md.water.usgs.gov/waterwatch/ for *Water Watch*). These query-based systems are quite comprehensive and flexible. On *NWISWeb*, the USGS provides surface-water data for more than 850,000 station years of time-series describing stream levels, streamflow (discharge), reservoir and lake levels, surface-water quality, and rainfall. The NWISWeb query system allows the user to select a site using four criteria: (1) *location* such as state, hydrologic region, and latitude and longitude extent;

(2) *site identifier* such as name, number, agency code, etc.; (3) *site attribute* such as altitude and drainage area; and (4) *data attribute* such as number of observations and period of record. The system displays the retrieved data in a variety of forms. The table of sites within a region can be sorted. The list of sites can be made scrollable, with a brief description for each site. The descriptions can be displayed as tables, tab-delimited files, or XML. Finally, one is allowed to choose what attributes or columns to be included in the display. In contrast to NWISWeb, which is primarily a data distribution site, our IJEDI WebCenter provides support for analysis. For example, we provide on-demand graphs and maps of dynamically processed data. Furthermore, our query system is map-based. The user can click on a station on a map to identify the station and generate instant graphs about that station.

Water Watch is a site for water resources in Maryland, Delaware, and the Washington, DC area. It is an integrated system as it includes surface water, ground water, weather, and agriculture data. For example, current ground water information maps are listed by county, categorized by water table well, or confined aquifer well, with five year information. The daily streamflow data is reported as percentiles and in real-time. When the user clicks on a station on a map, it brings up a webpage specific for that station. This webpage contains the following. It may have a photograph of the station. Then it has ancillary data such as the station ID, name, and location, its drainage area, period of record, gage, remarks, and so on. The measurements of the station can be displayed as a table, a graph, a fixed-width table, or a tab-delimited file. It also provides gage height statistics and daily mean flow statistics. Our IJEDI WebCenter is similar to Water Watch in many ways: both use a GIS-layered and supported map as the key mode for query, and both provide dynamically generated graphs. However, our IJEDI WebCenter allows for generations of graphs of multiple sites – from the same water basin as well as from different water basins. This feature allows the user to conveniently make visual comparisons of different stations. In addition, our IJEDI WebCenter offers a higher degree of manipulation – configuring the map along different layers: county, water basin, streams, lakes, etc., and real-time zooming in/out and panning.

2.2 The IJEDI Project

The Web-based application IJEDI WebCenter for Hydroinformatics is one of the products of our Intelligent Joint Evolution of Data and Information (IJEDI) project. The long-term goal of this project is to develop hydrological drought indicators (HDI) for monitoring and mitigation support that can provide decision-makers historical context of the current drought conditions and identify drought vulnerable regions. The WebCenter uses ESRI MapObjects (MO), Internet Map Servers (IMS), and Microsoft Visual Basic (VB) to describe drought events and hydrologic character and behavior with a geospatial component. The objective of the current phase of our research is to characterize the water basins in Nebraska. Understanding how water measurements relate and behave within a water basin will lay the important groundwork for the design of our drought index.

The underlying approach of our IJEDI approach is to combine knowledge discovery and data mining (KDD) with quality index analysis. Through KDD, we aim to combine both statistical analyses and domain expertise to identify useful patterns and distinct trends. We want to find rules that describe each water basin uniquely, rules that indicate the quality of data within a water basin and rules to classify watersheds into groups of similar hydrologic behavior. Rules may be generic that are applicable to all water basins; rules may be "type" specific that are applicable to a certain type of water basins; rules may be "water basin" specific that are applicable to only a particular water basin. We also incorporate site-based rules that contribute to the confidence value of the quality index.

3 Interfaces and Users

The field of human-computer interaction (HCI) addresses the need for computer systems to meet user needs (Diaper et al. 1998), providing intuitive interfaces for user friendliness, usability, and utility. Systems that are not intuitive often lead to a decrease in user acceptance (Johnson et al. 2002). Paradowski and Fletcher (2004) pointed out that high usability improves user acceptance and facilitates productive use of the software, regardless of a program's utility. This implies that easy-to-use systems are more likely to be used productively even when they are not that useful.

We use a task-based approach to improve the usability of our hydrological information system. It means that the workflow of our system is designed with the user and their tasks (Card et al. 1983, Nielsen 1993) or their information requirements (Richardson et al. 1998) in mind. In our framework, we investigated and identified the people who would use the software and the sequence and nature of the tasks. Based on this information, we designed the WebCenter to provide data, tools, and online help that are task-based.

Paradowski and Fletcher (2004) pointed out that the nature of the specific tasks users can and want to perform strongly influences the utility of the application. Further, the design of a software system that takes into account the existing tasks that users are faced with will be superior to a design that does not. For example, it is valuable to know how users completed tasks in the past (in the absence of software support) and what information is most important to them in the process. If tasks are analyzed to capture the cognitive activities within human-computer systems (Militello and Hutton 1998), it is possible to apply the analysis to better design the software. In the literature, one can find two general approaches to task analysis: (1) offline, pre-deployment analysis of user behavior (e.g. Ainsworth and Marshall 1998); and (2) online, post-deployment capture of user behavior, akin to end-user development (Sutcliffe and Mehandjiev 2004). The latter requires that the system, after deployment, is able to capture user behavior (and goals), perform analysis, map the behavior to certain functionalities of the system, and in turn modify the features of the system to better address the mapping (such as better on-task help menu, better sequence of functions to perform a task, etc.). The former requires researchers or developers to first determine user requirements, and then implement them into the system, and finally deploy it.

In addition to usability, there are several other factors that researchers have found to have positive effects on user's evaluation of a Web site. Teo et al. (2003) found out that increased level of interactivity on a Web site has positive effects on user's perceived satisfaction, effectiveness, efficiency, value, and overall attitude towards a Web site. Yi and Hwang (2003) showed that motivation variables such as self-efficacy, enjoyment, and learning goal orientation played a role in user acceptance of Web-based information systems. Davis (1989) and Davis et al. (1989) theorized that an individual's system usage was determined by the user's behavioral intention, which was in turn jointly determined by perceived usefulness and usability. In our framework, we aim to achieve usability through a task-based approach.

Further, our framework considers the content requirements of users (Fleming 1998, Fucella et al. 1998, Spool 1998). This means that the system should have adequate content relative to user expectations. This translates to our data and information repositories. With the content available, the system must also have a communication strategy to present the content to the users effectively. This translates to our visualization tools and products.

In summary, the design of an online interface should take into account usability and utility. The literature indicates that level of interactivity, content, and motivation variables also impact usability and utility. Our approach is task-based, designing our data access, tools, and online help menu from the viewpoint of accomplishing specific tasks. To discover theses tasks and corresponding features on our WebCenter, we performed task analyses during the design and development of the system.

4 Framework

In this section, we present the framework of our WebCenter design. As previously mentioned, our design is task-based in three areas: *data access and presentation*, *functions and tools*, and *online help* menu. Our design process included the following steps: (1) a comprehensive study of the domain applications, including the collection of data sources and development of software tools based on user needs; (2) an interface prototype for task analysis evaluating the usability and appropriateness of functions; (3) revision and refinement of the prototype; and (4) deployment of the Beta version of WebCenter.

4.1 User Needs

Our study started with comprehensive discussions with domain experts to identify research and user problems in the field of hydrology. We then identified common functions shared among these problems. Subsequently, we proceeded to collect and analyze data, and build software tools to support data access, visualization, and analysis. We also built a database to store the data. To determine what tools to build, we discussed with the experts (who are our potential users) the following:

1. **Types of data that they want to access:** In our case, the datasets consist of surface water measurements from stream gauges, ground water measurements using well data, and precipitation data collected from weather stations. Any hydrologic information system should have these different types of data available.
2. **What they want to access:** In general, there are two approaches to data access, visualization, and analysis. Many experts simply want to access the data sources. Other experts merely want to access the spatial information associated with the data sources. For example, one may want to find out about all the stations available in a particular watershed. One may want to find out the nearest wells given a particular stream gauge location. Here, we denote the former *data behavior access*, and the latter *metadata access*.
3. **How they want to access it:** The experts indicated that they prefer not to have to download the data; they prefer viewing the data online. This implied that the online interface must be able to provide timely data for viewing. Furthermore, the experts

prefer viewing different sources of data within a locality, such as within a watershed, or along a river. Thus the online interface must support data access in the context of watersheds, for example. That is, the user needs only to enter the name of a watershed to retrieve all the data he or she desires from that watershed.

4. **How they want to visualize it:** In general, the experts prefer viewing the data in multiple ways:
   (a) *For data behavior access*: First, the experts prefer viewing the data in GIS contexts, with other information layers such as the county boundaries, watershed boundaries, elevation (DEM), water bodies, and so on. In particular, watershed-based grouping is preferable. Second, the experts prefer viewing the data in graphs, showing the trends of the time series measurements for visual inspection. Third, the experts prefer viewing different data stations' measurements on the same graph for one-glance-comparisons. These preferences implied that the visualization tool should be flexible enough to allow multiple data series to be displayed at the same time and distinguish those series.
   (b) *For metadata access*: First, the experts prefer maps showing the data sources in GIS context, with other information layers as described above. Once again, watershed-based grouping is preferable. Second, the experts prefer viewing the sources with annotations on the maps – indicating a certain value for each source. Third, the experts prefer zooming capabilities to narrow to a particular region.
5. **How they want to analyze it:** In our case, the experts prefer flexibility in generating graphs for analysis, searching for stations within the same watershed, analyzing each set of stations separately, adding stations to a graph to visually compare the trends of different stations, and so on:
   (a) *For data behavior access*: First, the experts prefer to be able to manipulate temporal intervals and the set of time series measurements to be displayed on a graph. Second, the experts prefer to be able to perform statistical analysis on the data. Third, the experts prefer to be able to perform data mining on the data. These analytic options allow the experts to derive information from the multiple sources of data.
   (b) *For metadata access*: First, the experts prefer to be able to query for different stations or data sources based on names, watersheds, and types. Second, the experts prefer to be able to accumulate different information layers with the data sources on maps. Third, the experts prefer to obtain ancillary data of each station by clicking the location of the station on the map.

4.2 Common Functions

We then identified the common functions shared among the access, visualization, and analysis tasks described above. They are briefly listed below:

1. *An online mapping function* with the flexibility to add and remove a set of GIS layers.
2. *A text-based query function* that accepts query keywords and retrieves matching data stations.
3. *A map-based query function* that accepts GIS-based queries and retrieves data and information associated with each GIS item: For example, the user may click on the

map, highlighting a particular watershed, and query the system subsequently for the measurement time series of all the stations within the watershed.

4. *A graphing function* that can be invoked in several ways. First, the graphing function can be invoked with a single data station as the input. Second, the graphing function can be invoked with a single watershed as the input. Third, the graphing function can be invoked with a set of disparate stations as the input. In the first type of invocation, the function plots a single measurement time series. In the second type of invocation, the function plots a set of measurement time series (for all the stations found in the watershed) with each series color-coded. In the third type of invocations, the function plots a set of measurement time series, with stations found in different watersheds. Further, the graphing function also allows the users to enter different temporal intervals to focus on certain time periods of the measurements.
5. *A map-based zooming function* that allows a user to zoom in and out of a geographic area.

4.3 Prototype and Evaluation

After identifying the tasks and developing the basic functions and the complex tools to support these tasks, we built a prototype of our WebCenter (described in Section 5.4). We then presented the prototype to a set of experts and solicited their comments. We basically used the prototype to support our task analysis. Our discussions with the experts were the first phase of task analysis. This prototype evaluation constituted the second phase. Based on the evaluation, we refined and revised the prototype.

One of the insights that we gained from this prototype evaluation was to develop the online help menu. Initially, we had built a function-based online help menu, explaining what each function does. However, to accomplish a task, one may require a sequence of tasks. As a result, we added task-based explanations, e.g. "recipe" -like explanations. It puts the function in a task context with a specific objective to accomplish. These "recipe" -like explanations allow the users (even novices) to comprehend and appreciate the reason why particular functions are made available online, and help them learn how to use them to complete their own tasks.

4.4 Revision and Deployment

Finally, after revision, we deployed the system online (see http://water.unl.edu for additional details). We continue to solicit comments to continuously improve the interface. For the deployment, we also have to update the data, as more recent measurements are made available. We also have to maintain our databases to accommodate more metadata and derived information.

5 Design and Implementation

5.1 Data and Geographic Scope

Water is a strategic resource to Nebraska agriculture and rural communities. Past droughts in the mid-1890s, the "Dust Bowl" era, and the mid-1950s led to out-migrations from rural communities as farms failed, the collapse of small town businesses, and loss of community infrastructure. From recent droughts in 2000, 2002, and 2003, we see competition for water resources among small communities and the surrounding irrigated agriculture. In the past couple of years, surface irrigation allotments have been reduced and many new center pivot irrigation wells have been drilled to tap strained groundwater resources. Farmers are forced into making planting decisions in the winter months based upon long-term weather forecasts and estimates of water availability from snowpacks in Colorado's Rocky Mountains.

Nebraska ranks second in the nation in total irrigated croplands with more than 8 million acres (USDA NASS 2004), mostly derived from center pivot systems and groundwater. Nearly 86% of irrigated acres rely upon groundwater and the remaining 14% relies on surface water irrigation. Despite the reliance upon groundwater resources, the hydrologic unit concept (Seaber et al. 1987) has still been a useful framework for comparing stream behavior, land use and land cover, irrigation, cropping systems, and describing drought vulnerability. In Nebraska, there are 69 hydrologic units delineated at the 8-digit level (i.e. the *Hydrologic Unit Code* (HUC); see http://water.usgs.gov/GIS/huc.html for additional details).

High accuracy and good quality of data will lead to useful information and in turn valuable knowledge. Thus, data collection plays an important role in our research. We also base our dataset organization and subsequent analysis on water basins (with unique HUC). Each water basin has unique hydrological characteristics and is represented by a set of distinct parameters. Each watershed has a set of surface water (SW), groundwater (GW) and weather stations that measure different aspect of the hydrological state of the watershed. Two types of weather stations are used in our project: the cooperative stations of the National Weather Service (NWS) and the stations in the Automated Weather Stations Network (AWDN) of the High Plains Regional Climate Center. The stations in the AWDN network measure a number of additional parameters, such as wind speed and direction, relative humidity, solar radiation, and soil moisture.

Of the four types of measuring stations (i.e. SW, GW, NWS, and AWDN), only the stations that have more than 30 years of historical and continuous data are used in this study. For precipitation, we use all 274 NWS and 46 AWDN stations in Nebraska. For the streamflow and groundwater level, out of 274 SW and 166 GW stations, we use only 124 SW and 74 GW stations, respectively. We also use hydrology-related geospatial layers such as basins, counties, streams, rivers and lakes (see Table 1 for details).

We convert point coordinates for the monitoring stations to shapefiles, relying upon the Albers Equal Area Projection, NAD 1927 and Clarke 1866 spheroid, for all of our digital coverages (Ormsby et al. 2001).

5.2 Web-Based Interface Design

ArcIMS comes with a comprehensive suite of administrative tools and a whole set of functions that enable users to integrate local data sources with Internet data sources for display, query, and analysis in an easy-to-use Web browser (ESRI 2002). ArcIMS clients and servers communicate using ArcXML, which is a GIS extension to standard extensible markup language (XML). Since ArcIMS does not support most programming languages, we use MapObjects, to integrate high-level object-oriented programming languages.

To visualize and disseminate the results of our analyses in the IJEDI project, we have built a lightweight, online WebCenter (located at http://water.unl.edu) that creates customized maps, as well as seasonal and long-term trend analyses. Specific implementation steps include:

Table 1 GIS layers currently available on our IJEDI website

GIS Layers	Brief Description
Basin	Nebraska River Basins with 8-Digit Hydrologic Units from Nebraska Natural Resources Commission
Watershed	Nebraska River Basins with 11-Digit Hydrologic Units from Nebraska Natural Resources Commission
County	County data from Nebraska Natural Resources Commission
Streams	Streams draining a mapped watershed
Lakes	Lakes from Nebraska Natural Resources Commission
NWS	National Weather Service Surface Observations: Daily weather data includes evaporation, high temperature, low temperature, precipitation, and snowfall for first order (NWS forecast offices) and second order (cooperative observer network) sites
AWDN	Automated Weather Data Network: Hourly and daily weather data includes air temperature, precipitation, relative humidity, soil temperature, solar radiation, wind speed, wind direction, and much more
Surface Water	Abbreviation of all the surface water stations in Nebraska (Total 274, as downloaded from USGS)
Groundwater	Abbreviation of all the groundwater stations in Nebraska (Total 166, as downloaded from USGS)

- Using ArcMap for data capture and conversion.
- Using ArcIMS map server as the mapping service support.
- Using ESRI MapObjects 2.2 ActiveX control in Visual Basic (VB) to manipulate map layers with related GIS functions.
- Using ESRI WebLink ActiveX control embedded in Visual Basic (VB) to handle image transition between the server program and the Internet.
- Using Microsoft Chart, ActiveX control, and/or Java Applets to plot charts.
- Using Internet-based programming languages such as ASP, HTML, VBscript, Javascript, and CGI to capture user activities and invoke corresponding functions.

To use MapObjects (MO) to generate and display maps on the web, we first need a web server program on the server (e.g. Apache or Microsoft Internet Information Services). Considering the data size and security issues, we adopt the "client-requested" strategy where a client inputs a request, indicates a map function, and manipulates a map on the webpage (Ralston 2002). We use ArcIMS to process the client requests. The IMS passes the requests further to the VB/MO program running on the server. Subsequently, the VB/MO program (a DLL) parses each request and invokes the corresponding function to generate a bitmap. Then, the WebLink ActiveX embedded in VB/MO programs converts the bitmap to a JPEG file (Ralston 2002). This JPEG file is then displayed on the HTML webpage. Using ArcIMS allows us to run VB/MO programs is faster compared to those that required VB/MO programs to be loaded onto the server memory and unloaded per request. To use MapObject IMS in our design, the key is

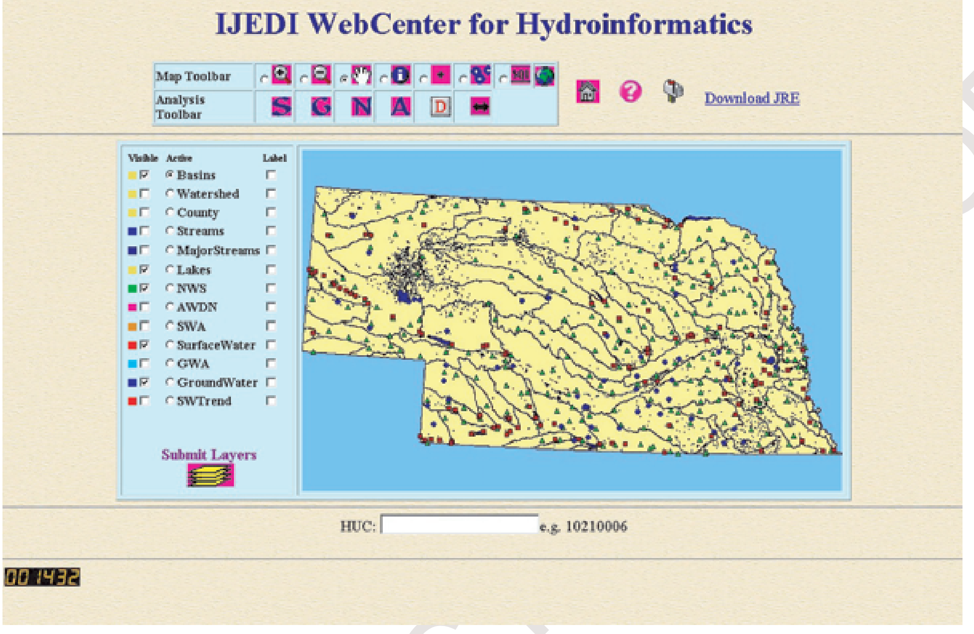

Figure 1 Interface of IJEDI WebCenter for Hydroinformatics. Only SW, GW, NWS, Basins and Lakes layers are active
This figure appears in colour in the electronic version of this article and in the plate section at the back of the printed journal

to incorporate the WebLink control into the VB/MO program and implement online communication and data-handling features.

Figure 1 shows a screenshot of the IJEDI WebCenter for Hydroinformatics, with major streams, 8-digit HUCs, USGS stream gauges, groundwater stations and AWDN and NWS cooperative weather stations presented. Currently we have a total of 12 digital coverages: basins (8-digit HUAs), watersheds (4-digit HUAs), TIGER 1:100,000-scale county boundaries, major streams, streams, NWS, AWDN, USGS Stream Gauges, and USGS Groundwater Monitoring Wells.

The IJEDI WebCenter for Hydroinformatics is not a pure GIS-based application. It combines GIS tools, Internet, and object-oriented programming. Our WebCenter consists of a Map Toolbar and an Analysis Toolbar. The Map Toolbar allows for basic functions such as *zoom in*, *zoom out*, and *pan*. It also allows for the identification of an entity on the map (e.g. a surface water station). The Analysis Toolbar provides customized graphs given user requests and allows for compare-and-contrast visual analyses.

5.2.1 Common Function 1: Identify

The Identify function (the "i" button in the middle of the Map Toolbar) is a graphical query function to extract information for a specific region or item on the map. Using this function, the user can identify a feature on the active layer and retrieve the information (name, location, charts, etc.) of the feature.

5.2.2 Common Function 2: Add Sites

This is a special function of our WebCenter (the "+" button in the middle of the Map Toolbar). This "Add Sites" function acts as a multi-site selector. When the active layer is a point-feature layer, such as the stream gauges, the user can use this function to select any points on the active layer, successively. Subsequently, the user can request a graph combining the measurements of all these sites or stations.

5.3.3 Common Function 3: Charting Graphs

Currently, the Analysis Toolbar of the WebCenter consists of mainly visualization of datasets (SW, GW, NWS, and AWDN) using graphing routines. Our online, real-time graph-charting functions can be invoked in three different ways:

- *Visualization of Single Station Data*: Suppose that the active layer is a point-feature layer (the stream gauge layer). If the user identifies a site or a station, and then clicks on "Surface Water Graph" ("S") button, the WebCenter will pop up a page with a Java Applet showing the graph for the measurements corresponding to the station. The user can change the time range of the measurements to create customized graphs. Figures 2 and 3 show the graphs for two different surface water stations with very different behaviors.
- *Visualization of data for multiple stations*: Using the "Add Sites" function, the user may click the "Surface Water Graph" ("S") button to display a graph of all these sites. This allows the user to make visual analysis of sites or stations from different water basins. In the above, we use the stream gauges or surface water sites in our examples. These functions are operational for all other sets of data sources supported by the WebCenter. Figures 4 and 5 show two instances of this form of visualization.

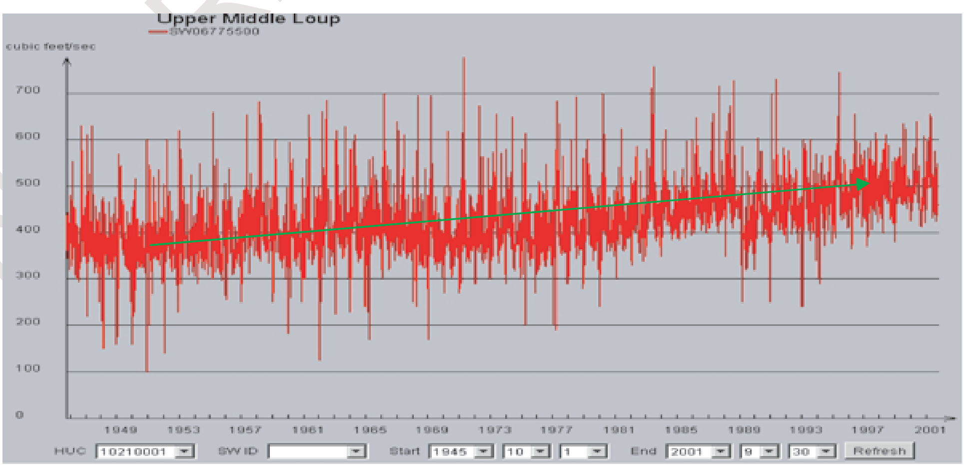

Figure 2 The Middle Loup River drains the Nebraska Sandhills and is strongly groundwater controlled, without influence of center pivot irrigation systems. The streamflow trendline is positive. Streamflows show less variability than observed in the loess and glaciated landscapes of northeast and southeast Nebraska
This figure appears in colour in the electronic version of this article and in the plate section at the back of the printed journal

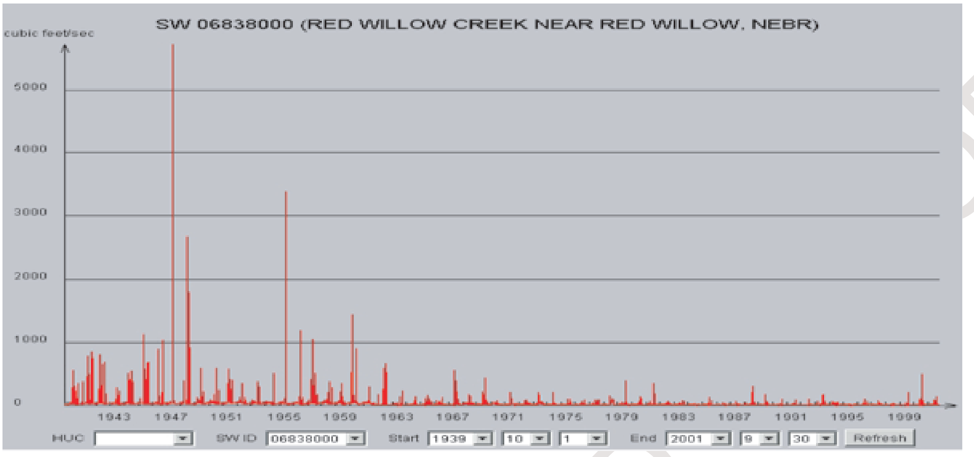

Figure 3 Red Willow Creek in southwestern Nebraska illustrates the impact of center pivot irrigation on streamflows through time. Center pivot systems adjacent to the stream are mining groundwater and recharge to the stream. Red Willow Creek is changing from a perennial stream to an intermittent or ephemeral stream through time
This figure appears in colour in the electronic version of this article and in the plate section at the back of the printed journal

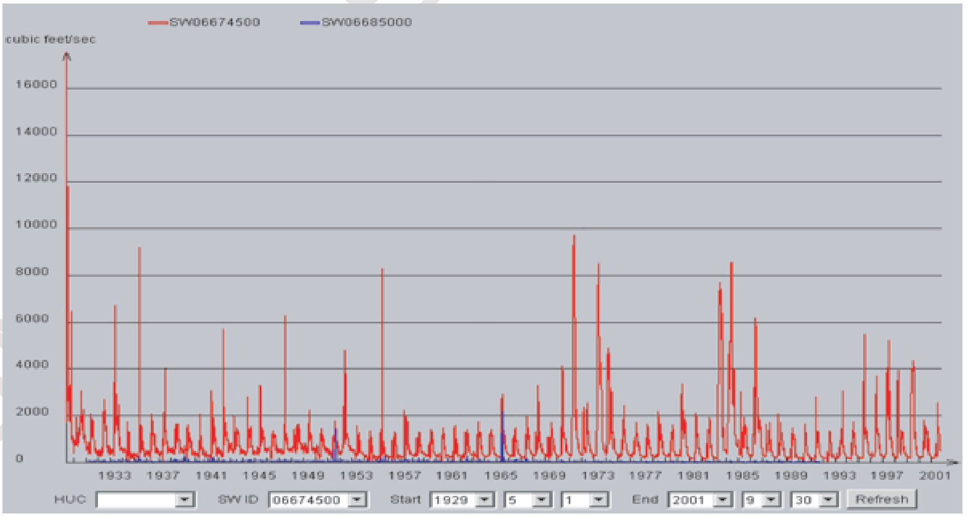

Figure 4 Measurements from two streams in adjacent watersheds. Measurements in North Platte River at WY-NE State Line (shown in red) is significantly higher that those in Pumpkin Creek near Bridgeport (shown in blue)
This figure appears in colour in the electronic version of this article and in the plate section at the back of the printed journal

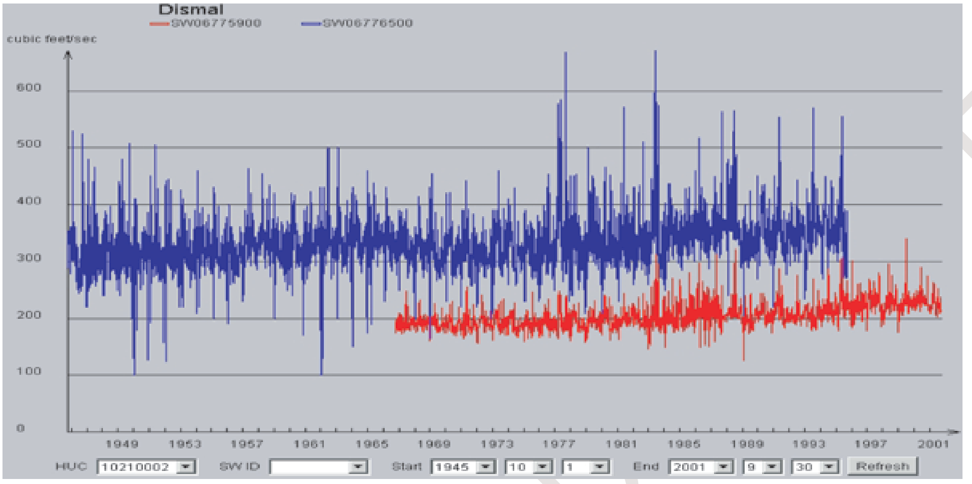

Figure 5 The measurements of the upstream and downstream gauges of the Dismal River in the Nebraska Sandhills. Both gauges show the increasing flow trend as seen at the Dunning gauge on the Upper Middle Loup River
This figure appears in colour in the electronic version of this article and in the plate section at the back of the printed journal

- *Visualization of all data for a water basin*: Suppose that the active layer is a polygon-feature layer, such as the basins layer. If the user identifies a basin and proceeds to click the "Surface Water Graph" ("S") button, our WebCenter will bring up a webpage with a Java Applet showing a graph. However, this time around, all surface water stations within the selected basin will be displayed on the graph. This allows the user to compare and contrast the multiple monitoring stations in the same basin. Figure 6 shows the steps in visualizing all the datasets for a given water basin.

5.2.4 Future Features

As described in Section 4.2, we have developed and built additional tools for the Web-server. These will be incorporated into the WebCenter to provide services such as text-based queries, clustering-driven search, station-based similarity queries, and stream gauge animation. We have conducted comprehensive data mining using unsupervised clustering. The clustering results will be used to build customizable online classifiers that will allow the user to find similar sites, basins, or watersheds.

6 Evaluation of the WebCenter for Hydroinformatics

In this section, we present a study to evaluate the usability and utility of our WebCenter. As outlined in MaGuire (2001), usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use". *Effectiveness* is defined as the "accuracy and completeness with which users achieve specified goals"; *efficiency* is the "resources

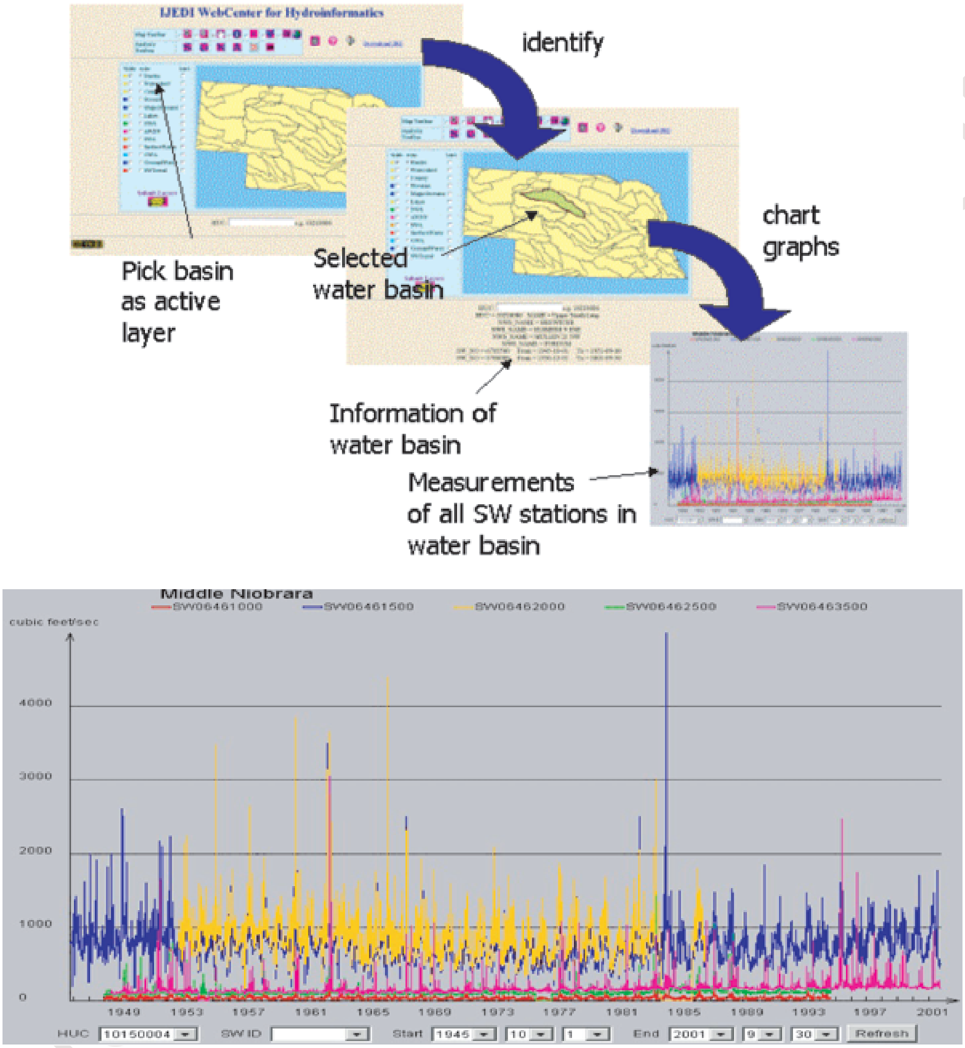

Figure 6 Steps in finding the measurements of all stream gauges in a water basin (top). The actual graphs for Middle Niobrara, from 1945 to 2001 are also shown (bottom)
This figure appears in colour in the electronic version of this article and in the plate section at the back of the printed journal

expended in relation to the accuracy and completeness with which users achieve goals"; *satisfaction* is the "freedom of discomfort, and positive attitude to the use of the product". In this study, we also look into some user-oriented aspects such as efficiency of attaining solutions, the rate of learning how to use the application, and the likelihood of error (MaGuire 2001) and user's expectations (De Marsico and Levialdi 2004).

Our approach to the study was to have two groups of users for evaluation: experts and novices. In our evaluation, the experts had at least 10 years of experience in hydrological data and analysis. The novices, on the other hand had no (or less than a few

Table 2 Likert questions posed in the evaluation form for the background and feedback surveys

Aptitudes	Interface	Functionality	Help Menu
Background knowledge in GIS	Easily accessible	Ease of use	Answers your questions
Web knowledge	Friendliness	Usefulness	Provides information you need
Knowledge about hydrology and meteorology	Logical Design	Effectiveness	Instructive and helpful
Reading ability	Level of Content	Speed	Easy to follow
Ability to follow instructions online	Layout	Correctness	
Familiarity with NE geography	Audience Appeal	Completeness	
		Suitability	
		Technical Elements	

months) experience in directly working with hydrological data or analysis. Each user was asked to complete five tasks using the IJEDI WebCenter for Hydroinformtics. For the experts, we first asked them to fill in a survey for an estimate of time and steps that would be required to accomplish some tasks (see Appendix 1). For each test, each user was given a form to fill out while carrying out the five tasks (Appendix 2). The form has four parts: (1) a background survey on user aptitudes; (2) a set of tasks; (3) a feedback survey; and (4) an open-ended survey for comments.

The background survey measures six aptitudes, as shown in Table 2. Our objective of this survey was to determine the relationship (if any) between user aptitudes and the usability and utility of the WebCenter.

The set of tasks used in our study are:

1. Identify the surface water station on the Nebraska-Wyoming boundary and observe its measurements using a chart;
2. Observe the measurements of all the groundwater stations in the "Dismal" basin;
3. Compare the measurements of all the surface water stations in "Middle Niobrara" basin from 1 October 1990 to 30 September 2001;
4. Select three surface water stations from three different basins and compare their measurements (using graphs); and
5. Find AWDN weather stations whose names start with "LINCOLN" and then observe the distribution of nearest NWS weather, surface water, and groundwater stations.

These tasks were designed to include a variety of activities ranging from simple to complex. The first task, for example, was the simplest as it involved locating the two states, their common boundary, the station on the boundary and clicking over it to get the information about it. The fourth and fifth tasks were more complex as they required the users to perform analytic-type activities online. The third task was designed to see whether the users can be precise in their use of the WebCenter.

Each evaluator was asked to answer several questions for each task.

1. One or two questions specific to the task with only one correct answer for each question. These questions allow us to determine without a doubt that the user has achieved the goal or objective of a task.
2. One question about the number of steps that the user took to complete the task. This allows us to compare the efficiency of the user compared to the ideal number of steps for each task.
3. One question about user's perceived effectiveness (in Likert scale) of the WebCenter.
4. One question about user's perception of whether the help menu provided enough instructions (in Likert scale) on the WebCenter.
5. An open-ended question prompting the user for suggestions.

The Likert scale is a popular technique for measuring the attitudes of survey respondents which ranks their response on a scale of Diagree – Agree (Likert 1932).

For each task, we asked the user to record the start and end times so we could compute the time users spent on each task. With this information, we can compare the efficiency of experts and the novices. We can also compare the times spent to accomplish the tasks with and without using the WebCenter.

Part III of the evaluation form is a feedback survey (using the Likert scale), prompting the user to evaluate the WebCenter in three areas: *interface*, *functionality*, and the *help menu*. We wanted to qualitatively measure the usability and utility of the WebCenter. Most questions for the interface and help menu areas pertained to usability. Most of the questions to evaluate the functionality of the WebCenter related to its utility. Table 2 shows the questions for each area.

Finally, in Part IV, we prompted each user to give additional comments on the following:

1. What are the strengths of the IJEDI WebCenter for Hydroinformatics?
2. What are the weaknesses of the IJEDI WebCenter for Hydroinformatics?
3. What features do you want to see in the future?

During each user's evaluation, one graduate research assistant was on standby in case of technical problems such as server disconnection or software crashes. Of the eight users, only one encountered a problem: due to the security system on the user's computer, the WebCenter's computation programs were not able to execute and deliver the results. The user eventually came to our research building to carry out the evaluation. In addition, for one novice, verbal help was administered as the novice failed to follow the online help menu to carry out her tasks. There were also questions about the geography of Nebraska and surrounding states. Some novices did not know where Wyoming was (part of Task 1).

6.1 Users

We recruited six novices and two experts for our study. The novices were graduate students, while one of the experts was a professor from another department and a researcher from a government agency here in Lincoln, Nebraska. Both experts have decades of experience in hydrology and water research. None of the novices were familiar with the WebCenter. The two experts had knowledge of the WebCenter's existence before the study, but had never used it before the study.

Table 3 Average aptitudes of the six novices and two experts (1: low; 5: high)

Aptitudes	Novices	Experts
Background knowledge in GIS	1.5	2.5
Web knowledge	4.3	3.5
Knowledge about hydrology and meteorology	1.2	4.5
Reading ability	4.0	4.0
Ability to follow instructions online	4.2	4.0
Familiarity with NE geography	1.5	4.0

From Table 3, we see that the novices reported having low background knowledge in GIS, about hydrology and meteorology and familiarity with Nebraska's geography. However, the novices were quite computer savvy, having reported high Web knowledge and ability to follow instructions online. Experts had a higher self-efficacy on their knowledge about hydrology and meteorology and familiarity with Nebraska's geography.

6.2 Correctness

All users accomplished all tasks correctly. All questions were answered correctly except for one: Question #4 of Task 3 for Novice #5. The question asked the user to identify the number of trends in the graph. The user mistakenly counted the number of trends.

The results show that the users, both novices and experts, were able to use our WebCenter correctly on their first attempt to accomplish a set of common tasks in hydrological analysis. This implies that our WebCenter's design supports users well in learning how to use the interface and in their task completion.

6.3 Task Completion

Table 4 shows the average time and number of steps spent by the novices and experts on the tasks. Before the experts evaluated the WebCenter, they were asked to fill out a

Table 4 Average time and number of steps spent by the novices and experts on each task. The "Ideal" number of steps denotes the number of steps that our own programmer took to accomplish each task

	Novices			Experts				
Tasks	Ave. (Mins)	Ave. #Steps	Ave. #Steps/Min	Ave. (Mins)	Ave. #Steps	Ave. #Steps/Min	Estimated Mins	Ideal #Steps
Task 1	8.0	4.0	0.5	3.0	4.5	1.5	7.5	3
Task 2	11.5	5.8	0.5	5.0	4.0	0.8	17.5	3
Task 3	11.8	8.8	0.7	6.5	7.5	1.2	17.5	4
Task 4	9.2	9.0	1.0	6.5	5.5	0.8	30	6
Task 5	11.0	17.5	1.6	7.0	8.0	7.5	50.0	7
Total	*51.5*	*45.1*	*NA*	*28.0*	*29.0*	*NA*	*122.5*	*23*

survey (see http://water.unl.edu/surveys for additional details) to estimate the time and number of steps they would take to accomplish each task. This information is also summarized in Table 4.

As expected, the experts were able to complete each task more efficiently than the novices, especially in simpler tasks such as Task 1 and Task 2. However, in Task 5, which is the most complicated among the five, the novices spent only 37.5% more time, the smallest gap among the five tasks. In terms of the total time spent on all five tasks, the novices spent close to twice as much time as the experts. These numbers indicate that the novices, without prior training and background in hydrology, GIS and Nebraska's geography, were able to accomplish their tasks but not as effectively and efficiently as the experts.

Compared to the ideal number of steps – which is the number of steps that our own programmer of the interface took to accomplish each task, the experts almost matched those numbers while the novices fared worse. This indicates that the experts were cognizant enough to be efficient and effective. One reason for the large average numbers of steps taken by the novices may be the tendency of the novices trying many steps before really thinking things through. It shows that, at this time, our WebCenter is not foolproof enough to prevent novices from losing focus. We also found:

1. It is apparent that the *novices* improved their efficiency (number of steps per minute) as they progressed from Task 1 to Task 5. Novices completed Tasks 1 and 4 in the least amount of time.
2. The *experts* did not improve their efficiency as they progressed from Task 1 to Task 5. As was the case with novices, the experts found Task 5 to be the most complex.

Table 4 also shows the time estimates by the experts for each task before the actual tasks were performed. Comparing these values with the actual time spent by the novices and experts in the evaluation, we observe that the experts were able to accomplish the five tasks 76.3% faster than what they had estimated. Indeed, the experts commented that the IJEDI Viewer has the "potential to save time and money", and the "ability to put all data in an easy to access format that is selectable by multiple attributes". What is even more interesting is that the novices were able to accomplish the five tasks 58.0% faster than what the experts had estimated. Other than Task 1, which is a simple task, the novices handily beat the estimates. This is especially striking for the complex tasks (Tasks 4 and 5).

From the above observations, we conclude that our WebCenter's usability and utility are high. Users were able to effectively and efficiently accomplish the tasks, especially when the tasks were complex.

6.4 Feedback Survey

In this section, we look at the feedback survey. Tables 5, 6, and 7 show the average scores the users gave for the interface, functionality and help menu, respectively.

From Table 5, we observe that the novices in general thought that the interface was easily accessible and the level of content was high. However, the audience appeal of the interface was about average. This may be due to the fact that these novices were computer science graduate students who had had exposure to online interfaces with more attractive designs. We also observe that the both the novices and experts found the interface to be of the same quality. The experts felt that the interface was not as easily

Table 5 Feedback by novices and experts on the WebCenter's interface (1: poor; 5: good)

Interface	Novices	Experts
Easily accessible	4.2	3.5
Friendliness	3.5	4.0
Logical Design	3.7	4.0
Level of Content	4.2	4.0
Layout	3.8	3.5
Audience Appeal	3.2	3.5
Total	22.6	22.5
Average	*3.8*	*3.8*

Table 6 Feedback by novices and experts on the WebCenter's functionality (1: poor; 5: good)

Functionality	Novices	Experts
Ease of use	3.5	4.5
Usefulness	4.2	4.0
Effectiveness	4.2	4.0
Speed	3.3	4.0
Correctness	4.6	3.5
Completeness	4.0	4.0
Suitability	3.8	4.0
Technical Elements	3.7	3.0
Average	*3.9*	*3.9*

Table 7 Feedback by novices and experts on the WebCenter's online help menu (1: poor; 5: good)

Help Menu	Novices	Experts
Answers your questions	3.8	4.5
Provides information you need	4.0	4.5
Instructive and helpful	3.8	4.0
Easy to follow	4.2	4.5

accessible as did the novices. Looking back at Table 3, we see that the experts' self-reported knowledge about the Web and ability to follow online instruction were not as high as those reported by the novices. We believe that these differences are reflected in Table 5. However, the experts felt that the interface was more user-friendly that did the novices – this could be due to the familiarity of the novices of other online GUI systems and the relative lack of exposure of the experts to such systems. On the other hand, the experts thought more highly of the system's logical design than did the novices. This could be due to the familiarity of the experts to the task-based design of the WebCenter and the tasks involved.

From Table 6, we see that both the novices and experts felt similarly about the functionality of the WebCenter overall. The novices in general thought that the interface was useful, effective, correct and complete. However, the speed of the WebCenter was judged to be average and the ease of use was about average as well. The experts, being more familiar with the tasks and functions, thought that the system was more easy to use than did the novices. The experts also felt that the WebCenter was faster than the novices. Once again, this could be due to the difference in the exposure levels to online interactions for the two groups of subjects. The experts, being knowledgeable, were also more critical about the correctness and technical elements of the WebCenter. On the other hand, the novices, being savvier about online interfaces, were more critical about the speed and ease of use of the WebCenter. Overall, we see that both groups thought the WebCenter was useful, effective, complete, and suitable.

From Table 7, we see that the novices in general thought that the help menu was helpful, easy to follow, informative, and answered their questions. We also see that the experts thought the help menu was more helpful than did the novices. This could be due to the lack of confidence in interacting with Web-based systems on the part of the experts. We believe that the experts, possibly uncomfortable working with a sufficiently complex online system, were pleasantly surprised to find that the WebCenter was easy to use and instructions easy to follow such that they evaluated the help menu highly.

Table 8 further shows the rating of the WebCenter's interface and help menu for each task. We observe the following:

1. *Novices*: For Task 2, it was quite straightforward and thus the help menu did not play a role. For Task 5, it was comforting to see that the novices, though rating the interface as moderately effective, rated the help menu to be useful. This was a key result that we welcome. We expected our help menu to become useful when the user hit a snag in their task completion.
2. *Experts*: For the experts, the interface effectiveness and help menu usefulness are in general independent of the tasks assigned. However, for Task 5, the experts gave full scores for the interface's effectiveness and the help menu's usefulness. Once again, even the experts valued the interface and help menu more when they encountered a more complex task such as Task 5.

Table 8 Feedback by how effective the interface was and how useful the help menu was for each task (1: poor; 5: good)

	Novices		Experts	
Tasks	Average Interface Effectiveness	Average Help Menu Usefulness	Average Interface Effectiveness	Average Help Menu Usefulness
Task 1	3.9	3.7	4.0	3.5
Task 2	3.4	3.0	4.5	3.5
Task 3	3.9	3.7	4.0	3.5
Task 4	4.0	3.5	4.0	3.5
Task 5	3.5	4.0	5.0	5.0

6.5 Correlation Analyses

In this section, we report the results of correlation analyses on the performance of the novices in the five tasks. Note that, with only six novices and two experts, our correlation analyses here are not statistically significant. We report these analyses here as they provide some insights into how the novices and experts approached the five tasks and how their self-reported aptitudes could play a role in how the novices completed each of the five tasks. Table 9 shows the correlations between completion times of the tasks. Table 10 shows the correlation between each aptitude and the completion time in minutes for each task.

From Table 9, we see that Tasks 1, 2, 3, and 5 were highly correlated. Task 4 was very unique. Task 4 asked the user to select three surface water stations from three different basins and compare their measurements. Upon closer analysis, Task 4 was a more open-ended task that required users to select on their own stations on the WebCenter, addressing their comfort level in "freelancing" around the interface. This correlation analysis suggests that though the tasks were different and had different average minutes to complete, the users were consistent (at least for Tasks 1, 2, 3, and 5). In a way, this also indicates that the WebCenter was able to solicit consistent behavior from the users.

Table 9 Correlations between the tasks in terms of task completion in minutes. Bold values are correlation values above 0.5, or below −0.5

Tasks	Task 1	Task 2	Task 3	Task 4	Task 5
Task 1	1.00	**0.92**	**0.65**	−0.21	**0.75**
Task 2		1.00	**0.77**	0.01	**0.92**
Task 3			1.00	−0.03	**0.80**
Task 4				1.00	−0.10
Task 5					1.00

Table 10 Correlations between novices' aptitudes and the task completion in minutes for each specific task. Bold values are correlation values above 0.5, or below −0.5. Note that when a user has high background knowledge in GIS, for example, the value for that aptitude is high. On the other hand, when a user quickly completes a task (more preferable), the value recorded in terms of minutes is small. Thus, a positive value in the above cells means a negative correlation, and vice versa. So, we see in the above that more background knowledge in GIS led to more time spent on all tasks, except for Task 4

Aptitudes	Task1	Task2	Task3	Task4	Task5
Background knowledge in GIS	**0.74**	**0.85**	**0.89**	−0.29	**0.95**
Web knowledge	−0.40	−0.40	0.06	−0.31	−0.19
Knowledge about hydrology and meteorology	−0.34	−0.41	−0.41	−0.36	−0.32
Reading ability	−0.05	−0.25	0.00	**−0.65**	−0.21
Ability to follow instructions online	−0.46	−0.29	0.01	−0.38	0.09
Familiarity with NE geography	**0.56**	0.40	0.25	−0.19	0.18

As expected, better web knowledge led to faster task completion. Better knowledge about hydrology and meteorology also led to faster task completion. Better ability to follow online instructions also led to faster task completion.

However, more background knowledge in GIS did not lead to faster completion of tasks (except for Task 4). We had expected that novices with less background knowledge in GIS would spend more time in each task. The first three tasks required the users to know Nebraska's geography, asking about the Nebraska-Wyoming border, the "Dismal" basin and the "Middle Niobrara" basin, respectively, while Task 5 required the users to find weather stations whose names start with "L". Possible explanations for this include: (1) users over-estimated their background knowledge in GIS; or (2) novices with better GIS background overlooked instructions and also the online help menu, resulting in degraded performance. The users were still able to be on-task and complete the tasks effectively.

Another interesting result is that the reading ability has a positive effect on the completion of Task 4. That is, the more proficient the user was in reading, the faster he or she was able to complete Task 4. Task 4 was different from the other tasks as it asked the users to choose three stations on their own. This difference might have caused the users to re-read the instructions. In addition, since choosing three stations meant that a user needed to read the names of stations, scan them, and choose faster surely ended up completing the task quicker.

Another interesting observation is that a user's familiarity with geography of Nebraska did not impact the completion of tasks positively (except for Task 4). Though not expected before the study, we realize that this observation was not completely surprising. The novices approached the study more mechanically and thus treated the geographic names as just another set of terms.

6.6 *Other Comments*

We observed that the experts were impressed with the WebCenter. They expressed that no other currently available systems were able to integrate different sources of data and link them in a single system. Further, the ability of the functions to fuse different data stations provided a powerful convenience to researchers in their analytical tasks. The novices, on the other hand, did not appreciate the utility of the WebCenter as much as the experts, since they did not have the background and understanding of the current data and systems related to GIS and hydrology. Instead, their comments focused mostly on the aesthetics of the interface, complaining that the interface was not designed well enough, not in terms of usability but in terms of attractiveness. This gives us a very important insight. One of our plans for the WebCenter is to use it to educate students about GIS in general and hydrology in particular. While the WebCenter has high utility and usability, it does not have features that could attract students and keep them focused.

6.7 *Future Improvements: Advanced Analysis Tools*

We see the functions described in Section 4.2 as basic components that are shared by multiple tasks and can be viewed a set of core functions for any hydrologic information system. From the study above, we realize that the users are sophisticated enough to use these online functions effectively, which has prompted us to continue to develop more advanced tools. Currently, we have already built or designed a set of advanced analysis tools which will be made available on the WebCenter:

1. **Quality-of-data computation tools:** For each data station, we have programs that automatically determine how good the measurements are based on the completeness, noise, length, and recency of the measurements.
2. **Drought parameters computation tools:** For the stream gauges, we have programs that compute a set of parameters that characterize drought events (including each event's duration and magnitude), derive drought frequencies and drought-overflow ratios.
3. **Pairwise relationship computation tools:** For each pair of data stations, we have programs that compute the time-lagged correlations of the two measurement time series.
4. **Trend analysis computation tools:** For each river, we have programs that compute the overflow and underflow statistics along the river, between each pair of stream gauges found on the river. We also have a linear regression program for each time series.
5. **Stress days computation tools:** We have programs that identify and compute the number of stress days for certain fish populations based on the low-flow streams and high temperatures.
6. **Clustering tools:** We have built a set of clustering modules to help us detect patterns within a set of data stations. We use these to support data mining. Currently, we are fine-tuning these modules to provide flexibility and ease-of-use and to be eventually used online.
7. **Statistical analysis tools:** So far, we have used commercially available statistics programs and a few of our own to perform statistical analysis. We plan to ultimately provide a suite of such tools online for users.

7 Conclusions

Understanding hydrological processes in a geographic area is a difficult task. Information related to these processes is stored in a variety of datasets that measure different aspects of the water cycle. Surface water, groundwater, aboveground climate and geomorphology all provide a component view of the overall hydrological cycle that characterizes a region. Integration of information from these diverse, but related sources is an essential step in understanding the hydrological processes (CUAHSI 2003). We have developed a web-based tool that can be used to simultaneously analyze and visualize the information from a variety of hydrological datasets. The IJEDI WebCenter for Hydroinformatics provides tools to analyze multiple hydrological datasets at the level of individual stations or at a watershed level.

Our design is task-based and based on a comprehensive study to collect data sources and develop software tools based on user needs. We have developed a prototype interface for task analysis. The design process went through a preliminary evaluation of the prototype in terms of usability and utility as reported in this paper. This evaluation led to revision and refinement of the prototype. Finally, we deployed the new version of the WebCenter. The task-based design is used in data access, visualization, and analysis. Common, basic functions as well as computation tools help users to complete their tasks.

Currently, we are adding a suite of computational tools – clustering, drought parameters, stress days, quality of data, statistical analysis, and so on – to the WebCenter.

We conducted a study to evaluate the WebCenter's usability and utility. A set of experts found the WebCenter to be highly useful. Both the novices and experts learned how to use the WebCenter on the first trial and were able to complete a set of five tasks effectively and efficiently. They also found the interface to be of good quality (3.8/5.0), the functionality to be of good quality (3.9/5.0) and the help menu to be of good quality (4.0/5.0). We concluded that our task-based approach to the WebCenter resulted in a good design.

As part of our future work, we will look into creating an enjoyable interface where there is a balance between the challenges of an activity and the skills required to meet those challenges (Pace 2004). In fact, information retrieval, which is akin to data access behavior in our discussion, was the most commonly reported flow-inducing activity (Chen et al. 1999), where a flow is the cognitive focus that a user experiences when he or she is absorbed in his or her tasks. For our objectives in education, we will look into aesthetics (e.g. Lavie and Tractinsky 2004) and interactivity, immersion, and connectivity (Bhatt 2004) for attracting students. To better support researchers, we will investigate the use of interface agents. Interface agents are computer programs that have the ability to learn a user's preferences and working habits, and to provide the user proactive and reactive assistance in order to increase the user's productivity (Schiaffino and Amandi 2004).

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Appendix 1 Survey Questions Posed to Experts before IJEDI WebCenter for Hydroinformatics Evaluation

1. If you are asked to identify the surface water station that sits on the Nebraska-Wyoming boundary and observe its measurements/trends,
   (a) How long will it take for you to find the station, get the surface water station measurement, plot the graph, and take a look at the graph? ________ minutes
   (b) How many steps will it take you to do this? (List the steps if you prefer, such as "Check the Nebraska/Wyoming map" "Locate water station" "Check the Web to retrieve water station measurement" "Use SAS to plot graph" . . .)
2. If you are asked to observe the measurements of all the groundwater (GW) stations in the "Dismal" river basin,
   (a) How long will it take for you to find the river basin, find all the GW stations, get their measurements, plot the graphs, and compare the graphs? _________ minutes
   (b) How many steps will it take for you to do this?
3. If you are asked to compare the measurements of all the surface water (SW) stations in the "Middle Niobrara" basin, from October 1, 1990 to September 30, 2001,
   (a) How long will it take for you to find the river basin, find all the SW stations, get their measurements only from 10/1/1990 to 9/30/2001, plot the graphs, and compare the graphs? ________ minutes/station
   (b) How many steps will it take for you to do this?
4. If you are asked to compare the measurements of three different surface water stations of different river basins – each water station comes from a different river basin,
   (a) How long will it take for you to find the three water stations, get the measurements, plot the graphs, and compare the graphs? _________ minutes
   (b) How many steps will it take for you to do this? (For this one, please also elaborate on how it you do the above.)
5. If you are asked to find all the Automated Weather Stations Network (AWDN) stations whose names start with the letter "L",
   (a) How long will it take for you to find all these weather stations? _________ minutes or _______ minutes/station
   (b) Suppose now you find out that there are two such stations. If you are asked further to find for each AWDN station you have found, the list of nearest National Weather Stations (NWS) weather, surface water, and ground water stations, how long will it take for you find all these other stations? _________ minutes or _______ minutes/AWDN-station
   (c) How many steps will it take for you to do this? (For this one, please also elaborate on how it you do the above.)

Appendix 2 IJEDI WebCenter for Hydroinformatics Evaluation Form

This evaluation form should reflect the experience of the participants at viewing IJEDI WebCenter for Hydroinformatics. Please complete this form after performing given tasks below. Evaluations will be tallied and results will be posted on the IJEDI Web site.

Thank you for taking time to complete this form!

Name: ________________________ Email: ________________________
Institution or Organization Name: ______________________________________
Date: ____

Part I. User Background Survey

Please answer (by circling the number) the following questions before using IJEDI Web-Center for Informatics.

Aptitudes	Low		Neutral		High
Background in GIS	1	2	3	4	5
Web knowledge	1	2	3	4	5
Knowledge about hydrology & meteorology	1	2	3	4	5
Reading ability	1	2	3	4	5
Ability to follow online instructions	1	2	3	4	5
Familiarity with geography of NE	1	2	3	4	5

Part II. Task

Open the web site at http://hydro.unl.edu and click IJEDI WebCenter for Hydroinformatics. Please browse the site as you wish, and then finish the following 5 tasks and answer questions for each task. You may click "Help" button on the Web page for help and instruction.

a. Identify the surface water station on the Nebraska-Wyoming boundary and observe its measurements using a chart

Start Time: ______________________________________

1) What are the site number and name of this station?

Site Number: ________________ ***Name:*** ____________________

2) What is the approximate average stream flow value of this station you observed from its chart?

Approximate average stream flow: ____________ *ft^3/sec*

3) How many steps did you take to complete the task?

4) How effective was this interface in helping you complete the task? (please select one)

(not effective) 1 2 3 4 5 (very effective)

5) Did the help menu provide enough instructions for this task? (please select one)

(low) 1 2 3 4 5 (high)

If no, please give some suggestions.

End Time: ____

b. Observe the measurements of all the groundwater stations in the "Dismal" basin

Start Time: ____

1) How many groundwater stations are there?

2) How many "good" stations are there? (A "good" station means the station has more than 30 years record and is currently active.)

3) From the chart of good stations, list the stations under increasing, decreasing, and neither trends in the following table.

Increasing	Decreasing	Neither

4) How many steps did you take to complete the task?

5) How effective was this interface in helping you complete the task? (please select one)

(not effective) 1 2 3 4 5 (very effective)

6) Did the help menu provide enough instructions for this task? (please select one)

(low) 1 2 3 4 5 (high)

If no, please give some suggestions.

End Time: ____

c. Compare the measurements of all the surface water stations in "Middle Niobrara" basin from October 1, 1990 to September 30, 2001

Start Time: ____

1) How many surface water stations are there?

2) How many "good" stations are there? (A "good" station means the station has more than 30 years record and is currently active.)

3) From the chart of good stations, list the stations under increasing, decreasing, and neither trends in the following table.

Increasing	Decreasing	Neither

4) Change the chart to range from ***October 1, 1998*** *to* ***September 30, 2001****. (Important Note: Now the range has shortened from 1990 to 1998.) How many trends do you see now on the chart?*

5) How many steps did you take to complete the task?

6) How effective was this interface in helping you complete the task? (please select one)

(not effective) 1 2 3 4 5 (very effective)

7) Did the help menu provide enough instructions for this task? (please select one)

(low) 1 2 3 4 5 (high)

If no, please give some suggestions.

End Time: ____

d. Select three surface water stations from three different basins and compare their measurements. (You must generate an online chart with all three series of measurements appearing on the chart.)

Start Time: ____

1) What "button" did you use to put all three stations from three different basins on the same chart?

2) Please fill in the following table for your selected basins and surface water stations.

Selected Basins	Selected Surface Water Stations

3) List the surface water stations under increasing, decreasing, and neither trends in the following table.

Increasing	Decreasing	Neither

4) How many steps did you take to complete the task?

5) How effective was this interface in helping you complete the task? (please select one)

(not effective) 1 2 3 4 5 (very effective)

6) Did the help menu provide enough instructions for this task? (please select one)

(low) 1 2 3 4 5 (high)

If no, please give some suggestions.

End Time: ____

e. **Find AWDN weather stations whose names start with "LINCOLN" and then observe the distribution of nearest NWS weather, surface water, and groundwater stations.**

Start Time: ____

1) How many AWDN stations are there, whose names start with "LINCOLN"?

2) Please list the names of the AWDN stations that you have found.

3) Zoom into the basins that contain these AWDN stations, and count the number of NWS weather, AWDN weather, surface water (SW) and groundwater (GW) stations in each of those basins?

Basin Name	# NWS stations	# AWDN stations	# Surface Water Stations	# Groundwater Stations

4) How many steps did you take to complete the task?

5) How effective was this interface in helping you complete the task? (please select one)

(not effective) 1 2 3 4 5 (very effective)

6) Did the help menu provide enough instructions for this task? (please select one)

(low) 1 2 3 4 5 (high)

If no, please give some suggestions.

End Time: ________________________________

Part III. Feedback

Complete the following overall evaluation for IJEDI WebCenter for Hydroinformatics, please provide us with your suggestions, comments and questions.

Interface	Low		Neutral		High	Not Applicable
Easily accessible	1	2	3	4	5	NA
Friendliness	1	2	3	4	5	NA
Logical design	1	2	3	4	5	NA
Level of content	1	2	3	4	5	NA
Layout	1	2	3	4	5	NA
Audience appeal	1	2	3	4	5	NA
Other	1	2	3	4	5	NA

Other questions and suggestions about interface?

Functionality	Low		Neutral		High	Not Applicable
Easy of use	1	2	3	4	5	NA
Usefulness	1	2	3	4	5	NA
Effectiveness	1	2	3	4	5	NA
Speed	1	2	3	4	5	NA
Correctness	1	2	3	4	5	NA
Completeness	1	2	3	4	5	NA
Suitability	1	2	3	4	5	NA
Technical elements	1	2	3	4	5	NA
Other	1	2	3	4	5	NA

Other questions and suggestions about functionality?

Help Menu	Low		Neutral		High	Not Applicable
Answers your questions	1	2	3	4	5	NA
Provides information you need	1	2	3	4	5	NA
Instructive and helpful	1	2	3	4	5	NA
Easy to follow	1	2	3	4	5	NA
Other	1	2	3	4	5	NA

Other questions and suggestions about help menu?

Part IV. Overall Comments

1. What are the strengths of the IJEDI WebCenter for Hydroinformatics?

2. What are the weaknesses of the IJEDI WebCenter for Hydroinformatics?

3. What features do you want to see in the future?