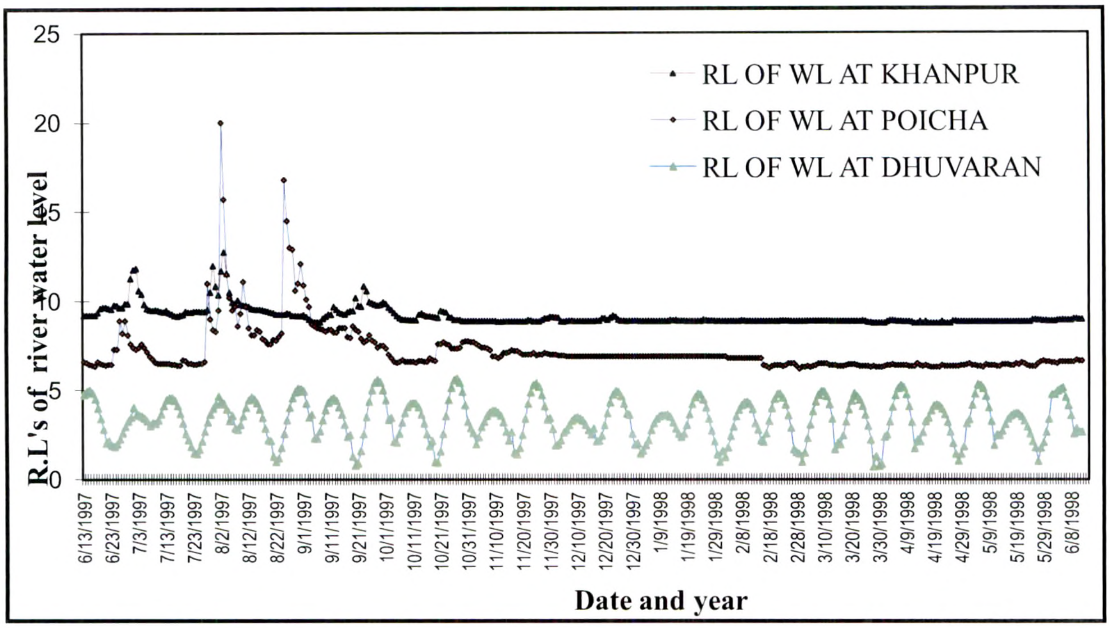
DATA COLLECTION & METHODOLOGY

4 DATA COLLECTION & METHODOLOGY

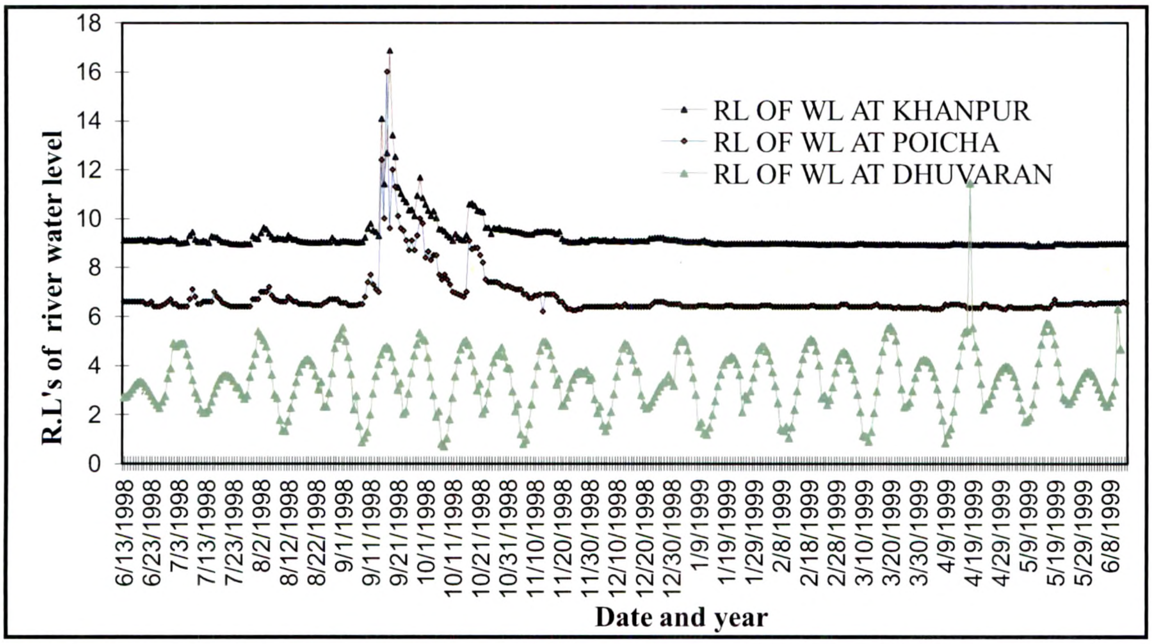
Data has been collected from Gujarat Water Resources Development Corporation Ltd. (GWRDC), Central Ground Water Board (CGWB), State Water Data Centre (SWDC), Vadodara Mahanagar Seva Sadan (VMSS), Central Water Commission (CWC), Water Resources Investigation Circle (WRIC), Vadodara Irrigation Circle (VIC), Mahi Irrigation Circle (MIC), Gujarat Engineering Research Institute (GERI), Sardar Sarovar Narmada Nigam Limited (SSNL) and Gujarat Electricity Corporation Ltd etc. are compiled and enlisted. The data to be used for model study as an input are prepared. In this chapter the model boundary is identified and construction of the model using GMS software is discussed.

4.1 RL's of Mahi River Water Level

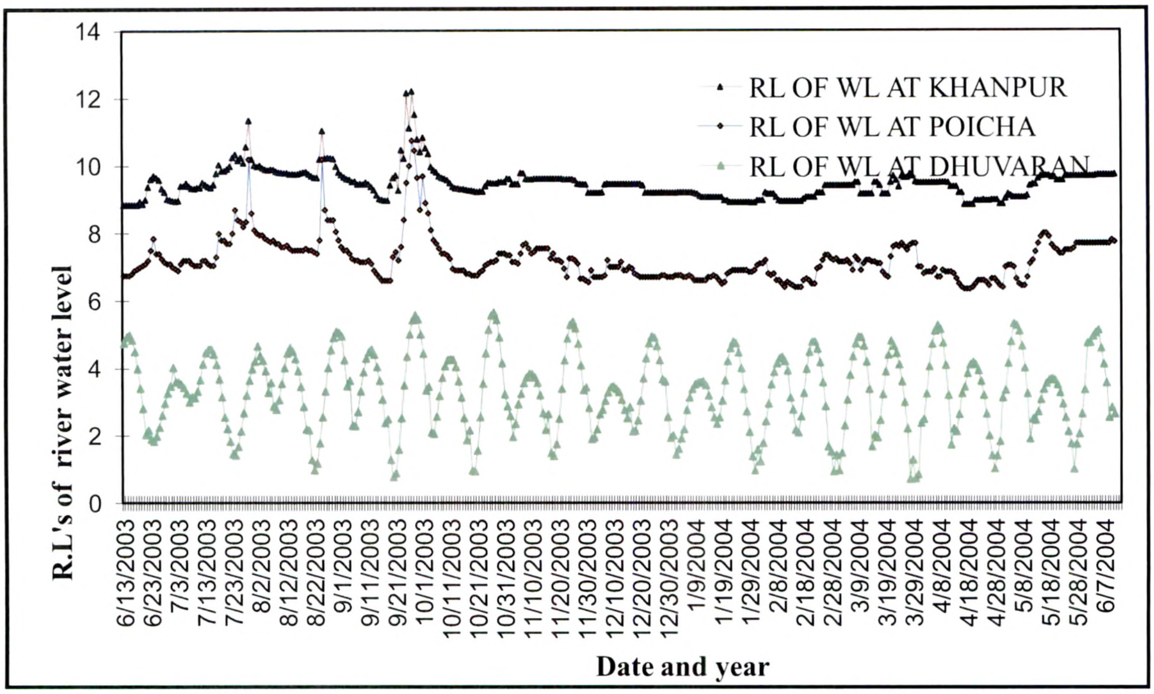
Daily RL's of Mahi water levels are collected at three sites namely Khanpur, Poicha and Dhuvaran for the duration June 1997 to June 1999, June 2003 to June 2005 and June 2005 to June 2007. RL's at Khanpur are collected from the Central Water Commission (CWC), Gandhinagar, RL's at Poicha are collected from Vadodara Mahanagar Seva Sadan (VMSS), Vadodara and RL's at Dhuvaran are collected from Gujarat Electricity Corporation Ltd. This data is presented in Annexure-I and graphically plotted viz. graphs 4.1 to 4.6.



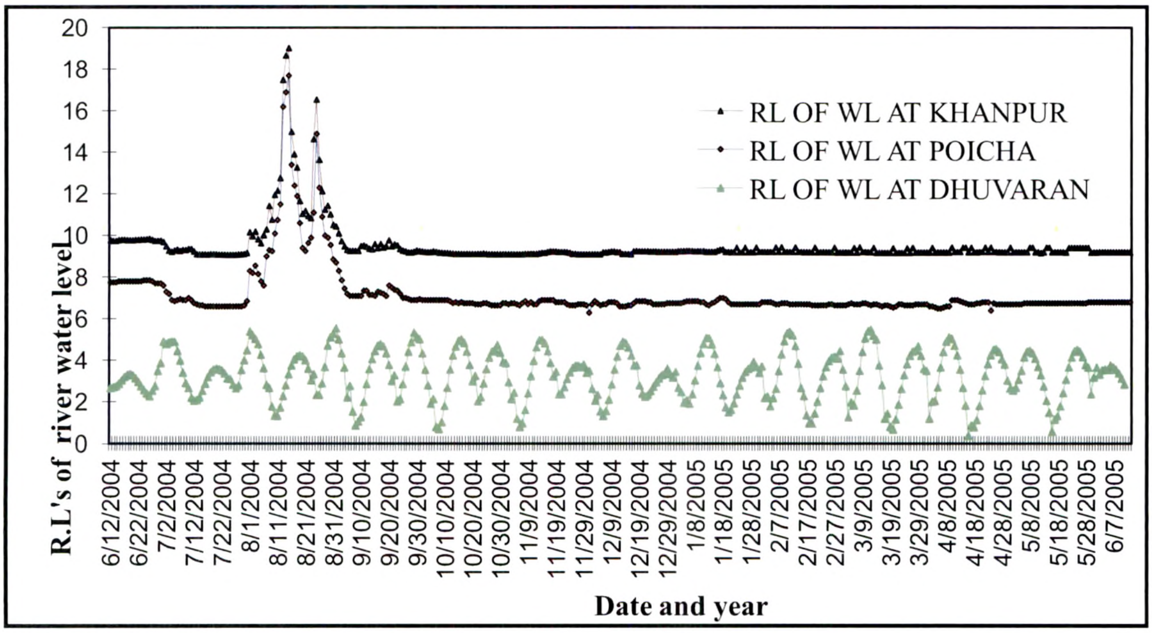
Graph 4.1 River Water Levels in m from m.s.l for Year June 1997 to June 1998



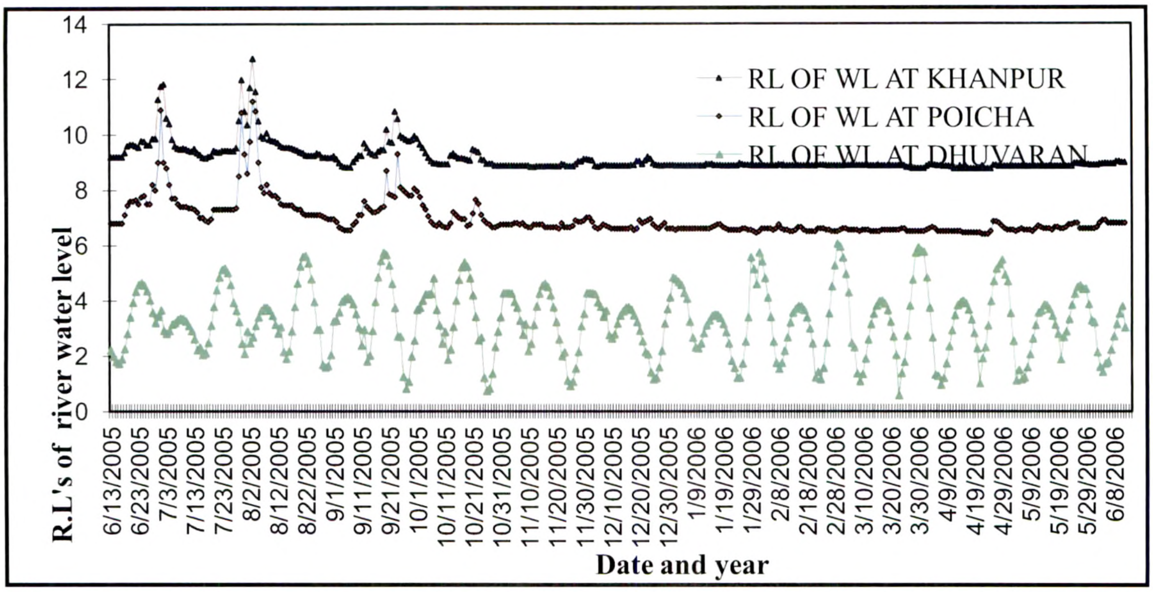
Graph 4.2 River Water Levels in m from m.s.l for Year June 1998 to June 1999



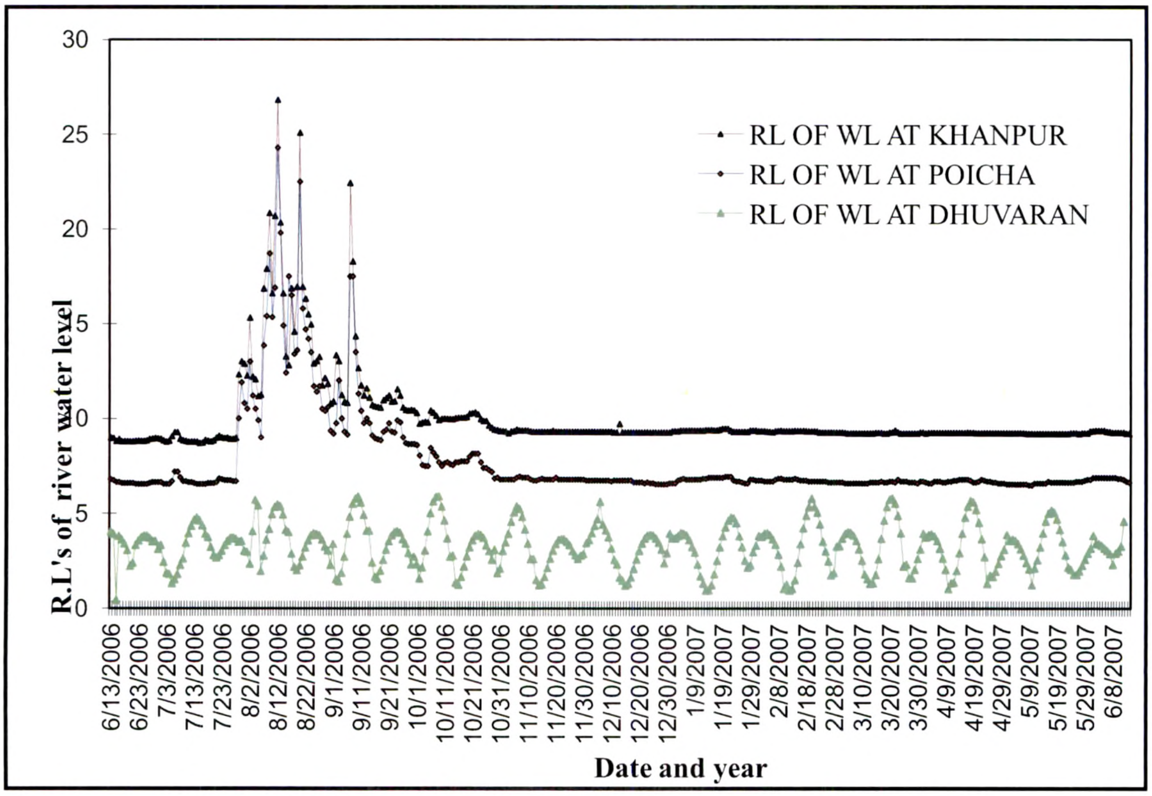
Graph 4.3 River Water Levels in m from m.s.l for Year June 2003 to June 2004



Graph 4.4 River Water Levels in m from m.s.l for Year June 2004 to June 2005



Graph 4.5 River Water Levels in m from m.s.l for Year June 2005 to June 2006



Graph 4.6 River water levels in m from m.s.l for year June 2006 to June 2007

4.2 RL's of Ground Level of Wells and River Bed

Reduced levels of ground levels of wells, piezometers, villages, river banks, river bed etc are collected from agencies like GWRDC, WRIC, VIC, CGWB and CWC. The river bed data have been completed by interpolating intermediate values in software surfer. These data have been contained in Annexure-II.

4.3 RL's of Bottom of Wells in Unconfined Aquifer

Contours of bottom of unconfined aquifer in Sardar Sarovar Command area (Source: Wallingford and Shah, (1994) "Data for Groundwater Model of Sardar Sarovar Command Area" Sponsored by Narmada Planning Group, Gandhinagar. Vol. III- Plates) have been transferred to base map of study area. They are used to work out RL's of bottom of wells by interpolation. They are presented in Annexure-III.

4.4 Horizontal Permeability 'HK' of Wells in an Unconfined Aquifer

Horizontal permeability of aquifer is estimated by superimposing figure of aquifer permeability zones of Sardar Sarovar Command area given in EX3183: Main Report, November 1995, Wallingford, by interpolation. They are represented in table 4.1

Table 4.1 Horizontal Permeability 'HK' of Wells

Zone Id	Taluka	Village	Well No.	X Latitude	Y Longitude	Hk m/day
552	Anand	Bedva	KR-08	298338.2188	2495240.50	50
553	Anand	Sarsa	KR-06	301609.5625	2494433 75	50
771	Anand	Vasad	KR-07	303395.9375	2488507.50	50
881	Savli	Anjesar	NCCA-14	311864.938	2486740.50	50
551	Borsad	Borsad	KR-19	283767.25	2479632 25	50
115	Petlad	Danteli	KR-70	268272.9	2482068.61	20
882	Savli	Manjusar	BD-48	313994 4063	2483237.25	50
661	Anklav	Anklav	KR-16	294427.55	2475901.85	50
114	Khambhat	Kanisha	KR-20	261564.14	2477128.29	10
772	Vadodara	Sokhda	BD-06	311648 4375	2480807.00	50
111	Khambhat	Gudel	KR-25	244895.8125	2478585.00	10
773	Vadodara	Dashrath	BD-05	309398.6563	2477047.00	50
112	Khambhat	Kansari	KR-23	256803.69	2471326.90	10
332	Borsad	Bhadran	KR-17	283689.9063	2474095.00	50
221	Khambhat	Bhuvel	KR-21	264060.8125	2468621.00	10
222	Khambhat	Haripura	KR-22	270508.31	2463701.40	20
662	Padra	Jaspur	NCCA-43	299932.24	2465442.61	50
334	Padra	Dabka	NCCA-44	289541.875	2461919.50	50
333	Borsad	Gajna	KR-18	283803.5625	2465232.25	50
113	Jambusar	Kavi	NCCA-48	256865.3	2456700.75	10
335	Padra	Karankuva	NCCA-45	291753.25	245608.25	50
331	Jambusar	Sarod	BR-14	280113.4375	2453554.00	20
441	Padra	Masar Road	BD-34	287036.875	2450600.50	50

4.5 Specific Yield 'S_y' of Wells in Unconfined Aquifer

Specific yields have been approximated by critically studying aquifer characteristics of study area and various reference studies, reports and manuals on this area. This data is presented in table 4.2

Table-4.2 Specific Yield of Wells

Zone Id	Taluka	Village	Well no	X Latitude	Y Longitude	Specific Yield Sy (fraction)
112	Khambhat	Kansari	KR-23	256803.69	2471326.90	0.11
221	Khambhat	Bhuvel	KR-21	264060.8125	2468621.00	0.09
111	Khambhat	Gudel	KR-25	244895.8125	2478585.00	0.113
115	Petlad	Danteli	KR-70	268272.9	2482068.61	0.097
114	Khambhat	Kanisha	KR-20	261564.14	2477128.29	0.106
222	Khambhat	Haripura	KR-22	270508.31	2463701.40	0.10
551	Borsad	Borsad	KR-19	283767.25	2479632.25	0.097
332	Borsad	Bhadran	KR-17	283689.9063	2474095.00	0.068
333	Borsad	Gajna	KR-18	283803.5625	2465232.25	0.079
661	Anklav	Anklav	KR-16	294427.55	2475901.85	0.091
771	Anand	Vasad	KR-07	303395.9375	2488507.50	0.087
552	Anand	Bedva	KR-08	298338.2188	2495240.50	0.093
553	Anand	Sarsa	KR-06	301609.5625	2494433.75	0.094
331	Jambusar	Sarod	BR-14	280113.4375	2453554.00	0.095
334	Padra	Dabka	NCCA-44	289541.875	2461919.50	0.086
441	Padra	Masar Road	BD-34	287036.875	2450600.50	0.094
773	Vadodara	Dashrath	BD-05	309398.6563	2477047.00	0.117
772	Vadodara	Sokhda	BD-06	311648.4375	2480807.00	0.098
882	Savli	Manjusar	BD-48	313994.4063	2483237.25	0.091
662	Padra	Jaspur	NCCA-43	299932.24	2465442.61	0.15
881	Savli	Anjesar	NCCA-14	311864.938	2486740.50	0.091
335	Padra	Karankuva	NCCA-45	291753.25	245608.25	0.091
113	Jambusar	Kavi	NCCA-48	256865.3	2456700.75	0.092

4.6 Lithology Data

The lithology data of wells, tube wells and piezometers of study area i.e. Anand, Borsad, Petlad, Khambhat talukas of Anand District; Savli, Vadodara and Padra talukas of Vadodara District and Jambusar taluka of Bharuch District have been collected from agencies like GWRDC,CGWB and GWSSB. From these 26 wells data have been tabulated viz Annexure-IV.

4.7 Reduced Water Level of Wells

The Reduced Water Levels of Wells are collected from GWRDC. These data have been tabulated viz table 4.3.

Table-4.3 Reduced Water Level of Wells in m from m.s.l.

Well no	X (Latitude)	Y (Longitude)	Pre monsoon 1995	Post monsoon 1995	Pre monsoon 1996	Post monsoon 1996	Pre monsoon 1997
KR-23	256803.69	2471326.90	9.17	12.17	9 52	12.57	9.77
KR-21	264060 81	2468621.00	4 28	4 78	4.28	5.18	3.98
KR-25	244895.81	2478585 00	13.35	15 65	13.85	15.60	14.4
KR-70	268272.9	2482068.61	13.75	14.35	13.05	15.10	13.3
KR-20	261564.14	2477128.29	11.36	13.06	11.66	12.71	11.76
KR-22	270508.31	2463701.40	6.53	6.68	4.93	5.38	4.58
KR-19	283767 25	2479632.25	28.10	28.30	27.90	29.40	27.4
KR-17	283689.91	2474095.00	19.22	19.92	17.52	20.12	20.02
KR-18	283803.56	2465232.25	-2.40	-1 70	-2.40	-2.20	-2.8
KR-16	294427 55	2475901.85	12.50	13.90	13.40	NA	13 55
KR-07	303395.94	2488507.50	32.42	32 62	31.47	32.22	31.62
KR-08	298338.22	2495240.50	37.69	38.09	36.84	38.59	36.99
KR-06	301609.56	2494433.75	30.27	00 77	30.62	30.47	27.97
NCCA-47	280030.91	2453555.00	1.69	2.29	1.13	1.85	0.39
BR-14	280113.44	2453554 00	-5.95	-5 40	-7.05	-6.70	-7.9
NCCA-44	289541.88	2461919.50	6.70	6 86	6.12	7.68	6.16
BD-34	287036.88	2450600.50	3.34	3 34	3.14	3.39	2.99
BD-05	309398.66	2477047.00	15.32	15.17	14.97	19.07	17.62
BD-06	311648.44	2480807.00	23.24	23 44	19.79	29.29	22.82
BD-48	313994.41	2483237.25	16.55	19.55	15.60	25.05	16.62
NCCA-43	299932.24	2465442.61	-5.68	-4.67	-5.32	-4 87	-5.9
NCCA-14	311864.94	2486740.50	3 06	3.03	0.50	6.05	2 56
NCCA-13	305511.11	2486551.80	NA	NA	NA	NA	NA
NCCA-45	291753 25	245608.25	-2.36	-2 62	NA	-1.57	-2.35
NCCA-48	256865.3	2456700.75	3.51	4.91	NA	0.12	0.69
NCCA-50	273528.22	2444055.18	-7.61	-7.81	-8.44	-7.14	-8.54

NA= Not Available

Well no	X (Latitude)	Y (Longitude)	Post monsoon 1997	Pre monsoon 1998	Post monsoon 1998	Pre monsoon 1999	Post monsoon 1999
KR-23	256803 69	2471326.90	13 77	10.07	14 07	11.47	10 92
KR-21	264060.81	2468621.00	7.68	5.68	9.08	8.48	6.18
KR-25	244895.81	2478585.00	15.55	13 55	15.6	14.6	15 65
KR-70	268272 9	2482068.61	18	14.1	15.6	14.75	15.60
KR-20	261564.14	2477128.29	13.66	11.86	13.26	12 61	13.46
KR-22	270508.31	2463701.40	8 23	4.03	9.63	7.23	4.53
KR-19	283767.25	2479632.25	31.05	28.2	31 4	28.9	30.00
KR-17	283689.91	2474095.00	21.72	20.42	23 37	21.67	21.12
KR-18	283803 56	2465232.25	-0.5	-1 9	-0.75	-1.6	-1.70
KR-16	294427.55	2475901.85	17.7	12.95	18.8	17.2	16.70
KR-07	303395 94	2488507.50	33.42	32.52	34.52	32.82	32.72
KR-08	298338.22	2495240.50	39.79	36 89	38.99	37.99	39.09
KR-06	301609.56	2494433.75	31.27	30.07	31.07	30.57	30.07
NCCA-47	280030.91	2453555.00	1.94	-0.66	2 51	2 74	2.22
BR-14	280113.44	2453554.00	-6.85	-7.6	-7 05	-7.45	-7.30
NCCA-44	289541 88	2461919.50	7 53	6.9	9.12	5.28	NA
BD-34	287036.88	2450600.50	3.79	8.14	5.99	8.14	8.24
BD-05	309398.66	2477047.00	19.97	18.22	20.27	18.37	18.27
BD-06	311648.44	2480807.00	29.09	23.89	30.39	23.64	23.99
BD-48	313994.41	2483237.25	22.2	17 5	25.6	16.7	22.70
NCCA-43	299932.24	2465442.61	-4.32	-2.62	-1.38	-4.82	NA
NCCA-14	311864.94	2486740.50	9.38	NA	NA	NA	NA
NCCA-13	305511.11	2486551.80	7.07	NA	NA	NA	NA
NCCA-45	291753 25	245608 25	-3.05	-1.5	-4.95	-1.7	-4.75
NCCA-48	256865.3	2456700.75	2.86	2.19	4 06	3 06	3.59
NCCA-50	273528.22	2444055.18	-5.86	-7.48	-5.06	-6.96	-5.54

Well no	X (Latitude)	Y (Longitude)	Pre monsoon 2000	Post monsoon 2000	Pre monsoon 2001	Post monsoon 2001	Pre monsoon 2002
KR-23	256803 69	2471326.90	8.25	10 87	9.87	9.97	8.22
KR-21	264060.81	2468621.00	2.38	2.18	1.18	0.88	0.08
KR-25	244895.81	2478585.00	12.85	13 75	11.75	13.75	12.05
KR-70	268272.9	2482068.61	NA	NA	NA	NA	NA
KR-20	261564.14	2477128.29	11.36	NA	7.26	7.96	4 96
KR-22	270508 31	2463701.40	2.83	1.73	2.03	2.53	NA
KR-19	283767.25	2479632.25	26.25	26.10	NA	NA	NA
KR-17	283689 91	2474095.00	16.92	15.32	13.72	14.32	11.82
KR-18	283803.56	2465232.25	-2.40	-3.10	-4.10	-3.60	-5 30
KR-16	294427.55	2475901.85	13.40	11.60	9.20	13.70	NA
KR-07	303395 94	2488507.50	NA	NA	NA	NA	NA
KR-08	298338.22	2495240.50	35.09	34.99	32.19	29.39	27 69
KR-06	301609.56	2494433.75	28.17	26.77	25.07	23.07	20.87
NCCA-47	280030 91	2453555.00	0.97	1.87	0.22	0.72	-0.33
BR-14	280113.44	2453554.00	-8.60	-9.20	-9.10	-7.45	NA
NCCA-44	289541.88	2461919.50	NA	NA	3.14	NA	NA
BD-34	287036 88	2450600.50	3.24	3.24	18.27	4.14	4.14
BD-05	309398.66	2477047.00	17.77	18.07	17.00	17.97	18.77
BD-06	311648.44	2480807.00	18.99	18.89	NA	22.19	NA
BD-48	313994.41	2483237.25	15.40	18.90	-3.30	17.30	16.10
NCCA-43	299932.24	2465442.61	-6.78	NA	1.90	-9.98	-12.18
NCCA-14	311864.94	2486740.50	NA	NA	NA	0.98	-5.75
NCCA-13	305511.11	2486551.80	NA	NA	1.89	NA	-0 26
NCCA-45	291753.25	245608 25	NA	NA	-10 00	NA	NA
NCCA-48	256865.3	2456700.75	NA	NA	NA	2.59	2 39
NCCA-50	273528.22	2444055.18	-8.84	-0.09	NA	-9.23	NA

Well no	X (Latitude)	Y (Longitude)	Post monsoon 2002	Pre monsoon 2003	Post monsoon 2003	Pre monsoon 2004	Post monsoon 2004
KR-23	256803.69	2471326 90	9.87	7.67	10.47	8.72	10.57
KR-21	264060.81	2468621.00	2 38	2.38	8.18	5.48	7.38
KR-25	244895.81	2478585.00	13 95	10.5	14.85	14.55	15.65
KR-70	268272.9	2482068.61	NA	NA	NA	NA	NA
KR-20	261564.14	2477128.29	7.76	5.06	12.06	8.51	12 36
KR-22	270508.31	2463701.40	2 03	0 33	4.53	2.48	1.33
KR-19	283767.25	2479632.25	NA	NA	NA	NA	NA
KR-17	283689.91	2474095.00	12.42	10.02	11.12	10.92	12.02
KR-18	283803.56	2465232.25	-3.80	-7.9	-1.6	-3 3	-1.5
KR-16	294427.55	2475901.85	NA	NA	NA	NA	NA
KR-07	303395.94	2488507.50	NA	NA	NA	NA	NA
KR-08	298338.22	2495240.50	28.39	27.19	29 59	29.34	31.39
KR-06	301609.56	2494433.75	22.47	21.37	24 97	24.27	27.97
NCCA-47	280030.91	2453555 00	0 39	-0.88	2.1	2.12	2.62
BR-14	280113.44	2453554.00	-8.85	NA	-8.6	-9.1	-9.1
NCCA-44	289541.88	2461919 50	NA	NA	NA	NA	NA
BD-34	287036.88	2450600 50	4.34	5.89	3 24	3.14	4.44
BD-05	309398.66	2477047 00	17.97	15.97	19 17	17.47	19.57
BD-06	311648.44	2480807.00	NA	16.79	23.19	21.64	30.29
BD-48	313994.41	2483237 25	20.70	16.8	19 5	17.2	23.9
NCCA-43	299932.24	2465442.61	-11.14	-16.75	-10.38	-11.08	-9.08
NCCA-14	311864.94	2486740 50	2.75	-4.82	7.42	-2.58	6.72
NCCA-13	305511.11	2486551.80	0.00	-10.03	-2.58	-3.33	-1.78
NCCA-45	291753.25	245608 25	NA	NA	NA	NA	NA
NCCA-48	256865.3	2456700.75	2 72	1.94	3.09	2.74	3.24
NCCA-50	273528.22	2444055.18	NA	NA	NA	NA	NA

Well no	X (Latitude)	Y (Longitude)	Pre monsoon 2005	Post monsoon 2005	Pre monsoon 2006	Post monsoon 2006	Pre monsoon 2007
KR-23	256803.69	2471326.90	8.17	13.27	10.17	13.57	NA
KR-21	264060.81	2468621.00	2.78	7.23	5.08	8 38	NA
KR-25	244895 81	2478585 00	13 95	15.45	14.4	15.15	NA
KR-70	268272.9	2482068.61	NA	NA	NA	NA	NA
KR-20	261564.14	2477128.29	8.36	12.91	10.71	12.61	NA
KR-22	270508.31	2463701.40	0.43	4.93	3.43	7.53	NA
KR-19	283767.25	2479632.25	NA	NA	NA	NA	NA
KR-17	283689.91	2474095.00	12 52	15.52	15.32	19.02	NA
KR-18	283803.56	2465232.25	-3.5	-1	-2 5	-2.1	NA
KR-16	294427.55	2475901.85	NA	NA	13.7	17 7	NA
KR-07	303395.94	2488507.50	NA	NA	NA	NA	NA
KR-08	298338.22	2495240.50	29.09	34.84	33.64	38.19	NA
KR-06	301609.56	2494433.75	23.57	31.02	28.57	33.07	NA
NCCA-47	280030.91	2453555.00	2.87	4.12	4.02	4 77	4 28
BR-14	280113.44	2453554.00	-9.55	-9.65	NA	NA	-0.9
NCCA-44	289541.88	2461919.50	NA	NA	NA	NA	NA
BD-34	287036.88	2450600.50	5.49	3.59	5.74	5.44	4.74
BD-05	309398.66	2477047.00	15.47	20.27	19.67	21.27	18.42
BD-06	311648.44	2480807.00	25.79	27.89	23.79	28.04	23.24
BD-48	313994.41	2483237.25	16.5	26 9	17.5	28.4	16.5
NCCA-43	299932 24	2465442 61	-9.12	-2.62	-4.23	2.42	-0.26
NCCA-14	311864.94	2486740.50	-4.38	11.22	0 07	11.22	3.4
NCCA-13	305511.11	2486551.80	-2.88	-0.33	0.07	2.57	2 74
NCCA-45	291753.25	245608.25	NA	NA	NA	NA	NA
NCCA-48	256865 3	2456700.75	NA	NA	NA	NA	NA
NCCA-50	273528 22	2444055.18	NA	NA	NA	NA	NA

4.8 Water Quality Data of Wells

The Water quality data of Wells such as TDS, EC, PH, Cl, CO3, HCO3, SO4, Mg, Na and K are collected from GWRDC. Using the Topographical sheet of the study area the distances from Kavi and from river of wells have been found out. The Year wise TDS of different wells etc are given in table 4.4.

Table-4.4 Water Quality Data of Wells

WELL	Village	Dist. from Kavi in km	Dist. from River in km	1995	1996	1997	1998
				Pre monsoon	Pre monsoon	Pre monsoon	Pre monsoon
				TDS in ppm	TDS in ppm	TDS in ppm	TDS in ppm
NCCA-48	Kavi	6.50	5 90	930	N A	2250	980
KR-23	Kansari	8.05	7.60	1110	1180	1350	1070
KR-21	Bhuval	10.60	10.50	750	1180	1040	1020
NCCA-47	Sarod	14 25	3 20	14720	13740	20870	14820
KR-22	Haripura	14.35	6.90	2710	2640	2270	2650
KR-20	Kanisha	15.00	15.00	810	940	820	970
KR-25	Gudel	18 40	18.40	720	700	540	860
KR-18	Gajna	26 50	2.45	450	660	720	540
NCCA-50	Piludra	24.40	6 55	2470	2830	3790	2480
KR-17	Bhadran	28.60	7.50	1160	1550	1360	1430
BD-34	Masar Road	29.65	11.45	2120	2020	2120	2660
KR-70	Danteli	30.00	22.50	850	980	920	1060
KR-19	Borsad	30 95	12.40	740	1000	740	830
NCCA-44	Dabka	32.75	1 80	2040	1960	2110	1680
NCCA-45	Karankuva	35.75	7.10	910	N A	1810	1770
KR-16	Anklav	38.75	5.65	980	1130	1390	1080
NCCA-43	Jaspur	42.50	2.30	1580	900	1850	1240
KR-07	Vasad	47.70	1.85	570	920	940	450
KR-08	Bedva	51.00	7.30	930	1240	1040	1060
BD-05	Dashrath	53.10	7.50	2510	1960	2180	1990
KR-06	Sarsa	53 25	4.20	690	720	550	451
BD-06	Sokhda	56 75	8.65	890	830	1230	810
NCCA-14	Anjesar	59.00	6 25	950	950	1420	N A
BD-48	Manjusar	59.45	10.55	270	220	250	240

NA- Note Available

WELL	Village	Dist. from Kavi in km	Dist. from River in km	1999 Pre monsoon TDS in ppm	2000 Pre monsoon TDS in ppm	2001 Pre monsoon TDS in ppm	2002 Pre monsoon TDS in ppm
NCCA-48	Kavi	6 50	5.90	2340	N A	1950	1340
KR-23	Kansari	8.05	7 60	1050	1040	1370	1600
KR-21	Bhuval	10.60	10 50	1640	820	900	1080
NCCA-47	Sarod	14 25	3.20	18310	17150	15970	18140
KR-22	Haripura	14.35	6.90	2790	2070	2280	1990
KR-20	Kanisha	15.00	15.00	1720	1540	1130	1460
KR-25	Gudel	18.40	18 40	990	820	830	1180
KR-18	Gajna	26.50	2.45	720	690	1180	900
NCCA-50	Piludra	24.40	6.55	2630	3400	3620	N A
KR-17	Bhadran	28.60	7.50	1760	1470	1540	1300
BD-34	Masar Road	29.65	11.45	2210	2160	2000	1830
KR-70	Danteli	30.00	22.50	1360	N A	N A	N A
KR-19	Borsad	30.95	12.40	1090	830	N A	N A
NCCA-44	Dabka	32.75	1.80	1560	1800	N A	N A
NCCA-45	Karankuva	35 75	7.10	1070	N A	N A	N A
KR-16	Anklav	38.75	5.65	1640	1080	1180	N A
NCCA-43	Jaspur	42.50	2.30	1440	1520	N A	1350
KR-07	Vasad	47.70	1 85	970	N A	N A	N A
KR-08	Bedva	51.00	7.30	1310	1000	1140	1240
BD-05	Dashrath	53.10	7 50	1600	1830	1930	N A
KR-06	Sarsa	53.25	4.20	640	590	660	680
BD-06	Sokhda	56.75	8.65	520	1130	N A	N A
NCCA-14	Anjesar	59.00	6.25	N A	N A	600	710
BD-48	Manjusar	59.45	10.55	290	360	340	830

WELL	Village	Dist. from Kavi in km	Dist. from River in km	2003	2004	2005	2006
				Pre monsoon	Pre monsoon	Pre monsoon	Pre monsoon
				TDS in ppm	TDS in ppm	TDS in ppm	TDS in ppm
NCCA-48	Kavı	6.50	5.90	1170	N A	N A	N A
KR-23	Kansari	8.05	7.60	1460	1820	1420	1190
KR-21	Bhuval	10.60	10.50	1080	1360	1080	970
NCCA-47	Sarod	14 25	3 20	17890	20130	15970	18110
KR-22	Haripura	14.35	6.90	1760	1490	2260	2150
KR-20	Kanisha	15.00	15.00	1470	2080	1290	1070
KR-25	Gudel	18.40	18.40	1850	630	1040	860
KR-18	Gajna	26.50	2 45	1310	740	1080	930
NCCA-50	Piludra	24.40	6.55	N A	N A	N A	N A
KR-17	Bhadran	28.60	7.50	1330	1600	1570	1690
BD-34	Masar Road	29.65	11.45	2340	2080	2150	3200
KR-70	Danteli	30.00	22.50	N A	N A	N A	N A
KR-19	Borsad	30.95	12.40	N A	N A	N A	N A
NCCA-44	Dabka	32.75	1.80	N A	N A	N A	N A
NCCA-45	Karankuva	35.75	7.10	N A	N A	N A	N A
KR-16	Anklav	38.75	5.65	N A	N A	N A	1160
NCCA-43	Jaspur	42.50	2.30	930	960	950	N A
KR-07	Vasad	47.70	1.85	N A	N A	N A	N A
KR-08	Bedva	51.00	7.30	1000	1030	1190	1380
BD-05	Dashrath	53.10	7 50	2170	400	1830	2010
KR-06	Sarsa	53.25	4.20	440	740	750	630
BD-06	Sokhda	56.75	8.65	990	790	870	600
NCCA-14	Anjesar	59.00	6.25	470	590	510	370
BD-48	Manjusar	59.45	10.55	N A	350	320	250

4.9 Rainfall Data

The average annual rainfall data have been collected from State Water Data Center (SWDC) and GWRDC for Anand, Borsad, Petlad, Khambhat talukas of Anand District; Savli, Vadodara and Padra talukas of Vadodara District and Jambusar taluka of Bharuch district from year 1994 to 2006. Talukawise rainfalls are as shown in table 4.5.

Table-4.5 Talukawise Rainfalls in mm

TALUKA/YEAR	Khambhat	BORSAD	ANAND	PETLAD
1994	935	819	1250	1288
1995	454	496	535	757
1996	262	331	377	508
1997	1068	1052	1330	1306
1998	896	937	704	606
1999	340	380	398	455
2000	340	365	370	190
2001	416	517	525	466
2002	573	362	545	425
2003	1122	1086	923	1073
2004	956	773	821	815
2005	2130	1733	1312	1440
2006	1707	1049	1379	997

TALUKA/YEAR	VADODARA	PADRA	SAVLI	JAMBUSAR
1994	1130	927	1205	975
1995	631	442	485	507
1996	1003	810	1590	400
1997	1170	849	1164	571
1998	1134	469	1199	776
1999	377	291	533	252
2000	835	255	610	262
2001	826	489	775	437
2002	835	378	661	616
2003	952	438	1102	613
2004	1153	445	770	559
2005	1755	1691	1346	539
2006	1790	1799	1441	825

4.10 Recharge Data

The norms provided by the Ground water Resources Estimation Committee, Ministry of Irrigation,(Ministry of Irrigation,1984 ; Ministry of Water Resources,1997) and the Indian Agricultural Research Institute (IARI,1983) are adopted to estimate the net annual recharge in the study area. The net annual recharges during (June to May) in study area for different talukas were estimated by the water table fluctuation approach.

For calculating the annual recharge during monsoon, the formula indicated below is adopted.

Monsoon recharge (in MCM/year) =

$$[\{(A * WTF * S_y) + D_w - (R_s + R_{igw} + R_{is})\} * NF] + R_s + R_{is} \quad \text{.......} \quad (4.1)$$

Where

$A * WTF * S_y$ = Rainfall recharge by WTF.

A= Net suitable area for groundwater recharge (sq.km.)

WTF= Groundwater table rise

S_y= Specific yield (fraction)

D_w= Gross kharif draft (MCM/Year)

R_s = Recharge due to monsoon seepage from canals and tanks (MCM/Year)

R_{igw} = Recharge due to monsoon seepage from groundwater irrigation (MCM/Year)

R_{is} = Recharge due to monsoon seepage from surface water irrigation (MCM/Year)

NF=Normalization factor.

The sample calculations of Vadodara taluka for the year 2003 are contained in Annexure-V.

Calculated values of all the talukas are adjusted by subsequent field checks of the study area and the Talukawise recharge in m/day are represented in table 4.6

Table-4.6 Talukawise Recharge in m/day

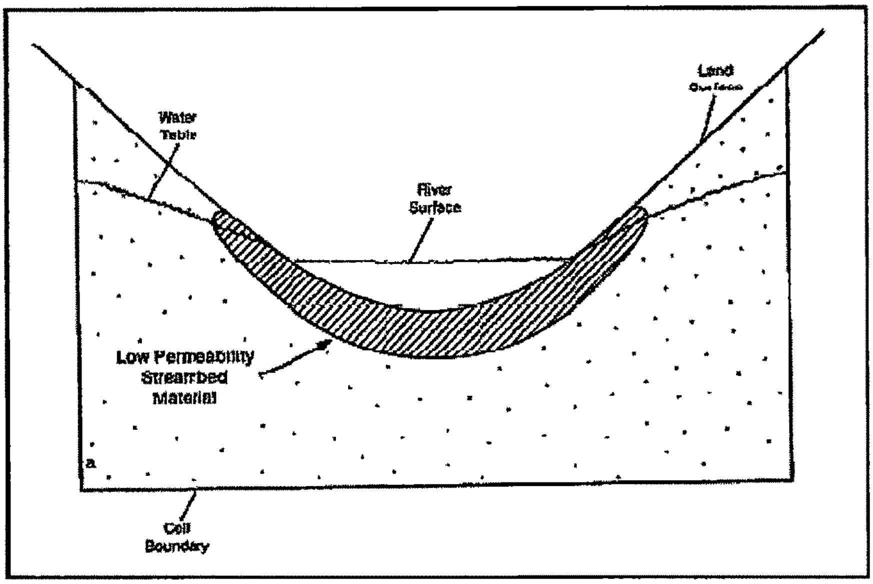
year	Season	Vadodara	Savli	Padra	Jambusar
1997	Monsoon	0.0015403	0.0015549	0.0017	0.0012
	Non monsoon	-0.0003772	-0.0003985	-0.0003	-0.00018
1998	Monsoon	0.0014921	0.0014921	0.0014	0.0011
	Non monsoon	-0.0003783	-0.0003996	-0.00035	-0.00018
2003	Monsoon	0.001638	0.0019867	0.0009153	0.0009546
	monsoon	-0.0004723	-0.000255	-0.0003776	-0.0003776
2004	Monsoon	0.0011575	0.0013959	0.0009396	0.0008705
	Non monsoon	-0.0005296	-0.000402	-0.0003809	-0.0003809
2005	Monsoon	0.0016081	0.00209627	0.0013403	0.0009525
	Non monsoon	-0.0005870	-0.0005480	-0.0003843	-0.0003843
2006	Monsoon	0.0013517	0.0020559	0.0013646	0.0010875
	Non monsoon	-0.0006444	-0.0006936	-0.0003876	-0.0003876

year	season	Khambhat	Borsad	Anand	Petlad
1997	Monsoon	0.001286	0.001286	0.00204	0.0015966
	Non monsoon	-0.00015	-0.00015	-0.000095	-0.0001
1998	Monsoon	0.0011568	0.0011568	0.0011	0.001
	Non monsoon	-0.0002	-0.00022	-0.00013	-0.00015
2003	Monsoon	0.002357	0.002357	0.0019979	0.0022286
	monsoon	-0.0002595	-0.0002595	-0.0000706	-0.0001043
2004	Monsoon	0.0015311	0.0015311	0.0018151	0.0018145
	Non monsoon	-0.0002926	-0.0002926	-0.0000967	-0.000132
2005	Monsoon	0.0011683	0.0023683	0.0023408	0.0024276
	Non monsoon	-0.0003056	-0.0003056	-0.0001229	-0.0001595
2006	Monsoon	0.0012287	0.0022287	0.002335	0.0021549
	Non monsoon	-0.0003186	-0.00031860	-0.0001490	-0.0001873

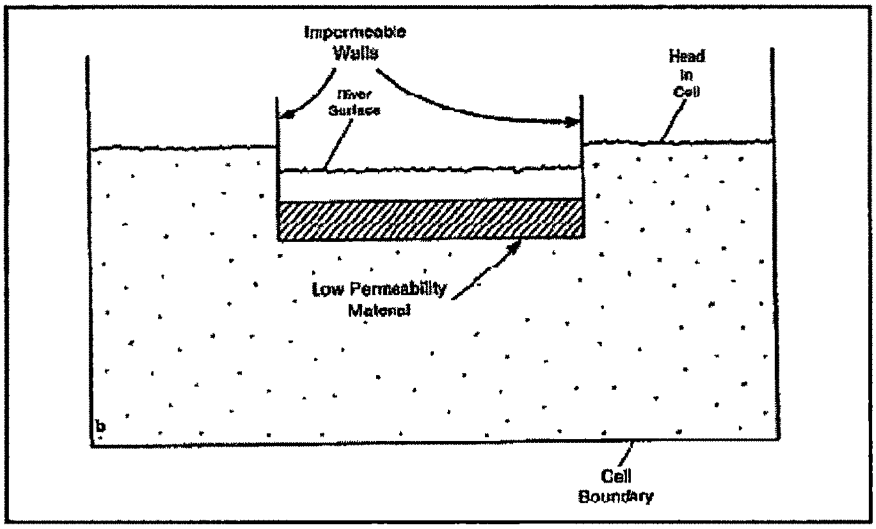
Note: Monsoon season from 15^{th} June to 14^{th} October

4.11 Conductance for the River

Rivers and streams contribute water to the groundwater system or drain water from it depending on the head gradient between the stream and the groundwater regime. The purpose of the river package is to simulate the effects of flow between surface water features and groundwater systems. The river package adequately represents most surface- groundwater systems.



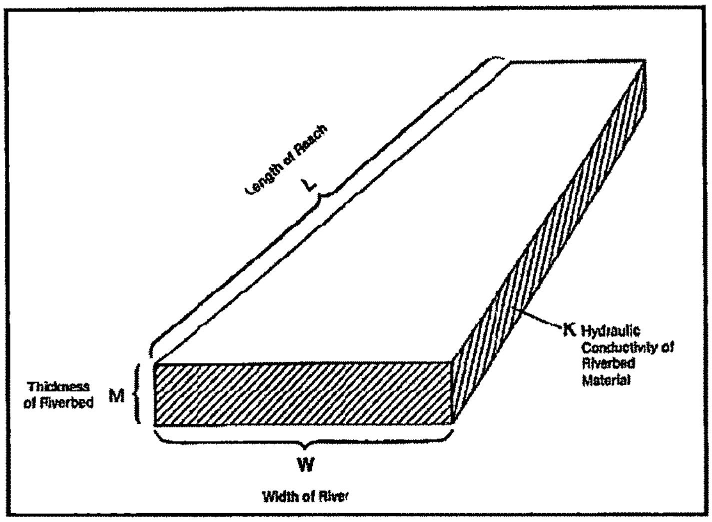
(a)



(b)

Figure 4.1 (a) Cross section of an aquifer containing a stream and (b) Conceptual representation of stream-aquifer interconnection in simulation

Source: McDonald, and Harbaugh, (1988).



Streambed conductance = KLW/M

Figure 4.2 Idealization of streambed conductance in an individual cell

Source: McDonald and Harbaugh, (1988).

Figure 4.1 (a) shows cross section of an aquifer containing a stream which represents a situation in which the open water of a stream is separated from the groundwater system by a layer of low permeability streambed material. Figure 4.1 (b) shows an idealization of this system in which the stream-aquifer interconnection is represented in simulation as a simple conductance through which one-dimensional flow occurs.

Figure 4.2 shows an isolated view of the idealized streambed conductance of figure 4.1 (b), as it crosses an individual cell. The length of the conductance block is taken as the length of the stream, L, as it crosses the node; the width is taken as the stream width, W; the distance of flow is taken as the thickness, M, of the streambed layer; and the hydraulic conductivity (vertical) of the streambed material is designated K. The river package uses the streambed conductance (CRIV) which is given by

Streambed conductance (CRIV) = KLW/M .... (4.2)

Flow (rate of leakage) between the stream and the groundwater system or aquifer is given by

$$QRIV = CRIV\ (HRIV - h_{i,j,k}) \qquad h_{i,j,k} > RBOT \quad \ldots\ldots\ldots\ldots (4.3)$$

Where QRIV is the flow between the stream and the aquifer, taken positive if it is directed into the aquifer; HRIV is the head in the stream; CRIV is the hydraulic conductance of the stream-aquifer interconnection (KLW/M), $h_{i,j,k}$ is the head at the node in the cell (in the aquifer) directly underlying the stream reach which corresponds to water table and RBOT is the bottom of the streambed.

Sometimes the water level (table) in the aquifer has fallen below the bottom of the streambed layer, leaving an unsaturated interval beneath that layer; if it is assumed that the streambed layer itself remains saturated, the head at its base will simply be the elevation at that point. If this elevation is designated RBOT, leakage stabilizes and the flow through the streambed (QRIV) is given by $QRIV = CRIV\,(HRIV - RBOT), \quad h_{i,j,k} \leq RBOT$ ..... (4.4)

If reliable field measurements of stream seepage and associated head difference are available, they may be used to calculate an effective conductance. Otherwise, a conductance value must be chosen more or less arbitrarily and adjusted during model calibration (McDonald and Harbaugh, 1988).

The river reach from Khanpur to Kavi (Sea) is divided into three arcs, namely upper, middle and lower arcs as shown in Figure 4.3. The initial conductance of 50, 60 and 20 per unit length (m) is estimated and given to upper, middle and lower arcs respectively. GMS automatically computes the appropriate cell conductance value when the river is assigned to the grid cells.

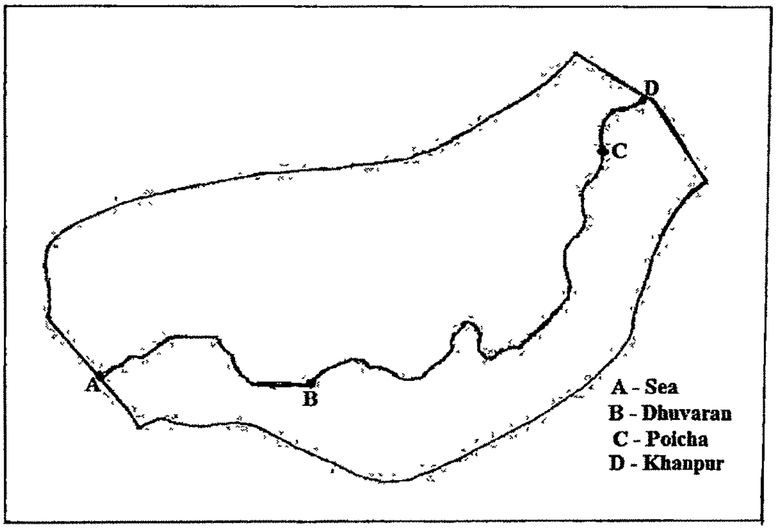


Figure 4.3 Locations of Arcs of River for Conductance

4.12 GMS 6.0 Software

The Department of Defense Groundwater Modeling System (GMS) is a comprehensive graphical user environment for performing groundwater simulations. The entire GMS system consists of a graphical user interface for ground water modeling (the GMS program) and a number of pre and post processor of multiple groundwater flow and contaminant transport analysis codes like MODFLOW, MT3DMS, RT3D, SEAM3D, MODPATH, MODAEM, SEEP2D, FEMWATER, WASH123D, UTCHEM (Goyal, R. 2003). The GMS interface was developed by the Environmental Modeling Research Laboratory of Brigham Young University in partnership with the U.S. Army Engineer Waterways Experiment Station. GMS was designed as a comprehensive modeling environment. Several types of models are supported and facilities are provided to share information between different models and data types. Tools are provided for site characterization, model conceptualization, mesh and grid generation, geostatistics, and post-processing.

GMS includes a powerful graphical interface to the MODFLOW 2000 model. Most popular MODFLOW packages are supported. Models can be constructed using either the grid approach or the conceptual model approach. Numerous options are provided for visualizing MODFLOW simulation results.

4.12.1 MODFLOW

MODFLOW is a finite-difference modeling program, which simulates groundwater flow in three dimensions. The code or computer program is written in FORTRAN 77. The program has a modular format, and consists of a 'main' program and a series of highly independent subroutines called 'modules'. The modules are grouped into 'packages'. Each package deals with a specific feature of the hydrologic system which is to be simulated, such as flow of rivers or flow into drains, or with a specific method of solving linear equations which describe the flow system. The division of the program into modules facilitates examination of each hydrologic feature in the model independently. Another advantage of having the modular structure is that new options/features could be added to the program without much change to the existing code.

4.12.2 The Conceptual Model Approach

A MODFLOW model can be created in GMS using one of two methods: assigning and editing values directly to the cells of a grid (the grid approach), or by constructing a high level representation of the model using feature objects in the Map module and allowing GMS to automatically assign the values to the cells (the conceptual model approach). Except for simple problems, the conceptual model approach is typically the most effective.

In GMS, the term conceptual model is used in two different ways. In the generic sense, a conceptual model is a simplified representation of the site to be modeled including the model domain, boundary conditions, sources, sinks, and material zones. GMS also has a conceptual model object, that can be defined in the map module using points, arcs, and polygons. Once the conceptual model object is defined, a grid can be automatically generated and the boundary conditions and model parameters are computed and assigned to the proper cells. This approach to modeling fully automates the majority of the data entry and eliminates the need for most or all of the tedious cell-by-cell editing traditionally associated with MODFLOW modeling.

A complete conceptual model object consists of several coverages. One coverage is typically used to define the sources and sinks such as wells, rivers, lakes, and drains. Coverage (or the same coverage) is used to define the recharge zones. Other coverages can be used to define the zones of hydraulic conductivity within each layer. Any number of coverages may be used, or all these attributes may exist in the same coverage. In addition to the feature data, a conceptual model may include other data (scatter points, boreholes, solids) to define the layer elevations. A specialized set of tools for manipulating layer elevation data is provided in GMS.

4.12.3 Advantages of the Conceptual Model Approach

There are numerous benefits to the conceptual model approach. First of all, the model can be defined independently of the grid resolution. The modeler does not need to waste valuable time computing the appropriate conductance to assign to a river cell based on the length of the river reach within the cell. This type of computation is performed automatically. Furthermore, transient parameters such as pumping rates for wells can also be assigned independently of model discretization. Transient parameters are entered as a curve of the stress vs. time. When the conceptual model is converted to the numerical model, the transient values of the stresses are automatically assigned to the appropriate stress periods. Since the conceptual model is defined independently of the spatial and temporal discretization of the numerical model, the conceptual model can be quickly and easily changed and a new numerical model can be generated in seconds. This allows the modeler to evaluate numerous alternative conceptual models in the space of time normally required to evaluate one, resulting in a more accurate and efficient modeling process.

A further advantage of storing attributes with feature objects is that the method of applying the boundary conditions to the grid cells reduces some of the instability that is inherent in finite difference models such as MODFLOW and MT3DMS. When the user enters individual values for heads and elevations, entering cell values one cell at a time can be tedious. It is also difficult to determine the correct elevation along a river segment at each cell that it crosses. The temptation is to select small groups of cells in series and apply the same values to all of the cells in the group. This results in an extreme stair-step condition that can slow or even prevent convergence of the numerical solver. By using GMS to interpolate values at locations along a linear boundary condition such as a river, the user insures that there will be no abrupt changes from cell to cell-thus minimizing the stair-step effect. It also produces a model with boundary conditions that more accurately represent real world conditions.

4.12.4 Groundwater Flow Equation Used In MODFLOW

The simultaneous equations used by MODFLOW for each finite difference cell is derived using Darcy's Law and the law of conservation of mass. The derivation gives a partial differential equation, which is used by MODFLOW. This partial-differential equation of groundwater flow used in MODFLOW-2000 is

$$\frac{\partial}{\partial X}\left[K_{XX}\frac{\partial h}{\partial X}\right] + \frac{\partial}{\partial Y}\left[K_{YY}\frac{\partial h}{\partial Y}\right] + \frac{\partial}{\partial Z}\left[K_{ZZ}\frac{\partial h}{\partial Z}\right] + W = S_S\frac{\partial h}{\partial t} \quad \text{.....................} (4.5)$$

Where,

Kxx, Kyy, and Kzz are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);

h is the potentiometric head (L);

W is a volumetric flux per unit volume representing sources and/or sinks of water, with $W<0.0$ for flow out of the ground-water system, and $W>0.0$ for flow in (T^{-1});

S_s is the specific storage of the porous material (L^{-1}); and

t is time (T).

Above Equation, when combined with boundary and initial conditions, describes transient three-dimensional ground-water flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions.

The Ground-Water Flow Process solves above equation using the finite-difference method in which the groundwater flow system is divided into a grid of cells (fig. 4.4). For each cell, there is a single point, called a node, at which head is calculated. The finite-difference equation for a cell is (Harbaugh et al. 2000)

$$\begin{aligned} & CR_{i,j-1/2,k}\left(h^m_{i,j-1,k} - h^m_{i,j,k}\right) + CR_{i,j+1/2,k}\left(h^m_{i,j+1,k} - h^m_{i,j,k}\right) \\ & + CC_{i-1/2,j,k}\left(h^m_{i-1,j,k} - h^m_{i,j,k}\right) + CC_{i+1/2,j,k}\left(h^m_{i+1,j,k} - h^m_{i,j,k}\right) \\ & + CV_{i,j,k-1/2}\left(h^m_{i,j,k-1} - h^m_{i,j,k}\right) + CV_{i,j,k+1/2}\left(h^m_{i,j,k+1} - h^m_{i,j,k}\right) + P_{i,j,k}h^m_{i,j,k} + Q_{i,j,k} \\ & = SS_{i,j,k}\left(DELR_j \times DELC_i \times THICK_{i,j,k}\right)\frac{h^m_{i,j,k} - h^{m-1}_{i,j,k}}{t^m - t^{m-1}} \end{aligned}$$

.... (4.6)

Where

$h^m_{i,j,k}$ is head at cell i, j, k at time step m(L);

CV, CR and CC are hydraulic conductances, or branch conductances, between node i, j, k and a neighboring node (L^2/T);

$P_{i,j,k}$ is the sum of coefficients of head from source and sink terms (L^2/T);

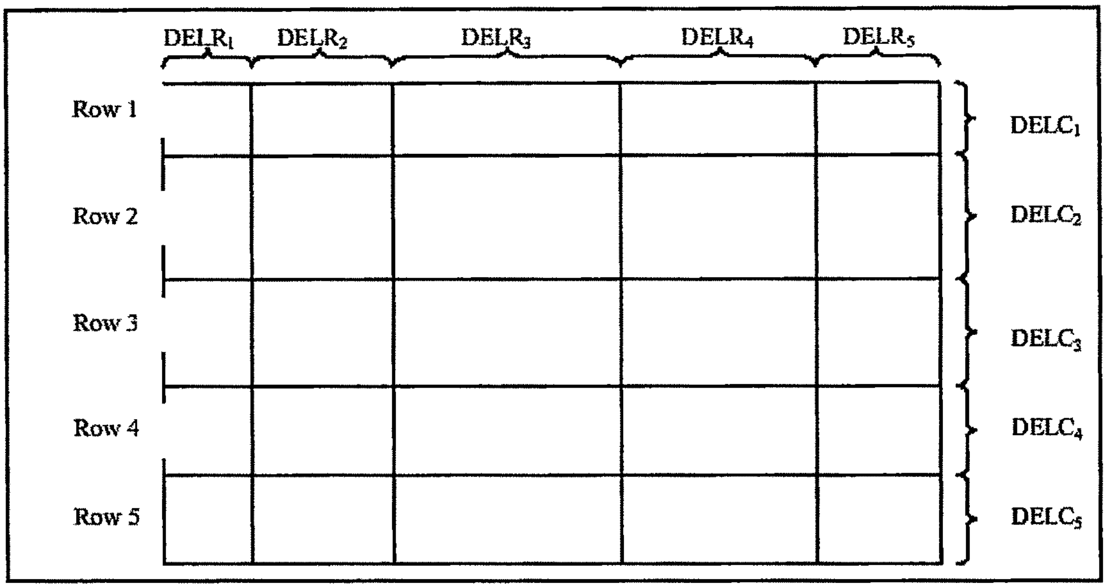
$Q_{i,j,k}$ is the sum of constants from source and sink terms, with $Q_{i,j,k} < 0.0\ for\ flow\ out\ of\ the\ ground-water\ system, and\ Q_{i,j,k} > 0.0\ for\ flow\ in\ \left(\frac{L^3}{T}\right)$;

$SS_{i,j,k}$ is the specific storage(L^{-1});

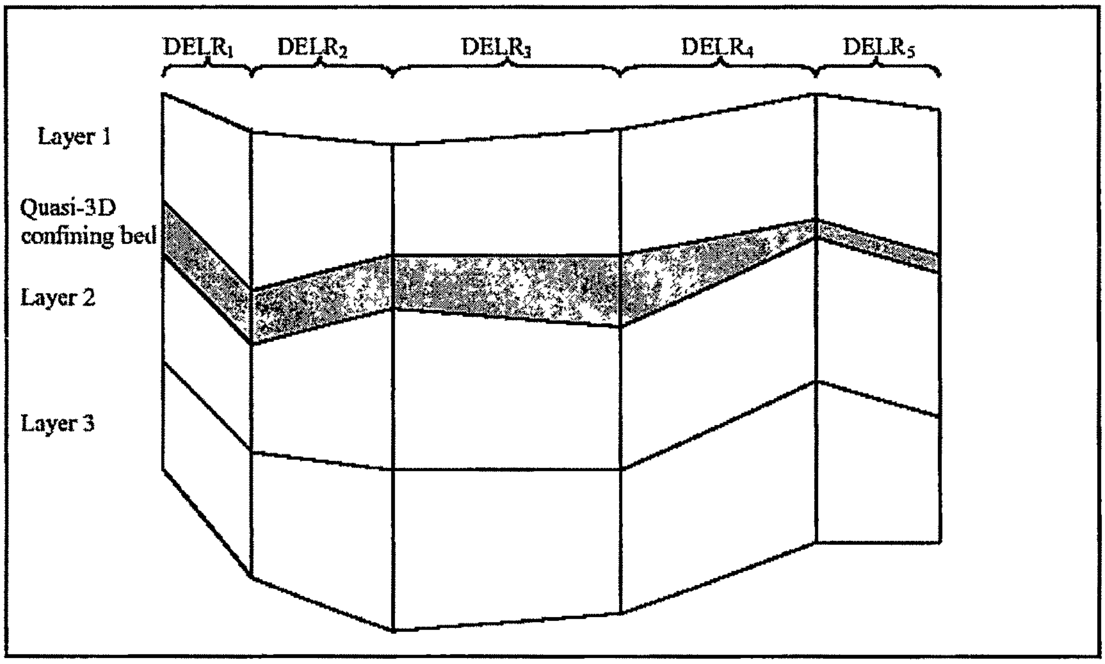
$DELR_j$ is the cell width of column j in all rows (L);

$DELC_i$ is the cell width of row i in all columns (L);

$THICK_{i,j,k}$ is the vertical thickness of cell i, j, k (L); and t^m is the time at time step m (T)



(A)



(B)

Figure 4.4 Finite-Difference Grid with (A) Plan View and (B) Cross-Section view.

Source: Harbaugh et al., MODFLOW-2000.

4.13 Groundwater Modeling

Groundwater modeling is a powerful management tool which can serve multiple purposes such as providing a framework for organizing hydrological data, quantifying the properties and behavior of the systems and allowing quantitative prediction of the responses of those systems to externally applied stresses. No other numerical groundwater management tool is as effective as a 3-dimensional groundwater model. A number of groundwater modeling studies have been carried out around the World for effective groundwater management. A digital groundwater model is an idealized representation of a groundwater system and describes in mathematical language, how the basin would function under various conditions. It considers relationship among parts of the system and stresses on the system simultaneously and describes the system studied in concise quantitative terms (ORG, 1982).

Conceptual models describe how water enters an aquifer system, flows through the aquifer system and leaves the aquifer system. Conceptual models start with simple sketches although in their final form they may be detailed three dimensional diagrams. Developing a conceptual model is not straightforward. It is necessary to examine all available data, other information, visit the area under different climatic conditions and talk to those who have used the aquifer. Insights can be gained from case studies in similar areas, but there will be always be new features to identify since every aquifer system has unique features. The conceptual model is put into a form suitable for modeling. The step includes design of the grid, selecting time steps, setting boundary, and initial conditions and preliminary selection of values for aquifer parameters and hydrologic stress.

Perhaps the most demanding task in preparing a numerical model from a conceptual model is the selection of appropriate values of the aquifer parameters. Inevitably there is insufficient information. Even if additional fieldwork is carried out, the selection of suitable parameter values requires skill, experience and judgment. Furthermore, the selection of parameter values is a time consuming task. Unless it is carried out systematically and thoroughly, a great deal of rethinking may required in later stages of model refinement. For each parameter it is advisable to quote the best estimate and arrange which represents the uncertainty. Numerical models should not have unnecessary complexity in terms of number of layers, number of mesh divisions and size of time steps. Another issue which requires careful attention is that there are some features which are not conveniently represented in certain numerical model codes. Refinement of numerical groundwater models when the model code is run for the first time there are likely to be many differences between field and modeled values of groundwater heads and flows. First of all there will be differences because of mistakes in preparing the input data; very careful checks must be made to ensure that the model boundaries parameter values, inflow and outflow are correctly included in the numerical model (Rushton, 2003).

A protocol for modeling includes code selection and verification, model design, calibration, sensitivity analysis and finally prediction (Anderson, 1992).

4.13.1 Assumptions and Considerations in Model Analysis

1. Basin is a single layered unconfined aquifer.
2. An impermeable basement boundary (either the basement is complex or the tertiary clays) exists at the bottom of aquifer.
3. The storage coefficient (specific yield) is constant with time.
4. Vertical flow components are negligible compared to horizontal flow components.

4.13.2 Construction of the Model for the Study Area

Study area's Northern and Southern limits are marked by catchment boundary of Mahi basin. The western limit is determined by the Gulf of Khambhat and in the east the area stretches up to Khanpur between catchment boundaries of Mahi basin. The study area comprises an area of 2298.23 sq. km and is enclosed within the North latitude 22°05'06" to 22°33'36" and East longitude 72°27'18" to 73°13'57".

The selection of MODFLOW is widely accepted model all over the world and many regional groundwater modeling studies based on MODFLOW are reported in the literature (Elango and Senthilkumar (2006), Elango (2009)). It has capabilities to handle unsteady, three dimensional groundwater flow problems with complex hydrogeogical features. Integration of MODFLOW in GMS provides calibration utility. Hence GMS software is selected for present study. Using the software Groundwater Modeling System (GMS 6.0) the Mahi estuarine area has been modeled. The analysis has been carried out using Layer Property Flow (LPF) package of MODFLOW-2000 (based on Finite Difference Method) in GMS6.0.

4.13.2.1 Base Map Preparation

For base map, a scanned image of study area has been registered in appropriate co-ordinate system (UTM co-ordinate system) using Arc view software (GIS) and shape (shp) file of this Mahi estuarine area is established. This shape file is imported to GMS and a base map for three dimensional groundwater flow model is obtained. Top elevation of Ground Level data modeling have been taken from Annexure-II.

The top elevation data are imported from database in GMS as a 2D scatter point data set and the top elevation TIN have been established using TIN Module in GMS using 2D scatter data set as shown in figure 4.5

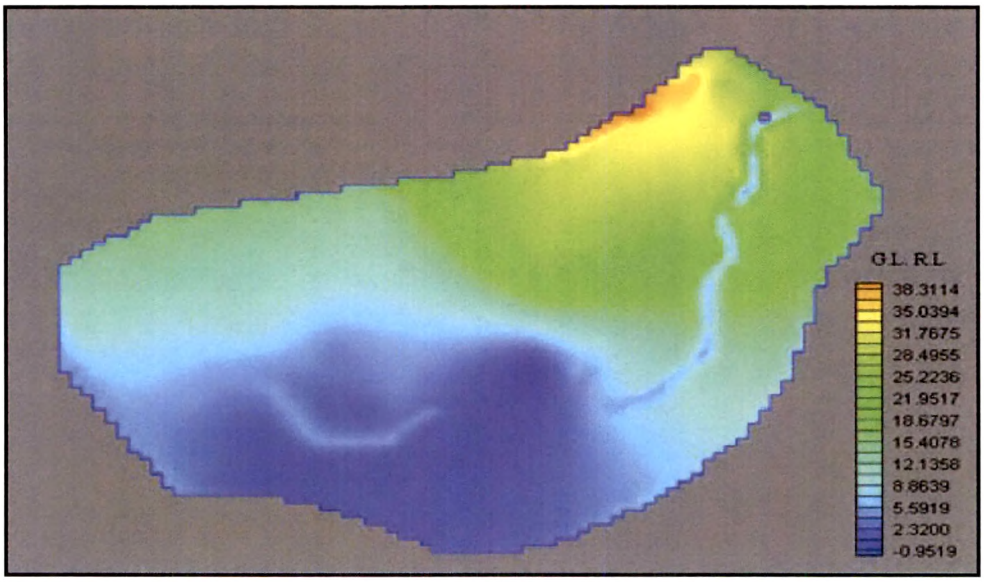


Figure 4.5 Top Elevation TIN

4.14 Conceptual Model of the Aquifer System

The model area is bounded by the catchment boundary of Mahi River Basin in the North and South. The Western limit is determined by the Gulf of Khambhat and in the East the area stretches up to Khanpur between catchment boundaries of Mahi River Basin.

The aquifer system of the model area is typical alluvial. Recharge to the aquifer system is mainly by infiltration of rainfall, seepage from rivers and the drainable surplus from irrigation. At present the most important discharge component is pumpage from wells for irrigation. It includes net groundwater recharge zones and other boundaries which can be represented as head dependent flow boundaries.

4.14.1 Fence Diagram, Solids and Longitudinal Sections

Fence Diagram has been prepared / developed by using the Lithology data of wells. The Lithology data of wells have been imported from database as a borehole data set using 2D scatter point module in GMS. Annexure-IV shows Lithology (borehole) data set which are imported to GMS.

From the above data set, GMS auto assigns Horizon IDs of material, and from these Horizon IDs, GMS auto creates cross sections of different wells and from these cross sections, GMS auto fill these cross sections using same horizon IDs of material (Environmental Modeling Research Laboratory, 2005) as shown in figure 4.6.

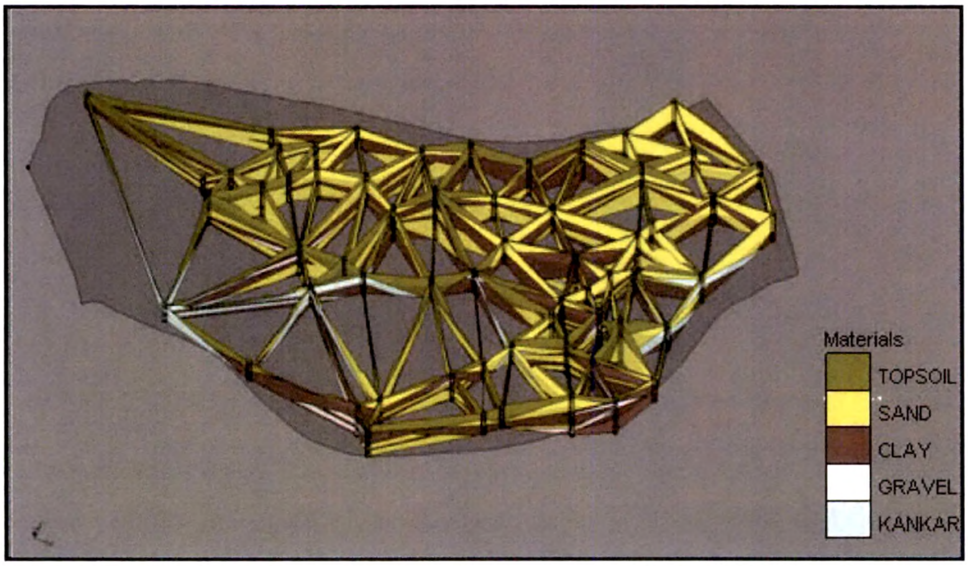


Figure 4.6 Fence Diagram of Study Area

From the above cross sections of different wells, The Solid module of GMS is used to construct three-dimensional models of stratigraphy using solids of study area created is shown in figure 4.7.

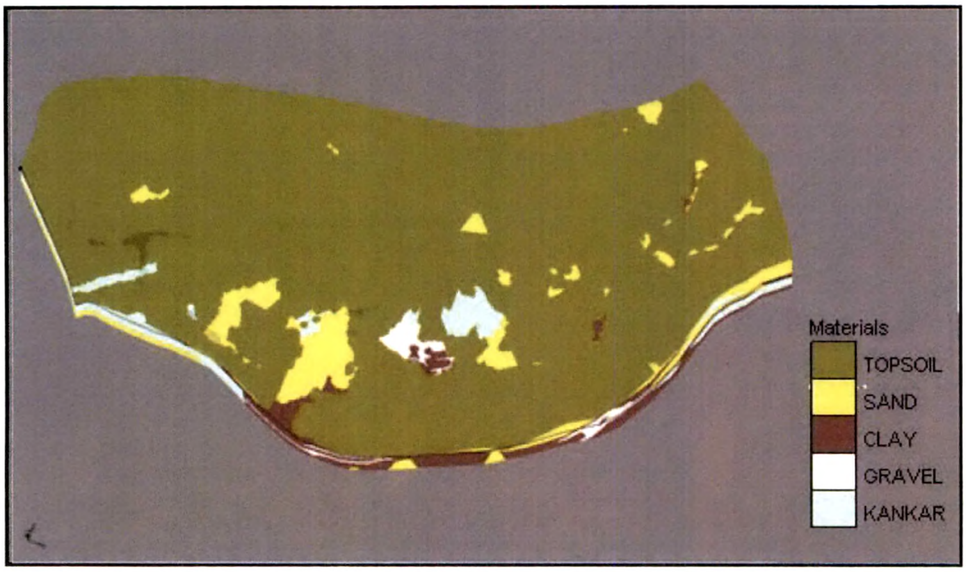


Figure 4.7 Solids of Study Area

Once the three-dimensional model (Solids) is created, cross sections can be cut anywhere on the model to create Longitudinal Sections. Fig 4.8 shows the three location of longitudinal sections i.e. along right bank (A-A'), along River (B-B') and along left bank (C-C') that have been cut for longitudinal sections as shown in figure 4.9 to 4.11.

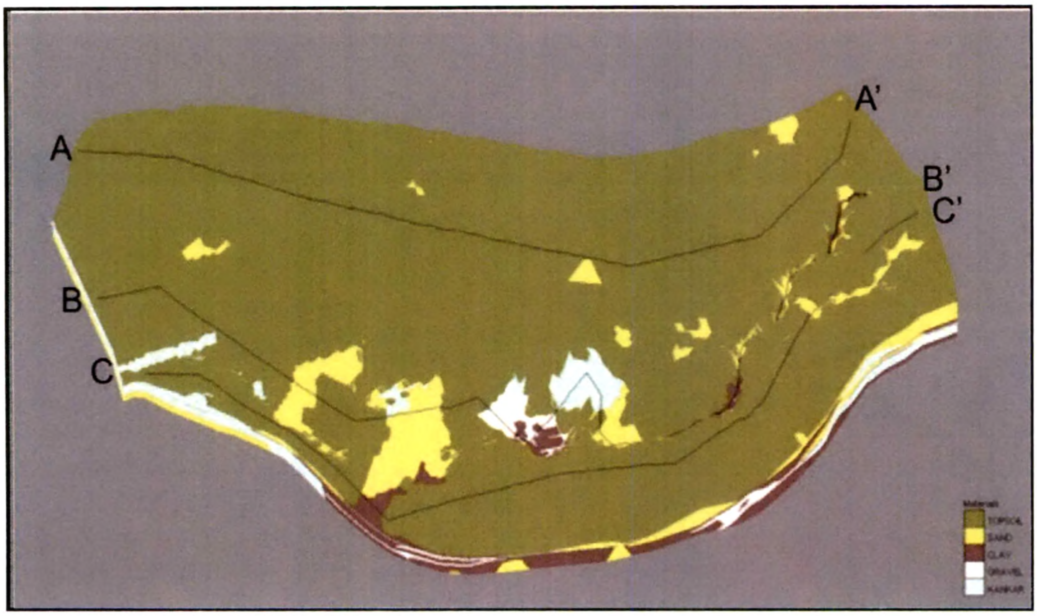


Figure 4.8 Three Locations of Longitudinal Section

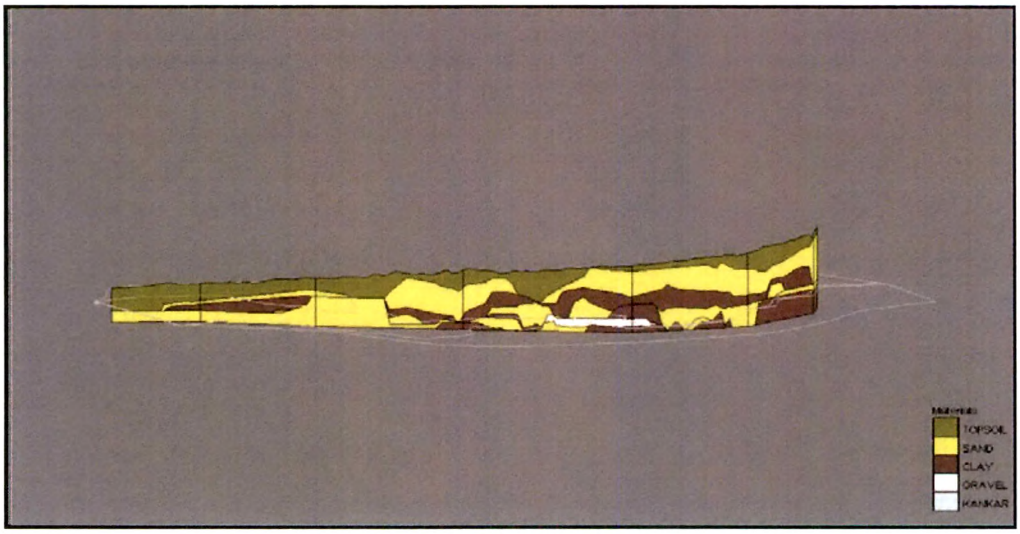


Figure 4.9 Longitudinal Section Along Right Bank (Section A-A')

From Kavi (sea) to Khanpur about 85 km U/S of Kavi

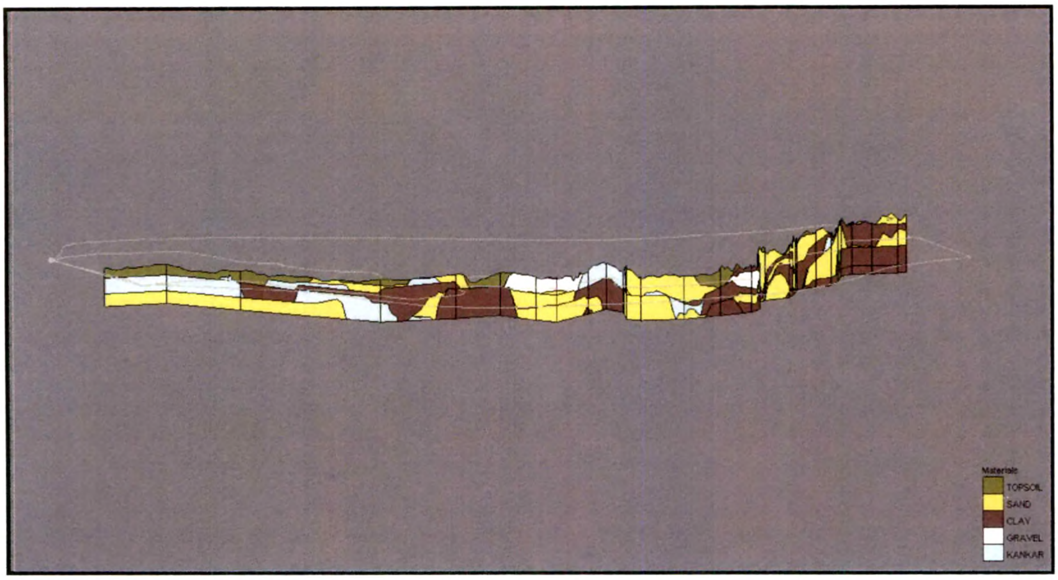


Figure 4.10 Longitudinal Section Along Mahi River (Section B-B')

From Kavi (sea) to Khanpur about 85 km U/S of Kavi

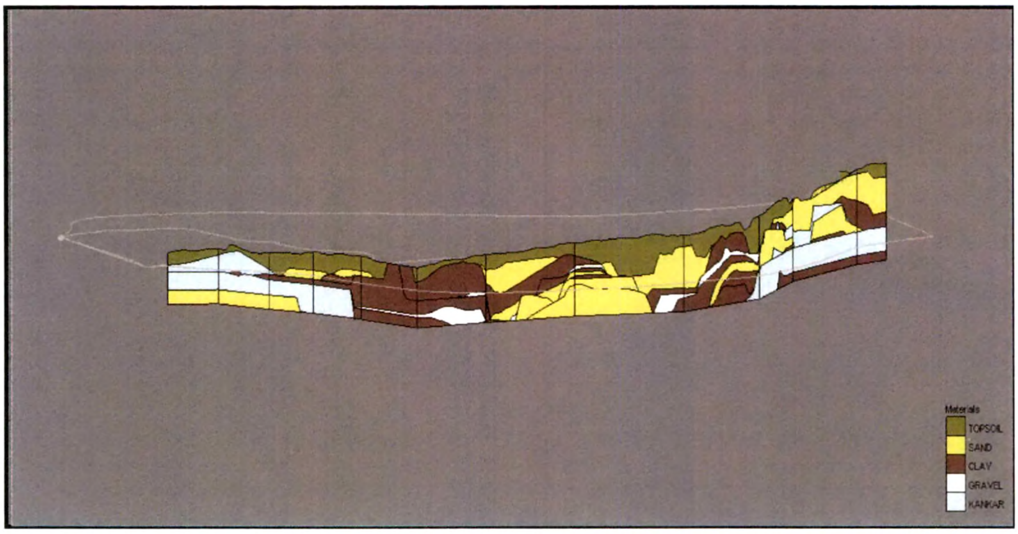


Figure 4.11 Longitudinal Section Along Left Bank (Section C-C')

From Kavi (sea) to Khanpur about 85 km U/S of Kavi

From above it is found that general geology confirm to alluvial area consisting alternate layers of clay, sand, gravel, occasionally mixed with kankar. Such strata are suitable for artificial recharge of groundwater.

4.15 Three Dimensional Model for Present Study

From the detailed study of lithology of wells and previous study reports the aquifer is considered as unconfined aquifer. As the thickness of unconfined aquifer is very less as compared to extent of study area (2298.23sq.km), the consideration of single layer unconfined aquifer in model to be appropriate for study of recharge. Using top elevation TIN and bottom elevation from Reduced Levels of bottom of wells in unconfined aquifer Annexure-III the three- dimensional groundwater model (solids) is created for present study.

4.15.1 Setting up the Recharge Zones

The study area is divided in to eight talukas and these polygons are considered as recharge zones as shown in figure 4.12.

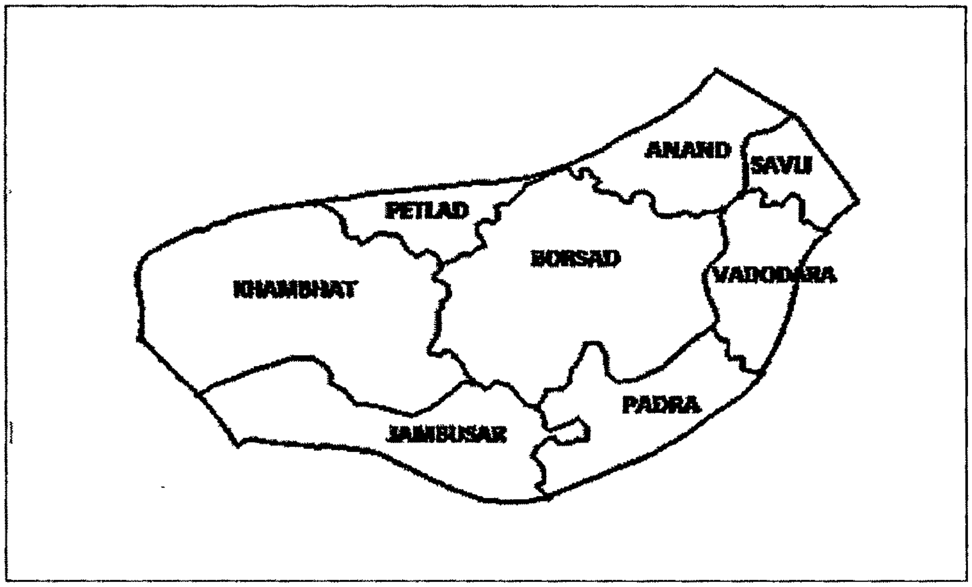


Figure 4.12 Recharge Zones of Study Area

4.15.2 Setting up the Horizontal Permeability Zones

On the basis of Horizontal permeability from pumping tests the model area has been divided into twenty three areal zones (polygons) as shown in figure 4.13.

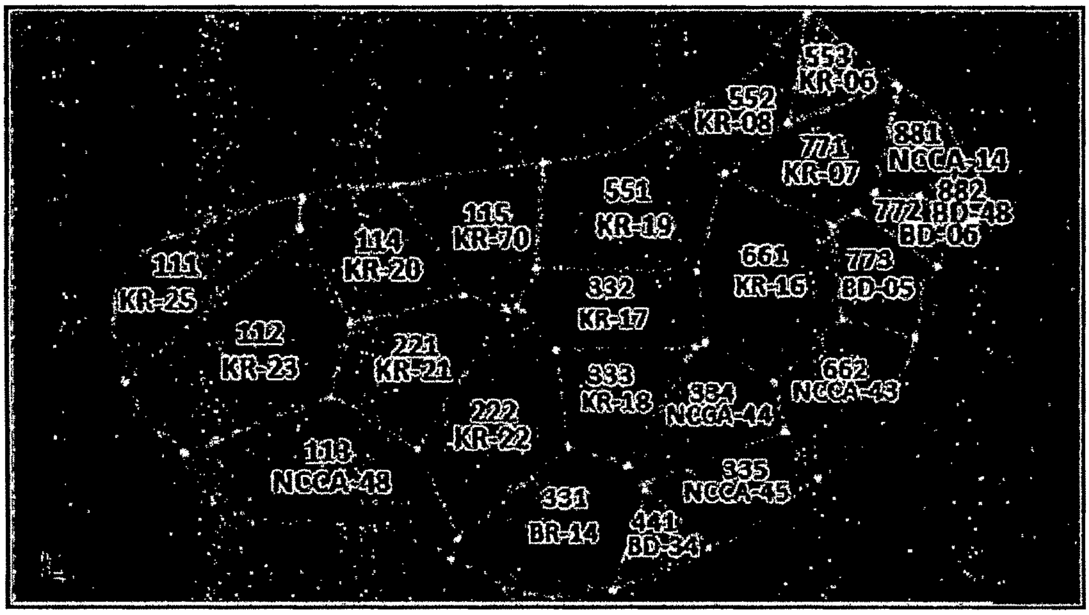


Figure 4.13 Zones of Study Area for Horizontal Permeability/Specific Yield

4.15.3 Setting up the Specific Yield Zones

Storage in the unconfined aquifer (or more correctly the specific yield of the alluvial material in the water table zone) is difficult to calculate accurately from pumping tests. It was recommended that the value of specific yield adopted for the modeled area is about 10 percent. For specific yield, the aquifer zones of study area were taken as coincident with the Horizontal Permeability zones i. e. 23 polygons as shown in figure 4.13. In conceptual model number of zones considered for horizontal permeability and specific yield are considered 23 which may be adequate to represent the variation in aquifer characteristics in the study area.

4.15.4 Setting up the Location of River Mahi

The Mahi River originates in the northern slopes of Vindhyas mountain ranges at an elevation of 500 m. above mean sea level at about 22° 35' N and 74 °15' E near the village Sardarpur in Dhar district of Madhya Pradesh. Its total length is 583 km, traversing 167 km. in Madhya Pradesh, 174 km. in Rajasthan remaining 242 km. in Gujarat. It flows initially in North-West direction through Dhar and Jhabua districts of Madhya Pradesh. Thereafter, it takes turn to the left and flow South-West direction through Banswara district of Rajasthan.

It enters the Gujarat State near Bhukia village in Rajasthan and runs through the Panchmahal and Anand districts of Gujarat State before joining the Arabian Sea in the Gulf of Khambhat. The Mahi River was explicitly represented in the model. The location is in figure 4.14. Based on field inspection this deep River is considered to be the only river in the modeled area which currently has major impact on groundwater level.

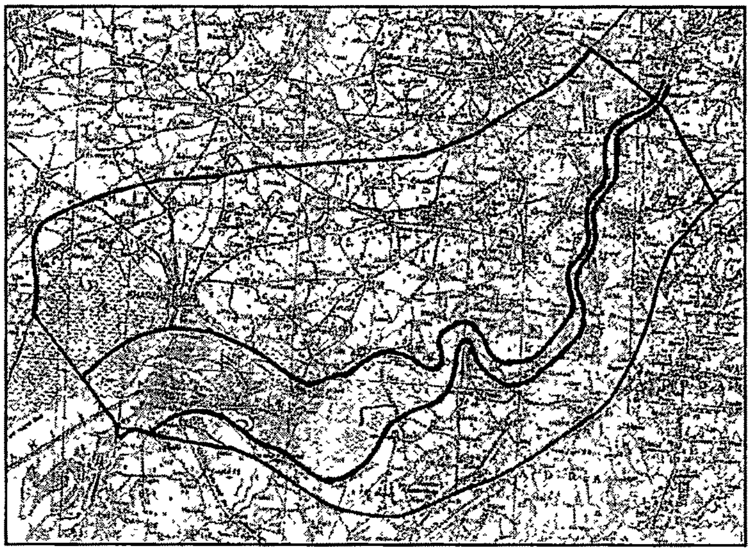


Figure 4.14 Location of River Mahi

4.16 Creating the 3D Grid

Before building a MODFLOW simulation, a 3D grid must be created which covers the area to be modeled. A grid can be created by selecting the Create Grid command in the Grid menu. A suite of tools and commands for editing grids (inserting rows, changing column widths, etc.) are also provided in the 3D Grid Module. If the conceptual model approach is used to construct a MODFLOW model, the grid can be automatically constructed from the conceptual model data using the Grid Frame and the Map -> 3D Grid command in the Feature Objects menu. The grid can be automatically refined around wells and cells outside the model domain can be inactivated. This 3D Grid contains 75 cells in X direction (75 columns), 75 cells in Y direction (75 rows) and 1 cell in Z direction i.e. this model is single layer. The Grid is cell centered type. The grid is shown in figure 4.15.

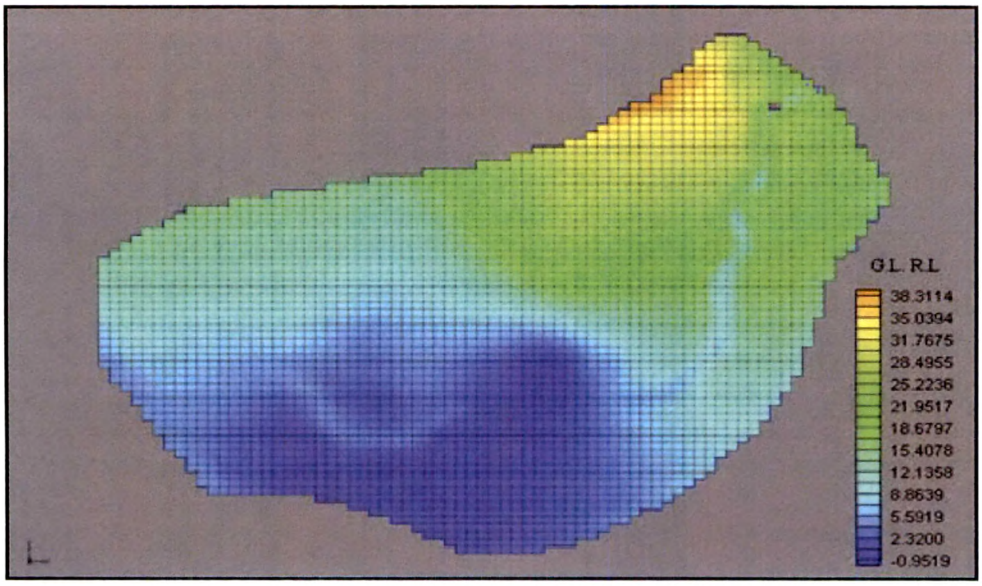


Figure 4.15 3D Grid of Study Area

4.17 Starting Heads to the Model

For Starting heads, ISO-RWL map is prepared using Surfer 6.0 software. From the ISO-RWL starting head values are stored in the database in the form of x coordinate, y coordinate, function value at different nodes. The starting head data obtained from Surfer have been imported from database in GMS as a 2D scatter point data set and RWL TIN has been established using TIN Module in GMS using 2D scatter data set as shown in fig 4.16.

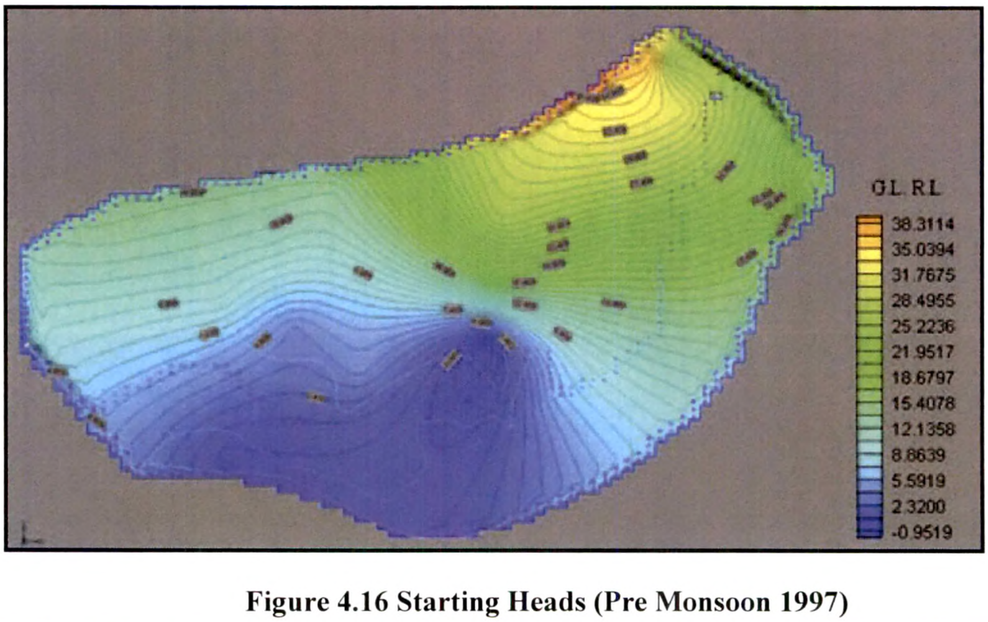


Figure 4.16 Starting Heads (Pre Monsoon 1997)

4.18 Boundary Conditions

The boundary is located along the catchment boundary of the Mahi Basin. The boundary of the study area is divided into number of segments. Twenty four points are selected on the perimeter of the study area as shown in figure 4.17. Heads on these points are obtained using available reduced water level of wells for pre monsoon and post monsoon periods of years 1997, 1998, 1999, 2003, 2004, 2005, 2006 and 2007.The Iso-RWL contour maps are prepared using surfer 6.0 Software and head at boundary points are interpolated or extrapolated. The heads on the South-West and North-East boundary of the study area are estimated using the RL's of Mahi River water levels at Khanpur and at Dhuvaran respectively. The flow domain is bounded by head-dependent flow (Transient head) boundary conditions. The transient heads on the boundary points are presented in table 4.7.

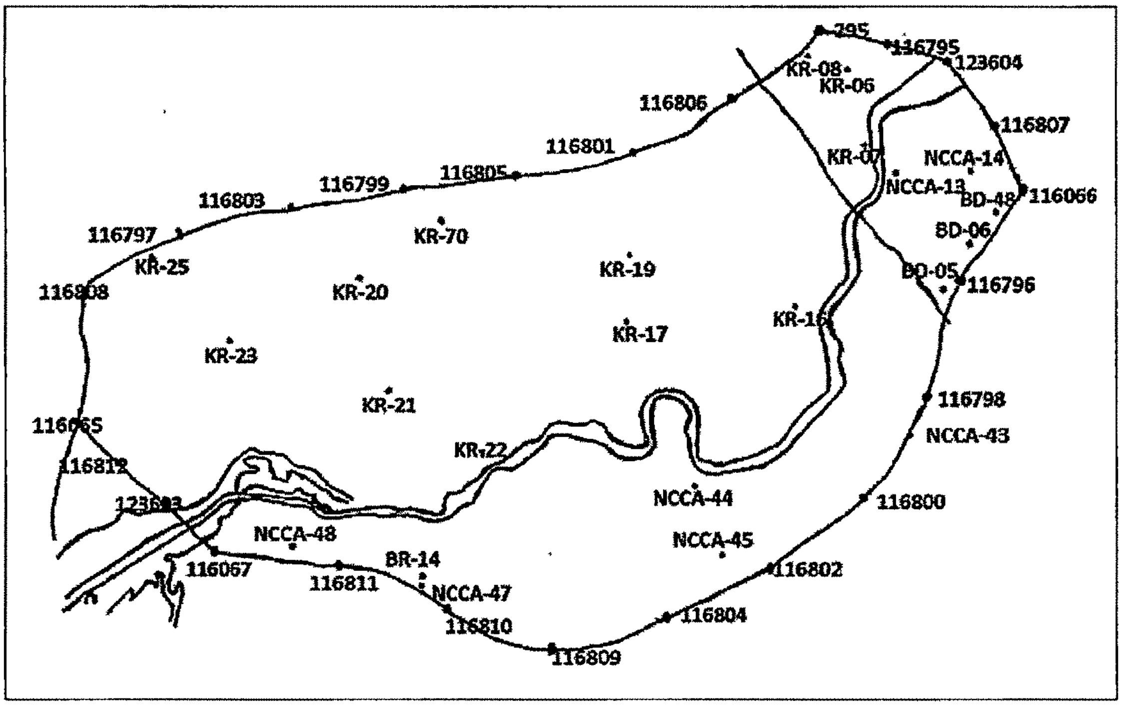


Figure 4.17 Location of Boundary points on the Study Area

Table-4.7 Transient Heads on the Boundary Points in m from m.s.l.

Boundary point id	X (Latitude)	Y (Longitude)	Pre monsoon 1997	Post monsoon 1997	Pre monsoon 1998	Post monsoon 1998	Pre monsoon 19 99
295	300487.6	2498279	29 6395	33.97558	32.17443	34 32598	32.93105
116806	293269.6	2492123	40 19563	45.44183	38.27858	41 26279	39 79873
116801	284935.2	2487628	33.1939	38.18979	32.8857	35.9767	33 86554
116805	275752.7	2485371	23 40196	28.2116	24.19556	26.36832	24.64922
116799	266341.2	2484208	14.43361	18 81532	14.97834	16.30085	15.48506
116803	256967.1	2482761	15.13609	17.18011	14 743	16.16428	15.23859
116797	247405.5	2481309	15.33259	16.10677	14.50044	16.42821	15.42935
116808	238644.4	2476772	13.3927	14.34984	12.75693	14.60397	13.76003
116065	238230.7	2467029	4.93	3.62	2.74	4 66	5.4
116812	241994.2	2462846	4.93	3.62	2.74	4.66	5.4
123603	245731	2458640	4.93	3.62	2.74	4 66	5.4
116067	248715.2	2454500	4.93	3.62	2.74	4.66	5 4
116811	257926	2454533	0.68	2.85	2 18	4.05	3.05
116810	267016.3	2452145	0 45	2	1.4	2 57	2.8
116809	275720.2	2448303	0.6	2.19	1 5	2.82	3 525964
116804	284982 4	2449798	3	3 8	8 15	6	8 15
116802	293675.9	2453759	6.444857	7.538505	10.37881	9.241808	8.784163
116800	301473.8	2459259	8 921953	11.08266	10.03031	10.60975	8 849905
116798	307199.5	2466670	10.94709	13.85149	10.09559	11.1281	9.91564
116796	309987.7	2475788	16.49044	19 81869	16.10677	17.7485	16.12328
116066	316048.3	2483030	16.41865	22 31932	14.19657	22.35152	13.16545
116807	312704.1	2488088	17.28	22.38	19.22411	25.72261	18.39045
123604	309579.7	2492724	18.18	22.45	23.19297	26.74786	22.60819
116795	304794.6	2495612	19.08337	22.50934	26.07027	27 38917	26 06337

Boundary point id	X (Latitude)	Y (Longitude)	Pre monsoon 2003	Post monsoon 2003	Pre monsoon 2004	Post monsoon 2004	Pre monsoon 2005
295	300487 6	2498279	19.58398	23.35236	22 06037	24.964	21.49521
116806	293269.6	2492123	22.99191	24.61112	25.36117	25.44177	25 85141
116801	284935.2	2487628	19.16735	20.78119	21.0171	21.54977	22.22657
116805	275752.7	2485371	15.34406	18.97043	17.58384	19 66712	18 63109
116799	266341.2	2484208	10.23106	16 5933	13.6889	17 15136	14.15016
116803	256967 1	2482761	9.069472	15.41206	12.75745	16 04943	12 89251
116797	247405.5	2481309	10 74959	15 69234	14.85976	15.47	14.31708
116808	238644.4	2476772	10 44662	14.24572	14.37572	15.16034	14.1221
116065	238230.7	2467029	4.93	3.62	2.74	4.66	1.99
116812	241994.2	2462846	4.93	3 62	2.74	4.66	1.99
123603	245731	2458640	4.93	3.62	2.74	4.66	1.99
116067	248715.2	2454500	4.93	3.62	2.74	4.66	1.99
116811	257926	2454533	1.513632	2.529131	2.300917	2 633886	4.604895
116810	267016.3	2452145	0.556495	2.350819	2 078263	1.644467	3.139967
116809	275720.2	2448303	1.723394	2 757459	3.08422	3.205629	4.604725
116804	284982.4	2449798	5.155396	3 216163	3.28827	4.445082	5.628322
116802	293675.9	2453759	6 617126	4.031621	3.601473	4.509408	4.313165
116800	301473.8	2459259	10.26745	7.881263	7.349482	6.951638	5.091483
116798	307199.5	2466670	15.38833	13 3559	12.57422	11.07234	7.58207
116796	309987 7	2475788	18.14591	19 81791	18.26859	19.37174	14.90551
116066	316048.3	2483030	21.88247	21.06157	19.87599	24.82737	16 98158
116807	312704.1	2488088	19.98	21.41	19.5	24 75	17.02
123604	309579.7	2492724	18.08	21 75	19.13	24.62	17.06
116795	304794.6	2495612	16.17604	22.0936	18.75957	24.48623	17.13901

Boundary point id	X (Latitude)	Y (Longitude)	Pre monsoon 2005	Post monsoon 2005	Pre monsoon 2006	Post monsoon 2006	Pre monsoon 2007
295	300487.6	2498279	21.49521	25.25	25.4	27.9	24.45
116806	293269.6	2492123	25.85141	28.73	29.94	33.81	32.8
116801	284935.2	2487628	22.22657	24.84	25.95	29.92	28.8
116805	275752.7	2485371	18.63109	22.15	21.65	24.1	23.06
116799	266341.2	2484208	14.15016	18.16	16.73	18.91	15.9
116803	256967.1	2482761	12.89251	16.63	14.8	16.28	13.1
116797	247405.5	2481309	14.31708	16.28	15.07	15.92	14.77
116808	238644.4	2476772	14.1221	15.22	14.34	15.04	14
116065	238230.7	2467029	1.99	3.06	3.93	2.77	4.33
116812	241994.2	2462846	1.99	3.06	3.93	2.77	4.33
123603	245731	2458640	1.99	3.06	3.93	2.77	4.33
116067	248715.2	2454500	1.99	3.06	3.93	2.77	4.33
116811	257926	2454533	4.604895	7.77	6.31	9.44	8.4
116810	267016.3	2452145	3.139967	5.94	5.03	7.85	8.1
116809	275720.2	2448303	4.604725	5.65	5.77	7.09	7.85
116804	284982.4	2449798	5.628322	6.68	5.91	7.15	7.3
116802	293675.9	2453759	4.313165	3.87	5.84	7.3	7
116800	301473.8	2459259	5.091483	7.94	7.5	9.5	7.6
116798	307199.5	2466670	7.58207	13.7	13	15.6	12.1
116796	309987.7	2475788	14.90551	20.95	20.08	21.1	16.7
116066	316048.3	2483030	16.98158	23.45	21.25	29.3	21.45
116807	312704.1	2488088	17.02	23.8	22.3	28.1	20.4
123604	309579.7	2492724	17.06	24.1	23.3	28.6	21
116795	304794.6	2495612	17.13901	24.5	22.87	29.15	21.8

In the present study, the groundwater model was calibrated and validated. The validated model was used for predictive simulation and is presented in chapter-5.

4.19 Regression Analysis

Water quality data of wells in unconfined aquifer collected from offices have been used to establish the average equations for linear relations between TDS and distance from Kavi. Similarly water quality data of wells used for establishing the average equations for linear relation between TDS and distance from centre line of river. The graphs have been prepared for this.

The Multiple Linear Regression Analysis has been carried out for establishing the linear relationships between three parameters such as TDS, Distance from Kavi and RWL. TDS has been taken as dependent variable because the analysis has been carried out to study the variation of salinity in Mahi estuarine area and other two have been taken as independent variables.

The effect of recharge due to Mahi Right Bank Canal (MRBC) irrigation have been observed in the area on right bank of the river, while in the area on the left bank of the river, the recharge due to irrigation is not observed as there is no left bank irrigation canal in past. So, the analysis for left bank, right bank and for both bank have been carried out separately.
Similarly the Multiple Linear Regression Analysis has been carried out for establishing the linear relationships between four parameters such as TDS, Distances from Kavi and RWL and rainfall.

4.19.1 Year Wise Variation in TDS With Reference to Rainfall and Lab Analysis for Water Quality

Another analysis which shows the year wise variation in TDS with reference to Rainfall for different wells in Anand, Borsad, Khambhat (Cambay), Savli, Vadodara and Padra talukas have been done.

Water samples of 36 wells parallel to Mahi river in May and Nov. 2003 collected and tested for important parameters like EC, PH, TDS, Ca, Mg, Na, CO3,HCO3, Cl,SO4, K and TH The results are graphically represented as TDS, Cl and TH v/s distances from Kavi and distances from centre line of river.