PIPELINE DESIGN

A PRE-FEASIBILITY STUDY

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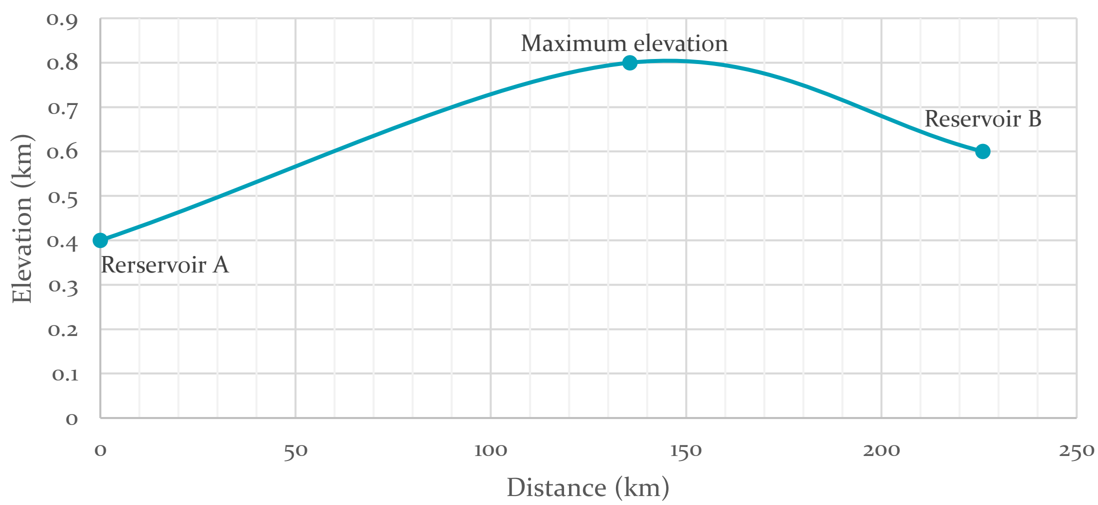
1.0 INTRODUCTION

This report is a pre-feasibility study for a water pipeline design that is required to carry water from reservoir A to reservoir B. Reservoir A is at an elevation of 400 m and reservoir B is at an elevation of 600 m. The horizontal distance between A and B is 226 km. The topography can be approximated as a parabolic with a maximum elevation of 800 m, which is reached at 135.6 km from A. This is shown in the figure below.

Figure 1. Topographic view of reservoirs A and B



The task requires the pipeline to be built from a selected number of pipelines ranging in diameter from 0.7 m to 1.4 m. Each pipe diameter has a different cost per km which is summarized in the following table.

Table 1: Estimated cost of installed pipe per km of pipe.

Pipe diameter (m)	Total Cost ($/km)
0.7	38,000
0.8	44,000
0.9	50,000
1.0	80,000
1.1	120,000
1.2	150,000
1.4	180,000

The pipes are made from commercial grade steel with a roughness of ε = 0.05 cm and a pressure rating of 150 m. The pumps selected can deliver a flow rate of 1 m^3/s at a head of 100 m. The cost of one pump is $10 million.

For a project of this magnitude, minor losses associated in the pipes, pumps or any other factors are negligible and therefore can be ignored.

2.0 CALCULATION OF PARABOLA

The requirements for this project gave three initial conditions that need to meet the parabolic equation. The equation follows the form $z = ax^2 + bx + c$. The three conditions are: (0,0.4), (135.6,0.8), (226,0.6). All values are in kilometers. To find the coefficients a, b and c, the following system needs to be solved:

$$c = 0.4$$

$$135.6^2 a + 135.6b + c = 0.8$$

$$226^2 a + 226b + c = 0.6$$

a = -2.2842×10^{-5} b = 0.0060472 c = 0.4

The equation or the parabolic is:

$$z = -2.2842 \times 10^{-5} x^2 + 0.0060472x + 0.4\ [km]$$

To calculate the minimum pressure for the system, the allowable pressure for the pipe is be considered. The pressure is 70% of the atmospheric pressure, which is 0.7*101300 Pa. The maximum pressure is 70,917 Pa. Using this maximum value, the minimum pressure head can be calculated with Bernoulli's equation. Dividing the maximum pressure by density*gravity gives the equivalent elevation head of h = 7.24 m. This restricts the HGL by not allowing it to fall lower than 7.24 m below the pipe centerline. This gives us a minimum equation for the parabolic:

$$z_{min} = -2.2842 \times 10^{-5}x^2 + 0.0060472x + 0.39276\ [km]$$

The pipes available have a maximum pressure rating of 150 m, which gives us a maximum equation for the parabolic:

$$z = -2.2842 \times 10^{-5}x^2 + 0.0060472x + 0.55\ [km]$$

The HGL for the solution is required to remain be within these bounds for a maximum factor of safety.

3.0 ERROR ESTIMATES

By estimating the length of the pipe to be the distance from A to B introduces some error. This can be calculated by finding the actual length of the parabola and then doing an error calculation. The actual length can be found by the following integral, which gives the real length of the parabola:

$$parabola\ length = \int_0^{226} \sqrt{1 + (0.0060472 - 0.000045684x)^\wedge 2}\, dx = 26.0010923\text{km}$$

This shows that the actual length of the pipe is 1 cm more than the horizontal distance.

The error can be calculated by:

$$error\ percentage = \frac{226.0010923 - 226}{226.0010923}\ x\ 100 = 0.000483\%$$

This value is very small to be of any significance and therefore can be ignored.

4.0 GENERAL CALCULATIONS

The following calculations are for 0.9m diameter pipe:

Relative roughness = E/D = 0.0005/0.9 = 0.000556 and velocity = Q/A = 1 / (pi*0.9²/4) = 1.572m/s.

$Reynold's\ number = Re = \frac{VD}{u} = \frac{1.57*0.9}{10^{-6}} = 1415000 \longrightarrow$ corresponding friction value = 0.0174.

The head loss can be calculated using:

$$H_{loss} = \frac{fLv^2}{2Dg} = \frac{0.01744 * 226000 * 1.572^2}{2 * 0.9 * 9.8} = 552\ m$$

The friction head loss per kilometer is equal to 0.552/226 = 0.00244 which is the same as the slope of the HGL.

A simplified Bernoulli analysis between reservoirs A and B can give us an equation for the total head required by the pump:

$$head\ for\ pump = elevation\ difference\ between\ B\ and\ A + head\ losses$$

$$H_{pump} = (Z_B - Z_A) + H_{loss}$$

Table 2. Shows the key values for different pipelines.

Pipe Diameter (m)	Cross-Sectional Area	Velocity (Q/A)	Cost $/km	Relative Roughness	Reynold's number	f value	Total Head loss (m)	Frictional Head Loss per km	Total Head Required
0.7	0.385	2.599	38000	0.000714	1818967	0.0183	2037.8	0.00902	2237.8
0.8	0.503	1.989	44000	0.000625	1591596	0.0178	1016.7	0.00450	1216.7
0.9	0.636	1.572	50000	0.000556	1414752	0.0174	551.6	0.00244	751.6
1.0	0.785	1.273	80000	0.000500	1273277	0.0121	226.0	0.00100	426.0
1.1	0.950	1.052	120000	0.000455	1157525	0.0168	195.0	0.00086	395.0
1.2	1.131	0.884	150000	0.000417	1061064	0.0166	124.4	0.00055	324.4
1.4	1.539	0.650	180000	0.000357	909484	0.0162	56.3	0.00025	256.3

5.0 STANDARD SOLUTION

The standard solution is the most simplistic way to solve the task of delivering water from reservoir A to B. It uses only 0.9m diameter pipe and 8 pumps. The HGL is required to stay within the maximum and minimum parabolas.

<u>Graph of Solution</u>

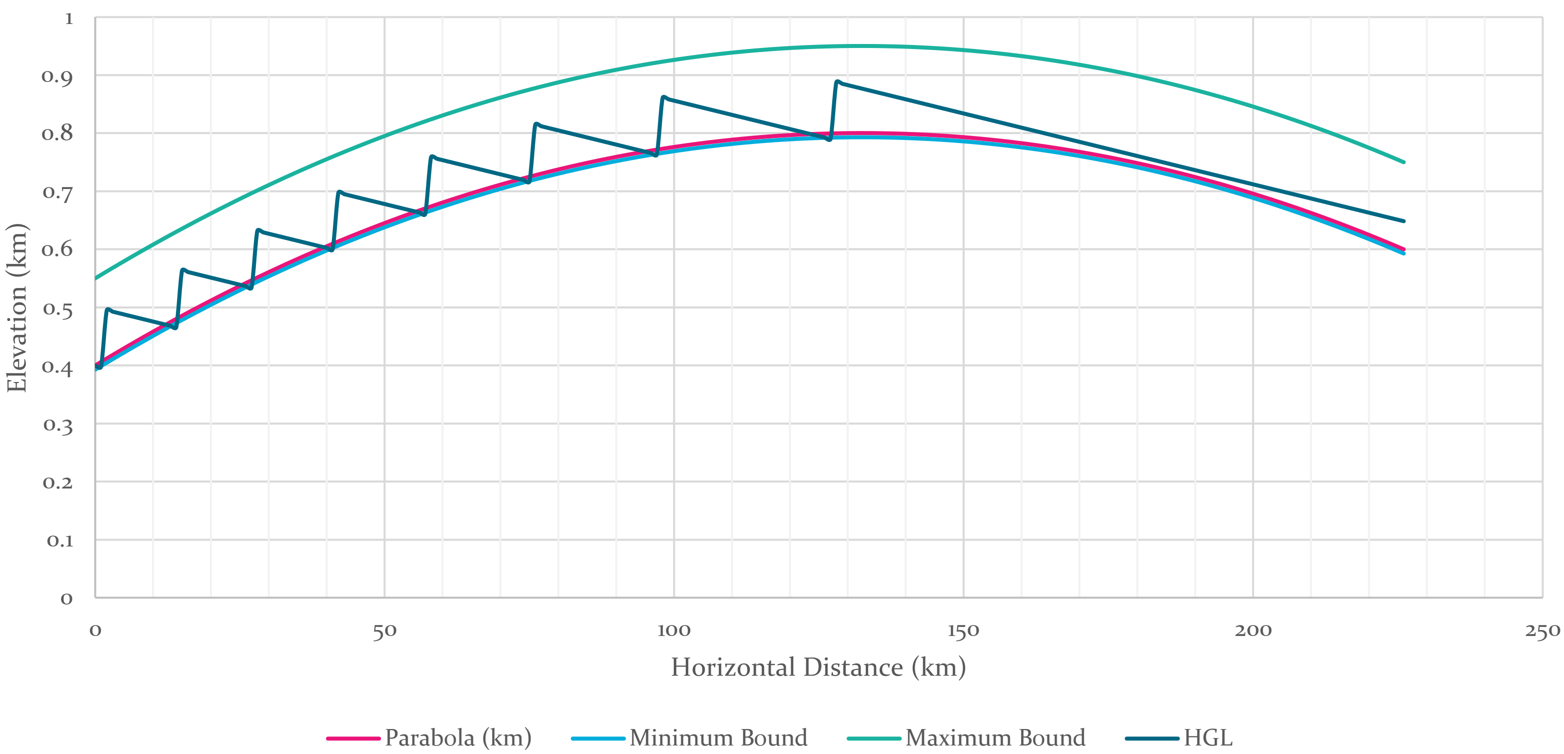


Figure 2. Parabola, Minimum and Maximum Bound, HGL vs Horizontal distance for Standard Solution

*Note that the HGL and the EGL are extremely similar, so the EGL has been removed for clarity.

The bounds are to ensure that the HGL doesn't go into the negative pressure zone, which would cause cavitation, or into a high-pressure zone that would be greater than the maximum pressure rating of the pipes.

Total Costs

Cost of Pipe $/km	Length of Pipe (km)	Total Pipe Cost	Number of Pumps	Total Pump Cost	Total Cost
50,000	226	$ 11,300,000	8	$ 80,000,000	$ 91,300,000

Table 3. Total costs for Standard Solution

Location of Pumps

Pump Number	1	2	3	4	5	6	7	8
Pump Location	2km	15km	28km	42km	58km	76km	98km	128km

Table 4. Location of pumps from Reservoir A for Standard Solution

TOTAL COST: $91,300,000

6.0 OPTIMIZED SOLUTION

The optimized solution uses 3 different pipe types and a reduced number of 6 pumps. It follows the same restraints as the standard solution and has no excess head at the exit at reservoir B.

Graph of Solution

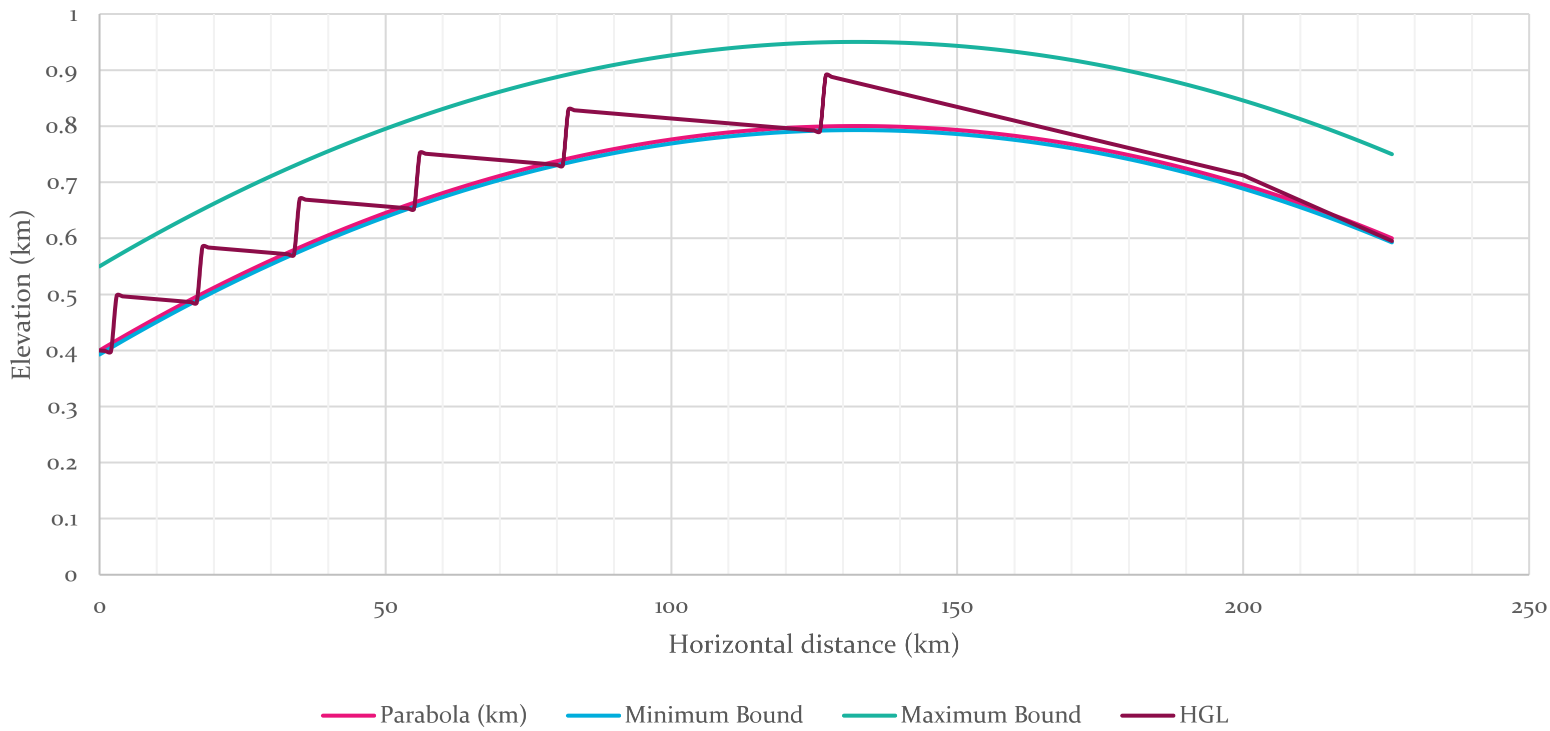


Figure 3. Parabola, Minimum and Maximum Bound, HGL vs Horizontal distance for Optimized Solution

*Note that the HGL and the EGL are extremely similar, so the EGL has been removed for clarity.

The optimized solution is more suitable than the standard as it is cheaper, and the HGL ends at 600m, which is more desired.

The figure below displays the location of the pumps, the location of the pipes, and the diameter of the pipes used.

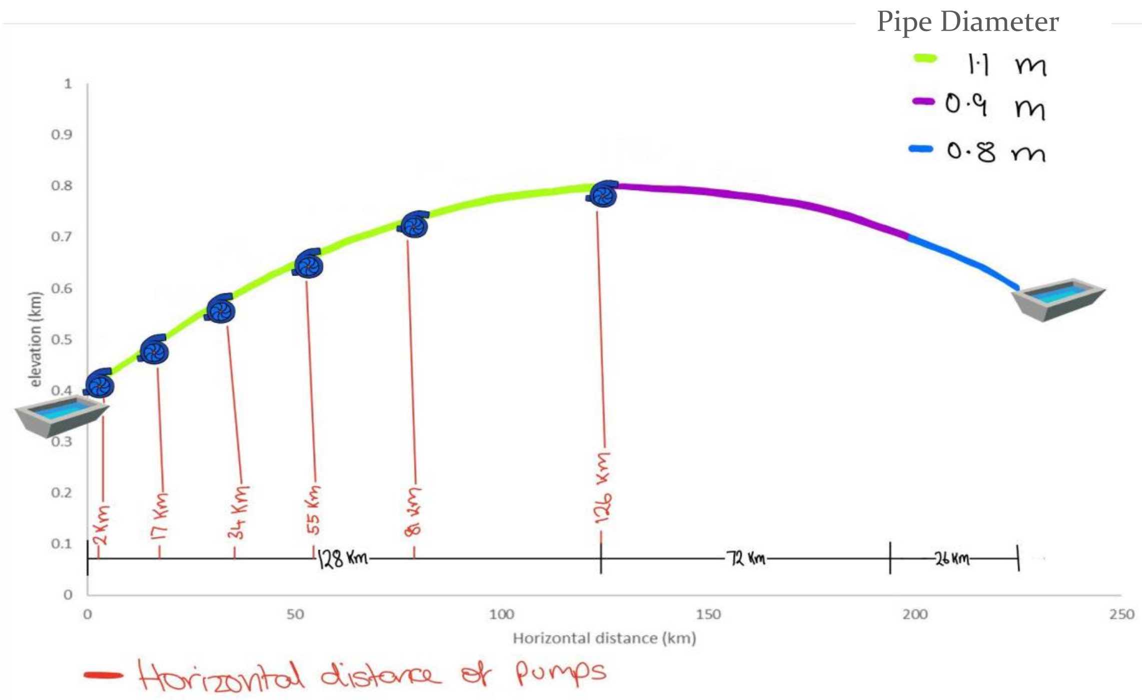


Figure 4. Pipeline and pump location schematic

Total Costs

Type of Pump (m)	Cost of Pipe $/km	Length of Pipe Segment (km)	Total Segment Cost	Number of Pumps	Total Pump Cost	Total Costs
1.1	$ 120,000	128	$ 15,360,000	6		
0.9	$ 50,000	72	$ 3,600,000	-		
0.8	$ 44,000	26	$ 1,144,000	-	$ 60,000,000	$ 80,104,000

Table 5. Total costs for Optimized Solution

Location of Pumps

Pump Number	1	2	3	4	5	6
Pump Location	2km	17km	34km	55km	81km	126km

Table 6. Location of pumps for Optimized Solution

TOTAL COST: $81,104,000

TOTAL SAVED: $11,196,000

7.0 CONCLUSION

Both solutions meet the requirements. The extra 50m of head in the standard solution might cause issues when designing a receiving system, but the optimized solution would have no issues. The optimized solution also saves $11,196,000. Both solutions are correct and accurate to my knowledge. If there are any inquiries about the design or if you would like to see my calculations and workings, feel free to contact me at mehramanish@live.com or 6047827983.

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