Water transport cost

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Abstract

In order to calculate water transport cost from any desalination plant to where the desalted water is consumed, technical, economical evaluation and assessment of the water transport should be analyzed, therefore a technical and economical parameters are need as input data. The developed package uses these identified parameter and water transport methodology to calculate the water transport cost per m^3. Afterwards this routine is been included to DEEP3.1 to become DEEP3.11. Three generic comparative case studies were preformed using three different methods of calculation (DEEP3.11, EES and the hand calculations). The comparison has showed identical results. Thus, the new version of DEEP3.11 is completed and ready to be used.

1. Introduction

Water transport is essential in any type of potable water production plant such as desalination plant; it costs sometimes twice as much as the water production cost itself. Therefore in this sense water transport cost should be included in any water production cost.

The objective of water transport system computer program is to facilitate the technical, economic evaluation and assessment of the desalted water transport system. The evaluation and assessment of the water product and transport costs help the decision maker to take an interested decision based on the optimization of the water product and transport costs.

The water transport system was modeled as a hydraulic model and was solved by using EXCEL software program. The economic evaluation of the desalted water transport system was also investigated and solved by EXCEL software program.

The technical and economic water transport program was built as an integrated structure and joined into the DEEP program through the water plant capacity, the purchased electricity price, the discount and interest rate.

2. Water transport Model Description

2-1 Technical Evaluation :

Figure 1 illustrates schematic diagram of the water transport system flow which, point (1) represents the water production point and point (2) represents the consumer point. Between those two points lays the pipes, pumping stations and storage tanks …

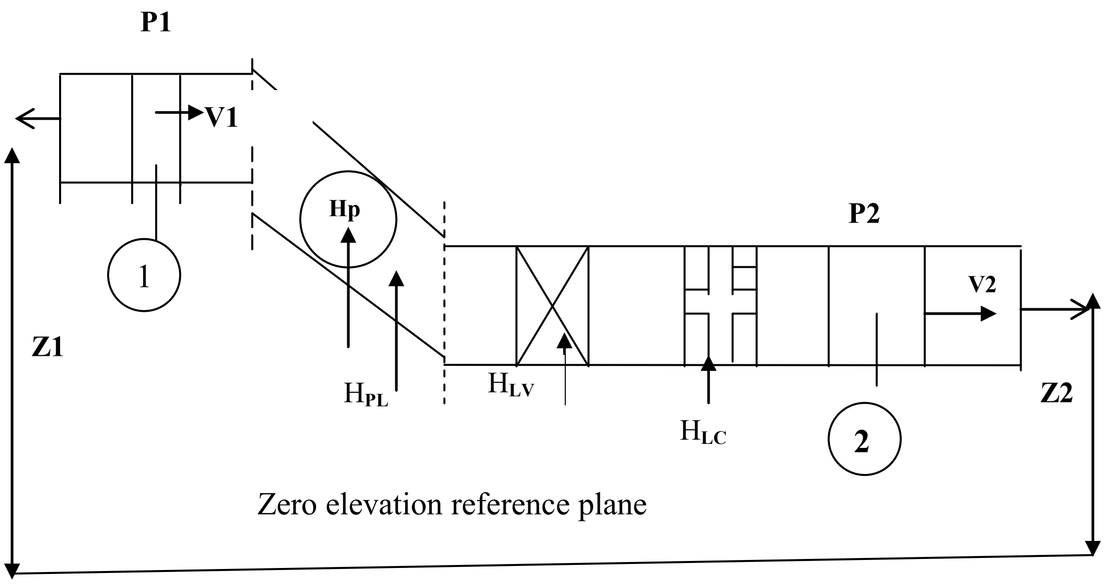

FIG.1 water transport system schematic diagram

Applying energy equation between points (1) and (2) yields the following equation[1]:

$$Z_1 + P_1/\gamma + V_1^2/2g + H_p - H_{loss} = Z_2 + P_2/\gamma + V_2^2/2g \quad 1$$

Z = potential energy

P/γ = fluid energy

$V^2/2g$ = kinetic energy

H_P = pump head

H_{loss} = total head loss in the system (pipes (h_p), entrance of the pipe (h_{ep}), valves (h_v), elbows (h_e), and coupling (h_c)).

$$H_{loss} = h_p + h_{ep} + h_v + h_e + h_c \quad 2$$

Head losses in pipes can be found by using Darcy's Equation [1].

$$h_p = f\ (L/d).\ (v^2/2g) \qquad 3$$

Where:

f = friction factor
L = length of the pipe
d = pipe inside diameter
V = average fluid velocity
g = acceleration of gravity

f can be calculated from the Haaland formula as follow [2]

$$f = \left[\frac{1}{-1.8 \cdot \log\left(\frac{6.9}{Re} + \left[\frac{\varepsilon}{d \cdot 3.7} \right]^{1.11} \right)} \right]^2 \qquad 4$$

Where Re is Reynolds number and ε is the pipe roughness.
Losses in entrance of the pipe, valves, elbows, and coupling can be calculated from the equation [1]:

$$h = K\ V^2/2g \qquad 5$$

Where K is the proportional constant factor of pipe entrance, valves, elbows and coupling.
The pump head (H_p) can be estimated using equation 1, and the pump power can be calculated from the following equation:

$$P = H_p \cdot \gamma_w \cdot Q \quad (hp) \qquad 6$$

Where γ_w is specific gravity for water ($kg/m^2.sec^2$) and Q is water flow rate (m^3/sec)

2-2 Economic evaluation

The economic evaluation of the plant can be determined using two main parameters capital cost and variable costs as figure 1 shows the cost analysis of water transport cost.
The capital cost equal the sum of pipe and pump cost (taxes, interest during construction and installation cost which include the pipe excavation and laying), these cost could be either entered as input data if available or use appendix 2 . The variable costs consist of electricity consumption and O&M for pipes and pumps.

The water transport cost per m^3 can be determined using the annuity cost (the annuity cost can be defined as the water cost times the charge rate) divided on the annuity water production. Detailed descriptions of these cost calculations are listed in the appendix 1.

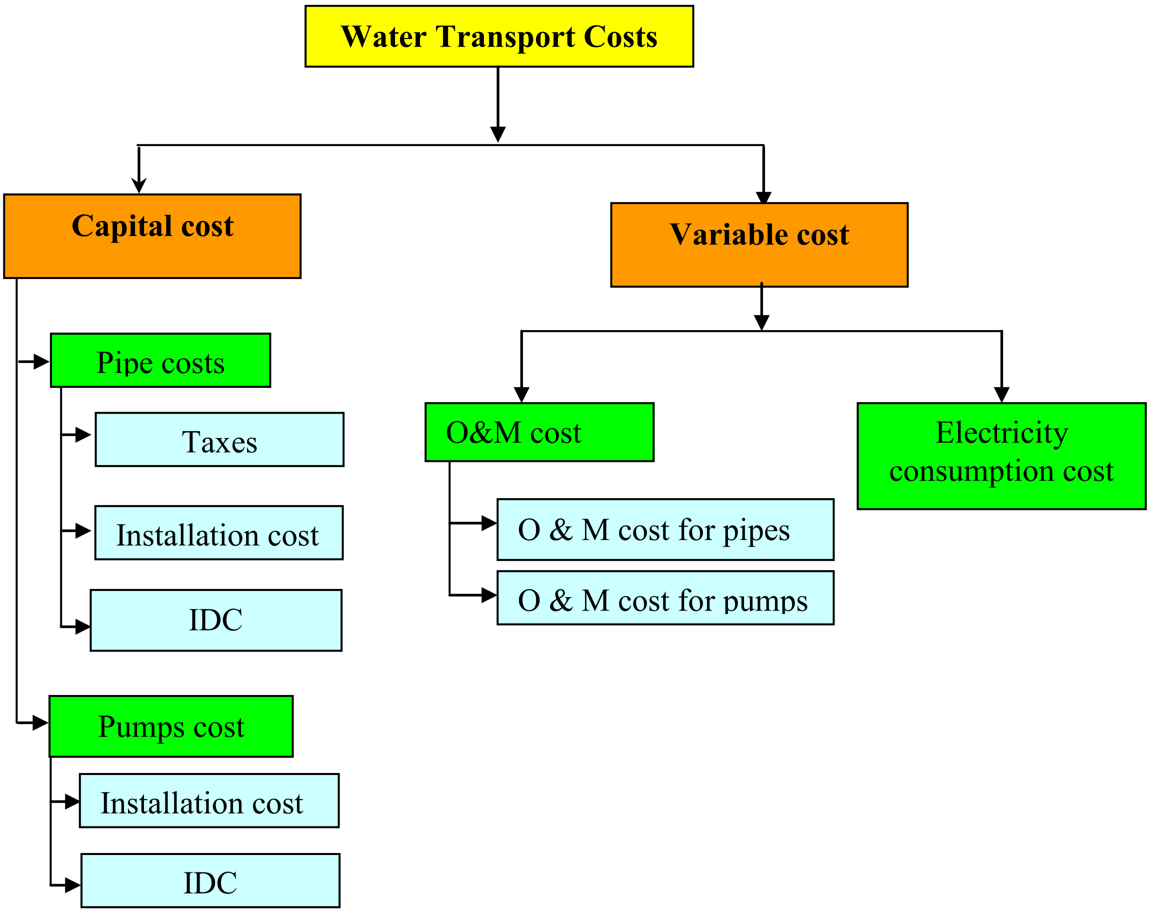

Figure 1. Water transport cost analysis

3. The water transport software

The software is preformed using EXCEL spreadsheet according to the technical and economical evaluations, which were mentioned above. Table 1 shows the software spreadsheet which includes many parameters was taken as input. Then many variables are being calculated such as pipe diameter, total pressure loss, capital and variable cost, water transport cost per m3 and water transport cost per m3 and km.

The water transport module is introduced to the DEEP 3.1 version in the same format as DEEP. The module is attached to the 38 different template files. Afterwards the main DEEP.XLs is modified to allow the user to edit the input data and show the results.

Table 1. The water transport spread sheet

WATER TRANSPORTATION MODULE DEFINITION			
INPUT			
Technical Description	-	-	
Total flow rate	(m^3/day)	Q_d	140000
Actual length of the pipe	(m)	L	30000
Velocity of fluid at inlet	(m/sec)	V_1	1
Velocity of fluid at outlet	(m/sec)	V_2	1
Pipe roughness	m	epsilon	0
Number of pipes line		C_3	2
Number of pumps including basic pumps& aux. pumps		C_4	4
Number of basic pumps		C_5	2
Elevation at inlet from datum	(m)	Z_1	0
Elevation at outlet from datum	(m)	Z_2	0
Pressure at inlet	(Pa)	P_1	1
Pressure at outlet	(Pa)	P_2	1
Number of elbows for pipe line		C_1	6
Loss coefficient for elbow		K_e	0.42
Number of valves for pipes line		C_2	6
Loss coefficient for valve		K_v	1
Number of coupling		n	5000
Loss coefficient for coupling		K_c	0.2
PI (π)		PI	3.14
Gravity acceleration		g	9.814
Dynamic viscosity (μ)	(kg/m.sec)	mu	0.00114
Water density	(kg/m^3)	rho_w	1000
Specific gravity for water		gamma_w	9797
Economic Description			
The interest rate	%	i_r	8
The discount rate	%	d_r	8
Construction lead time	months	Con_p	0
Pipeline operational availability factor	%	F_av	100
Energy price	($/Kw.h)	A_9	0.06
Pipe price per unit length	($/m)	A_1	308
Installation price for basic lines	($/m)	A_2	160
life time for pipes	(Year)	X_1	30
Specific pump price	($/Mwe)	Fp	110000
Pumps installation & building cost	($)	A_12	100000
life time for pumps	(Year)	X_2	15
sales tax factor		Fs	0.15
Annual O&M cost factor for pipes	(%/year)	Fo_1	0.03
Annual O&M cost factor for pumps	(%/year)	Fo_2	0.04
Performance Calculation			
Total flow rate per line	m^3/s	Q	0.810185185

Total flow rate	m^3/s	Qtot_1	1.62037037
Total annual water transported	$m^3/year$	Qtot_2	51100000
Cross section area of pipe	(m^2)	A_c	0.810185185
Inside Diameter of the pipe	(m)	d	1.015914878
Head losses due to entrance of the pipe	(m)	H_i	0.025473813
Head loss due to elbows	(m)	H_e	0.128388017
Head loss due to couplings	(m)	H_c	50.94762584
Reynolds number		R_e	891153.4014
friction factor get from moody diagram for smooth pipe		F	0.011814781
Head losses due to friction in the pipe	(m)	H_f	17.77516106
Head losses in the valves	(m)	H_v	0.305685755
Total head loss	(m)	H_loss	69.18233448
Required pump head	(m)	H_p	69.18233448
Pump power	W	P	549126.7727
Cost Calculation			
1- capital cost			
Pipe price including sales tax	($/m)	A_s	354.2
Pipe cost per unit length	($/m)	A_3	514.2
Pipe cost for single line	($)	A_4	15426000
Interest during construction for pipe line	($)	IDC_l	0
Total pipe cost	($)	A_5	30852000
Annual total pipe cost	($/year)	A_6	2740503.975
Pumps price	($)	A_11	241615.78
Interest during construction for pumps	($)	IDC_p	0
Total pumps cost	($)	A_13	341615.78
Annual total pumps cost	($/year)	A_14	39910.81612
Annual capital cost	($/year)	A_23	2780414.791
Capital cost	($/$m^3$)	A_24	0.054411248
2- Consumed Energy Cost			
Annual consumed energy	(kwh/year)	A_8	4810350.529
Annual consumed energy cost	($/year)	A_10	577242.0635
Consumed energy cost	($/$m^3$)	A_28	0.011296322
3- O&M Cost			
Annual O & M cost for pipes	($/year)	A_15	925560
Basic operating pumps price	($)	A_16	120807.89
Total basic operating pumps cost	($)	A_17	220807.89
Annual O&M cost for pumps	($/year)	A_18	8832.3156
Annual O&M cost for pipes & pumps	($/year)	A_19	934392.3156
O&M cost	($/$m^3$)	A_26	0.018285564
Annual total cost	($/year)	A_20	4292049.17
Water transport cost per m^3	**($/$m^3$)**	**A_22**	**0.083993134**
Water transport cost per m^3 and km	**($/$m^3$/km)**	**A_29**	**0.002799771**

4. Case Studies

Three generic case studies are prepared (table 2 shows the input data for the three generic case studies) [3,4,5,6] using the modified version of DEEP (DEEP3.11). For validation purposes, results obtained are compared against both Engineering Equation Solver (EES) software and hand calculations. Table 3 illustrates the comparison of the three cases using the three different methods of calculations which appears they are identical.

Table 2. Input Data of the Generic Case Studies

Items \ Case	Case 1	Case 2	Case 3
Total flow rate [m3/day]	140000	300000	600000
Actual length of the pipe [m]	30000	320000	2000000
Velocity of fluid at inlet [m/sec]	1	2.3	2.3
Velocity of fluid at outlet [m/sec]	1	2.3	2.3
Pipe roughness [m]	0	0.007	0.007
Number of pipes line	2	1	1
Number of pumps including basic pumps& aux. pumps	4	2	2
Number of basic pumps	2	1	1
Elevation at inlet from datum [m]	0	0	0
Elevation at outlet from datum [m]	0	860	500
Pressure at inlet [pa]	1	1	1
Pressure at outlet [pa]	1	1	1
Number of elbows for pipe line	6	10	10
Loss coefficient for elbow	0.42	0.42	0.42
Number of valves for pipes line	6	100	100
Loss coefficient for valve	0.02	0.02	0.02
Number of coupling	5000	55000	55000
Loss coefficient for coupling	0.02	0.02	0.02
PI (π)	3.14	3.14	3.14
Gravity acceleration [m/sec2]	9.814	9.814	9.814
Dynamic viscosity (μ) [kg/m.sec]	0.00114	0.00114	0.00114
Water density [kg/m3]	1000	1000	1000
Specific gravity for water [m]	9797	9797	9797
The interest rate [%]	8	8	8
The discount rate [%]	8	8	8
Construction lead time [months]	0	25	25
Pipeline operational availability factor [%]	100	90	90
Energy price [$/kw.h]	0.06	0.04	0.04

Pipe price per unit length [$/m]	308	308	308
Installation price for basic lines [$/m]	160	160	160
Life time for pipes [years]	30	30	30
Specific pump price [$/MWe]	110000	130000	130000
Pumps installation & building cost [$]	100000	100000	100000
Life time for pumps [years]	15	15	15
Sales tax factor [%]	0.15	0.15	0.15
Annual O&M cost factor for pipes [%/year]	0.03	0.03	0.03
Annual O&M cost factor for pumps [%/year]	0.04	0.04	0.04

Table 3. Comparative of **Generic Case S**tudies for DEEP3.11

Case \ Items		Water transport cost per m3	Water transport cost per m3/km
Case 1	DEEP	0.0760256	0.002534
	ESS	0.07603	0.002534
	Hand Calc.	0.07603	0.0025337
Case 2	DEEP	0.588239	0.001838
	ESS	0.58819	0.001838
	Hand Calc.	0.5882	0.001840
Case 3	DEEP	1.69389	0.0008469
	ESS	1.6940	0.0008469
	Hand Calc.	1.69388	0.000847

5. Conclusion

This work provides the user to calculate the water transport cost in any place, with acceptable accuracy. The user needs only to specify the water flow or the capacity, the pipeline length and the elevation from the see level or the difference in the elevation of the beginning and the end of the pipeline routs. Therefore it would be a quite good tool to be considered with DEEP in order to evaluate desalination cost and water transport cost.

6. Recommendation

Thermohydraulic and economic models need to be reviewed to validate DEEP software.

Some of technical and economic default values embedded in the DEEP templates should be updated according to present technologies.

References

[1] Anthony Esposito "Fluid Power with Applications, Fourth addition, Department of Manufacturing Engineering, Miami University, Oxford, Ohio, 1997.

[2] Frank M. White, "Fluid Mechanics", Fourth Edition, McGraw-Hill, 2001.

[3] Future Pipe Industries (F.P.I), 6 OCT. City, Egypt, Private communication, 2007.

[4] The Egyptian Company for Pipes and Cement Products (Sigwart), Massara Factory, Helwan, Egypt, Private communication, 2007.

[5] The Egyptian Company for Pipes and Chemicals (Alfa Pipe), Badr City Fourth Industrial Zone, Egypt, Private communication, 2007.

[6] Damascus Water Supply from coastal Area, IBG, DHN: Pipeline route alternatives analyses Document Number (1714-PL-RE 001) Damascus 2002

Appendixes:
Appendix 1

A1.1 The Capital costs:

Total annual capital Cost

=

Annual total pipe cost

+

Annual total pump cost

a- Annual total pipe cost

Annual total pipe cost (A_6) is Calculated as follow

$$A_6 = A_5 * \left(\frac{d_r * (d_r + 1)^{X_1}}{(d_r + 1)^{X_1} - 1}\right)$$

Where:

- d_r is the discount rate
- X_1 is life time for pipes
- A_5 is the total pipe cost

$$A_5 = C_3 * A_4 + IDC_l$$

- C_3 is the number of pipes line
- A_4 is Pipe cost for single line

$$A_4 = A_3 * L$$

- IDC_I is the interest during construction for pipe line

$$IDC_l = C_3 * A_4 * \left((1 + i_r)^{\frac{Con_p}{24}} - 1\right)$$

- I_r is the interest rate
- Con_p is the construction period.

- A_3 is the specific cost for basic lines

$$A_3 = A_s + A_2$$

- A_2 is the installation price for basic lines
- A_s is pipe price including sales tax

$$A_s = (1+Fs) * A_1$$

- A_1 is the the pipe price for basic lines
- Fs is the sales tax factor

b- <u>Annual total pumps cost</u>

Annual total pump cost (A_{14}) is Calculated as follow

$$A_{14} = A_{13} * \left(\frac{d_r * (d_r + 1)^{X_2}}{(d_r + 1)^{X_2} - 1} \right)$$

Where:

- X_2 is life time for pumps
- A_{13} is the total pumps cost

$$A_{13} = A_{11} + A_{12} + IDC_p$$

  - A_{12} is the pumps installation & building cost
  - A_{11} is the pumps price

$$A_{11} = C_4 * Fp * A_7$$

  - IDC_p is the interest during construction for pumps

$$IDC_p = (A_{11} + A_{12}) * \left((1 + i_r)^{\frac{Con_p}{24}} - 1 \right)$$

- C_4 is the number of pumps including basic pumps& aux. pumps
- Fp is the specific pump price
- A_7 is the Pump power

A1.2 <u>The variable costs</u>

a- <u>Annual consumed energy cost</u>

Annual consumed energy cost (A_{10}) is Calculated as follow

$$A_{10} = C_5*A_8*A_9$$

Where:

- C_5 is the number of basic pumps
- A_9 is the energy price
- A_8 is the annual consumed energy

$$A_8 = A_7*1000*8760*F_{av}$$

- A_7 is the Pump power
- F_{av} is the availability factor

b- <u>Annual O&M cost</u>

Total annual capital Investment Cost

=

Annual O & M cost for pipes

+

Annual O & M cost for pumps

b.1 <u>Annual O & M cost for pipes</u>

Annual O & M cost for pipes (A_{15}) is Calculated as follow

$$A_{15} = A_5 * Fo_1$$

- A_5 is the total pipe cost
- Fo_1 is the annual O&M cost factor for pipes

b.2 <u>Annual O & M cost for pumps</u>

Annual O & M cost for pipes (A_{18}) is Calculated as follow

$$A_{18} = A_{17} * Fo_2$$

- Fo_2 is the annual O&M cost factor for pumps
- A_{17} is the total basic operating pumps cost

$$A_{17} = A_{12} + A_{16}$$

- A_{16} is the basic operating pumps price

$$A_{11} = C_5 * Fp * A_7$$

- C_5 is the number of basic operating pumps

A1.3. <u>Water transport cost</u>

- **Water transport cost per m^3 (A_{22}) is calculated as follow:**

$$A_{22} = \frac{A_{23} + A_{10} + A_{19}}{Q_{tot}}$$

Where:

- A_{23} is the annual total capital cost
- A_{10} is the annual consumed energy cost
- A_{19} is the annual O&M cost
- Q_{tot} is the anuual water transported

- **Water transport cost per m^3 and km (A_{29}) is calculated as follow**

$$A_{29} = \frac{A_{22}}{L} * 1000$$

Where:

- L is the total pipe length

Appendixes 2

The construction cost

The construction cost is divided to two main parts construction cost of the pipes and tanks and the construction cost of the pumping station.

A2.1. Construction cost of the pipes and tanks.

The construction cost of pipes usually is calculated according the diameter of the pipe, figure A2.1 shows the Construction cost of the pipes and tanks according to the pipe diameter and this cost was carried out according to study was preformed by Ministry of housing under the title:"Damascus Water Supply from coastal Area" [1], as for tank cost unit size of 50000 m^3 was considered using the last reference to determine the cost of the unit size 3,306,432 [4]. By fitting the data in the diagram of figure 1 we get the following equation:

$$\mathrm{spcc} = 10.82 \cdot (\mathrm{Dn})^4 + 115.34 \cdot (\mathrm{Dn})^3 - 417.07 \cdot (\mathrm{Dn})^2 + 1944.5 \cdot (\mathrm{Dn}) \qquad \text{A2.1}$$

Where Dn is the diameter given in mm

A2.2. The construction cost of the pumping station

It is related directly to the power of the pumping station as show in figure A2.2 [1], by fitting the data in the diagram of figure A2.2 we get the following equation:

$$\mathrm{pump\,cos\,t} = 0.00001 \cdot (\mathrm{N})^3 + 0.0024 \cdot (\mathrm{N})^2 + 0.7459 \cdot (\mathrm{N}) + 36.702 \qquad \text{A2.2}$$

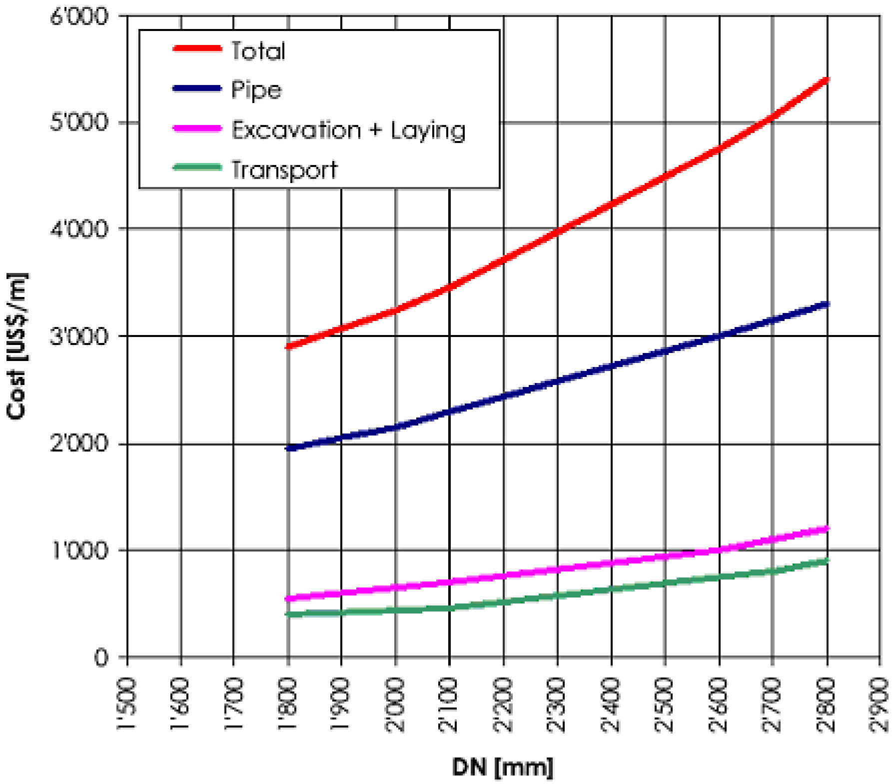

Figure A2.1. The construction cost of pipe according the pipes diameter

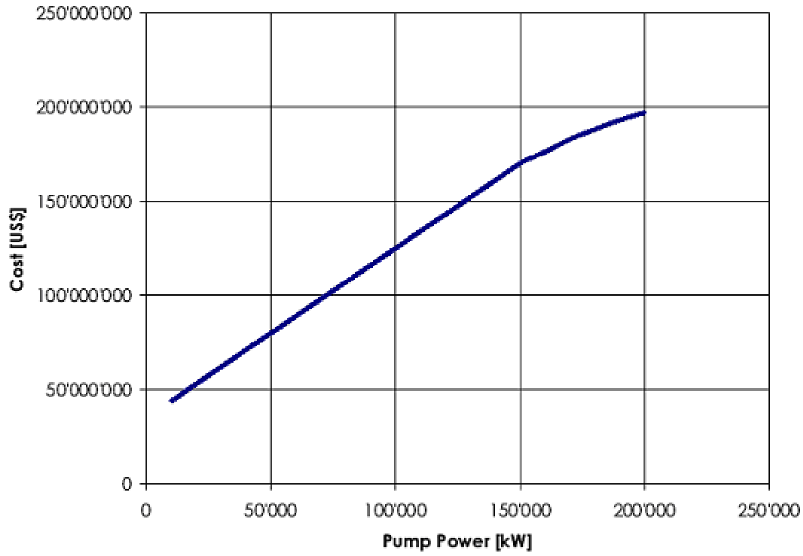

Figure A2.2. The cost of pumping station according the power

References

[1] Damascus Water Supply from coastal Area ,IBG ,DHN: Pipeline route alternatives analyses Document Number (1714-PL-RE 001) Damascus 2002