HYDRO-METEOROLOGICAL INFORMATION SYSTEM: IMPLEMENTATION OF MULTI-USER GEODATABASE CONCEPT IN NEPAL

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ABSTRACT

Hydrological and metrological data have a wide variety of applications such as water resources, agriculture, energy, and other development activities. Furthermore, these data are the basis of hydrological and meteorological forecasts, which are very necessary for public, mountaineering expedition, civil aviation, and for the mitigation of natural disasters. However, the forecasts require that the data are reliable as well as in ready-to-use form. In such context, a tool that helps to process data efficiently so as to derive the desired information plays the crucial role. As the data of hundreds of years need to be considered in the analysis, the tool is even more desirable in the field of hydrology and meteorology. For this purpose, a system called Hydro-meteorological Information System has been recently developed for Department of Hydrology and Meteorology of His Majesty's Government, Ministry of Science and Technology.

The paper lists the major features of hydro-meteorological information system. The architecture of the system will be presented. The most important hydrological and meteorological objects and their implementation with ESRI's geodatabase concept will be discussed. The paper will also discuss how both the spatial and time series data have been stored and managed in Oracle RDBMS. The connectivity of front-end application with Oracle database through ESRI's Spatial Database Engine will be discussed. Finally, the paper will present the practical benefits of geodatabase over the conventional flat file GIS model.

1. INTRODUCTION

One of the principle activities of the Department of Hydrology and Meteorology (DHM) is to collect and disseminate hydrological and meteorological information for water resources, agriculture, energy, and other development activities as well as to issue hydrological and meteorological forecasts for public, mountaineering expedition, civil aviation, and for the mitigation of natural disasters (URL1). Since, these activities require a massive data handling, computer based information systems naturally seem to a desirable tool. Accordingly, the department has felt a need for a computer-based information system to cope with new challenges and requirements of the country, and envisaged building and implementing Hydro-Meteorological Information System at the corporate level (WDN, 2001).

Hydro-meteorological Information System (HIS) is an application developed for the Department of Hydrology and Meteorology (DHM) for the data management, time series analysis, spatial analysis and production of hydrological and meteorological atlases. As a number of people at DHM need to work on the same data, obviously the application requires to serve a number of concurrent users in a true multi-user environment. For this purpose, the ESRI's geodatabase concept has been used in developing HIS. The Oracle has been used as the Relational Database Management System (RDBMS), which in HIS can store both the time series and spatial data. ESRI's Spatial Database Engine (SDE) plays the role of middleware between the data repository and the front-end application that has been developed with the use of Visual Basic (VB) as a programming tool. The ESRI's desktop products (Arcview 8.1 and ArcInfo 8.1) have been heavily customized with ArcObjects programming to develop the interface for the spatial data. Besides, other ArcGIS extensions such as 3D Analyst, Spatial Analyst and Geostatistical Analyst have also been used in HIS. STATISTICA, yet another package, has been used for a variety of statistical analyses.

2. THE HIS SYSTEM ARCHITECTURE

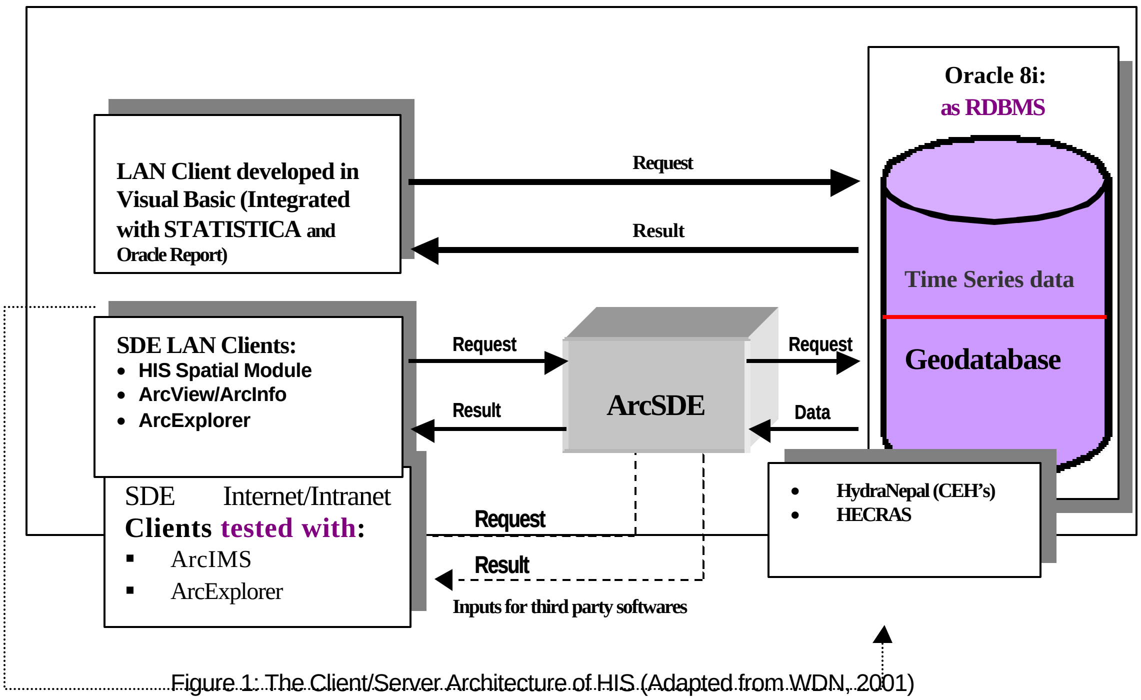


Figure 1: The Client/Server Architecture of HIS (Adapted from WDN, 2001)

HIS is designed and implemented in three-tier client/server architecture as shown in the Figure 1. This architecture is proposed against the simple file sharing where the data sharing mechanism is limited to only the features offered by network operating system.

As shown in the figure 1, Oracle stores both time series and spatial data in its relational tables. The use of Oracle also allows storing Binary Large Objects as BLOB data type. This is of particular interest of DHM to store the images of the gauzing stations and other relevant events. In HIS, the database is conceptually divided into two parts. The Spatial data is stored in the Geodatabase part of HIS while the time series data is stored as independent tables, which are not registered with the Geodatabase. This provides more flexibility to the Time Series data storage since it is not tightly integrated with the spatial database. The spatial and Time Series data can still be integrated whenever required. Hence, the geometric aspects of hydrological and meteorological entities is represented and stored in Oracle RDBMS as spatial objects in ordinary rows and columns. The integration of spatial and time series data is done through the unique object Ids. The purpose of partitioning the spatial and time series data is that the users of time series data do not need to use the ArcSDE license. Such a user can access the time series data directly. In contrary to this, the users of spatial data need to go through ArcSDE to access the spatial data stored in geodatabase.

As in Figure 1, ArcSDE is used as GIS application server to process the request by the clients from Spatial Module of HIS. The Spatial Module comes up with the most common functionalities that are of high demand for Hydrologists and Meteorologists. If the user requires the functionalities other than HIS Spatial Module supports, the architecture has been designed in such a way that ESRI's standard desktop products like ArcView, ArcInfo, ArcEditor, ArcExplorer etc. can be used as the clients. The architecture equally supports the applications developed with JAVA, Map Objects or other programming tools. The Spatial Module has been developed with extensive ArcObjects programming. The time series part of HIS application has been developed by using Visual Basic as the programming language. The outputs of HIS can also be fed in to the third party softwares such as HydraNepal, HECRAS for further processing. Though it was not implemented in this phase of the project, the architecture has been proposed so that HIS can be extended for the web application in the future.

3. AN EXAMPLE OF HIS OBJECT MODELS

ArcHydro Data Model (Maidment, 2000) has been refined for schema creation of HIS database. The HIS geodatabase consists of five feature datasets. They include Drainage, Network, Hydrography, Channel and Administrative. In figure 2, the object model for hydrography is illustrated. This component of the ArcHydro Data model describes Hydro Point, Hydro Line and Hydro Area feature classes. These store information about hydrographic features that are not incorporated into the network or other model classes. The important components covered by Hydro Point are Structure, Flow Change and Monitoring points. *Structure* points are intended to represent any feature, manmade or natural, which restricts or changes the movement of water. Examples include dams, bridges, weirs, and culverts. *Flow Change Points* differ from *Structures* in that at these points, water is withdrawn from or discharged to the stream. *Monitoring Points* store the locations of Hydrological, Meteorological, Flood forecasting and Snow and Glacier stations. These are linked with the Time Series data types with the station number.

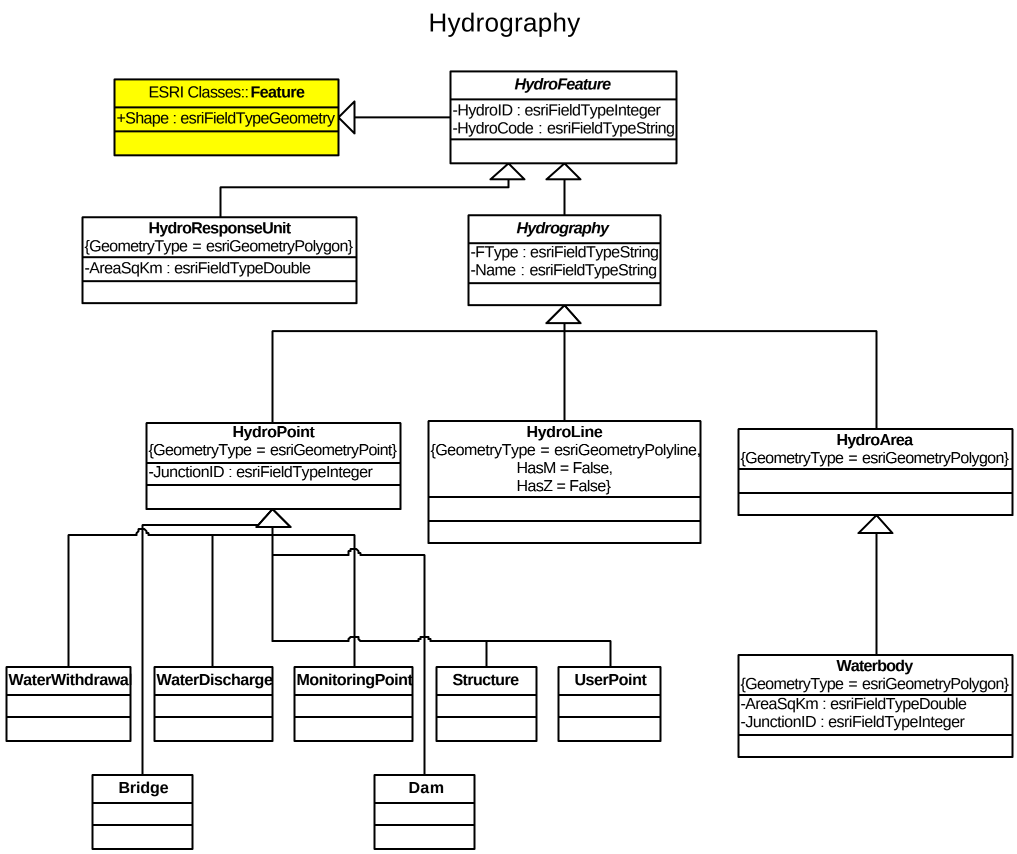


Figure 2: ArcGIS Hydro Data Model (Source: URL2)

4. AN OVERVIEW OF DIFFERENT HIS MODULES

The HIS consists of four major modules. The **System Administration** module offers system administration and maintenance functionalities. Besides others, the module provides features to define different levels of access rights and thus helps to maintain the integrity of the data and keep it secured. The **Master Data Definition** module allows the user to define master data and their management. The **Spatial** module adds the spatial dimension to HIS. This module can be used to capture, analyze and visualize hydrological and meteorological situations/phenomenon with simulated geography. The context sensitive menus developed as part of HIS helps the user to get the information about any hydrological and meteorological objects at a click of the mouse. One of the rich features of this module is that it can generate basin boundary on the fly. The fourth module called **Time Series** module, which provides a wide range of time series analysis tools to the users.

One of the most crucial aspects of HIS is the validation of the data collected at the stations. There are a number of factors threatening the reliability of the data stored in the system. Therefore, HIS has given emphasis on data validation. The validation sub module consists of four main tools: Screening, Time Series Graph, Double Mass Analysis and Relation Curve. The data screening can be performed using maximum / minimum limit and mean standard deviation. Time Series Graph generates the plot of time verses measured values, it enables user to obtain a quick insight in the measured values as well as possible measurement errors for these sort of graph generation HIS uses the functionalities of STATISTICA. The double mass analysis is used to check consistency of collected data. This validation too is graph based and uses STATISTICA. Relation curve generates the plot of two different series of same or different stations. Deviation of a data series from established relation curve can be used to check validity of a data.

HIS has the analysis tools, which come under two different headings Hydrological Analysis (consisting of Rating Curve, Hydrograph, Unit Hydrograph and Flow Duration Curve) and Meteorological Analysis (consisting of Wind Rose, Evaporation Estimation and Evapotranspiration Estimation). In each of these analysis methods there are several models developed for analyzing wherever applicable. For example, evapotranspiration estimation itself consists of 10 different models including Penman Method, FAO pan evaporation method, Christiansen Method, Radiation Method, Makking Method, Jensen-Haise Method, Blaney-Criddle Method, Mass Transfer Method, Thornthwaite Method and Penman-Monteith Method.

For Data Processing four sub modules has been developed each with a few methods. Filling missing data has Arithmetic average method, Normal Ratio method, Inverse Distance method, and Relation Curve method. Stage to Discharge conversion, Data aggregation and Data desegregations are the other modules.

The Spatial Module of HIS is the customized interface of ArcGIS 8.1 Desktop. The customization of the interface has been done with ArcObjects. The HIS Spatial module has tools for geographic as well as time series data visualizing. It also has some advanced analysis tools where time series as well as spatial data is used for analysis. Many hydrological and meteorological analyses have to depend upon spatial inputs to derive result i.e. peak flow or low flow estimation of ungauged catchments using WECS/DHM method requires spatial inputs like area of the watershed below 5000 meter height. This sort of information can be automatically derived and fed into the method for calculation.

5. DATA DEVELOPMENT AND STORAGE

The table given below lists the time series data that were identified and considered in HIS database design. The list is open to be added with new data as and when required.

Hydrological Data	Meteorological Data
River Stage	Hourly Temperature
Continuous River stage	Precipitation
Discharge measurement	Evaporation
Rating table	Sunshine
Sediment	Wind
Snow	Synoptic Data
Snow depth	Hourly Relative Humidity
Water Quality	Hourly fall

	Hourly Wind speed
	Hourly Wind direction
	Hourly Radiation
	Soil and Grass Temperature

Table 1: The list of Time Series data in HIS

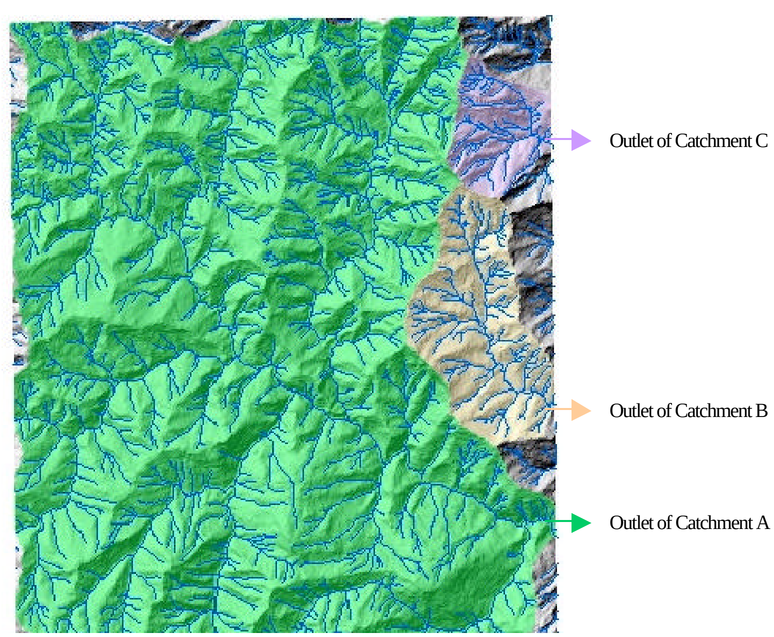
For the spatial data, a digitized toposheet of 1:25K scale in shapefile format was purchased from Department of Survey, of His Majesty's Government of Nepal. The hydrology layers were presented as line feature and Polygon feature in separate shapefiles. A centerline for the polygon features of hydrology was generated using ArcInfo Grid. After deriving the centerline it was merged with the line features of the hydrology. After this processing, a seamless line feature representing the drainage network of the toposheet was obtained. The generation of centerline was important to develop a network on which analysis could be performed. The network analyses in case of HIS are to find path upstream and trace downstream. This drainage network was then imported to a temporary personal Geodatabase and a geometric network was generated. Thus, a point feature class having all the junction points in the network was derived.

Digital elevation model or DEM was realized to be one of the most important data sources for a distributed catchment model, as it determines the catchment drainage network and the surface and river gradients (Srikantha, et al, undated). Digitized contour of 20-meter interval was taken as the base data for creating a DEM. A TIN was generated from the contour shapefile. Using *TIN to Raster* tool of *3D Analyst* the TIN was converted to DEM with cell size 10. During the test, this cell size seemed to give somewhat accurate watershed delineation when matched with the watershed delineated on paper map. The processing time with this size of DEM was optimum. Decreasing the resolution of DEM gives a coarse output and if the cell size is increased to more than 25 for this toposheet area, the flow accumulation comes as broken lines. Due to this one cannot get a complete watershed. In Figure 3, dark blue lines are representing the digitized rivers from toposheets and the three different colors are representing three catchments. Catchment A extends its area in other surrounding toposheets while catchments B and C are smaller catchments having area within the toposheets.

6. KEY FEATURES OF HIS

HIS application is integrated with STATISTICA and Oracle Report. STATISTICA provide HIS with statistical tools containing different models for statistical analysis. Along with this, it also gives flexibility to the HIS in generating graphs with numerous options. The user however, does not need to directly interact with STATISTICA. The HIS application modules, which is processing the users request with STATISTICA. Oracle Report is used to generate Reports.

HIS Spatial Module provides tools to delineate watershed boundaries on the fly, calculating Bifurcation Ratio, Drainage Density, Drainage Slope etc. Further, it provides spatial inputs to different hydrological models to calculate Basin Lag (Kirpich's method, Linsley's Method and Snyder's Method), Long Term average, Low flow (Hydra Nepal, MIP and WECS/DHM method), Peak flow (Dickens's, Global/Regional, Modified Dicken's, Rational and WECS/DHM methods). All these methods have been



programmed in the Application.

Figure 3: Watersheds derived from DEM with Hillshade in its backdrop

Regarding the meteorology, HIS has been incorporated with isoline generation features along with tools to calculate the average precipitation using Arithmetic Mean and Isohyets Method. The isohyets method of calculating average precipitation can be a good example of spatial and temporal (Time Series) data integrity. Once this method is selected, it asks for the date range and needs the stations to be selected, which will participate in this calculation.

In Figure 4, red color represents the streams, which has been converted from flow accumulation. The blue lines are the actual digitized streams from toposheets. These two lines are almost moving along with each other. When measured on an average, the streams generated from raster analysis is deviating from original toposheet streams by 25 meters. At the meanders the deviation has increased up to 30 meters.

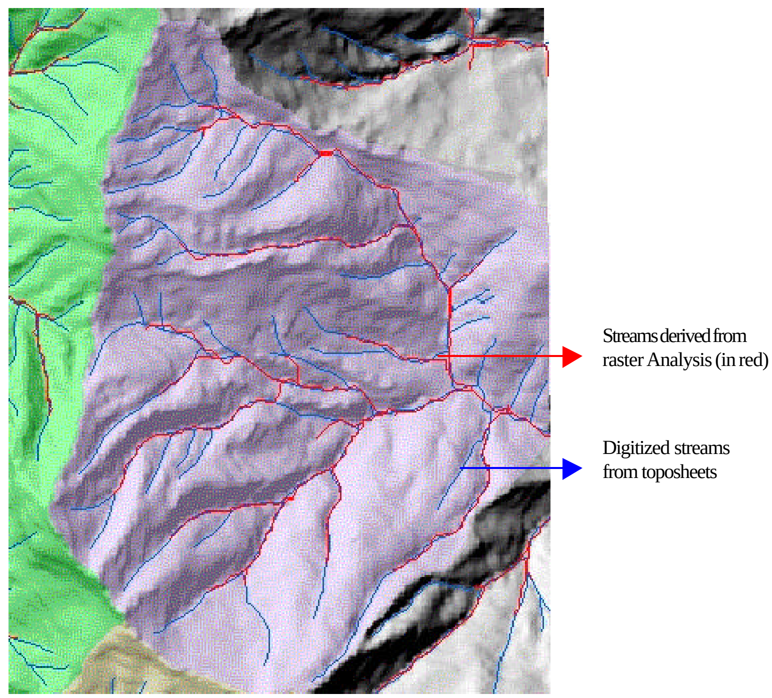


Figure 4: Digitized rivers and rivers derived from DEM

There are a number of other features in HIS such as estimation of hydropower potential, generation of rating curve, flow duration curve, hydro graphs, estimation of evaporation, evapotranspiration.

7. BENEFITS OF GEODATABASE OVER FLAT FILE GIS MODEL

• Uniform repository of geographic data	all stored and centrally managed in single database
• Data entry and editing is more accurate	validation constraints
• Users work with more intuitive objects	users model of data, not GIS model of data
• Features have richer context	topological, spatial, and general relationships defined
• Better maps can be prepared	more control over how features are drawn
• Map features are dynamic	respond to changes in neighboring features
• Shapes of features better defined	constraints defined upon map creation
• Sets of features are continuous	very large sets of features allowed without tiles
• Many simultaneous users and editors	conflicts are reconciled
• Version Control	Users can view the same data in their own style
• Uses the facilities provided by RDBMS	More security of the data

9. CONCLUSIONS

Hydro-meteorological information system is an application developed using ESRI's geodatabase concept. As both the time series and spatial data have been stored and management in Oracle, the GIS implementation benefits from a set of rich database management features of industry standard RDBMS. Some of the analysis that would take a considerable amount of time in traditional methods can now be performed within relatively shorter duration. The validation of the data can be done much easier with the tools provided by HIS. The data stored in the Oracle database can be shared among the users within the Department in an efficient manner.

The government-private sector partnership in the development and implementation of information system can be one of the attractive options especially in those government agencies with poor human capacity in the field of information technology.

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