We construct water demand model & water supply model for determining an effective, feasible, and cost-efficient Water Strategy 2025 for Saudi Arabia, since it’s a desert country died for water. These models can give accurate construction plans based on city to help the whole Saudi Arabia develop.

The water demand model can help us efficiently forecast the water demand in the future till 2025, which consist of three parts: industrial, domestic and agricultural water demands. Then we build three sub-models called IWD (Industrial Water Demand), DWD (Domestic Water Demand), and AWD (Agricultural Water Demand). In IWD, we use Binomial fitting to analyze Industrial Production firstly and then get the equation of industrial water demands. About DWD, we use population logistic model to estimate the population of the Kingdom of Saudi Arabia and then get the equation of domestic water demands. As for AWD, we found that it has been staying steady since 1990s due to an agriculture policy made by the kingdom government. So we take the AWD as a constant value. The kingdom’s Water Strategy 2025 will be based on this water demand model.

The water supply model use dynamic programming to figure out a feasible solution which meets the requirements of water that was calculated by the water demand model. It's easy to understand, practical and applicable. The implementation result from the model is credible and cost-efficient including construction of reservoirs, desalination plants and transfer water through aqueduct, and some other water conservation measures. In particular, we take the schedule of projects and efficiency into consideration. Our water study strategy most based on 6 major cities (include 50% population of the kingdom) in consideration of the characteristics of Saudi Arabia (urban districts are concentrated at oasis and surrounding by vast desert). This model can also be extended to other cities of Saudi Arabia. If we have plenty of historical data, we can achieve a more precise solution.

Finally, after roundly considering the implication on economic, geography, environment caused by the project, we formulated the national water strategy from 2013 to meet the water demand in 2025.
Problem Description

Water supply is a serious problem in many countries. The problem is to determine an effective, feasible, and cost-efficient water strategy for one of those five given countries. Before we build a mathematical model to achieve a solution, we should know the water demand of this country so that we can calculate what goal must the strategy finish.

After we get the water demand predict model, we need to find a way to combine four methods to meet the water demand of each year. Those four methods include storage, movement, desalination and conservation which can produce water or reduce the demand of water.

When we come up with a solution we may try to use our model to discuss the economic, physical, and environmental implications of our strategy.

In a word, the problem can be concluded as follow:

- Find a water demand model to predict the water demand for every year of the whole countries.
- Achieve an optimizing model to determine the water strategy for the country.
- Discuss the economic, physical, and environmental implications of the strategy.

Introduction

We chose Saudi Arabia from those five countries because of its well-known short of water. Once upon a time, the water is more expensive than the oil. Even nowadays, fresh water is an important limiting constraint for development in Saudi Arabia.

To determine an effective, feasible, and cost-efficient water strategy, we first build a mathematical model to predict the water demands in Saudi Arabia which we found is consist of domestic water demand, industrial water demand and agricultural water demand. Specifically, we found three points to help us to figure out the demand predict model:

The domestic water demand of that year in whole country is determined by the population size.

The industrial water demand is positively associated with the industrial production.

The agricultural water demand will be fixed in a long time which is determined by the government policy of Saudi Arabia.

In model 2, we establish a model of Water Supplying depending on Water Storage, Water Movement, De-salinization and Water Conservation to satisfy the Water Demands. As Saudi Arabia is a deserted country and the conditions of different country are much different (such as amount of precipitation), we can divide the kingdom into some pieces to analyze. One division method is that we can divide the kingdom with different province but desert occupies most of the provinces’ area and the cities is like some points distributing in oasis and cities is a good division for evaluating the supply model. So we determine to select the cities on the first 6 places of population to analyze.
Assumptions

- The kingdom is on a stable situation, there is no war between Saudi Arabia and the other countries, and no disasters will happen in Saudi Arabia.
- The population growth in Saudi Arabia meets the condition demand of the Population Logistic Model so that it can be predicted.
- The geographical conditions of Saudi Arabia are not going to change within 15 years.
- People in various regions of the country have the same annual water consumption.
- The unit costs of desalination in different regions are the same.
- Population movements do not affect the ratio of one city’s population to country’s total population.
- In the time which we concerned, through education can always get a fixed water conservation rate.
- This year’s water supply is equal to the water demand.

Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>Year</td>
</tr>
<tr>
<td>N(t)</td>
<td>Water demand in whole Saudi Arabia in year t</td>
</tr>
<tr>
<td>DW(t)</td>
<td>Domestic water demand in year t</td>
</tr>
<tr>
<td>IW(t)</td>
<td>Industrial water demand in year t</td>
</tr>
<tr>
<td>AW(t)</td>
<td>Agricultural water demand in year t</td>
</tr>
<tr>
<td>P(t)</td>
<td>Population in year t</td>
</tr>
<tr>
<td>AL(t)</td>
<td>Agricultural land area in year t</td>
</tr>
<tr>
<td>I(t)</td>
<td>Industrial production in year t</td>
</tr>
<tr>
<td>y</td>
<td>Year y since 2013</td>
</tr>
<tr>
<td>a</td>
<td>water efficient use factor</td>
</tr>
<tr>
<td>b</td>
<td>the water use rate except groundwater</td>
</tr>
<tr>
<td>AN[y]</td>
<td>One city’s water demand in year y subtract 2013</td>
</tr>
<tr>
<td>DamLim</td>
<td>The limit quantity of one city’s dams</td>
</tr>
<tr>
<td>DamNow</td>
<td>The quantity of one city’s dams nowadays</td>
</tr>
<tr>
<td>DamBL</td>
<td>The ascension space of the quantity of one city’s dams</td>
</tr>
<tr>
<td>DamCost</td>
<td>The construction cost for a dam</td>
</tr>
<tr>
<td>DamSup</td>
<td>The water supply a dam can achieve in a year</td>
</tr>
<tr>
<td>DesCost</td>
<td>The construction cost for a desalination plant</td>
</tr>
<tr>
<td>Pip</td>
<td>The unit costs of pipeline</td>
</tr>
<tr>
<td>PipCost</td>
<td>The cost of building a desalination plant along the coast for city i in year t</td>
</tr>
<tr>
<td>DPCost</td>
<td>The construction cost for a desalination plant(include the maintenance cost)</td>
</tr>
<tr>
<td>DesSup</td>
<td>The water supply a desalination plant can achieve in a year</td>
</tr>
<tr>
<td>I</td>
<td>The number of dam constructions</td>
</tr>
<tr>
<td>j</td>
<td>The number of desalination constructions</td>
</tr>
<tr>
<td>F[y]</td>
<td>The whole investment from this year to year y</td>
</tr>
</tbody>
</table>
1. Water Demands Model

The Water demands consist of Industrial Water Demands, Domestic Water Demands and Agriculture Water Demands. So we determine to figure out water demands from three aspects.

1.1 Analysis of Industrial Water Demands

It is difficult for us to analyze the industrial water demands directly and we think the industrial productions are related to Industrial water demands. So we analyze the industrial productions firstly and then analyze the water demands of industry.

1.1.1 Industrial Productions

The industrial productions of Saudi Arabia are highly developed during the last few years. We get some data from Industrial Development in Saudi Arabia[1] as following:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Productions (SR Billion)</td>
<td>8.7</td>
<td>12.7</td>
<td>22.7</td>
<td>23.2</td>
<td>32.9</td>
<td>47.1</td>
<td>64.6</td>
<td>87.8</td>
</tr>
</tbody>
</table>

It is obviously seen that the development of Industrial Productions is influenced by many factors, such as industrial structure, technology, demand, factory management and government’s policy.

Government Policy

During the recently years, Saudi Arabia has always been regarded as an economy relying solely on crude oil exports. A closer look at its activities proves that this is absolutely not the case. Government’s policy is the most important factor. The government is making more effort to change sectorial composition of the Saudi manufacturing industries. It will result in accumulative effect. Its contribution to the growth rate of the Industrial Productions ($\Delta I$) is at.

Other Factors

It is obviously that the better of factory management and the development of technology and factors contribute the liner growth of Industrial Productions. It’s to say that the influence of other factors to $\Delta I$ is b.

Forecast the development of Industrial Productions

From the analysis above, we get

$$\Delta I = (at + b)\Delta t$$

As the change is continuous, we assume

$$\frac{dl}{dt} = at + b$$

We get

$$l = ct^2 + dt + e$$

By fitting of the polynomial, we figure out

$$\begin{cases}
  c = 0.0626 \\
  d = -0.6832 \\
  e = 12.9304
\end{cases}$$
Where \( x = t - 1970 \)

\[
I(x) = 0.0626x^2 - 0.6832x + 12.9304
\]  
(1)

The coefficient of determination

\[ R = 0.9948 \]

The \( R = 0.9948 \) is very closely to the 1, so the fitting is acceptable.

The fitting result is shown below in Figure 1.1.

1.1.2 Industrial Water Demands

1) Evaluating the correlation coefficient between Industrial Productions and Industrial Water Demands

We get data from Future Of Saudi Arabian Water Aquifers[2] in Table 1.2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Demands(MCM)</td>
<td>20</td>
<td>56</td>
<td>190</td>
<td>290</td>
<td>450</td>
<td>480</td>
</tr>
</tbody>
</table>

For Equation 1, we let \( x = [1970 1980 1990 2000 2003 2010] - 1970 \), then \( I(x) = [12.9304 12.3577 24.3042 48.7696 58.5505 85.7542] \) and we assume the result matrix as \( X \). Also we assume the Water Demands in Table 1.2 as \( Y \).

Then we can figure out the correlation coefficient between \( X \) and \( Y \) is 0.9572.

\( R = 0.9572 \) is closely to 1, so we can think they are related to each other.

The figures of Equation 1 and above fitting polynomial Equation are in the same drawing board as shown in Figure 1.2.1
It is vividly shown in Figure 1.2, Industrial Productions and Industrial Water Demands are highly related to each other. So we can get the Equation of Industrial Water Demands IW (t) from the Industrial Productions Equation 1.1.

2) Figure out the Equation of Industrial Water Demands

As the two data much related, so we determine to get the Equation of Industrial Water Demands IW (t) from the Industrial Productions Equation 1.1.

So the relation between the two groups of values can be regarded as a linear function. We assume the Industrial Productions as the function’s X axis value and Industrial Water Demands as the function’s Y axis value.

We use data X= [12.9304 12.3577 24.3042 48.7696 58.5505 85.7542] from I(x) and Y= [20 56 190 290 450 480] from Table 1.2.

By linear fitting, we get the following result:

\[
\begin{align*}
    a &= 6.3716 \\
    b &= -10.0308
\end{align*}
\]
So we get the Equation of Industrial Water Demands, where \( x = t - 1970 \)
\[
l(x) = 0.39886216x^2 - 4.3507712x + 72.35653664 \tag{2}
\]

### 1.2 Analysis of Domestic Water Demands

It is also difficult for us to analyze Domestic Water Demands directly and we think the Domestic Water Demands is related to Population of the kingdom. So we analyze the population of the kingdom firstly and then analyze Domestic Water Demands.

#### 1.2.1 Population of the Kingdom

We select the logistic model to estimate the population of the kingdom. From logistic model, we get
\[
\begin{aligned}
\frac{dp}{dt} &= rp \left(1 - \frac{p}{k}\right) \\
p(0) &= p_0
\end{aligned}
\]

By calculate, we can get
\[
P(t) = \frac{K}{1 + \left(\frac{K}{p_0} - 1\right) \times e^{-rt}}
\]

We get data from World Bank[3], as shown in Table 1.2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>16139053</td>
<td>16669764</td>
<td>17189075</td>
<td>17679720</td>
<td>18117969</td>
<td>18491845</td>
</tr>
<tr>
<td>Population</td>
<td>18786467</td>
<td>19020639</td>
<td>19256649</td>
<td>19578923</td>
<td>20045276</td>
<td>20681576</td>
</tr>
<tr>
<td>Year</td>
<td>2002</td>
<td>2003</td>
<td>2004</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
</tr>
<tr>
<td>Population</td>
<td>21463072</td>
<td>22334371</td>
<td>23213767</td>
<td>24041116</td>
<td>24799436</td>
<td>25504176</td>
</tr>
<tr>
<td>Year</td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
<td>2011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>26166639</td>
<td>26809105</td>
<td>27448086</td>
<td>28082541</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We use matlab to nonlinear fitting the Population Data in Table 1.2 and we figure out:
\[
\begin{aligned}
K &= 9.741537192132743 \times 10^9 \\
r &= 0.026131
\end{aligned}
\]

Where \( x = t - 1990 \)
\[
P(x) = \frac{9.741537192132743 \times 10^9}{1 + 602.6002974977988 \times e^{-0.0026131x}} \tag{3}
\]

The coefficient of determination
\[ R = 0.9927 \]

The R= 0.9927 is very closely to the 1, so the fitting is acceptable.
The nonlinear fitting is shown in Figure 1.2.1

![Figure 1.2.1 Population Fitting Curve](image)

### 1.2.2 Domestic Water Demands

1) Evaluating the correlation coefficient between Population of the kingdom and Domestic Water Demands

We get data from Future Of Saudi Arabian Water Aquifers[2] in Table 1.2

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Demands(MCM)</td>
<td>200</td>
<td>446</td>
<td>1508</td>
<td>1800</td>
<td>2300</td>
<td>2700</td>
</tr>
</tbody>
</table>

For Equation 3, we let \( x = [1970 1980 1990 2000 2003 2010] - 1970 \), the \( P(x) = 1.0 \times 10^7 \times [0.9576 1.2433 1.6139 2.0948 2.2652 2.7186] \) and we assume the result matrix as \( X \). Also we assume the Water Demands in Table 1.2 as \( Y \).

Then we can figure out the correlation coefficient between \( X \) and \( Y \) \( r \) is 0.9810.

\( r = 0.9810 \) is closely to 1, so we can think they are related to each other.

So we can get the Equation of Domestic Water Demands from the Equation 3.

2) Figure out the Equation of Domestic Water Demands

As the two data much related, so we determine to get the Equation of Domestic Water Demands \( DW(t) \) from the Population of kingdom Equation 3.

So the relation between the two groups of values can be regarded as a linear function.

We assume the Population of kingdom as the function's \( X \) axis value and Domestic Water Demand as the function's \( Y \) axis value.

We use data \( X = 1.0 \times 10^7 \times [0.9576 1.2433 1.6139 2.0948 2.2652 2.7186] \) from \( P(x) \) and \( Y = [200 446 1508 1800 2300 2700] \) from Table 1.2.

By linear fitting, we get the following result:

\[
a = 1.4746 \times 10^4 - 004 \\
b = -1185
\]
The figures of Equation 2 and above fitting polynomial Equation are in the same drawing board as shown in Figure 1.2.2

![Figure 1.2.2 Domestic Water Demand Fitting Curve](image)

So we get the Equation of Domestic, where \( x = t - 1990 \)

\[
DW(x) = \frac{1.4365 \times 10^6}{1 + 602.6003 \times e^{-0.026131x}} - 1184.953
\]

### 1.3 Analysis of Agriculture Water Demands

It is also difficult for us to analyze Agriculture Water Demands directly and we think the Agriculture Water Demands is related to Agriculture land of the kingdom. So we analyze the Agriculture land of the kingdom firstly and then analyze Agriculture Water Demands.

#### 1.3.1 Agriculture land of the kingdom

We get data about Agriculture land of the kingdom from World Bank [3] in Table 1.3

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td>1234810</td>
<td>1236720</td>
<td>1237460</td>
<td>1737850</td>
<td>1737850</td>
<td>1737850</td>
<td>1735000</td>
</tr>
<tr>
<td>Year</td>
<td>1997</td>
<td>1998</td>
<td>1999</td>
<td>2000</td>
<td>2001</td>
<td>2002</td>
<td>2003</td>
</tr>
<tr>
<td>Land</td>
<td>1737850</td>
<td>1737850</td>
<td>1737850</td>
<td>1737850</td>
<td>1737910</td>
<td>1737930</td>
<td>1737980</td>
</tr>
<tr>
<td>Year</td>
<td>2004</td>
<td>2005</td>
<td>2006</td>
<td>2007</td>
<td>2008</td>
<td>2009</td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>1737090</td>
<td>1737170</td>
<td>1736740</td>
<td>1736750</td>
<td>1735300</td>
<td>1734350</td>
<td></td>
</tr>
</tbody>
</table>
And the line graph of the land is shown in Figure 1.3.1

![Agriculture Land of the Kingdom](image)

**Figure 1.3.1 Agriculture Land of the Kingdom**

As shown in Figure 1.3.1, we find that the agriculture of the kingdom remain unchanged after 1994.

Because the agriculture need much water and the agriculture can achieve self-sufficiency. So the government decided to keep the land of agriculture unchanged.

So we can assume Agriculture Land from 2013 to 2025 is 1734350.

### 1.3.2 Agriculture Water Demands

We get data from Future of Saudi Arabian Water Aquifers[2] in Table 1.4

**Table 1.4 Agriculture Water Demand Data**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Demands(MCM)</td>
<td>6018</td>
<td>9470</td>
<td>18776</td>
<td>19271</td>
<td>20083</td>
<td>19271</td>
</tr>
</tbody>
</table>

![Agriculture Water Demands](image)

**Figure 1.3.2 Agriculture Water Demands**

Agriculture Water Demands also stand still after 1990.

So we can conclude that Agriculture Water Demand can be regarded as 19271 MCM.

It is said $AW(t) = 19271$
1.4 Evaluating of Total Water Demands

Above all, we get Water Demands for three parties and were shown in Figure 1.4.1.

We get Equation 4 for total water demands, where $x = t - 1990$

$$N(x) = \frac{1.4365 \times 10^6}{1 + 602.6003 \times e^{-0.026131x}} + 0.39886(x + 20)^2 - 4.353x + 18071.347$$  \hspace{1cm} (4)

2. Supply Model

In this part, we establish a model of Water Supplying depending on Water Storage, Water Movement, Desalination and Water Conservation to satisfy the Water Demands.

As Saudi Arabia is a deserted country and the conditions of different country are much different (such as amount of precipitation), we can divide the kingdom into some parts to analyze. One division method is that we can divide the kingdom though different province but desert occupies most of the provinces’ area and the cities is like some basic points distributing in oasis and cities is a good division for evaluating the supply model. So we determine to select the cities on the first 6 places of population to analyze.

There are four factors mainly influencing the Water Supply such as building dams; building desalination plants and transfer water through aqueduct; and water conservation. We valued the cost and the throughput of the unit constructions, and then run a dynamic programming application that we made to determine the scheduling plan of those constructions of each year.
2.1 Method of Supply Water

2.1.1 Dam

Building Dam is a method mainly used for Water Storage.

Parameters of Dam

The Ministry of Water and Electricity has approved the construction of 90 new dams in different parts of the Kingdom at a total cost of SR1.16 billion.

So the average cost of one dam is:

\[
\text{DamCost} = \frac{1.16 \times 10^3}{90} = 12.89 \text{(MSR)} \quad (\text{MSR: Million Saudi riyal})
\]

Official statistics show Saudi Arabia has 225 dams with a total capacity of 850 million cubic meters.

\[
\text{DamSup} = \frac{850}{225} = 3.78 \text{(MCM/year)}
\]

MCM: Million Cubic Meters

2.1.2 Upper limit of the number of a city’s dam

1. Evaluating a city’s maximum dam

Since the dam is to store the water, the number of the dam is much related to the amount of precipitation of a city.

For easily evaluating, we use Area of city plus average annual precipitation.

![Figure 2.1](image_url) Map of Saudi Arabia showing the distribution of annual rainfall for a 50 year period (1950-2000) based on rain gauge observations.
The dams limit in one city:

\[ \text{DamLim} = \left[ \frac{Aera \times Rainfall}{\text{DamSup}} \right] \]

Figure 2.1 is got from Google Map. From Figure 2.1, we can measure the area of the first 6 cities. From Wikipedia, we get the Annual Rainfall. Apply the data to Equation 2.1; we can calculate the Dams limit. The Data was shown in Table 2.1.

### Table 2.1 City Dam Limit Data

<table>
<thead>
<tr>
<th>City</th>
<th>Area (km²)</th>
<th>Annual Rainfall (mm)</th>
<th>Dams limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Riyadh</td>
<td>1815</td>
<td>130</td>
<td>62</td>
</tr>
<tr>
<td>Jiddah</td>
<td>3000</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Makkah</td>
<td>1200</td>
<td>130</td>
<td>41</td>
</tr>
<tr>
<td>Al-Madinah</td>
<td>589</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>Ad Dammam</td>
<td>800</td>
<td>70</td>
<td>15</td>
</tr>
<tr>
<td>Buraydah</td>
<td>1290</td>
<td>210</td>
<td>72</td>
</tr>
</tbody>
</table>

### 2. Evaluating the number of dams a city having now

Now, the kingdom has 225 dams and we assume that the distribution of the dams is related to the population of a city.

We get the kingdom first six large cities’ population as shown in Table 2.2

### Table 2.2 City Population Data[3]

<table>
<thead>
<tr>
<th>City</th>
<th>Population</th>
<th>Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Riyadh</td>
<td>5,254,560</td>
<td>19.36</td>
</tr>
<tr>
<td>Jiddah</td>
<td>3,456,259</td>
<td>12.74</td>
</tr>
<tr>
<td>Makkah</td>
<td>1,675,368</td>
<td>6.17</td>
</tr>
<tr>
<td>Al-Madinah</td>
<td>1,180,770</td>
<td>4.35</td>
</tr>
<tr>
<td>Ad Dammam</td>
<td>903,597</td>
<td>3.33</td>
</tr>
<tr>
<td>Buraydah</td>
<td>614,093</td>
<td>2.26</td>
</tr>
<tr>
<td>Kingdom</td>
<td>27,136,977</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Source: Census 2010, Central Department of Statistics & Information, Kingdom of Saudi Arabia.

Depending on the above assumption, we can get the number of dams of each city by the rate of population. The result was shown in Table 2.3.

### Table 2.3 City Dam Nowadays Data[5]

<table>
<thead>
<tr>
<th>City</th>
<th>Rate (%)</th>
<th>Dams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Riyadh</td>
<td>19.36</td>
<td>43</td>
</tr>
<tr>
<td>Jiddah</td>
<td>12.74</td>
<td>28</td>
</tr>
<tr>
<td>Makkah</td>
<td>6.17</td>
<td>13</td>
</tr>
<tr>
<td>Al-Madinah</td>
<td>4.35</td>
<td>9</td>
</tr>
<tr>
<td>Ad Dammam</td>
<td>3.33</td>
<td>7</td>
</tr>
<tr>
<td>Buraydah</td>
<td>2.26</td>
<td>5</td>
</tr>
<tr>
<td>Kingdom</td>
<td>100.00</td>
<td>225</td>
</tr>
</tbody>
</table>

### 3. Figure out upper limit of the number of a city’s dam

We can easily know that the value of the dams a city can has subtract the value of a city has now is the upper limit of the number of a city’s dam.

\[ \text{DamBL} = \max \left\{ \frac{\text{Dam Lim} - \text{Dam Now}}{0} \right\} \quad (2.2) \]
Apply the Equation 2.2, we get the flowing results in Table 2.4.

<table>
<thead>
<tr>
<th>City</th>
<th>Dams Limit</th>
<th>Dams Now</th>
<th>Dam Build Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Riyadh</td>
<td>62</td>
<td>43</td>
<td>19</td>
</tr>
<tr>
<td>Jiddah</td>
<td>40</td>
<td>28</td>
<td>12</td>
</tr>
<tr>
<td>Makkah</td>
<td>41</td>
<td>13</td>
<td>28</td>
</tr>
<tr>
<td>Al-Madinah</td>
<td>8</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Ad Dammam</td>
<td>15</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Buraydah</td>
<td>72</td>
<td>5</td>
<td>67</td>
</tr>
</tbody>
</table>

**2.1.3 Desalination Plant and Pipeline System**

1. **Estimating the construction cost of Desalination Plant**
   
   From *Water and National Strength in Saudi Arabia*[10] we get the government has spent $25 billion on building and operating plants. From NOMINATION OF Ministry of Water & Electricity Kingdom of Saudi Arabia[5], we get the kingdom now has 30 Desalination Plant. So the average construction cost of one desalination plant is (included long period maintain cost):
   
   \[
   \text{DesCost} = \frac{95 \times 10^3}{30} = 3166.67 (MSR)
   \]
   
   We get from NOMINATION OF Ministry of Water & Electricity Kingdom of Saudi Arabia[5] that all the Desalination Plant can supply 1033 MCM water.
   
   \[
   \text{DesSup} = \frac{1033}{30} = 34.43 (MCM/\text{year})
   \]

2. **Estimating the construction cost of Pipeline System**
   
   From constructionweekonline.com[6], we get the government has spent SAR 892.5 million on Pipeline System and build a 217.4-km pipeline and a pumping station to supply 80,000m$^3$ of water daily. So we can get PCP(include pump and storage station cost):
   
   \[
   \text{Pip} = \frac{892.5}{217.4 \times 80000 \times 365 \times 10^{-6}} = 0.14 (MSR/(km \cdot MCM))
   \]
   
   The construction cost of Pipeline System of a city equal to the length of Pipe plus water supply of Desalination Plant plus PCP as shown in Equation 2.3
   
   \[
   \text{PipCost} = \text{Pip} \times \text{distance} \times \text{DesSup} \tag{2.3}
   \]
   
   The total cost of a city:
   
   \[
   \text{DPCost} = \text{DesCost} + \text{PipCost} \tag{2.4}
   \]
We can measure the length of Pipe from city to desalination plant using Google Map.

![Desalination Water Pipeline Map](part177x583to420x754.png)

Figure 2.2 Desalination Water Pipeline Map from SWCC (Saline Water Conversion Corp)

By measuring and calculating, we can get the following result in Table 2.5

<table>
<thead>
<tr>
<th>City</th>
<th>Pipe Length(km)</th>
<th>PipCost(MSR)</th>
<th>DPCost (MSR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Riyadh</td>
<td>391.5</td>
<td>1887.11</td>
<td>5053.78</td>
</tr>
<tr>
<td>Jiddah</td>
<td>0</td>
<td>0.00</td>
<td>3166.67</td>
</tr>
<tr>
<td>Makkah</td>
<td>70.3</td>
<td>338.86</td>
<td>3505.53</td>
</tr>
<tr>
<td>Al-Madinah</td>
<td>170.9</td>
<td>823.77</td>
<td>3990.44</td>
</tr>
<tr>
<td>Ad Dammam</td>
<td>0</td>
<td>0.00</td>
<td>3166.67</td>
</tr>
<tr>
<td>Buraydah</td>
<td>724.0</td>
<td>3489.82</td>
<td>6656.49</td>
</tr>
</tbody>
</table>

Table 2.5 City Desalination & Pipeline Cost

2.1.4 Enhancing the advertise of water conservation

The supply water lost on leakage is becoming a big problem. We get from the newspaper WATER IN THE KINGDOM OF SAUDI ARABIA: SUSTAINABLE MANAGEMENT OPTIONS[7] those leakage losses are about 35% in KSA. So the leakage problem cannot be ignored. Although KSA is a country short of water, the leakage problem can lay greater pressure on water supply. So saving water is very important and the government should take actions to advertise water conservation.

As shown in Table 2.6, the domestic water reduce though various conservation programs

<table>
<thead>
<tr>
<th>Option</th>
<th>Water conservation strategy</th>
<th>USA</th>
<th>Saudi Arabia (ARAMCO 1983)</th>
<th>Cost of implementing a conservation program ($/m3)2</th>
<th>Proposed water reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water saving devices and leak control</td>
<td>15-30(many cities)</td>
<td>5-30</td>
<td>1.05</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Public education water and use awareness</td>
<td>5-35(California, Nevada, Colorado)</td>
<td>4-6</td>
<td>0.10</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Metering, billing and excess water use penalty</td>
<td>30-60(California, Colorado)</td>
<td>16-22</td>
<td>0.40</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>Wastewater reuse and recycle</td>
<td>10-60(many cities)</td>
<td>4-54</td>
<td>1.60</td>
<td>10</td>
</tr>
</tbody>
</table>
2.1.5 Agricultural Innovation

Though agriculture water demands accounts for a large proportion of the total water demands and it is said in Water Conservation in the Kingdom of Saudi Arabia[8] that we can reduce the amount of water demands by the development of agriculture technology, we should try our best to improve the technology of agriculture.

We believe that wasting water can be reduced by 20% through the technology nowadays.

2.2 Dynamic Programming Model for each city

Now the demand for groundwater is 80 percent and the groundwater is limited. So we reduce the demands for groundwater and we reduce the demand for groundwater by 1%

The y year’s water used rate except groundwater b[y] 

\[ b[y] = 20\% + 1\% \times y \]

So we can figure out the actual demand AN[y]

\[ AN[y] = \frac{N[y] \times b[y]}{a} \]

With the development of technology, the cost of fresh water reduce by 5.3%

\[ DPCost[y] = DPCost[2013] \times (1 - 5.3\%)^y \]

As for the dynamic demands for water and the dynamic cost of those projects, we use dynamic programming to plan the project until 2025.

The dynamic programming model is shown below

\[
F[y][i][j] = \left\{ \begin{array}{ll}
\min F[y-1][i'][j'] + DamCost \times (i - i') + DPCost \times (j - j') \\
i' \in [0, i], \\
i' < DamLim, \\
j' \in [0, j], \\
DamSup \times i' + DesSup \times j' > AN[y - 1]
\end{array} \right.
\]

The best plan of 2025 is shown below

\[
Best Plan = \left\{ \begin{array}{ll}
\min F[2025 - 2013][i][j] \\
i \in [0, DamLim], \\
j \in [0, AD[2025 - 2013]/DesSup], \\
DamSup \times i + DesSup \times j > AN[2025 - 2013]
\end{array} \right.
\]

We estimate the biggest six cities to undergo the working of dynamic programming model

Al-Riyadh

Riyadh is the capital of the nation.

<table>
<thead>
<tr>
<th>Table 2.7 Riyadh Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Rate</td>
</tr>
<tr>
<td>19.36%</td>
</tr>
</tbody>
</table>

For Al-Riyadh, the result is shown below
Jiddah

Jiddah is the second largest city after Riyadh, the major urban center of western Saudi Arabia, and the largest sea port on the Red Sea.

Table 2.8 Jiddah Data

<table>
<thead>
<tr>
<th>Population Rate</th>
<th>DamCost</th>
<th>DesCost</th>
<th>PipCost</th>
<th>DPCost</th>
<th>DamBL</th>
<th>DamSup</th>
<th>DesSup</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.74%</td>
<td>12.89MSR</td>
<td>3166.67MSR</td>
<td>0.00MSR</td>
<td>3166.67MSR</td>
<td>12</td>
<td>3.78MCM</td>
<td>34.43MCM</td>
</tr>
</tbody>
</table>

The result is shown below

Makkah

Makkah is the first holy city for Moslems.

Table 2.9 Makkah Data

<table>
<thead>
<tr>
<th>Population Rate</th>
<th>DamCost</th>
<th>DesCost</th>
<th>PipCost</th>
<th>DPCost</th>
<th>DamBL</th>
<th>DamSup</th>
<th>DesSup</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.17%</td>
<td>12.89MSR</td>
<td>3166.67MSR</td>
<td>338.86MSR</td>
<td>3505.53MSR</td>
<td>28</td>
<td>3.78MCM</td>
<td>34.43MCM</td>
</tr>
</tbody>
</table>
The result is shown below

![Makkah Construction Plan](image)

Figure 2.5 Makkah Construction Plan

Figure shows vividly plan of the city and the total cost is 154.68MSR.

**Al-Madinah**

Madinah is the first holy city for Moslems, is a modern city in the Hejaz region of western Saudi Arabia.

**Table 2.10 Al-Madinah Data**

<table>
<thead>
<tr>
<th>Population Rate</th>
<th>DamCost</th>
<th>DesCost</th>
<th>PipCost</th>
<th>DPCost</th>
<th>DamBL</th>
<th>DamSup</th>
<th>DesSup</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.35%</td>
<td>12.89MSR</td>
<td>3166.67MSR</td>
<td>823.77MSR</td>
<td>3990.44MSR</td>
<td>0</td>
<td>3.78MCM</td>
<td>34.43MCM</td>
</tr>
</tbody>
</table>

The result is shown below

![Al-Madinah Construction Plan](image)

Figure 2.6 Al-Madinah Construction Plan

Figure shows vividly plan of the city and the total cost is 3778.95MSR.

**Ad Dammam**

Dammam is the capital of the Eastern Province, the most oil-rich region in the world.
### Table 2.11 Dammam Data

<table>
<thead>
<tr>
<th>Population Rate</th>
<th>DamCost</th>
<th>DesCost</th>
<th>PipCost</th>
<th>DPCost</th>
<th>DamBL</th>
<th>DamSup</th>
<th>DesSup</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.33%</td>
<td>12.89 MSR</td>
<td>3166.67 MSR</td>
<td>0.00 MSR</td>
<td>3166.67 MSR</td>
<td>8</td>
<td>3.78 MCM</td>
<td>34.43 MCM</td>
</tr>
</tbody>
</table>

The result is shown below

![Ad Dammam](image)

**Figure 2.7 Dammam Construction Plan**

Figure shows vividly plan of the city and the total cost is 90.23 MSR.

### Buraydah

Buraydah is the capital of Al-Qassim Province in north central Saudi Arabia in the heart of the Arabian Peninsula.

### Table 2.12 Buraydah Data

<table>
<thead>
<tr>
<th>Population Rate</th>
<th>DamCost</th>
<th>DesCost</th>
<th>PipCost</th>
<th>DPCost</th>
<th>DamBL</th>
<th>DamSup</th>
<th>DesSup</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.26%</td>
<td>12.89 MSR</td>
<td>3166.67 MSR</td>
<td>3489.82 MSR</td>
<td>6656.49 MSR</td>
<td>67</td>
<td>3.78 MCM</td>
<td>34.43 MCM</td>
</tr>
</tbody>
</table>

The result is shown below

![Buraydah](image)

**Figure 2.8 Buraydah Construction Plan**

Figure shows vividly plan of the city and the total cost is 64.45 MSR.
Water Strategy

Figure 3 Water Strategy

As show in Figure 3, we Water strategy consists of Demand management and Demand satisfaction. Demand management consists of demand prediction and demand control. In Water Demands Model, we do the job of demand prediction. We take some actions such as water conservation measures, legal measures and so on. We do some engineering to satisfy the demand. In the article of our water supply model, we evaluate engineering construction.

Conclusion

A water strategy is to guide the country to a long term sustainable development, to help the governmental leadership determine a water strategy, we use model one to predict the water demand of the country in the future, and then use model two to calculate the constructions that the main cities can execute.

From the results of two models, we can forecast and make a plan to predict and fulfill the water demand at the same time.

Strengths and Weaknesses

Strengths:
Our model is not evaluating the water demands directly but evaluating the highly related factors because of uneasily evaluating it.
Our model is based on credible data.
Our model divides the water demands into three parties, industrial water demands, domestic water demands and agriculture water demands.
We viewed a single city as unit to evaluate and it is easy for us to evaluate.
Our model is practical and applicable.
Our model is credible and cost - efficient

Weaknesses
We are lack of data.
Due to time limit, some factors are not taken into consideration.
The society might undergo large change of policy.
References


   http://www.nar.ucar.edu/2008/RAL/goal_1/priority_2.php 2012


A position paper to the King of Saudi Arabia

My respected king,

As we all know, the climate is hot and arid all the year round in most of Saudi Arabia. The fresh water is one of the most important elements to restrict the development of country. Nowadays, the population of Saudi Arabia still maintain a fast pace. Meanwhile, formulated by the state, the industrial development project can also lead to consumption of fresh water increased rapidly. Therefore, the state needs an effective and feasible water strategy desperately.

At this time, water desalination technology in Saudi Arabia is quite mature. Desalinated water has already met the demand of most national domestic water. However, water used in agriculture and some other aspects still relies heavily on exploiting ground water. As a result, the ground water resource consumes largely.

We suggest that the government adopt the following water strategy:

- Reduce the exploitation of groundwater year after year.
- Utilize water storage project and renewable precipitation resources rationally.
- Develop water desalination technology vigorously and reduce the cost of it.
- Educate national on science, advocate people to save water rationally, protect the water ecological environment and avoid the waste of water resources and pollution.

During the implementation of the water strategy, we propose the most appropriate solution for each city, reaching the minimum annual target for the input of this project. The total cost of these projects may around SR14.2billion for six main cities which have half of the population of the kingdom. It will enable the government to put a minimum expenditure and meet the annual national water demand from this year to 2025. In addition, as Saudi Arabia has mature water desalination and water pipeline transport technology, the technology link of these solutions is also feasible.

Because of the relationship between our water demand and water supply from the country, with emphasis on the construction of the long-term project, the water strategy we present not only can meet the national needs of long-term development, but also play an important role in promoting the economy geography, environment and some other aspects. After solving the problem of fresh water, the state can expand oasis area based on water and intensify the development of diversified economy, reducing the dependence of national development on oil, ground water and some limited natural resources. It can also make the country embarked on the road of sustainable development scientifically.

To sum up, the water strategy, which we proposed, is suitable for the situation of Saudi Arabia and can make a contribution to the development of the country. It is the best choice of water strategy.

Thank you for your consideration.

Sincerely,

MCM Team 17567