PUMP AND PIPELINE HYDRAULICS
CIV2300a
Semester 1 Coursework Brief

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1 Introduction

This coursework is based around the design of a new gravity fed bulk water transfer pipeline that is due to be constructed between Grantham and Lincoln in Lincolnshire. The pipeline is required to provide a new source of water to the growing city of Lincoln from the hills to the south.

This coursework will initially allow you to build up and test a series of small scale hydraulic models of the pipeline. You will then asked to design the pipeline, following the predetermined route as arranged with the local council, see Figure 1. The route travels from the upstream supply reservoir to the south to the local water treatment reservoir just to the north west of Lincoln. The pipeline route is 84 km long, and the elevation of the ground drops by about 125 m over the distance travelled. Finally you are asked to consider the impact of ensuring a water supply to the RAF base at RAF Waddington.

This coursework is designed to let you explore flow in pipes in a little more detail than we have time for in tutorial questions and get used to managing a large amount of calculations. The initial series of tasks you will have to undertake of increasing complexity that will test your knowledge of networks of pipe flows, and provide you with the tools to analyse the design of the new pipeline.

You may need to do some additional reading around the subject of water supply systems and pipe networks to address all the points in the coursework.

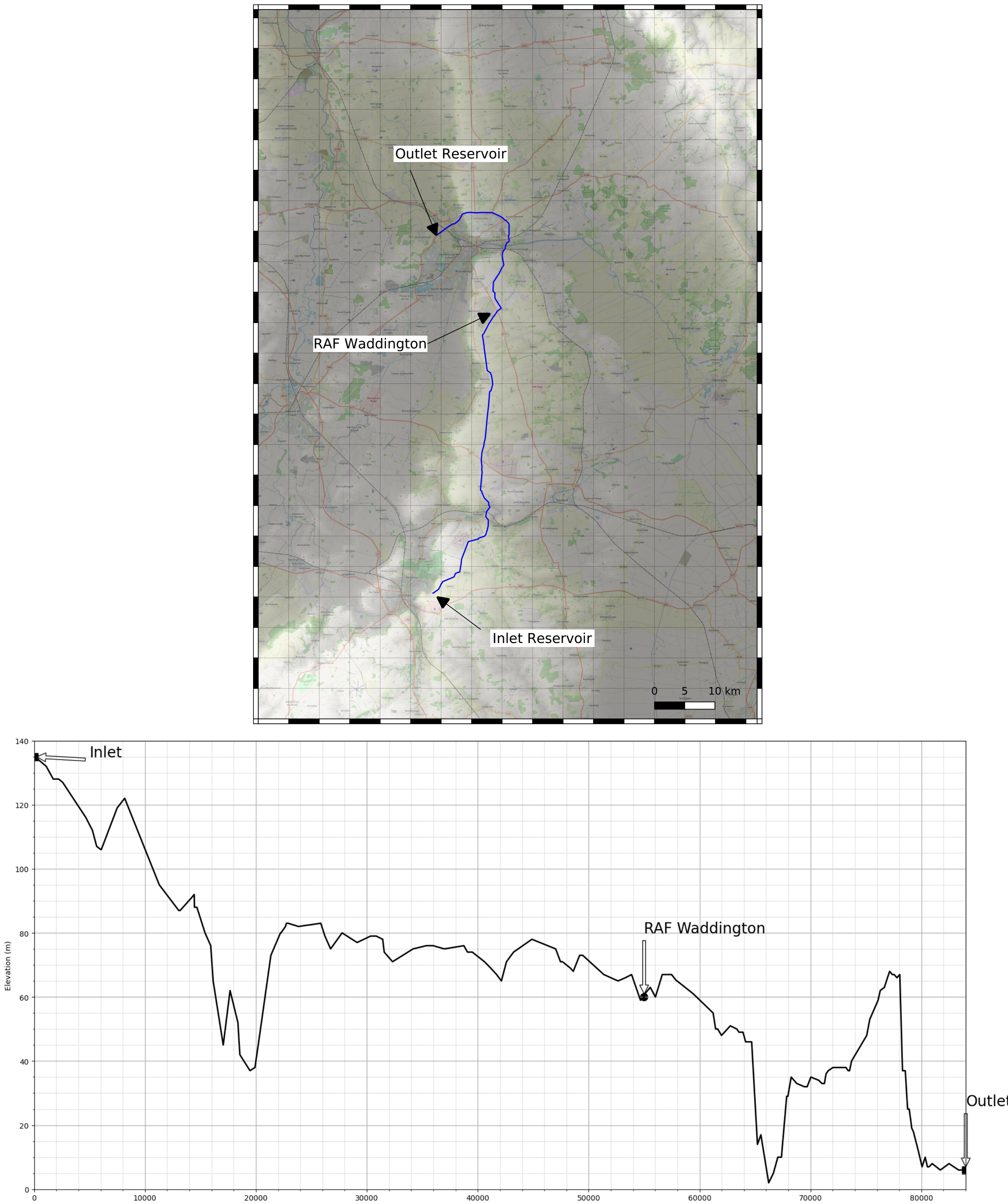

Figure 1: *Pre-agreed route of the pipeline from Grantham to Lincoln and route profile*

2 Coursework Problem

The first task is to build a series of conceptual models which address some common pipelines and networks. For this section of the coursework you will each have individual input data to use for your calculations.

2.1 Part 1: Flow between two reservoirs

For the first part of the work you need to assess the flow between two reservoirs assuming there are no customers or other connections drawing water from along the pipeline. The reservoirs are connected by two pipes with different properties, connected in series. This can be considered to be a simple representation of the final pipeline. Figure 2

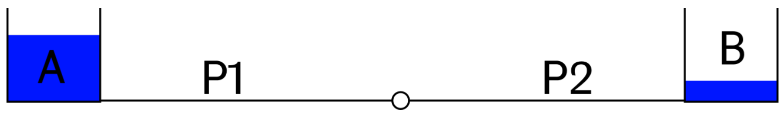

Figure 2: *Two reservoirs connected by two pipes (P1 & P2) in series*

You need to calculate

- the **flow rate** between the two reservoirs
- the **total head** at the junction between the two pipes

2.2 Part 2: Flow between two reservoirs, with a demand

To further assess the capacity of the pipeline, you need to ensure that the pipeline is capable of feeding additional of customers. In this simple stage you should assume that all the customer demands are lumped together as a single demand, Q_D, at the junction between the two pipes. This simple model might represent the potential for supply of water to RAF Waddington.

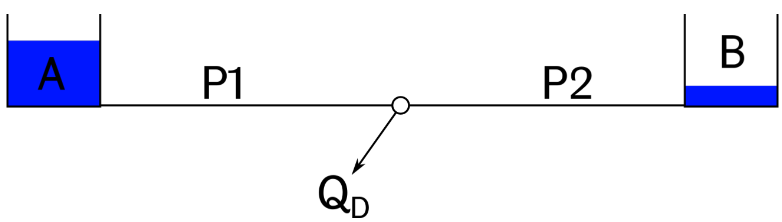

Figure 3: *Two reservoirs connected by two pipes (P1 & P2) in series with a demand (Q_D) at the junction between pipes*

You need to calculate

- the **flow rate** in each of the two pipes
- the **total head** at the junction between the two pipes

Input Data for the first 2 parts

To help ensure that the coursework is individually undertaken each student has their own data set for the first 2 calculation problems. You will find the data on the module Blackboard **Coursework Brief** tab, please let me know at the first opportunity if you cannot find your data set or you think there is an issue with the data.

You will each receive an individual set of pipe properties, reservoir heads and demands for this piece of coursework. You will find the this data in the file `Civ2300_CourseWork_Variables_20.xls`. This file is a table that lists all the required parameters against student ID numbers; first find your student ID number and read across for your individual properties. 'Length 1 (m)' corresponds to the length of the pipe P1 in the figures below, 'Diameter 2 (m)' to the diameter of pipe P2 etc. 'QD (l/s)' is the demand flow in Figure3.

The final two columns 'HA (m)' and 'HB (m)' give the **Total Head** at the first and second reservoir surfaces respectively, where the question only relates to a single reservoir use the values for 'HA (m)'.

For the first two parts you can assume all pipes have an absolute roughness of 0.01 mm, and that the elevation of the pipe is constant, you do NOT need to include minor losses in your calculations

2.3 Part 3a: Grantham to Lincoln Pipeline design

For this part of the work, rather than calculate a flow rate for given pipe properties you will have to make some decisions on pipe properties and produce a design for the Grantham - Lincoln pipeline.

Design Brief
The local water company requires a pipeline design that will allow the maximum continuous flowrate between the upstream reservoir at Grantham and downstream reservoir at Lincoln WTW, safety and integrity of the design are critical. This pipeline is designated as a piece of critical infrastructure so cost considerations are not the primary concern and do not need to be assessed however preference would be given to designs that demonstrate minimal environmental impacts.

Coursework Task
Whilst the **route** and **elevation** of the pipeline is fixed by the topography of the land (Figure 1), by consideration of a suitable hydraulic gradient you are required to make design choices about the **types** of pipe and the **diameters** of you wish to use at different sections of the route. You can break the pipeline into as many sections as you require.

Tables of pipe properties, and trenching conditions, can be found in Appendices B, other properties you should be able to determine from materials given to you during the course. Additional pipe furniture; valves, expansions, contractions etc. can be used if required.

You can assume that the water surface at the inlet reservoir is 4 m above the ground elevation at the start of the pipeline, and the water surface at the outlet reservoir is 2 m above the ground elevation at the end of the pipeline.

Your final solution will need to be supported by design calculations that demonstrate the viability of your solution and how it meets the brief.

2.4 Part 3b: Grantham to Lincoln Pipeline design with flow take off

The pipeline passes next to RAF Waddington, an active RAF base. To support and ensure the resilience of the RAF base the water company has been approached by the RAF to assess the potential for an additional water supply to the base. For this part of the coursework briefly detail the impact of supplying the base with a constant 10 l/s water supply would have on your pipeline design.

3 Assessment and Submission

The coursework needs to be submitted in two parts, the numerical solutions to the problems need to be submitted via a Google Form https://goo.gl/forms/XHoZQfwPnEAWJnDY2. All answers should be given to a suitable precision.

Part 3a and b needs to be submitted as a short (no more than 4 page, including all figures, appendices and references) outline of your design and a justification of decisions made. The coursework report needs to be submitted into Turnitin using the *Assessments/CIV2300 Report (Autumn)* section

Please ensure that any numerical calculations presented as part of the written report, are well laid out and clearly presented.

You will receive marks based on the numerical accuracy of the answers to the first 2 parts of the coursework (25%), and your design and the justification for your design choice for part 3a and b (75%). In addition the first three parts are not weighted equally:

- Part 1: 10%
- Part 2: 15%

The submission date for the coursework is **9 am on Friday 19th of November, Week 8**. I remind you that coursework can be submitted before the deadline.

4 Solution Techniques

I don't want to proscribe how you should undertake this coursework, the calculations should be able to be completed with hand calculations, using a spreadsheet or using a more general programming solution like PYTHON. However this assessment has been designed such that the early sections should be helpful for the later sections. Therefore if you create a suitable script for the first part it should be reusable in later parts etc., I hope that this should steer you towards something like PYTHON. Also you may have to undertake many iterations to get a converged solution, so it will be an awful lot of hand calculations, so that may also steer you towards a computational approach.

4.1 Hints on iterative solutions in PYTHON

This section is designed to help you undertake the problem using some basic PYTHON scripts.

The basic way of iterating through a calculation in PYTHON is to employ a **loop**. There are a number of different types of loop but the easiest to setup is the **for** loop. An example of this in *pseudocode* is given in Listing 1

```
P = 2  #Some parameter

A = 1  #Initial Guess of variable
for n in range(1,100):
  A = f(A,P)  #some function that calculates A using A and the parameter P

print(A)   #Final value of the variable
```

Listing 1: *Pseudo-code to undertake an iterative calculation*

This is a very simple approach but can be usefully employed to solve problems in pipeline flows. Listing 2 shows a *for* loop being used to calculate the flow rate along a pipe if the headloss is known, and it is already known that the flow will be **laminar**. If you copy this code and run it in a PYTHON script you will see that it will always run for 20 iterations, and the Reynolds number converges to approximately 381.

```
import numpy as np
# The physical properties
rho = 998
mu = 1e 3
g = 9.81

# The system properties
d = 0.005
l = 500
hl = 5

#Initial guess of the Reynolds Number
Reynolds = 1e2

# Looping through 20 times
for i in range(20):
  lam = 64 / Reynolds; #Calculating the laminar friction factor
  V = np.sqrt(2 * g * d * hl / (lam * l)); #Calculating the velocity from the Darcy Equation
  Reynolds = rho * V * d / mu #Calculating the Reynolds Number associated with the calculated
    velocity

#Check that the Reynlds number for the last few iterations hasn't changed
#The final flow rate
Q = V * np.pi * d**2 / 4
print(Q)
```

Listing 2: *Python code to calculate the flow rate for known headloss for laminar flows*

This loop uses the previously calculated Reynolds number as the start point for the next step of the loop, which is not always the most efficient method, however it should get you to a solution. The loop is also not intelligent as it doesn't know when to stop, the number of iterations is pre-determined before running. If you change the system properties and the initial guess of Reynolds number you will be able to find examples which converge after only one or two iterations (or maybe not at all). It is possible to programme more intelligent loops that will stop when the solution is suitably converged (i.e. the difference between the current and previous result is smaller than some preset value), this can be achieved via a *while* loop or *conditions* (*if* and *else* statements)inside the *for* loop.

When programming if you can write down step by step what you want to achieve (either in words or equations) you can programme it. All you then need is the exact suitable commands, and the best place for that is Google. *'How do I ... in PYTHON'*.

Appendices

A Route Profile

A digital version of the route profile, Figure 1, can be found from the excel file `Profile.xlsx`, which is in the Coursework Brief folder in the module Blackboard Page.

B Pipeline Properties

B.1 Polyethylene Pipe

Embodied Carbon for PE pipes 2.52 (kg CO_2 /kg)

Table 1: *Polyethylene Pipe weights*

Polyethylene Pipe					
	Pressure Rating				
	PN 2.5	PN 4	PN 6	PN 10	PN 16
Nominal Diameter (mm)	Pipe Weight (kg/m)				
20				0.11	0.16
25			0.13	0.17	0.24
32			0.19	0.28	0.39
40		0.21	0.29	0.44	0.61
50		0.32	0.45	0.68	0.95
63	0.33	0.48	0.7	1.1	1.5
75	0.46	0.69	0.9	1.5	2.1
90	0.65	0.99	1.4	2.2	3.1
110	0.96	1.5	2.1	3.2	4.6
125	1.3	1.9	2.7	4.1	5.9
140	1.6	2.4	3.4	5.2	7.8
160	2	3.1	4.4	6.8	9.6
180	2.5	3.9	5.6	8.6	12.1
200	3.1	4.8	6.9	10.6	15
225	3.9	6	8.7	13.4	19
250	4.9	7.4	10.7	16.4	23.4
280	6.1	9.2	13.4	20.6	29
315	7.6	11.8	17	26	37
355	9.7	14.9	21.6	33	47
400	12.3	18.8	27.3	41.9	60
450	15.9	24.3	35.3	54.3	77
500	19.7	30	43	67	
560	24.5	37.7	54.5	84	
600	26.9	43.7	63	96	
630	31	47.7	69	106	
710	39.5	60.5	88		
800	50	77	111		
900	63	97	141		
1000	78	120	173		
1200	112	172			
1400					
1600	199	306			

Table 2: *Polyethylene pipe ratings*

Pressure Rating	Max Pressure (bar)
PN 2.5	2.5
PN 4	4
PN 6	6
PN 10	10
PN 16	16

B.2 Cast Iron Pipe

Table 3: *Cast Iron Pipe weights and maximum allowable pressures*

	Cast Iron Pipe					
	Schedule 40		Schedule 80		Schedule 160	
Nominal Diameter	Weight (kg/m)	Pressure Max (bar)	Weight (kg/m)	Pressure Max (bar)	Weight (kg/m)	Pressure Max (bar)
DN8	0.37	56.5	0.47	78.7		
DN10	0.63	55.0	0.8	74.1		
DN12	0.84	45.4	1.1	62.9		
DN15	1.27	43.7	1.62	58.9	1.95	75.4
DN20	1.69	36.1	2.2	49.2	2.9	70.0
DN25	2.5	34.0	3.24	45.8	4.24	63.9
DN32	3.39	28.4	4.47	38.6	5.61	50.6
DN40	4.05	25.6	5.41	35.4	7.25	49.7
DN50	5.44	21.8	7.48	30.9	11.11	48.7
DN65	8.63	23.8	11.41	32.3	14.92	43.9
DN80	11.29	20.8	15.27	28.8	21.35	42.1
DN100	16.07	17.7	22.32	25.2	49.11	37.8
DN125	21.77	15.6	30.97	22.7	67.56	36.5
DN150	28.26	14.2	42.56	21.9	111.27	35.3
DN200	42.55	12.6	64.64	19.5	172.33	35.2
DN250	60.31	11.4	96.01	18.6	238.76	34.6
DN300	79.73	10.7	132.08	18.1	281.7	33.8
DN350	94.55	10.5	158.1	18.0	365.35	33.5
DN400	123.3	10.5	203.53	17.7	459.37	33.3
DN450	155.8	10.5	254.55	17.5	564.81	33.1
DN500	183.42	10.0	311.17	17.3	672.26	32.5
DN600	255.41	9.6	442.08	17.1	808.22	32.8

Embodied Carbon for Cast Iron pipes 1.45 (kg CO_2 /kg)

B.3 Trench Properties

Table 4: *Pipe trench sizes*

Pipe Nominal Size (mm)	Minimum Trench Width (mm)	Minimum Trench Depth (mm)
< 80	300	Pipe Nominal Size + 1000
$80 - 600$	Pipe Nominal Size + 300	
> 600	Pipe Nominal Size + 600	

Carbon Equivalent for pipe trench excavation and reinstatement 4.18 (kg CO_2 / m^3)

C Suggested Reading

- Hydraulics in Civil and Environmental Engineering, Chadwick and Morfett

- Drinking Water Distribution Systems: Assessing and Reducing Risks (2006) Chapter: 1 Introduction available at: https://www.nap.edu/read/11728/chapter/3
- Twort's Water Supply, Ratnayaka, available as an electronic resource through StarPlus