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Design of Object-Oriented Water Quality Software System

A Case Study of Upper Godavari River Paithan, Aurangabad (MS) India.

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Abstract- Software models are important for the evaluation and management of environmental resources. This paper presents a framework for developing a software system for water quality analysis of river ecosystems. A major component of the system is a database that permits inclusion of analytical water quality and sediment data, river geometry and sampling site characteristics, hydrologic measurements, and reference information on water quality parameters and criteria. Associated with the database is software for managing, analyzing, and representing the information in the database. An object-oriented strategy is applied to derive a model of the software system. The resulting object-oriented design is then translated into an entity-relationship model, which is in turn translated into a relational model. The formality of this translation process ensures consistency among the successive design stages. The overall development approach to system design and implementation is de-scribed, and an application for evaluating water quality conditions in the upper Godavari River is presented.

I. Introduction

Environmental engineers and scientists often are called upon to provide reliable water quality information to guide the man-agement and protection of water resources (Becker and Neitzel 1992; Fuhrer et al. 1996). Typical uses of these data are to assess compliance with permits and water supply standards, evaluate trends in water quality, develop remediation plans for contamination problems, assess and design water quality mon-itoring systems, and optimize operations at industrial, waste-water, and water supply facilities. The data collected to support these diverse water quality management objectives can be combined into a single large database, accessible to each analyst and decision maker in a river basin (*Transportation Research Board* 1997). With all the available data made ac-cessible, decision making can be improved, uncertainty in pre-dictions (usually) reduced, redundant monitoring programs identified, and data usage maximized.

In this paper, a prototype database and analysis system is developed for water resources data from the upper Godavari River. The system was developed for the Godavari River. The project goals are to evaluate and analyze data collected between the years 1960 and 2012. These data represent a suite of parameters describing water quality and hydrology in the upper Godavari River environment. The sources of the data are the Center for Bioenvironmental Research of Aurangabad municipal corporation (AMC). Geological Survey (AMCGS), the Aurangabad Department of Environmental Quality (ADEQ), the Aurangabad Department of Pollution and the Environment, and several other agencies. The multitude of authorities, sources, quality criteria, and analysis methods significantly complicates data integration.

One way to begin structuring a database is to define the types of queries that are expected from the data, and optimize database design based on these queries. For example, suppose that the data will be used to assess the effect on water quality of upper Godavari River. In this case, a database that links land use data with time series data on nutrient sales, nutrient con-centrations in the river, and upper Godavari River flow rates would be constructed. On the other hand, a database intended to help evaluate the efficacy of cap-ping contaminated aquatic sediment would include contaminant concentrations in the sediment, sediment transport char-acteristics, parameters of natural contaminant degradation, bathymetric surveys, etc.

The output format would be struc-tured to appeal directly to the type of problem under consid-eration and to subsequent use of the data. For example, the output from the database might be used directly for decision making, or might be linked to hydrologic or water quality modeling systems. An interface with a geographic information system (GIS) or with a statistical package might be designed into the system.

In some cases, databases are created without knowing *a priori* how they will be used. Thus, it is necessary to make the database as flexible, inclusive, and adaptable as possible. The prevalence of very large data sets is increasing. As more and more data are made available in electronic form and on the Internet, there is a greater drive to consolidate and apply as much as is relevant to a water quality management problem. No longer are boundaries between data gathered by different organizations considered restrictive — water quality managers are expected to include all available data in their analyses. Much of these data is now available on the Internet but has not been translated into usable form and conceptual uniformity.

Furthermore, there is now an emphasis on finding time trends in water quality data, such as determining whether regulatory efforts and improvements in pollution technology have resulted in improved water quality, or made a difference in the rate of change in environmental quality. To answer these questions, it is necessary to merge data taken at different time periods, which often means the data set will include measurements taken with varied levels of precision and different parameters describing the same phenomenon (for example, polychlorinated biphenyls (PCBs) were once reported under the product name ''Aroclors,'' which were combinations of many congeners; now the analytical chemistry instrumentation has improved, so that PCBs may be reported on a congener-specific basis.)

This is the situation we explore in this paper: how to de-velop a water quality database system encompassing data from many sources, taken over several decades, without a specified decision objective, and permissive of including additional data in the future. Since this problem came to the writers' attention while designing the software system for the upper Godavari River.

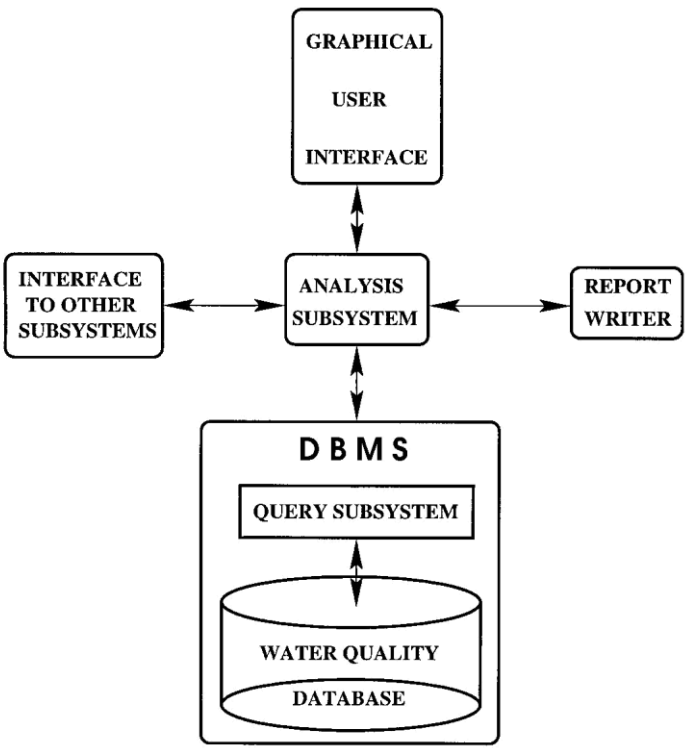

FIG. 1. Structure of Water Quality Software System

Water Quality Project, we will refer to this system throughout the paper. An important aspect of the design of the upper Godavari River software system is its use by people with little experience in database design, GIS, modeling, or applied statistics. Thus, the system is accessible to a broad range of people ex-ploring water quality management problems from many per-spectives.

II. WATER QUALITY MODEL DEVELOPMENT

A water quality information system should be capable of integrating large amounts of heterogeneous data collected by various sources and of providing a consistent conceptual model of the water body. Typically, existing water quality databases have been organized as flat structures; that is, the data are collected into one big monolithic table. Real-world con-cepts and their interrelationships as such are lost in the implementation, thus making the model far removed from the problem domain. Consequently, users confront a database that is neither user-friendly nor suitable for the type of analyses they need. We have explicitly addressed these issues by designing a conceptual model that supports various interests and lends itself to analysis of trends, identifying factors that affect trends and highlighting the relationships among these factors. Generically, the analysis process addresses questions of the form who, what, when, where, how much, and how many. Specifically, questions to explore the availability of data and their geographic distribution, the concentration levels and distribution of parameters, the hydrology of the river, and the relationships among the various variables are supported directly. Analysis questions address the following categories:

- **Inventory:** Data availability, temporal and spatial cover-age, sampling types and their frequency, and collecting agencies and their respective stations. The questions also explore the relationships among the different attributes of parameters, stations, and agencies.
- **Geography:** Geographic point data such as sampling lo-cations, flow information, and continuous data such as land use, soils, and geology.
- **Water quality parameters:** Parameter and time series con-centrations from which statistical analysis can be made.
- **Hydrology**: Flow characteristics of the river from which statistics about river stage and discharge are determined.
- **Comparison:** Relations among the various measured en-tities. Concentration, discharge, stage, time, and bathymetry data are analyzed in relationship to each other to de-termine potential factors that affect the state of the river.

We adopt an object-oriented (OO) view of a. Thus, modeling a river consists of identifying the major components that form the structure of the river, establishing the interrelations that exist among these components, and specifying the behavior of the entire structure and of each component. Such an approach emphasizes problem-related issues. In general, the OO design approach allows the designer to generate models that are closer to the real-world objects being modeled. The development of the model described here uncovered some major issues. One of them, related to the monitoring and management of water resources, is the scarcity of tools providing capabilities to integrate heterogeneous data, manipulate data, support analyses, and report results. To ad-dress this issue, we set out to design an automated water quality database system for the lower Mississippi River with the following characteristics: (1) The system is generic, i.e., it does not depend on the particular data it manipulates; (2) the system is user-friendly; and (3) the system is extensible, i.e., future extensions can be made without altering the existing components. The implementation provides a sophisticated system for manipulating the water quality database and for analyzing wa-ter quality data. Manipulating the database includes such func-tions as entering new data, retrieving specific data, updating the database to reflect changes in the riverine environment, and generating reports from the data. Analyzing the water quality data involves querying in combination with mathematical and statistical procedures.

III. System Structure

The structure of the software system is shown in Fig. 1. The major component is the analysis subsystem that supports different water quality analysis procedures. The main part of the procedures is implemented as a set of nested and grouped queries. Query results from the water quality database are re-trieved and transposed according to conditions specified by the analysis procedures and the user. The analysis subsystem also provides the interface for inserting new data in the database and updating information.

The graphical user interface supports an intuitive and effective-to-use interaction of users with the analysis subsystem and other system components. It allows the users to manipulate windows, menus, controls, and other graphic objects in specifying requests and responds interactively to the user's input actions.

The report writer is used to output the results of database querying and data analysis. The reports can be formatted by including headers and footers, forms, and graphics, computing totals or data summaries, and performing computations on the data.

An interface to other subsystems is provided to facilitate the interaction with specialized software for data analysis, such as a GIS used to create maps of river study areas, statistical packages, and mathematical analysis packages. This interface consists of two main modules: an export module and an import module. The export module outputs stored data and results of retrievals into a format that can be processed by the specialized software. The import modules consist of several modules that convert collected data in various formats into a uniform format and create files to be inserted into the database. Compared to the other database design tasks, the conversion task is one of the most tedious due to the heterogeneity of formats and conventions imposed by the various sources.

The water quality database shown in Fig. 1 consists of two types of files: data files and reference files. The distinction between these two types of files is based on the dynamic nature of the data. Information in the data files tends to be dynamic and ever changing, whereas information in the reference files is static. Basically, data files capture the dynamic behavior of the object being modeled, and reference files capture its static structure. The data files contain the following data:

- Concentration of water quality parameters and methods of detection. In the case of the upper Godavari River Water Quality Project, the data consist of 780 parameters that include metals, volatile organics, semi-volatile organics, pesticides, nutrients, herbicides, and radio chemicals. Some of these parameters were measured both in the water column and sediments.
- Collected information on physical characteristics of the river, including geographic, bathymetric, and hydrologic data.
- Descriptive data on sampling stations and water quality agencies.
- Other information related to the environment of the river under study.

Reference files contain general information related to each water quality parameter:

- Reference information on water quality parameters extracted from the EPA Storage and Retrieval (STORET) database and applicable to all data sources used in this study. This includes items such as Chemical Abstract Ser-vice (CAS) number, unit of measurement, and carcinogenicity.
- Concentration limits for contaminants as specified by fed-eral and state water quality guidelines. Federal guidelines for water quality criteria that were developed by EPA are used (EPA 1986). They include acceptable limits for aquatic life and human health protection, such as fresh water acute criteria, fresh water chronic criteria, and drinking water maximum contaminant level.

The catalogue stores meta-data that represent environmental database definitions available for users as on-line system documentation. Meta-data include descriptions of the database system schemas, users and their access rights, information on storage structure and access paths, database fields and record sizes, and usage statistics.

IV. Development Lifecycle

The activities related to the construction of the water quality software model constitute the development life cycle. They include the following phases (Elmasri and Navathe 1989; Pressman 1995):

1. Object-oriented (OO) modeling: Producing a requirements specification and developing an OO model of the system. This activity is described in the section on water quality database development.
2. Conceptual design: Transforming the OO model into a conceptual schema. This includes the identification of data required for processing and their natural relationships and constraints with respect to performance, integrity, and security. This activity is described in the section on conceptual design.
3. Database design: Transforming a conceptual data model into the relational data model, as described in the section on water quality database design and implementation.
4. Implementation: Writing internal database definitions, creating empty database files, and developing application software.
5. Database population: Integrating fields from various files and then converting these files into database formats. An initial data validation process is carried out

to ensure consistency. The process involves the detection of miss-ing values, typographical errors, improbable values, and duplicate values.

6. Testing: The new system is tested against performance criteria and user requirements.
7. Monitoring and modification: During database system operation, monitoring indicates modifications to improve performance and satisfy changing user requirements.

V. WATER QUALITY DATABASE DEVELOPMENT

The first activity involves an object-oriented analysis and design. As part of the object-oriented analysis, the user's're-quirements are analyzed in order to extract objects. A prelim-inary analysis of the requirements results in the following ob-servations:

1. Many sampling stations are located along the river. Each station's identifier code, name, river mile location, and coordinates, including latitude and longitude, must be stored. A station may be used to collect data on water quality or river stage and may be located at only one segment. Water quality organizations may calculate dis-charge rates from river stage data.
2. At each station, data are collected by an organization that has a name, identifier code, jurisdiction, mailing address, and phone number. An organization may collect data at several stations, and more than one organization may collect data at the same station.
3. Each station participates in a project described by an identifier code and a definition. Several stations may par-ticipate in the same project.
4. For each stage measurement, taken at a given station, the information to be maintained includes the stage value, date (month, day, and year), and time of measurement. Stage data in the database consists of MCA data col-lected twice daily. (Hourly stage data are also available from the MCA. These data might be particularly use-full when performing modeling studies of transient conditions such as dynamic plume modeling. However, be-cause of their infrequent use, they are not included yet in the database.)
5. For each discharge rate measurement taken at a given station, the information to be maintained includes the daily average discharge rates and the sampling date (month, day, and year). Most discharge values in the da-tabase are from the MCA and are available from the MCA only as daily average values. Other water quality organizations, including the MCAGS, have collected instantaneous discharge values on an ad hoc basis, and these have also been included in the database.
6. Each water quality measurement taken at a given station is analyzed. The information to be maintained about analyzed samples includes the compound STORET number, the station identifier, sampling date, sampling time, project identifier, medium, sampling depth, sampling method, analytical method, and compound concentration.
7. A compound is described by a STORET number, name, CAS number, chemical symbol, octanol water coeffi-cient, carcinogenicity, and detection limit. In addition, the fraction (whole, dissolved, suspended), status as a priority pollutant, and toxicity are recorded for each compound. At this stage, the data set does not include fish tissues and other biological media.
8. Ambient water quality criteria may be available for some compounds. These criteria assign compound concentra-tion limits and include the following values: EPA fresh water acute criterion, EPA fresh water chronic criterion, EPA drinking water maximum contaminant level, state water acute criterion, state water chronic criterion, state drinking water criterion, and state drinking water supply criterion.
9. The river is divided into segments, and summary statistics describing the water quality can be computed for each segment. Each has an identifier code, a name, and lower and upper bounds specified by river mile location. Segment boundaries may be defined in any way desired; one potential method is to divide the river into segments based on the designated use categories, such as primary contact recreation, secondary contact recreation, propagation of fish and wildlife, drinking water supply, oyster propagation, agriculture, outstanding natural resource waters, limited acquatic life, and wildlife use. The delineation of segments adopted here is the one defined by LADEQ.

Once the user's requirements are defined and the water qual-ity data are identified (EPA 1986; Becker and Neitzel 1992; Fuhrer et al. 1996; Meade 1995), an object-oriented model is developed (Booch 1994). The object-oriented strategy of mod-eling is based on identifying real-world objects and describing their structure, interrelationships, and behavior. Fig. 2 shows a partial object-oriented view of the model.

VI. CONCEPTUAL DESIGN

The second phase in the database design and implementation process is the conceptual design (Fig. 3). It involves the development of a conceptual model or schema that shows all the data and their relations. An effective method for conceptual data modeling is entity-relationship (ER) modeling (Codd 1970; Teorey 1990), allowing the capture of real-world data requirements in a simple and meaningful way. Also, the trans-lation from the object-oriented model to the ER model is one-to-one, thus ensuring the consistency of the design process. Fig. 4 provides a conceptual view of the water quality design based on ER modeling. Before we describe this design in detail, a short explanation of the ER concepts and terms is given.

Entities are any objects worth representing in the database. In this model (Fig. 4), rectangular boxes represent entities. Entities whose existence depends on the presence of some other entity (known as the owner) are depicted with a double-bordered rectangle. Thus, STAGE depends on the entity STA-TION and ANALYZED SAMPLE has two owner entities: STATION and COMPOUND. Various relations that may exist among entities are represented by diamond boxes linked to the entities that participate in a relation. Relations have a domain, a range, and an ''arity,'' that is, they may be binary, ternary, or *n*-ary, depending on whether they involve two, three, or *n* entities. A blank diamond denotes a one-to-one relation, and a half-shaded diamond denotes a one-to-many relationship. Thus, the connectivity that COMPOUND and CONCENTRA-TION LIMITS in the relationship ''are assigned'' is one-to-one, whereas the connectivity of STATION and ANALYZED SAMPLE in the relationship ''samples'' is one-to-many. The participation of an entity in a relation is defined as either total or partial. The partial participation is specified by a 0 on the line between an entity and a relationship. Thus, the partici-pation of STATION in the relationship ''measures'' is partial (not every station measures the river stage), whereas the par-ticipation of STATION in COLLECTS DATA ON is total (at every station, data are collected by an organization).

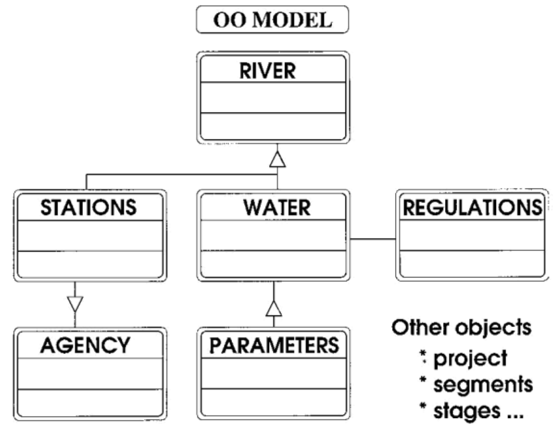

FIG. 2. Water Quality Object-Oriented Model

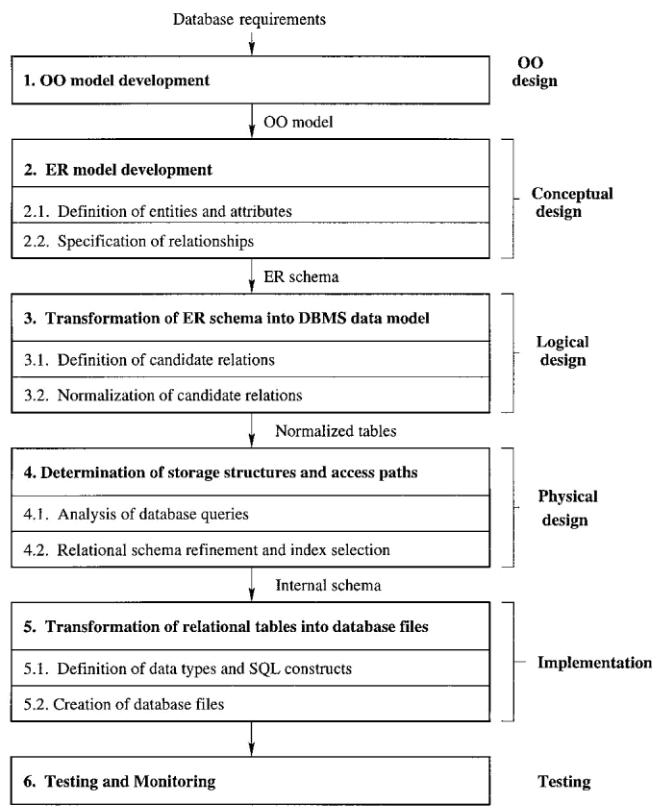

FIG. 3. Lifecycle Activities

Properties (attributes) are associated with entities. These are shown as columns in Fig. 5. Some properties are simple (atomic, indivisible); others are composite (made up of more than one property). Thus, some of the properties of the entity AGENCY are the agency identification (AGENCY ID), the agency name (Name), the agency jurisdiction (Jurisdiction), the agency address (Address), the agency city (City), and the agency phone (Phone). Except for the agency address, which is composite, all the other fields are simple.

The analysis of these requirements resulted in the ER schema displayed in diagrammatic form in Fig. 4. A further refinement of this figure results in the design shown in Fig. 5. Each entity is now refined to show its components. For ex-ample, the entity SEGMENT has the following components: SEGMENT ID, Segment Name, Upstream Mile, and Down- stream Mile. Accessing and retrieving data require that entries in the database be identified uniquely by attributes or a com-bination of attributes, called keys. A key belonging to an entry in a given table that is used to identify the entries in the same table is called a primary key. A key belonging to a table entry that is used to identify entries in other tables is called a foreign key. Primary key attributes are shown in bold face, and foreign key attributes are shown in italics in Fig. 5.

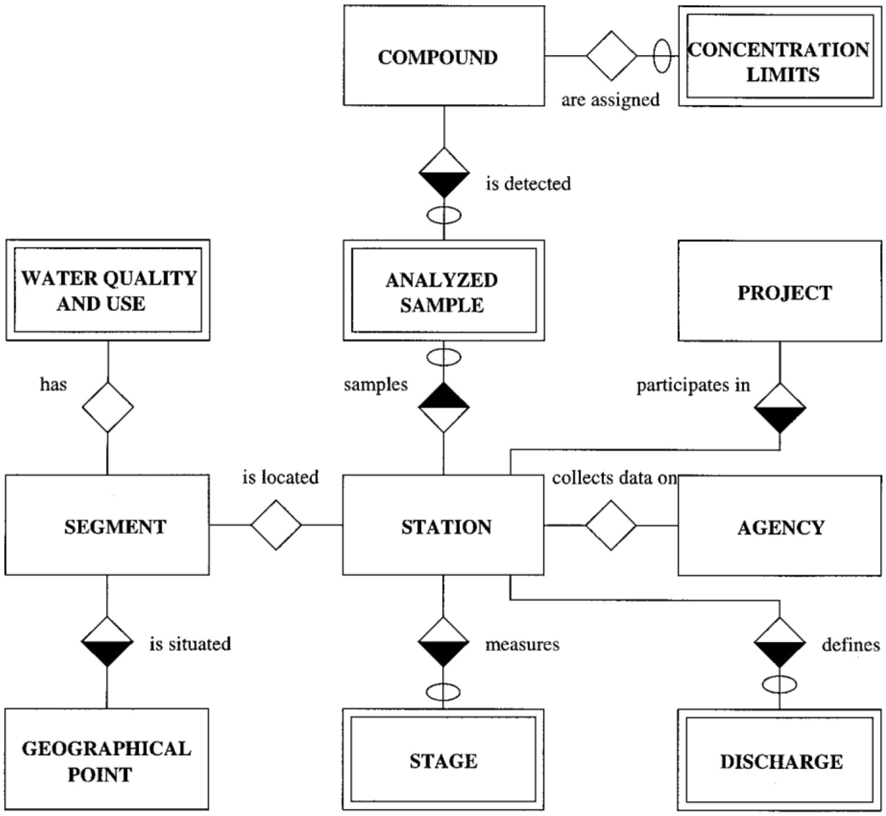

FIG. 4. Top Level ER Schema Diagram for Water Quality Database

Segment

SEGMENT ID	Segment Name	Upstream Mile	Downstream Mile

Geographic Point

POINT NAME	Point River Mile	Point Latitude	Point Longitude	City Name	Population	*SEGMENT ID*

Station

STATION ID	Name	Type	Latitude	Longitude	River Mile	*AGENCY ID*	*SEGMENT ID*	*PROJECT ID*

Agency

AGENCY ID	Name	Jurisdiction	Address	City	Phone

Stage

DATE	STATION ID	Maximum	Minimum	Average

Discharge

DATE	STATION ID	Maximum	Minimum	Average

Analyzed Sample

STORET #	STATION ID	DATE	TIME	proj_id	st_type	media	method	date2	concentration	analysis_method

Compound

STORET #	Name	Symbol	Fraction	Class	subclass	CAS	Toxicity	Carcinogenicity	Priority

Concentration Limits

STORET #	Federal Acute	Federal Chronic	Drinking Water MCL	State Acute	State Chronic	Drinking Water Supply	Nondrinking Water Supply

FIG. 5. Major Relations Design

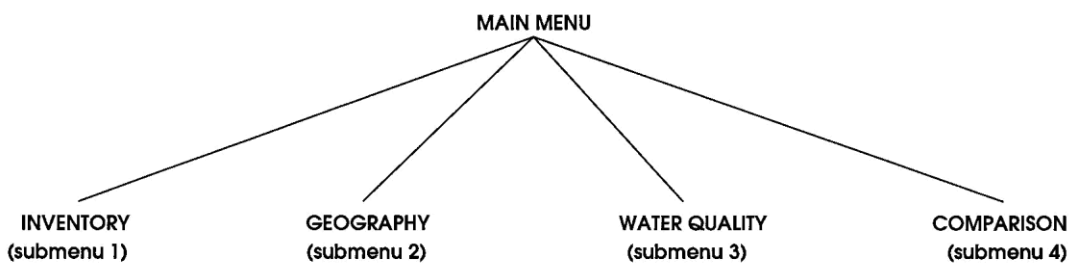

FIG. 6. Schematic of Menu Interface

Water Quality Database Design and Implementation

The next phase of database design and implementation is the choice of a database management system (DBMS) (Fig. 3). For the upper Godavari River Water Quality database implementation, DBMS Oracle is chosen. This DBMS implements the relational data model most appropriate for water quality data with many interrelations. A relational DBMS ensures high data integrity, recovery, and concurrency control and supports the high-level query language SQL. Such a language has the necessary computational power to enable users to perform sophisticated data retrievals used in water quality analysis.

The ER model is transformed into a relational data model by the following general mapping procedure (Elmasri and Na-vathe 1989):

1. For each entity in the ER schema, a relation including all the simple attributes of the entity is created. The key attribute of the entity becomes the primary key of the

relation, such as SEGMENT ID. A primary key is simply a unique identifier for the given relation.

2. For each weak entity, a relation is created and all simple attributes are included as attributes of the relation. The key attribute of the relation corresponding to the owner entity is included as a foreign key. (A foreign key is created when a primary key is used as a key in another relation). The primary key of the created relation is the combination of the primary key of the owner and the partial key of the weak entity.
3. For each binary one-to-one relationship, the primary key of the relation with partial participation is included as the foreign key in the relation with total participation in the relationship.
4. For each binary one-to-many relationship, the relation primary key belonging to the relation domain is included as a foreign key in the relation range.

The next step in the database design process involves the normalization of the relations. Normalization ensures that the relations have certain properties, such as integrity and maintainability (Teorey 1990). During physical design, behavior analysis of database queries is carried out in order to assess the execution efficiency of these queries. Dominant queries with high frequency of execution and high volume of data access and modification were identified to become candidates for further optimization. The basic modification is to add at-tributes to existing relational tables to speed up join operation. For example, the query ‘‘Show measured concentrations of a given parameter in a given year as a function of station lo-cation’’ is executed by a join of tables ANALYZED SAMPLE (500,000 records) and STATION (700 records) and was ex-amined for adding attributes StatName and StatRivMile to ANALYZED SAMPLE. The application of the usage refine-ment algorithm (Teorey 1990) resulted in optimized queries.

The formal database schema design is implemented by us-ing Stuctured Query Language (SQL), a language for manip-ulating databases, to create table statements. For each table, the SQL statement defines the name of table, the name and data types of its fields, and the integrity constraints.

Application Software Development

The Water Quality Database System is implemented on an IBM RISC System/6000 running UNIX. The system applica-tion software consists of a package of C programs using SQL statements to access the database supported by ORACLE. The Pro*C precompiler is used for embedding SQL statements. The developed application allows the user to enter and update environmental data, to do sophisticated retrievals from the da-tabase, and to generate reports on analytical data. The software presently supports numerous queries and update transactions. Queries processing is extremely fast. Typically, it takes ap-proximately 2 s for a query retrieving data from two relations. At least 2 GB of hard disk space are required for programs and files, although this requirement increases as the database is populated.

The RISC System version of the database supports a menu-based interface (Fig. 6). The main menu is organized accord-ing to groups of analytical queries about parameters, parameter concentration, stations, agencies, segments, time, hydrography, and geography. By selecting and entering options from this and secondary menus, the user can create the required query. If necessary, the user is asked to enter the input query param-eter (compound STORET number or station identification code). The results of querying are presented in tabular form. For large output data lists, page breaking is supported.

VII. EXAMPLES OF ANALYSIS USING SYSTEM

Suitability of Database for Time Series Analysis

For some water quality mangement issues, it may be desir-able to develop a time series of water quality data. Examples include assessing trends in water quality, correlating pollutant concentrations with loading, and comparing concentrations of a pollutant at several locations throughout the water body. The database is particularly well suited for developing these types of subsets of the database. For example, a query asking for all mean weekly values of phosphate in Segment 3 would be con-structed as in the following sequence: (1) Select the parameter name; (2) select the function (e.g., mean); (3) select the weekly interval; (4) select the overall range; and (5) select the seg-ment.

An example of a time series data analysis that is done with this data set is the modeling of the seasonality of the nitrate concentration in the area of the upper Godavari River around

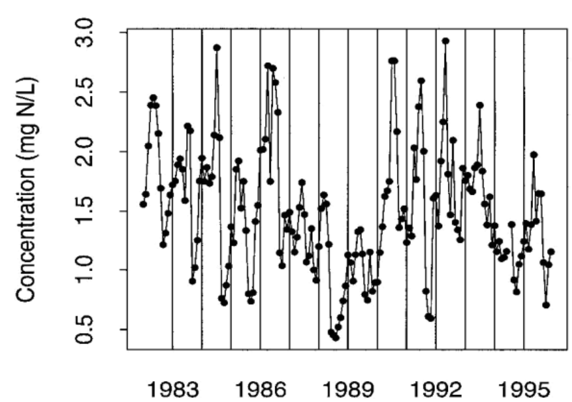

FIG. 7. Nitrate Concentrations of Godavari **(mg N/L)**

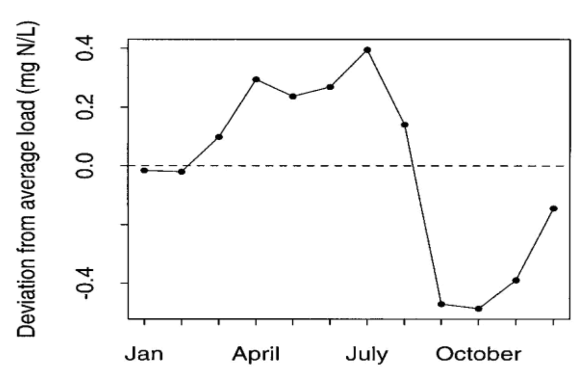

FIG. 8. Monthly Seasonality of Nitrate Concentration of Godavari River

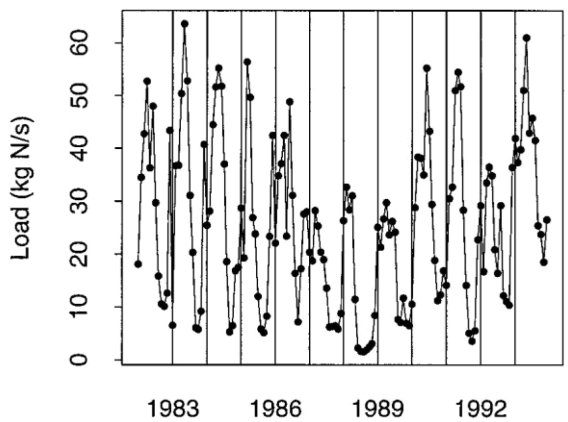

FIG. 9. Time Series of Nitrate Load of Godavari River

A search of the database indicated that the most dense data set of nitrate concentrations in this region was taken at river kilometer 16, the Aurangabad Water Works (AWW) intake location at Kopargaon. This is just 1.1 km upstream of New Orleans. The query produced a time series of nitrate concentration values along with the associated date of measurement. Also available for each measurement, if desired, were any combination of the following: sampling time, sampling depth, compound STORET number, the station identifier, sampling date, sampling time, project identifier, medium, sampling depth, sampling method, analytical method, and compound concentration.

We loaded these data into Splus, a statistical package, grouped the measurements by month, averaged to find monthly values, and produced the time series of monthly data shown in Fig. 7. We then computed monthly seasonality using a moving average filter (Brockwell 1996). The results are shown in Fig. 8. Subsequently, a fuller time series analysis using Auto-Regressive Integrated Moving Average (ARIMA) modeling on these data could be performed.

Interdependence of Water Quality Parameters

One of the issues relating to water quality in the upper Godavari River is its effect on the ''Dead Zone'' during the summer months and is believed to be created as a result of high nutrient loadings from the upper Godavari River. To assess this hypothesis, we queried the database for seasonal nitrate loading of the Godavari River. Since the AWW is less than 16 km from the mouth of the river, we used these data in the loading analysis. We then queried the database to find the clos-est hydrological monitoring station. This yielded the MCACOE site at Tarberts Landing, approximately 322 km upstream of the AWW monitoring site.

We loaded the flow data into Splus, matched it by date with nitrate concentration at JWW, and multiplied the flow by the nitrate concentration. This yielded an approximate load of ni-trate passing JWW on a given day. Then we grouped the com-puted loads by month, averaged to find monthly values, and produced the time series of monthly data shown in Fig. 9. We then computed monthly seasonality using a moving average filter (Brockwell 1996). The results are shown in Fig. 10. Once again, this analysis could be extended into a full time series analysis of the nitrate load.

We also used the database to find the correlation between nitrate plus nitrite and total phosphorus by segment. We que-ried the database for all nitrate plus nitrite and total phosphorus concentrations in each segment. Downloading the data to Splus, we matched the concentrations by date and computed the correlations (Table 1).

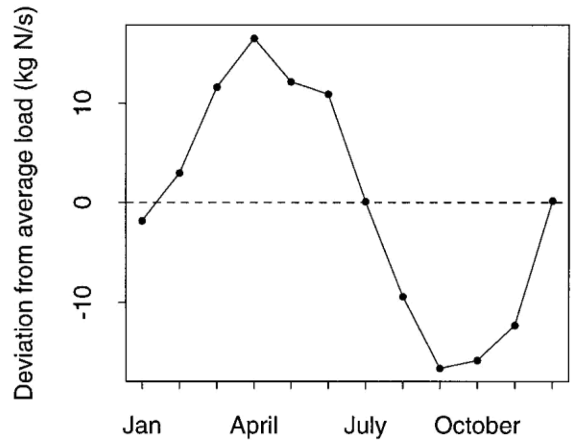

FIG. 10. Monthly Seasonality of Nitrate Load of Mississippi RIver at JWW, New Orleans

TABLE 1. Correlation of Nitrate Plus Nitrite with Total Phos-phorus by Godavari River **Segment**

Segment (1)	Correlation (2)	*n* (3)
1 and 2	20.1	369
4	0.35	394
5	0.28	364
6	0.29	142
7	0.22	152

Table 2, Average physico-chemical properties of upper Godavari River (Jan1989-Dec2010).

Sr.No.	Parameters	Summer	Rainy	Winter
1	Turbidity	1.6	4.61	1.79
2	pH	7.46	7.55	7.6
3	Chlorides	56.36	48.18	51.13
4	Free saline ammonia	0.06	0.08	0.12
5	Albuminoid Ammonia	0.12	0.16	0.24
6	Dissolved oxygen	0.93	1.67	1.31
7	Nitrate	2.81	3.05	2.46
8	Total hardness	137.11	131.86	141.47
9	Total dissolved solids	281.09	300.25	293.96
10	Iron (Fe)	0.21	0.28	0.13
11	Fluoride (F)	0.18	0.21	0.19
12	Total alkalinity as CaCO3	129.19	127.29	128.4

VIII. CONCLUSIONS

The Water Quality Software System is a computer-based system that helps manage and assess the water quality of river ecosystems. It facilitates the integration of several data sources, as well as the sharing of data among interested parties. It supports input of environmental data, water quality analysis through the use of sophisticated querying, construction and output of reports on water quality parameters, and interfaces with specialized statistical and geographical information systems. The water quality database includes general reference data on water contaminants and water quality criteria and collected data on the environment of the river under study. Future research in this area includes the integration of a decision-support system and inclusion of preventive and remedial actions based on the state of the ecosystem.

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