

Optimum Design of Storing Water and Predicting Storage Unit Cost in Al-Baha, Kingdom of Saudi Arabia

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Abstract This paper aims to achieve optimum design of storing water through dams, and also to predict the storage unit cost through dams. The storage unit cost means the cost for storing 1 m³ of water. For these objectives, data are collected for forty dams that were constructed in Al-Baha, Saudi Arabia, for storing water from 1975 till 2012. For the optimum design of storing water according to the required capacity, it is concluded that considering the type of the required dam gives more accurate results. For earth fill dams, the water capacity does not matter. While for concrete dams, the water capacity of 4 million m³ is significant. An equation is obtained to get the optimum design of storing water through earth fill dams. Two equations are obtained to get the optimum design of storing water less than and more than 4 million m³ through concrete dams. Concerning the storage unit cost of water through dams, it is concluded that introducing the type of the required dam gives only slightly more accurate results. An equation is obtained to predict the storage unit cost of water through dams regardless the type of the dam. Also, two equations are obtained to predict the storage unit cost of water through earth fill dams. Finally, an equation is obtained to predict the storage unit cost of water through concrete dams.

Keywords Optimization, Water Resources, Unit Water Storage, Dams, Regression

1. Introduction

Storing water for later use is essential for Kingdom of Saudi Arabia, KSA, as there are no natural surface water resources. KSA, west of Asia, is classified among arid regions. It has neither rivers nor lakes. The main water resources in KSA are ground water and rain water falling only in some provinces.

Rain ranges between 110 mm/year and 300 mm/year on the western south provinces. The flowing rain water is estimated, in the year 1998, to be approximately 5,000 million m³/year, 60% of them occur on the western south provinces. A small part of this water feeds the ground water reservoirs, while the other part flows to the red sea, west of KSA.

Water resources in KSA in the year 2014 are 16,307 million m³, [1]. These various resources are summarized as percentage ratios of the total amount and are shown in figure 1. It is a good trend to treat water collected after being used for both municipal and industrial purposes, the sewage water, and agricultural purposes, the drainage water. Also, it can be noted that the treated sewage water is much more than the treated drainage water. That is due to the limited surface irrigation systems and the nature of sandy soil.

Depending on the non-renewable ground water, confined ground water with no recharge, as a main resource of water is a critical situation.

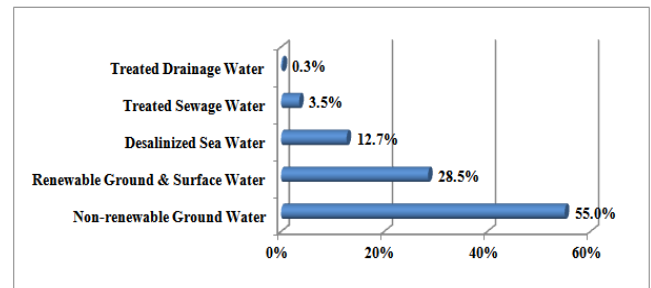


Figure 1. Water Resources in KSA

Uses of water in KSA are set to be equal to the available water resources, [1]. These different uses are summarized as percentage ratios of the total amount and are represented in figure 2.

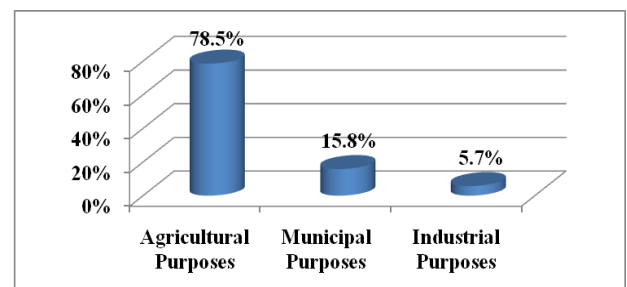


Figure 2. Uses of Water in KSA

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Dams as a tool for storing water are widely constructed in different provinces of KSA for irrigation purposes, recharge wells downstream the dams, potable water supply, and protection against dangerous floods. The types of dams in KSA are concrete, earth fill or rock fill and underground dams.

The total amount of stored water in KSA is 1,354 million m^3 through 302 dams in the year 2009 in all provinces, [1].

It is planned to increase the stored water to be 2,500 million m^3 in the year 2014, [1].

2. Storing Water in Al-Baha

Al-Baha is a province located on the western south of KSA. It contains six governorates in addition to Al-Baha city. It has the smallest area among the provinces of KSA with a total population of about 430,000 capita.

Water budget for Al-Baha province is 143 million m^3 in the year 2014, [1]. These amounts of water represent only 0.88 % of the total water budget of KSA. Figure 3 illustrates uses of water in Al-Baha province as percentage ratios of the total amount for the year 2014.

Comparing figures 2 and 3, it can be noted that the quantity of water used for agricultural purposes in Al-Baha province is less than that used in KSA. This may be due to the mountain nature of Al-Baha.

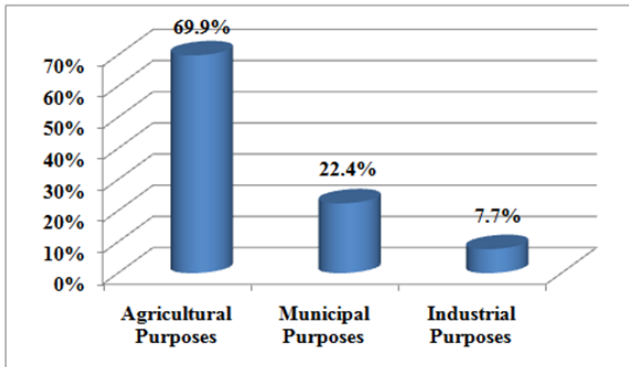


Figure 3. Uses of Water in Al-Baha Province

This paper aims to achieve the optimum design of storing water according to the required capacity, and also to predict the unit cost for storing water through dams. The unit cost means the cost for storing 1 m^3 of water.

For these objectives, storing water through dams in Al-Baha province is reviewed during about 37 years, specifically from 1975 till 2012. Data are collected for forty dams that were constructed in Al-Baha province during this period, [2] & [3]. The data are tabulated ascending according to the water capacity, as shown in table 1, appendix A.

The purposes of the forty dams are illustrated as percentage ratios in figure 4. The recharge dams are used for storing water to recharge the ground water, the potable dams are used for water supply purposes, the control dams are used for directing water to the desired directions, and the irrigation dams are used for agricultural purposes.

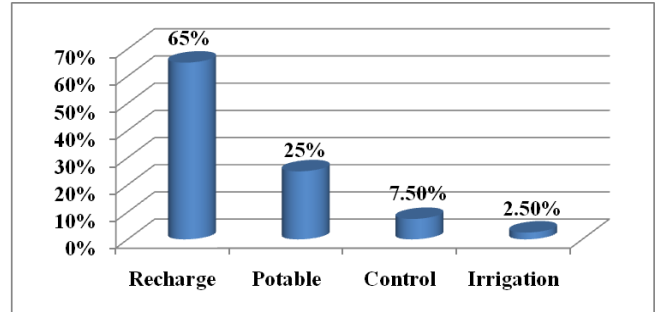


Figure 4. Purposes of Dams in Al-Baha Province

The types of the forty dams are illustrated as percentage ratios in figure 5. The earthfill dams depend mainly on rocks, while the concrete dams depend mainly on plain and reinforced concrete.

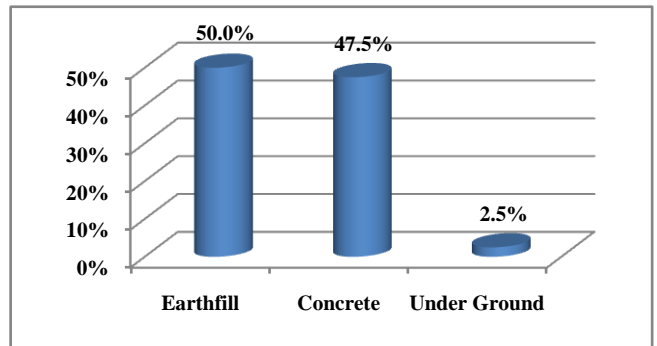


Figure 5. Types of Dams in Al-Baha Province

3. Analyses of the Data

It is obvious from the collected data that the costs of dams are of different years. To analyze these data, a datum year is fixed for all costs. That is the current year. The present values for these costs in the current year, 2014, are definitely different. That is to say that if these dams are to be constructed this year, their costs will be different. That is correct due to the inflation rates that lead to decreasing the value of money along the years. That refers to a general rise in prices measured against a standard level of purchasing power.

Introducing the inflation rates, the costs in 2014 are calculated using the simple equation:

$$C_{2014} = IC (1 + i)^n \quad (1)$$

Where, C_{2014} : the cost in the current year, 2014.

IC : the cost in the year of constructing the dam.

i : the inflation rate.

n : number of years from construction till the year 2014.

The inflation rate (i) is considered to be 1.25%, [4], as an average for the studied years. The data of C_{2014} for these dams are shown also in table 1, appendix A.

It has to be mentioned that the costs of dams are collected in Saudi Riyal which is the currency of KSA. One American dollar is equal to 3.75 Saudi Riyal, [5].

To achieve the first objective of this paper concerning the optimum design of storing water according to the required capacity, the cost C 2014 is plotted versus the water capacity for all dams. Then regression analyses are done employing micro soft excel software. Equations are obtained to get the optimum design of storing water.

To achieve the second objective of this paper concerning the storage unit cost of water through dams, the costs C 2014 are divided by the corresponding water capacities to get the costs for storing 1 m³ of water. The data of the storage unit cost of water for all dams are shown also in table 1, appendix A. Similarly, the storage unit cost is plotted versus the water capacity for all dams. Then regression analyses are done employing micro soft excel software. Equations are obtained to predict the storage unit cost of water through dams.

It has to be referred that there are many regression analyses through micro soft excel software. In this paper, the chosen type of regression is that associated with the highest value of correlation factor R², as possible.

4. Optimum Design of Storing Water

It was found that the type of the dam has no effect on the cost for the dams with storage capacities less than or equal 500,000 m³, [6]. Also, the type of the dam has to be taken into consideration for the values more than 4 million m³ to get the optimum water storage, [7].

However, in this study, the data of 40 dams for storing water are reviewed. It is noticed that there are five dams with the same capacity of 100,000 m³. Also there are three dams with the same capacity of 200,000 m³. Taking the average cost associated with these two values of water capacity, the number of dams is reduced to be 34 dams.

Figure 6 illustrates the cost C 2014 versus the water capacity for all 34 dams. Then regression analyses are done employing micro soft excel software, as shown also in figure 6. It is obvious that the exponential regression with R² of 73.7% is better than the linear regression with R² of 68.6%.

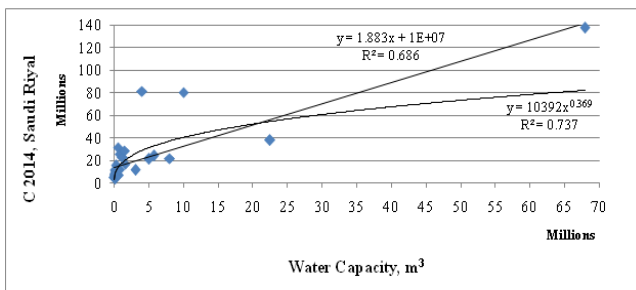


Figure 6. Cost C 2014 versus Water Capacity for all 34 Dams

However, the obtained equation to get the optimum design of storing water is:

$$C = 10,392 WC^{0.369} \quad (2)$$

Where: C : The optimum cost, Saudi riyal.

WC : Water capacity, m³.

Although the value of obtained correlation factor R² is not high, this equation may be used to get the optimum design of storing water.

To reach better results, the types of dams for storing water are introduced into consideration. The gathered data contain 20 earth fill dams, 19 concrete dams, and only 1 underground dam.

The underground dam will be disregarded as it is only one dam, and both the earth fill dams and the concrete dams are going to be studied.

Concerning the 20 earth fill dams, it is found that there are two dams with the same capacity of 200,000 m³. Taking the average cost associated with this value of water capacity, the number of dams is reduced to be 19 dams.

The cost C 2014 versus the water capacity for the earth fill dams is shown in figure 7 that includes also the trend line obtained from the linear regression analysis.

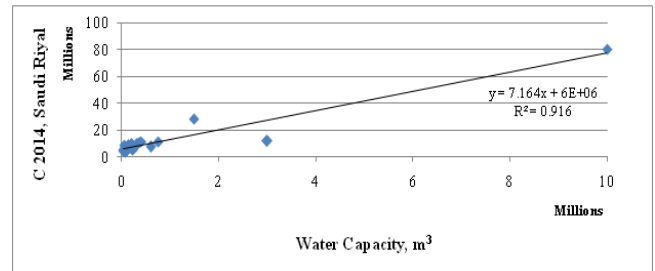


Figure 7. Optimum Design of Storing Water through Earth Fill Dams

The obtained equation to get the optimum design of storing water through earth fill dams is:

$$C = 7.164 WC + (6 \times 10^6) \quad (3)$$

Where: C : The optimum cost, Saudi riyal.

WC : Water capacity, m³.

This equation can be used effectively to get the optimum design of storing water through earth fill dams.

Concerning the 19 concrete dams, it is found that there are four dams with the same capacity of 100,000 m³. Taking the average cost associated with this value of water capacity, the number of dams is reduced to be 16 dams.

The cost C 2014 versus the water capacity for the concrete dams is shown in figure 8 that includes also the trend line obtained from the linear regression analysis.

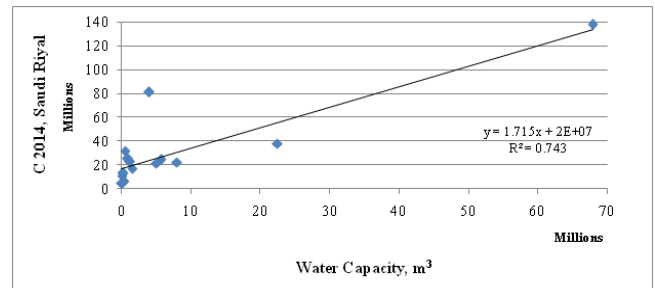


Figure 8. Cost C 2014 versus Water Capacity for the Concrete Dams

The obtained equation to get the optimum design of storing water through concrete dams is:

$$C = 1.715 WC + 20,000,000 \quad (4)$$

Where: C : The optimum cost, Saudi rial.

WC : Water capacity, m³.

Although the value of obtained correlation factor R² is not high, this equation may be used to get the optimum design of storing water through concrete dams.

From figure 8, it is obvious that the value of water capacity of 4 million m³ is significant with respect to the associated cost. The concrete dams are divided into two groups of dams. The first group includes the dams with water capacity less than 4 million m³. This group contains the first eleven dams. The second group includes the dams with water capacity more than 4 million m³. This group contains the other five dams.

For the two groups of concrete dams, the cost C 2014 is plotted versus the water capacity, as illustrated in figures 9 and 10 respectively. Each figure includes also the trend line obtained from the regression analysis employing micro soft excel software.

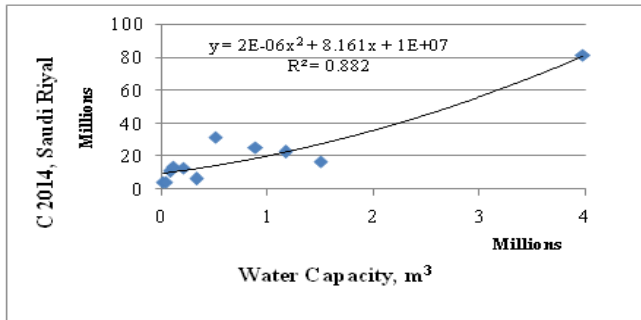


Figure 9. Optimum Design of Storing Water Less than 4 million m³ through Concrete Dams

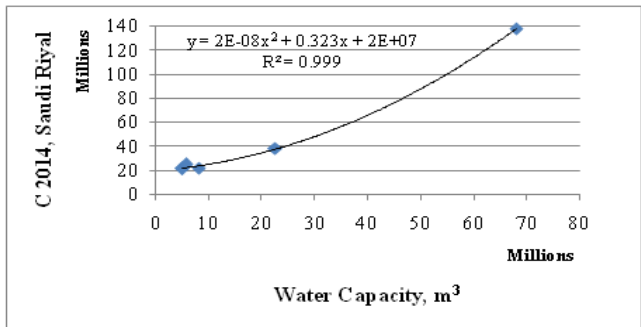


Figure 10. Optimum Design of Storing Water More than 4 million m³ through Concrete Dams

The obtained equation to get the optimum design of storing water less than 4 million m³ through concrete dams is:

$$C = (2 \times 10^{-6}) WC^2 + 8.161 WC + 10^7 \quad (5)$$

Where: C : The optimum cost, Saudi rial.

WC : Water capacity, m³.

This equation can be used effectively to get the optimum design of storing water less than 4 million m³ through concrete dams.

Similarly, the obtained equation to get the optimum design

of storing water more than 4 million m³ through concrete dams is:

$$C = (2 \times 10^{-8}) WC^2 + 0.323 WC + (2 \times 10^7) \quad (6)$$

Where: C : The optimum cost, Saudi rial.

WC : Water capacity, m³.

This equation can be used effectively to get the optimum design of storing water more than 4 million m³ through concrete dams.

5. The Storage Unit Cost

The second objective for this paper is to predict the storage unit cost of water through dams that means the cost for storing 1 m³ of water. Figure 11 illustrates the storage unit cost versus the water capacity for all 34 dams. Then regression analysis is done employing micro soft excel software, as shown also in figure 11.

However, the obtained equation to predict the storage unit cost of water through dams is:

$$Uc = 10,392 WC^{-0.63} \quad (7)$$

Where: Uc : The storage unit cost, Saudi rial.

WC : Water capacity, m³.

This equation can be used effectively to predict the storage unit cost of water through dams.

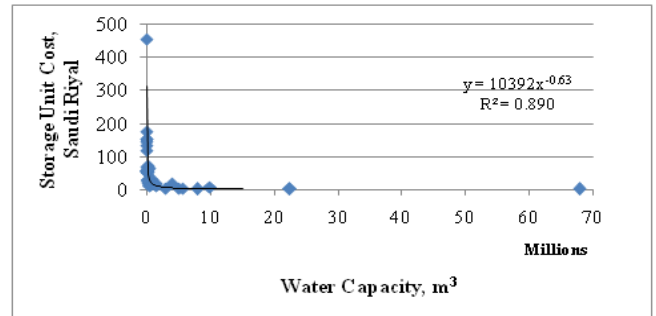


Figure 11. Storage Unit Cost versus Water Capacity for all 34 Dams

For more investigation, the types of dams for storing water are introduced into consideration.

The storage unit cost versus the water capacity for the earth fill dams is shown in figure 12 that includes also the trend line obtained from the regression analysis.

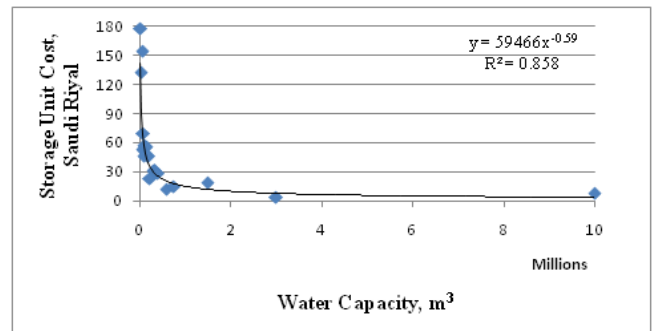


Figure 12. Storage Unit Cost versus Water Capacity for all Earth Fill Dams

The obtained equation to predict the storage unit cost of water through earth fill dams is:

$$Uc = 59,466 WC^{-0.59} \quad (8)$$

Where: Uc : The storage unit cost, Saudi riyal.

WC : Water capacity, m^3 .

This equation can be used to predict fairly the storage unit cost of water through earth fill dams.

There is a gap between the last two earth fill dams with respect to the water capacity. Excluding the last earth fill dam, the regression analysis becomes more precious as shown in figure 13.

The obtained equation to predict the storage unit cost of water through earth fill dams with water capacity up to 3 million m^3 is:

$$Uc = 20,372 WC^{-0.7} \quad (9)$$

Where: Uc : The storage unit cost, Saudi riyal.

WC : Water capacity, m^3 .

This equation can be used effectively to predict the storage unit cost of water through earth fill dams with water capacity up to 3 million m^3 .

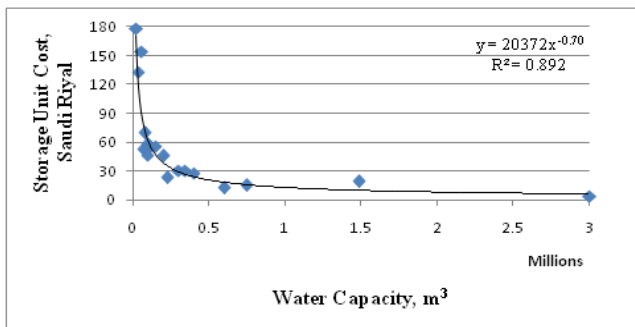


Figure 13. Storage Unit Cost of Water through Earth Fill Dams with Water Capacity Up to 3 million m^3

Similarly, the storage unit cost versus the water capacity for the concrete dams is shown in figure 14 that includes also the trend line obtained from the regression analysis.

The obtained equation to predict the storage unit cost of water through concrete dams is:

$$Uc = 23,319 WC^{-0.67} \quad (10)$$

Where: Uc : The storage unit cost, Saudi riyal.

WC : Water capacity, m^3 .

This equation can be used effectively to predict the storage unit cost of water through concrete dams.

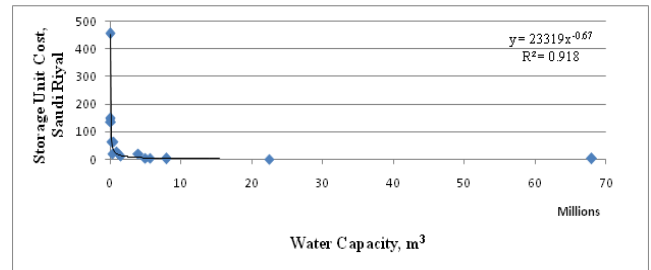


Figure 14. Storage Unit Cost of Water through Concrete Dams

6. Conclusions and Recommendations

For the optimum design of storing water according to the required capacity, it is concluded that considering the type of the required dam gives more accurate results. For earth fill dams, the water capacity does not matter. An equation is obtained to get the optimum design of storing water through earth fill dams. While for concrete dams, the water capacity of 4 million m^3 is significant. Two equations are obtained to get the optimum design of storing water less than and more than 4 million m^3 through concrete dams.

Concerning the storage unit cost of water through dams, it is concluded that introducing the type of the required dam gives only slightly more accurate results. An equation is obtained to predict the storage unit cost of water through dams regardless the type of the dam. Also, two equations are obtained to predict the storage unit cost of water through earth fill dams. The first equation concerns all values of water capacity. The second equation, with slightly more accuracy, is set for water capacities up to 3 million m^3 . Finally, an equation is obtained to predict the storage unit cost of water through concrete dams.

It is recommended to study the storage unit cost of water through earth fill dams with water capacity more than 3 million m^3 .

It is recommended also to apply the results of this paper to more cases of storing water through dams in other provinces of KSA.

Appendix A

Table 1. Data for Dams, Al-Baha Province

No	Name	Purpose	Type	Year	Cost, IC, Saudi Riyal	Water Capacity, m^3	Cost 2014, C 2014, Saudi Riyal	Storage Unit Cost, Saudi Riyal
1	Al-Habis	Control	Concrete	1983	3100000	10000	4556251	455.6
2	Matwa	Recharge	Earthfill	1983	2900000	24000	4262300	177.6
3	Dabdab	Control	Concrete	1983	3000000	30000	4409276	147.0
4	AlArishain	Recharge	Earthfill	1983	3351000	37000	4925161	133.1

Table 1. Data for Dams, Al-Baha Province (Cont.)

No	Name	Purpose	Type	Year	Cost, IC, Saudi Riyal	Water Capacity, m ³	Cost 2014, C 2014, Saudi Riyal	Storage Unit Cost, Saudi Riyal
5	Alratq	Recharge	Earthfill	2011	8620100	57975	8947411	154.3
6	Zagat	Recharge	Earthfill	1983	2500000	70000	3674396	52.5
7	Alsoror	Recharge	Concrete	2011	10541700	72300	10941976	151.3
8	Al-Kama'a	Recharge	Earthfill	1983	3800000	80000	5585082	69.8
9	Tharwah	Recharge	Earthfill	1983	3850000	98000	5658570	57.7
10	Al-Haijah	Recharge	Earthfill	1983	3150000	100000	4629739	46.3
11	Al-Mleh	Control	Concrete	1983	3900000	100000	5732058	57.3
12	Qoub	Recharge	Concrete	1983	10000000	100000	14697585	147.0
13	Ajlan	Recharge	Concrete	1983	11000000	100000	16167344	161.7
14	Shaba	Recharge	Concrete	1983	12000000	100000	17637102	176.4
15	Al-Morba'a	Recharge	Earthfill	1983	4500000	120000	6613913	55.1
16	Al-Karrar	Recharge	Earthfill	1983	5700000	150000	8377624	55.9
17	Al-Jahafin	Recharge	Earthfill	1997	4723100	200000	5833681	29.2
18	Al-Khalah	Recharge	Concrete	1975	8000000	200000	12986623	64.9
19	Al-Talkiah	Recharge	Earthfill	1981	8300000	200000	12505877	62.5
20	Maana	Potable	Under Ground	2011	14960000	216000	15528042	71.9
21	Al-Heliah	Recharge	Earthfill	1997	4318000	230000	5333327	23.2
22	Sabihah	Recharge	Earthfill	1983	6300000	300000	9259479	30.9
23	Al-Dhayan	Recharge	Concrete	1999	5233900	320000	6305955	19.7
24	Jarab	Recharge	Earthfill	2010	9986500	344100	10495266	30.5
25	Almathlmat	Recharge	Earthfill	1983	7650000	400000	11243653	28.1
26	Al-Ssadr	Irrigation	Concrete	1981	21000000	500000	31641375	63.3
27	Almesheref	Recharge	Earthfill	2009	6944460	600000	7389476	12.3
28	Al-Marzook	Recharge	Earthfill	1986	8000000	750000	11327938	15.1
29	Neera	Potable	Concrete	2011	24286307	884446	25208475	28.5
30	M'ashoqa- Darek-Alagaada	Recharge	Concrete	2010	21439400	1168917	22531637	19.3
31	Douqa	Potable	Earthfill	2010	26894900	1487240	28265070	19.0
32	Medhas	Recharge	Concrete	1986	12000000	1500000	16991908	11.3
33	Baidah	Recharge	Earthfill	1984	8000000	3000000	11612907	3.9
34	Olib	Potable	Concrete	2011	78095719	3972060	81061068	20.4
35	Aljanabeen	Potable	Concrete	2009	20000000	5000000	21281643	4.3
36	Wadi-Raneh	Potable	Concrete	2012	23626800	5660000	24221162	4.3
37	Tharad	Potable	Concrete	2008	20291600	8000000	21861829	2.7
38	Alahseba	Potable	Earthfill	2011	77171490	10000000	80101746	8.0
39	Al-Aqiq	Potable	Concrete	1987	27000000	22500000	37759795	1.7
40	Wadi Arda	Potable	Concrete	2012	134106178	68000000	137479787	2.0

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