Chapter 4

Study Area and Data Collection

4.1 General

The present study has been carried out in Region I and II of Sardar Sarovar Project (SSP) in Gujarat state; which is one of the biggest Inter State Multipurpose projects of India. Gujarat state has 18.8 million hectares of geographical area, of which 9.9 million hectares is covered under cultivation. The annual rainfall varies significantly in temporal and spatial, throughout the state with low rainfall of 300 mm in Kutch, and high rainfall of 2000 mm in of south west of state. Around 83 percent of state area falls in 30-60 coefficient of variation of rainfall. Gujarat has ultimate potential of surface water as 2.59 million hectare meter. Ultimate total irrigation potential is of 5 million hectares, including 1.8 million hectare from ground water. The Sardar Sarovar Project command area lies between 21^{o} - $40^{'}$ to 24^{o} - $30^{'}$ N latitudes and 68^{o}-$20^{'}$ to 73^{o}-$45^{'}$ E longitudes covering 3344 villages. The gross command area of Sardar Sarovar is of 3.43 million hectare, while CCA is of 2.12 million hectare. The project is a joint venture of four states Gujarat, Madhya Pradesh, Maharashtra and Rajasthan in India, with a terminal major dam on river Narmada in Gujarat. The project quenches the thirst of three major states, by irrigating 1.79 million hectare in Gujarat, 75,000 hectare in Rajasthan, and 37,500 hectare in Maharashtra. Net irrigation requirements for the command have been estimated by Sardar Sarovar Narmada Nigam Limited (SSNNL), by using modified Penman's method, with assumption of overall efficiency of 60 percent for irrigation water use. Utilizable ground water available in Sardar Sarovar command is 0.33 million hectare meters. The entire command has been divided into 13 different homogeneous agro climatic zones (regions), based on topography soil classification, rainfall, and weather. The climate of area is semi arid; the rainfall is erratic and non uniform. Type of surface soil prevalent is deep black, goradu sandy loam, coarse soil from granite, and coastal alluvial. Major food crops of Gujarat state are paddy, wheat, bajra, jowar, and tuver, while non food crops of the state are cotton, tobacco, and groundnut. In terms of production, Gujarat state contributes 61 percent tobacco, 29 percent groundnut, 25 percent cotton, 12 percent bajra, and 6 percent jowar in the country.

Narmada project has been designed with inherent two technical features; first feature is of operating the reservoir and canal conveyance system, such that peak requirements of water are met in the first fortnight of November, in order to ensure water availability for Kharif

crops, and also Rabi crops which need water for sowing. The main canal capacity has been worked with basically three aspects: i) Fulfilling the agriculture and non agriculture fortnightly peak demand in November, ii) Fulfilling Rajasthan's peak demand, and iii) Emergency strategic plan, for fulfilling the requirements during drought, as 73 percent of the command is prone to drought, and it is necessary to provide protective irrigation to un-irrigated Kharif crops, which would else perish due to inadequate rainfall. Second feature is running the canals during (November to April), so as to sustain developing agriculture land under irrigation, by enforcing indirectly conjunctive use of canal and ground water, during summer and other seasons. This feature has been incorporated after carrying out detailed studies of ground water reserve balances for whole command, and specifically for Narmada-Mahi doab with calibrated conjunctive use model of canal and groundwater. Conjunctive use of canal water and groundwater has been planned, keeping in mind to prevent water logging and salinity of agriculture fields, with the objective of maximizing benefits. After studying the physical characteristics of land, aquifer characteristics, ground water table reserves, and rainfall of all the regions, water availability of groundwater in command was estimated, considering the recharge due to irrigation and rainfall. It is decided to use ground water reservoir as a source along with canal water, for balancing the demand and supply, for entire command for future years to come ahead (Pathak, 1989). Water scarcity, especially in arid and semi arid regions in Kutch and Saurashtra, requires a need of an irrigation system that ensures water is distributed in adequate quantities, and at right moment throughout the command area to meet the crop water requirements.

4.1.1 Canal Distribution System and their Operations

Irrigation water will be conveyed to 8 hectare blocks through a network of conveyance and distribution system, consisting of main canal having capacity (1133 cumecs), 42 branch canals off taking from main canal (some of them Vadodara, Miyagam having capacity more than 75 cumecs). The branch canals and distributory upto 8 hectare block will be lined. Field channels are to be provided in entire CCA. Under conventional projects, an average outlet size caters to about 40 hectares of area. In Narmada command irrigation water will be supplied down to outlet covering 8 to 20 hectares with all channels lined. Thus, under each outlet 3 to 5 farmer units only on an average will be there in a network, making it easy to manage. Canal systems up to village levels (VSA - Village Services Area) will be operated by SSNNL. Below the VSA it is to be operated by farmer organizations.

Table 4.1: Region I and Region II selected Branch canal discharge capacities

Block	Name of branch	Off-taking chainage from main canal/Por/VBC in Km	Discharge Capacity of branch canal at head in cumecs
1	Wadia	9.931	6.928
2	Tilakwada	17.871	5.664
3A & 3B	Mandava	25.263	10.07
4A & 4B	Bhiloda	32.674	9.967
5	Sankheda	45.110	4.106
6A1, 6A3R2	Miyagam	62.906	143.80
8	Gojali	70.236	7.0
9A1, 9A2R2	Vadodara	81.84	76.04
10	Dena	88.77	6.795
11A1 & 11A2	Sakarda	102.953	21.745
12	Desar	126.309	3.719
13A	Dumad	100.26	4.591
13B	Jumkha	107.236	2.269
13B	Nahara	111.676	3.823
6BR2	Untiya	14.950 (Por)	5.600
9B1R2	Kundhela	6.100 (Vadodara Branch Canal)	11.68

Source: SSNNl

The water supply will be volumetric and on rotational basis through canal automation, fully computerized and remotely operated upto 8.5 cumecs (Raj 1996). In the present study area total 16 numbers of branch canals are off-taking, from main canal and other branch canals. Discharges in cumecs at head along with chainages from Narmada main canal, Por branch and Vadodara branch canals have been illustrated in Table 4.1.

4.1.2 Study Area

The study area region I and II is located in SSP command area phase – I, which lies between 21^0 45'to 22^0 –53' N latitudes and 72^0–31' to 73^0 – 43' E longitudes, as shown in Figure 4.1**.** Region I and II is situated between Narmada, and Mahi rivers in districts of Narmada, and

Vadodara in Gujarat state. The study area covers total 20 blocks (16 blocks of region I and 4 blocks of region II) of SSP phase I. Region I, comprises area of Sankheda and Savli Taluka having gross command area (GCA) of 253100 ha, and culturable command area (CCA) of 161900 ha. Region II includes area of Sinor, and Vadodara Taluka having GCA and CCA of 273100 ha, and 187600 ha respectively.

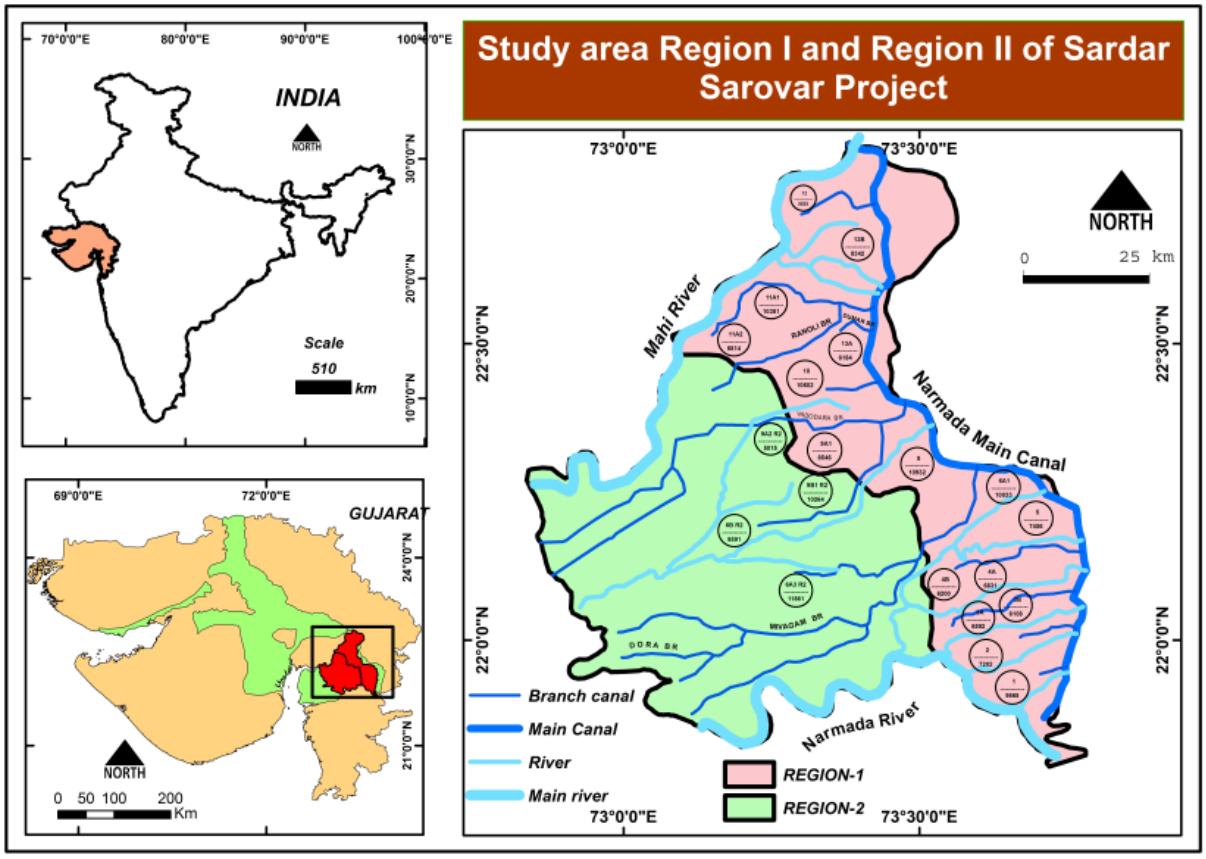

Figure 4.1: Study area Region I and Region II of Sardar Sarovar Project

4.1.3 Climate and Rainfall

To estimate reference evapotranspiration, and actual crop evapotranspiration, as per FAO 56, latitude, altitude of selected weather stations, and their daily climate data of precipitation, wind speed, sunshine hours, maximum and minimum temperature, and relative humidity, for study period 2003 to 2010 are collected, from State Water Data Centre, Gandhinagar. Data was used for the purpose of block wise simulation. The daily climate data were collected, from weather stations of Naswadi, Bodeli, Bhilapur, Waghodia and Karjan weather station, considering the availability, and proximity to the blocks. The rainfall data of Naswadi, Tilakwada, Vora, Wasna, Bodeli, Sankheda, Deo, Bhaniyara, Sansoli, Karjan, Bhilapur, and Waghodia rain gauge station is taken, in accordance to their proximity of blocks as shown in Table 4.2

Table 4.2: Rain gauge stations for various blocks in region I and II

Name	Latitude	Longitude	Rain gauge Station for block
Naswadi	22.0254 N	73.4358 E	1, 3A
Tilakwada	21.5158 N	73.3620 E	2
Vora	22.0324 N	73.3655 E	3B
Wasna	22.0704 N	73.4441 E	4A, 4B
Bodeli	22.1548 N	73.4328 E	5
Sankheda	22.1012 N	73.3618 E	6A1
Deo	21.4310 N	73.9506 E	8
Bhaniyara	22.3904 N	73.2692 E	9A1, 10, 11A2, 13A
Sansoli	22.8554 N	72.7540 E	11A1, 12, 13B
Karjan	22.0530 N	73.1235 E	6A3R2
Bhilapur	22.1200 N	73.4194 E	6BR2
Waghodiya	22.3026 N	73.3869 E	9A2R2, 9B1R2

Source: State Water Data Centre, Gandhinagar

The climate of area is semi arid; the rainfall is erratic and non uniform. Mean annual rainfall in region I and II is between 800-1000 mm (Pathak 1989).

Sarker (1989) established from Indian Meteorological Department data, the average annual rainfall between 700 to 1200 mm in agro climatic region I and II of central Gujarat. The average 15 years rainfall has been found to increase by 32 percent, while the number of rainy

days has declined from fifty three days per year (1936-1950) to forty two days per year (1995-2010). The intensity of very heavy rainfall in 24 hrs has almost doubled, from seven days to sixteen days during the period. The relative humidity is low most of the time, except monsoons.

4.1.4 Rainfall Criteria for Sowing Operations

The agriculture is mostly dependent on the south west monsoon, wherein sowing and other farm related activities are decided, according to the monsoon rains during Kharif, while in case of Rabi the sowing period is decided, in accordance to soil moisture retentive condition post monsoon and irrigation availability. Rainfall criteria for sowing operations require at least 25 mm rainfall in period of 7 days, after the onset of monsoon with 2.5 mm rainfall in at least 3 days. Inter spell duration should not exceed 10 days. On analyzing the rainfall data of 80 years, mean dates for Central Gujarat show the commencement of sowing rains between 25thJune to 30th June. Standard deviation of less than 16 days is seen in Vadodara district (Sarker, 1989). In order to obtain good simulation results the sowing date for Kharif crops was fixed 1st July.

4.1.5 Soils

The land surface is undulated in region I, while in region II it is flat however, both the regions are well drained. Type of surface soil, prevalent is deep black, goradu sandy loam, coarse soil from granite, and coastal alluvial. Soils moistly between Narmada-Mahi are clayey to deep clayey loam with good fertility, and primarily alluvial sandy soil. Unconsolidated deposits of Alluvium with bed rock formation, consisting of Deccan Traps, Granites & Oneises are found. The type of soil, hydrologic soil group and soil properties were sorted out in various blocks of region I and II, after procuring soil data from Soil department of SSNNL, which is demonstrated in Table 4. 3 and Table 4.4

4.1.6 Hydrogeology

Generally the natural surface drainage system is well developed in this region. Density of natural drains with outfall conditions is very good. In region 1 and 2, the natural surface drainage is well developed, but at certain locations it is not enough. Average stream gradient in region I and II are respectively 1:650, and 1:700 respectively. Geohydrological condition in this doab consists of alluvial deposits with a complex system of sand, and clay horizons with maximum thickness of alluvium exceeding 100 m (Pathak, 1989).

Table 4.3: Block 1 to 9A1 soil type, hydrologic soil group and soil properties as percent of volume

Block	Predominant Soil Type	Depth	Percentage	Soil Taken	HSG	Soil Properties, as a percent of volume	
1	Sandy clay, Silty clay, Clay	0-30	75.81	Sandy clay	C	Saturation	32.1
		30-60	79.49			F.C.	27.64
		>90	nil			Wilt Point	18.27
		Avg. Depth	77.65			A.W.C.	9.37
2	Sandy clay, Silty clay, Clay	0-30	68.58	Sandy clay	C	Saturation	32.1
		30-60	51.84			F.C.	27.64
		>90	nil			Wilt Point	18.27
		Avg. Depth	60.21			A.W.C.	9.37
3A	Sandy clay, Silty clay, Clay	0-30	48.81	Sandy clay	C	Saturation	32.1
		30-60	52.15			F.C.	27.64
		>90	34.26			Wilt Point	18.27
		Avg. Depth	45.07			A.W.C.	9.37
3B	Sandy clay, Silty clay, Clay	0-30	48.81	Sandy clay	C	Saturation	32.1
		30-60	52.15			F.C.	27.64
		>90	34.26			Wilt Point	18.27
		Avg. Depth	45.07			A.W.C.	9.37
4A	Clay loam, Sandy clay loam, Silty clay loam	0-30	52.42	Sandy clay loam	C or B	Saturation	33
		30-60	49.67			F.C.	25.13
		>90	46.37			Wilt Point	12.16
		Avg. Depth	49.49			A.W.C.	12.97
4B	Sandy clay, Silty clay, Clay	0-30	70.61	Sandy clay	C or B	Saturation	32.1
		30-60	61.43			F.C.	27.64
		>90	7.66			Wilt Point	18.27
		Avg. Depth	46.57			A.W.C.	9.37
5	Sandy loam, fine sandy loam	0-30	60.15	Sandy loam	A	Saturation	41.2
		30-60	32.19			F.C.	23.74
		>90	55.22			Wilt Point	8.02
		Avg. Depth	49.19			A.W.C.	15.72
6A1	Sandy clay, Silty clay, Clay	0-30	46.31	Sandy clay	C	Saturation	32.1
		30-60	64.22			F.C.	27.64
		>90	45.15			Wilt Point	18.27
		Avg. Depth	51.89			A.W.C.	9.37
8	Sandy clay, Silty clay, Clay	0-30	56.73	Sandy clay	C	Saturation	32.1
		30-60	70.16			F.C.	27.64
		>90	52.38			Wilt Point	18.27
		Avg. Depth	59.76			A.W.C.	9.37
9A1	Clay loam, Sandy clay loam, Silty clay loam	0-30	93.01	Sandy clay loam	C	Saturation	33
		30-60	68.8			F.C.	25.13
		>90	42.56			Wilt Point	12.16
		Avg. Depth	68.12			A.W.C.	12.97

Note: F.C. = Field Capacity, A.W.C. = Available Water Holding Capacity, HSG = Hydrologic Soil Group
Source: SSNL

Table 4.4: Block 10 to 9B1R2 soil type, hydrologic soil group and soil properties as percent of volume

Block	Predominant Soil Type	Depth	Percentage	Soil Taken	HSG	Soil Properties, as a percent of volume	
10	Clay loam, Sandy clay loam, Silty clay loam	0-30	57.98	Sandy clay loam	C	Saturation	33
		30-60	63.91			F.C.	25.13
		>90	35.61			Wilt Point	12.16
		Avg. Depth	52.50			A.W.C.	12.97
11A1	Clay loam, Sandy clay loam, Silty clay loam	0-30	52.71	Silty clay loam	C	Saturation	43.2
		30-60	42			F.C.	36.02
		>90	57.18			Wilt Point	19.38
		Avg. Depth	50.63			A.W.C.	16.64
11A2	Sandy clay, Silty clay, Clay	0-30	33.58	Sandy clay	C	Saturation	32.1
		30-60	37.31			F.C.	27.64
		>90	18.66			Wilt Point	18.27
		Avg. Depth	29.85			A.W.C.	9.37
12	Sandy loam, fine sandy loam	0-30	44.19	Sandy loam	A	Saturation	41.2
		30-60	34.88			F.C.	23.74
		>90	46.34			Wilt Point	8.02
		Avg. Depth	41.80			A.W.C.	15.72
13A	Sandy clay, Silty clay, Clay	0-30	42	Sandy clay	C	Saturation	32.1
		30-60	73			F.C.	27.64
		>90	67			Wilt Point	18.27
		Avg. Depth	60.67			A.W.C.	9.37
13B	Sandy clay, Silty clay, Clay	0-30	48.72	Sandy clay	C	Saturation	32.1
		30-60	48.72			F.C.	27.64
		>90	25.64			Wilt Point	18.27
		Avg. Depth	41.03			A.W.C.	9.37
6A3R2	Sandy clay, Silty clay, Clay	0-30	92	Clay	D	Saturation	38.5
		30-60	93			F.C.	34.07
		>90	59			Wilt Point	22.34
		Avg. Depth	81.33			A.W.C.	11.73
6BR2	Sandy clay, Silty clay, Clay	0-30	68.93	Silty clay	C	Saturation	42.3
		30-60	78.64			F.C.	36.72
		>90	50.49			Wilt Point	22.45
		Avg. Depth	66.02			A.W.C.	14.27
9A2R2	Clay loam, Sandy clay loam, Silty clay loam	0-30	86	Silty clay loam	C	Saturation	43.2
		30-60	77			F.C.	36.02
		>90	72			Wilt Point	19.38
		Avg. Depth	78.33			A.W.C.	16.64
9B1R2	Clay loam, Sandy clay loam, Silty clay loam	0-30	72.59	Clay loam	C	Saturation	39
		30-60	51.98			F.C.	30.99
		>90	71.5			Wilt Point	16.55
		Avg. Depth	65.36			A.W.C.	14.44

Note: F.C. = Field Capacity, A.W.C.= Available Water Holding Capacity, HSG = Hydrologic Soil Group
Source: SSNL

Water levels in the unconfined aquifer range in depth from less than 6 m to 30 m. Region I & II are having good ground water quality, and having total dissolved salts (TDS) less than 2000 ppm. However, a small patch of saline pocket exists near Vadodara. Alluvial aquifers lay in both regions I and II; however, in some portions of region I, aquifer in basalt is also noticed. Mostly groundwater is extracted by shallow tube wells, as the salinity in upper aquifer is low (Pathak, 1989). The ground water is potable and suitable for irrigation in both regions. All the area in region I, from ground water development point of view is good, while region II has certain pockets saline to the tune of 0.026 million hectare. Distribution of potential area for groundwater in region I and II, and area under different ranges of depth of water table in Sq. Km are shown in Table 4.5. The Table 4.5 demonstrates that around 40 percent of area in region I have depth to water table less than 10 m in region I, while a large area for region II has range between 10 to 35 m, as per recent data collection. So, the long term irrigation strategy is needed to prevent water logging in near future. Mathematical modeling studies stated that over irrigation in the study area could result in water logging. Scenarios without conjunctive use demonstrated that surface irrigation applications up to about 500 mm per year could lead to significant water logging problem. Area probable to get water logged by the end of Kharif season varied between 25 to 38 per cent of the GCA, which could be largely brought down, if ground water abstraction to the extent of 200 MCM was initiated from the 7^{th} year onwards (Pathak, 1989). Hence evaluation of irrigation strategies is very much required.

Table 4.5: Distribution of potential area for groundwater in region I and II and area under different ranges of depth of water table in Sq. Km.

Region	Total area	Alluvial area	Hard rock area	Saline area	Depth to Water Table		
					0 to 5 m	5 to 10 m	More than 10 m
1	2530	550	1980	---	30	1010	1490
2	2730	2730	---	260	---	230	2500

Source: Pathak, 1989; Regionalization of Narmada command, ORG May, 1982.

4.1.7 Groundwater Recharge

Irrigation intensity in Narmada-Mahi doab pre SSP implementation was about 21 percent. After the implementation of the Sardar Sarovar Project, annual ground water recharge is going to be enhanced almost twice to the rate of previous recharge, which will result into rise of water table very fast, thus causing water logging and salinity. The recharge of ground water due to irrigation has been estimated, after carrying out mathematical modeling studies, accounted, and utilized for planning of irrigation in the command as a conjunctive use (Raj, 1996). Long duration pump tests were conducted in Dabhoi, Savli, Padra, and Karjan talukas, for evaluation of hydrological parameters of the aquifer. Water level monitoring of 96 wells is carried out between Narmada-Mahi doab over and above the 35 existing open wells, which are periodically monitored for fluctuations in water level in pre and post monsoons since 1970, and also peizometric mapping of confined aquifer is planned (Pathak, 1989)

Observations made by GWRDC, for depth to water table in pre monsoon and post monsoon (mean 1970-79) show that average June – October fluctuations in water levels is of the order of 1.5 m to 2 m per year. Recharge estimates have been envisaged to the tune of 210 mm, from the observations conducted over 10 years of open wells in region 1 and 2, while net withdrawals from the area is about 190 MCM, of which mostly the abstraction is due to pump sets installed on open wells. The net withdrawals as found by the tests is less than rainfall recharge (Pathak, 1989). Groundwater initial storage has been taken as 200 MCM, for the purpose of initiating simulation.

4.2 Crop Water Requirement and Irrigation Management

Suitable cropping patterns have been recommended for each region in SSP. Major Crops grown in the present study area is cotton, pigeon pea, wheat, and jowar. Crop water requirement and irrigation scheduling for total fourteen crops Rice, Wheat, Sorghum, Bajra, Maize, Pigeon pea, Gram, Sugarcane, Cabbage, Cotton, Groundnut, Castor, Tobacco and Alfalfa grown in the region I and II are taken up for study purpose. The crop data were procured from agriculture department, and from Vadodara District Panchayat Office Statistical Branch taking year 2003 as base period. Cropped area, in each block for selected major crops in region I and II has been tabulated in Table 4.6 and Table 4.7.

To estimate crop water requirements and yield, the crop data for all major crops used in study i.e. crop seasonal length (initial, mid and late), basal crop coefficients (initial, mid and late season), depletion factor, yield response factor, maximum height and root depth, and

maximum potential yield are collected from, FAO 56 and relevant literature from field observations and demonstrated in Tables 4.8 and 4.9.

Table 4.6: Cropped area in base year 2003 in hectares under block 1 to block 9A1 in region I

	Block 1	Block 2	Block 3A	Block 3B	Block 4A	Block 4B	Block 5	Block 6A1	Block 8	Block 9A1
	9868	7202	6592	6108	6831	6200	7456	10033	10932	8546
Crops	Area in Hectares									
Rice	131	96	88	81	202	184	221	297	324	762
Wheat	125	91	84	78	312	283	341	459	500	1227
Jowar	69	50	46	43	113	102	123	166	180	928
Bajri	0	0	0	0	87	79	95	128	140	181
Maize	644	470	430	399	1072	973	1171	1575	1716	470
Tuver	0	0	0	0	555	503	605	815	888	606
Chana	448	327	299	277	68	62	75	100	109	69
Sugarcane	0	0	0	0	125	113	136	184	200	3
Cabbage	442	323	295	274	952	864	1039	1399	1524	238
Cotton	6587	4807	4400	4077	2739	2486	2990	4023	4384	3136
Groundnut	256	187	171	158	211	192	230	310	338	57
Castor	270	197	181	167	185	168	202	272	296	339
Tobacco	0	0	0	0	0	0	0	0	0	29
Alfalfa	894	653	597	553	193	175	211	284	309	460

Source: District Statistical Data, 2004-05.

Table 4.7: Cropped area in base year 2003 in hectares under block 10 to block 13B in region I and block 6A3R2 to 9B1R2 in region II

	Block 10	Block 11A1	Block 11A2	Block 12	Block 13A	Block 13B	Block 6A3R2	Block 6BR2	Block 9A2R2	Block 9B1R2
	10602	10381	6814	5525	6184	8342	11861	8591	5015	10264
Crops	Area in Hectares									
Rice	946	872	572	464	519	701	0	1101	447	916
Wheat	1522	1080	709	575	643	868	267	1393	720	1474
Jowar	1151	104	68	55	62	83	38	219	545	1115
Bajri	225	626	411	333	373	503	6	233	106	218
Maize	583	71	46	38	42	57	0	28	276	565
Tuver	752	1010	663	538	602	812	187	0	356	728
Chana	86	8	5	4	5	7	7	36	41	83
Sugarcane	3	0	0	0	0	0	1991	364	2	3
Cabbage	296	249	164	133	148	200	324	440	140	286
Cotton	3891	4255	2793	2265	2535	3419	8642	4197	1841	3767
Groundnut	71	4	3	2	2	3	2	15	34	69
Castor	421	135	89	72	80	108	155	248	199	407
Tobacco	36	1685	1106	897	1004	1354	0	10	17	35
Alfalfa	570	171	112	91	102	138	241	308	270	552

Source: District Statistical Data, 2004-05.

Table 4.8: Crop Parameters of following crops Rice, Wheat, Sorghum, Pearl millet, Maize, Pigeon Pea and Chick Pea

Crop		Rice	Wheat	Sorghum	Pearl millet	Maize	Pigeon pea	Chick Pea
Category		Cereals	Cereals	Cereals	Cereals	Cereals	Legumes	Legumes
Typical Planting Month		June - July	Nov	June-July	June-July	Oct	June-July	Oct – Nov
Stage Length [days]	Initial	30	15	20	15	20	40	20
	Development	30	25	30	20	30	35	25
	Mid Season	40	40	40	35	40	60	30
	Late	30	30	25	20	10	25	30
	Total	130	110	115	90	100	160	105
Basal Crop Coefficient Kcb	Initial	1	0.15	0.15	0.15	0.15	0.15	0.15
	Mid Season	1.15	1.1	1	0.95	1.1	1.1	0.95
	Late	0.6	0.15	0.35	0.2	1	1.05	0.25
Depletion Factor [0-0.99]	Initial	0.2	0.55	0.55	0.55	0.5	0.5	0.5
	Mid Season	0.2	0.55	0.55	0.55	0.5	0.5	0.5
	Late	0.2	0.55	0.55	0.55	0.5	0.5	0.5
Yield Response Factor, Ky:	Initial	0.4	0.2	0.2	0.4	0.40	0.20	0.20
	Development	0.90	0.6	0.4	0.6	0.40	0.60	0.60
	Mid Season	1.50	0.5	0.55	1.25	1.30	1.10	1.10
	Late	0.50	0.4	0.2	0.8	0.50	0.75	0.75
	Overall	1.25	1	0.9	1	1.25	1.15	1.15
Maximum Height [m]		1.0	1	1.5	1.5	1.5	1.2	0.5
Root Depth [m]	Minimum	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	Maximum	0.75	1.25	1.5	1.5	1	0.8	0.9
Maximum Potential Yield in Kg hectare		4500	4000	3000	2000	3000	1500	1600
Method of Irrigation		Check Basin	Border	Furrow	Border	Furrow	Furrow	Furrow

Source: FAO-56, GAEZ, 2012

Table 4.9: Parameters of fallow and following crops Sugarcane, Cabbage, Cotton, Groundnut, Castor, Tobacco and Alfalfa

Crop		Sugarcane	Cabbage	Cotton	Ground nut	Castor	Tobacco	Alfalfa	Fallow
Category		Sugar Cane	Vegetables	Fibre Crops	Legumes	Oil Crops	Fibre Crops	Forages	Fallow
Typical Planting Month		July - Aug	Sept	June-July	June	March	July-Aug-Sep	Jun	
Stage Length [days]	Initial	30	40	30	25	25	30	5	365
	Development	50	60	50	30	40	60	20	
	Mid Season	180	50	60	40	65	60	10	
	Late	60	15	55	25	50	30	10	
	Total	320	165	195	120	180	180	45	365
Basal Crop Coefficient Kcb	Initial	0.15	0.15	0.15	0.15	0.15	0.15	0.3	0.01
	Mid Season	1.2	0.95	1.15	1.1	1.1	1	1.15	0.01
	Late	0.7	0.85	0.45	0.5	0.45	0.6	1.1	0.01
Depletion Factor [0-0.99]	Initial	0.65	0.45	0.65	0.5	0.5	0.5	0.55	0.5
	Mid Season	0.65	0.45	0.65	0.5	0.5	0.5	0.55	0.5
	Late	0.65	0.45	0.65	0.5	0.5	0.5	0.55	0.5
Yield Response Factor, Ky:	Initial	0.5	0.4	0.4	0.4	0.20	0.20		
	Development	0.8	0.4	0.4	0.6	1.10	1.0		
	Mid Season	1.2	0.5	0.5	0.8	0.75	0.5		
	Late	1	0.5	0.4	0.4	0.20	0.5		
	Overall	1.1	0.95	0.85	0.7	1.15	0.9	1.1	
Maximum Height [m]		2	0.4	1.35	0.4	3.0	1	0.7	0.15
Root Depth [m]	Minimum	0.15	0.15	0.15	0.15	0.15	0.15	1	0.15
	Maximum	2	0.8	1.35	0.9	1.5	0.8	1.5	0.15
Maximum Potential Yield in Kg/ha		75000	70000	2500	2500	2500	3000	3000	
Method of Irrigation		Furrow	Furrow	Furrow	Furrow	Furrow	Furrow	Border	_

Source: FAO -56, GAEZ, 2012

4.2.1 Rice (*Oryza sativa*)

Rice is grown in Kharif season, Rabi season and summer period in India. Rice is grown under varied conditions (i) lowland (or paddy) rice are raised under ponding water throughout the crop growth period, and (ii) upland rice, require well drained, non saturated soils without ponding water. Total requirement of water for rice is between 1200 to 1400 mm, while daily consumptive use of rice is 6 - 10 mm. Water requirements and losses of water in rice fields are illustrated in Table 4.10. Critical crop growth stages for water stress for rice is tillering, panicle initiation, boot leaf stage, heading, and flowering. Soil moisture should be maintained at saturation level during these stages. Suspending irrigation before 10-14 days caused uniform ripening with optimum yield and savings in irrigation water. As per thumb rule 200mm water saturates the root zone. A water depth of 100 mm is usually kept standing, throughout the growing season. Studies have shown that higher yields could be achieved with low submergence of 50 mm of water.

Table 4.10: Water requirement and losses of water in rice fields

Particular	Clay Loam	Silty Clay	Loam	Sandy Loam
Water requirement	1583	1602	1995	2261
Irrigation	1125	1200	1500	1775
Runoff	207	191	193	161
Percolation	893 (56 %)	870 (54 %)	1187(60 %)	1515 (67 %)
Evapotranspiration	690 (44 %)	732 (46 %)	808 (40 %)	745 (33 %)

Source: FAO; Agropedia

Yields of 4500 Kg/hectare could be achieved with irrigation at soil saturation/ soil cracking/ alternate wetting and drying thereby saving water up to 22-64 percent (Prihar and Sandhu, 2002). Average yields for upland rice is 1000kg/ha but for aerobic rice with pristine conditions can reach upto 4000-6000 kg / hectare. (Steduto et al. 2012)

4.2.2 Wheat (*Triticum spp.*,)

Wheat is one of the popular crops of India, and is grown in winter (Rabi), and spring season. Crop growing period of wheat is between 110 to 300 days, and can grow in variety of soils, but soils of medium textured are preferable over others, however, peaty soils should be avoided (FAO Wheat 2001). Total cumulative evapotranspiration, throughout the growth

period ranges between 200-500 mm, which can even exceed 600-800mm in irrigated areas and can be even less in semi-arid non irrigated areas (Steduto et al. 2012). The critical period for water demand in wheat is flowering stage, and even supplying water at later stage does not help in recovering the loss in yield. The critical stages from date of sowing from the irrigation demand point of view are demonstrated in Table 4.11.

Table 4.11: Recommended scheduling of six irrigations for wheat according to critical stages; else there would be reduction in yield (WALMI, n.d.)

Phenological Stages of Wheat	Irrigation required from day of sowing	Yield reduction, if irrigation not applied during the stage in percent
Crown root initiation	18 to 21	36
Tillering	35 to 40	21
Booting	50 to 55	20
Flowering	65	-
Milky	75 to 80	25
Dough	90 to 95	9

Source: WALMI, (n.d.)

Experiments suggest that good yields are attained on irrigating wheat, when 50 percent of ASM is left in the top 30 cm layer (Prihar and Sandhu, 2002). Irrigation around 70 mm - 80 mm depth can be considered permissible depth for most type of soils. The last irrigation can be scheduled till one week to three weeks before harvest without significantly affecting the yield (FAO Wheat, 2001). Optimum yield of 4000 Kg / hectare can be achieved with total irrigation requirement between 400 mm to 450 mm for wheat.

4.2.3 Sorghum (*Sorghum bicolor*) (Jowar)

Jowar is next important grain after rice and wheat in terms of area cultivation. It is used for fodder also, and is grown in semiarid regions, where rainfall may not be properly distributed. Jowar is grown in dry areas normally, under rainfed conditions in Kharif season and in Rabi season, especially in deep black soils, where moisture retention is high. Rainfall between 500-800mm and evenly distributed over the season is sufficient enough for the crop. Jowar is grown on variety of soils ranging from sandy loam to clayey. Crop season length varies from 110-130 days depending upon the variety of the crop. It is a drought resistant crop. The water

requirement of jowar is between 450-600 mm. Number of irrigations to be applied ranges, from one to four depending upon climatic conditions, soil texture, and variety. The surface irrigation method of border/basin/corrugation is usually practiced. According to the type of variety two or four irrigations are applied at 20 days interval post monsoon respectively Source WALMI, (n.d.). Irrigation scheduling recommended for jowar in Narmada command, according to critical crop growth stage is demonstrated in Table 4.12.

Table 4.12: Critical Growth period for water demand in Jowar

Critical Growth period for water demand in Sorghum	Irrigation required Days after sowing	Effect of Moisture Stress
Seeding Stage	25-30	
Flag leaf to Flowering	30-45	Reduces number of grains
Flowering Stage	55-65	Pollination failure
Grain filling	85-95	Small grain

Source: WALMI, (n.d.)

The irrigation scheduling should be such that water deficits are minimized during establishment, flowering, and early yield formation periods (FAO Sorghum, 2001). Potential yield of 3000 Kg/hectare can be achieved provided pristine conditions prevail.

4.2.4 Pearl Millet (*Pennisetum glaucum*) (Bajra)

Pearl Millet known locally as Bajra is grown in arid and semiarid tropic areas, which are warm and have low seasonal rainfall between 150 mm to 500 mm. Crop seasonal length varies from 85 to 95 days. Bajra is a rainfed crop grown in Kharif season with the onset of monsoon. It is given priority over wheat, maize and sorghum in regions where rainfall is inadequate (200-600 mm), as it being comparatively a drought and heat resistant crop. Usually no post sowing irrigation is required in comparison to other Kharif crops; provided the significant rain is at an interval of 15 days. Studies show that under water stress conditions, Bajra adapts a mechanism of reducing the number of tillers, leading to reduction of transpiration area, which helps crop to withstand water stress (Ismail, 2012). Drought stress during the vegetative period is less damaging to pearl millet, than at later growth stages (Misra, 1991). The crop water requirement varies from 150-200 mm across India and the studies suggest that it responds well to supplemental irrigation. Visible signs such as drooping and withering of leaves, and leaves felt little warmer during noon instead of cool

would indicate the irrigation requirement of the crop (Yadav, 2012). Experimental studies show that post sowing single irrigation at 45 days, for double irrigation once at 15 days and other at 30, or 45 days, for higher yield is recommended (Saiffullah et al., 2011). Potential yield of 2000 kg/hectare can be attained in pristine conditions.

4.2.5 Maize (*Zea mays*)

Maize is known as corn around the world and used both as grain and green forage fodder. Maize is grown in monsoon as Kharif crop under rainfed conditions and in Rabi season under irrigated conditions. The crop performs quite well on all type of soils. Crop is susceptible to water logging. Crop season length is between 80-140 days, depending upon the variety of maize. Maize stem is sensitive to water thus grown on ridges and furrow irrigation is recommended Indian Council of Agricultural Research (2013). Maize crop being sensitive to moisture stress as well excessive water needs regulation of irrigation in various growth stages. (i) Sowing and establishment stage 1-14 days, (ii) Vegetative stage 15-40 days, (iii) Flowering stage 41-65 days and (iv) Maturity stage 66-95 days. (TNAU: Maize, 2005.) The critical growth stages, when demand of water is required to be met are shown in Table 4.13.

Table 4.13: Critical growth period for water demand in Maize

Critical Growth period for water demand in Maize	Irrigation required Days after sowing	Effect of Moisture Stress
Vegetative period	40	Reduces size of cob and number of grains per cob
Flowering	60	Causes little or no formation due to silk drying
Yield formation	70-90	Reduces yield due to reduction in size of grains
Ripening	95-100	Little effect on grain size

Source: WALMI,(n.d.)

Crop has little effect of moisture stress, during vegetative and ripening period, while severe moisture stress during flowering period has an unrecoverable effect, which would result into little or no grain (FAO Maize, 2001). Irrigation requirement of maize is between 500 mm to 800 mm water depending on type of soil, climate and season in which it is grown. Potential yield of 3000 kg/hectare under pristine conditions is attained if average recurrence of irrigation or significant rain is 15 days interval.

4.2.6 Pigeonpea (*Cajanus cajan L. Milsp.*) (Arhar/ Tuver)

Pigeon pea is a legume and second most popular pulse crop, also known as Redgram/Arhar/Tuver across India. Tuver is grown in varied type of soils from lighter sandy loam to heavy black clayey soils provided the soil is deep and well drained (Indian Council of Agricultural Research, 2013). The crop is mostly grown in Kharif season under rainfed conditions. It is grown in arid and semi-arid climates, the crop best grows in regions with 500 mm to 1000 mm rainfall. The crop is drought resistant thus can thrive also in less rainfall, but it cannot bear frost and water logging. Crop is planted on ridges and furrow irrigation is applied to avoid water logging. The water requirement for Tuver ranges from 300 mm to 500 mm. The critical stages for water demand of the crop are branching, flowering and pod filling. The crop is usually irrigated post monsoon one month for better yields (Gangaiah, n.d.). Irrigation scheduling for Tuver as recommended in Narmada command (WALMI, n.d.) are as follows: Tuver if grown in 3rd week of June than irrigation scheduling is recommended at an interval of 35 days after monsoon. Farmers sowing the crop in Kharif are advised to give two irrigations; first irrigation after one month end of monsoon and second irrigation is applied after 35 days interval.

4.2.7 Gram (*Cicer arietinum*) (Chick Pea/Chana)

Gram also known as Chick Pea (Chana) is a pulse crop usually sown in areas where rain is sufficient to let the crop thrive on it without any irrigation. The crop season length is 110-130 days depending on variety and environment. The crop thrives best having a seasonal rainfall of 150-250 mm. Every second row of crop is irrigated by furrow irrigation method. The crop is drought tolerant to certain extent. It is grown in soils having high retention capacity. The crop is very sensitive to over irrigation or water logging even for short periods and reduces yield upto 100 percent (Kang et al. 2008), thus avoid irrigation if likely to rain. Chana grown as Rabi crop during Oct-Nov would require irrigation especially during branching (30-33 days after sowing), flowering (45-55 days after sowing) and pod formation (70-75 days after sowing). Higher yields are attained if chickpea is water stressed during vegetative stage and there after irrigated normally (Mafakheri et al., 2010; Hirich et al., 2011). It is advised to irrigate when soil moisture deficit is of around 60-70 percent of field capacity. Potential yield of 1600 Kg/ hectare could be attained with standard conditions. Average recurrence interval of significant rainfall, or irrigation required for Chana is 20 days.

4.2.8 Sugarcane (*Saccharum spp.*)

Sugarcane is a cash crop mostly grown in tropical regions. The crop seasonal length is 10, 12, 15, and 18 months depending on crop variety. The peak evapotranspiration rates vary between 6-15 mm/day, and cumulative seasonal evapotranspiration ranges between 800-2000mm of water depending on cultivar, growth period and climatic conditions (FAO Sugarcane 2001). The crop water requirement depending upon soil texture and climate conditions is in range of 1500-2500 mm. To increase sucrose content the last cut off irrigation is 20-30 days ahead of harvest. The crop is preferably grown in areas, where the water supply is assured. The permissible depletion level of 30 percent of total available soil water is required to be adhered. Irrigation interval in Rabi and hot weather are 15 and 10 days respectively. In initial stage light but frequent irrigation/wettings are required. Irrigation method selected for application of water is furrow, sprinkler or drip depending on prevailing conventional practices. Potential yield of 75000 kg/hectare can be attained depending on climatic and pristine environment conditions.

4.2.9 Cabbage (*Brassica oleracea*)

Cabbage is preferably grown in cool climate in well drained soils. It requires the growth period of 100-200 days. Cabbage is well suited to heavy loam soils, and under high rainfall areas, sandy or sandy loam soils are considered better, as they are well drained. It needs to be planted on ridges so as to irrigate by furrow method. Crop water requirement varies from 400 to 500 mm. The irrigation depth and frequency varies according to climate, growth period and soil; the irrigation frequency can range between 3-25 days. Cabbage requires immediate irrigation after sowing, or transplanting, and afterwards seven irrigations of 80mm depth is recommended at intervals of 10-12 days, in heavy soils, and 7-9 days in light soils. First irrigation is given after replanting, followed by second after one week, and the rest others given at an interval of 20-25 days (Krishi Darshan, 2005). In Kharif season irrigation is applied considering soil moisture condition. During Rabi season the irrigation interval is usually 12-15 days, while in hot weather the irrigation interval is kept as 10-12 days as reported by (WALMI, n.d.). Maximum yield of cabbage can be attained between 70-110 tons per hectare under ideal conditions of climate, water supply, type of soil and crop management practices (FAO Cabbage 2001).

4.2.10 Cotton (*Gossypium hirsutum*)

Cotton is a fibre crop which requires warm and long frost free period with moderate rainfall, or irrigation of 600-1200 mm, for optimum growth. Crop being salt and drought tolerant is mostly grown in arid and semi-arid regions. The growth period varies between 150-180 days. Crop is rainfed and grown from onset of the monsoon, and requires one or two watering if rainfall is not normal, and uniformly distributed. Cotton is grown in south Gujarat in heavy black soils. Best results are achieved in fertile, deep, and well drained soils (Indian Council of Agricultural Research, 2013). The crop is tolerant to water logging for short periods, but heavy rains can damage the crop. The continuous rainfall during flowering and boll opening would reduce the fibre quality (FAO: Cotton, 2001). Depending on prevalent pristine climatic conditions; the water requirement need is 700 to 1300 mm (Steduto et al., 2012). Water stress during sowing is detrimental to plant growth. Critical stage from irrigation point of view, for cotton is early stage of flowering. Irrigation is scheduled usually when 40 percent of available moisture levels are left out in the 75 cm root zone depth. Conventional practices in Gujarat followed by cultivators are to irrigate one month post monsoon. Last cut off irrigation is applied 20-25 days before harvest. Irrigation scheduling recommendations by Krishi Darshan for Narmada command: Farmers growing hybrid-6 cotton are advised to give five irrigations of 80 mm in heavy black soils. First irrigation one month post monsoon. Remaining irrigations be given at an interval of 18-21 days. Good yield around 2500-4000 Kg/hectare could be achieved under ideal climatic and irrigation conditions, depending on type of soil and crop variety.

4.2.11 Groundnut (*Arachis hypogaea*)

Groundnut is popularly known as peanuts worldwide. The crop is grown in semi arid regions mostly as rainfed, usually in the third week or fourth week with onset of monsoon. Under rainfed conditions the water requirement is between 500-700 mm depending on ideal climatic conditions and total crop season length. The crop responds well to water supply during vegetative and reproductive growth. However, excessive soil water in root zone for long period hampers nitrogen fixation (FAO: Groundnut, 2001). Broad bed with furrow irrigation method is widely practiced locally. Before 2-3 days of harvesting irrigation be applied, so as to make ease in pulling of the groundnut from soil (ICRISAT, n.d.). The irrigation scheduling for ground nut crop is 1-3 irrigations of 50mm, during critical stages of flowering (40-50 days after sowing), Soya stage (55 days after sowing), and Pod formation stage (70-80 days

after sowing) to supplement the water requirement, if deficit, or erratic rainfall (WALMI n.d.) Potential yield of 2500 Kg/hectare can be attained in pristine conditions.

4.2.12 Castor (*Ricinus communis L.*)

Castor is grown in tropical and semi-tropical regions as a cash crop. Gujarat has certain varieties of castor which are wilt resistant. The crop is planted in areas having moderately high temperature for a period of 140-160 days (American Society of Agronomy, 2011). The crop is grown in rainfed, and as well as in irrigated conditions, depending upon soil type, rainfall and climatic conditions. However, best yields are attained under supplemental irrigations. Under rainfed conditions sowing one week before onset of monsoon is suggested. Water requirement of castor is 500 mm. (Tnau: Castor, 2005).

The crop is grown on ridges and irrigation is applied by furrow method. Castor is a drought tolerant crop and mostly grown in marginal soils because of higher priority given to food crops to grow in fertile lands. The crop is able to recover fast after severe drought on application of water. Castor is highly sensitive to water logging and recorded yield reduction if subjected for short period, but would perish, if subjected to continuous inundation for 3-4 days (Severino et al., 2011). Krishi darshan recommends 4 irrigations of 80 mm in black soil for G.C.H-4 castor variety. First irrigation is given 40 days post monsoon. Second irrigation is given at an interval of 20-25 days. Third and fourth irrigation is given at an interval of 30 days. Potential yield of 2500 Kg/hectare can be achieved under standard conditions.

4.2.13 Tobacco (*Nicotiana tabacum*)

Tobacco is grown in India in Kharif season. Water requirement of tobacco ranges from 400 to 600 mm. Furrow irrigation is best among the different surface irrigation methods. Maximum water requirement is needed 50-60 days after transplanting. The crop is not irrigated during ripening to get good quality of yield. Crop if grown in heavy black soils usually does not require irrigation, as it can thrive best on high retentive soils. The crop cannot stand water logging for more than two days. Critical stage for Tobacco is immediately after transplanting. Mild deficit irrigation can be practiced in ripening stage; however severe deficit could result into poor quality of tobacco. Over irrigation, or excess rain has a negative impact on yield and quality of tobacco. Water deficits during certain periods are encouraged as it increases yield, and also resistance of crop towards drought. Strategy of applying water during transplanting, frequent irrigation in period of rapid growth, and early yield formation period, under limited water supply conditions could provide optimum yield (FAO: Tobbaco,

2001). Irrigation is applied 15-20 days after cessation of monsoon, and around 8-10 irrigations are recommended at an average irrigation interval of 20 days, or significant rainfall.

4.2.14 Alfalfa (*Medicago sativa*)

Alfalfa is a major irrigated forage crop grown all over the world. It is a perennial legume crop, and adapts to wide range of climate, and soil conditions. The yield increases with the advancement of cuttings, the maximum yield attained after fourth cutting is around 3 tons per hectare. The total evapotranspiration loss varies from 100 to 220 mm in different cuttings. An increasing trend is observed in evapotranspiration rate of crop from first to fourth cutting (Rai et al. 2014). The maximum value of evapotranspiration rate is approximately 7 mm per day which corresponds to fourth cutting. Water requirement for Alfalfa ranges between 500mm to 1150 mm, during the crop season length, depending upon climate, growing season, number of cuttings, and Alfalfa variety. Flooding method of irrigation is mostly adopted by farmers. Alfalfa requires 7 to 10 irrigations at an interval of 15 days in Rabi season. The depth of irrigation varies between 50 to 75 mm, provided soil is well structured to allow penetration. It is less tolerant to water logging in comparison to other forages (Steduto et al., 2012). The irrigation requirement for alfalfa is determined by rainfall, and the water holding capacity of the soils in which the crops are grown.

4.3 Closure

In study area the canal conveyance system is operated, such that peak requirements of water are met in the first fortnight of November, to ensure water availability for Kharif and Rabi crops, which need water for sowing. Canals are run during November to April, so as to sustain developing agriculture land under irrigation, by enforcing indirectly conjunctive use of canal and ground water during summer, and other seasons. The study area covers total 20 blocks (16 blocks of region I and 4 blocks of region II) of SSP phase I. The daily climate data were collected from five weather stations, and rainfall data of twelve rain gauge station is taken, in accordance to their proximity of blocks. Rainfall criteria for sowing operations were followed, thus the sowing date for Kharif crops was fixed 1st July for simulation.

In next chapter data collected from various agencies regarding soil, crop parameters and climate are used to evaluate irrigation strategies for fourteen major crops, for period 2003 to 2010 in the study area.