Bharathidasan University

Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. **M.Tech. Geological Technology and Geoinformatics**

Course code : **MTIGT0604**

GEOINFORMATICS IN WATER RESOURCES MANAGEMENT

Unit-5 : Hydrological Models

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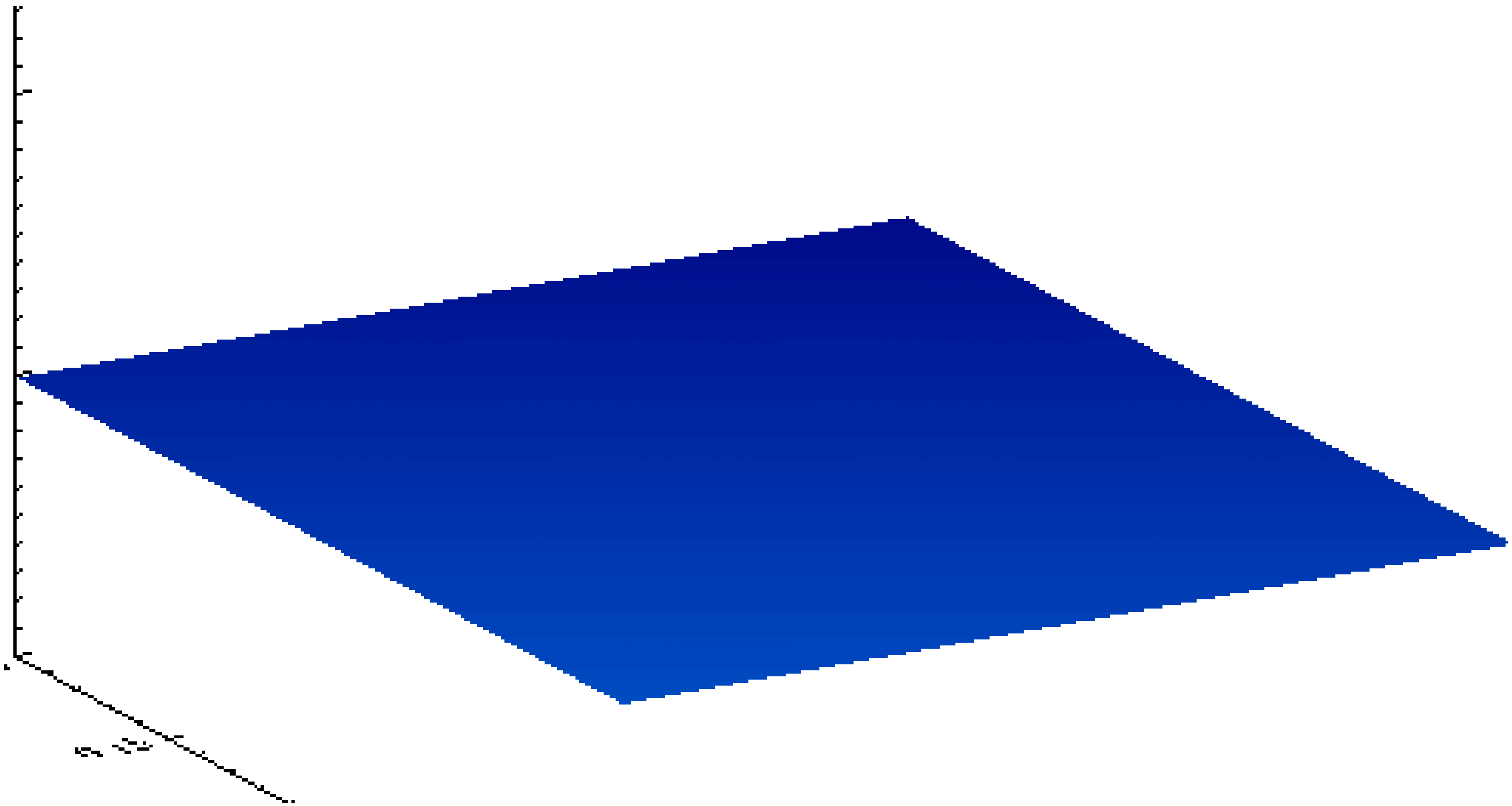
Professor, Department of Remote Sensing

MTIGT0604: SURFACE AND GROUNDWATER HYDROLOGY AND MANAGEMENT --- 4 Credits

UNIT-5. Hydrological Models: Surface Water Hydrological Models: Snow melt Runoff modeling – GIS based Runoff modeling – Various hydrological models using Geoinformatics. Models for Inter watershed water transfer. Groundwater models: Stochastic – MOD Flow- Linear – Finite Element Modeling. **12 Hrs.**

Modelling assumptions

- Assumption for developing a model includes **several independent** and **a dependent** parameters / variables and with some **constants-** as **Phenomena.**
- For e.g., Size of drop, Speed of it's fall over a calm surface water body, area, boundaries, etc.



Output from a shallow water equation model of water in a bathtub. The water experiences five splashes which generate surface gravity waves that propagate away from the splash locations and reflect off the bathtub walls

Choice of equation

- Phenomena and model geometry
- Choice of variables and parameters
- Data and knowledge acquisition
- Model building
- Calibration and verification
- Results presentation

Example-1,

– Darcy's Law of surface water flow

– User defined Equations – Quantification of surface Runoff

Example-2

- Volume of water against water spread area of tanks in a study area

Example-3

- Land management models for improving Natural Recharge of Hard rock terrain
  - Regression Model – Establishing the relationship between different terrain controlling parameters quantitatively

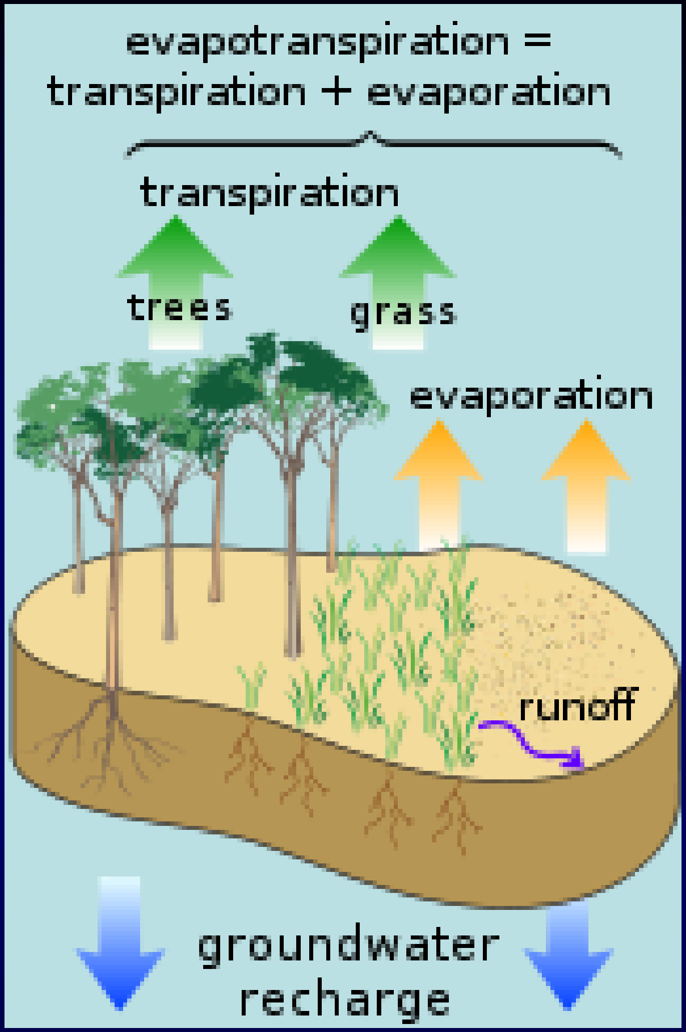
Calibration and Verification

- Model Calibration can be done by inputting a user defined value – may be density sliced values from an existing data or
- By inserting expected value ranges
- Verification can be done by conducting ground truth / field surveys or with existing secondary data

Watershed wise water management plans

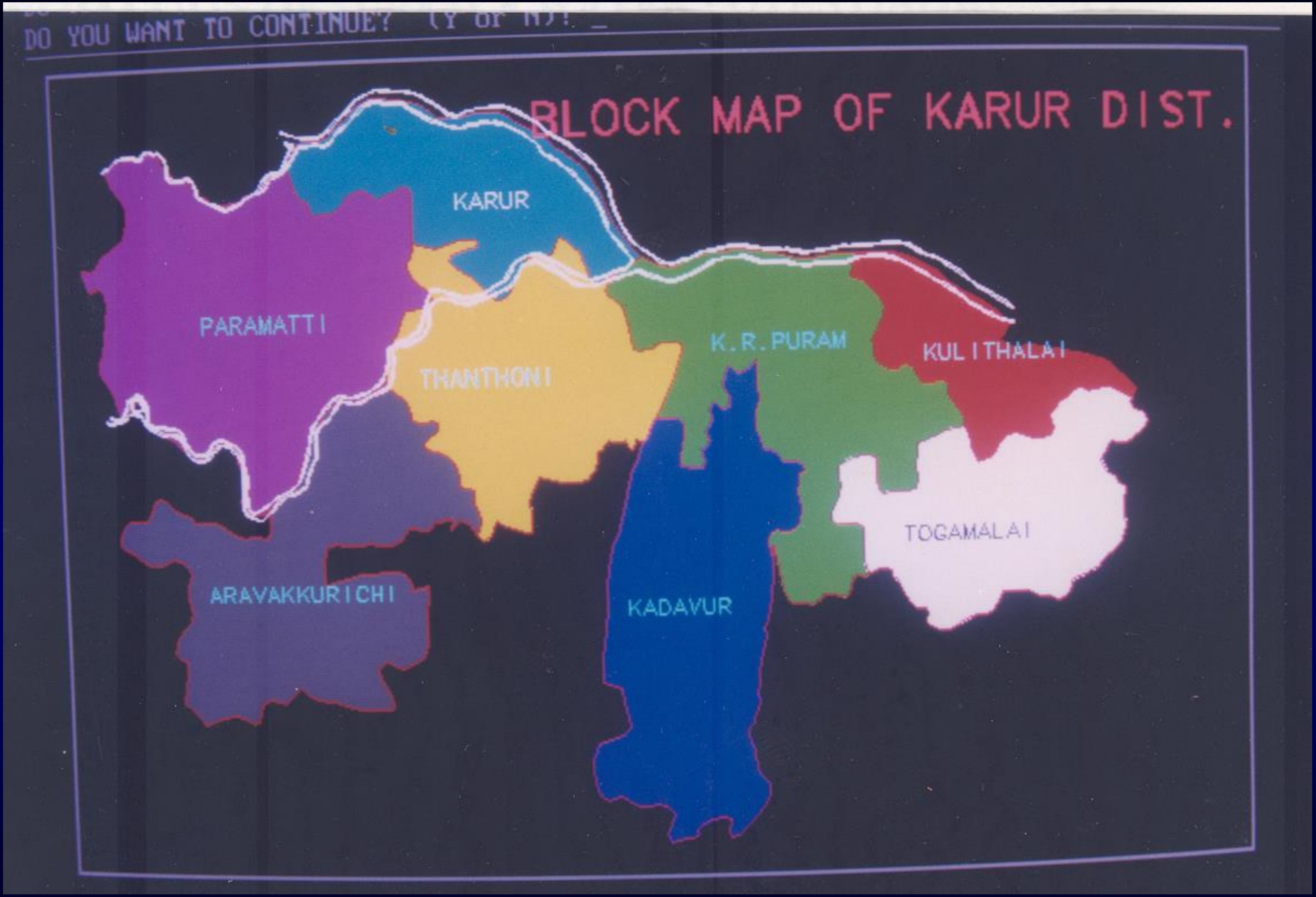
- Runoff modelling /Sw Potential
- Groundwater targetting
- Aqufer Function modellling
- GW Exploitation
- Natural Recharge model
- Artificial Recharge model
- Water Budgetting
- Interwatershed water transfer

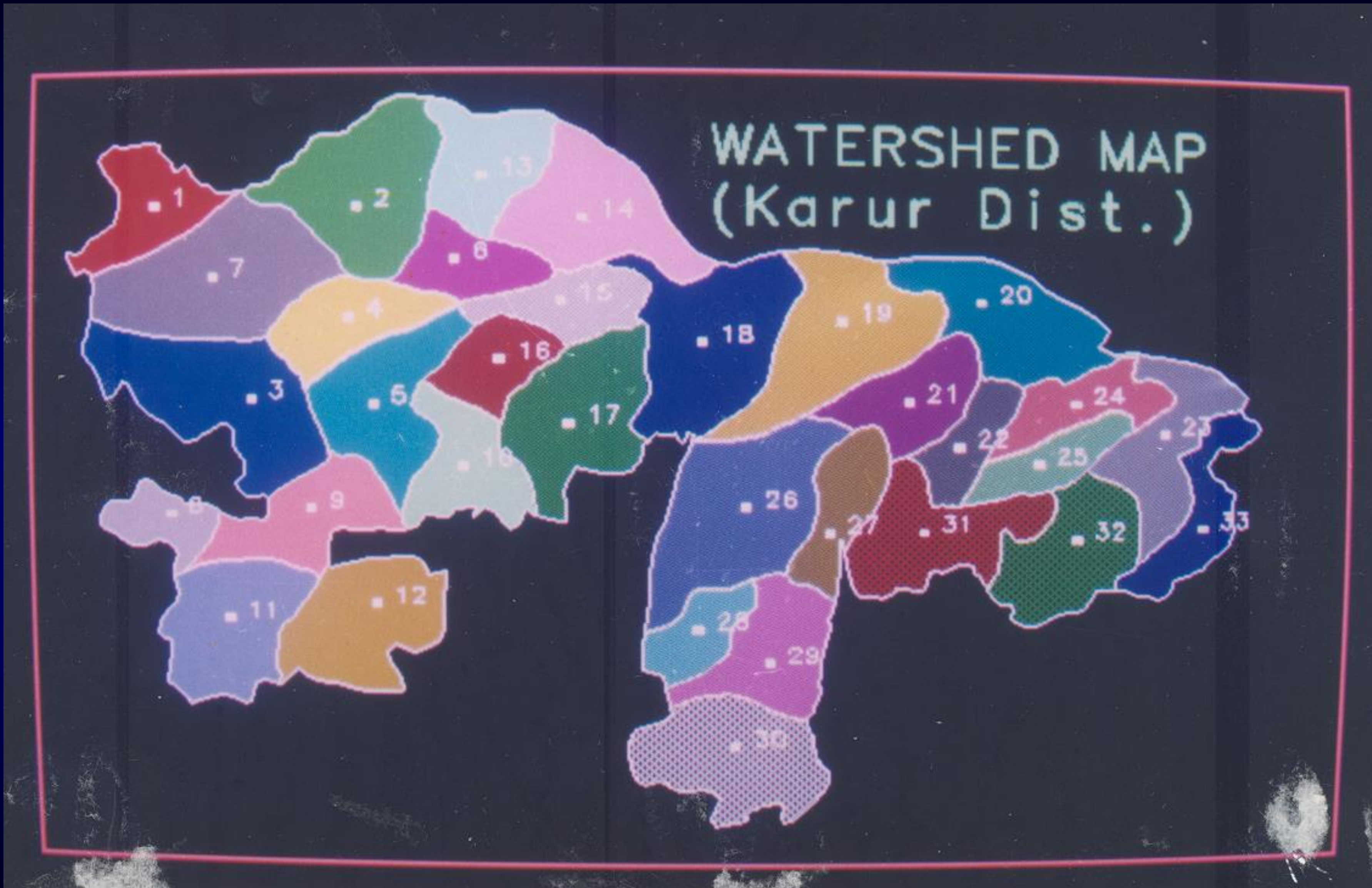
Estimation of Surface Water Potential/Runoff



Runoff from the water balance

Runoff =
(Rainfall / Snowmelt / Groundwater oozing) – (Evapotranspiration + Groundwater Recharge)


DO YOU WANT TO CONTINUE? (Y or N)! _
BLOCK MAP OF KARUR DIST.
KARUR
PARAMATTI
THANTHONI
K.R.PURAM
KULITHALAI
TOGAMALAI
ARAVAKKURICHI
KADAVUR


WATERSHED MAP
(Karur Dist.)
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The Surface water potential on watershed basis,
DRY-DAMP-WET method

For Example,

Karur District was divided into 33 sub watersheds

Subsequently other data bases were generated on

- Daily Rainfall for 30 Years (from 23 rain gauge stations)
- Mean Slope for each Watershed
- Hydrological Soil Group and
- Landuse and Land Cover

TABLE 1

SLOPE DATA

SL.NO.	WATERSHED NO.	SLOPE IN RADIANCE
1	1	0.02616
2	2	0.27610
3	3	0.02035
4	4	0.02442
5	5	0.01744
6	6	0.01744
7	7	0.03198
8	8	0.01453
9	9	0.02035
10	10	0.15180
11	11	0.04797
12	12	0.06154
13	13	0.01744
14	14	0.01744
15	15	0.02350
16	16	0.01599
17	17	0.01686
18	18	0.01744
19	19	0.01279
20	20	0.01221
21	21	0.01162
22	22	0.01279
23	23	0.01628
24	24	0.01762
25	25	0.16280
26	26	0.01162
27	27	0.01744
28	28	0.12210
29	29	0.01192
30	30	0.22677
31	31	0.04797
32	32	0.03488
33	33	0.03458

TABLE 2

HYDROLOGICAL SOIL GROUP DATA

SL.NO.	WATERSHED NO.	AREA IN Sq.Km. A	B	C	D
1	1	0.30	69.96	0.00	0.00
2	2	0.00	127.00	3.08	0.00
3	3	0.50	148.17	0.64	0.00
4	4	2.30	64.55	0.04	0.00
5	5	0.00	96.77	2.22	0.00
6	6	1.06	50.41	0.87	0.00
7	7	0.03	150.80	3.14	0.00
8	8	0.00	38.67	0.00	0.00
9	9	0.02	80.16	0.14	0.00
10	10	2.73	64.95	1.07	0.00
11	11	0.34	107.25	0.00	0.00
12	12	0.11	106.71	0.23	0.00
13	13	0.00	69.79	2.31	0.00
14	14	0.00	105.00	2.73	0.00
15	15	0.00	50.58	0.99	0.00
16	16	0.00	47.06	2.37	0.00
17	17	0.84	110.35	0.78	0.00
18	18	0.83	122.82	4.61	0.00
19	19	0.00	130.31	7.99	0.00
20	20	0.03	103.94	3.84	0.00
21	21	0.00	65.63	0.86	0.00
22	22	0.00	43.66	0.19	0.00
23	23	0.13	82.71	3.85	0.00
24	24	0.00	55.22	0.33	0.00
25	25	0.00	44.77	0.25	0.00
26	26	0.18	138.03	8.66	0.00
27	27	0.00	56.37	0.12	0.00
28	28	0.10	41.86	0.58	0.00
29	29	2.96	79.14	0.00	0.00
30	30	2.47	90.65	17.94	0.00
31	31	0.11	93.21	6.61	0.00
32	32	0.00	87.28	10.00	0.00
33	33	0.00	62.57	0.00	0.00

TABLE 3
LANDUSE AND LANDCOVER DATA

SL.NO.	WATERSHED NO.	AREA IN Sq.Km.			
		WETCROP	DRYCROP	NATURAL VEGETATION	BARREN LAND
1	1	5.56	4.12	0.00	61.07
2	2	19.25	7.25	0.00	106.96
3	3	14.75	3.43	0.00	111.95
4	4	1.81	2.06	0.00	67.63
5	5	12.65	3.87	0.00	72.85
6	6	15.62	10.06	0.00	33.44
7	7	3.75	1.43	0.00	145.20
8	8	31.30	5.75	0.00	14.95
9	9	6.25	13.87	0.00	69.56
10	10	6.47	7.81	0.00	68.95
11	11	5.50	3.93	0.00	98.82
12	12	7.43	8.75	3.25	94.07
13	13	96.06	7.60	0.00	44.38
14	14	45.56	10.62	0.00	58.32
15	15	15.93	3.00	0.00	33.05
16	16	7.25	13.50	0.00	39.50
17	17	9.94	23.62	0.00	95.01
18	18	29.93	5.75	0.00	87.94
19	19	12.62	38.12	0.00	79.60
20	20	82.87	2.00	0.50	27.16
21	21	6.27	8.39	0.25	29.53
22	22	8.06	17.75	0.00	42.35
23	23	27.50	0.25	0.00	64.88
24	24	28.00	7.00	0.00	18.50
25	25	7.13	9.25	0.00	31.00
26	26	13.08	7.82	1.00	106.35
27	27	11.24	6.25	0.00	42.35
28	28	6.00	1.50	6.75	22.15
29	29	12.93	2.00	16.00	57.57
30	30	7.50	1.80	38.50	45.80
31	31	11.30	12.68	0.00	70.70
32	32	16.50	15.87	0.00	52.78
33	33	22.31	3.00	0.00	42.31

Data Analysis and Runoff Estimation

- **Using the daily rainfall, slope, hydrological soil group and landuse / land cover data, the average annual runoff was worked out for each watershed independely**

- **The average monthly runoff was worked out for each of the 33 watersheds and for each year independently then the actual runoff was estimated for each watershed and for each year by feeding such monthly runoff, aerial coverage of hydrological soil groups, slope and aerial coverage of various landuse/land cover classes in the dedicated software.**

- **Ultimately the average final annual runoff was worked out for each watershed by averaging such annual runoff worked out for 30 years for each watershed.**

- **Finally estimated actual runoff or surface water potential showing the figure**

- **This information clearly shows the quantity of water available in each watershed which can be recharge in the respective watershed themselves as otherwise they will flow out into the adjacent watersheds and ultimately into the rivers as loss.**

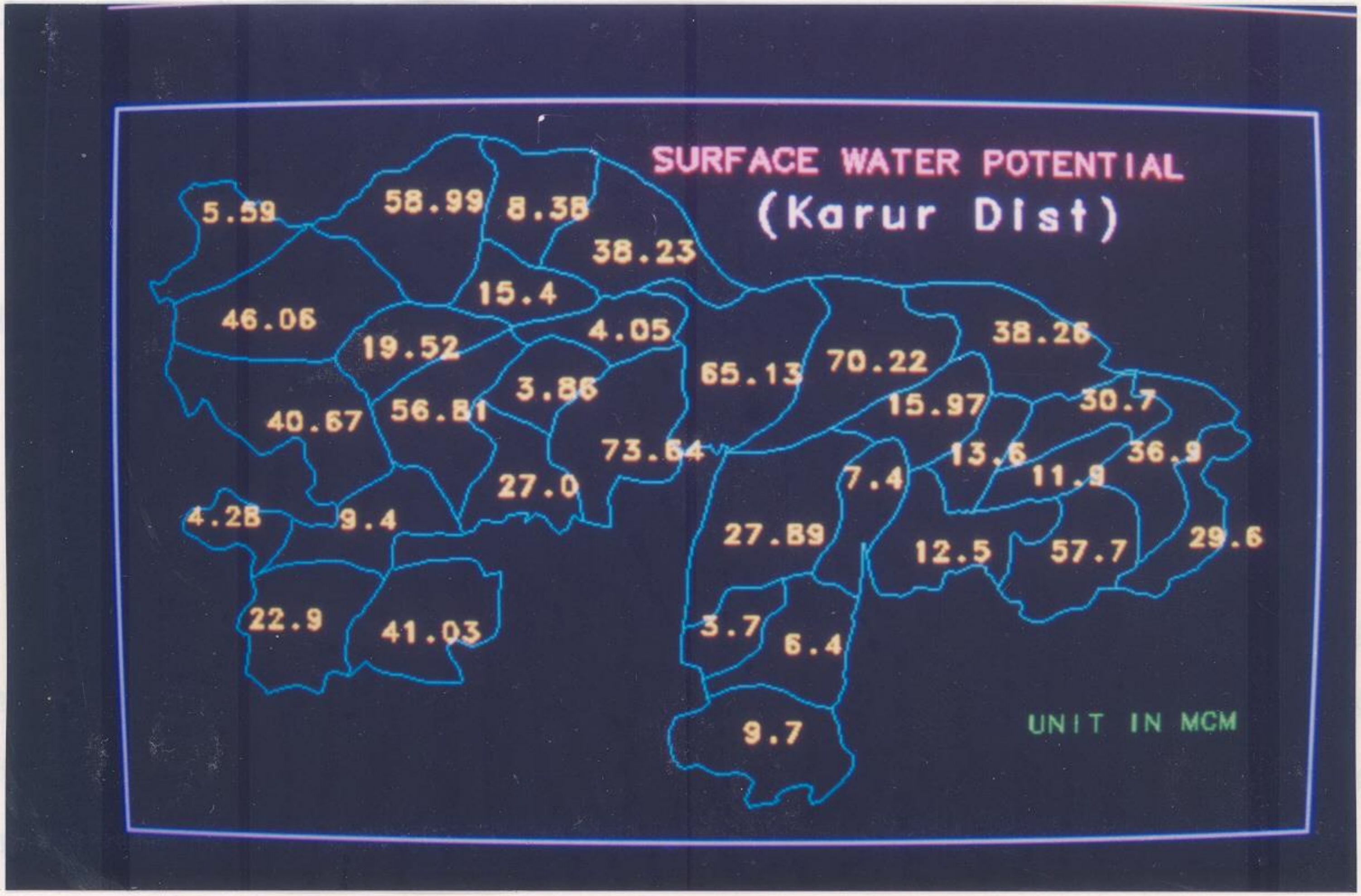


Fig. 3

GIS Image Showing Surface Water Potential/Run-off

Groundwater Targeting

Date base Generation

- Transmissivity
- Permeability
- Specific yield
- Water level

Transmissivity

From the pumping tests conducted in 32 dugwells and dug cum bore wells the transmissivity values were generated

These data were plotted in the respective well locations and contours were drawan

The entire study area was gridded into 3135 (1sq.km size)

Such a grid mesh was placed over these contours and corresponding transmissivity data were gulled out from contour values for each grid

Such transmissivity data of 3135 grids have varied from 0.42gpd/ft to 1850 gpd/ft. these ware linearly stretched from 1 to 100 by using following formula

$$\frac{(X-Xmin)}{(Xmax - Xmin)} *99)+1$$

Data analysis and groundwater targeting

Such stretched data on Transmissivity, Specific capacity, permeability and 1/WL were added and averaged for the corresponding grids in all the above themes and a cumulative numerical data base was generated on TKS 1/WL for 3135 grids

Such final added and averaged data for 3135 grids were also dynamically stretched from 1 to 100.

Finally the grids having in more then 50 numerical values were buffered out as Potential Groundwater Targets.

TABLE 4

TRANSMISSIVITY, SPECIFIC CAPACITY, PERMEABILITY AND WATER LEVEL DATA

(Sample Data)

1 GRIDNO	2 TRANSMISSIVITY	3 TRANSMISSIVITY STRETCHED DATA	4 SPECIFIC CAPACITY	5 SPECIFIC CAPACITY STRETCHED DATA	6 PERMEABILITY	7 PERMEABILITY STRETCHED DATA	8 WATER LEVEL	9 WATER LEVEL INVERSE DATA	10 WATER LEVEL INVERSE STRETCHED DATA
1	1.508	6	1.511	4	1.405	18	1.83	0.546	1
2	4.761	16	4.795	10	4.457	55	5.90	0.169	1
3	3.752	13	3.786	8	3.549	44	4.79	0.209	1
4	2.489	9	2.522	6	2.439	30	3.27	0.306	1
5	3.343	12	2.835	6	2.841	35	4.18	0.239	1
6	2.061	8	1.905	4	1.906	24	2.81	0.356	1
....	.....	..	.....	..	.....	..	....	.....	..
....	.....	..	.....	..	.....	..	....	.....	..
....	.....	..	.....	..	.....	..	....	.....	..
3130	0.445	2	0.273	1	0.014	1	1.12	0.893	2
3131	0.252	2	0.049	1	0.010	1	0.66	1.515	2
3132	1.248	5	0.250	1	0.050	2	2.78	0.360	1
3133	0.527	3	0.367	2	0.022	1	1.17	0.855	2
3134	0.646	3	0.320	2	0.019	1	1.05	0.952	2
3135	0.136	1	0.101	1	0.005	1	0.27	3.704	5

Aquifer Function Modelling

Data base generation

After identifying the potential groundwater targets, the Aquifer Function Model was Developed.

The normal aquifer controlling geological parameters pertaining to hard rock systems were generated.

Such parameters considered were

- Lineament Density
- Thickness of Topsoil
- Thickness of Weathered zone
- Thickness of Fractured zone
- Depth to Bedrock
- Slope
- Drainage Density
- Geomorphology
- Landuse/Land cover

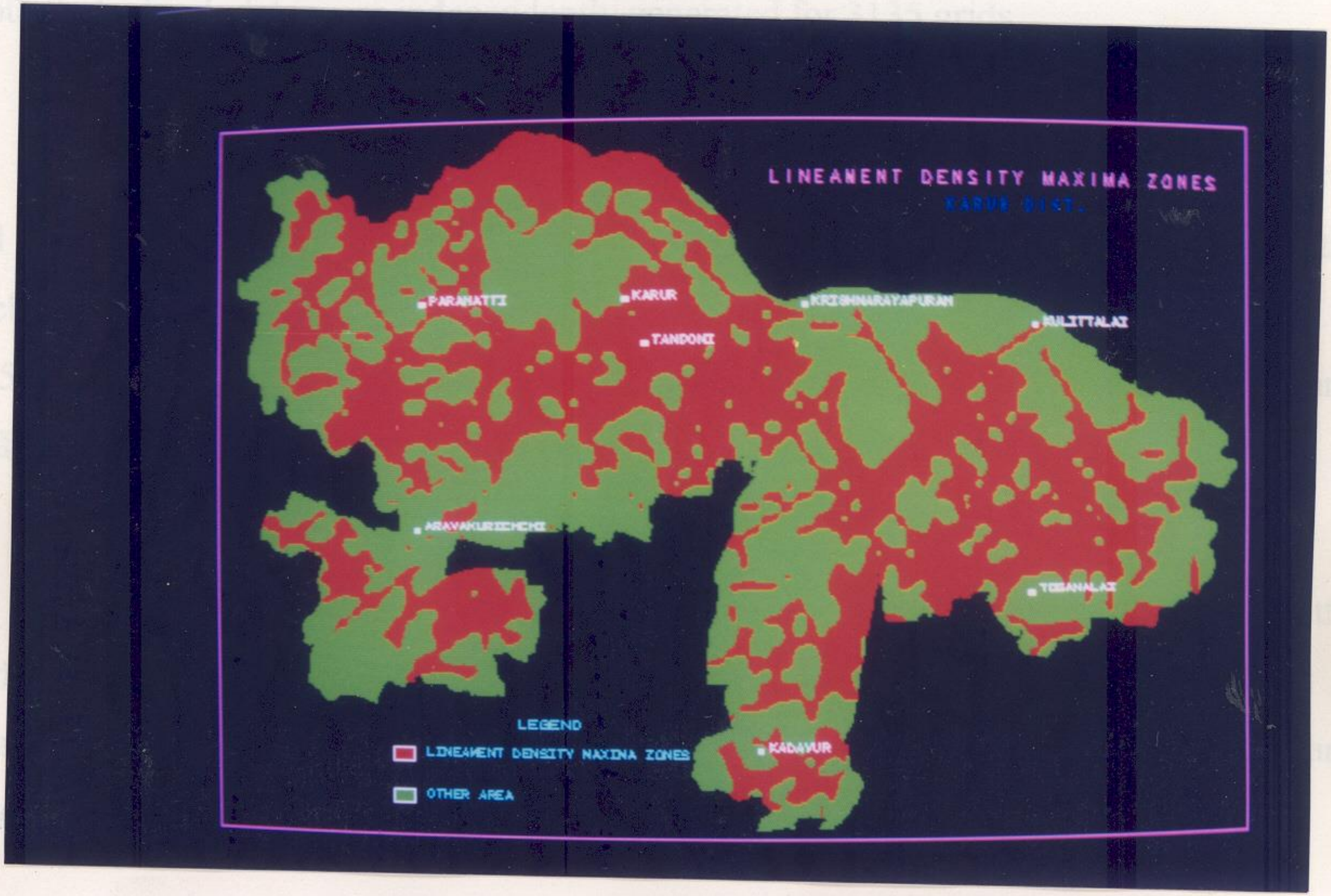


Fig. 5

GIS Image Showing Lineament Maxima Zones

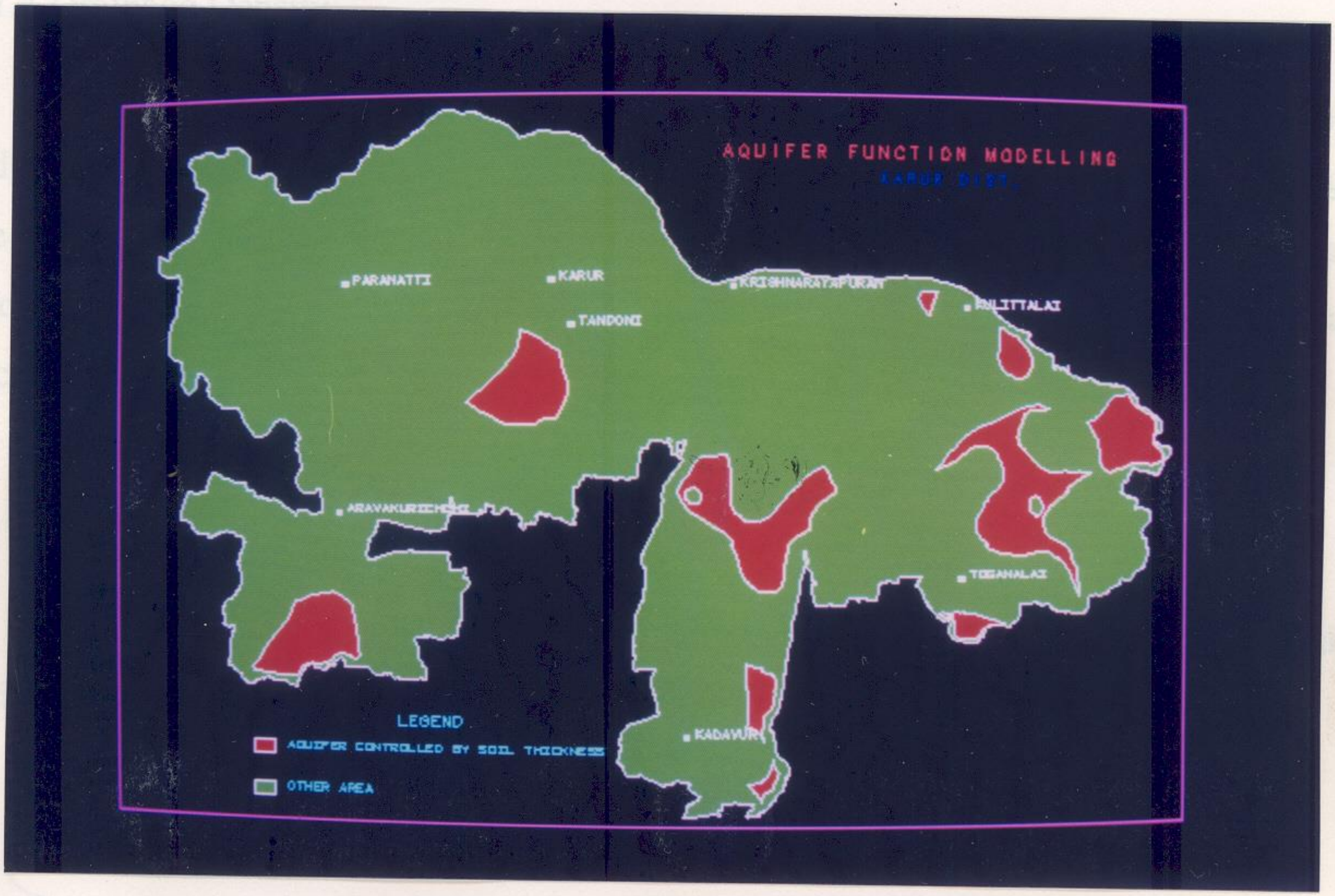


Fig. 6

GIS Image Showing Topsoil Maxima Zones

Data analysis and Modeling

The generation of various buffered image on Lineament Density, Thickness of top Soil, weathered zone, fractured zone, depth to bed rock, slope, drainage density, geomorphology and landuse / land cover was integrated with these image to understand the function of aquifer.

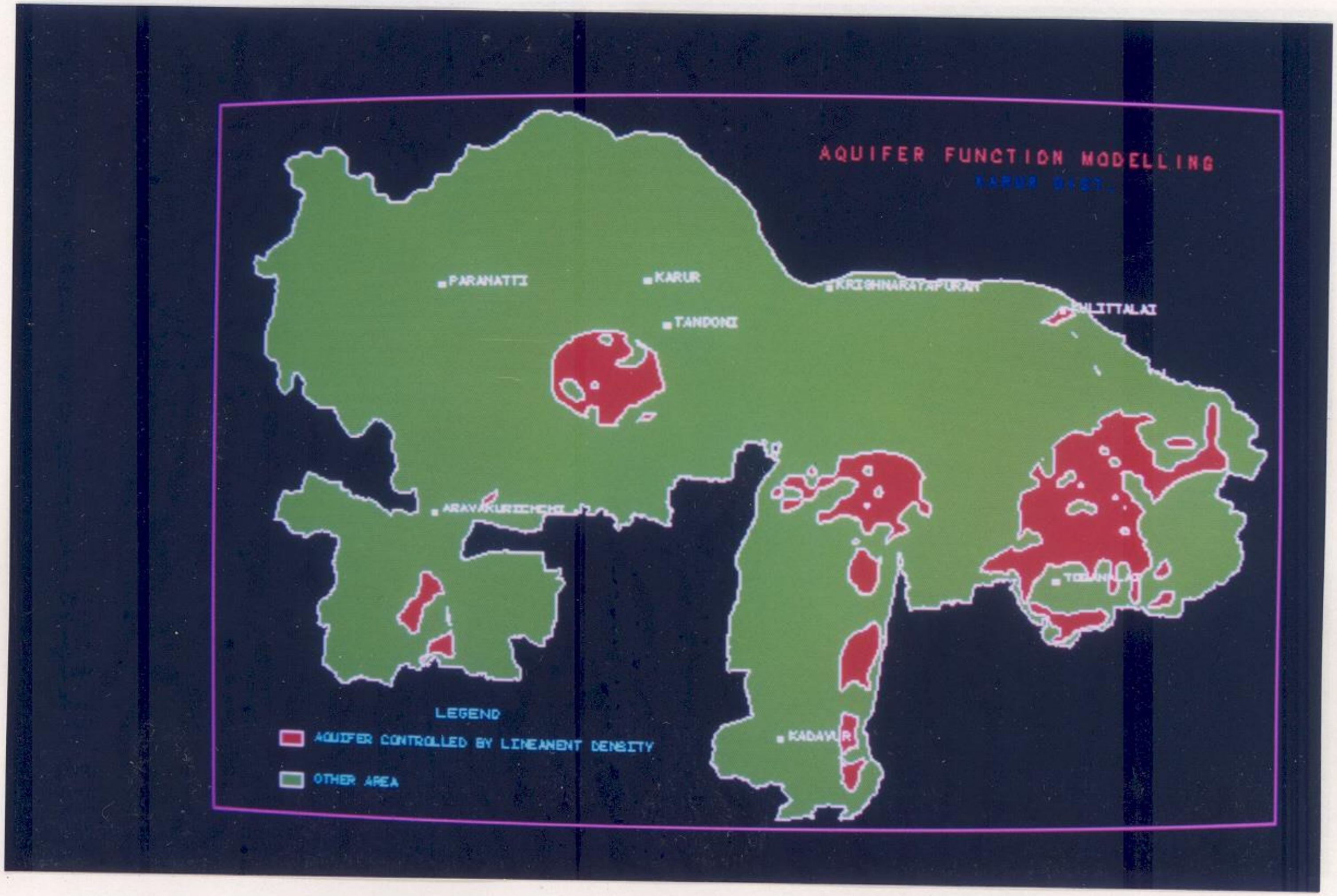


Fig. 7

GIS Image Showing Lineament Controlled Aquifer Systems

Fig. 8

GIS Image Showing Lineament and Soil Controlled Aquifer Systems

GROUNDWATER EXPLOITATION

- The monthly water level data were collected from 39 control wells for 26 years from 1971 to 1997

- For each well, average water level for 26 number of January to December were worked out.

- With help of such data, the hydrograph was drawn for each well, such hydrograph have shown that the water level has generally increased from October to January (aquifer recharge) and decreased during June & September (aquifer discharge).

- From such recharge and discharge status of exploitation was worked out for each well independently.

For Example,

- If the width of recharge was 5mt and discharge was 2.5mt then the status of Groundwater exploitation was worked out for the particular well as 50%.

- On the contrary, if the recharge was 2.5mt and discharge was 5 mt, then the status of groundwater exploitation was worked out as 200%.

- Such percentage were worked out for each of the 39 control wells and plotted in the respective well locations and contoured.

- The entire Karur district has the groundwater exploitation to the maximum 80% to 260% with a maximum exploitation in the western parts of the Karur district.

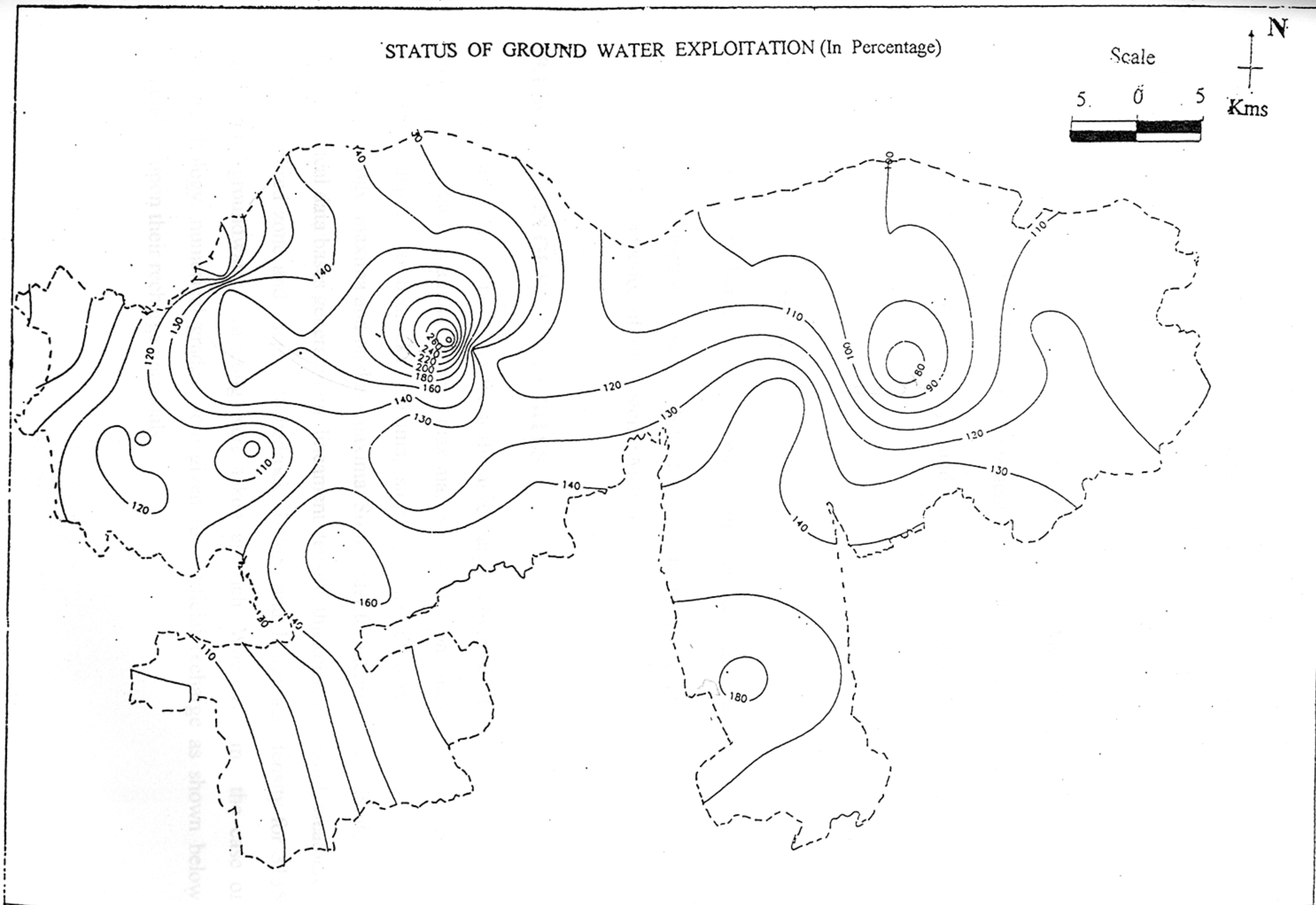

STATUS OF GROUND WATER EXPLOITATION (In Percentage)
Scale
5 0 5
Kms
N
140
130
120
110
100
90
80
160
180
200
220
240
260

Fig . 10

Natural Recharge

- The water level data were collected from 39 wells for 276 months from such 276 monthly water level data, mean premonsoon water level and mean Postmonsoon water level were worked out for each well separately.

- The difference between postmonsoon and premonsoon was calculated for each control well and plotted in respective well locations and contoured.

- Such contours have shown that the quantum of natural recharge varies from 0.22 to 1.7 mt. in the entire study area and hence the area falling in >1mt. Water level rise was demarcated as the area where natural recharge is going on appreciably.

- In such lineament controlled natural recharge domains, hydrofracturing has been recommended and as the same will effectively improve the natural recharge.

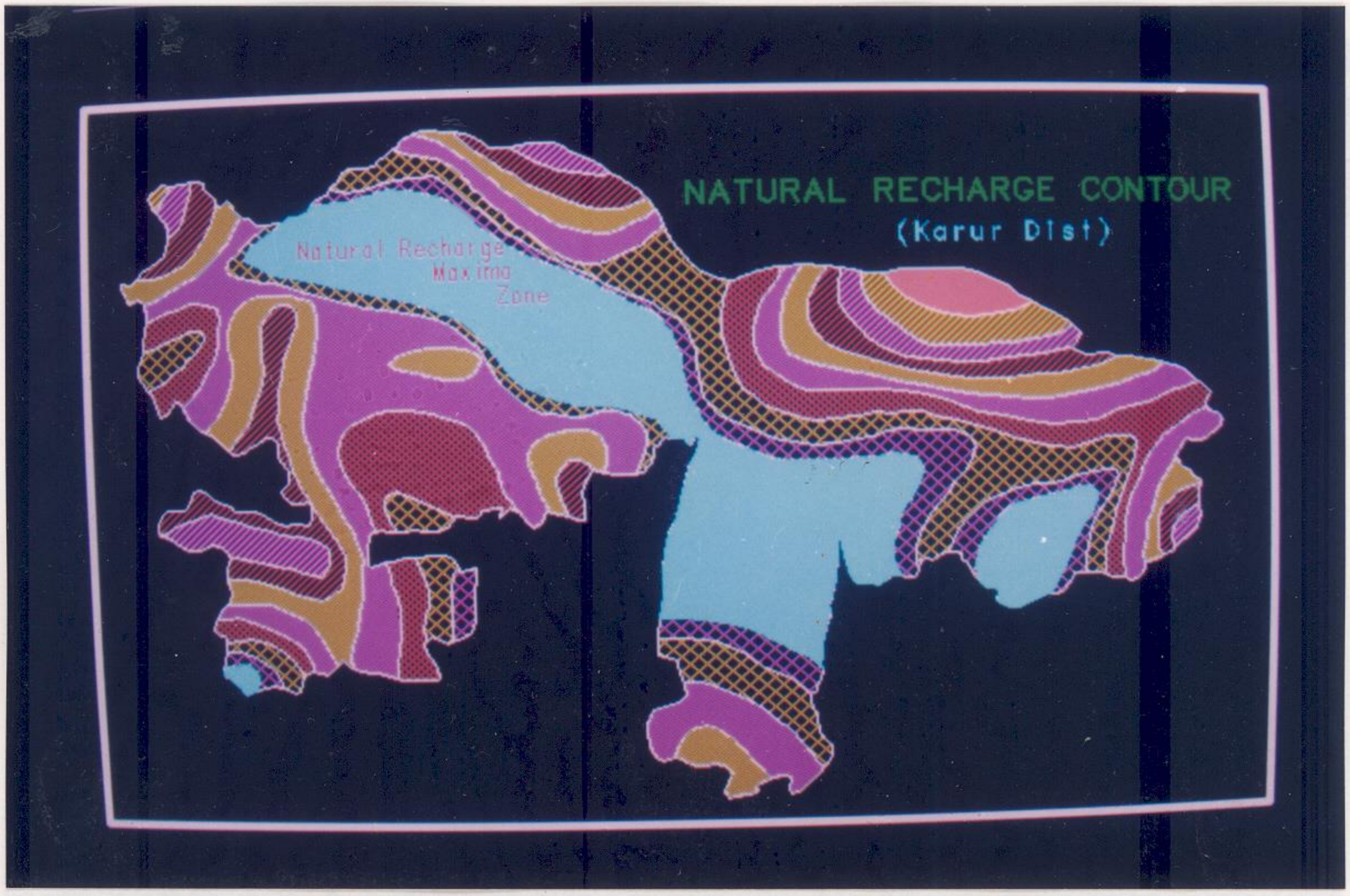


Fig. 11

GIS Image Showing Natural Recharge Zone

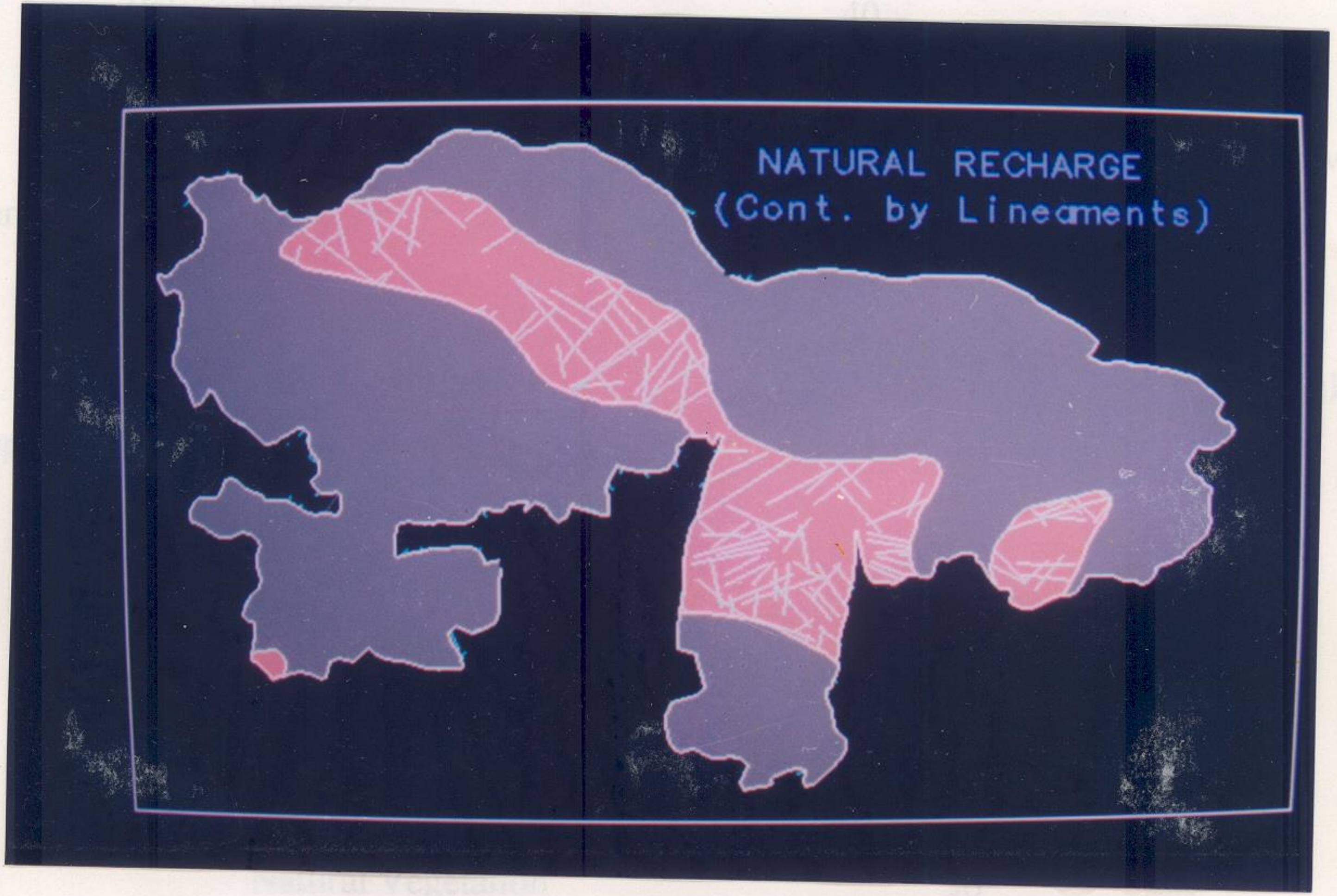


Fig. 12

GIS Image Showing Natural Recharge Controlled by Lineaments

Inter-Watershed Transfer

- After working out the surface water potential, groundwater potential, natural recharge, artificial recharge was done to suggest strategies for inter-watershed transfer

- The aerial extent of rechargeable formations, volume of rechargeable formations total thickness of unsaturated zone, volume of recharge formations available for recharge, volume of allowable recharge etc were worked out.

- To workout the volume of rechargeable formations, the aerial extent of rechargeable formations was multiplied with the depth to bedrock data. The water level data was multiplied with the area of artificially rechargeable formations to arrive the volume of rechargeable formations available for recharge.

- As the area exposes mostly Gneisses, the storage coefficient of 0.23 or 23 % was taken as allowable storage. The data arrived at column 7 was multiplied with 0.23 to arrive the volume of allowable recharge (column 8)

- The total water potential available as run-off was less than the volume of allowable recharge (column 8) the said watershed was declared as deficit watershed. Instead, if the run-off was more than volume of allowable recharge, then it was declared as water surplus watershed

ANNEXURE - II

INTER WATERSHED TRANSFER

1 SL.No	2 WATER-SHED No	3 SURFACE WATER POTENTIAL	4 AREA OF ARTFICIAL RECHARGEABLE FORMATIONS IN MM^2	5 VOLUME OF RECHARGEABLE FORMATIONS IN MCM	6 THICKNESS OF UNSATU-RATED ZONE IN M	7 VOLUME OF RECHARGEABLE FORMATIONS AVAILABLE FOR RECHARGE IN MCM	8 VOLUME OF ALLOWABLE RECHARGE IN MCM (Storage coefficient)	9 REMARKS
1	1	5.590	58.834	2353.360	9.00	529.506	121.786	DEFICIT
2	2	58.990	24.613	246.130	8.50	209.211	48.119	SURPLUS
3	3	40.690	48.353	1160.472	4.90	236.930	54.494	DEFICIT
4	4	19.520	39.254	863.588	8.50	333.659	76.742	DEFICIT
5	5	56.810	20.481	491.544	7.50	153.608	35.330	SURPLUS
6	6	15.400	26.575	797.250	9.00	239.175	55.010	DEFICIT
7	7	46.060	71.908	2588.688	11.50	826.942	190.197	DEFICIT
8	8	4.280	22.798	1094.304	8.50	193.783	44.570	DEFICIT
9	9	9.400	24.909	647.634	10.00	249.090	57.291	DEFICIT
10	10	27.000	39.173	783.460	8.00	313.384	72.078	DEFICIT
11	11	22.900	4.233	186.252	11.00	46.563	10.709	SURPLUS
12	12	41.030	68.298	1434.258	11.50	785.427	180.648	DEFICIT
13	13	8.380	15.186	425.208	12.00	182.232	41.913	DEFICIT
14	14	38.230	15.074	361.776	14.00	211.036	48.538	DEFICIT
15	15	4.050	28.877	721.925	12.00	346.524	79.701	DEFICIT
16	16	3.860	12.925	361.900	9.50	122.788	28.241	DEFICIT
17	17	73.640	43.443	868.860	9.00	390.987	89.927	DEFICIT
18	18	65.130	51.270	1230.480	10.00	512.700	117.921	DEFICIT
19	19	70.220	39.181	940.344	9.00	352.629	81.105	DEFICIT
20	20	38.260	12.398	347.144	10.00	123.980	28.515	SURPLUS

ANNEXURE - II (Contd...)

INTER WATERSHED TRANSFER

1 SL.No	2 WATER-SHED No	3 SURFACE WATER POTENTIAL	4 AREA OF ARTFICIAL RECHARGEABLE FORMATIONS IN MM^2	5 VOLUME OF RECHARGEABLE FORMATIONS IN MCM	6 THICKNESS OF UNSATU-RATED ZONE IN M	7 VOLUME OF RECHARGEABLE FORMATIONS AVAILABLE FOR RECHARGE IN MCM	8 VOLUME OF ALLOWABLE RECHARGE IN MCM (Storage coefficient)	9 REMARKS
21	21	15.970	52.453	839.248	10.50	550.757	126.674	DEFICIT
22	22	13.600	44.320	975.040	11.00	487.520	112.130	DEFICIT
23	23	36.900	81.835	2618.720	10.50	859.268	197.632	DEFICIT
24	24	30.700	30.375	364.500	11.00	334.125	76.849	DEFICIT
25	25	11.900	27.099	541.980	12.50	338.738	77.910	DEFICIT
26	26	27.890	81.835	1964.040	8.50	695.598	159.988	DEFICIT
27	27	7.400	58.848	1647.660	9.00	529.605	121.809	DEFICIT
28	28	3.700	2.163	69.216	7.00	15.141	3.482	SURPLUS
29	29	6.400	50.991	1733.694	7.50	382.433	87.960	DEFICIT
30	30	9.700	3.908	132.872	6.50	25.402	5.842	SURPLUS
31	31	12.500	59.989	2159.604	9.50	569.896	131.076	DEFICIT
32	32	57.700	30.963	743.112	11.50	356.075	81.897	DEFICIT
33	33	29.600	5.325	127.800	9.50	50.588	11.635	SURPLUS

STOCHASTIC MODELS IN GROUNDWATER HYDROLOGY

Water Resources Systems are very complex due to

- ***The variety of objectives***
- ***Conflicting nature of water uses and***
- ***Their impact on Socio-Political Environment***

The design of groundwater systems – more complicated

Further because of,

- **Hydrological variables**
- **Precipitation**
- **Runoff**
- **Evaporation**
- **Topography**
- **Reservoir Properties**
- **Climate**
- **Landuse/Land Cover, etc.**

STOCHASTIC : ***aim at, guess***

Having a random probability distribution or pattern that can be analyzed statistically (but not precisely)

- **Continuous Distributions**

- **Discrete Distributions**

- **Estimation and probability plotting**
- **Correlation and regression**
- **Time series analysis**
- **Auto correlation analysis**

Univariate

Multivariate

Random variates

Models

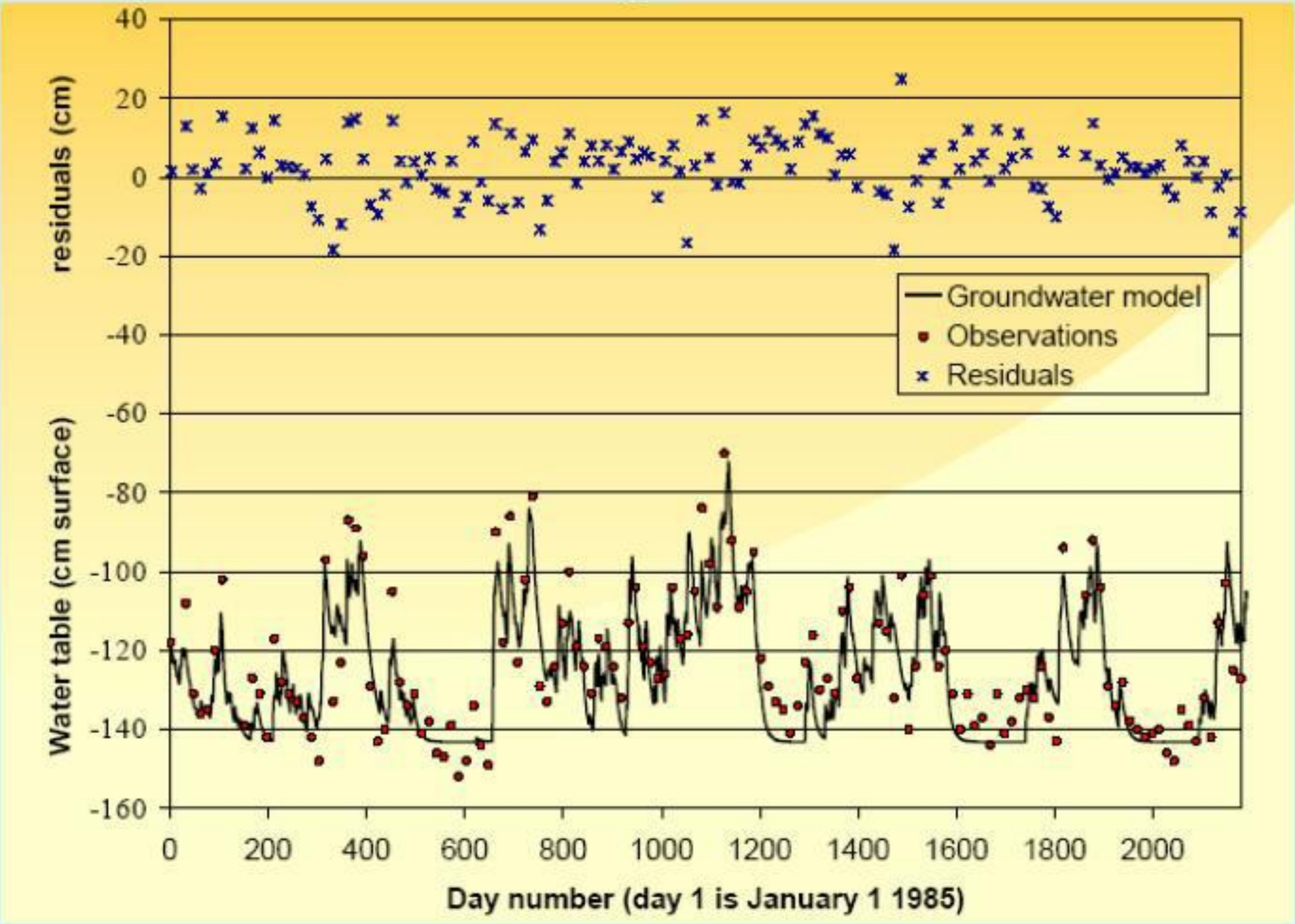
- Daily Flow
- Seasonal flow
- Multi site Annual Model

What is "Stochastic"?

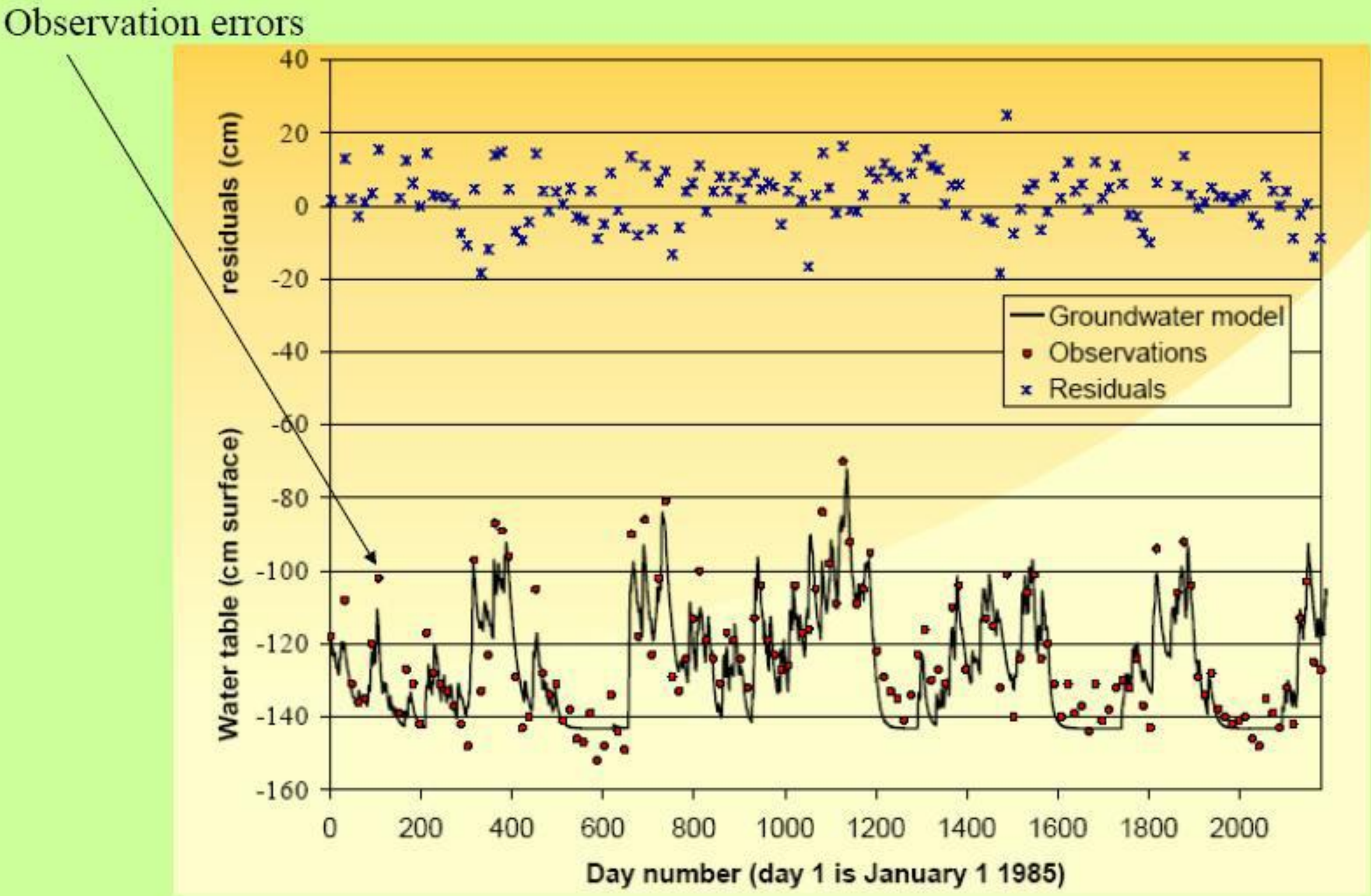
- It has been derived of a Greek word.
- It means seer and refer to predicting the future.

- In the modern methods: the stochastic method means the methods for prediction of a variable at some non-observed time and locations.

Similar to seer, our predictions are uncertain, why?



What are the causes of these differences?



What are the causes of these differences?

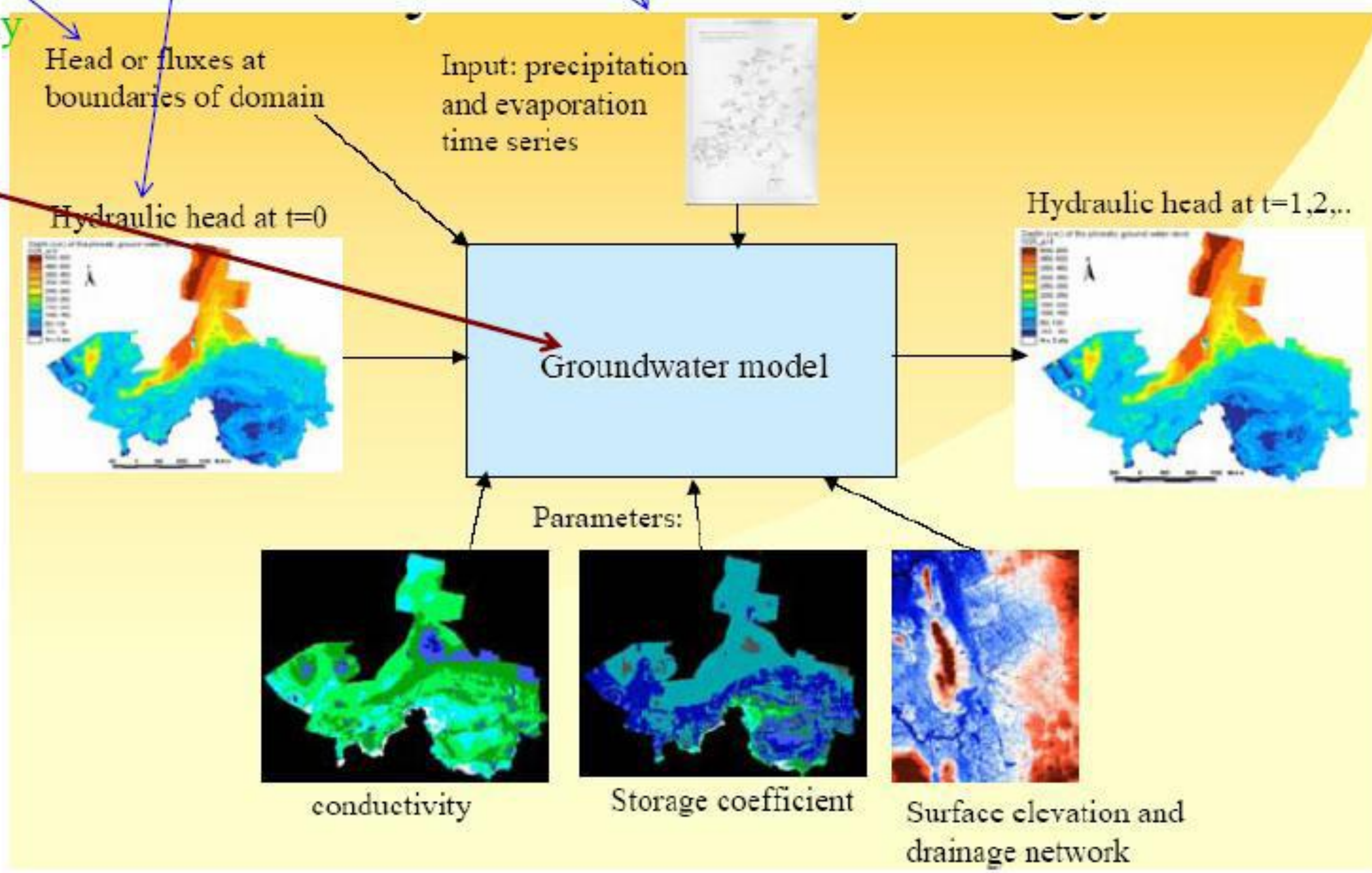
Boundary conditions, initial conditions, inputs errors

Unknown heterogeneity and parameters

"What are heterogeneity and homogeneity?"

Scale discrepancy

Model errors



There are two ways to deal with these differences:

- **Deterministic Hydrology**: The models are calibrated, thus the residual errors are minimized.

$$E = z - \breve{z}$$

Deterministic modeling

Minimum error

observations

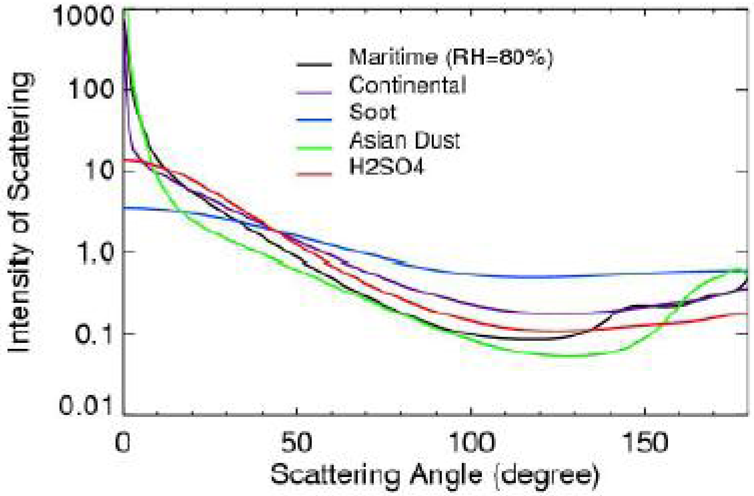
- **Stochastic Hydrology**: not only tries to model the system for prediction, but also it tries to quantify the errors of model outcome (E) and use of it in modeling.

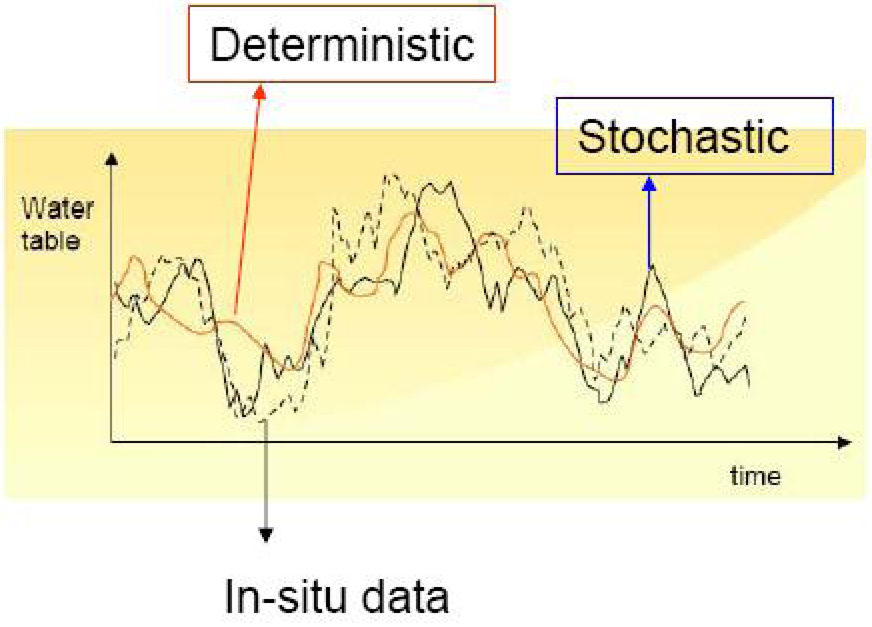
$$Z = \breve{z} + E$$

Stochastic modeling

Why Stochastic models?

- Deterministic models are smooth and usually over estimate, but the real world is messy and rugged.
- But stochastic models are able to consider these behaviors.





Why Stochastic Models?

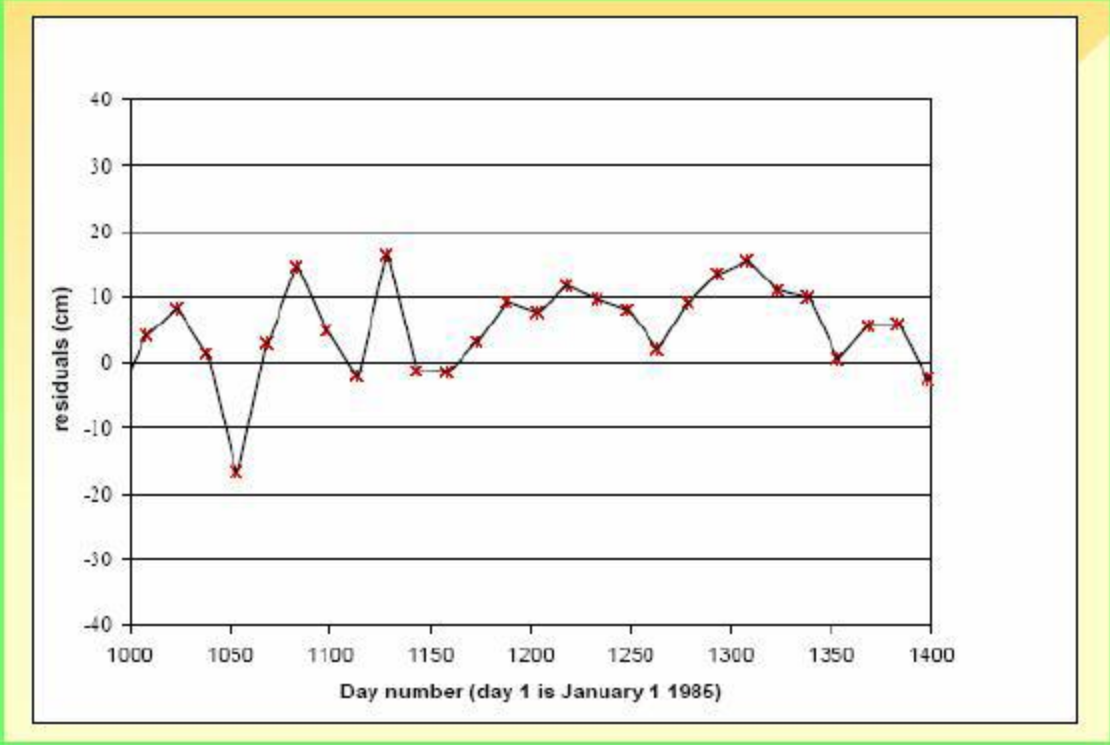
When the system is non-linear and the parameters are erroneous, the stochastic modeling is better than deterministic models.

Why Stochastic models?

- Residual have information. We try to extract this information in stochastic modeling.

$$Z = \breve{z} + E$$

Stochastic modeling



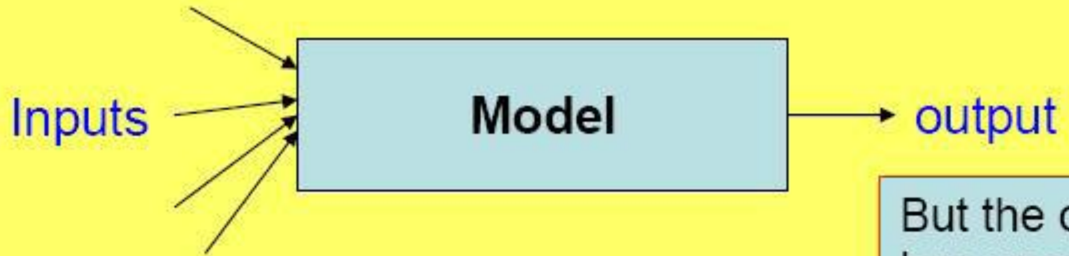
Why Stochastic models?

- WHEN and WHERE you should do in-situ measurement?

Your money is fixed, then find the best locations and times for measurements…

Stochastic modeling can lead you to the optimum times and locations for in-situ measurements.

Why Stochastic models?



But the output has uncertainty. This uncertainty is highly related to the uncertainty of input variables

Stochastic can help you to find the error sources and rank them.

Then you can judge that which input needs to improvement and needs to spend more money for it.


Thank You