Key Features

User Friendly
Fully Menu Driven
Vector-GIS Analysis
On-Line SQL for Adhoc Queries
On-line Report Generation
On-line Help
Most commonly used data in Master tables (minimize data entry and error)
Parameter Based Machine Installation
Parameter Based Validation Checks

Modules

SITE
- Ψ **Well**
- Ψ **Artificial Recharge Structure**
- Ψ **Hydrometeorological Station**
- Ψ **Surface Water Sites**

Dynamic Data
- Ψ **Water level**
- Ψ **Rainfall**
- Ψ **Other Meteorologic Data**
- Ψ **DWLR**
  - o **Translation of DWLR Formats**
  - o **Pre-processing & Validation**
  - o **Time Series Analysis**

Water Quality
- Ψ **Parameter Validations**
- Ψ **Ionic Balancing**
- Ψ **Water-Quality Plots**
- Ψ **Suitability Indices**

Geophysical Investigation
- Ψ **Sounding**
- Ψ **Profiling**
- Ψ **Logging**

Statistical Analysis
- Ψ **Test of Hypotheses**
- Ψ **Multivariate Analysis**
- Ψ **Categorical Data Analysis**
- Ψ **Time Series Analysis**

Resources Targeting, Estimation & Analysis
- Ψ **Estimate Balancing Components**
- Ψ **Sensitivity Analysis**
- Ψ **Subjective Weight-rank Modelling**

Mapping, Spatial Interpolation and Contouring
- Ψ **Union, Identity and Overlay Analysis**
- Ψ **Kriging & Other Standard Interpolations**
- Ψ **Fence and Cross-Section**

Other Specific Analysis
- Ψ **Aquifer Tests**
- Ψ **Grain Size Analysis**
- Ψ **Hydrogeological Map**
- Ψ **Morphometric Analysis**
- Ψ **Event Analysis (Change Analysis)**

Growth in population, urbanization and living standards has led to multi-fold increase in demand of water for diverse purposes of irrigation, domestic and industrial uses. Simultaneously the water quality has been showing continuous deterioration. Water, the most essential natural resources for life next to air, demands an integrated approach of analysis of groundwater flow, identification of potential groundwater zones and pollution vulnerability studies.

GROUNDWATER ESTIMATION AND MANAGEMENT SYSTEM is a comprehensive solution for groundwater management, developed for the **Central Ground Water Board** (CGWB), Ministry of Water Resources, Government of India under the Hydrology Project. It is a World Bank funded project, implemented in throughout nine Indian states, catering to 475 users at 191 sites all over India.

GEMS provides tools to effectively compile, visualize, and analyze hydrogeologic and allied attributes of groundwater resources. Its integration with business software of multiple domains makes it a thorough and complete solution for exploration, planning, development and management of groundwater resources.

GEMS is built using MapInfo Professional (GIS), MapInfo Vertical Mapper (spatial interpolation and contouring), SPSS (statistical analysis) and R2V (raster-vector data conversion). MapInfo's solutions offer a unique combination of software allowing customers to map, visualise, profile, compare and act upon information.

GEMS covers geophysical investigations, water quality studies, borehole/well logs, time series analysis of water level, rainfall and other meteorological data, as well as spatial analysis in targeting and estimating groundwater resources. GEMS, with specific alterations, can reasonably meet the needs of the above domains. Available GIS based spatial analysis tools, provided by MapInfo in GEMS such as interpolation, contouring, predictive modeling and forecasting can be effectively used to analyze data of the above domains.

Functional domains of the system

- Location and Non-Spatial Information – SITE
- Geophysical Investigation
- Water Quality
- Statistical Analysis
- Groundwater Resources Targeting, Estimation and Analysis
- Mapping, Surface Interpolation and Contouring
- Miscellaneous Utilities
  (Validations and Pre-processing of raw data, Queries & Reports, Export & Import, Database Maintenance, Work-Area, On-line Help)

System Architecture

Location and Non-Spatial Information – SITE

SITE is the base module of GEMS, which maintains the Location and Non-Spatial Information pertaining to rain-gauge and hyrometeorlogical station, artificial recharge structure, surface water site and well (observation, exploratory or piezometric). All these structures contain locational and access details with reference to state, district, tahsil, block, village, basin, sub-basin, watershed, mohalla, agency, altitude and specific landmark for easy access to a location.
General details of well site includes the geology, major water bearing formation stratigraphy, elevation, nearest bench mark, etc. The wells are classified as dug, bore, dug cum bore, tube well, slim hole and springs. Well specific information includes details on drilling, construction, well assembly, sealing/grouting/gravel packing and well development. The application maintains depth-wise monitoring of water bearing zones, drill-time, subsurface geology and lithology, geophysical signatures, well-hydraulic parameters. Preliminary yield test, aquifer performance test and step drawdown tests are provided to study well performance. Grain size analysis, geophysical logging, zone test are other specific analysis tools available in this module. These sites maintain dynamic data of multiple intervals. The system provides translation of some of the standard DWLR (digital water level recorder) formats.

Each hydrometeorologic and rain-gauge station maintains normal rainfall data, computed from historical data and maintained by meteorologic departments. These stations maintain dynamic data of hourly, daily and monthly intervals of rainfall, potential evaporation, potential evapotranspiration, soil moisture, relative humidity, run-off, temperature, wet and dry bulb temperatures, station level pressure, wind speed and direction, and number of sun-shine hours.

The Artificial Recharge Structures include percolation tank, cement plug, nullah bund, injection bore well, injection tube well and recharge shaft. Each of these sites maintain location, area or/and perimeter details, infiltration test, catchment area & capacity curve, spillway details, geophysical logging, grain size analysis, and aquifer performance test.

Grain size analysis

Extraction of sediment composition populations from grain size analysis depicts depositional environment and changing hydrodynamic conditions, paleo-hydrological changes, and sedimentary facies zonation within a watershed. Geographically dispersed data generate a

sorted/graded sediment zonation map. Environmentalists use sediment composition populations to analyze pollutant dispersion and accumulation, and biodiversity.

The application provides cumulative probability distribution functions of % finer or % retained vs. the size of grains of Standard ASTM and BSS Sieves. Few statistics viz. Effective Size, Uniformity Coefficient, Grading Coefficient, Sorting Coefficient and Screen Size are extracted to characterize aquifer material.

Aquifer Performance Test

Aquifer tests, an integral part of interpretive ground-water investigations, analyze hydraulic characteristics studied in terms of hydraulic conductivity, transmissivity and storativity of a specific aquifer or aquifer system. They also analyze the complete critical components of groundwater flow-system and define solute-transport analyses.

GEMS provides Aquifer Performance, Step Draw-down and Yield Tests to optimize planning for new well location, developing effective pumping rate and duration, understanding well-interference etc. Graphical analysis and reporting of time-drawdown and distance-drawdown, time-drawdown with discharge and well-specific capacity are available. An aquifer test comprises of information such as distance from the exploratory (pumped) wells to all observation wells, location of any boundaries, streams, springs, ditches, pumping or flowing wells, or other features that possibly could interfere with the results, well construction details viz. screened- and open interval(s), casing and screen diameters, location of filter pack and grouted intervals.

Well/ Borehole Log

Well/ borehole Logs provides integrated 3D geological data visualization in the form of a Fence and Cross-section of lithology, stratigraphy, water-bearing zones, geophysical and geochemical signatures, fracture and fault zones, well assembly, drill-time and discharge.

Time Series Analysis Of Water level and Rainfall

The system provides translation of data from some of the standard DWLR, statistical pre-processing and analysis for their further use in groundwater resources evaluation. Pre-processing includes rejection of erratic water level and rainfall data using a probability distribution function of data from the same period of the previous years. Time Series plots, trend of rainfall and water level over year, lag time analysis, rainfall events, change detection of rainfall on water level, and other event based analysis are available in analyzing groundwater regime.

Geophysical Investigation

Geophysical investigations encompass a broad range of studies and techniques to detect and interpret physical parameters, waves, or fields measured at the earth's surface for the sub-surface characterization. Although these signatures provide fuzzy or ambiguous images of the subsurface, they have proved effective in defining or delineating the three-dimensional geometry of sedimentary basins, young volcanic-tectonic depressions, active or recently active faults, major fault zones and rock contact. These significantly analyze allied problems in salt-water intrusion, geothermal, mineral, and hydrocarbon exploration,

groundwater modeling, toxic waste dispersion, crustal structure and plate tectonic investigations, and monitoring of deformation and subsurface mass movement associated with volcanic activity, earthquakes, and groundwater extraction.

Geophysical module facilitates capturing sounding and profiling data pertaining to electrical, magnetic, electro-magnetic, gravity and seismic investigation. The electrical methods include induced polarization, resistivity, self-potential, misse-la-masse while the electromagnetic methods includes VLF and HLEM. Varied electrode configurations for profiling or sounding viz. schlumberger, half-schlumberger, wenner, dipole-dipole (axial, radial, perpendicular, parallel, equatorial, azimuthal) and lee-partitioning) are available as per the method of investigations.

The borehole-logging methods include caliper, fluid conductivity, resistivity (lateral, long-normal, short-normal), single resistance, self-potential, natural gamma radioactivity, neutron, temperature and differential temperature.

Water Quality

The Water Quality module has been designed and developed specifically for handling aqueous geochemical data, graphical and numerical interpretations and analysis. The chemistry data is grouped into general details, field parameters, general parameters, cations and anions, bacteriological and biological parameters, pesticides and micro-organics. However, the system facilitates inclusion of any water-quality parameter to any of the above groups. For purged samples, the system facilitates storage of pump details, storage volume etc. General details include location and accessibility, source, date, depth (in case of groundwater) of sample, sampling type (direct or indirect), device, container, preservation and pre-treatment method adopted, type of monitoring (baseline, trend, trend cum surveillance), laboratory and date of chemical analysis.

Field parameters include colour, odour, temperature, pH, EC, DO while the general parameters include the laboratory analyzed pH, EC, TSS, TDS, tubidity, TH, total alkalinity, phenolphthalein alkalinity. The cations and anions include Ca, Mg, Na, K, total Fe, carbonate, bicarbonate, hydroxide, chloride, sulfate, nitrate, phosphate, floride and sulfide. Very rarely used water quality parameters such as ammonia and nitrogen, silica, boron and colloidal nitrogen are grouped together. In addition to the generally analyzed bacteriological and biological parameters viz. BOD, COD, chlorophyll A, TOC, colliform and faecal colliform, the system similarly allows adding more entities to this group. The heavy metal group carries all the heavy metals of the periodic table. Each parameter is validated using standard ionic balancing equations and recommended exceedence values, while storage.

The analytical capability of the Water Quality module is complimented by a comprehensive selection of commonly used graphical techniques to portray the chemical characteristics of water quality from single or multiple samples. Standard water-quality plots to characterize groundwater and uses for irrigation, domestic and industrial water-supply include Stiff, Piper, Schoeller, Scatter, Pie, US-Salinity, Durov, Wilcox, Collins' Bar and Vector. Other parameters of useful to infer the favourability of water for 'irrigation uses' are Sodium Absorption Ratio (SAR), Residual Carbonate (RC), Na%. The diagram of "USDA classification for agricultural uses", plots the SAR and Conductivity, and classify diagram into standard regions of Sodium hazards and Salinity hazards. Further, the system facilitates representation of most of the single sample plots on a Map. Time Series graphs, trend and correlation analysis are some of the statistical tools implemented for analysis.

Statistical Analysis

Statistical Analysis exploits the existing functionalities of SPSS and is limited to the specific requirements of hydrogeologic problem solving. It covers multiple methods of univariate to multivariate analysis. Principal Component Analysis (data Aggregation), Factor Analysis (Grouping variables into multiple sets), Cluster Analysis (unsupervised classification of data into multiple groups) and Reliability Analysis (how accurate, on the average, the estimate of the true score is in a population of objects to be measured) mostly cover the multivariate statistical analysis. Multiple regression analysis, mostly used by Geoscientists for trend, model fitting, prediction, relative/effective variable(s) in a fitted model uses a linear, logarithmic, power or exponential model, as per the behavior of data. The Polytomous Logit Universal Models (PLUM) apply regression techniques to ordinal outcomes (such as low, medium and high), which is a generally used method for geoscientists as the data are mostly categorical (ex. soil type, rock types, geomorphology). Factorial Design and analysis is another multivariate analysis of variables, which executes categorical variables in their analysis, model fitting and prediction.

Time Series analysis includes studies on auto-correlation, cross-correlation, curve estimation, forecasting, spectral analysis and seasonal decomposition. The module includes Auto-regressive, Moving Average, Auto-Regressive Integrated Moving Average (ARIMA) methods of model fitting to facilitate analyzing nature of water level, rainfall, evaporation, evapotranspiration and other meteorologic data, and their effect on hydrology.

Different test statistics, available in SPSS and which are of use while model fitting viz. testing significance of variable or a fitted model include Pearson chi-square, the likelihood-ratio chi-square. The module also includes Fisher's exact test, and Yates' corrected chi-square (continuity correction), Spearman's correlation coefficient, Phi (coefficient), Cramer's V, Contingency coefficient, Lambda (symmetric and asymmetric lambdas and Goodman and Kruskal's tau), Uncertainty coefficient, Kendall's tau-b, Kendall's tau-c, Somers' d, Eta, Cohen's Kappa, odds ratio, McNemar, Cochran's and Mantel-Haenszel, Breslow-Day and Tarone's statistics.

The figure below shows results of a logistic regression analysis using independent variables viz. Lithology (LITH_UNI), "Lineament Proximity" (DESCR), "Drainage Density" (DDENSE), "Drainage Frequency" (DFREQ), Slope (SLOPE) and the dependent variable ''Water Level''. All the variables are categorized while the target variable water level is classed as binary 0 or 1, indicating presence or absence of groundwater potential zones. The fitted model can be used to predict possible occurrences of groundwater resources in areas of similar hydrological conditions.

Groundwater Resources Targeting, Estimation And Analysis

The Groundwater Resources Targeting, Estimation And Analysis module integrates data from all the possible sources available in the system and analyzes for estimation of groundwater resources, detection of effective components to groundwater storage change, and targeting potential zones for groundwater exploration and exploitation.

An exhaustive Vector-GIS based computation of groundwater recharge or loss from several natural and artificial structures such as rainfall, canals, irrigated fields, tanks, ponds, submerged lands, inter-aquifer flow, evapotranspiration, evaporation, stream-aquifer interflow and inter-watershed flow, and draft components for irrigation, domestic and industrial uses is included. These estimates are used for analysis of components viz. Net Annual Groundwater Availability, Stage of Groundwater Development, Water Table Trend, Allocation of Groundwater for Domestic and Industrial Water Supply, Net Groundwater Availability for Future Irrigation Uses, and Categorization of areas for scope of Future Groundwater Development.

Hydraulic parameters including rainfall, water level, evaporation and evapotranspiration of points of a particular time interval are interpolated and contoured. These processed layers, along with the controlling variable geology (which describes the rainfall infiltration factor or specific yield), are modeled using GIS based overlay analysis to estimate the recharge or loss of groundwater.

Multivariate statistical analysis tools are used to detect and prioritize the sensitive groundwater balancing component leading to storage change. The estimated groundwater draft and recharge components of different years are regressed with the independent variable "Storage Change". The modelling procedure allows step-wise removal of insignificant variables and adding new variable(s) into the fitted model of previous steps. The final fitted model can be used to predict the storage change for a different year or for a different region of similar hydrogeologic conditions.

Targeting for potential zones for groundwater resources development and pollution vulnerability analysis uses subjective weight-rank based predictive modelling. The evidence layers (ex. soil, rocktype etc) are assigned relative weights and the associated attributes of each layer are assigned with a relative rank. Selected specific evidence layers are modeled with a GIS based Overlay analysis whereby the generated discrete objects in the predicted map are estimated.

This analysis involves certain pre-processing methods such as conversion of point and line objects into polygons. The point data (water level, rainfall etc) are interpolated, using existing functionalities of Vertical Mapper (viz. kriging, triangulation, voronoi polygonization, inverse distance weighting, bilinear and natural neighborhood) and contoured, whereas the line objects (fault, fracture, lineaments etc) are buffered. As topographic elements such as slope, aspect and relief have also a control on the groundwater flow and its occurrences, these are prepared from topographic maps.

Mapping, Surface Interpolation and Contouring

The spatial data integration of GEMS is facilitated through its integration with MapInfo Professional. The spatial structure is defined in terms of a point, line or polygon as it is a vector-GIS based application. Prominent pre-processing tools include buffer, clean, combine, disperse, disaggregate, convert (regions to polylines or vice versa), smoothening (lines), split, and intersect. Spatial parameter extraction tools include area, centroid, distance, length and perimeter. Others include creation of buffers, polygon of standard geometry, line and point. Several mathematical operators, logical operators (and, or and not), geographic operators (like, contains, contains entire, within, entirely within, intersects) help in spatial query building for extraction of spatial and non-spatial information. Spatial operations in analyzing

multiple layers include overlay, identity and union. Thematic mapping comprises of classifying attributes using equal count (frequency), equal range, natural break (clusters), and standard deviation and quantile (using a probability distribution function). Extraction of basic statistics help in generalization-based knowledge extraction.

Morphometric studies of the drainage pattern extracts drainage density, drainage frequency and bifurcation ratio.

Integration of Vertical Mapper with GEMS facilitates in the analysis of data using interpolation methods viz. point and block kriging (ordinary, simple and universal), triangulation, voronoi polygonization, inverse distance weighting, bilinear and natural neighborhood. Variogram modeling includes manipulation of lag distance and tolerance and analysis of anisotropism. The system facilitates user-defined grid dimension, tolerance for coincident point aggregation, and other required parameters specific to the method of interpolation while model fitting. The contouring method (classifying the interpolated values) is user-defined or of equal ranges. The system also provides facility for building slope, aspect and relief maps from topographic contours. The interpolated and classified maps can be further processed and, along with a topographic map, help create a Digital Elevation Model (DEM) and Digital Terrain Model (DTM).

Miscellaneous Utilities

Validations and Pre-processing of raw data

The system maintains validation of raw data at different levels. The primary validations are maintained at field-level data entry. For secondary validations (ex. EC/TDS ratio), erratic data are maintained with a flag. Time series data, mostly those from DWLR are validated with a probability distribution function of data for the same period of previous years. Manual data relating to positional information are validated with reference to maps.

Query & Report

The system provides the ability to query, process, view and analyze data from all the modules. In addition to certain standard map and non-map based queries and reporting, GEMS facilitates creation of ad-hoc maps, reports and thematic maps.

Export & Import

Apart from the ASCII format, GEMS facilitates Export of data to certain standard groundwater softwares viz. MODFLOW and Surfer. It is possible to store graphical and map outputs for further use. The system provides facilities to import historical data (mdd, mdb) and multiple standard DWLR formats.

Database Maintenance

The system provides facilities for database backup in three ways viz. Database System Backup (all Control Files, Redo Log Files, tablespaces), Full Backup (all tablespaces of all users from the database), Application database Backup (all tablespaces of all users required for GEMS from the Database. Data Transfer facilitates transfer of selected data for a period of one/multiple modules. Data extracted (exported through GEMS) from one database can be imported to another. Apart from these, the system provides a general export in the form of flat files.

Work-Area

GEMS facilitates setting up a machine work-area, which comprises of Administrative and Hydrologic boundary details. Selection of administrative boundary is to the scale of a block while that for a hydrologic boundary is a watershed. The user work-area, a subset of it, allows selection of Administrative and Hydrologic boundaries from only those available in the machine work-area.

On-line Help

The robustness of the system in terms of it functionalities and technology (GIS, Data Conversion, Image Pre-processing and Analysis and Statistical Analysis) demanded an extensive On-line Help to facilitate users comfortably execute GEMS.