A

Project Report

On

LITHOLOGIC AND STRATIGRAIC ANALYSIS OF BOREHOLE DATA USING ROCKWARE SOFTWARE & STUDY OF WATER QUANTITY OF NCT DELHI

CARRIED OUT AT

NATIONAL INSTITUTE OF HYDROLOGY (ROORKEE)

Submitted In Partial Fulfillment of the Requirement for the Award of the Degree of

MASTER OF TECHNOLOGY

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SANDEEP KUMAR

DEPARTMENT OF GEOLOGY

KURUKSHETRA UNIVERSITY KURUKSHETRA

HARYANA(INDIA)

ABSTRACT

Ground Water is required for all living beings. Without water life is not possible. It is the first requirement of life. Earth is covered by 75% of water and 25% of land surface. But fresh water is only 1% . But the source of fresh water is continuouslydepleting. Contamination of ground water is also big problem. There are different types of sources which are responsible for the ground water pollution. It is polluted by solid waste, fertilizers used in crops etc. Water contains many natural occurring substances. Many factorsaffect water quality like bicarbonates, sulphates, sodium, chlorides, calcium, magnesium, and potassium. Substances present in the air affect rainfall. Dust, volcanic gases, and natural gases in the air, such as carbon dioxide, oxygen, and nitrogen, are all dissolved or entrapped in rain. When other substances such as sulphur dioxide, toxic chemicals, or lead are in the air, they are also collected in the rain as it falls to the ground. In opposite cleaning of water have many methods. Water is clean by naturally and artificially. Water is purified in large part by the routine actions of living organisms. Energy from sunlight drives the process of photosynthesis in aquatic plants, which produces oxygen to break down some of the organic material such as plant and animal waste. This decomposition produces the carbon dioxide, nutrients and other substances needed by plants and animals living in the water. The purification cycle continues when these plants and animals die and the bacteria decompose them, providing new generations of organisms with nourishment.

CONTENT

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Sandeep Kumar

Roll No. 482253

CHAPTER 1

INTRODUCTION

India is blessed with a rich and vast diversity of natural resources, water being one of them. Water is nature's most wonderful, abundant and useful compound. There are many essential elements for the existence of living beings; water is rated to be of the greatest importance. Without food, humans can survive for a number of days, but without water one cannot survive for more than a day. Water is not only essential for the lives of animals and plants, but also occupies a unique position in industries. Groundwater is an important source of water supply throughout the world. Groundwater occurs almost everywhere beneath the earth surface not in a single widespread aquifer but in thousands of local aquifer systems and compartments that have similar characters. Knowledge of the occurrence, replenishment, and recovery of groundwater has special significance in arid and semi-arid regions due to discrepancy in monsoonal rainfall, insufficient surface waters and over drafting of groundwater resources.

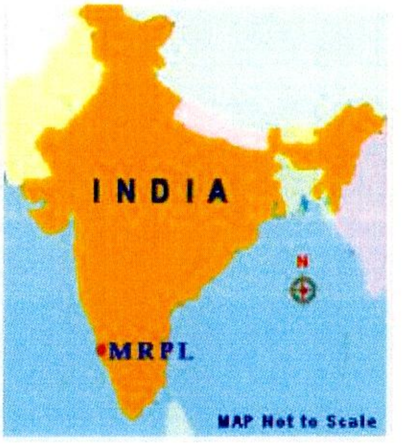
The ground water quality is still important to the community, therefore it is important to ensure its quality is high at all time so that the consumer health is not compromised. Groundwater resources are affected in principle by three major activities. First of these activities is excessive use of fertilizers and pesticides in agricultural areas. The second one is untreated/partially treated wastewater to the environment. Finally, excessive pumping and improper management of aquifers result. The activity of solid waste disposal in open un-engineered landfill is the one of the factor that cause the ground water pollution due to lack of pollution control interventions such as water proof layer, leachate treatment pond, monitoring wells etc. (Mohamad et al., 2007). Groundwater pollution also occurs due to clandestine disposal of toxic wastes, especially from industrial sites, or undetected leakage from pipes, waste storage containers, or underground tanks. According to WHO organization, about 80% of all the diseases in human beings are caused by water. Once the groundwater is contaminated, its restoration to actual condition requires prolonged time and decontamination is not possible by just stopping the ingress of pollutants from the source. Contamination of groundwater by domestic, industrial effluents and agricultural activity is a serious problem faced by developing countries. The industrial waste water, sewage sludge and solid waste materials are currently being discharged into the environment indiscriminately. These materials enter subsurface aquifers resulting in the pollution of irrigation and drinking water (Girija et al., 2007). High rates of mortality and morbidity due to water borne diseases are well known in India. Access to safe drinking water remains an urgent necessity, as 30% of urban and 90% of rural households still depend completely on untreated surface or groundwater (Palanisamy et al. 2007).

The quality of water is defined in terms of its physical, chemical and biological parameters. Its development and management plays a vital role in agriculture production, poverty reduction, environmental sustenance and sustainable economic development. In some areas of the world, people face serious drinking water shortage because of the ground water contamination. Assessing risk involves identifying the hazard associated with a particular occurrence, action, or circumstance and determining the probability of that hazard occurring. Hence, evaluation of groundwater quantity and quality is important for the development of further civilization and to establish database for planning future water resources development strategies. The quality of water may depend on geology of particular area and also vary with depth of water table and seasonal changes and is governed by the extent and composition of the dissolved salts depending upon source of the salt and soil, subsurface environment.

Monitoring of ground water regime is an effort to obtain information on ground water levels and chemical quality through representative sampling. In India, most of the population is dependent on groundwater as the only source of drinking water supply. The groundwater is believed to be comparatively much clean and free from pollution than surface water. But prolonged discharge of industrial effluents, domestic sewage and solid waste dumping results in pollution of groundwater and health problems. Natural phenomena such as volcanoes, algae blooms, storms, and earthquakes also cause major changes in water quality and the ecological status of water. As per the latest estimate of Central Pollution Control Board, about 29,000 million litre/day of wastewater generated from class-I cities and class-II towns out of which about 45% is generated from 35 metro-cities alone (Mangukiya et.al, 2012).

1STUDY AREA :

1.1 INTRODUCTION:



MRPL, a schedule 'A' CPSE and a subsidiary of ONGC is a State of Art Grassroot Refinery located in a beautiful hilly terrain, north of Mangalore city, in Dakshin Kannada region. The Refinery has got a versatile design with high flexibility to process Crudes of various API and with high degree of Automation.

MRPL has high standards in refining and environment protection matched by its commitments to society. MRPL has also developed a Green Belt around the entire Refinery with plant species specially selected to blend with the local flora

MRPL has a design capacity to process 15 million metric tons per annum and have 2 Hydrocrackers producing Premium Diesel (High Cetane). It also has 2 CCRs producing Unleaded Petrol of High Octane..

1.2 LOCATION :

Mangalore Refinery and Petrochemicals Limited (MRPL), is an oil refinery at Mangalore and is a subsidiary of ONGC, set up in 1988. The refinery is located at Katipalla, north from centre of Mangalore city. The refinery was established after displacing five villages of Bala, Kalavar, Kuthetoor, Katipalla, and Adyapadi.

MRPL is situated in 442 Acres of land in the Mangalore Special Economic Zone (MSEZ), and is fully integrated with MRPL. At 100% operational load, the complex shall produce 914 KTPA Para-xylene and 283 KTPA Benzene.

The all-weather Mangalore Port is only 14 km from OMPL plant and is connected by dedicated pipeline, enabling hassle free export & import of products and feed stocks.

CHAPTER 2

REVIEW OF LITRATURE

Mangalore Refinery and Petrochemicals Limited (MRPL), is an oil refinery at Mangalore.

The refinery has a versatile design with high flexibility to process crudes of various API gravity and with high degree of automation.MRPL has a design capacity to process 15 million metric tonnes per annum and is the only refinery in India to have two hydrocrackers producing premium diesel (high cetane).It also has a Polypropylene unit with a capacity of 4,40,000 MT/annum. It is also the only refinery in India to have two CCRs producing unleaded petrol of high octane. Currently, the refinery is processing about 14.65 million tonnes of crude per year and had a turnover of US$ 9 billion during last year.

MRPL, which was a joint sector company, become a PSU subsequent on acquisition of its majority shares by ONGC. As on 1 April 2007, 71.62% shares are held by ONGC, 16.95% shares are held by HPCL, and remaining shares are with public and financial institutions. MRPL has also been declared as Miniratna, a mini jewel, by Government of India in 2007.

Before acquisition by ONGC in March 2003, MRPL was a joint venture oil refinery promoted by M/s Hindustan PetroleumCorporation Limited (HPCL), a public sector company and M/s IRIL & associates (AV Birla Group). MRPL was set up in 1988 with the initial processing capacity of 3.0 million metric tonnes per annum that was later expanded to the present capacity of 15 million metric tonnes per annum.

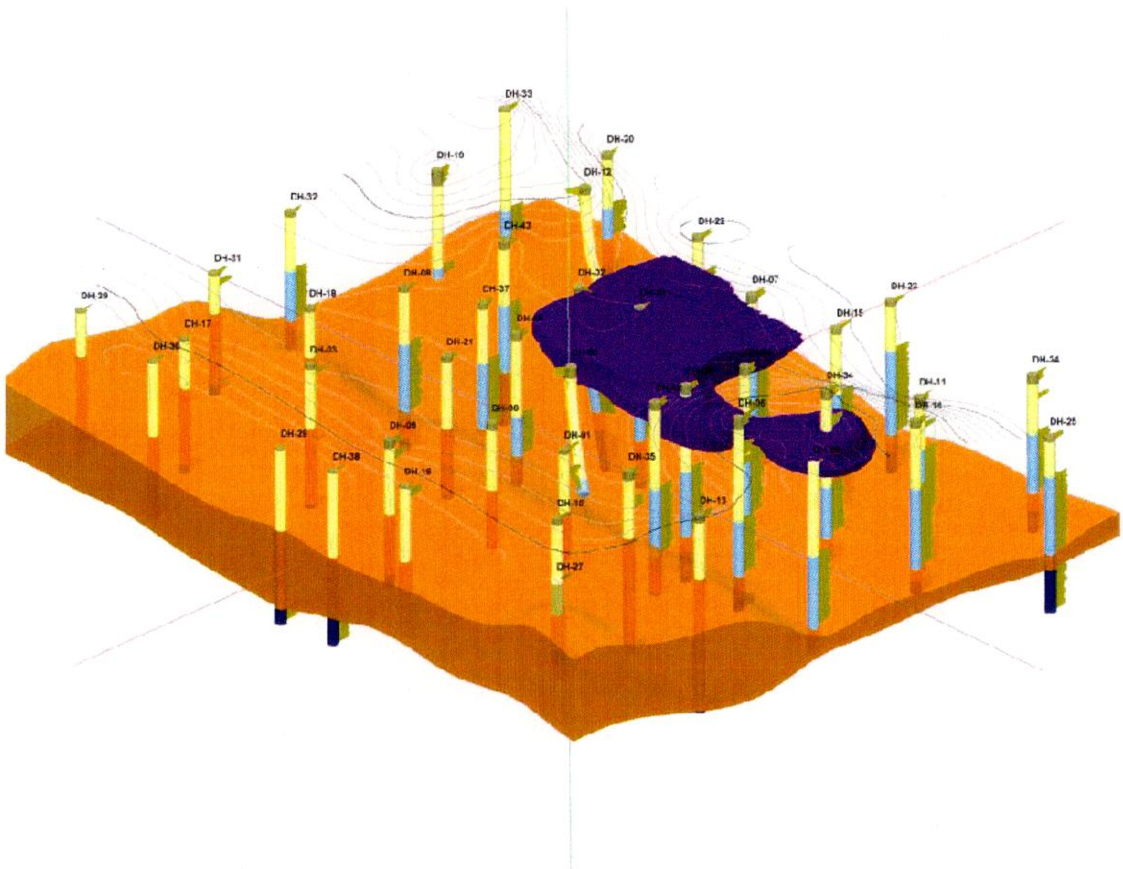
The refinery was conceived to maximise middle distillates, with capability to process light to heavy and sour to sweet crudes with 24 to 46 API gravity. On 28 March 2003, ONGC acquired the total shareholding of A.V. Birla Group and further infused equity capital of Rs.6 billion thus making MRPL a majority-held subsidiary of ONGC. The lenders also agreed to the debt restructuring package (DRP) proposed by ONGC, which included, *inter alia*, conversion up to Rs36554884 core of their loans into equity. Subsequently, ONGC has acquired equity allotted to the lenders pursuant to DRP raising ONGC's holding in MRPL to 71.62 percent.

CHAPTER 3

SOFTWARE USED AND METHOD APPLIED

3.1 ROCKWARE15 SOFTWARE :

®RockWorks15



RockWare®
Since 1983

3.2 INTRODUCTION TO SOFTWARE:

RockWorks is an integrated software package for geological data management, analysis, and visualization.

RockWorks specializes in visualization of subsurface data as logs, cross sections, fence diagrams, solid models, structural and isopach maps in both 2D and dynamic 3D windows.

The borehole data manager is used for easy entry of well data: geophysical / geotechnical / geochemical measurements, observed lithologies, stratigraphic contacts, water levels, fractures, downhole well surveys, all in linked database tables. From this data you can create point, contour, plan-view, and lithology/stratigraphy surface (geology) maps; logs; cross sections; and profiles.

In addition there's an assortment of 3D diagrams: logs, surfaces, fence diagrams, and solid models.
RockWorks also contains a "flat" spreadsheet-style data window for use with the program's

RockWorks Utilities:

Basic gridding and contouring, solid modeling, volumetrics, hydrology and hydrochemistry tools (drawdown & flow diagrams, Piper and Stiff diagrams), 2D and 3D feature analysis (rose and stereonet diagrams, lineation maps and densities), statistical computations and diagrams (histograms, scatterplots, ternary plots), survey mapping, coordinate conversions, and more. The RockWorks Utilities portion of the program can be purchased separately.

There are three graphic display windows in RockWorks :

RockPlot2D:

Displays 2-dimensional, "flat" images such as maps, logs, and cross sections. It offers save, export, and printing tools, as well as on-screen editing, drawing, digitizing and measurement tools.

RockPlot3D :

It is an interactive graphic display window that utilizes OpenGL for easy visualization of 3D images such as logs, fence diagrams, solid models, and 3D surfaces. It provides interactive rotation, panning, zooming, and layering of different images. Adjust lighting, filter solids, adjust colors, append images easily and quickly. View volumes instantly on the screen.

ReportWorks :

Itis used to lay out pages for display and print.
Insert RockPlot graphics (maps, cross sections, logs, diagrams, etc.) and raster images,
draw scale bars and shapes, add text and legends, and more. Print and export tools takeyour RockWorks images to presentation stage quickly and easily.

3.3 System Requirements :

The minimum system requirements for RockWorks may vary, depending on the type of data you will be processing and the types of diagrams you will be creating and viewing.

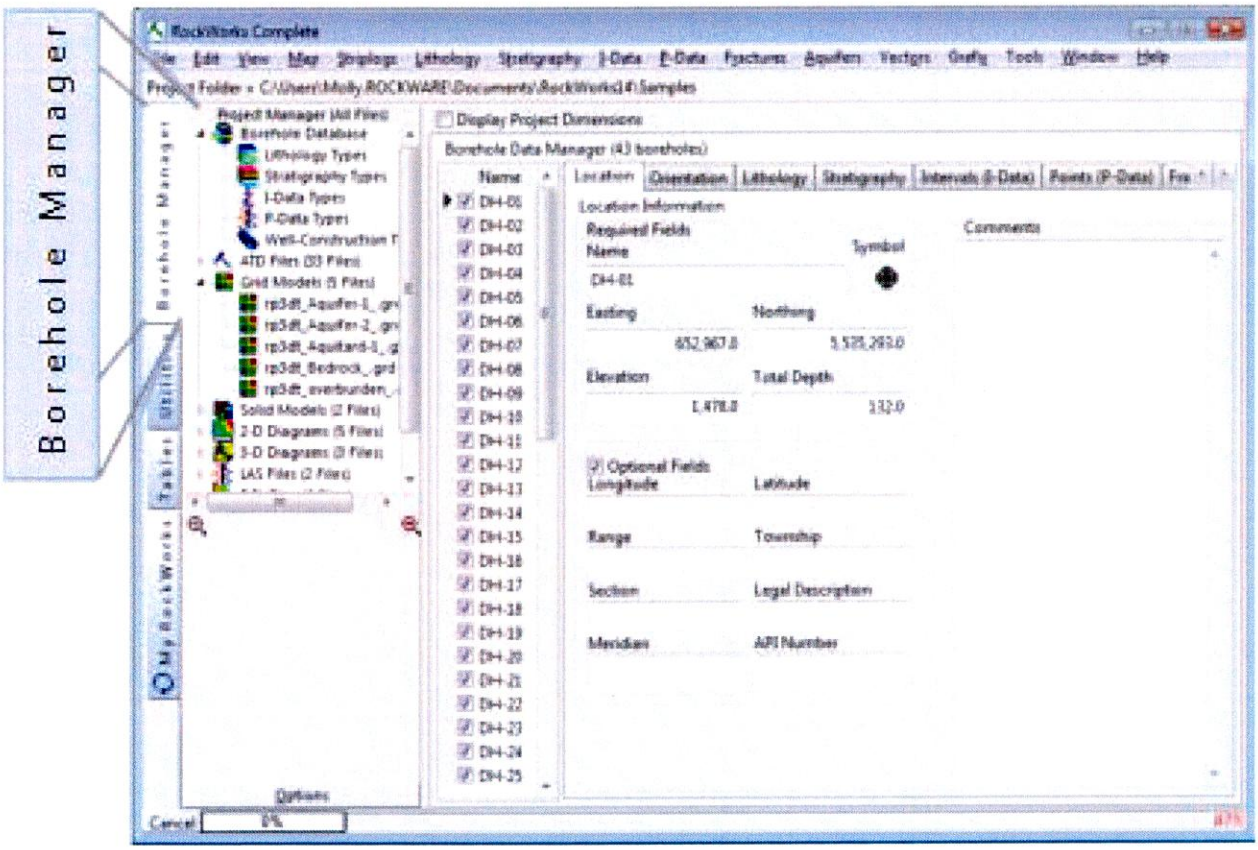
In general, the more RAM, the faster the processor, the newer the operating system, the better.

Here is our minimum recommended system setup for use of RockWorks:
Windows2000, NT, XP, Vista, or Windows 7.
(Windows98 & Windows ME are not supported.)
1 GB + of RAM
1.4 GHz or faster CPU.
Plenty of free disk space.
Display set to GREATER than 800 x 600 pixel

3.4 USE OF SOFTWARE :

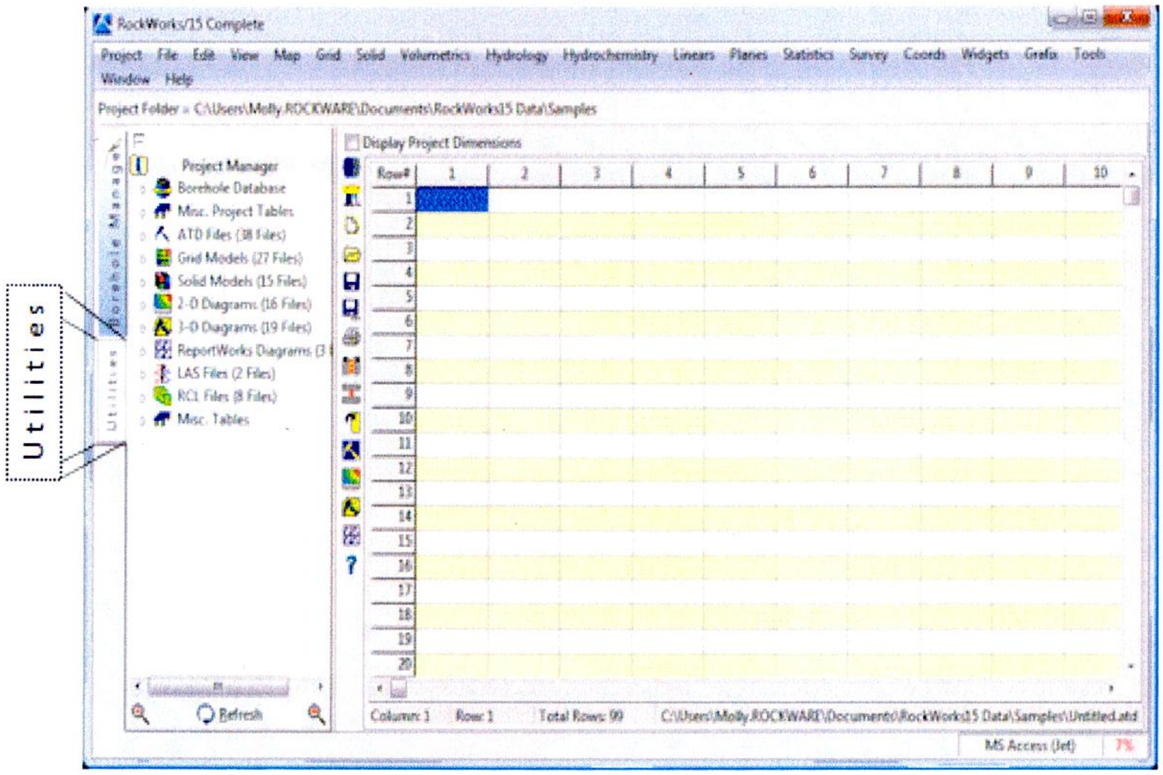
Here are some important landmarks within RockWorks:
The Borehole Manager:

This is the data window and suite of menus for entering and working with borehole data. Here is where you do most of the sub-surface modeling and visualization in RockWorks: 2D and 3D logs, cross sections, fence diagrams, solid models, stratigraphic models, structure maps, etc. Borehole data is stored in a database (Access MDB by default). You can access the Borehole Manager using its tab along the left edge of the program window.



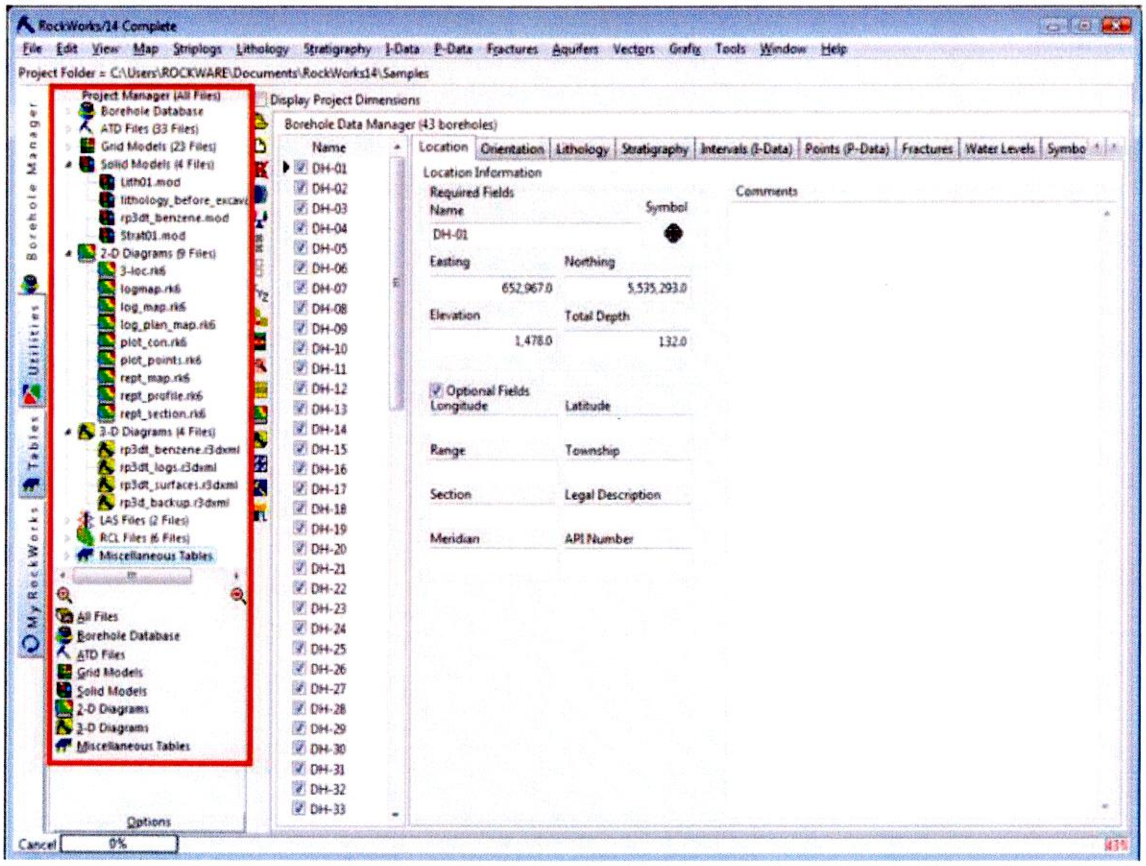
The RockWorks Utilities:

This is a simpler, row-and-column type of data window with its own suite of menus. Here you can create many different types of maps, charts, and diagrams. Even if you are working primarily with borehole data, you will still use many of the tools in the RockWorks Utilities for analytical work (statistical analysis, grid & solid model math/filtering tools, etc.). You can access the Utilities window using its tab along the left edge of the program window



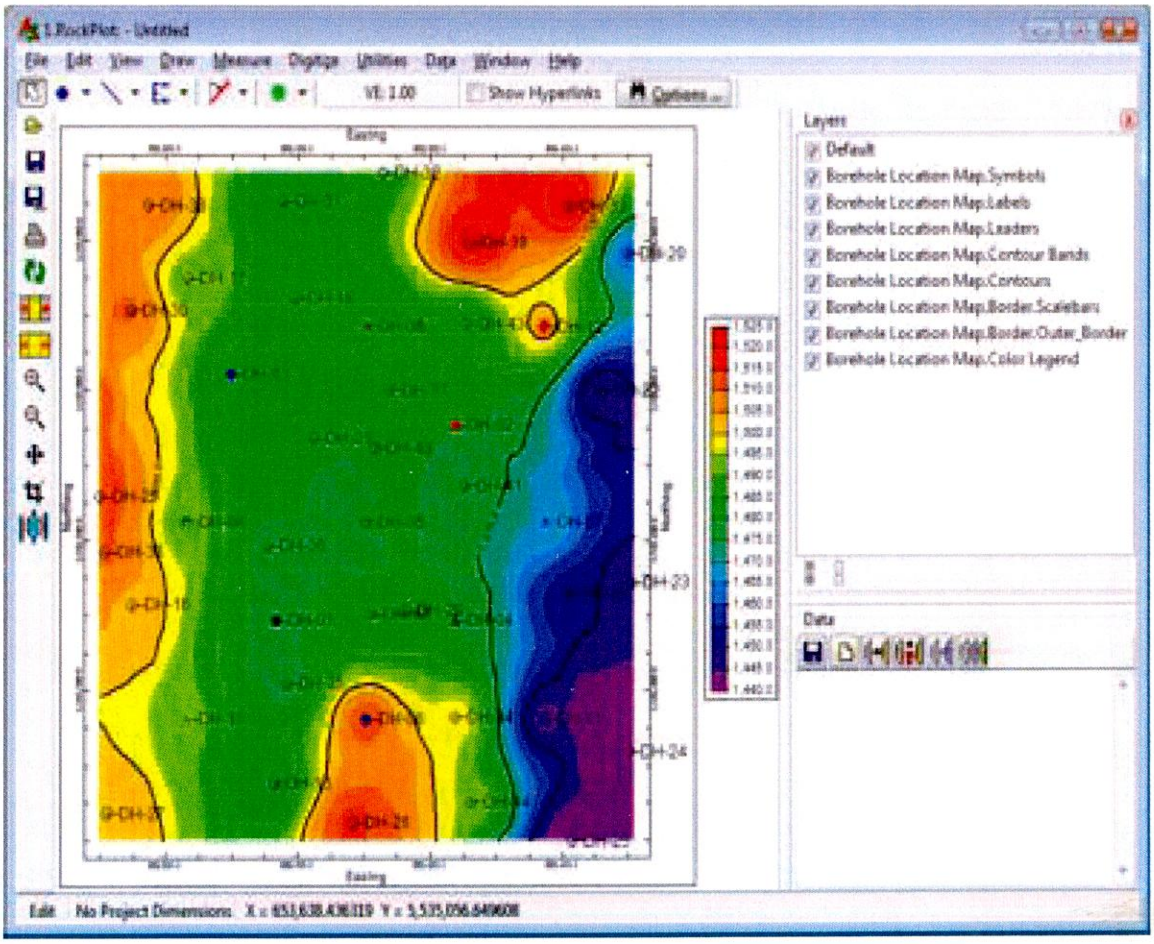
Project Manager:

This pane, along the left edge of the program window, displays RockWorks files that reside in the current project folder, and tables in the project database, for quick and easy access: Hover over graphic files to see previews, doubleclick on files to open them



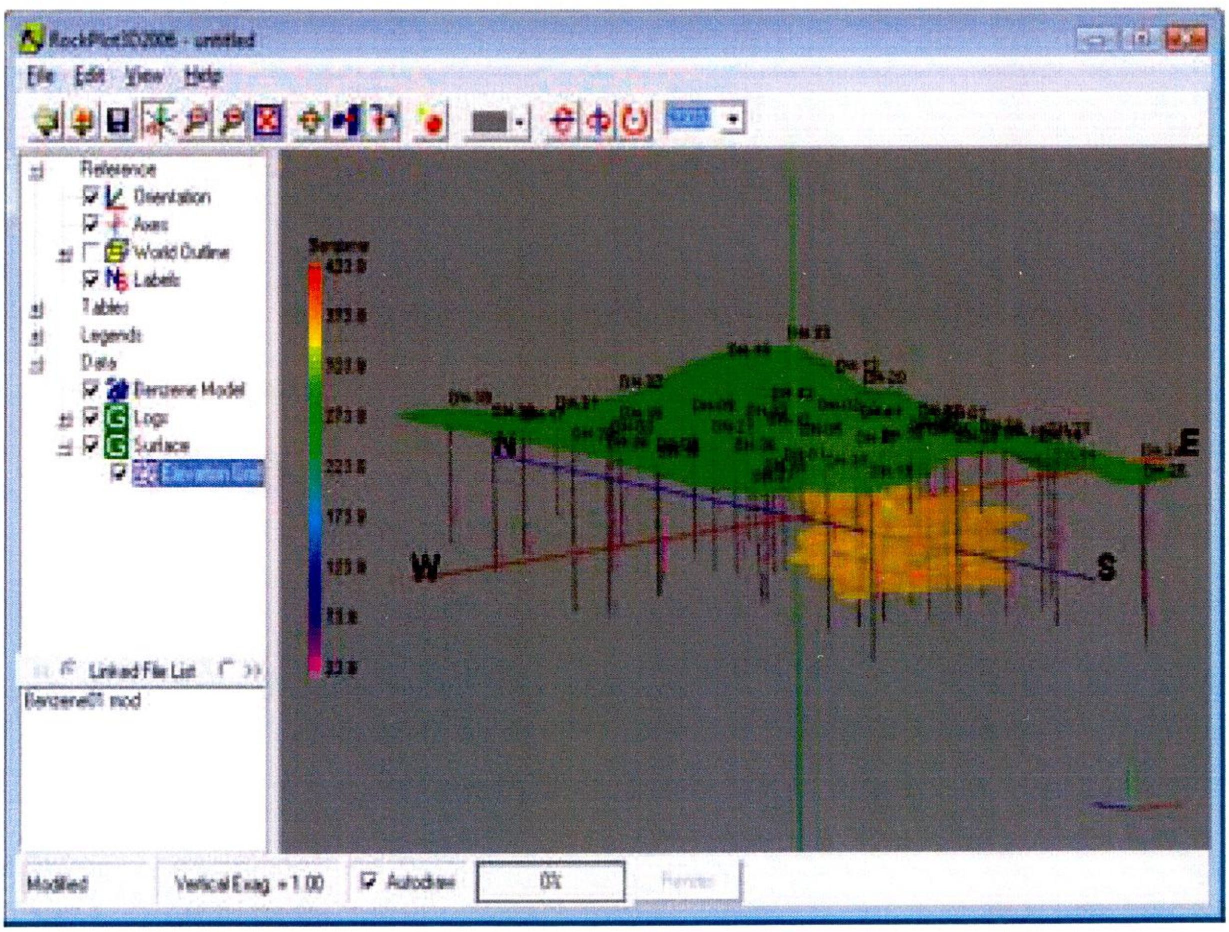
RockPlot2D:

This is the window in which 2D (flat) maps, logs, and diagrams are displayed. This window is displayed automatically each time that a 2D graphic is generated. This window can either be embedded in the program Options window, or displayed as a stand-alone window. You can open a blank RockPlot2D window using the Window / RockPlot2D menu option. You can open saved RockPlot2D files using the Project Manager.



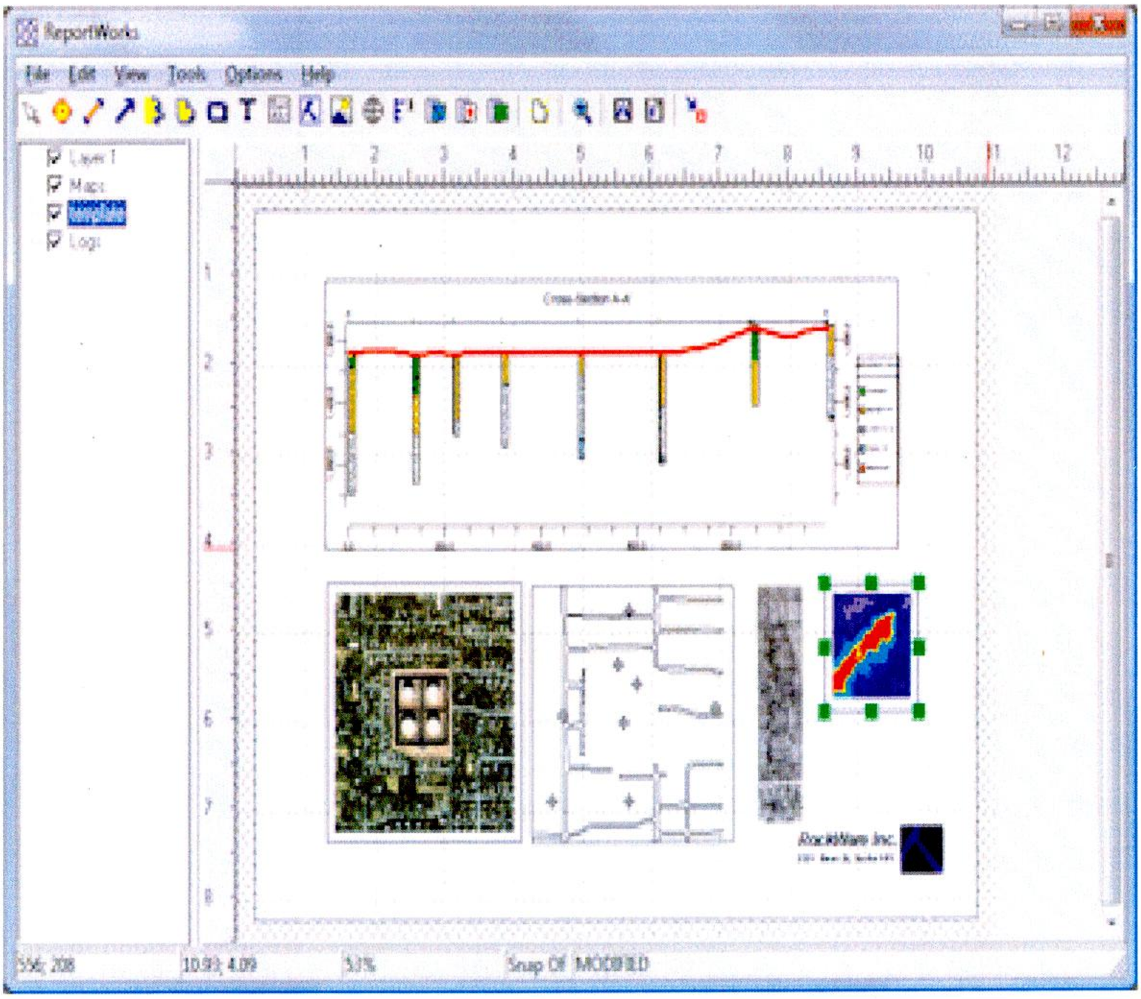
RockPlot3D:

This is the interactive window in which 3D images are displayed (surfaces, solids, 3D logs, fence diagrams, and more.) This window is displayed automatically any time that a 3D graphic is generated. This window can be embedded in the program Options windows or displayed as a stand-alone window. You can open a blank RockPlot3D window using the Window / RockPlot3D menu option. You can open saved RockPlot3D files using the Project Manager.



ReportWorks:

This is the page layout program for raster images, RockPlot2D images, with legend, text, shape, scale bar annotations. You can open a blank ReportWorks window using the Window / ReportWorks menu option. You can open saved ReportWorks files using the Project Manager.



3.5 Getting Started in the Borehole Manager :

Here are some reminders about how RockWorks works and things to remember when working with the RockWorks Borehole Manager.

1. Create New Project: When you're starting a new project, launch RockWorks and create a new project using Project / New.

Borehole data for each project is stored in a Microsoft Access database or MDB file. Each project has its own database in its own project folder. Models and graphics are stored in the project folder, too.

2. Enter Data: Once the project is created, you can enter your data. You can import your borehole data from Excel files, and other formats.You can also hand-enter the borehole data. Use File / New Log to add a new borehole record.

. Use the Edit / Edit Data as Spreadsheet as a neat tool for spreadsheet-style editing of a table, including copy/pasting, etc.

Location Data :

LOCATION	EASTING	NORTHING	LATTITUDE	LONGITUDE	ELEVATION	TD
Mangalore S1	2,575.00	3,060.00	12.974318	74.841544	7.6	54
Mangalore S2	2,675.00	3,060.00	12.974319	74.842466	5.49	50.7
Mangalore S3	2,705.00	3,160.00	12.975223	74.842742	5.96	44
Mangalore S4	2,970.00	3,725.00	12.980334	74.845182	5.96	49
Mangalore S5	2,920.00	3,790.00	12.980921	74.844721	5.805	55
Mangalore S6	3,290.00	3,740.00	12.980471	74.848133	7.08	53
Mangalore S7	3,280.00	3,650.00	12.979657	74.848041	12.24	60.4
Mangalore S8	3,275.00	3,505.00	12.978346	74.847996	12.25	76
Mangalore S9	3,496.00	3,440.00	12.977759	74.850034	23.17	68
Mangalore S10	3,420.00	3,427.50	12.977646	74.849333	26.6	58
Mangalore S11	3,520.00	3,440.00	12.97776	74.850255	9.7	56
Mangalore S12	3,750.00	3,410.00	12.977489	74.852376	8.54	76
Mangalore S13	3,275.00	3,045.00	12.974186	74.847998	5.85	63.4
Mangalore S14	3,986.00	3,145.00	12.975094	74.854554	11.56	43.5
Mangalore S15	4,445.00	3,160.00	12.975232	74.858786	16.07	68.4
Mangalore S16	3,835.00	3,914.50	12.982052	74.853157	57.13	61.1

Lithology Data :

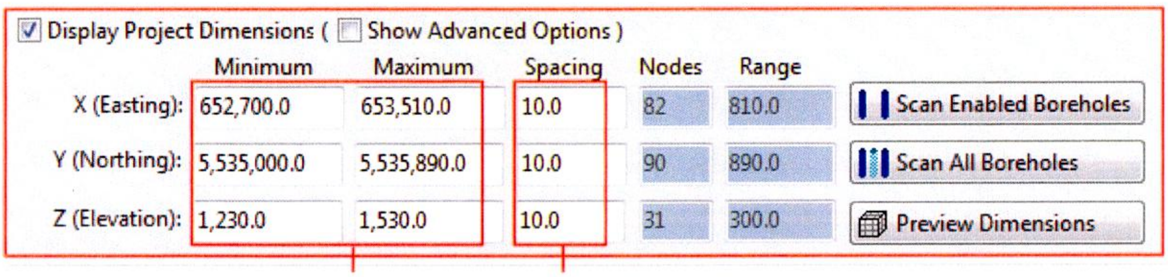
borehole	depth1	depth2	LITHOLOGY
Mangalore S1	0	9.7	Alluvium
Mangalore S1	9.7	54	Granite
Mangalore S2	0	11.9	Alluvium
Mangalore S2	11.9	50.7	Granite
Mangalore S3	0	4.8	Alluvium
Mangalore S3	4.8	44	Granite
Mangalore S4	0	5	Alluvium
Mangalore S4	5	49	Granite
Mangalore S5	0	5.75	Alluvium
Mangalore S5	5.75	55	Granite
Mangalore S6	0	4.6	Alluvium
Mangalore S6	4.6	53	Granite
Mangalore S7	0	6.5	Alluvium
Mangalore S7	6.5	60.4	Granite
Mangalore S8	0	8	Alluvium
Mangalore S8	8	76	Granite
Mangalore S9	0	2	Alluvium
Mangalore S9	2	68	Granite
Mangalore S10	0	11.5	Alluvium
Mangalore S10	11.5	58	Granite
Mangalore S11	0	9	Alluvium
Mangalore S11	9	56	Granite
Mangalore S12	0	6.5	Alluvium
Mangalore S12	6.5	76	Granite
Mangalore S13	0	10.8	Alluvium
Mangalore S13	10.8	63.4	Granite
Mangalore S14	0	1.5	Alluvium
Mangalore S14	1.5	43.5	Granite
Mangalore S15	0	8.75	Alluvium
Mangalore S15	8.75	68.4	Granite
Mangalore S16	0	10.1	Alluvium
Mangalore S16	10.1	61.1	Granite

Stratigraphy Data :

borehole	depth1	depth2	STRATIGRAPHYY
Mangalore S1	0	9.7	Alluvium
Mangalore S1	9.7	54	Granite
Mangalore S2	0	11.9	Alluvium
Mangalore S2	11.9	50.7	Granite
Mangalore S3	0	4.8	Alluvium
Mangalore S3	4.8	44	Granite
Mangalore S4	0	5	Alluvium
Mangalore S4	5	49	Granite
Mangalore S5	0	5.75	Alluvium
Mangalore S5	5.75	55	Granite
Mangalore S6	0	4.6	Alluvium
Mangalore S6	4.6	53	Granite
Mangalore S7	0	6.5	Alluvium
Mangalore S7	6.5	60.4	Granite
Mangalore S8	0	8	Alluvium
Mangalore S8	8	76	Granite
Mangalore S9	0	2	Alluvium
Mangalore S9	2	68	Granite
Mangalore S10	0	11.5	Alluvium
Mangalore S10	11.5	58	Granite
Mangalore S11	0	9	Alluvium
Mangalore S11	9	56	Granite
Mangalore S12	0	6.5	Alluvium
Mangalore S12	6.5	76	Granite
Mangalore S13	0	10.8	Alluvium
Mangalore S13	10.8	63.4	Granite
Mangalore S14	0	1.5	Alluvium
Mangalore S14	1.5	43.5	Granite
Mangalore S15	0	8.75	Alluvium
Mangalore S15	8.75	68.4	Granite
Mangalore S16	0	10.1	Alluvium
Mangalore S16	10.1	61.1	Granite

3. Project Dimensions:

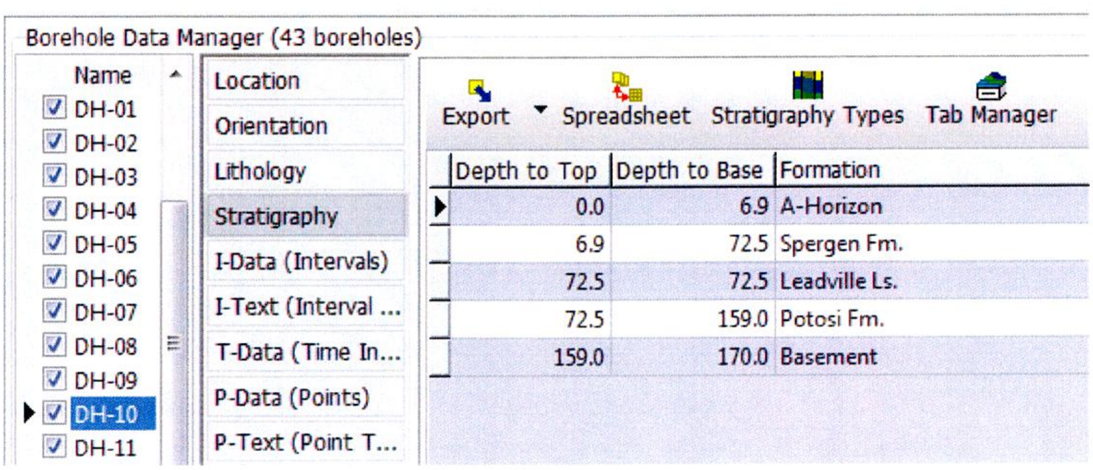
When your borehole data is entered/imported, be sure to
establish the project dimensions.
This is easily done by scanning all/enabled boreholes using the buttons.



4. Types Tables:

Remember that lithology materials, stratigraphy formations, and well construction materials link to respective "Types" tables that you create.
The formations in the Stratigraphy Types Table must be listed in order from the ground downward for proper modeling to take place.
RockWorks uses the background colors you've selected for the materials when displaying 3D logs, and 3D surfaces and solids.

STRATIGRAPHY TABLE :



DATA ADDED AS SPREADSHEET :

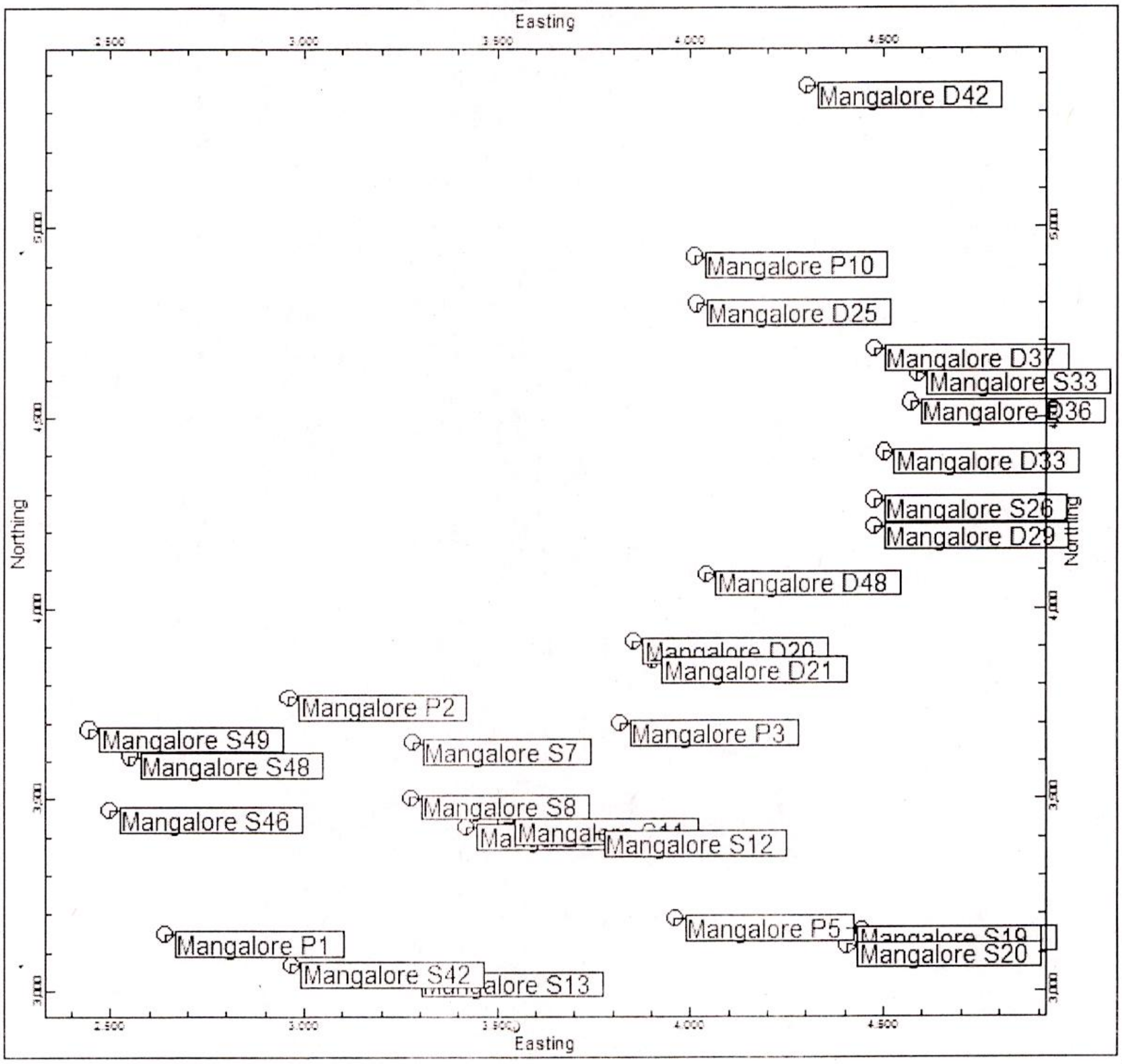
Borehole Name	Enabled	Easting	Northing	Elevation	Total Depth	Longitude	Latitude	Township	Symbol
Mangalore D10	FALSE	3,420.00	3,460.00	28.786	28.5	74.84933	12.97794	483,660.00	14/0
Mangalore D20	TRUE	3,851.00	3,914.50	59.03	50.6	74.85331	12.98205	484,091.00	14/0
Mangalore D21	TRUE	3,901.00	3,865.50	60.13	70.5	74.85377	12.98161	484,141.00	14/0
Mangalore D23	FALSE	4,470.00	5,225.00	72.256	20	74.85901	12.99391	484,710.00	14/0
Mangalore D24	FALSE	4,295.00	5,079.50	78.33	20	74.85739	12.99259	484,535.00	14/0
Mangalore D25	TRUE	4,015.00	4,800.00	58.5	50.2	74.85481	12.99006	484,255.00	14/0
Mangalore D27	FALSE	4,205.00	5,020.00	78.184	20	74.85656	12.99205	484,445.00	14/0
Mangalore D28	FALSE	4,690.00	4,055.00	68.07	20	74.86104	12.98333	484,930.00	14/0
Mangalore D29	TRUE	4,475.00	4,215.00	68.03	65	74.85906	12.98477	484,715.00	14/0
Mangalore D30	FALSE	4,500.00	4,225.00	67.635	60.6	74.85929	12.98486	484,740.00	14/0
Mangalore D31	FALSE	4,640.00	4,260.00	67.52	20	74.86058	12.98518	484,880.00	14/0
Mangalore D32	FALSE	4,700.00	4,260.00	70	77.4	74.86113	12.98518	484,940.00	14/0
Mangalore D33	TRUE	4,500.00	4,410.00	73.96	65	74.85929	12.98654	484,740.00	14/0
Mangalore D35	FALSE	4,500.00	4,540.00	74.08	20.45	74.85929	12.98771	484,740.00	14/0
Mangalore D36	TRUE	4,570.00	4,540.00	74.14	65.4	74.85993	12.98771	484,810.00	14/0
Mangalore D37	TRUE	4,475.00	4,680.00	73.973	70.3	74.85906	12.98898	484,715.00	14/0
Mangalore D38	FALSE	4,555.00	4,660.00	74.039	70	74.85979	12.9888	484,795.00	14/0
Mangalore D39	FALSE	4,565.00	4,900.00	78.25	20	74.85988	12.99097	484,805.00	14/0
Mangalore D41	FALSE	4,480.00	5,200.00	72.126	20	74.8591	12.99368	484,720.00	14/0
Mangalore D42	TRUE	4,300.00	5,370.00	69.721	63	74.85744	12.99522	484,540.00	14/0
Mangalore D43	FALSE	4,820.00	4,190.00	57.13	55	74.86224	12.98455	485,060.00	14/0
Mangalore D44	FALSE	4,820.00	4,270.00	68.23	65	74.86224	12.98527	485,060.00	14/0

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS :

4.1.1 BOREHOLE LOCATIONS :

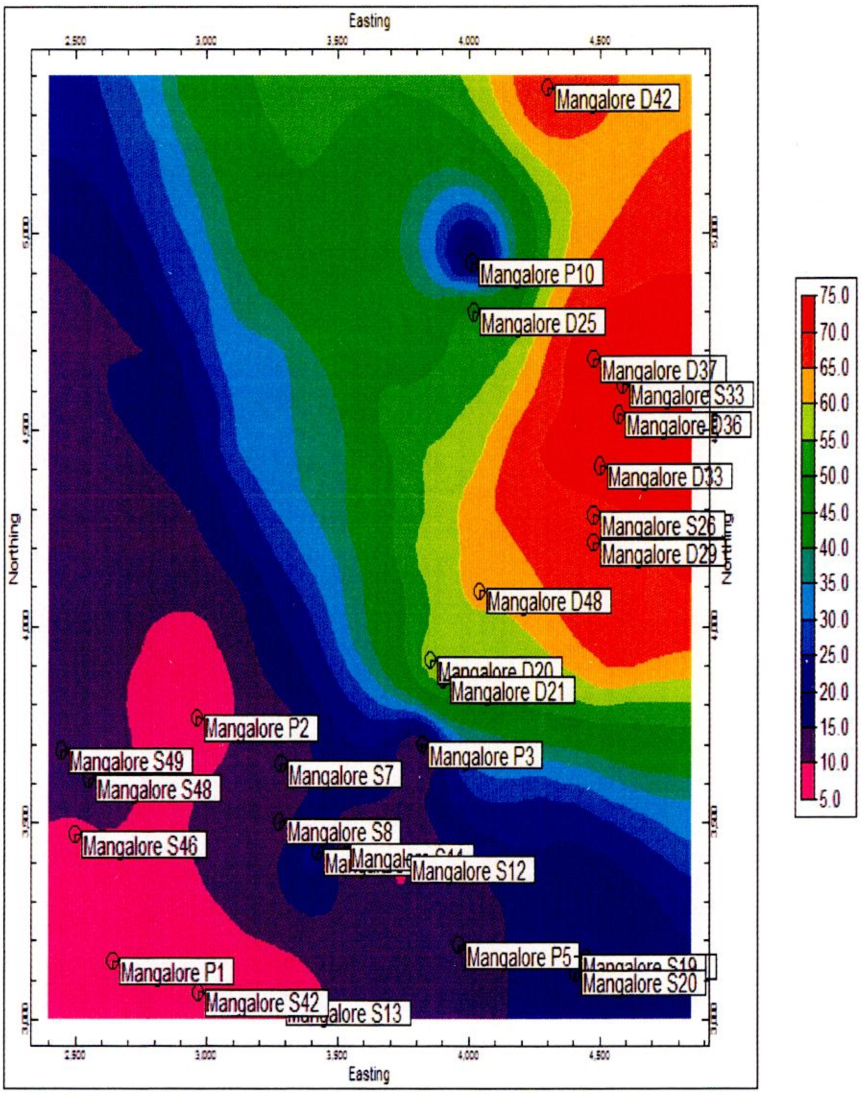


BOREHOLE LOCATION :

Borehole location can be shown in two different views :

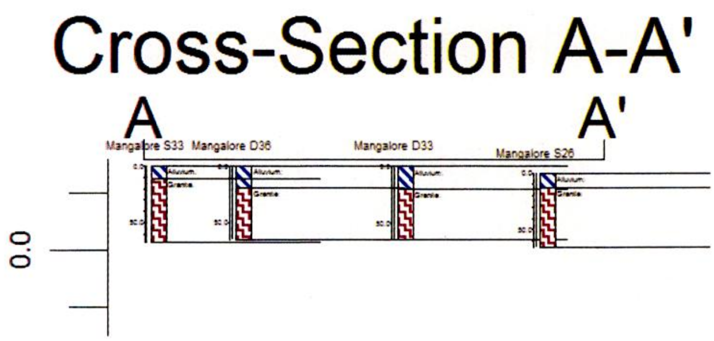
As shown in fig. Borehole locations can be created . These locations are of boreholes entered in rockware data.

CONTOUR BASED BOREHOLE LOCATIONMAP :



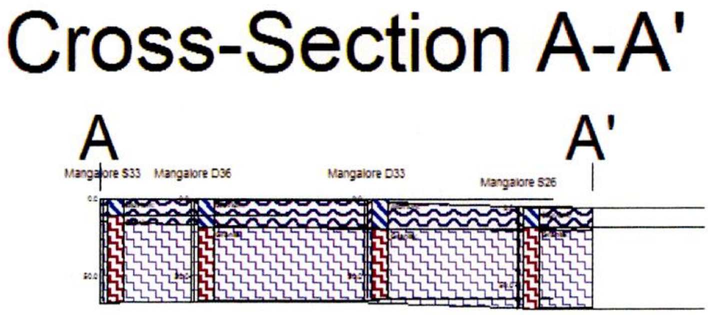
A contour based map of boreholes can also be created using rockware software. This fig shows the boreholes formation .

4.1.2 LITHOLOGIC SECTION :



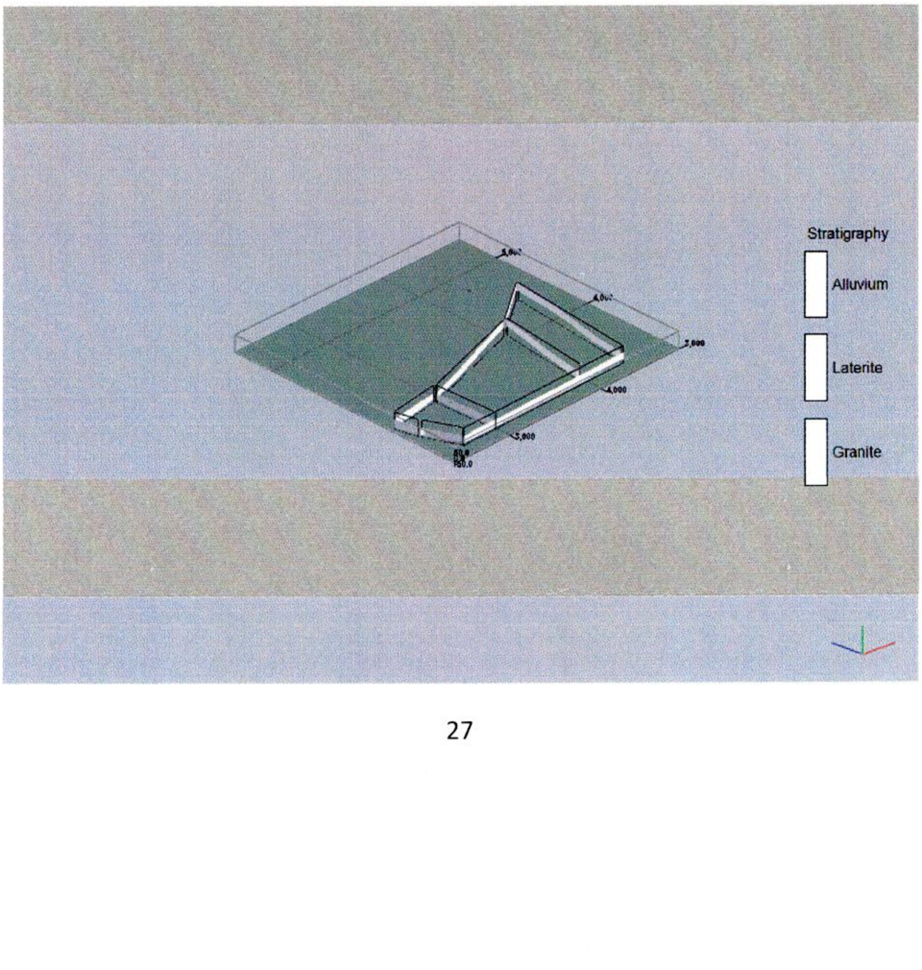
In rockworks software , lithologic sections are created . Above given diagram shows lithologic section of different boreholes . This section shows the formation of boreholes like of which soil they are made. Fig shows alluvium and granite which forms the lithology of boreholes .

4.1.3 STRATIGRAPHY SECTION :



Stratigraphic section shows the stratigraphy of the boreholes . Above given diagram shows the stratigraphy of boreholes . This section shows alluvium and granite formation

4.1.4 STRATIGRAPHY FENCE DIAGRAM :



FENCE DIAGRAMS :

Fence diagrams made are of two different types

Fence diagram is created in stratigraphic section . This diagram shows the location of different boreholes with a connected branch of themselves .

FENCE DIAGRAM USING GOOGLE EARTH :

Fence diagram using google earth can be plotted as shown in above given figure . Thisdiagram is different in sense from the simple fence diagram .The difference is that it shown on google map and shows the location of boreholes which are selected for the location purpose on google map .

4.2 DISCUSSION :

As is known , rockware 15 is used for creating profiles ,sections (lithologic and stratigraphic) , and fence diagrams are also created using google earth.

Borehole data entered is processed and worked out for creating section maps. Data used is processed and diagrams of desired formations are mapped . these diagrams are used for understanding lithology of that place where boreholes were made .

As is known that lithologic sections and profiles can be created . these section are also seen by cutting across the section of different boreholes .

Stratigraphy sections , profiles , fence diagrams are also useful in understanding the stratigraphy of the ara , boreholes created over that place . Fence diagrams are made using google earth in rockware .

Rockwrae is thus useful in showing stratigraphy of the area , boreholes, their fence diagrams using google earth . which makes the work easy to understand and workable .

PART 2

STUDY OF WATER QUANTITY IN DELHI

1 INTRODUCTION :

1.1 LOCATION :

National Capital Territory (NCT) of Delhi lies between 28^0 24' 17" N to 28^0 53' 00" N Latitudes and 76^0 50' 24" to 77^0 20' 37" E Longitudes. The State covers an area of 1485 km^2 out of which 1039 km^2 is rural. The maximum length and width of the area are 51.90 km and 48.48 km respectively (Director of Census Operations, 1971). Presently, about 16.2 million people are living in NCT Delhi.

Recently NCT Delhi has been divided into 9 districts and 27 Tehsils / sub from administrative point of view. As per the census of 2001, Delhi has 3 Statutory Towns, 59 Census Towns and 165 Villages.

Table : Administrative details of NCT, Delhi

Sl. No.	Name of the district	Area (km²)	Population in million	Density Per km²
1.	North West	440	2.85	6,471
2.	North	60	0.78	12,966
3.	North East	60	1.76	29,395
4.	East	64	1.45	22,637
5.	New Delhi	35	0.17	4,909
6.	Central	25	0.64	25,760
7.	West	129	2.12	16,431
8.	South West	420	1.75	4,165
9.	South	250	2.26	9,033
	Total	1,483	13.78	9,294

1.2 FORMATION :

The Delhi region is a part of the Indo-Gangetic Alluvial Plains, situated at an elevation ranging between 198 and 220 m above mean sea level (amsl), transacted by a quartzite rocky ridge (maximum elevation of 318.52 m amsl) extending roughly from north-east to south-east. The ridge forms the principal watershed of the area and acts as a groundwater divide between the western and eastern parts of NCT, Delhi.

2 HYDROLOGICAL FEATURES OF NCT DELHI :

2.1 METEOROLOGY

The NCT, Delhi has a tropical steppe climate. The general prevalence of continental air leads to relatively dry conditions with extremely hot summers and cold winters. Monthly mean temperatures range from 14.3° C in January (minimum 3°C) to 34.5°C in June (maximum 47°C). Daily maximum temperatures during hottest months of May and June exceed 40°C. The annual mean temperature is 25.3° C.

The main seasonal climatic influence is the monsoon rainfall, typically from June to September. The mean annual rainfall in NCT Delhi is 611.8 mm with large year-to-year variation (Fig. 2.1-1). About 573 mm rainfall occurs during the monsoon months. Most of the rainfall occurs in three months of July, August and September (about 81%). The rest of the annual rainfall is received as winter rains and as thunderstorms in the pre and the post monsoon seasons. During the 100 years period (1901-2000), 1933 was the year with highest annual rainfall, which amounted to 1535 mm (251% of the normal). The lowest rainfall amounting to only 269mm (44% of the normal) was recorded in 1951. Table provides details of normal rainfall and average number of rainy days during different months in a year. Normal rainfall distribution and pan evaporation are depicted in figure.

Thunderstorms and dust storms are most common during April to June. Some of the thunderstorms are dry whereas others are accompanied with heavy rain-fall and occasional hail.

Records of rainfall in the NCT are available for 13 stations viz. Chandrawal, New Delhi (Safdarjang), Delhi University, New Delhi (Palam), Okhla, Mehrauli, Delhi Sadar, Nangloi, Shahdara, Najafgarh, Badli, Alipur and Narela. On an average, rain of 2.5 mm or more falls 27 days in a year. Of these, 19 days are during the monsoon months. Two to three days in June are rainy days. The heaviest rainfall in 24 hours recorded at any station in the territory was 495mm at Safdarjung on 9th September 1875.

Table: The normal monthly rainfall for NCT Delhi

Months	*Normal rainfall (mm)*	***Average number of rainy days with rainfall 2.5 mm or more.***
January	14.5	1.2
February	13.2	1.0
March	9.9	0.8
April	5.5	0.5
May	9.2	0.8
June	38.8	2.1
July	191.6	7.4
August	197.4	7.9
September	105.3	4.0
October	19.3	0.8
November	2.8	0.1
December	4.3	0.4

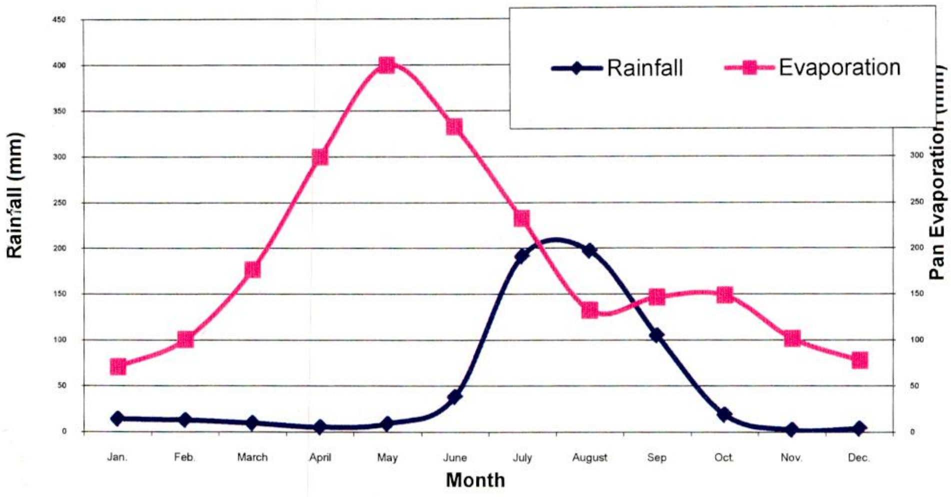


Fig: Normal Rainfall and Pan Evaporation

2.2 GEOMORPHOLOGY :

Delhi is located in the heart of Indian Sub-continent between Himalayan and Aravali ranges of mountains. It is surrounded by Uttar Pradesh in the East and Haryana in the West, North and South.

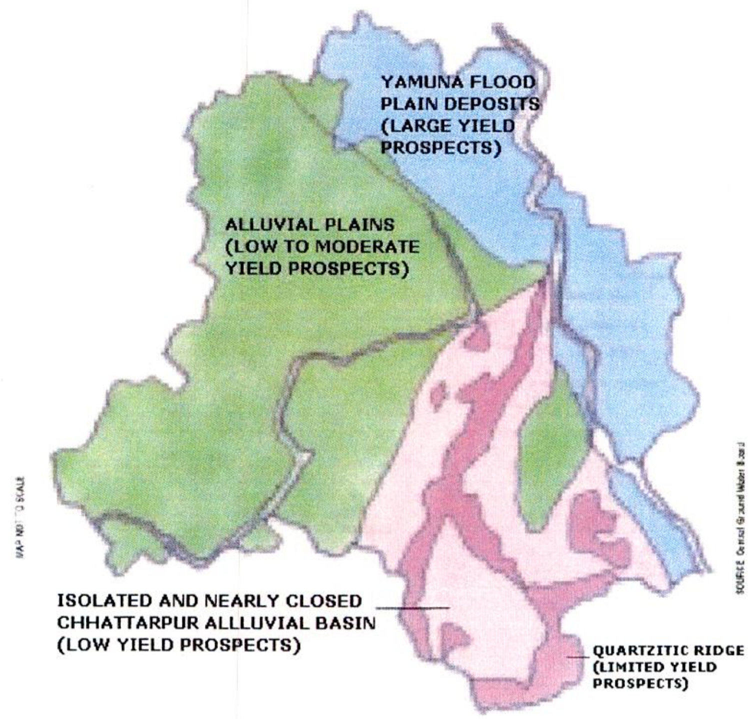
Physiographically, the NCT, Delhi can be divided into four parts: (1) the Delhi Ridge, (2) the alluvial plain to the east of the Delhi Ridge; (3) the alluvial plain to the west of the Delhi Ridge; and (4) the closed basin of Chatttarpur

2.3 HYDROGEOLOGY :

The Delhi ridge, which is the northern most extension of Aravali mountain range, consists of quartzite rocks and extends from southern part of the territory to western bank of river Yamuna for about 35 km. The alluvial formations overlying the quartzitic bed rock have different nature on either side of the ridge. The alluvium thickness varies from less than one meter to about 30 m in the central and southern parts and more than 300 m in the western and eastern parts. Both the shallow as well as the deeper wells have a common groundwater table.

Table: General stratigraphic sequence in NCT Delhi

Quaternary	Newer Alluvium	Unconsolidated, Inter-bedded lenses of sand, silt, gravel and clay in narrow flood plains of YamunaRiver.
	Older Alluvium	Unconsolidated inter bedded, inter-fingering deposits of sand, clay and kankar, moderately sorted. Thickness variable, at places more than 300 m.
Pre-Cambrian	Alwar Quartzites	Well stratified, thick bedded, brown to buff colour, hard and compact, intruded locally by pegmatite and quartz veins inter-bedded with mica schist.



Hydrogeological map of NCT, Delhi

2 WATER DEMAND SCENARIO :

Past and Projected Population of NCT Delhi from 1951 to 2016

Population as per census		Projected Population	
Year	Population (million)	Year	Population (million)
1951	1.74	2006	16.2
1961	2.66	2011	18.2
1971	4.07	2016	19.9
1981	6.22		
1991	9.42		
2001	13.78		

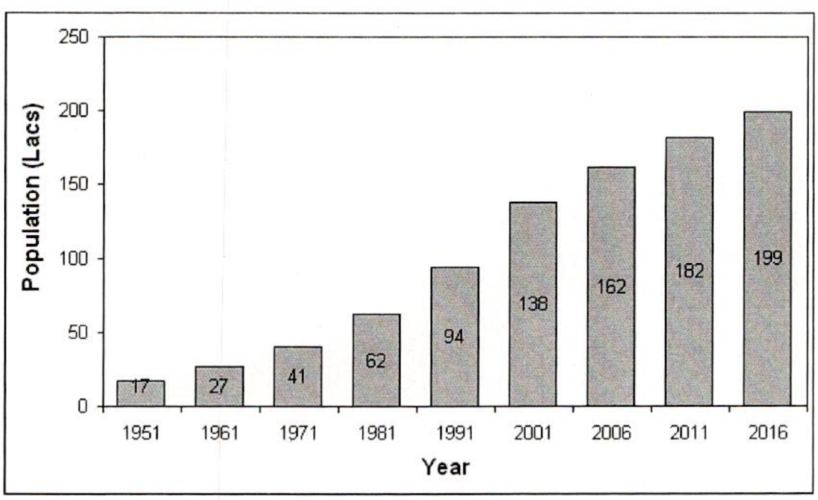


Fig: Population of Delhi from 1951 and projected upto 2016.

3.1 WATER DEMAND

To estimate future water demand, two norms are in vogue. As per the Central Public Health and Environmental Engineering Organisation's (CPHEEO) norms prescribed in MPD 2001, water demand is assessed as 274 LPCD (60 GPCD).

Table : Break-up of water Requirement as per CPHEEO Norms

S No	Norm	Water Requirement (LPCD)
1	Domestic (@150 LPCD + 15% losses)	172
2	Industrial, commercial and community requirement @45000 liters per hectare per day *	47
3	Fire protection based on 1% of the total demand *	3
4	Floating population and special uses like hotels and embassies *	52
Total with losses		274 (60 GPCD)

LPCD / GPCD– litre/ gallon per capita per day. 1 GPCD = 4.546 LPCD

Table : Break-up of water demand as per DDA norms

S No.	Norm		Potable (GPCD)	Non-potable (GPCD)	Total (GPCD)
1	Domestic	Residential	30	20	50
2	Non-domestic	Irrigation, horticulture, recreational, construction, fire protection @6.75 LPCD + losses	-	10	10
		Public, Semi-public, Industrial, commercial	5	15	20
Total inclusive of losses			35	45	80 (364 LPCD)

Using both these norms, the projected water requirement for NCT Delhi is given in *Table* Based on the norm of CPHEEO, the projected water demand for NCT Delhi in the year 2006 is 972 MGD, in 2011 is 1092 MGD and in the year 2016 is 1194 MGD .

GROUND WATER RECHARGE:

GROUND WATER REACHARGE THROUGH RAINFALL:

The normal annual rainfall in NCT Delhi varies from 337 mm to 888 mm measured at 13 meteorological observatories. The lowest rainfall is recorded in West district and the highest rainfall in North and North East districts. The annual groundwater recharge from rainfall in NCT Delhi is 150.02 MCM (15042 HaM), highest being in North West and South West districts that have larger areas and lowest in Central and New Delhi districts.

GROUND WATER RECHARGE THROUGH OTHER SOURCES:

CANAL SEEPAGE: The most prominent canal and drainage systems in Delhi are Western Yamuna Canals and Najafgarh drain. The annual recharge to the groundwater from canal seepage is the highest in South West district, followed by West district, and North West district (around 1000 ham or more). In the districts of North, East, North East and South districts, the annual recharge from canal seepage is within 5 MCM (500 HaM). Central and New Delhi districts do not have any prominent drainage system. Recharge from canal seepage for the NCT Delhi is 68.42 MCM (6842 HaM).

RETURN FLOW FROM SURFACE IRRIGATION: As per 3rd M.I. Census (draft), surface irrigation is prevalent only in the North West district. The annual recharge from return flow from irrigation in North West district is 1.03 MCM (103 HaM).

RETURN FLOW FROM GROUND WATER IRRIGATION: Groundwater irrigation is most common in North West district, followed by South West district and West district. East, North East and South districts have smaller shares of groundwater irrigation. Hence, return flow from groundwater irrigation is in the descending order for North West > South West > West > South >, East > North East districts. Recharge from groundwater irrigation in NCT Delhi is 58.29 MCM (5829 HaM).

RECHARGE FROM RETURN FLOW FROM FARMHOUSES: Farmhouses use groundwater in large quantity. These are more prevalent in South West district followed by South district. The groundwater recharged through return flow from farmhouses in NCT Delhi is estimated to be 4.55 MCM (455 HaM).

RECHARGE FROM WATER CONSERVATION STRUCTURES: Water conservation structures constructed by Government, non-government, private and individuals efforts in the form of roof top rainwater harvesting, artificial recharge to groundwater and rainwater harvesting are common in South and South West districts followed by New Delhi. In rest of the districts, rainwater harvesting is negligible. The total annual recharge from water conservation structures for entire NCT Delhi is 13.90 MCM (1390 HaM).

RECHARGE FROM SEEPAGE FROM WATER BODIES: Water bodies occur predominantly in the rural areas of North West and South West districts followed by South district. The East and West districts have few water bodies while in rest of the districts (mostly falling in the city area), water bodies are insignificant. The annual recharge from water bodies in North West and South West district is about 17 HaM and 16 HaM, respectively. In South district, annual recharge from water bodies is 8 ham while in East and West districts, it is 4 and 2 ham respectively. The total recharge from water bodies in NCT Delhi is about 0.48 MCM (48 HaM) per year.

RECHARGE FROM OTHER SOURCES: The most significant source of recharge from other sources is seepage from drains in South West district and return flow from groundwater irrigation in North West district. The total annual recharge from other sources in NCT Delhi is of the order of 146.68 MCM (14668 HaM).

TOTAL ANNUAL GROUND WATER RECHARGE: The total annual groundwater recharge in NCT Delhi is 297.10 MCM (29710 HaM). The maximum recharge is in South West district where recharge from other sources contributes more than rainfall recharge. In North West district, contribution from rainfall is more than other sources. Central district experiences the lowest groundwater recharge annually.

RECHARGE ZONES:

The major recharge regions in the NCT Delhi are located mainly along the Delhi Ridge (mostly in the southern parts of Chattarpur Basin, Safdarjung and Shastri Park), WYC, Supplementary Drain and Najafgarh Drain.

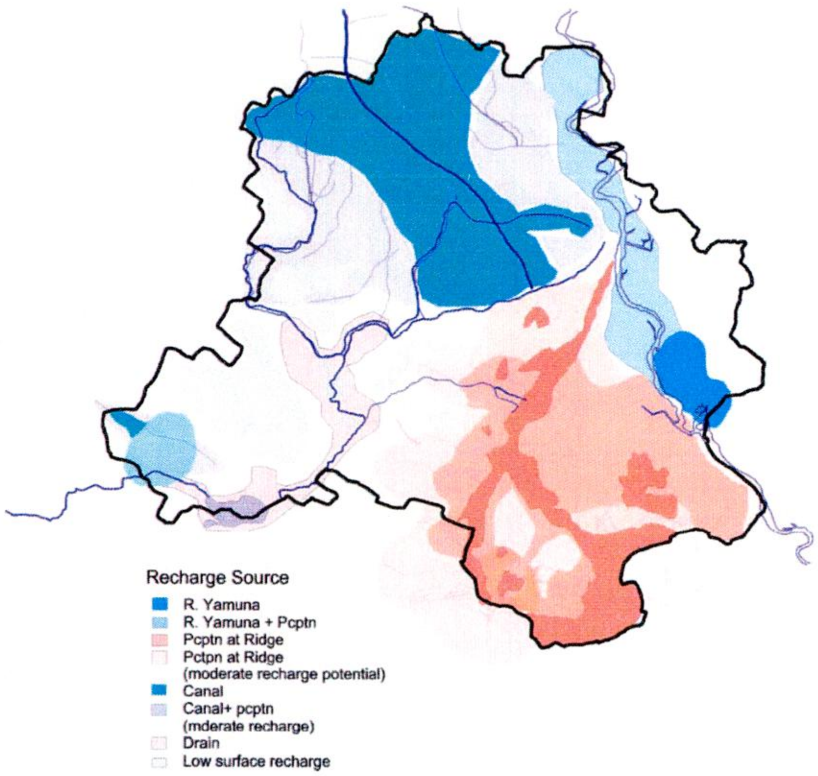


Fig : Groundwater recharge sources and recharge zones in the NCT-Delhi

GROUND WATER DRAFT:

IRRIGATION DRAFT: The total annual irrigation draft in NCT Delhi is 200.02 MCM (20002 HaM), with higher values in North West and South West districts, followed by West district. North East, East and South districts have smaller irrigation draft. Rest of the districts fall in urban area and thus do not have any irrigation draft from the groundwater.

DOMESTIC DRAFT: Domestic draft has several components viz. draft by individual households through private ownership, DJB and other civic water supply bodies and water drawn by the Institutions. The annual domestic draft of NCT Delhi is 215.06 MCM (21506 HaM), maximum being in South West district followed by South district.

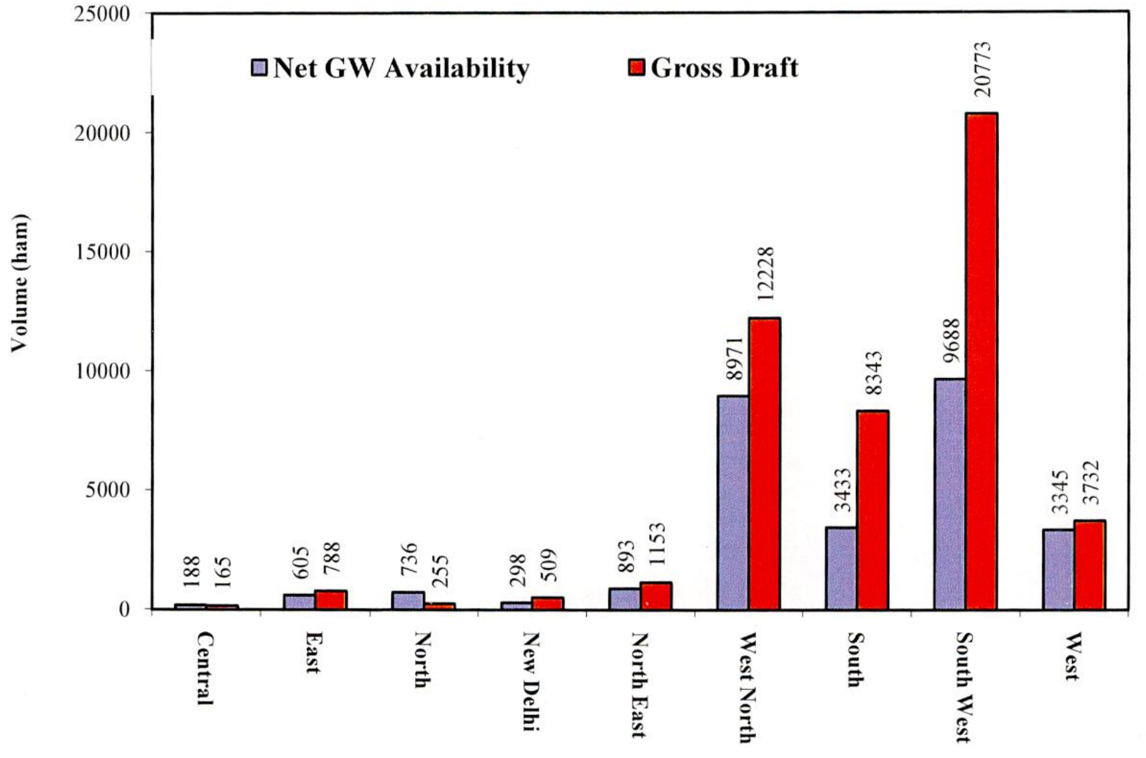


Fig.: Annual Net Groundwater Availability and Gross Groundwater Draft (ha m)

INDUSTRIAL DRAFT: Industries are mostly located in the North West, West, South, South West, East and North East districts. Industrial draft is conspicuously higher in North West, West and South districts. Central, North and New Delhi do not have any industrial area. The total annual industrial draft in NCT Delhi is about 43 MCM

GROUND WATER POTENTIAL IN DELHI :

Groundwater potential of NCT Delhi is shown in Fig.and is given in Table. Though the groundwater occurrence is controlled by hydrogeological setting, its availability in space and time is governed by recharge and pumping pattern at any given point of time. The excessive withdrawal of groundwater mainly in South, Southwest, New Delhi and Central districts has resulted into persisting decline in groundwater table.

Total Annual Groundwater Recharge in NCT Delhi is 281.57 MCM, of which 50% is through rainfall and other half through other sources. The annual gross draft for all uses is 479.46 MCM and the over-all stage of groundwater development is 170%. Highest groundwater developments has been recorded in South and South West districts of Delhi (> 200%), followed by New Delhi district (171%). In Central and North districts, the stage of groundwater development is comparatively low (<100%), which can be attributed to the proximity of these districts to the ridge that acts as a recharge zone.

Fig.: Categorization of Districts in NCT Delhi

SURFACE WATER AVAILABILITY:

Surface water contributes to over 85% of Delhi's total water supply. The Yamuna, being a perennial river, fulfills the major need while the Ganga and Sutlej rivers also meet the demand partially. The quantity of water allocated to NCT Delhi from Yamuna, Ganga and Satluj (Bhakra System) through interstate agreements/ MoUs/ understandings is as follows;

Yamuna	=	724.00 MCM (consumptive)
Ganga	=	178.80 MCM
Sutlej (Bhakra System)	=	300.02 MCM
Total	=	1202.82 MCM (~722 MGD)

THE YAMUNA RIVER WATER:

Based on 75% dependability, the notional virgin flow in the Yamuna River (upto Okhla) has been assessed as 11.70 Billion Cubic Meter (BCM) and mean annual availability has been assessed as 13.00 BCM. In order to maximize the utilization of surface water flow in the Yamuna River, a number of Storages have been planned in Himalayan Foothill Region.

Memorandum of Understanding (MoU) dated 12.05.1994 states that "Considering their irrigation and consumptive drinking water requirements, the Basin States agree on the allocation of the utilizable water resources of river Yamuna assessed on mean yearly availability subject to the following table:

Table : State-wise Allocation of Utilizable flows of Yamuna

S. No.	State	Allocation (MCM)
1	Haryana	5,730
2	Uttar Pradesh	4,032
3	Rajasthan	1,119
4	Himachal Pradesh	378
5	Delhi	724
	Total	11,983

1. Pending construction of the storages in the upper reaches of the river, there shall be an interim seasonal allocation of the annual utilizable flow of Yamuna River as given in *Table* provided that the interim seasonal allocation are distributed on 10-daily basis.

Table : Seasonal Allocation of Yamuna Water

States	Seasonal Allocation of Yamuna waters (MCM)			
	July-Oct	Nov-Feb	March-June	Annual
Haryana	4,107	686	937	5,730
Uttar Pradesh	3,216	343	473	4,032
Rajasthan	963	70	86	1,119
Himachal Pradesh	190	108	80	378
Delhi	580	68	76	724
Total	9,056	1,275	1,652	11,983

Further, the said interim seasonal allocations shall be progressively modified, as storages are constructed, to the final annual allocations as indicated above.

2. Separate agreement will be executed in respect of each of the identified storage within the framework of overall allocation made under this agreement.
3. The allocation of available flows amongst the beneficiary States will be regulated by the Upper Yamuna River Board within the overall framework of this agreement

The provisions further indicate that in a year when the availability is more than the assessed quantity, the surplus availability will be distributed amongst the States in proportion to their allocations. Also, in a year when the availability is less than the assessed quantity, first the drinking water allocation of Delhi will be met and the balance will be distributed amongst Haryana, U.P., Rajasthan and H.P. in proportion to their allocations"

The MoU also envisages that "a minimum flow in proportion of completion of upstream storages going upto 10 cumec shall be maintained downstream of Tajewala and downstream Okhla Head works throughout the year for ecological considerations, as upstream storages are built up progressively in a phased manner. It also assessed that a quantum of 0.68 BCM may not be utilizable due to flood spills".

However, supply to Delhi is no longer governed by this seasonal distribution, and as per a Supreme Court order of 29-2-1996, Delhi gets about 310 MGD, i.e. 171 MCM for every four-month period, evenly throughout the year.

The Ganga River Water: Delhi is getting 200 cusecs (178.8 MCM) of Ganga water since April 1983 and a 100 MGD Water Treatment Plant is in operation at Gokulpuri using this water (2005-06). To give legal sanctity to the supply of this water, a MoU between Delhi Jal Board and UP government is to be executed.

There is also a proposal to supply 300 cusecs of Ganga water to NCT Delhi from Tehri dam through Upper Ganga Canal at Muradnagar.

The Sutlej Water (Bhakra System): As per the agreement of 31st December 1981 on allocation of surplus Ravi-Beas water and implementation of Sutlej-Yamuna Link Canal project between Punjab, Haryana and Rajasthan, 0.20 MAF (246.4 MCM) of water has been earmarked for Delhi water supply. Para (i) of this agreement states "According to the flow series 1921-60, the total mean supply of Ravi Beas waters is 20.56 MAF (25329.92 MCM). Deducting the pre- partition uses of 3.13 MAF (3856.16 MCM) and transit losses in the Madhopur Beas Link of 0.26MAF (320.32 MCM), the net surplus Ravi- Beas water according to the flow series 1921-60 is 17.17 MAF (21153.44 MCM) as against the corresponding figures of 15.85 MAF (19527.2MCM) for the flow series 1921-45, which forms the basis of water allocation under the 1955 Agreement. It is now agreed that the mean supply of 17.17 MAF (Flow and Storage) may be reallocated as under.

Share of Punjab	:	4.22 MAF (5199.04 MCM)
Share of Haryana	:	3.50 MAF (4312.0 MCM)
Share of Rajasthan	:	8.60 MAF (10595.2 MCM)
Quantity earmarked for Delhi water supply	:	0.20 MAF (246.4 MCM)
Share of Jammu & Kashmir	:	0.65 MAF (800.8 MCM)
	Total	17.17 MAF (21153.44 MCM)

CHAPTER 7

CONCLUSION

A number of key messages emerge from the foregoing discussion of water resources. Demand for these limited resources continues to increase as populations grow and move. Sound management depends on reliable information about the quantity and quality of water available and how this availability varies in time and from place to place. It is important to enhance the understanding of all elements of the water cycle and how human activities affect it, so that water resources can be protected and developed sustainably.

- Climate change greatly affects weather, precipitation, and the entire water cycle, including water resources both above and below ground.
- The growing problem of surface water availability and the increasing levels of water pollution and water diversions threaten to hamper or even disrupt social and economic development in many areas, as well as the health of ecosystems.
- Groundwater resources can help meet demand, but too much of it is being withdrawn and some of it is being polluted. It is important to better control the use of underground waterthat will not be replenished.
- Longstanding practices, such as collecting rainwater, are being refined and supplemented by newer techniques such as artificial recharge, desalination and re-use. More support is needed, not only for innovative technical solutions to improve supplies, but also for the management of demand and the promotion of efficiency in water use.
- Growing changes in the availability of water resources will require political support for the collection of information on water resources. That information will allow policy-makers to make better decisions about the management and use of water.

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