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Use of Shallow Groundwater in Sprinkler Irrigation (Case Study)

Aqeel Al-Adili, Mohammed R. Mohammed, Haider H. Alwash

Building and Construction Engineering Department, University of Technology, Baghdad, Iraq

Email address:
aqeeladili@hotmail.com (A. Al-Adili), moiraq2003@yahoo.com (M. R. Mohammed), hmalwash@yahoo.com (H. H. Alwash)

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Abstract: The study area is located in the desert region west of the road to Karbala-Najaf cities. The unconfined Al-Dibdibba aquifer in this area is considered as a source of water. Recently, the project of the city of Al-Imam Al-Hussein farm has been established in this area which depends on the groundwater for irrigation. The general direction of ground water in the aquifer is from the west and the south west towards the east and the northeast. The storage of the aquifer is about 46.8 Million m^3. Two different sites were selected; the first site is the front field which includes 4 wells, while the second site is the back field which includes 20 wells. Basins have been suggested to be constructed with a volume of 3000 m^3 for each one of farms A and B in the back field and a volume of 1500 m^3 for farm C in the front field. The results of electrical conductivity-EC of ground water-GW samples indicate that are suitable for wheat, barley, maize, and sugar beet. Simulation models have been used at two phases in this research with an area of 51 donums for the back field and 33 donums for farm C in the front field. The first phase is to find crop water requirement and irrigation requirements for wheat and barley as a winter crops and maize and sugarbeet as a summer crops using CROPWAT8.0 simulation model, while the second phase includes irrigation network design using EPANET2.0 simulation model. This study has revealed that the final designed semi-permanent sprinkler system capacity in this research is 321m^3/hr to irrigate area of 51 donum, within 4 days of 7 hours per day for the back field. Thus, the application of sprinkler irrigation will assist in the increase of cultivation by about 2.5 times. Also, results from simulation showed that the operation time of wells has been reduced about 40%. Crop yield produced by donum for each crop was increased by about 50%.

Keywords: Groundwater, Simulation Techniques, CROPWAT, Epanet, Sprinkler Irrigation Systems

1. Introduction

As global population grows, the demand for food also grows; thereby increasing the water demand for household, industrial, energy purposes and agriculture that are coincide with water deficiency around the world; therefore, it is necessary to find new and good water resources to sustain life and exploitation of many areas that are unutilized agriculturally. Compared to other Middle Eastern countries, Iraq is considered a wealthy country with respect to water resources. These resources, however, are becoming more and more constrained due to population growth, climate change, and decreasing surface water inflow from neighboring countries (Turkey, Syria and Iran). In the last decade, the demand for groundwater to meet many purposes has increased; therefore, groundwater resource management is an important issue, especially with regard to potential agricultural (Jassas and Merkel, 2014). Groundwater is vital and the sole resource in some parts of Iraq (especially western and southwest parts). The supply of groundwater is not unlimited and therefore its use should be properly planned based on the understanding of the groundwater systems behavior in order to ensure its sustainable use. The main water resources depletion is due to agricultural water use where inefficient irrigation systems resulted in soil and water quality problems. Simulation technique is the process of duplicating the behavior of an existing or proposed system. The main advantage of simulation models lies in their ability to accurately describe the reality. Simulation models are used for designing irrigation network, reconstruction or modernization and modification and may be used for the existing system or maintenance of different tasks while managing them.

2. The Study Area

The study area is located in the mid-south of Iraq. Al-Dibdiba aquifer was chosen in this study as a source of groundwater. This area extends between latitudes 32° 00´ to 32° 45´ N and longitudes 43° 30´ to 44° 25´ E and represented by the triangular in the desert region to the west of the road to Karbala-Najaf cities as shown in Figure 1. In this study, the project of the city of Al-Imam Al-Hussein (p.b.u.h) farm which lies on Al-Dibdiba aquifer was chosen as a case study for this investigation of the irrigation system to improve -as possible- the water distribution system, reduce water losses, reduce soil quality deterioration and develop field crop productivity; using simulation techniques.

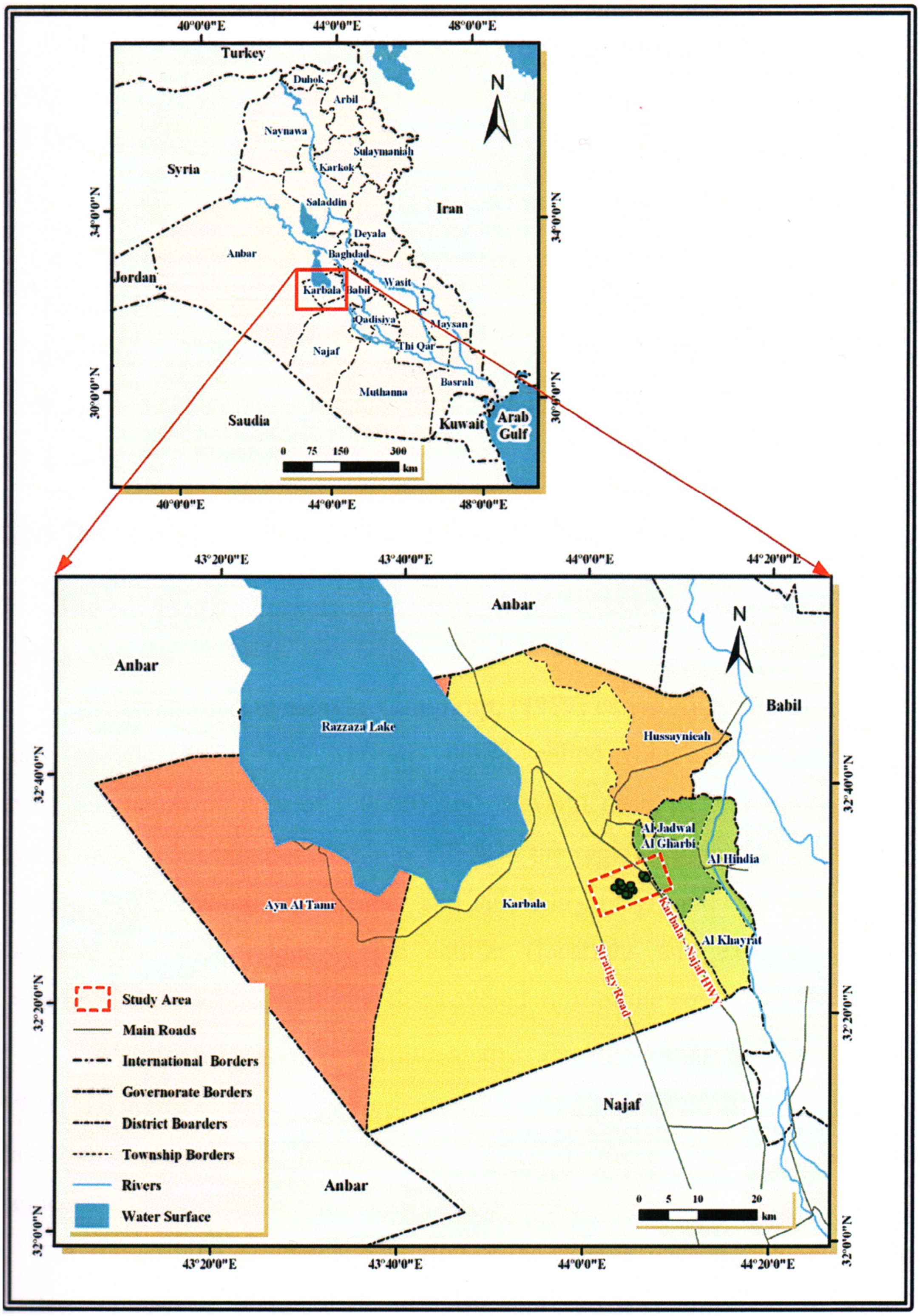

Figure 1. *Location map of the study area.*

2.1. Al-Dibdibba Aquifer

Al-Dibdibba aquifer represents the main aquifer in the study area. The type of aquifer is unconfined (Ramadhan et al., 2013). The thickness of Al-Dibdiba formation is about 45-80m which increases towards Al-Najaf city while decreases towards the main road. The saturated thickness of aquifer is variable with the distribution area reaches to 30-36.5m and increases towards the Euphrates River (Ali, 1994). The general direction of groundwater flow is from the west and the south west towards the east and the northeast towards the Euphrates River that is the east of aquifer. Al- Dibdiba aquifer fed with water from rainfall. The renewed storage of Al-Dibdibba aquifer is about 46.8 Million m^3.

2.2. The Front Field

The first site which was chosen in the project of the city of Al-Immam Al-Hussein farm is the front field which lies near the main road between Karbala-Najaf cities between latitudes 32° 30′ to 32° 32′ N and longitudes 44° 06′ to 44° 10′ E and covers an area of 100 dunam (250000m^2). The front field includes 4 wells penetrated the regional unconfined aquifer (Al- Dibdibba). The details of these wells are illustrated in Table 1.

Table 1. *Characteristics of the front field wells (Ministry of Water Resources, 2014).*

Well No.	Longitude	Latitude	Well depth (m)	Static water level (m)	Q m^3/hr
WF1	44 º 6′ 11′′	32 º 31′ 46′′	18	4.4	21.6
WF2	44 º 6′ 20′′	32 º 31′ 58′′	18	7.6	28.8
WF3	44 º 6′ 2′′	32 º 31′ 58′′	18	9.1	28.8
WF4	44 º 6′ 30′′	32 º 31′ 45′′	18	4.2	25.2

2.3. The Back Field

The second site which was chosen in the project of the city of Al-Immam Al-Hussein farm is the back field which falls about 5 km from the main road between Karbala-Najaf cities towards the west between latitudes 32° 30′ and 32° 33′ N and longitudes 44° 00′ and 44° 05′ E and covers an area of 900 dunam (2250000m^2). Table 2 shows the characteristics of the 20 wells which included in the back field.

Table 2. *Characteristics of the back field wells (Ministry of Water Resources, 2014).*

Well No.	Longitude	Latitude	Well depth (m)	Static water level (m)	Q m^3/hr
WB1	44° 5′7′′	32° 30′ 38′′	42	18.8	25.2
WB2	44° 4′48′′	32° 30′ 34′′	42	16.7	32.4
WB3	44° 4′20′′	32° 30′ 22′′	42	21.6	27
WB4	44° 3′31′′	32° 30′ 36′′	42	22.6	28.8
WB5	44° 3′30′′	32° 30′ 52′′	42	23.7	25.2
WB6	44° 4′21′′	32° 30′ 9′′	42	20.7	14.4
WB7	44° 4′34′′	32° 30′ 12′′	42	21.2	14.4
WB8	44° 4′12′′	32° 30′ 11′′	42	23	14.4
WB9	44° 3′31′′	32° 31′ 20′′	42	20.1	28.8
WB10	44° 3′35′′	32° 31′ 4′′	42	18.5	28.8
WB11	44° 3′50′′	32° 30′ 56′′	42	15.5	28.8
WB12	44° 4′ 6′′	32° 30′ 47′′	42	18.75	28.8
WB13	44° 4′23′′	32° 30′ 38′′	42	18.75	28.8
WB14	44°4′ 53′′	32° 30′ 48′′	42	17.2	28.8
WB15	44°4′ 50′′	32° 31′ 2′′	42	18.5	28.8
WB16	44° 4′ 53	32° 30′ 47′′	43.5	13.5	28.8
WB17	44° 4′46′′	32° 31′ 7′′	42.6	13.1	28.8
WB18	44° 3′55′′	32° 30′ 57′′	42.6	13.2	28.8
WB19	44° 3′44′′	32° 31′ 16′′	42.4	12	18
WB20	44°4′ 13′′	32° 30′ 16′′	43.2	22.35	18

2.4. Properties of Al-Dibbdiba Groundwater

Laboratory Works included:

Collect water samples from 6 wells of the project of the city of Al-Immam Al-Hussein farm, samples were collected from well WF2, WF3 and WF4 in the front field, while samples were collected from well WB6, WF8 and WF10 in the back field. The collected ground water samples were analyzed for the cations, such as, Calcium (Ca^{+2}), Magnesium (Mg^{+2}), Potassium (K^{+1}), Sodium (Na^{+1}); the anions, Chloride (Cl^{-1}), (SO_4^{-2}) according to the standard methods and techniques as shows in Table 3. The chemical analysis has been done in the chemical laboratory of the Environment Directorate in Najaf Province.

Table 3. *Hydrochemical properties of groundwater in the study area (February, measured in 2015).*

Well No.	K^+ (ppm)	Na^+ (ppm)	Mg^+ (ppm)	Ca^{++} (ppm)	Cl^- (ppm)	SO_4^- (ppm)	T.H as $CaCO_3$ (ppm)	T.D.S. (ppm)	Na %	SAR
WF2	79	808.5	92.72	608	1450	1951.7	1900	3776	49.4	8.06
WF3	12	544	166	340	725	1368	-	3570	52.4	6.0
WF4	4	439	110	230	506	803	-	3500	56.6	4.2
WB6	88	511	148	308	690	1228	-	5040	57.6	4.2
WB8	42	304.5	24.2	520	540	1494.6	1400	5082	33.81	3.53
WB10	80	400	127	265	547	986	-	4566	55	3.6

2.4.1. Electrical Conductivity (EC)

The data shown in Tables (4 and 5) represent the EC values in the study area. The maximum values of EC are 6490 (µs/cm) and 7090 (µs/cm) in the front field and the back field respectively, while the minimum values of EC are 6230 (µs/cm) and 3420 (µs/cm) in the front field and the back field respectively.

Table 4. *Values of Electrical Conductivity (EC) of the front field.*

Well No.	EC (µs/cm)
WF1	6350
WF2	6230
WF3	6490
WF4	6280
	Avg. 6337

Table 5. *Values of Electrical Conductivity (EC) of the back field.*

Well No.	EC (µs/cm)
WB1	5440
WB2	6320
WB3	5300
WB4	5890
WB5	5900
WB6	4350
WB7	3420
WB8	5900
WB9	4950
WB10	4740
WB11	5740
WB12	4630
WB13	4930
WB14	4500
WB15	4930
WB16	7090
WB17	6870
WB18	6980
WB19	3520
WB20	5070
	Avg. 5323

2.4.2. Sodium Content (Soluble Sodium Percent (SSP))

Table 6 shows the classification of irrigation water based on SSP. According to this Table, the SSP of groundwater samples in the study area as listed in Table 3 is classified as good to permissible class for the front field and for the back field.

Table 6. *Classification of irrigation water based on SSP (Todd, 2005).*

Water Class	SSP (Na %)	Wells of the study area
Excellent	< 20	
Good	≥20 – <40	WB8
Permissible	40 – <60	WF2, WF3, WF4, WB6 and WB10
Doubtful	60 – <80	
Unsuitable	> 80	

2.4.3. Sodium Absorption Ratio (SAR)

Table 7 shows the classification of irrigation water based on SAR value (Fipps, 2003). Water samples analysis of the study area indicates that the water has low sodium hazard values (see Table 3).

Table 7. *The sodium hazard of water based on SAR values (Fipps, 2003).*

SAR values	Sodium hazard of water	Comments	Wells of the study area
1-10	Low	Use on sodium sensitive crops such as avocados must be cautioned.	All water samples
10 - 18	Medium	Amendments (such as Gypsum) and leaching needed.	
18 - 26	High	Generally unsuitable for continuous use.	
> 26	Very High	Generally unsuitable for use.	

3. Cropwat Simulation Model

3.1. Cropwat Simulation Model Input Data

CROPWAT is a powerful tool to simulate different crop water need scenarios under different planting dates and thus enables the user to select most optimal sowing date to realize higher yields and water use efficiencies by matching the probable canal water supplies with crop needs.

Climatic Data of the Study Area

A climate data for the recent twenty years (1994-2014) was gathered from Karbala meteorological station that located in Karbala city and listed in Table 8.

Table 8. *Climate characteristics of Karbala area (average for period of 1994-2014).*

Month	Mean air temp. °C	Relative humidity %	Wind speed (m/s)	Sun shine (hr/day)	Evaporation (mm)	Rain (mm)
Jan.	11.3	74.5	1.57	5.9	58.4	18.5
Feb.	13.9	60.7	1.87	7.1	91.8	12.1
Mar.	18.3	50.0	2.24	7.8	167.6	9.8
Apr.	24.7	42.4	2.24	8.3	232.1	10.4
May	30.7	35.2	2.17	9.5	315.6	2.5
Jun.	34.9	30.0	3.0	10.8	398.3	0.0
Jul.	37.1	31.0	2.84	11.1	426.9	0.0
Aug.	36.8	32.4	2.24	10.8	387.0	0.0
Sep.	32.7	38.0	1.72	9.9	290.1	0.1
Oct.	26.9	46.4	1.50	8.1	197.9	3.2
Nov.	18.0	63.0	1.27	7.0	95.6	15.4
Dec.	12.6	71.0	1.42	6.1	62.3	14.2
Ave.	24.8	47.8	2.0	8.5	---	---
Sum.	---	---	---	---	∑ 2723.5	∑ 86.2

3.2. Soil Data and Spaw Model

The Soil-Plant-Air-Water (SPAW) Model was developed by the United States Department of Agriculture (USDA). The results of the SPAW model (field capacity, wilting point, texture class and saturation hydraulic conductivity), are used to determine the crop water requirement and irrigation requirement for the selected study areas by CROPWAT8.0 Model. The soil for both selected areas (the back field and the front field) contain a high percentage of sand, which maintains (20%) of irrigation water; Thereby the nature of the soil led to use the area for agricultural purposes.

Cropping Pattern

There are different ways of growing crops which can be used to give maximum benefit, and they are called Cropping Patterns. A summary of the cropping patterns for the city of Al-Imam Al-Hussein farm area are shown in Table 9. Plants tolerance differs for total dissolved solids and electrical conductivity (Todd, 2005), Table 10. When comparing the values of EC of groundwater in the study area with those standards (specifications), it is clear that the groundwater of the studied area is suitable for wheat, barley, maize and sugar beet.

Table 9. *Cropping patterns for the city of Al-Imam Al-Hussein farm.*

Crops	Area (donum)	Area %
Wheat	22	14.56
Barley	15	9.94
Maize	35	23.17
Plastics Houses include Vegetables	39	25.83
Eucalyptus, Olive as well as Palm trees function as windbreaks.	40	26.5
Project area	151	100

Table 10. *Acceptable limits of salinity in irrigation water for different crops based on EC values (Todd, 1980).*

Types of crops	Crops resisting low concentrations of EC in water	Crops resisting moderate concentrations of EC in water	Crops resisting high concentrations of EC in water
	<3000 µS/cm	≥3000 - < 4000 µS/cm	≥4000-10000 µS/cm
	Lemon		
	Strawberry	Olive	
	Peach	Fig	Date Palm
Fruit Crops	Apricot	Pomegranate	
	Almond		
	Orange		
	Apple		
	Pear		
	3000- < 4000 µS/cm	≥4000- < 10000 µS/cm	≥10000-12000 µS/cm
		Cucumber	
		Feas	
	Green bean	Onion	Spinach
Vegetable Crops	Celery	Carrot	Kale
	Baddish	Potato	Beet
		Lettuce	
		Cauliflower	
		Tomato	
	4000- < 6000 µS/cm	≥6000 - < 10000 µS/cm	≥10000-16000 µS/cm
		Sun flower	
Field Crops		Flax	
	Field bean	Corn	Cotton
		Rice	Sugar Beet
		Wheat	Barley

3.3. Cropwat Model Output Data

Geographical location, climatic parameters, soil type and cropping pattern data of the study areas were adopted as input data to CROPWAT Model, in addition to other required information related to field and crops characteristics. Once all the data entered to the software, CROPWAT automatically calculates ETcrop, effective rainfall and total irrigation requirements of wheat, barley, maize and sugarbeet crops that will be cultivated in the selected fields.

Reference Evapotranspiration Estimation

The climate data for Karbala region has been obtained from the meteorological stations for the (1994-2014) periods then applied to the CROPWAT8.0 software. The results of net radiation and reference crop evapotranspiration are obtained by the model shown in Figure 2.

Water Requirement of Wheat, Barley, Maize and Sugarbeet.

Evaluation of crop water requirement (CWR) using CROPWAT Model can be carried out by calling up successively the climate, rainfall, crops and soil data sets related to the study areas. Figures 3, 4, 5 and 6 illustrate crop water requirements ETcrop for wheat, barley and maize calculated by CROPWAT Model application.

Monthly ETo Penman-Monteith - C:\Documents and Settings\All Users\Application Dat...

Country: Iraq Station: Karbala
Altitude: 34 m. Latitude: 32.50 °N Longitude: 44.00 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	6.1	16.6	75	136	5.9	10.7	1.50
February	8.1	19.7	61	162	7.1	14.1	2.46
March	12.0	24.7	50	194	7.8	17.8	3.95
April	18.0	31.4	43	194	8.3	20.9	5.56
May	23.6	37.8	35	188	9.5	23.9	7.19
June	27.4	42.4	30	259	10.8	26.2	9.60
July	29.7	44.6	31	245	11.1	26.3	9.81
August	29.1	44.6	33	194	10.8	24.8	8.58
September	25.1	40.4	38	149	9.9	21.3	6.48
October	19.8	34.0	47	130	8.1	16.0	4.42
November	12.0	24.0	63	110	7.0	12.2	2.42
December	7.2	18.1	71	123	6.1	10.2	1.61
Average	18.2	31.5	48	173	8.5	18.7	5.30

Figure 2. *Calculating of radiation and reference evapotranspiration by CROPWAT (Karbala).*

Crop Water Requirements

ETo station: Karbala Crop: MAIZE (Grain)
Rain station: Karbala Planting date: 25/06

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	3	Init	0.30	2.94	17.7	0.0	17.7
Jul	1	Init	0.30	2.94	29.4	0.0	29.4
Jul	2	Deve	0.35	3.51	35.1	0.0	35.1
Jul	3	Deve	0.61	5.78	63.6	0.0	63.6
Aug	1	Deve	0.88	7.93	79.3	0.0	79.3
Aug	2	Mid	1.13	9.72	97.2	0.0	97.2
Aug	3	Mid	1.20	9.50	104.5	0.0	104.5
Sep	1	Mid	1.20	8.65	86.5	0.0	86.5
Sep	2	Mid	1.20	7.80	78.0	0.0	78.0
Sep	3	Late	1.19	6.88	68.8	0.2	68.6
Oct	1	Late	0.96	4.91	49.1	0.5	48.7
Oct	2	Late	0.68	2.99	29.9	0.7	29.3
Oct	3	Late	0.44	1.63	11.4	1.3	9.3
					750.6	2.7	747.1

Figure 3. *Crop water and irrigation requirement of maize (The Back Field).*

Crop Water Requirements

ETo station: Karbala | Crop: Sugarbeet
Rain station: Karbala | Planting date: 15/05

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	2	Init	0.35	2.52	15.1	0.4	14.8
May	3	Init	0.35	2.80	30.8	0.4	30.4
Jun	1	Deve	0.36	3.19	31.9	0.1	31.8
Jun	2	Deve	0.54	5.25	52.5	0.0	52.5
Jun	3	Deve	0.78	7.68	76.8	0.0	76.8
Jul	1	Deve	1.03	10.10	101.0	0.0	101.0
Jul	2	Mid	1.21	11.97	119.7	0.0	119.7
Jul	3	Mid	1.22	11.51	126.6	0.0	126.6
Aug	1	Mid	1.22	10.93	109.3	0.0	109.3
Aug	2	Mid	1.22	10.43	104.3	0.0	104.3
Aug	3	Mid	1.22	9.58	105.4	0.0	105.4
Sep	1	Late	1.17	8.39	83.9	0.0	83.9
Sep	2	Late	1.06	6.90	69.0	0.0	69.0
Sep	3	Late	0.96	5.57	55.7	0.2	55.4
Oct	1	Late	0.86	4.38	43.8	0.5	43.3
Oct	2	Late	0.75	3.33	33.3	0.7	32.6
Oct	3	Late	0.70	2.61	2.6	0.2	2.6
					1161.6	2.5	1159.4

Figure 4. *Crop water and irrigation requirement of sugar beet (The Back Field).*

Crop Water Requirements

ETo station: Karbala | Crop: Barley
Rain station: Karbala | Planting date: 16/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.30	0.70	3.5	2.8	0.7
Nov	3	Init	0.30	0.63	6.3	5.3	1.0
Dec	1	Deve	0.48	0.91	9.1	4.6	4.4
Dec	2	Deve	0.81	1.31	13.1	4.4	8.6
Dec	3	Mid	1.10	1.73	19.0	4.9	14.0
Jan	1	Mid	1.13	1.66	16.6	5.8	10.7
Jan	2	Mid	1.13	1.58	15.8	6.4	9.4
Jan	3	Mid	1.13	1.98	21.8	5.6	16.2
Feb	1	Mid	1.13	2.41	24.1	4.5	19.6
Feb	2	Late	1.05	2.57	25.7	3.8	21.9
Feb	3	Late	0.79	2.34	18.7	3.6	15.1
Mar	1	Late	0.53	1.83	18.3	3.4	14.9
Mar	2	Late	0.31	1.22	6.1	1.6	4.5
					198.0	56.8	141.1

Figure 5. *Crop water and irrigation requirement of Barley (The Back Field).*

Crop Water Requirements

ETo station: Karbala | Crop: Whaet
Rain station: Karbala | Planting date: 16/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.30	0.70	3.5	2.8	0.7
Nov	3	Init	0.30	0.63	6.3	5.3	1.0
Dec	1	Deve	0.33	0.61	6.1	4.6	1.5
Dec	2	Deve	0.48	0.77	7.7	4.4	3.2
Dec	3	Deve	0.66	1.03	11.3	4.9	6.4
Jan	1	Deve	0.83	1.22	12.2	5.8	6.4
Jan	2	Deve	1.00	1.41	14.1	6.4	7.6
Jan	3	Mid	1.14	1.99	21.9	5.6	16.3
Feb	1	Mid	1.15	2.45	24.5	4.5	20.0
Feb	2	Mid	1.15	2.82	28.2	3.8	24.4
Feb	3	Mid	1.15	3.39	27.1	3.6	23.5
Mar	1	Mid	1.15	3.96	39.6	3.4	36.2
Mar	2	Mid	1.15	4.53	45.3	3.1	42.2
Mar	3	Late	1.14	5.13	56.5	3.2	53.3
Apr	1	Late	0.97	4.87	48.7	3.6	45.1
Apr	2	Late	0.70	3.87	38.7	3.8	34.9
Apr	3	Late	0.42	2.58	25.8	2.8	23.0
					417.5	71.7	345.7

Figure 6. *Crop water and irrigation requirement of Wheat (The Back Field).*

4. Irrigation Systems

Any irrigation system is a composite of canals, laterals, structures, and equipment involved in the transport of water from where it is available to where it is required. There are two basic types of irrigation systems namely open canal systems and pressurised piped systems. Experience gained from many countries in arid and semi-arid zones has shown that pressure piped irrigation techniques are replacing successfully the traditional open canal surface methods at farm level (Phocaides, 2000). The pressurised irrigation system, specifically sprinkler irrigation, has been adopted in this research for irrigating the selected fields in the study areas to increase the irrigation efficiency. In sprinkler irrigation, water is applied from the sprinkler nozzle, which produces a jet breaking up in thousands of drops of different diameters. The procedure for designing sprinkler systems can be divided into two phases; preliminary design steps and the final design adjustment process and adjustment or final design steps (Savva and Frenken, 2001).

5. Preliminary Sprinkler Irrigation Design Steps

The preliminary design factors that are needed to be established are; depth of water application per irrigation, irrigation frequency, duration of irrigation per set and required system capacity (discharge).

5.1. Net Depth of Water Application

The depth of water application is the quantity of water, which should be applied during irrigation in order to replenish the water used by the crop during evapotranspiration.

$$dnet=(FC-PWP)*RZD*P \quad (1)$$

Where dnet represent the readily available moisture or net depth of water application per irrigation for the selected crop (mm), FC is the soil moisture at field capacity (mm/m), PWP is the soil moisture at the permanent wilting point (mm/m), RZD represent the depth of soil that the roots exploit effectively (m) and P is the allowable portion of available moisture permitted for depletion by the crop before the next irrigation. The maximum computed dnet values for crops by CROPWAT model for both fields was 47.9 mm for sugar beet which take place in July in the back field, and 54.8 mm for maize which take place in September in the front field.

5.2. Selected Fields Areas

i. For the Back Field

- Two farms were selected; farm A and farm B, The area of each selected farms is 51 donums (12.75 ha) with 510 $*$ 250 meter dimensions, each of the selected farms is supplied with water from 10 wells as shown in Figure 7.
- For farm A, barely as a winter crop and sugar beet as a summer crop is adopted to be cultivated while wheat as a winter crop and maize as a summer crop is adopted in the farm B.

ii. For the Front Field

- The area of the front field (farm C) is 33 donums (8.25 ha) with 330 $*$ 250 meter dimensions, divided into two farms C1 and C2 with 16 donums for each one of these farms, and supplied with water from 4 wells as shown in Figure 7.
- Barley in farm C1 and wheat in farm C1 adopted to be cultivated as a winter crop and maize is suggested to be cultivated in both farms C1 and C2 as summer crop.

5.3. Irrigation Frequency at Peak Demand

The peak daily water use is the peak daily water requirement (Etc) of the crop determined by subtracting the rainfall from the peak daily crop water requirements.

$$\text{Irrigationfrequency (IF)}=dnet/ETC \quad (2)$$

Where IF represent the irrigation frequency (days), dnet is the net depth of water application (mm) and ETC is the peak daily water use (mm/day).

The maximum ETc for sugar beet in the back field is 11.97 mm/day, while the maximum ETc for maize in the front field is 11.30 mm/day and both occur throughout summer season.

By applying Equation (2) the results are as follows:

i. For the Back Field

The irrigation frequency is equal to (47.9/11.97) = 4.001 days (≈4 days) for sugarbeet.

ii. For the Front Field

The irrigation frequency is equal to (54.8/11.30) = 4.84 days (≈ 5 days) for maize.

5.4. Gross Depth of Water Application

The gross depth of water application (dgross) equals the net depth of irrigation divided by the farm irrigation efficiency (E). According to FAO, (1992) farm irrigation efficiencies for sprinkler irrigation in hot climate regions like middle and south of Iraq climates are 70%.

$$dgross = dnet / E \quad (3)$$

Therefore, the gross depth of irrigation will be (47.88/0.7) = 68.4 mm (≈ 69 mm) for the back field and (56.5/0.7) = 80.71 mm (≈ 81 mm) for the front field.

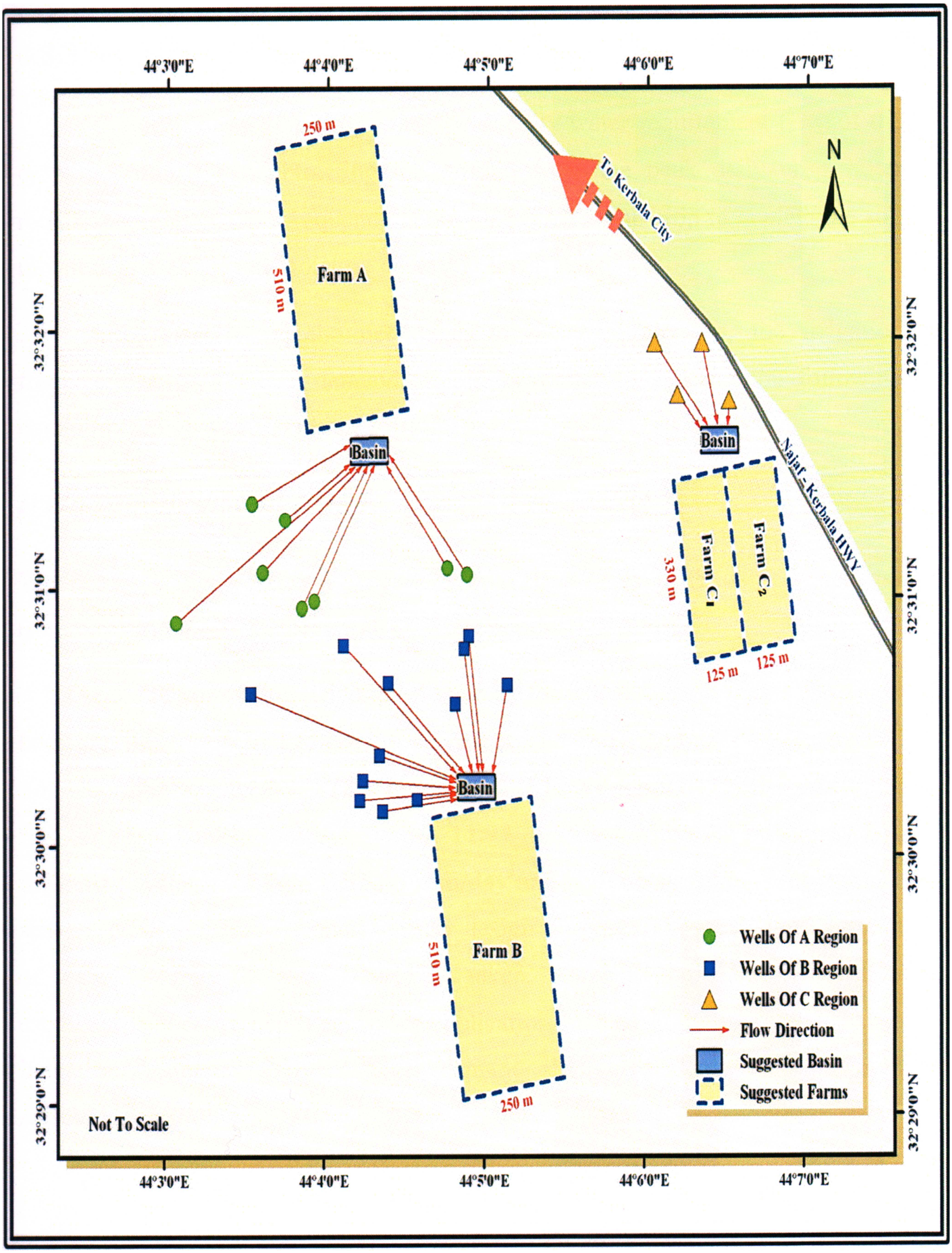

Figure 7. Location of the farms in the study area.

6. Final Sprinkler Irrigation System Design Steps

The final sprinkler irrigation design steps are the selection of the sprinklers characteristics and spacing. According to Savva and Frenken (2001), the following procedures may be followed to reconcile the preliminary design parameters:

6.1. Sprinkler Selection and Spacing

The selected sprinkler should fully satisfy the irrigation water requirements and the irrigation frequency. Referring to the SPAW model results that depended on the soil characteristics of the back and front zones, it can be noted that the soil basic infiltration rate is 69.41 mm/hr for the back field, while the soil basic infiltration rate is 72.09 mm/hr for the front field. It should be pointed out that in order to avoid runoff; the sprinkler application rate should not exceed the basic soil infiltration rate. Manufacturers' Tables can be used to select the sprinklers and their spacing.

In order to avoid the runoff, the sprinkler application for the both study areas should be less than 69.41 mm/hr and 72.09 mm/hr which is compatible with the soil and crop.

There are several nozzle sizes, pressure and sprinkler spacing combinations, but another aspect to be consider in selecting a sprinkler is the uniformity of application. In addition, it should be noted that the lower pressures are preferable as long as the uniformity of application is not compromised. The Coefficient of Uniformity (CU) is a measure of the uniformity of water application. As a rule, the selected sprinkler should have a CU of 85% or more. Where locally manufactured sprinklers are not tested for CU determination, it is advisable to avoid using the lowest pressure since usually this is the pressure that corresponds to low CU values (Savva and Frenken, 2001). So, for achieving the required CU values, the mean wind velocity of the windiest months of the year should be considered and compared with the wind speed values in Table 11 to select the appropriate sprinkler spacing.

Table 11. *Maximum sprinkler spacing as related to wind velocity, rectangular pattern, (Savva and Frenken, 2001).*

Average Wind Speed (km/hr)	Spacing as Percent of Wetted Diameter (D)
Up to 10	40% between sprinklers, 65% between laterals
10 - 15	40% between sprinkler, 60% between laterals
above 15	30% between sprinklers, 50% between laterals

Refering to meteorological characteristics of the study areas, the maximum mean wind speed is about 10.7 km/hr (≈ 11 km/hr) and takes place in June. Therefore, the sprinkler spacing should be based on 60% of D x 40% of D for rectangular pattern. It should be noted that in the rectangular pattern, better distribution is obtained when the lateral is placed across the prevailing wind direction. The next step is to determine whether the possible spacing's above satisfying the wind requirements. According to Table 10, as well as the conditions in Table 11, the 12x15 sprinkler spacing satisfies the wind speed as well as suits the nature of the soil in which the prevailing type of high infiltration rate in both study areas. The wetted diameter of the 5.0 mm nozzle size at pressure of 350 kPa is 34.30 m, and from Table 11, for a wind speed of 11 km/hr, 40% of D and 60% of D for the 12 x 15 meter spacing are 13.72 m (> than 12 m sprinkler spacing) and 20.58 m (> than 15 m lateral spacing) respectively.

6.2. Sprinkler System Layout

The system layout is obtained by matching the potentially acceptable spacing with the dimensions of the field such that as little land as possible is left out of the irrigated area.

6.3. Sprinkler System Type Specification

Sprinkler system type should be specified depending on the field dimensions and the set time (Ts), which is the time each set of sprinklers should operate at the same position in order to deliver the gross irrigation depth.

$$Ts = d_{gross} / Pr \quad (4)$$

Where; Ts is set time (hr) and Pr is the sprinkler precipitation rate (mm/hr). Since the sprinkler precipitation rate is 10.22 mm/hr, and by substituting gross depth values in equation (4), the set time for the back and the front fields respectively will be:

$$Ts = \frac{68.4}{10.22} = 6.7 \text{ hr } (\approx 7\text{hr})$$

$$Ts = \frac{80.71}{10.22} = 7.8\text{hr } (\approx 8\text{hr})$$

6.4. Operation Management of the Sprinkler System

In this study, sprinkler networks are designed as follow:

6.4.1. For the Back Field

- Farm with dimension of 510 ∗ 250 meter with separate pump plant accordance with semi-permanent sprinkler system is considered and simulated for farm A and it can also used it for farm B (Figure 8).
- 34 lateral positions (510/15 space between laterals) to cover the total area.
- A little land as possible is left out of the irrigated area for roads around the farm; 32 lateral positions can be enough to cover the total area.
- A more favorable arrangement from the operational point of view can be attained by locating the main line in the middle of the farm; such a layout will permit the rotation of the laterals around the mainline and the completion of irrigation will be in 4 days and one shifts per day using 16 laterals (64 positions / 4 days).
- Number of sprinklers are 21 (250/12 space between

sprinklers).

- Laterals will operate with one shift per lateral per day, 8 laterals with 11 sprinklers (with the sprinkler in the mainline) and another 8 laterals with 10 sprinklers (without the sprinkler in the mainline).
- The discharge of nozzle is 1.84m^3/hr, so the discharge of each lateral is 20.24m^3/hr ($11 * 1.84$) and 18.4m^3/hr ($10 * 1.84$) respectively operating at the same time in order to complete the irrigation cycle.

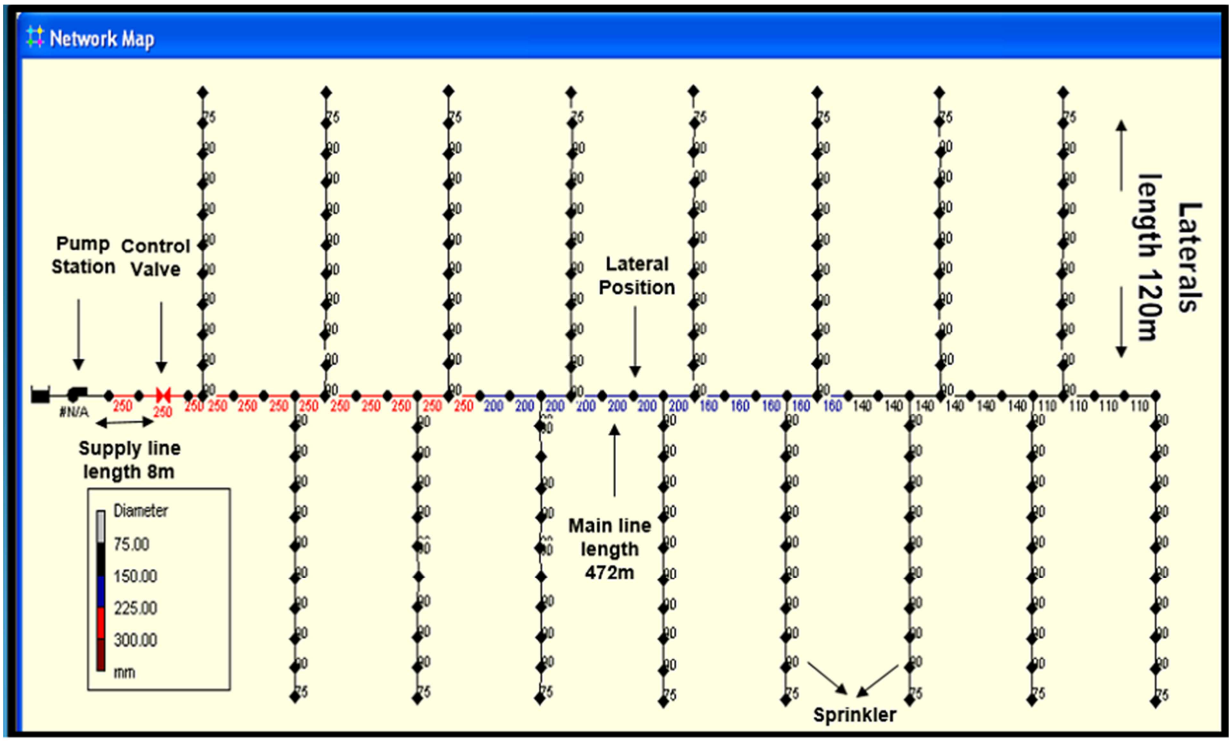

Figure 8. *Simulated sprinkler system pipes diameter for the back field (farm A and/or farm B).*

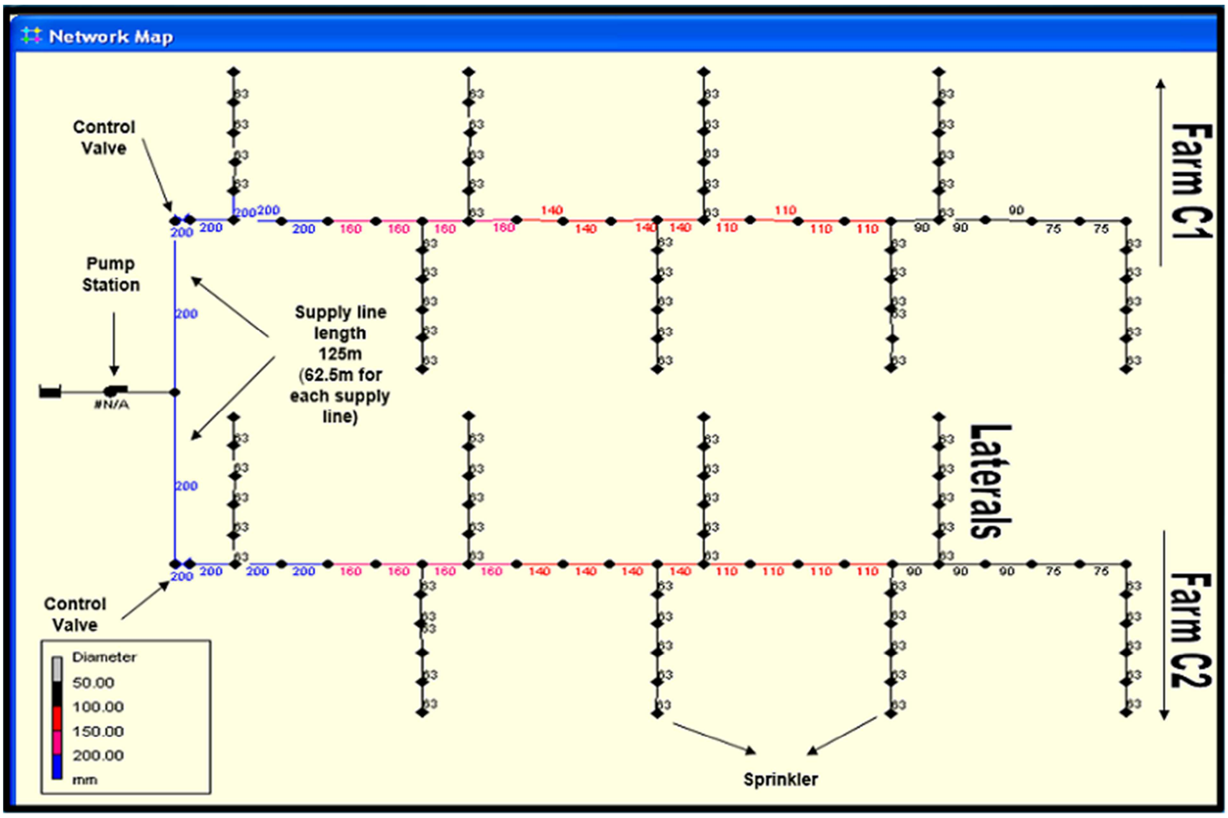

Figure 9. *Simulated sprinkler system pipes diameter for the front field (unify pump for farm C1 and farm C2).*

6.4.2. For the Front Field

- Farm with dimension of 330 ∗ 250 meter is considered and simulated for farm C (Figure 9).

For better operation and management of the study area sprinkler system, farm C with 330 ∗ 250 meter will be divided into two farms, C1 and C2, each farm with dimensions 330 ∗ 125 meter with separate pump plant and then the choice of connecting the two farms network with a unify pump station is considered and simulated.

- 22 lateral positions (330/15 space between laterals) to cover the total area.
- A little land as possible is left out of the irrigated area for roads around the farm; 20 lateral positions can be enough to cover the total area.
- A more favorable arrangement from the operational point of view can be attained by locating the main line in the middle of the farm; such a layout will permit the rotation of the laterals around the mainline and the completion of irrigation will be in 5 days and one shifts per day using 8 laterals (40 positions / 5 days).
- Number of sprinklers are 11 (125/12 space between sprinklers).
- Laterals will operate with one shift per lateral per day, 4 laterals with 6 sprinklers (with the sprinkler in the mainline) and another 4 laterals with 5 sprinklers (without the sprinkler in the mainline).
- The discharge of nozzle is 1.84m^3/hr, so the discharge of each lateral is 11.04m^3/hr (6 ∗1.84) and 9.2m^3/hr (5 ∗ 1.84) respectively operating at the same time in order to complete the irrigation cycle.

The capacity of such a system can be calculated using equation:

$$Q = Nc * Ns * Qs \quad (5)$$

Where; Q is the system capacity (m3/hr), and Nc represent the number of laterals operating per shift while Ns is the number of sprinklers per lateral and Qs is the sprinkler discharge (1.84 m^3/hr from Table 10). Therefore, by applying equation (5), the farm system capacity will be:

i. For the Back field

The capacity of farm A or farm B is 309.12m^3/hr (≈ 310 m^3/hr) as a primary design ((8 laterals ∗ 11 sprinklers ∗ 1.84 m^3/hr discharge of sprinkler) + (8 laterals ∗ 10 sprinklers ∗ 1.84 m^3/hr discharge of sprinkler)) for 4 day irrigation cycle and laterals will operate with one shift per lateral per day.

ii. For the Front field

The capacity of each one of farm C1 and C2 is 80.96m^3/hr (≈ 81 m^3/hr) as a primary design ((4 laterals ∗ 6 sprinklers ∗ 1.84 m^3/hr discharge of sprinkler) + (4 laterals ∗5 sprinklers ∗ 1.84 m^3/hr discharge of sprinkler)) for 5 day irrigation cycle and laterals will operate with one shift per lateral per day. If the two farms (C1 and C2) will use a unified pump station, then the total field system capacity will be 162m^3/hr (81m^3/h ∗ 2) for 5 day irrigation cycle.

6.5. Operation Management of the Wells

6.5.1. For the Back Field

- Two rectangular basins with 3000 m^3 are suggested to be constructed in the back field; one for farm A and another for farm B as presented in Figure 7.
- 10 wells (WB5, WB9, WB10, WB11, WB14, WB15, WB16, WB17, WB18 and WB19) with total discharge of 273m^3/hr are pumping into the basin for farm A as shown in Figure 7. Each one of these wells should operate 8.5hr ((321m^3/hr resulting from the final design ∗ 7hr) / 273m^3/hr) in summer for the irrigation of sugar beet and 7 hr ((321m^3/hr ∗ 6hr) / 273m3/hr) in winter for the irrigation of barely.
- 10 wells (WB1, WB2, WB3, WB4, WB6, WB7, WB8, WB12, WB13 and WB20) with total discharge of 232m^3/hr pumping into the basin for farm B as presented in Figure 7. Each of 10 wells should operate 8.5 hr in summer for the irrigation of maize and 8.5 hr in winter for the irrigation of wheat ((321m^3/hr ∗ 6hr) / 232m^3/hr).

6.5.2. For the Front Field

- A rectangular basin with 1500 m^3 is suggested to be constructed in the front field for farms C1 and C2 (Figure 7).
- 4 wells (WF1, WF2, WF3 and WF4) with total discharge of 104.4m^3/hr pumping into the basin as shown in Figure 7. Each one of these wells should operate 12.5 hr ((164m^3/hr resulting from the final design ∗ 8hr) / 104.4m^3/hr) in summer for the irrigation of maize and 11 hr ((164m^3/hr ∗ 7hr) / 104.4m^3/hr) for the irrigation of wheat and 9.5 hr ((164m^3/hr ∗ 6hr) / 104.4m^3/hr) in winter for the irrigation of barley.

6.6. Allowable Pressure Variation

Pressure differences throughout the system or subunit should be maintained in such a range so that a high degree of uniformity of water application is achieved. Hence, the friction losses in the lateral should be kept to a minimum and for the practical purposes, the allowable pressure variation should not exceed 20% of the sprinkler operating pressure (Savva and Frenken, 2001). Thus, for both selected fields, the selected spacing (12 x 15 meter) and nozzle size of 5.0 mm operating at pressure of 350 kPa, and the allowable pressure variation in the system should not exceed 20% of the sprinkler operating pressure, which is 70 kPa (350 ∗ 0.2) or 7 meters.

6.7. Pipe Size Determination

One of aims of the design of the network is to find the optimal pipe size for each pipe in the network for a given layout and satisfying hydraulic constraints of the system. The constraints of the system are maximum allowable flow velocity in pipe stretches and minimum operating pressure of the sprinklers (Ansah, 2011). There are a number of different types of pipes. It should be considered what pipes are available in the market and their costs. Manufacturers provide friction loss coefficient, which can be used in sizing the pipes (Savva and Frenken, 2001). Using the correct size of pipe will help keeping low friction which will help to reduce pressure loss.

7. Final Simulated Sprinkler System Layout (Simulation Result)

A final design result including field layout configuration, pipes types and sizes and pumps, product type, topographical configuration of the area will be adopted and simulated using EPANET simulation model technique to evaluate the network performance and the conformity of results (head, velocity and irrigation demands) with the hydraulic conditions and irrigation water application requirements.

The final layout and network configuration for farm A and farm B in the back field is 51 donums with 510 ∗ 250 meter for each selected farms and 16.5 donums with 330 ∗ 125 meter dimensions; that represents a part of the total irrigation scheme (33 donums) for farm C in the front field. The system components include pipes (supply, mainlines and laterals), flow control valves and sprinklers as well as pump station. For farm C in the front field, a simulation will be done to a separate farm network then link the two farms C1 and C2 with unify pump station and simulate the total field system.). The system components include pipes (supply, mainlines and laterals), flow control valves and sprinklers as well as pump station.

EPANET simulation model resulted in layout characteristics which are considered the final adopted system design, including the number and size of pipes (network configuration), pump specifications, system capacity and the velocity in the pipes are briefly described below:

7.1. Sprinklers Distribution

Sprinklers of 5.0 mm nozzle size, 350 kPa pressures, 34.30 m wetted diameter with 1.84 m^3/hr sprinkler discharge and 10.22 mm/hr precipitation rates; with spacing 12x15 meter are selected for both fields. So, the number of sprinklers will be 168 sprinklers for farm A or farm B in the back field system and 44 sprinklers for each one of farm C1 and farm C2 in the front field system Figures (8 and 9). Nodes in the EPANET2.0 network represent a sprinkler and models as emitters with Equation (6) (Rossman, 2000):

$$\mathbf{Q = kp^n} \tag{6}$$

Where; Q is the discharge of each sprinkler (m^3/hr), k represents the sprinkler coefficient (0.311 according to Eq. (6)), P is the operating pressure of sprinkler (m) and n represents the sprinkler exponent (0.5 for sprinkler).

7.2. Laterals and Main Lines Distribution Characteristic's and Distribution

For the Back field:

Sixty four lateral positions for farm A and for farm B are distributed every 15 meter along the mainline, and 16 laterals are working at the same time to provide irrigation water with 4 days irrigation cycle. Laterals are divided into two classes; one with 11 sprinklers (with the sprinkler in the mainline) and the other with 10 sprinklers (without the sprinkler in the mainline) (Figure 8). Laterals are laid on the soil surface and connected to the mainline through hydrants and an UPVC pipes (Hazen & Williams factor, C=150) of 75 mm and 90 mm diameters are used with 6 meter length of each pipe segment, then the number of pipes segments in the system (per one farm) will be 320 pipe segments, 32 pipe of 75 mm and 288 pipe segment of 90 mm diameter.

For the Front field:

Forty lateral positions for each one of farm C1 and farm C2 are distributed every 15 meter along the mainline, and 8 laterals are working at the same time to provide irrigation water with 5 days irrigation cycle. Laterals are divided into two classes; one with 6 sprinklers (with the sprinkler in the mainline) and the other with 5 sprinklers (without the sprinkler in the mainline) (Figure 9). Laterals are laid on the soil surface and connected to the mainline through hydrants and an UPVC pipes (Hazen & Williams factor, C=150) of 63 mm diameters are used with 6 meter length of each pipe segment, then the number of pipes segments in the system (per one farm) will be 480 pipe segments of 63 mm diameter.

The mainline length is 472 meter for farm A or farm B in the back field as shown in Figure 8 while the length of the mainline for each one of farm C1 and farm C2 in the front field is 292 meter as shown in Figure 9. Unplasticized polyvinyl chloride (UPVC) suggested to be used.

8. Pressure and Velocity Simulation Results of the System

The pressure in the system should not be below the sprinkler operating pressure of 35m and the allowable pressure variation between the lowest point and the highest point is within 20%, the variation then should not exceed 7m. The minimum pressure are 35.43m and 35.05 m for the back field and front field respectively occurring at the furthest node on the system, whilst the maximum reference pressure is 40.28m for the back field and 36.66m for the front field, so the pressure variation is 4.85 m and 1.61m for the back and front fields respectively, which is within the limit and the minimum pressure requirement satisfies the constraint sprinkler operating pressure. It should be concentrated here that the simulation results in case of adopting a unify pump station network option for the front field to supply the whole field does not much differ from the separate pump station. Where; minimum pressure in the furthest node is 35.35 m, while in the reference node is 36.97 m.

Velocity limits are the most important constraint in pressurized network design, the lowest velocity led to less head loss per unit length of pipe while the high velocities tend to increase the unit head losses in the pipe stretches.

9. Energy Usage Simulation Results of the System

To finalize the design and simulation process determining the pump characteristics is required including discharge and corresponding head to calculate some parameters values such as velocity and pressure which they are determine the pump characteristics. EPANET2.0 model can generate pump curve to describe the relationship between the head delivered by the pump and the flow through the pump. So, from the simulation result the required pump characteristics are 45 m head and 315 m^3/hr discharges to supply the back field system, while the required pump characteristics are 41 m head and 81 m^3/hr discharges to supply the front field system.

10. Conclusions

1. The nature of the soil and the depth of groundwater appeared to be suitable for agricultural purposes.
2. The boundary conditions of Dibdiba aquifer are semi-closed basin which allow the aquifer to keep the input water to it. The direction of flow is from the southwest to the northeast and east; (towards the study area); which led to increase the saturated thickness in the study area.
3. the range of electrical conductivity values are 3420 to 7090 µs/cm, therefore groundwater should be used only with selection of a plant with high bearing to high proportion of salt content and sodium content (SSP) of groundwater samples in the study area is classified as good to permissible class (52.8% for the front field and 48.8% for the back field), while water samples analysis of the study area indicates that the water has low sodium absorption ratio (SAR) (6.1 for the front field and 3.7 for back field).
4. The final designed semi-permanent sprinkler system capacity in this research is 321m^3/hr to irrigate area of 51 donum, within 4 days of 7 hours per day for each lateral in the back field, while the capacity of the system in the front field is 164m^3/hr to irrigate area of 33 donum, within 5 days of 8 hours per day for each lateral. Thus, the application of sprinkler irrigation will assist in increasing the region of cultivation by about 2.5 times.
5. Results from simulation showed that the operation time of wells has been reduced about 40% from 14hrs to 8hrs. Also, crop yield produced by donum for each crop will be increased at least 50%.

Abbreviations

EC = electrical conductivity
GW =ground water
EPANET2.0 = simulation model
CROPWAT = Program Model
ETcrop = Evapotranspiration of the crop
dnet = The readily available moisture or net depth of water application per irrigation
FC = is the soil moisture at field capacity (mm/m)
PWP = is the soil moisture at the permanent wilting point (mm/m)
RZD = is the depth of soil that the roots exploit effectively (m)
P = is the allowable portion
IF = is the irrigation frequency (days)
dnet = is the net depth of water application (mm)
ETC = is the peak daily water use (mm/day).
dgross = is the gross depth of water application
E = irrigation efficiency
Ts = is set time (hr)
Pr =is the sprinkler precipitation rate (mm/hr)
Q = is the system capacity (m3/hr)
Nc =represent the number of laterals operating per shift
Ns = is the number of sprinklers per lateral
Qs = is the sprinkler discharge
k = represents the sprinkler coefficient
p^n = is the operating pressure of sprinkler (m) to the sprinkler exponent (n)

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