6 Results and Conclusions

6.1 Results

6.1.1 Pumping Test

Pumping test at four sites nearer to reservoir sites was carried out and analyzed to find out aquifer parameters like Transmissibility and Permeability. Results are listed below.

Village (Near Structure)	Geology	Pumping Test		Recuperation Test	
		T	K	T	K
		m^2/day	m/day	m^2/day	m/day
Ambarama (Nr. Medha Creek TR)	**Weathered Basalt**	27.32485	6.537045	27.611	6.6055
Math (Nr. Mul Dwarka TR)	**Miliolite Limestone**	51.4929	13.9170	45.6191	12.3295
Langodra (Nr. Shardagram	**Miliolite Limestone**	52.911	9.8347	-----	-----
Visanvel (Nr. Meghal TR)	**Gaj Limestone**	43.0388	7.1138	40.4365	6.6837

Table 6.1: Results of Pumping Test

T = Transmissibility. K = Permeability.

6.1.2 Recharge Rate for Seawater Intrusion Preventive Structures

6.1.2.1 Medha Creek Tidal Regulator

Year	Recharge Rate in mm/day			
	Maximum	Minimum	Yearly Average	Average
1999	27.03	2.00	11.87	11.83 mm/day
2000	29.35	4.09	13.57	
2002	29.41	2.11	10.29	
2003	29.22	5.28	11.59	

Table 6.2: Recharge Rate for Medha Creek TR

6.1.2.2 Meghal Tidal Regulator

Year	Recharge Rate in mm/day			
	Maximum	Minimum	Yearly Average	Average
1998	49.488	10.264	18.25	22.43 mm/day
2000	61.622	15.740	24.07	
2001	48.793	13.073	24.45	
2003	50.653	15.989	22.93	

Table 6.3: Recharge Rate for Meghal TR

6.1.2.3 Mul Dwarka Tidal Regulator

Year	Recharge Rate in mm/day			
	Maximum	Minimum	Yearly Average	Average
1999	46.83	12.99	23.02	21.58 mm/day
2001	50.89	9.26	17.66	
2002	43.83	16.99	24.31	
2003	48.59	8.48	21.33	

Table 6.4: Recharge Rate for Mul Dwarka TR

6.1.2.4 Barda Bandhara

Year	Recharge Rate in mm/day			
	Maximum	Minimum	Yearly Average	Average
1999	45.21	10.62	18.58	19.56 mm/day
2001	47.97	11.07	18.43	
2002	38.75	18.07	23.97	
2003	36.32	10.87	17.26	

Table 6.5: Recharge Rate for Barda Bandhara

6.1.2.5 Shardagram Bandhara

Year	Recharge Rate in mm/day			
	Maximum	Minimum	Yearly Average	Average
1999	84.62	18.55	41.38	42.05 mm/day
2000	75.02	18.38	45.29	
2001	69.37	18.11	44.81	
2003	74.35	19.06	36.72	

Table 6.6: Recharge Rate for Shardagram Bandhara

6.1.3 Recharge Rate Equation from Log-Log Graph

(Cumulative days v/s Recharge Rate)

6.1.3.1 Medha Creek Tidal Regulator

Year	Intercept on Y axis (Rech. Rate)	Slope of graph	Recharge Rate Equation
	α	β	
1999	87.390	-0.5584	$I = 77.973\ T^{-0.5394}$
2000	86.349	-0.5259	
2002	57.710	-0.4964	
2003	80.444	-0.5770	
Average	**77.973**	**-0.5394**	

Table 6.7: Recharge Rate Equation for Medha Creek TR

6.1.3.2 Meghal Tidal Regulator

Year	Intercept on Y axis (Rech. Rate)	Slope of graph	Recharge Rate Equation
	α	β	
1998	74.317	-0.4235	$I = 79.165\ T^{-0.3653}$
2000	95.194	-0.3685	
2001	70.835	-0.3304	
2003	76.315	-0.3389	
Average	79.165	-0.3653	

Table 6.8: Recharge Rate Equation for Meghal TR

6.1.3.3 Mul Dwarka Tidal Regulator

Year	Intercept on Y axis (Rech. Rate)	Slope of graph	Recharge Rate Equation
	α	β	
1999	98.143	-0.4199	$I = 84.54\ T^{-0.3972}$
2001	70.582	-0.3222	
2002	95.803	-0.4689	
2003	85.633	-0.3778	
Average	87.540	-0.3972	

Table 6.9: Recharge Rate Equation for Mul Dwarka TR

6.1.3.4 Barda Bandhara

Year	Intercept on Y axis (Rech. Rate)	Slope of graph	Recharge Rate Equation
	α	β	
1999	84.059	-0.4314	$I = 70.124\ T^{-0.3578}$
2001	69.995	-0.3338	
2002	69.391	-0.3611	
2003	57.051	-0.3050	
Average	70.124	-0.3578	

Table 6.10: Recharge Rate Equation for Barda Bandhara

6.1.3.5 Shardagram Bandhara

Year	Intercept on Y axis (Rech. Rate)	Slope of graph	Recharge Rate Equation
	α	β	
1998	106.34	-0.2427	$I = 122.8625\ T^{-0.2635}$
2000	147.27	-0.2956	
2001	132.50	-0.2523	
2003	105.34	-0.2634	
Average	122.8625	-0.2635	

Table 6.11: Recharge Rate Equation for Shardagram Bandhara

As all the structures are located in Miliolite Limestone geological formation the average recharge rate equation for Miliolite Limestone area is found to be

$$I = 86.9324\ T^{-0.3846}$$

6.1.4 Volume of Water Stored and Recharged

6.1.4.1 Medha Creek Tidal Regulator

Year	Volume of Water Stored & Recharged (m^3)				
	Vol. Stored	Vol. Lost	Vol. Bal. in Res.	Vol. Rech.	% Rech. Efficiency
1999	27506336	23390336	4116000	16901020	72.26
2000	42130000	35954000	6176000	26350423	73.29
2002	11160000	8695280	2464720	6266606	72.07
2003	49000000	41416000	7584000	30680273	74.08

Table 6.12: Volume of Water Stored, Lost, Recharged and % Recharge Efficiency for Medha Creek TR

6.1.4.2 Meghal Tidal Regulator

Year	Volume of Water Stored & Recharged (m^3)				
	Vol. Stored	Vol. Lost	Vol. Bal. in Res.	Vol. Rech.	% Rech. Efficiency
1998	8028241	7622682	405559	6427891	84.33
2000	11131956	10767167	364789	8988631	83.48
2001	9537632	9116388	421243	7724209	84.73
2003	6422189	6176437	245752	5279542	85.48

Table 6.13: Volume of Water Stored, Lost, Recharged and % Recharge Efficiency for Meghal TR

6.1.4.3 Mul Dwarka Tidal Regulator

Year	Volume of Water Stored & Recharged (m^3)				
	Vol. Stored	Vol. Lost	Vol. Bal. in Res.	Vol. Rech.	% Rech. Efficiency
1999	602853	580158	22695	480322	82.79
2001	3185891	3170263	15629	2475442	78.08
2002	363423	322669	40754	268234	83.13
2003	2156115	2137346	18769	1762811	82.48

Table 6.14: Volume of Water Stored, Lost, Recharged and % Recharge Efficiency for Mul Dwarka TR

6.1.4.4 Barda Bandhara

Year	Volume of Water Stored & Recharged (m^3)				
	Vol. Stored	Vol. Lost	Vol. Bal. in Res.	Vol. Rech.	% Rech. Efficiency
1999	1076186	1055447	20739	875369	82.94
2001	3245516	3225404	20112	2585725	80.17
2002	598313	548299	50015	459862	83.87
2003	9832327	9788474	43852	7562532	77.26

Table 6.15: Volume of Water Stored, Lost, Recharged and % Recharge Efficiency for Barda Bandhara

6.1.4.5 Shardagram Bandhara

Year	Volume of Water Stored & Recharged (m^3)				
	Vol. Stored	Vol. Lost	Vol. Bal. in Res.	Vol. Rech.	% Rech. Efficiency
1999	2910000	2389760	520240	2115917	88.54
2000	3446000	2920940	525060	2610338	89.37
2002	5494800	4984200	510600	4475537	89.79
2003	2910000	2380120	529880	2123109	89.20

Table 6.16: Volume of Water Stored, Lost, Recharged and % Recharge Efficiency for Shardagram Bandhara

6.1.5 Zone of Diffusion

6.1.5.1 Medha Creek Tidal Regulator

Zone of Transition for the Medha Creek TR area is demarcated in the sectional view (Map 5.16). From the map it is derived that zone of transition ranges from 1.9 km to 5.9 km.

6.1.5.2 Meghal Tidal Regulator

For the entire Meghal TR area is falling in the zone of transition for the season May 2002. This zone extends upto well no 15 & 16 which are located at a distance of 2.0 and 2.15 km from structure. (Map 5.36) So Location of this zone is 2.15 km inland from structure situated on coast.

6.1.5.3 Mul Dwarka Tidal Regulator

Zone of Transition for the Mul Dwarka TR area is demarcated in the sectional view (Map 5.53). From sectional view it is derived that zone of transition ranges from 2.0 km to 9 km.

6.1.6 Impact of SIP Structures

6.1.6.1 Development of Freshwater Resources

Effect of SIP structures with reference to development of freshwater resources is found to be very positive. At majority of locations after monsoon considerable rise in water level is observed in range of 2 to 6m. Not only this, but during pre-monsoon season when freshwater sources has declined these structures have acts as a barrier against the seawater intrusion.

6.1.6.2 Water Quality

As per HLC report the rate of seawater intrusion in 1971 to 1978 was 0.5 km/year and it was found to be 6.0 to 7.5 km inland in 1977, but because of construction of these structures the present location ranges in the same range or at some place it decreases. In case of Meghal TR freshwater zone starts at a distance of 2.15 km from coast. This is a positive impact of this structure. In Mul Dwarka the transition extends in between 2 to 9 km. At some locations it is in the same range of 1977 situation which also shows efficacy of these structures against seawater intrusion. With the construction of structures the number of wells withdrawing water has also been increased to manifold. Water quality in the vicinity of these structures is observed improved or sometimes it is found in stagnant situation.

At some places it is observed from geochemical maps that marine sediments are being leached. Improvement in water quality of coastal aquifer after deterioration due to seawater intrusion is a decade's long process.

Log – Log Graph of Chloride to Carbonate and Bicarbonate Ratio v/s Cl^- (in meq/l) for water samples collected from observation wells surrounding the structures under the study are developed. The graph for Medha Creek TR shows an improvement in water quality with reference to chloride content. Graph for Meghal TR shows deterioration in water quality which might be due to intrusion of saline water that taking from sides of the structure. Graph for Mul Dwarka TR Shows that number of well are shifting to fresh water zone.

6.1.6.3 Improvement in Crop Production

Crop	Basin								
	Noli			Meghal			Shingoda		
	Year		% Change	Year		% Change	Year		% Change
	1992	2003		1988	2003		1988	2003	
Coconut	50	85	70	50	90	80	-	-	-
Groundnut	15	25	67	11.2	27	141	9.88	11.5	16
Wheat	10	21	110	20	40	100	18.7	31	66
Millet	-	-	-	17.9	29	62	8.64	14.5	68
Sugarcane	-	-	-	-	-	-	422.3	550	30

Table 6.17: Change in Crop Production for Noli, Meghal & Shingoda Basin

- Production of Coconut is in Number/Tree/Year
- All other crops are measured in Qtl/Ha.

6.2 Conclusions

- Permeability value for Miliolite Limestone in the study area was found in the range of 9.83 to 13.970 m/day and for Gaj limestone it is found to be 7.1138 m/day. For weathered basalt its value is found to be 6.53 m/day. Transmissibility value for Miliolite Limestone in the study area was found in the range 52.0 m^2/day and for Gaj limestone it is found to be 43.03 m^2/day. For weathered basalt it is found to be 27.32 m^2/day.

- Miliolite Limestone is highly porous formation and aquifer parameters depend on the porosity of the formation. The analysis of pumping test indicates that transmissibility is found highest near Shardagram area and Mul Dwarka area. While in Medha creek area in weathered basalt is encountered in upper and east side reaches of reservoir it is nearly half. Permeability value is found highest at Math (13.97 m/day) and 9.83 m/day at Langodra.

- At Shardagram where Permeability and Transmissibility values are found considerably high, indicates highly porous nature of Miliolite Limestone formation. This is also seen from geochemical maps of that area. The chloride values in geochemical maps and graph are elevated. RWL maps of post-monsoon season also shows reverse hydraulic gradient

- Average recharge rate in Miliolite Limestone geology is higher. The highest value is 23.43 mm/day in Meghal TR and the lowest is 11.27 mm/day at Medha Creek TR where weathered basalt is found in reservoir and surrounding area. Recharge rate is observed in initial period of monsoon which is nearly 50 mm/day for Meghal TR, Mul Dwarka TR and Barda Bandhara, while it is nearly 30 mm/day in Medha Creek TR. The Maximum recharge rate of 84.62 mm/day is observed at Shardagram Bandhara. Here the Transmissibility value is also highest 52.910 m^2/day which indicate highly porous Miliolite Limestone formation in the Shardagram Bandhara region.

- The average recharge rate equation for Miliolite Limestone area is found to be $\mathbf{I = 86.9324\ T^{-0.3846}}$

- The maximum value of α is found in Shardagram area, which indicates that because of highly porous formation recharge and discharge of freshwater will be faster as compare to other structures.

- Average % recharge efficiency is nearly 74% and above in all the structures. The highest recharge efficiency of about 90% is found in Shardagram area which indicates that these structures are successful.

- After construction of seawater intrusion preventive structures groundwater quality has been increased in the vicinity of the structure and more number of dug and pumping wells are constructed which in turn has increased the rate of groundwater withdrawal. Due to this the effect of seawater intrusion preventive structures in terms of set back of seawater intrusion line is not noticed but if we refer to crop production data, it is clearly indicating the effect of these structures. Because of the availability of the recharged fresh groundwater the land of the coastal strip become fertile and the farmers of the region can take up to three crops. Thus crop yield has also been increased. For some crops more than 100% yield in crop production is noted (in Noli and Meghal Basin for Wheat and Groundnut crops) after the construction of these structures.

- No desilting of any reservoir is noticed. However at one place i.e. at Lambora (Noli) Rechage Reservoir farmers themselves were doing desilting of reservoir. This will serves two purposes for them, they are laying desilted soil in their farms to serve as manure to improve the fertility and at the same time by desilting, efficiency of recharge structure gets increased.

- The seawater intrusion once taken place cannot be removed easily. According to Ghyben - Herzberg relationship, fresh water cushion over the intruded saline water is approximately 40 times. It should be lasting for a longer period by constructing recharge structures as well as salinity control structures, but because of heavy pumping of groundwater for various purposes and due to erratic rainfall in the coastal belt, this is not so.

From the above one can deduce that to judge the efficacy of SIP structures constructed in coastal Saurashtra belt following parameters are playing very important role.

1) Aquifer parameters like transmissibility and permeability.

2) Recharge rate which can be judge from recharge rate equation

3) Geochemical parameters such as different ion ratio maps like Na/Cl, $Cl/(CO_3+HCO_3)$, (Mg+Ca)/Cl to get water quality trend.

4) Log - Log Graph of Chloride to Carbonate and Bicarbonate Ratio v/s Cl^- (in meq/l)

6.3 Recommendations

- Gates of the structures should be closed / installed timely during monsoon flow to arrest the maximum possible runoff. The gates are mainly made up of steel. It is observed in the coastal belt that gates are corroded due to salty weather near coast and become inoperative and are now replaced by concrete wall (Bandhara Type) e.g. Mul Dwarka TR, Sodam Bandhara, Gosabar TR etc. Due to this desilting of reservoir is not possible. Looking to all these circumstances, it is recommended that structures should be gated but the material of the gate should be such that it should be non-corrosive, can withstand salty weather, light weight so that it will be easy to operate and should have zero scrap value. Looking to all these parameters Glass Reinforced Fiber gates can be best replacement of steel gates.

- Unlimited withdrawal of the groundwater used for the irrigation should be restricted in the affected area. To achieve this farmer of the affected area should be initiated to use latest irrigation techniques which will utilize less quantity of water as compare to conventional methods. By doing this huge amount of fresh groundwater can be saved which will in turn create a cushion of fresh water over saline water intruded in aquifer.

- In near future Kalpsar project will be implemented which will create a low height, huge size freshwater reservoir. This water can be utilised for filling up series of seawater intrusion preventive structures to set back seawater intrusion line.

- The canal network of Narmada project is still in progress. The full canal network construction may take 5 to 10 years to complete. During this period the Narmada water can be transferred to these structures.

- Looking to the geology of coast and aquifer parameters determined spreading channel parallel to the coast gives best results thus construction of spreading channel should be accelerated. Moreover, construction of radial canals, which takes off from upstream end of the reservoir and flows against gradient in landward side, should be accelerated. This will not only create additional storage of fresh water in that area but farmers of the surrounding area can also take advantage of this stored water and can irrigate their fields and thereby reducing withdrawal of groundwater.

- As far as possible, all the recharge structures like check dams; bandharas etc. should be desilted regularly to improve recharge rate and life of the structure. Deposited silt is one of the best manure and local farmers should be encouraged to take this silt from site and deposit in their farms with their own cost.

- When there is a rainfall above normal, large quantity of runoff will go to sea, which indicates that there is still possibility of construction of micro recharge structures. A series of check dams, storage ponds should be constructed at the upper reaches of the stream so that maximum runoff can be arrested during rains.

- To increase recharge through spreading channel and radial channel, recharge shafts should be constructed in bed of the channel.

- As far as possible mining of limestone in the coastal belt should be prohibited. Mining of limestone will increase the rate of seawater ingress, as it will acts as a barrier against ingress. Moreover whatever mines already exists in the coastal belt should be used as a recharge tank by diverting fresh water in it.