A Regional Information System for Environmental Data Analysis*

B.H.C. Cheng, R.H. Bourdeau, and B.C. Pijanowski

Abstract

Many organizations addressing "grand challenge" problems, such as those defined by Earth sciences, require the integration of both physical and human resource databases in an interactive manner. Such a capability allows reasonably informed policy analysts to query an "environmental science workstation" so as to better understand how human uses impact our natural resource base. This paper describes a prototype software tool that supports access to and understanding of diverse environmental information. The tool, ENFORMS (Environmental Information System), is currently being developed for use in a regional watershed analysis project. ENFORMS consists of two general components: an object-oriented archive of multimedia information objects and a querying facility to search the archive for relevant information. The archive can be populated with a variety of different types of information, including documents, satellite imagery, aerial photographs, tabular data, color-coded charts, maps, and illustrative animations. The archive component also supports data integration activities using tools such as a geographical information system (GIS) and environmental models.

Introduction

Information needed to address environmental problems transcends the natural science domain with implications into the social science domain, such as how human population dynamics, economics, behavior, and political systems affect and are affected by the environment (Committee on Global Change, 1990; Committee on Earth and Environmental Sciences, 1992). Providing policy analysts and researchers with information required to address environmental problems is an important task. Relevant information is sometimes difficult to acquire, and, once acquired, its sheer volume may make managing the information a very challenging task. In addition, environmental studies require the integration and analysis of physical, biological, and human resource databases to produce useful information for the research and policy communities. Often, the tools required to integrate this information are complex (e.g., geographic information systems, statistical analysis, and models), thus potentially hindering the effective use of the information.

Investigations at Michigan State University (MSU) have been underway for the past two years by a multidisciplinary research team whose members are from four colleges and 22 different university departments. The principal objective of this team has been to develop an extensible, regional information system following a user-driven, science-guided, and technology-based approach. This team has focused its work on three tightly integrated activities: user needs assessment, scientific analysis, and computing technology. This paper describes the development of ENFORMS (Environmental Information System) a prototype software tool that supports access to information and data integration tools needed to understand environmental problems.

The topics addressed by this project include crop productivity, land use, pollution, distribution of human and animal populations, and economics. ENFORMS is currently being developed for use in a regional watershed analysis project (Bourdeau and Cheng, 1992). This project is a preliminary attempt to address the problem of how to make vast quantities of heterogeneous information available and useful to a large audience.

ENFORMS consists of two general components: a heterogeneous, object-oriented archive of information objects and a querying facility to search the archive for relevant information. A variety of different types of information objects can be stored in the archive, including documents, satellite imagery, aerial photographs, tabular data, color-coded charts, georeferenced mapsets, and illustrative animations. The archive component also supports data integration activities using tools such as a geographic information system (GIS) and environmental models. ENFORMS provides a sophisticated, but user-friendly, graphical user interface to make the complexity of the different integrated tools transparent to the user. The archive is accessed using an issue-based classification scheme that is explicitly represented by the querying facility.

While only a single querying facility has been developed for a demonstration version of the prototype, the system can be extended to accommodate different querying paradigms and interfaces. More specifically, within the object-oriented design and implementation, there is a clear separation between the user interface and the underlying system that provides the data access and retrieval (Cheng *et al.*, 1994).

The remainder of this paper is organized as follows. The first section discusses the configuration process involved in creating an archive with ENFORMS. This is followed by a description of the watershed analysis project for which this system originally was developed; sample scenarios created

*A preliminary version of this paper was presented at the 25th International Symposium, Remote Sensing and Global Environmental Change, Graz, Austria, 408 April 1993.

B.H.C. Cheng is with the Department of Computer Science and B.C. Pijanowski is with the Entomology Spatial Analysis Laboratory, at Michigan State University, East Lansing, MI 48824.

R.H. Bourdeau is with the Software Engineering and Systems Development Section at the Consortium for International Earth Science and Information Network, Saginaw, MI 48710.

Photogrammetric Engineering & Remote Sensing,
Vol. 62, No. 7, July 1996, pp. 855–861.

0099-1112/96/6207–855$3.00/0

```
BEGIN-ITEM
   KEY = drybeanprod
   EXTTYPE = map
   DESCRIPTION = Dry bean production in Michigan for 1992
   BEGIN-MANIPULATORS
      M-BEGIN
         DESCRIPTION = Display Map
         HANDLE      = access1
         MANIPULATOR = imview
         BEGIN-PARAMETERS
            IMAGE PATH = /home/msuciesin/local/grass4.0/archive/gifs
            IMAGE NAME = drybean.gif
            IMAGE TYPE = GIF
         END-PARAMETERS
      M-END
      M-BEGIN
         DESCRIPTION = Read Description
         HANDLE      = access2
         MANIPULATOR = textdisp
         BEGIN-PARAMETERS
            FILE PATH  = /home/msuciesin/local/grass4.0/archive/ascii
            FILE NAME  = 307A.CAP
            SEARCHABLE = YES
         END-PARAMETERS
      M-END
   END-MANIPULATORS
END-ITEM
```

Figure 1. An example object descriptor.

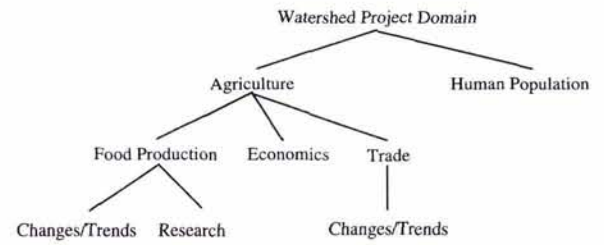

Figure 2. Example IPAR hierarchy.

with the system are provided. The next section contrasts ENFORMS with other systems. Finally, conclusions are given, and current and future investigations are briefly described.

Creating an ENFORMS Archive

ENFORMS is a highly configurable archiving system defined by three sets of metadata: a *classification scheme specification, object descriptors,* and *object classifications.* A data object, referred to as an *item,* is a specific piece of information that has a set of defined operations. For example, a text file has *read* and *print* operations, and a set of georeferenced maps can be *manipulated* by a compatible GIS, where the set of maps is considered to be a single item. Items may also be executable programs such as a static animation with *run* and *stop* operations.

An item descriptor is one type of metadata that defines an item for the system. An item is made accessible through the system by adding its descriptor to the *registration database,* a text file containing these descriptors. Descriptors contain two types of information: system information for internal use by ENFORMS and user information that is presented to the user in various formats. An example registration is shown in Figure 1. All information is specified in the form *name* = *value,* such as **KEY** = **drybeanprod**. There are four basic pieces of information that constitute a descriptor: a *key,* a *type,* a *description,* and a set of *access descriptors.* Each item that is in the archive must have a unique key that is specified by the keyword **KEY** (system information). **EXTTYPE** specifies the item's type, and **DESCRIPTION** is a brief description of the item, both of which are user information. An example illustrating how this information is displayed to the user is given in Figure 7, where the **Items of Interest** window contains the user information. Access descriptors are listed in the section enclosed by a **BEGIN-MANIPULATORS/END-MANIPULATORS** pair in Figure 1. An access descriptor, specified by a **M-BEGIN/M-END** pair, provides the system with information as to how the item can be used with specific integrated software tools (manipulators). Each manipulator has a unique name that is recognized by ENFORMS according to the keyword **MANIPULATOR**. Currently, four manipulators are provided by ENFORMS: **textdisp** can display text files, **imview** can display images in a wide variety of formats, **OpenGrass** is a GIS tool that can process georeferenced maps in the GRASS format (Westervelt, 1991), and **app** can launch arbitrary GUI-based applications. Each manipulator has specific parameters that it uses to perform the necessary task.

The second type of metadata needed by ENFORMS is a classification scheme that configures the system's query facility. ENFORMS currently supports a simple hierarchical classification scheme called *IPAR*; the height of the hierarchy is limited to four tiers: the *Issue, Problem, Aspect* (subtopic), and *Refinement* tiers (hence the acronym). An instantiation of the classification scheme consists of a specific hierarchy, such as that shown in Figure 2. In this figure, the root node is the name of the classification scheme, and the children of the root node are the issues. A classification scheme is supplied to ENFORMS in the form shown in Figure 3, where each branch in the hierarchy has an entry (because there is only one root note, it is not repeated for each classification).

The third type of metadata needed are the data classifications that define how the registered items are to be located by queries, where a query is a request for items that "match" a given set of classifications. The *item classification database* is a text file that consists of entries of the form shown in Figure 4. Each classifier gives the key of the item being classified and a list of classifications. Adding a classification such as **Agriculture** > **Food Production** to an item's classifier implicitly asserts that the given item represents information related to the problem of **Food Production** as it relates to the issue **Agriculture**. Note that the item classifications must be consistent with the system's overall classification scheme. For example, the classification **Agriculture** > **Food Production** is consistent with the hierarchy defined in Figure 3 but **Trade** > **Research** is not.

An Example Configuration

Information from studies of the Saginaw Bay watershed was used to populate the ENFORMS archive and was used to demonstrate ENFORMS' utility. The Saginaw Bay watershed was selected because a vast array of data and experience currently exist at Michigan State University that can be used to examine environmental problems related to the Great Lakes region.

The Saginaw Bay watershed region is located in central

```
BEGIN-IPATUPLES
   Agriculture > Food Production > Changes/Trends
   Agriculture > Food Production > Research
   Agriculture > Economics
   Agriculture > Trade > Changes/Trends
   Human Population
END-IPATUPLES
```

Figure 3. Classification scheme specification.

Michigan around the mouth of the Saginaw Bay of Lake Huron. It is over 12,000 square kilometres in size. Large areas are devoted to industry and agriculture. Several state and national forests also are located in the area. There is also one major river in the area (Saginaw River) with many tributaries that flow into Saginaw Bay. Thus, the entire watershed affects the quality of many of the Great Lakes. The region is an excellent area to study how humans affect the environment because the major types of land uses exist in the area. In addition, the Saginaw Bay watershed region is an important resource for the state of Michigan as well as for the United States. The region is the center of some of the most productive agricultural soils in the country, contains several large industrial centers, and thus supports many facets of the states' economy.

The Saginaw Bay watershed region also has been identified by several United States government agencies (e.g., the United States Environmental Protection Agency (EPA) and the United States Department of Agriculture (USDA)) as an area of environmental concern due to the massive amount of soil erosion that occurs in the area. The Great Lakes Commission has reported that nearly 606 million tons of soil are lost annually from the Great Lakes area, at a cost of over 3 billion U.S. dollars worth of lost nutrients and productivity (Great Lakes Committee, 1992).

User Needs and Scientific Analysis

One of the first tasks of the project was to conduct a user needs assessment survey. Nearly 700 potential users of the Saginaw Bay configuration of ENFORMS were identified. These potential users included policy analysts, researchers, administrators, educators, business persons, and environmental organization personnel. The users were asked to identify the types of environmental issues they encounter, their knowledge of computing technology, and the format in which the information should be provided to them in a computer environment (Michigan State University/CIESIN, 1992).

Because environmental problems have been assessed over the past several years by various members of the research team for separate projects, the results from their user needs analyses (He *et al.*, 1992) also were included in this project's user needs assessment. A majority of those interviewed stated that soil erosion and non-point source pollution problems were some of the most frequent issues that they encountered. In all, over 200 issues were identified in the survey study.

The results of the assessment were analyzed by science members of the project team in order to identify data and the different types of data analysis that would help to address some of the users' concerns. A sampling of the types and sources of data that were identified and used to populate the watershed configuration of ENFORMS are given in Figure 5. Once the data were identified and acquired, they were classified according to the perspective obtained from the survey study.

```
BEGIN-ITEMCLASSIFIER
   KEY = drybeanprod
   BEGIN-CLASSIFICATION
      Agriculture > Food Production
      Agriculture > Economics
   END-CLASSIFICATION
END-ITEMCLASSIFIER
```

Figure 4. Example of object classification.

TYPES OF DATA	DATA SOURCE
PHYSICAL	
Land use	Landsat TM (1984 and 1992) and CRIES
Land use change	Landsat TM (1992) versus MIRIS 1978
Lakes, rivers, streams and drains	Michigan Resource Information System (MIRIS) of the Michigan Department of Natural Resources
Watershed boundaries	MIRIS and U.S. Geological Survey
Climate	NOAA's National Climatic Data Center (NCDC)
Soils (STATSGO)	USDA Soil Conservation Service
Topography (digital elevation model)	USDA Soil Conservation Service and the Defense Mapping Agency
Geology	MSU Center for Remote Sensing
Aquifer vulnerability	MSU Center for Remote Sensing
BIOLOGICAL	
Surface conditions	NOAA AVHRR
Endangered species	Michigan Natural Features Inventory Heritage Program and the Nature Conservancy
Non-indigenous species	MSU Department of Entomology
Forest maps	Comprehensive Resource Inventory Evaluation System (CRIES)
Watershed bibliography	Saginaw Valley State University
SOCIO-ECONOMIC	
Urban land use	MSU Imagery Archive Laboratory
Population and economics (TIGER)	U.S. Bureau of the Census
Employment and income	MSU Institute for Public Policy and Social Research
Human health, economics	MSU Institute for Public Policy and Social Research
County boundaries and transportation	MIRIS
Crop production	Michigan Agricultural Statistics Service and National Agricultural Statistics Service
Management practices	MSU Cooperative Extensions Service and USDA Soil Conservation Service
Government policies	Documents from Various Sources
Policy analyst directory	MSU Institute for Water Resources

Figure 5. Sampling of data types and sources available through the demonstration prototype.

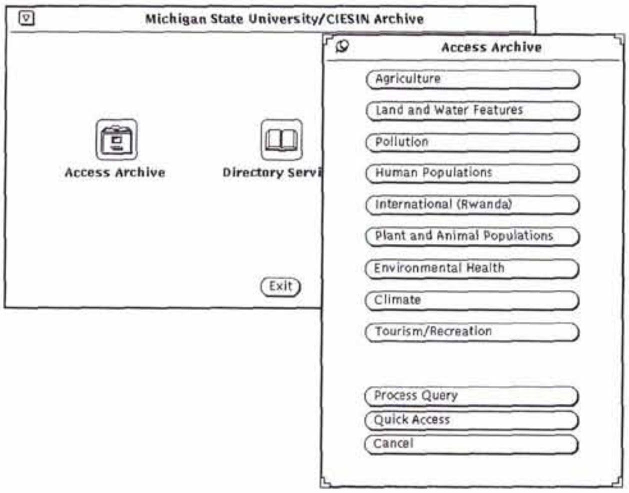

Figure 6. Opening screens for the watershed demonstration prototype.

User Scenarios

This section illustrates the use of the system through sample user scenarios. Figure 6 displays the opening screens of the demonstration prototype for the Saginaw Bay watershed project and a list of environmental issues available in the system for browsing.

The user may select a specific issue, which displays the corresponding *issue panel*. Suppose that the user is interested in *pollution* and specifically in locating information related to the problem of *groundwater contamination*. Figure 7 shows the issue panel for *Pollution*, where the problems *Surface Water Contamination* and *Groundwater Contamination* are displayed. In order to view all problems in the issue panel, the user may use the horizontal scroll bar at the bottom of the window. Below each problem is a vertical scrolling list of subtopics related to that problem. Some of the subtopics, such as *Research* in the *Surface Water Contamination* column of Figure 7, have further levels of refinement (indicated by the arrow next to the name). Selection of subtopics with refinements invokes the display of an additional menu. The values in parentheses indicate the number of objects in the archive that match a specific subtopic. This feature is included to give the user a high-level view of the density of information in the archive and also minimizes the number of queries that have no matches. Disjunctive queries are formed by displaying multiple issue panels, where more than one instance of a given issue panel is allowed. In Figure 7, the entire column of *Groundwater Contamination* problems has been selected (using the checked box), indicating that the query is to find all relevant items for this problem. The results of the query are listed in the **Items of Interest** window where, among other types of data, a mapset, a document, and a chart are available for examination. Notice that there are two ways to "examine" the chart object: *Read Description* and *View Chart*. Associated with each data object is a set of manipulations that provide access to that object, thus encapsulating each piece of information. Figure 8 displays examples of the different types of available items for the previous query examined using their respective manipulators, including a pie chart describing contamination sources and its textual description. It also shows a digital elevation map overlaid by a watershed boundary map (from the mapset item) displayed using a GIS manipulator, OpenGrass, a simplified graphical interface to GRASS (Geographical Resources Analysis Support System) (Westervelt, 1991).

Figure 9 shows a query constructed by selecting the *Changes/Trends* aspect in the *Nonindigenous Species* problem column on the *Plant and Animal Populations* issue panel. Figure 9 also contains some of the query results that are in the form of two color-coded maps that depict the gypsy moth population in Michigan in 1985 and 1990, respectively. A user might be interested in this information because the gypsy moth is a serious defoliator of oak and aspen trees in the Saginaw Bay watershed region. Using visual data integration, an analyst can clearly determine that there is a need for some type of action to address the gypsy moth problem. Also, an analyst may want to learn more about the physical characteristics of the gypsy moth. Images and photographs of the gypsy moth can be retrieved by selecting *Categories/Types* (Figure 10).

User Evaluations

The watershed configuration of the prototype system has been used as a means of communication with users for the evaluation of their needs. It has been evaluated by potential users (policy analysts, township officials, federal agency staff, and environmental science researchers from international organizations) at a CIESIN workshop (Pijanowski *et al.*, 1992) that occurred approximately two months after the implementation stage of the system.

Feedback from this group of users was used to refine the interface and to assign priorities to additional features for the system. During the past year, the system has been demonstrated to many more potential users in order to obtain additional ideas to make the system more useful to a larger community. The overall response from users has been very positive. Suggestions have been made regarding specific types of new features such as statistical analysis for tabular data, specific predictive models, and more sophisticated GIS capabilities. We also have received feedback relating to the classification scheme and to the identification and location of other relevant data sets.

Related Work

The International Institute for Advanced Systems Applications (IIASA) develops environmental decision support systems (Fedra, 1990). IIASA systems are developed to be application specific. That is, an extensive analysis is performed by

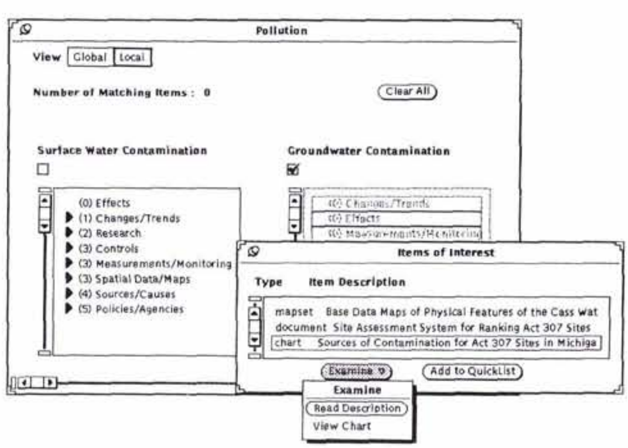

Figure 7. Query results for the pit groundwater contamination problem.

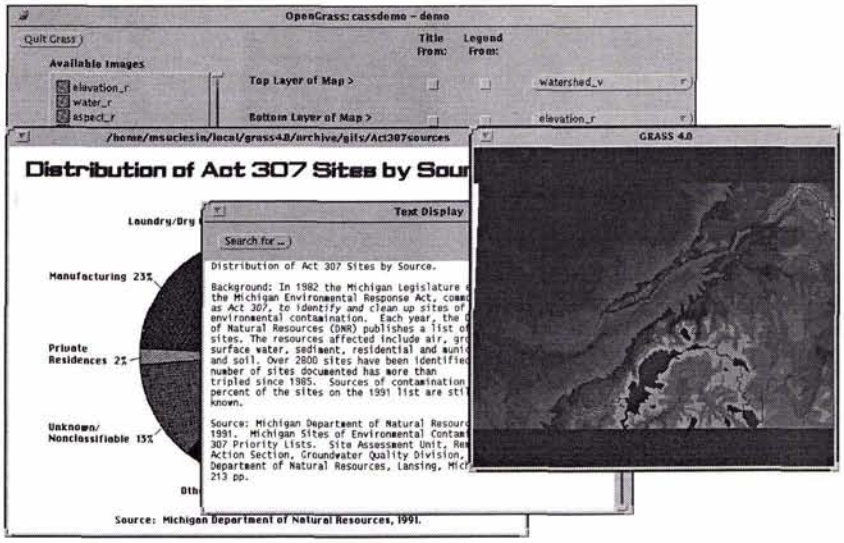

Figure 8. Sample types of available objects as viewed by different manipulators.

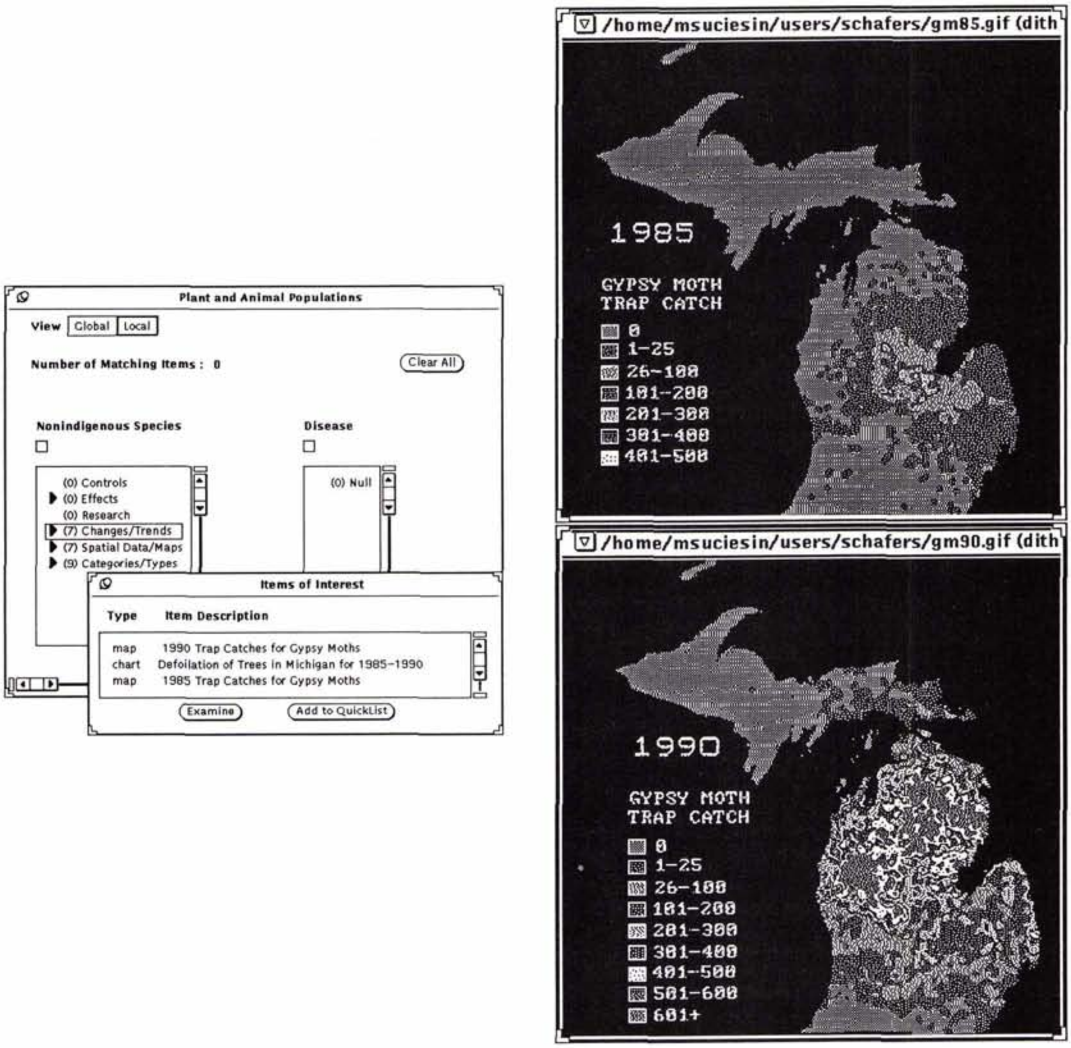

Figure 9. Query of pit changes/trends for gypsy moth and corresponding results.

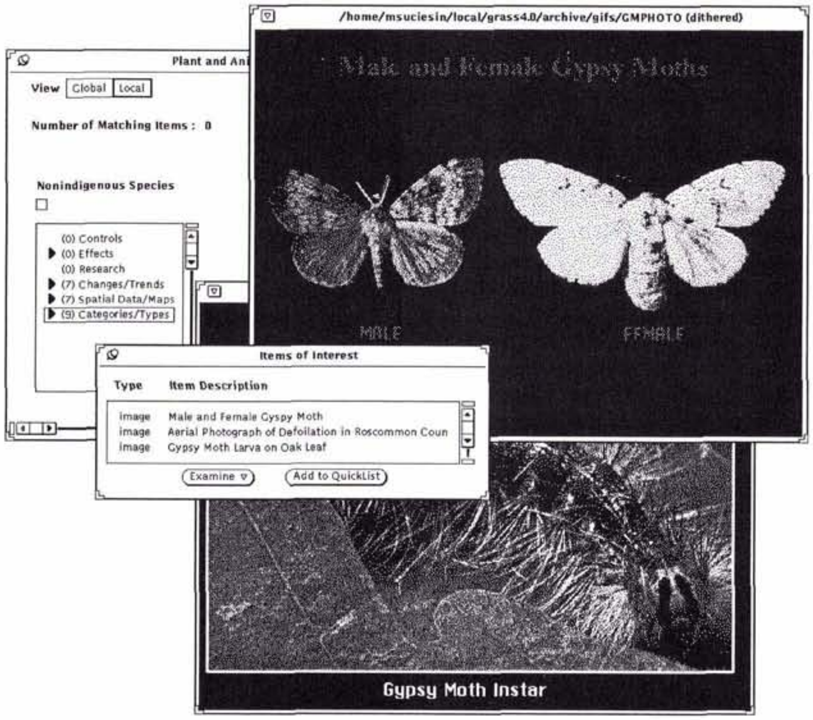

Figure 10. Query of pit categories/types of gypsy moth and image results.

the IIASA team with a given client to determine specific details about a given problem. After the initial expert analysis is completed, tools are identified and models are constructed to capture the types of analysis that the experts would like to perform. While sophisticated, these systems are only usable for the specific problems for which they were developed and are static by nature. In contrast, ENFORMS can be reconfigured completely and repopulated by the user/administrator without any changes to the software. ENFORMS provides a run-time configurable archive that serves as a repository for information.

ENFORMS is perhaps more similar to the widely available information servers such as Gopher and WAIS. The principle difference between ENFORMS and these systems is that ENFORMS presents information in an object-oriented fashion, and provides a classification-scheme-based access mechanism. Also, neither Gopher nor WAIS provide interfaces to GIS tools or models.

Conclusions and Future Investigations

ENFORMS is a configurable information system that can be tailored externally to address specific regional problems. ENFORMS provides access to data in two stages: the system is queried by the user for relevant data items, and located data items can then be manipulated by a variety of integrated tools. While separately accessible, the archive and analysis components can be used in tandem to facilitate the selection of data appropriate to the user's interests and subsequent analysis of that data. ENFORMS utilizes a sophisticated, but user-friendly, graphical user interface to make the complexity of the different analysis tools and their integration transparent to the user. Currently, ENFORMS is populated with a variety of different types of information, including documents, satellite imagery, aerial photographs, tabular data, color-coded charts, and georeferenced mapsets, all of which are used for a regional watershed analysis project.

Analysis, design, and implementation using object-oriented principles have proven to be beneficial in the development of ENFORMS (Cheng *et al.*, 1994), a generic and easily extensible system. The design of the ENFORMS framework specifically addresses scalability to national and global levels. The types of analysis, data integration, and general access supported by ENFORMS can be tailored to specific classes of users with different perspectives and objectives by reconfiguring the graphical user interface and archive organization. Potential users include scientists who are very familiar with the underlying tools and data sets, resource managers who are somewhat familiar with the data sets, but need assistance in finding the data and applicable analysis tools, and finally, users who are interested in becoming more aware of the regional environmental issues.

Currently, ENFORMS is being reconfigured to contain data needed to address water quality issues in the U.S./Mexico border region (Cheng and Schafer, 1994). Also, we are extending the system to operate on a distributed platform, where data may reside on several remote filesystems (Sharnowski *et al.*, 1995).

Acknowledgments

The authors would like to thank the many people who have contributed significantly to this project to make it a success. We particularly recognize the tremendous efforts exerted by G.C. Gannod, D.F. Robinson, S.R. Schafer, C. He, Y.T. Kang, T. Zahniser, L. Wolfson, L. Beer, K. Tenwolde, and the entire MSU/CIESIN Advisory Team. This work is supported in part by funding from the National Science Foundation, United

States Department of Agriculture, National Aeronautics and Space Administration, and the Consortium for International Earth Science Information Network.

References

Bourdeau, R., and B.H.C. Cheng, 1992. *Distributed Environmental Multimedia Archive: Software Requirements Specification Document*, Technical Report MSU/CIESIN WDP-CPS-1, Michigan State University, East Lansing, Michigan.

Cheng, B.H.C., R.H. Bourdeau, and G.C. Gannod, 1994. The object-oriented development of a distributed multimedia environmental information system, *Proceedings of IEEE 6th International Conference on Software Engineering and Knowledge Engineering*, pp. 70-77.

Cheng, B.H.C., and S.R. Schafer, 1994. *Design Document for 1993 Knowledge Transfer Prototype Regional Information System for US/Mexico Border*, Technical Report MSU-CPS-94-37, Department of Computer Science, Michigan State University, A714 Wells Hall, East Lansing, Michigan.

Committee on Earth and Environmental Sciences, 1992. *Our Changing Planet: The FY 1992 Research Plan*, Federal Coordinating Council on Science, Engineering, and Technology, Technical report, Office of Science and Technology Policy, Washington, D.C.

Committee on Global Change, 1990. *Research Strategies for the United States Global Change Research Program*, National Academy Press (the CGC is part of the Commission on Geosciences, Environment and Resources).

Fedra, K., 1990. *Interactive Environmental Software: Integration, Simulation and Visualization*, Technical Report RR-90-10, International Institute for Applied Systems Analysis, Advanced Computer Applications, Laxenburg, Austria.

Great Lakes Committee, 1992. Keeping it on the land: Improving Great Lakes water quality by controlling soil erosion and sedimentation, *The Advisor*, June/July.

He, C., W. Zhao, and T. Edens, 1992. *Report on the Saginaw Bay Area Environmental Policy, Planning and Management Survey*, Technical report, Michigan State University, East Lansing, Michigan (project report submitted to the Michigan State University Water Resources Research Program FY 1991).

Michigan State University/CIESIN, 1992. *User Needs Survey for Saginaw Bay Watershed Project*.

Pijanowski, B., C. He, and B.H.C. Cheng, 1992. Integration of human and natural science data for planning and management within a regional framework: The Saginaw Bay watershed project, *Proceedings of the Building a Global Environmental Change Information Cooperative: First CIESIN Users Workshop*.

Sharnowski, J., G.C. Gannod, and B.H.C. Cheng, 1995. A Distributed Multimedia Environmental Information System, *Proceedings of the 1995 IEEE International Conference on Multimedia Computing and Systems*, Washington, D.C., May 1995, pp. 142–149.

Westervelt, J., 1991. *Geographical Resources Analysis Support System (GRASS): Introduction and Programming Manual*, GRASS Information Center, U.S. Army CERL, Champaign, Illinois.

(Received 9 September 1993; accepted 7 March 1994; revised 10 October 1994)

Forthcoming Articles

Articles listed in the July Forthcoming Articles are those scheduled through December 1996 only.

Michael Abrams, Remo Bianchi, and *Dave Pieri*, Revised Mapping of Lava Flows on Mount Etna, Sicily.

M. Aniya, H. Sato, R. Naruse, P. Skvarca, and *G. Casassa*, The Use of Satellite and Airborne Imagery to Inventory Outlet Glaciers of the Southern Patagonia Icefield, South America.

M.J. Barnsley and *S.L. Barr*, Inferring Urban Land Use from Satellite Sensor Images Using Kernel-Based Spatial Re-Classification.

Timothy L. Bowers and *Lawrence C. Rowan*, Remote Mineralogic and Lithologic Mapping of the Ice River Alkaline Complex, British Columbia, Canada, Using AVIRIS Data.

Eduardo Brondizio, Emilio Moran, Paul Mausel, and *You Wu*, Land Cover in the Amazon Estuary: Linking of Thematic Mapper with Botanical and Historical Data.

Pat S. Chavez, Jr., Image-Based Atmospheric Corrections—Revised and Improved.

O. Dikshit and *D.P. Roy*, An Empirical Investigation of Image Resampling Effects upon the Spectral and Textural Supervised Classification of a High Spatial Resolution Multispectral Image.

Sam Drake, Visual Interpretation of Vegetation Classes from Airborne Videography: An Evaluation of Observer Proficiency with Minimal Training.

John W. Dunham and *Kevin P. Price*, Comparison of Nadir and Off-Nadir Multispectral Response Patterns for Six Tallgrass Prairie Treatments in Eastern Kansas.

Allan Falconer, Landscape Cover-Type Mapping Modeling Using a Multi-Scene Thematic Mapper Mosaic.

Leila M.G. Fonseca and *B.S. Manjunath*, Registration Techniques for Multisensor Remotely Sensed Imagery.

Bruno Garguet-Duport, Jacky Girel, Jean-Marc Chassery, and *Guy Pautou*, The Use of Multiresolution Analysis and Wavelets Transform for Merging SPOT Panchromatic and Multispectral Image Data.

Greg G. Gaston, Peggy M. Bradley, Ted S. Vinson, and *Tatayana P. Kolchugina*, Forest Ecosystem Modeling in the Russian Far East Using Vegetation and Land-Cover Regions Identified by Classification of GVI.

Philip T. Giles and *Steven E. Franklin*, Comparison of Derivative Topographic Surfaces of a DEM Generated from Stereoscopic SPOT Images with Field Measurements.

Joachim Höhle, Experience with the Production of Digital Orthophotos.

Pamela E. Jansma and *Harold R. Lang*, Applications of Spectral Stratigraphy to Upper Cretaceous and Tertiary Rocks in Southern Mexico: Tertiary Graben Control on Volcanism.

N.G. Kardoulas, A.C. Bird, and *A.I. Lawan*, Geometric Correction of SPOT and Landsat Imagery: A Comparison of Map and GPS Derived Control Points.

Eric F. Lambin, Change Detection at Multiple Temporal Scales: Seasonal and Annual Variations in Landscape Variables.

Kenneth C. McGwire, Cross-Validated Assessment of Geometric Accuracy.

Sunil Narumalani, John R. Jensen, Shan Burkhalter, John D. Althausen, and *Halkard E. Mackey, Jr.*, Aquatic Macrophyte Modeling Using GIS and Logistic Multiple Regression.

Elijah W. Ramsey III and *John R. Jensen*, Remote Sensing of Mangrove Wetlands: Relating Canopy Spectra to Site-Specific Data.

Tian-Yuan Shih, The Sign Permutation in the Rotation Matrix and the Formulation of Collinearity and Coplanarity Equations.

C.R. de Souza Filho, S.A. Drury, A.M. Denniss, R.W.T. Carlyon, and *D.A. Rothery*, Restoration of Corrupted Optical Fuyo-1 (JERS-1) Data Using Frequency Domain Techniques.

A.P. van Deventer, A.D. Ward, P.H. Gowda, and *J.G. Lyon*, Using Thematic Mapper Data to Identify Contrasting Soil Plains and Tillage Practices.

Jim Vrabel, Multispectral Imagery Band Sharpening Study.

Jianjun Wang, Gary J. Robinson, and *Kevin White*, A Fast Solution to Local Viewshed Computation Using Grid-Based Digital Elevation Models.

Eric A. Williams and *Dennis E. Jelinski*, On Using the NOAA AVHRR "Experimental Calibrated Biweekly Global Vegetation Index."

Zhangshi Yin and *T.H. Lee Williams*, Obtaining Spatial and Temporal Vegetation Data from Landsat MSS and AVHRR/NOAA Satellite Images for a Hydrologic Model.

Davie A. Yocky, Multiresolution Wavelet Decomposition Image Merger of Landsat Thematic Mapper and SPOT Panchromatic Data.