Potable Water Supply Design Project

Optioneering Report

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Group 6

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EXECUTIVE SUMMARY

The group has been called upon by Scottish Infrastructure Solutions PLC to provide a design solution for a water treatment facility in North Kilbride. Raw water is to be taken from the available Buzzardland Reservoir and sanitised so as to meet applicable Scottish water quality standards. It is to be delivered to an approximate population of 40000 in nearby developments, plus some light industry. Cost, area, ability and risk assessments were carried out for the various available treatment processes, allowing the group to put forward the most appropriate and effective option for the design process.

The chosen design proposal employs screening, coagulation, mixing and flocculation, dissolved air flotation, rapid deep bed filtration and chlorination. This combination efficiently removes or reduces impurity levels to the required safety levels. Options for the waste disposal, road, pipe and site layouts have also been provided in the report. Environmental impacts have been taken into account, with special consideration for the Buzzardland Muir Site of Special Scientific Interest.

The estimated cost of the design option put forward is £8 209 000.

CONTENTS

1. INTRODUCTION

The group has been given the task of designing a new water treatment works to replace the current supply to North Kilbride. Furthermore, the treatment works are to be designed to supply a new development to North Kilbride, Buzzardland village and some light industry. The following report explores the possible options for treatment processes and delivery. The final proposal is intended to deliver purified water the quality of which is in accordance with the relevant Scottish water quality legislation[1]. A preliminary costing will be devised.

2. HYDROLOGY REPORT

2.1 Raw Water Supply

The water input into the new water supply system is from the Buzzardland reservoir. An intake will be constructed in the form of a 3 valve system at different levels, located immediately east of the dam structure and this will take water from the reservoir. Water availability calculations are based on flow data taken from the gauging station on the Leadwash River situated 6km downstream of the reservoir.

2.1.1 Assumptions

- The difference in the flow of the river at the gauging station and out the reservoir due to rain fall, run-off and suchlike is negligible. Therefore flow data from the gauging station is used for flow calculation at the reservoir.

- The total outflow of the reservoir at any point is constant and any water taken into the treatment plant will equal the resultant drop in flow in the Leadwash River. The reservoir outflow to the treatment plant is equal to the total demand flow = $0.110 m^3/s$, the calculations for which can be seen in Appendix 2.

- For environmental reasons listed later in section 6, a lower limit LL = $0.3\ m^3/s$ has been used for the stream, below which it is undesirable for the flow to drop.

2.1.2 Statistical analysis

The supply data from the Leadwash River gauging station consists of a daily average flow (m^3/s) for every day between Dec 1956 and Nov 2005. This data was statistically analysed in order to assess the ability of the river to meet the demand of the new water treatment plant, and to see how the flow in the river is affected by the plant. Graphs have been made for an overview, as seen in Appendix 1.

The statistical analysis has resulted in the conclusion that summer was the season which provided the highest probabilities of low flow; hence the results presented below deal with the dataset as a whole and the summer season.

Probability of flow falling below demand flow (= $0.110 m^3/s$):
Summer: 0.04%
All year: 0.04%

Probability of flow falling below environmental minimum (= $0.410 m^3/s$):
Summer: 8.93%
All Year: 3.72 %

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[1] Scottish Statutory Instrument 2001, No 207: The Water Supply (Water Quality) (Scotland) Regulations 2001, http://www.opsi.gov.uk/legislation/scotland/ssi2001/20010207.htm#sch2, accessed 7/10/08.

The probability of the flow dropping below demand is well within acceptable limits and so a 24hr service reservoir is sufficient.

The probability of the flow dropping below the environmental minimum is less than 10%. This is deemed acceptable.

2.2 Raw Water Demand

The new water treatment plant is to replace the existing water supply to the town of North Kilbride, population 30 000, and provide for its new development of 4000 homes and supply the village of Buzzardland. Water is also required for light industry in the area. Industrial water use may vary depending on the type and scale of industry

The total water demand is calculated to be 0.110m3/s. The calculations for this are available in Appendix 2.

3. TREATMENT PROCESSES

3.1 Water Quality Standards

The objective of the treatment systems explored below is to produce a final water supply which will comply with the conditions and limit values presented in the The Water Supply (Water Quality) (Scotland) Regulations 2001[2].

3.2 Impurities Present in Raw Water Supply

The source of raw water for the proposed works is the Buzzardland Reservoir. As with most water sources, the reservoir will contain a number of substances and organisms which, if not removed or reduced, will prevent the supply from meeting the applicable quality requirements. The impurities to be considered are listed below:

- floating debris (branches, gravel, etc.)
- suspended solids (causing turbidity)
- manganese and iron (in solution)
- bacterial pollution
- colour
- tastes
- odour
- algae

The relevant standard values are shown in the following table, together with the equivalent values of the raw water supply from the Buzzardland Reservoir.

Parameter	**Maximum Allowable Value**	**Current Maximum of Raw Water Supply**	**Current Average of Raw Water Supply**
Turbidity (NTU)	1	13.3	1.42
Colour (mg/l Pt/Co)	20	145	17.82
Iron (µgFe/l)	200	654	179
Manganese (µgMn/l)	50	80.72	32.6
pH	6.5 – 9.5	8.9	7.21

Table 1: Quality standard values and corresponding values of raw water supply

After communication with local authorities in the surrounding area of the Buzzardland Reservoir, it can be concluded that taste and odour are also present in the raw water supply. As a result measures must also be taken for the removal of these impurities.

See Appendix 3 for an outline of the various processes which were considered for the removal of or reduction of such impurities to acceptable levels.

[2] Scottish Statutory Instrument 2001, No 207: The Water Supply (Water Quality) (Scotland) Regulations 2001, http://www.opsi.gov.uk/legislation/scotland/ssi2001/20010207.htm#sch2, accessed 7/10/08.

3.3 Removal of Impurities

Below is a table which summarises the ability of each of the aforementioned to remove particular contaminants and impurities. It should be noted that reference has only been made to the impurities that are actually present in the raw water supply from the Buzzardland Reservoir - the number of contaminants which may be removed by the treatments has not been exhausted.

Process	**Debris**	**Algae**	**Turbidity**	**Colour**	**Taste**	**Odour**	**Iron**	**Manganese**	**Pathogens**
Screening	Y								
*Floc Blanket Clarification**		Y	Y	Y			Y		
*Dissolved Air Flotation**		Y	Y	Y			Y		
Rapid Deep Bed Filtration			Y	Y			Y	Y**	
Slow Sand Filtration		Y	Y						
Ultrafiltration				Y*					
GAC		Y		Y	Y	Y			
UV Irradiation									Y
Ozonation		Y			Y	Y			Y
Chlorination					Y	Y	Y***	Y***	Y

Y = Yes
*In conjunction with coagulation and flocculation
**When used with oxidation and pH adjustment
***When used as the oxidant before filtration

Table 2: Ability of processes to remove impurities

3.4 Costs and Area Required

An estimate of the required area and consequential cost for each of the treatment processes is shown in Appendix 11. The civil, mechanical and land costs are also included, allowing for a comparison of the economical and physical demands of the individual treatments.

It should be noted also, that a redundancy factor has been included, to allow for continued service even if faults occur in any of the separate processes. With regards to the land required, an estimate of extra land needed for mechanical parts, storage etc has been made as a percentage of that required for the beds.

3.5 Process Selection

The information in sections 3.3 and 3.4 can be used to draw comparisons and eliminate several treatments:

Slow sand filtration:
Clarifying processes are capable of removing the same contaminants as slow sand filtration as well as others, and so it is impractical to use slow sand filtration. Furthermore, the capital cost of slow sand filtration is 250% more than either clarification methods. Therefore this process has been discarded.

Ultrafiltration:
With regards to the water taken from the Buzzardland Reservoir, ultrafiltration would only be effective in removing colour. However there are other processes which are capable of removing colour together with other contaminants. If the supply contained cryptosporidium or was particularly high in colour, then consideration would be given towards ultrafiltration; however this is not the case and so it has

been disregarded.

UV Irradiation:
UV radiation has the advantage of requiring little area; however its lack of residual effect leaves it vulnerable to contamination further downstream. Furthermore, unlike both ozonation and chlorination, it doesn't have the ability to remove taste or odour. Consequently this process can be discounted.

It is necessary to eradicate any pathogens which are present in the water supply. After the above eliminations, the only remaining treatments which do so are ozonation and chlorination. However as with UV irradiation, the use of ozone provides no residual effects and so its decontamination abilities are only temporary - the supply is once again vulnerable to contamination downstream. This would then impose the use of chlorination to eradicate the reoccurring bacteria; therefore it is practical to use chlorination for the sole disinfection of the water.

3.6 Risk Assessment

At this stage a risk assessment is to be carried out on both the mechanical and the chemical aspects of the remaining treatments. These can be seen in Appendix 12.

3.7 Sequences of Processes

From the remaining treatments, three combinations have been decided on for the purification of the raw water supply from the Buzzardland Reservoir and can be seen in Appendix 3. Each sequence has the capability to treat the water adequately, ensuring it meets the applicable standards. They can each be seen below.

To decide upon a final sequence, comparisons are required between floc blanket clarification and dissolved air flotation:

- Dissolved air flotation has a lower capital cost but a higher operating cost than floc blanket clarification.
- The area required for the bed for dissolved air flotation is a quarter of that needed by floc blanket clarification, resulting in a more compact treatment with less land purchase costs.
- Floc blanket clarification requires a very high level of control over the flow rate - if the rate is too high, the floc blanket could rise to the top and overflow into the clean water. This would have a detrimental effect on the performance of downstream treatment units. The flow rate is not such a concern for dissolved air flotation.
- Dissolved air flotation is more susceptible to mechanical failure than floc blanket clarification due to the greater number of mechanical parts.
- Dissolved air flotation is preferable over floc blanket clarification for waters which are high in colour and low in turbidity - this is the case for Buzzardland reservoir water.

These reasons lead to the conclusion that dissolved air flotation is the better choice of clarification process.

The final consideration is whether or not to use GAC in the treatment of the water supply. Activated carbon is an excellent method for removing impurities like taste, colour and odour, all of which are present in this supply. However these impurities are removed to the required levels by other process units, therefore GAC is not needed. Although GAC is disregarded presently it should be noted that it also removes impurities such as algae, organic compounds, algal toxins, total organic carbon (TOC) and pesticides. If the water was to become contaminated with these impurities, then GAC would be a viable option of removal.

It can therefore be concluded that sequence 2 is the preferable combination of processes.

4. TREATMENT WORKS DESIGN

Refer to Appendix 4.

Figure 7 shows the proposed site for the water treatment works, which will supply Buzzardland Village, and North Kilbride including the new development and some light industry. A site investigation report has been carried out. The boreholes allowed a set of data on the soil conditions for the site to be produced. This data will be used in the next stage of design to finalise the placement of structures and to design their foundations. Ideally the works will be situated close to the dam in the reservoir and the road already in place. This will keep costs to a minimum.

A summary of the borehole findings can be found in Appendix 4.

The site investigation shows conditions that suggest the area is suitable for construction of the water treatment works. It is advised that the area characterised by borehole 4 should not be used for construction due to a potential cost increase.

Using the information from the ground survey, a layout for each of the three different processes proposed. These can be seen in Appendix 5.

5. TREATED WATER DELIVERY

The treated water will be delivered to North Kilbride and Buzzardland village through a series of pipelines and service reservoirs. The sludge produced during treatment will have to be disposed of accordingly.

5.1 Delivery Options

The pipeline is required to connect the new water treatment plant to the town of North Kilbride including its new development via a service reservoir. Presented are two options for the placement and number of service reservoirs, and two for the route taken by the pipeline. All of these options can be seen in Appendix 7.

5.1.1 Pipeline Route Options

A. This Route cuts directly through the countryside, Southwards from the treatment plant to the reservoir. It passes the SSSI on the west side. It is about 11km in length.

B. This option follows the road, staying on the west side, and passes between SSSI and the road. It follows the road all the way to North Kilbride Route B follows the lie of the land and would only need the one pipe that would go around the village. If service reservoir Option 1 is used, the pipe will skirt the town and new development to reach the reservoir. It is about 15km in length.

Route A has the advantage of being very direct and therefore shorter, but it does cut through a greater amount of open countryside than route B. This disrupts the environment more, and makes access to build and maintain the pipeline more difficult.

Route B would be easier to access when laying the pipe. Less land would need to be bought as runs parallel to the road with this option, but the pipeline itself will be longer than route A, particularly if it is to skirt the town. This route has more fluctuations in height.

The approximate cost of the pipe was estimated at £500 000 and the pump required would cost £8100. Details of this calculation can be found in Appendix 10.

Recommendation
The route that is recommended is service and route A. This will provide the best service for cost.

5.1.2 Service Reservoir Location Options

Domestic demand varies throughout the day due to lifestyle. Industrial water use has been assumed to be regular throughout the day and overnight due to the possibility that equipment is running 24 hours a day. The options for the service reservoir are as follows:

1. The first is to have one Service reservoir to supply the Town, new development and light Industry, and another supplying the village:

    i. For the town, reservoir would be located on the highest point of the map provided, just west of the new development.
    ii. For the village, the reservoir would be located North-West of the Village. This will be a very small reservoir.

    This arrangement has the advantage of being immediate. A It will also serve as a buffer after the treatment plant itself.

2. The other possible situation for the service reservoir would be beside the new treatment works.

Option 1 provides the North Kilbride with a reservoir with the greatest hydraulic head. Also its close proximity to the town is advantageous. By doing this, another reservoir to serve the village will need to be created. This second reservoir could potentially be dual-purpose as it could also be used as buffer between treatment and pumping.

Option 2 has the advantage of being on location of the main build, where the ground is already tested and the bulk of the construction will be happening anyway. Also, it serves both the Buzzardland Village and North Kilbride.

Recommendation
It is advised that option 1 be taken forward to the design process. The better service it provides outweighs the comparative inconvenience and increase of cost.

5.1.3 Service Reservoir Tank Dimensions

The dimensions are summarised below, and the calculations can be found in Appendix 8

Reservoir 1i and 2

Volume	=	1200 m^3
Length	=	20 m
Width	=	20 m
Depth	=	3 m

Reservoir 1ii

Volume	=	240 m
Length	=	20 m
Width	=	12 m
Depth	=	3 m

5.2 Sludge Disposal Proposals

Sludge is collected from the dissolved air flotation and the rapid deep-bed filtration stages of the water treatment system. Sludge thickening is required to increase the percentage of dry solids in the waste. Thickening the sludge reduces the volume that has to be treated further, therefore reducing costs and size of follow on units. Sludge dewatering can be carried out once a polyelectrolyte has been added. The sludge is pumped into a filter press for the dewatering process to increases the solid concentration to 20% allowing it to be transported to a landfill site. The water that has been extracted from the mixture is then either pumped back into the system or disposed of into the local stream. In this instance it has been decided that the waste will be recycled back into the system. An alternative disposal method would be to discharge the waste in the sewer system. This is only a possibility if the sludge concentration is kept low and permission is granted from sewerage authorities. Pipes to allow the sludge to enter the sewer system have to be designed and would add to the costs of the project.

5.2.1 Sludge thickening

The sludge thickening tank will need to hold the total volume of the sludge that needs to be treated. Therefore a tank of 4m deep with a radius of 5m would be suitable.

5.2.2 Sludge dewatering

Press dimensions for sludge tank
1.42m x 100.44m

Refer to Appendix 9 for calculations for sludge disposal.

5.3 Road Construction Works

In order to access the new treatment facility the existing road needs to be upgraded to be suitable for the increased amount of traffic. The road currently follows the valley from the existing town on North Kilbride to the old mine works alongside the River Leadwash. The decision to upgrade the existing road rather than design a new route was made as would be the cheaper option. The road currently goes through the Buzzardland Muir which is a site of special scientific interest (SSSI) due to badger breading. The impact of resurfacing the road should be minimal and not have a significant impact on the surrounding area.

A cost for the upgrade of the road can be done based on the length of the route and can be seen later in section 7. Depending on where the plant is situated beside the old mine works a small section of new road may be required.

6. ENVIRONMENTAL IMPACT ASSESSMENT

The area of land between the proposed treatment works and the town is designated as a Site of Special Scientific Interest (SSSI). The principal interest in the area is the population of badgers and their suitable habitat allowing them to bread in the designated areas. The most likely impact to badgers would be disturbance due to noise from the construction, which could potentially disrupt the breeding patterns of the badgers. Therefore as far as possible the new water treatment, pipeline and the access road should avoid the Muir. If this is not possible the construction should be kept to a minimum and construction methods thought through to minimise the environmental impact in the area. Consultations may need to be carried out with parties such as the Scottish natural heritage (SNH) if work is to be carried out within the SSSI. Restrictions as to the time of year work can be carried out could be put in place.

Environmental impacts should be kept to a minimum with all work that is to be carried out to prevent damage to wildlife and plants. Any work involving chemicals could result in localised pollution of the river. The impacts would depend on the substance concerned and the water flows and catchments of the river. Appropriate planning permission will need to be given before any work can be carried out on site.

When taking water from the reservoir, it important to consider the Leadwash River. Should too much water be taken by the plant, the river will run low, or dry up completely. This would be very bad for environment; many species of plant and animal life depend on the river for habitat, water, food and breeding. The size of the area affected by overdrawing from the stream is quite large. Wildlife for a matter of kilometres would be affected, and there would be affects all the way downstream. To counter this, precautions and limits will be put in place to ensure that the river is not dried up.

7. COSTING BREAKDOWN

7.1 Tank Cost

Reservoir 1i and 2

Cost = 3.0787 x volume^$^{0.55929}$
= 162 376
= £ 163 000

Reservoir 1ii

Cost = 3.0787 x volume^$^{0.55929}$
= 66007.87
= £ 66 000

7.2 Road

Assuming that the existing road is in need of upgrading for adequate access to the plant, the resurfacing will cost[3]:

Resurfacing road = £500 000 per km
Length of road = 10.4 km
Cost = 500 000 x 10.4
= £5 200 000

7.3 Land

The following calculations show the total area of the site and the cost of purchasing the entire site for which the site investigation has been undertaken. More detailed workings for these calculations can be found in Appendix 6.

Area of entire site = 33.83 Ha
Land costs = £5000 / Ha

Total cost of available land = 33.83 x 5000
= £169 150
= £170 000

Using the AutoCAD drawings for the site layouts the following data was found:

Option	**Area (m^2)**	**Cost of Land Purchase (£)**
1	13400	6700
2	10600	5300
3	13000	6500

Table 3: Cost and area of land for each option

From this we can see that Option 2 requires the least space and therefore costs the least to buy the land.

[3] Calculations completed with the aid of Civil Engineering first year road project figures, University of Edinburgh

7.4 Costs Summary

A summary of the costs for each of the three process options are shown in the table below:

Item	Process 1	Process 2	Process 3
Equipment	1035.41	976.69	1085.62
Sludge	494.23	494.23	494.23
Land	6.7	5.3	6.5
Piping	508.1	508.1	508.1
Roads	5200	5200	5200
Service reservoir	1024.39	1024.39	1024.39
Total	**8268.83**	**8208.71**	**8318.84**

Table 4: Summary of costs (£1000's)

8. CONCLUSIONS & RECOMENDATIONS

At this stage the group is putting forward a reccommendation of proposal 2 to be developed in greater detail. After considering all options, this design provides a safe and reliable method of purifying the raw water supply to the applicable standards. The pipeline is to cut across the countryside taking the most direct route. There are to be two service reservoirs one located by the village and the other beside the new development. the access road is to be resurfaced so it is suitable for access. The environmental imapct of the project will be kept to a minimum. A layout of the treament works has been proposed.

APPENDIX 1: WATER SUPPLY INFORMATION

Process

- The dataset was scanned for extraordinary/incorrect readings. All flow entries for Jan 1958 read -9999.0 m^3/s. These were discounted.

- The dataset was split into bins and a distribution plot made (Figure 1). This plot appeared to be exponential, so the Natural log distribution was also plotted (Figure 3 This gave a Normal Distribution.

- Using the cumulative distribution function, probabilities of particular flows were found.

- The dataset was spilt into seasons throughout the year, and the process repeated for each.

Winter	December - February
Spring	March - May
Summer	June - August
Autumn	September - November

  The distribution for summer can be seen in Figure 3.

Adjusted data and statistical analysis are available on excel documents.

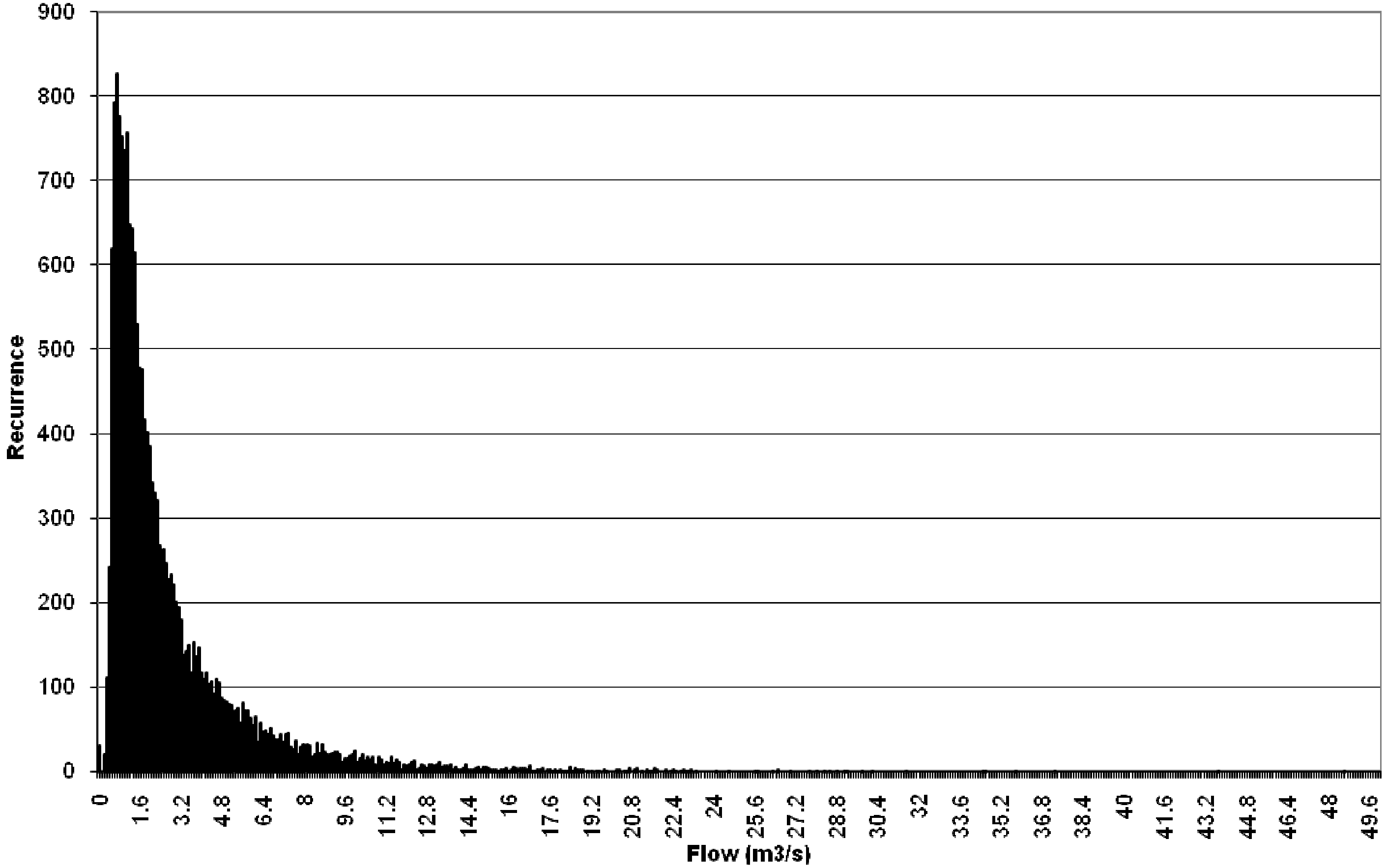


Figure 1: Distribution plot of data set

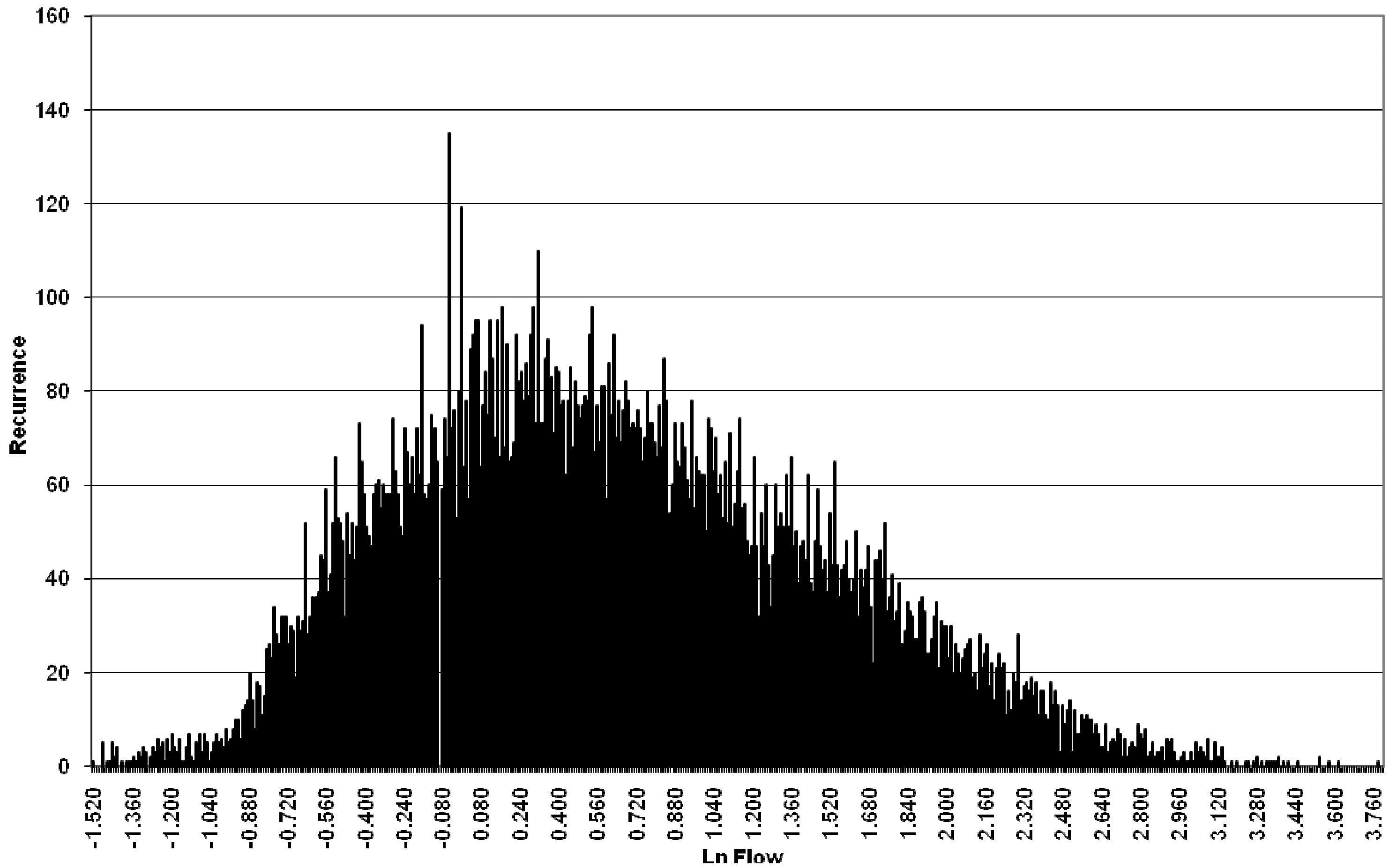


Figure 2: Natural log (Normal) distribution plot of dataset

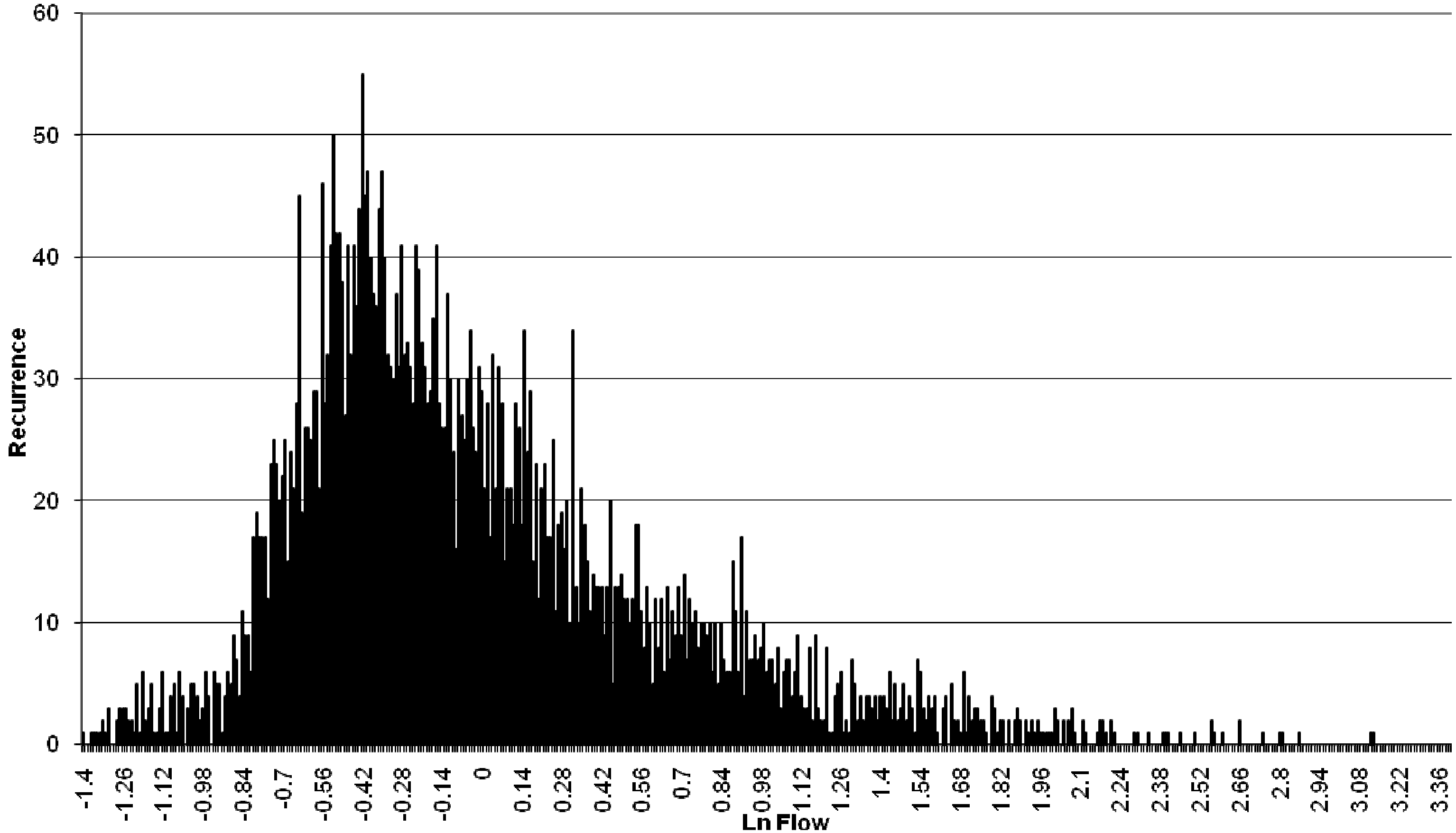


Figure 3: Natural Log (Normal) Distribution for summer season only

APPENDIX 2: SUPPLY/DEMAND

Supply is for:

A.	30000 heads	(North Kilbride town)
B.	4000 homes	(New development)
C.	650 heads	(Buzzardland Village)
D.		(Light industry)

Assumptions:

- 160 l per day per head
(seasonal differences in this are negligible)[4]
- 2.22 heads per home[5]
- +50% Domestic demand to cover light industry requirements[6]

A: North Kilbride

30000 x 160 = 4.8×10^6 l per day
= 4800 m^3/day

B: The New Development

4000 x 2.22 x 160 = 1.4208×10^6 l per day
= 1420.8 m^3/day

C: Buzzardland Village

650 x 160 = 104000 l per day
= 104 m^3/day

D – Light Industry

Water Demand due to industry and further development:

6324.8 x 0.5 = 3162.4 m^3/day
= 0.037 m^3/s

Total domestic demand

= A + B + C
= 4800 + 1420.8 + 104
= 6324.8 m^3/day
= 0.073 m^3/s

Total water demand

= A + B + C + D
= 9487.2 m^3/day
= 9500 m^3/day
= 0.110 m^3/s

4 Value obtained via email at simon.smith@ed.ac.uk
5 Value obtained via www.gro-scotland.gov.uk, accessed on 05/10/08
6 Value assumed

APPENDIX 3: TREATMENT PROCESSES

Treatment Overview

Screening:
A pre-treatment which is essential to prevent large debris such as branches, leaves, etc from entering the works. A number of coarse screens are followed by finer mesh screens, often in the shape of a rotating drum. The screens must be cleaned on a regular basis to prevent clogging.

Coagulation and Flocculation:
A coagulating chemical such as aluminium sulphate is added and rapidly mixed into the raw water to encourage the precipitation of suspended substances. These are then allowed to flocculate into visible particles, known as floc, and coalesce to become bigger. This floc is then separable as sludge from the water to be treated, to be removed by a clarification process.

Clarification:
The floc is retained as an expanded blanket of sludge and is removed via a number of processes, two of which are explored below. The waste is disposed of accordingly (discussed later).

Floc Blanket Clarification

Coagulated water is fed into the bottom of the tank, causing the water to flow in an increasing upward flow pattern, and encouraging further flocculation. When the settling rate of the floc equals the velocity of the upward flow, they become suspended in the middle of the tank in the form of a floc blanket. The blanket then serves as a filter bed for smaller particles, leaving the treated water above it. The floc is the removed using hoppers in the middle of the tank.

This process can be varied by using conical hoppers which provide more control over the water flow rate, due to the increasing cross-sectional area. This however increases the plant area required.

Dissolved Air Flotation

Air is dissolved into a small proportion of the treated water at high pressure prior to being released into the raw water. The subsequent decrease in pressure causes the air to form micro bubbles, which when rising, attach to the floc particles resulting in a combined density which is less than that of the water. The bubbles rise to the surface, taking the floc with them; the sludge can then be removed, normally by mechanical scrapers.

Filtration:
Any remaining particulate matter is removed by one of the following methods:

Rapid Deep Bed Filtration:

Filters are designed and employed to remove any remaining particles in the water throughout the depth of a media, namely sand. The direction of flow is downwards, with accumulated material being removed periodically by back-washing; this is done using recycled treated water. If multiple layers are used with different media as well as the sand, such as anthracite or gravel, the efficiency of the filtration process can be optimised.

When combined with coagulation, this process removes colour, iron, aluminium and turbidity. If an oxidant is applied with a pH adjustment, manganese can also be removed.

Slow Sand Filtration:

This form of filtration is much less complex than rapid deep bed filtration, using biological processes to work. It operates with lower flow rates and with much finer sand. The water is passed through a layer of sand, on which a layer of bacteria and algae form, called 'Schmutzdecke'. The sand supports this 'Schmutzdecke', which in turn is able to consume further impurities present in the water. This layer is then able to consume further biodegradable matter in the water, purifying the water.

If necessary, the water can be further purified by the following processes:

Ultrafiltration:

Finer particulate matter is removed from the water when it is forced against a semi-permeable membrane at high pressure. The filter is back-washed by air and treated water to clean it of any build-up of solids. The filters are arranged in hollow tubes and coagulants can be used for the removal of colour and other colloidal matter.

Granular Activated Carbon Adsorption (GAC):

The combustion of carbonaceous material produces a very porous media with a large surface area available for adsorption. The water containing negatively charged contaminants is passed through and held by the positively charged carbon. The high affinity of the GAC is used to remove trace organic compounds, taste and odour compounds colour, algae and total organic carbon.

As opposed to using GAC adsorption, powdered activated carbon can be fed into the stream to be later removed by filtration.

Disinfection:

Disinfection is an essential stage of water purification for the eradication of any remaining pathogens or viruses which could be potentially lethal if not removed. Methods of decontamination are as follows:

Ultraviolet Irradiation:

High power UV light is passed through the clear water, denaturing molecules within bacteria and so killing the bacteria. This process is virtually instantaneous, but has no residual effect.

Ozonation:

Ozone-enriched air is a powerful oxidant; when diffused through the water it oxidises impurities and pathogens, and can be used to treat taste and odour, algae and organic material.

Chlorination:

Another form of disinfectant, chlorine also works to oxidise impurities by the formation of hypochlorous acid and hypochlorite. Together these cause an antibacterial action. Taste, odour and colour are also treated.

Process Schematics

The following diagrams illustrate the 3 options put forward for water purification.

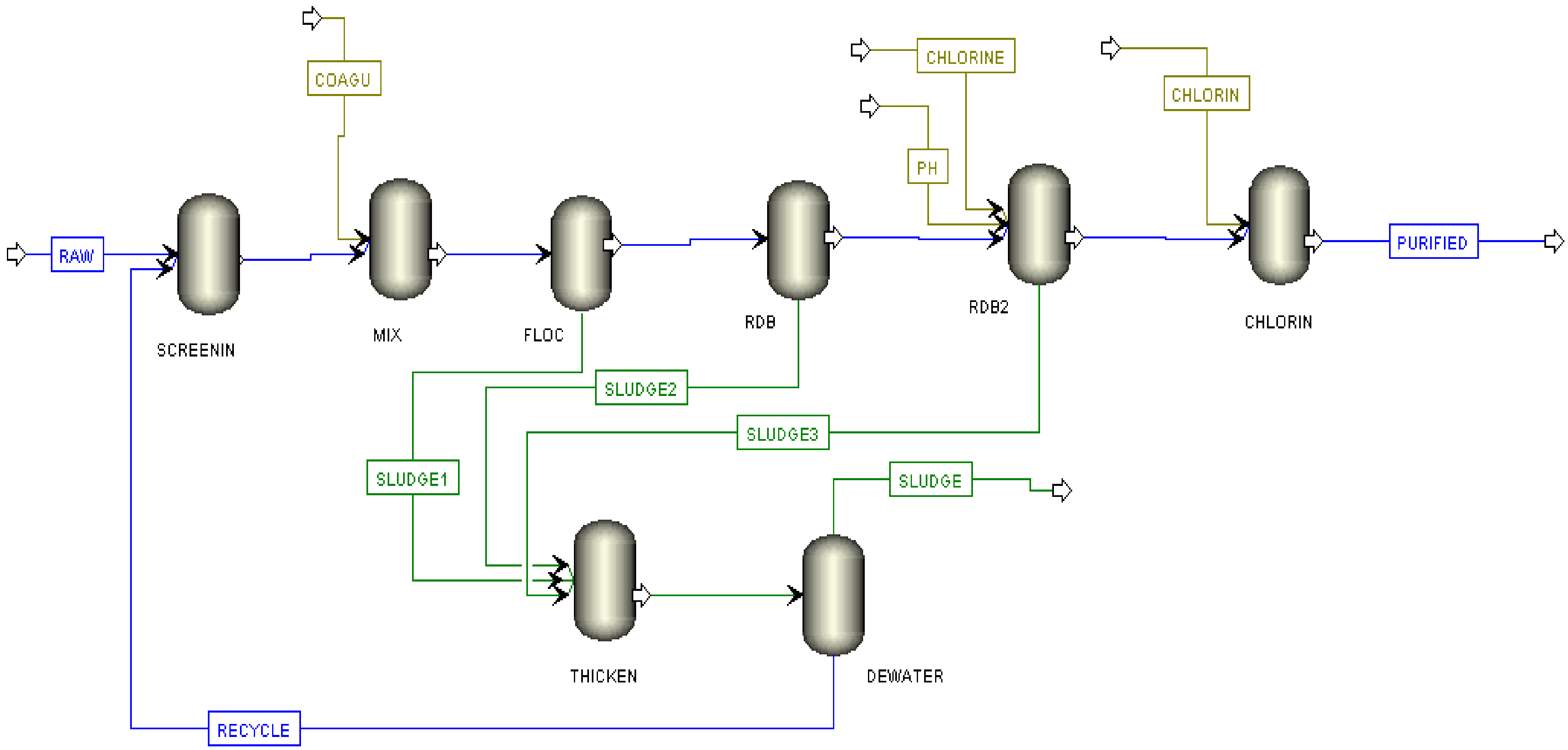


Figure 4: Schematic for process 1

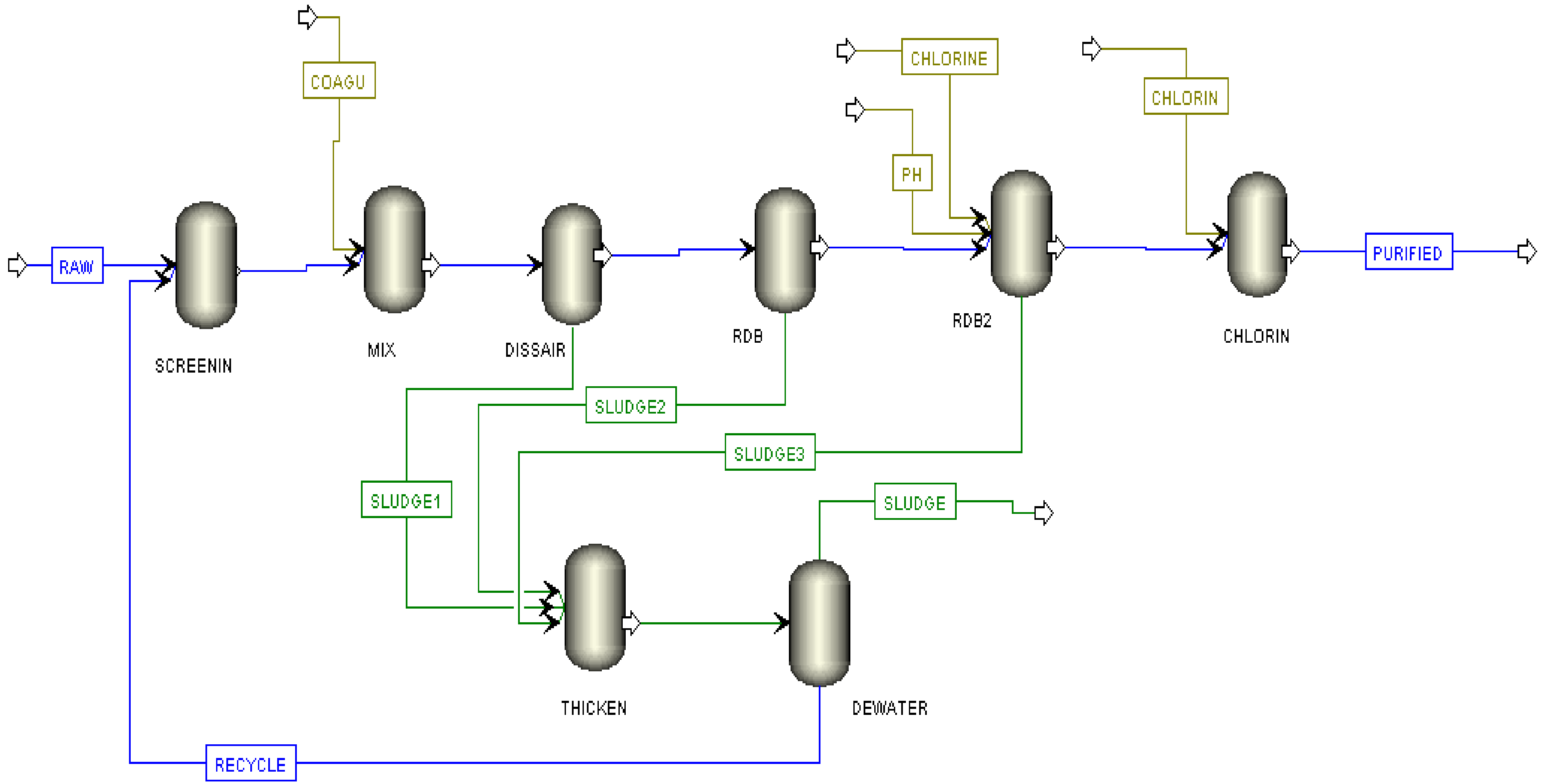


Figure 5: Schematic for process 2

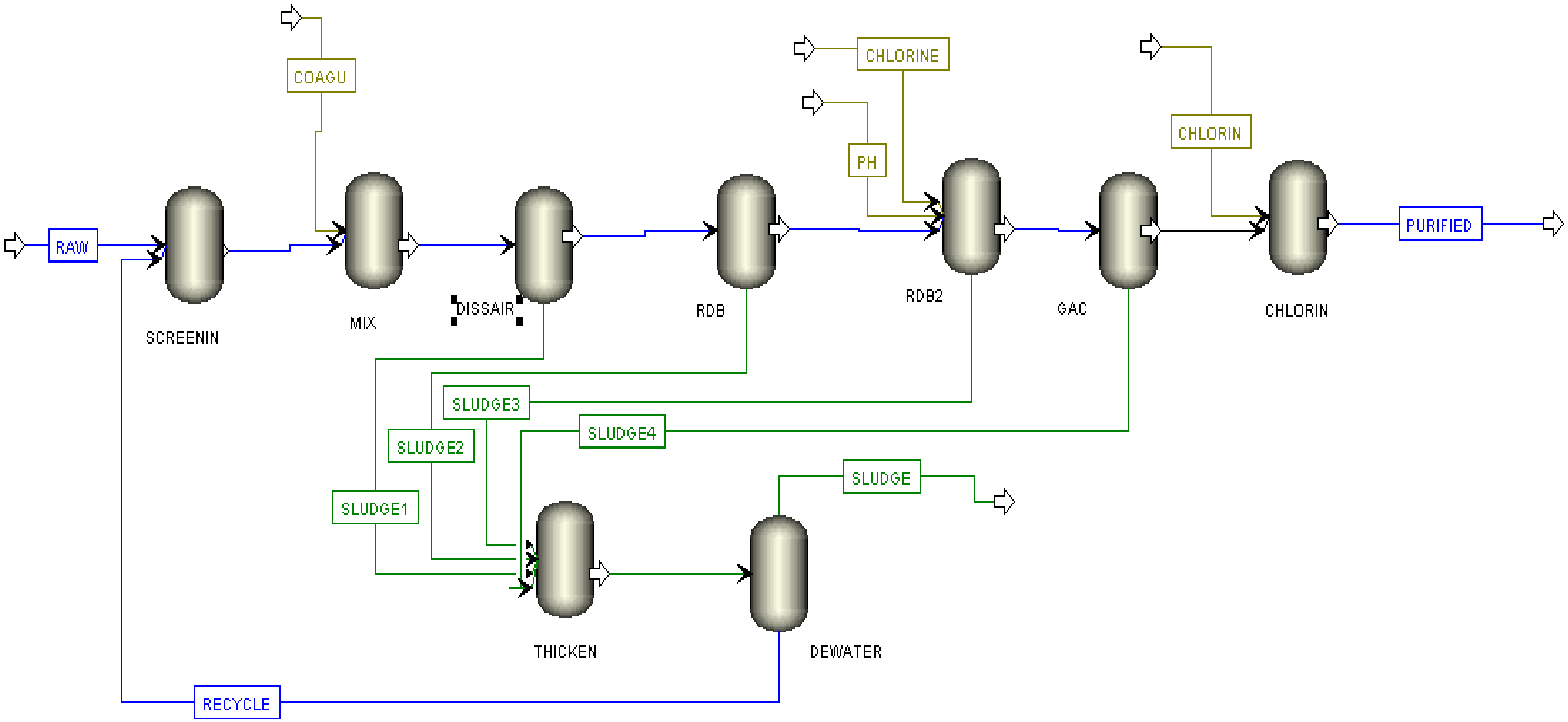


Figure 6: Schematic for process 3

APPENDIX 4: GROUND SURVEY

Borehole Locations

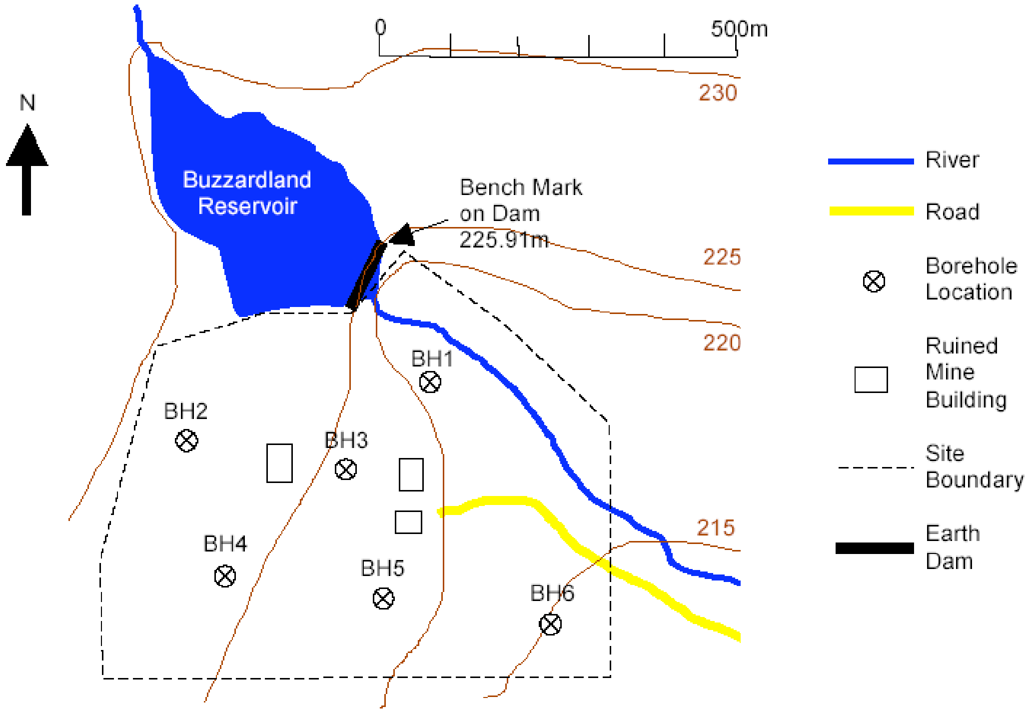


Figure 7: Site plan including borehole locations[7]

Borehole Findings Summary[8]

Borehole 1:
Ideal for construction. Gravel was found up until 7.25 m depth and then sandstone was found for another 3 m. These conditions mean that construction is advised for this area.

Borehole 2:
Suitable for construction, though not as good as BH 1. Gravel was found down to 3 m depth and from there until 10 m depth gravel and cobbles were found.

Borehole 3:
Suitable for construction. Shows three different soil types - gravel in two different silt combinations and then cobbles from 7 m. All can be used for construction.

Borehole 4:
Undesirable for construction. There is 3 m of soft clay that would need to be examined carefully before construction. This area can be used if it is required, but would likely incur additional costs.

Borehole 5:
Suitable for construction. The two different types of sandstone that can be found in this area are adequate for construction.

Borehole 6:
Suitable for construction. Gravel and cobbles are found for the first 3 m, then sandstone thereafter for the remaining depth.

[7] Figure taken from data provided by Scottish Infrastructure Solutions PLC
[8] Based upon information from Site Investigation Report, as provided by Scottish Infrastructure Solutions PLC

APPENDIX 5: SITE LAYOUTS FOR EACH OPTION

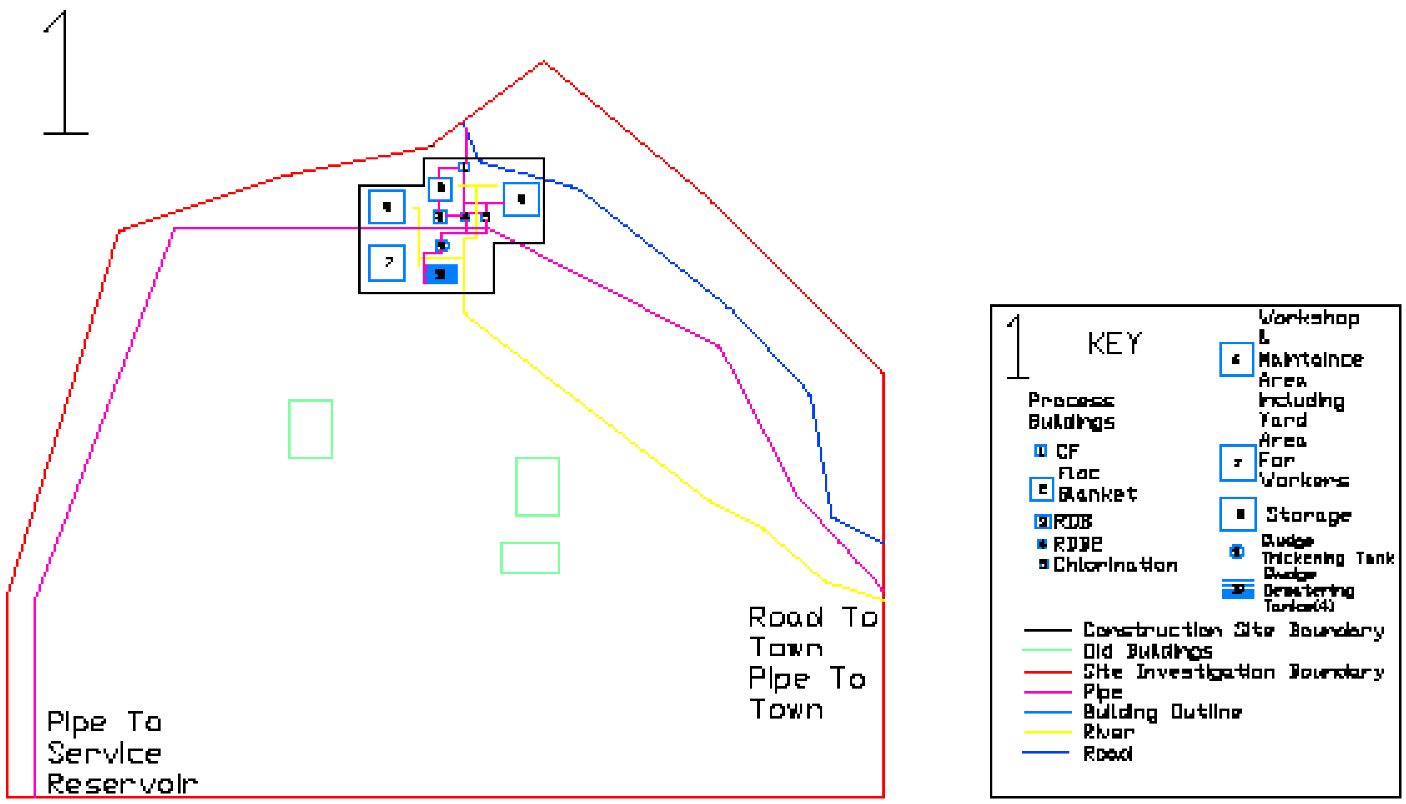


Figure 8: Site layout for option 1

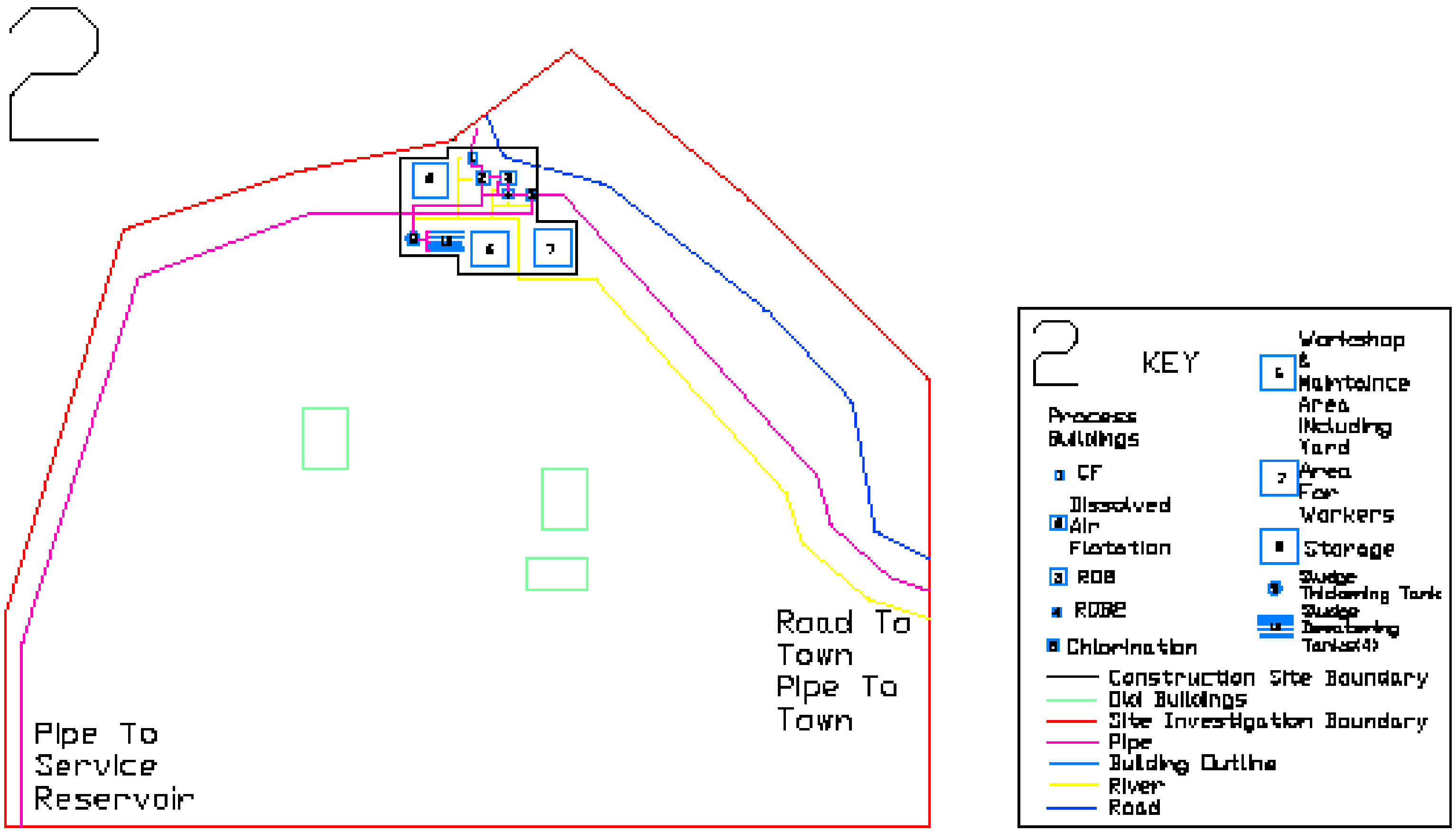


Figure 9: Site layout for option 2

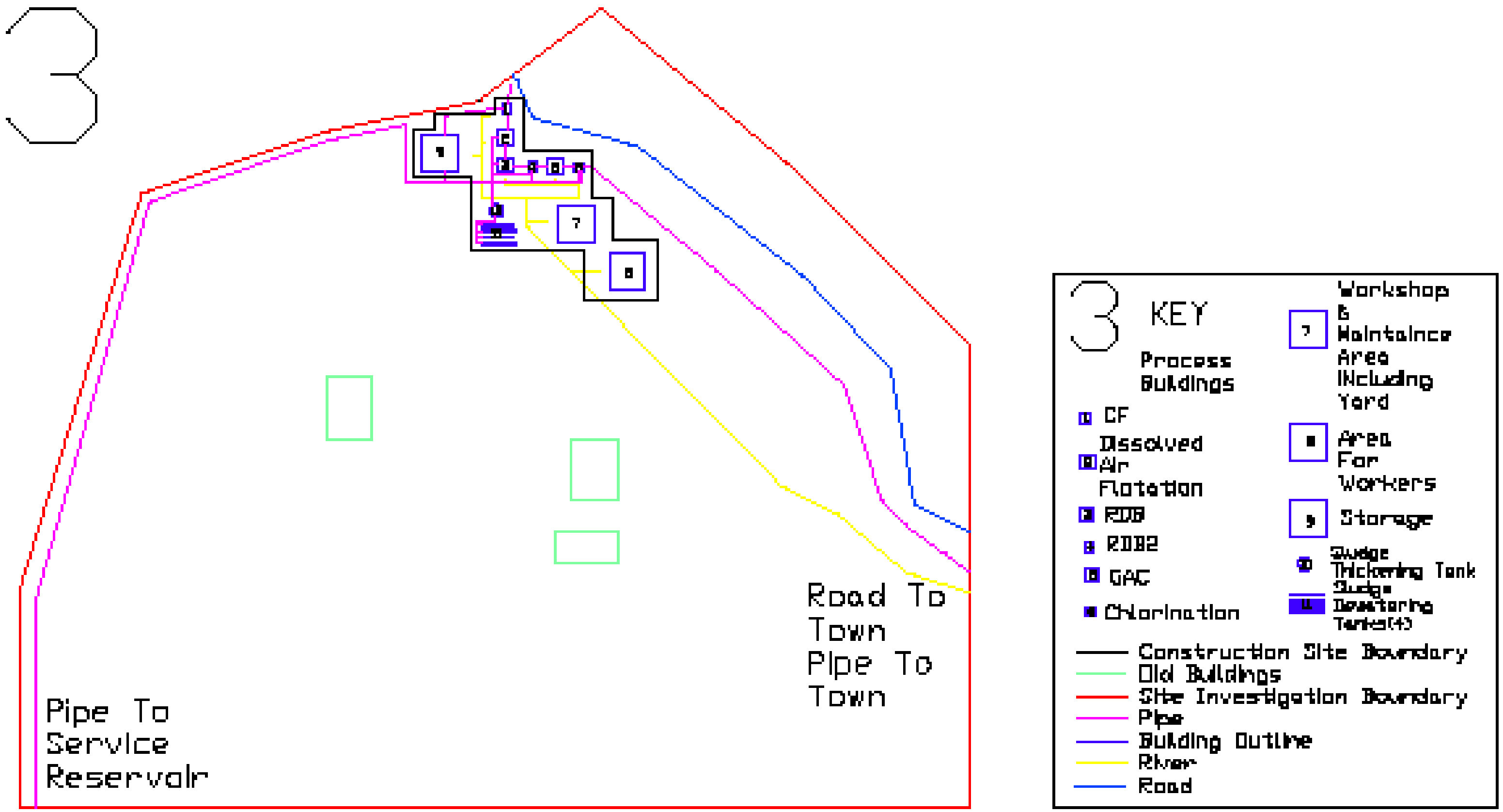
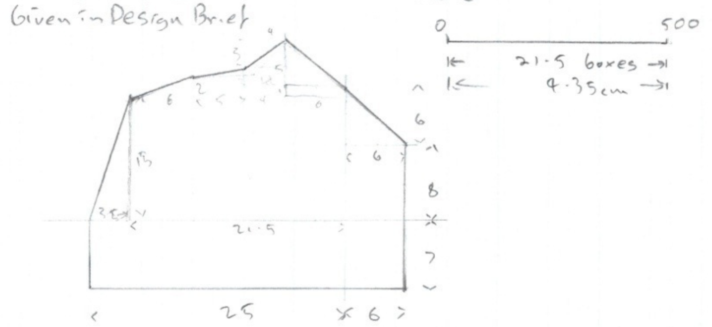


Figure 10: Site layout for option 3

APPENDIX 6: CALCULATIONS FOR AREA OF SITE

Area Calculations For Entire Site.

Traced from Site Map
Given in Design Brief



$\frac{500m}{21 \cdot 5 \text{ boxes}}$ = 23·26 m Long per box

length of one box = $\frac{0 \cdot 2cm}{4 \cdot 35cm}$ × 500 = 22·98 m Long per box

conclude each box is 23 meters long

area of one box = 23 × 23 = 529 m^2

∴ find number of boxes in area × 529
= Area of Space (m^2)

Number of Boxes

$= (25 \times 7) + (6 \times 15) + \left(\frac{6 \times 6}{2}\right) + 6 + \left(\frac{5 \times 6}{2}\right) + \left(\frac{4 \times 3}{2}\right)$
$+ 12 + (2 \times 5) + 1 + \left(\frac{6 \times 2}{2}\right) + \left(\frac{3 \cdot 5 \times 13}{2}\right) + (21 \cdot 5 \times 13)$

= 175 + 90 + 18 + 6 + 15 + 6 + 12 + 10 + 1 + 6 + 22·75 + 279·5

= 641·25 boxes

Area of Space = 339221·25

= 33·92 hectares
× 5000 £/hectare
= 169 600

= £170,000 cost of purchasing entire site

APPENDIX 7: PIPELINE ROUTES

[9]

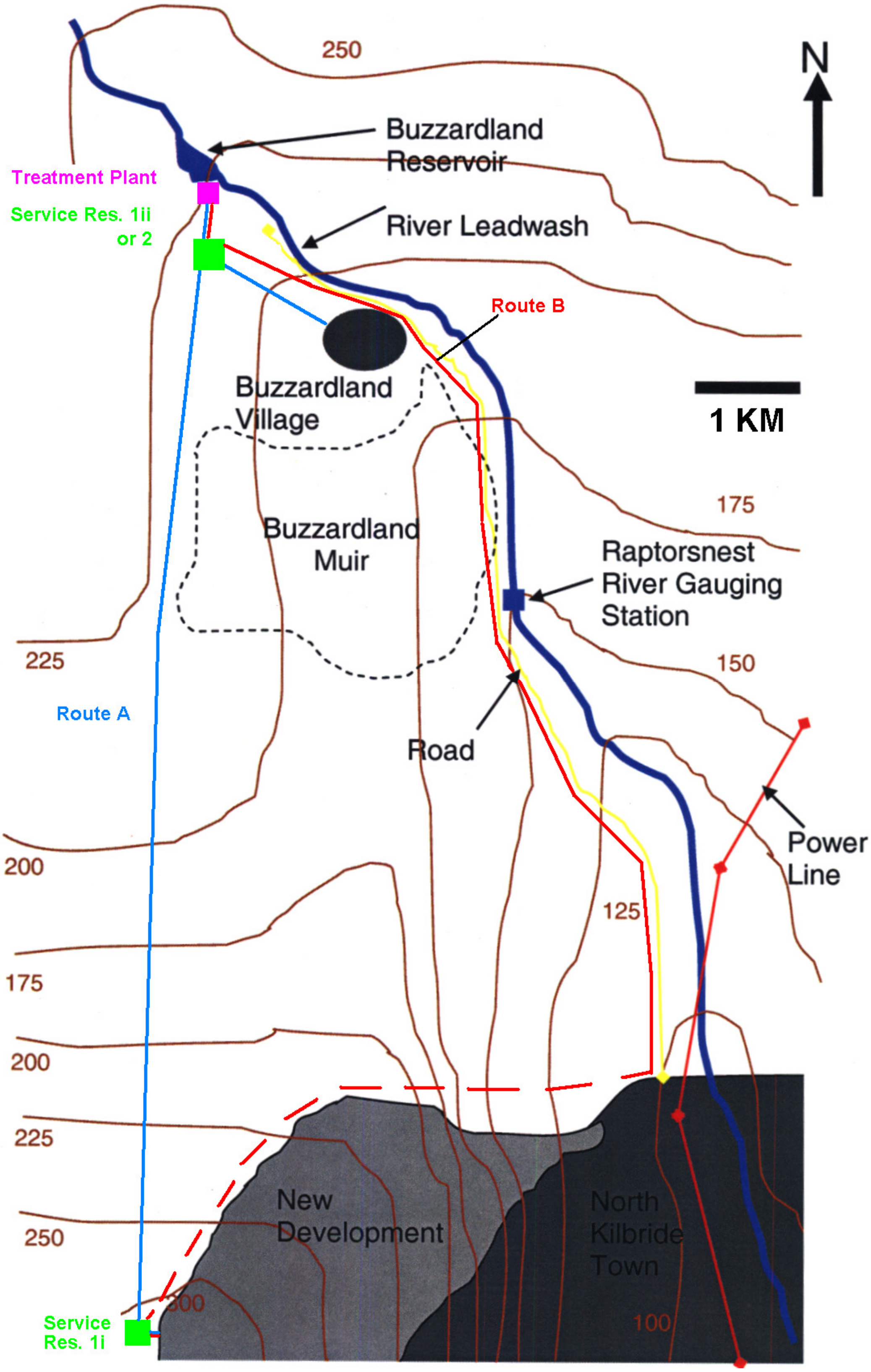


Figure 11: Map illustrating options for pipeline routes

[9] Original map provided by Scottish Infrastructure Solutions PLC

APPENDIX 8: SERVICE RESERVOIR[10]

Reservoir 1i and 2

24 hr mean demand

Time Period (hrs)	Percent of domestic daily demand (%)	Domestic demand m^3/s	Industrial use of water	3hr demand m^3/s
0000 - 0300	4.65	0.027	0.037	0.064
0300 – 0600	4.65	0.027	0.037	0.064
0600 – 0900	18.6	0.107	0.037	0.144
0900 – 1200	13.95	0.081	0.037	0.118
1200 – 1500	13.95	0.081	0.037	0.118
1500 – 1800	16.28	0.095	0.037	0.132
1800 – 2100	18.6	0.107	0.037	0.144
2100 - 0000	9.3	0.054	0.037	0.091

Table 5: Calculations for mean demand

Total 3 hr demand = 0.876
24hr Mean demand = 0.875 / 8
= 0.109 m^3/s

Minimum storage required for reservoir

Time Period (hrs)	Total demand m^3/s	Cumulative demand (m^3/s)	Deficit (m^3/s)	Cumulative deficit (m^3/s)
0000 - 0300	0.064	0.064	0.045	-0.045
0300 – 0600	0.064	0.128	0.045	0.000
0600 – 0900	0.144	0.272	-0.035	-0.035
0900 – 1200	0.118	0.390	-0.009	-0.043
1200 – 1500	0.118	0.508	-0.009	-0.052
1500 – 1800	0.132	0.640	-0.023	-0.075
1800 – 2100	0.144	0.784	-0.035	-0.109
2100 - 0000	0.091	0.875	0.018	-0.091

Table 6: Calculations for minimum storage required

Maximum deficit = 0.109 m^3/s over 3 hours
Minimum storage = 0.109 x 60 x 60 x 3
= 1179 m^3

Tank Dimensions & Cost

Volume = 1200 m
Length = 20 m
Width = 20 m
Depth = 3 m

Cost = 3.0787 x volume$^{\wedge 0.55929}$
= 162 376
= £ 163 000

[10] All calculations in Appendix 8 done with the aid of *Water Resources 2, Course Notes,* Dr Robin Wardlaw, University of Edinburgh

Reservoir 1ii

24 hr mean demand

The village has a demand of 104 m^3/day = 0.0012 m^3/s.

Reservoir 1ii is designed to take into account other failures in the system so an extra 20% has been added to the daily demand.

Time Period (hrs)	Percent of domestic daily demand (%)	3hr demand (m^3/s)
0000 - 0300	4.65	0.0011
0300 – 0600	4.65	0.0011
0600 – 0900	18.6	0.0043
0900 – 1200	13.95	0.0032
1200 – 1500	13.95	0.0032
1500 – 1800	16.28	0.0038
1800 – 2100	18.6	0.0043
2100 - 0000	9.3	0.0022

Table 7: Calculations for mean demand

Total 3 hr demand = 0.0232 m^3/s
24hr Mean demand = 0.0232 / 8
= 0.0029 m^3/s

Minimum storage required for reservoir

Time Period (hrs)	Total demand m^3/s	Cumulative demand (m^3/s)	Deficit (m^3/s)	Cumulative deficit (m^3/s)
0000 - 0300	0.0011	0.001	-0.001	-0.021
0300 – 0600	0.0011	0.002	-0.001	0.000
0600 – 0900	0.0043	0.006	-0.004	-0.004
0900 – 1200	0.0032	0.010	-0.003	-0.007
1200 – 1500	0.0032	0.013	-0.003	-0.010
1500 – 1800	0.0038	0.017	-0.004	-0.014
1800 – 2100	0.0043	0.021	-0.004	-0.018
2100 - 0000	0.0022	0.023	-0.002	-0.020

Table 8: Calculations for minimum storage required

Maximum deficit = 0.021 m^3/s over 3 hours
Minimum storage = 0.021 x 60 x 60 x 3
= 226.8 m^3

Tank Dimensions & Cost

Volume = 240 m
Length = 20 m
Width = 12 m
Depth = 3 m

Cost = 3.0787 x volume$^{\wedge 0.55929}$
= 66007.87
= £ 66 008

APPENDIX 9: SLUDGE DISPOSAL CALCULATIONS

Volume of Sludge

Sludge from dissolved air flotation

Volume	=	0.25% of 9500 m^3/day
	=	23.75 m^3

Sludge from rapid deep-bed filtration

Volume	=	3% of 9500 m^3/day
	=	285 m^3

Volume of sludge to be treated = 308.75 m^3 /day

% solids = (23.75 x 0.04 +285 x 0.0001) / 308.75
= 0.32%

Sludge Thickening

Sludge solids (kg/d) = Thru x (2 x Turb + 0.2 x Col + 1.9 x Fe + 2.9 x Al + 1.6 x Mn)

Assuming average values:

Thru	=	9.5 Ml/d
Turb	=	1.43 NTU
Col	=	7.82 ^{o}Hazen
Fe	=	179 mg/l
Al	=	0 mg/l
Mn	=	32.6 mg/l

Sludge solids = 3787.5 kg/d

5% dry solids, therefore:
Density of water = 1000 kg/ m^3
Density of solids = 4000 kg/ m^3
Sludge solids = ((0.05 x 3787.5) / 4000) + ((0.95 x 3787.5) / 1000)
= 3.65 m^3 /d

A polyelectrolyte is added to the system at 5kg/tonne for sludge dewatering.

Sludge Dewatering

$$\text{Cake volume} = \frac{(1-0.6S) \times \text{Dry solid load (tonne/week)}}{S \times \text{No. pressings per week}}$$

$$= \frac{(1-0.6 \times 0.2) \times (3.65 \times 7)}{0.2 \times 5}$$

= 22.5 m^3

Overall press width	=	1.35 x Plate size +200
	=	1.35 x 900 + 200
	=	1.42m
No. of chambers	=	62 x cake volume – 3
	=	62 x 22.5 – 3
	=	1392
Overall press length	=	3000 + (No. of chambers x (cake thickness(mm)+30))
	=	3000 + (1392 x (40+30))

= 100.44 m

Press dimensions

1.42m x 100.44m

Costing

Sludge thickening

Picket Fence Thickener

Civil cost (£000s)	=	$45.849 \times Vol^{0.392}$
	=	£433 770
M & E cost (£000s)	=	14.366 + 3.5228 x Dia
	=	£31 980

Sludge dewatering

Sludge pressing

TDS	=	Total solid produced
	=	cake volume x no. of presses per week x no. weeks in a year
	=	(22.5 x 4000) x 5 x 52
	=	900000 kg/y
	=	900 (000kg/y)

M & E cost (£000s)	=	$19.68 \times TDS^{0.03154}$
	=	£558 640

Total cost

= £1 024 390

APPENDIX 10: WATER MAINS SIZING

Assumptions

Elevations:

- Pipe feed elevation = 215 m (lowest point of site)
- Pipe out elevation = 315m (point above North Kilbride)
- Lowest point of pipe = 175 m (only one couture of 175)

Pipe supply rate:

The pipe must supply 9500 m^3/day

Water properties:

Assuming properties of pure water

$\rho = 1000 kg/m^3$

$\mu = 1.729lcP$

Pipe

- Pipe is straight with no pressure losses due to tight bends or other obstructions.
- The pipe length is 11.4 km (calculated from Figure 11)

Approximate Sizing[11]

$$d_{opt} = 293G^{0.53}\rho^{-0.37}$$

where:

d_{opt} = economic optimal diameter in mm

G = flowrate in kg/s

ρ = density kg/m^3

This equation uses generalisations and assumptions to give us an initial diameter on which more rigorous calculations can be based.

In the case of our water main, a value of 289 mm is produced.

Using a table of standard pipe diameters[12], a nominal pipe size of 12" (323.85 mm outer diameter) was selected.

This can be used to calculate an average velocity in the pipe of 1.6 m/s

Pressure Drop

Using an on-line pressure drop calculator[13], the pressure drop along the pipe was calculated to be 15.17 bar or 155 m head.

Therefore the pump must be capable of producing 255 m head.

---

[11] Equation obtained from *R K Sinnott, Chemical Engineering Design*, 2005 (Forth Edition). Coulson & Richardson's Chemical Engineering Series, Volume 6.

[12] Obtained from *R K Sinnott, Chemical Engineering Design*, 2005 (Forth Edition). Coulson & Richardson's Chemical Engineering Series, Volume 6.

[13] Available at http://www.pressure-drop.com/Online-Calculator/index.html, accessed on 10/10/08.

Whilst this value would need to be checked at a later date, it allows costing of the pipe and pump and an energy requirement to be obtained.

Costs

The purchase cost of pump can be estimated as £(10 x diameter + 20 x head)
Purchase cost of pump = £8100

The purchase cost of pipe can be estimated as = £ 150 * Length$^{0.73}$ x Dia$^{(0.91*dia/(1000+dia))}$
Purchase cost of pipe = ~£500 000

Assuming a pump efficiency of 60%, 457kW would be required to pump the water to the service reservoir costing £280 500 per year

APPENDIX 11: DETAILED COSTING CALCULATIONS

Capital Costs

Process	Civil	M&E	Land	Other	Total
Floc Blanket	467.85	114.08	170.70	-	**752.63**
Dissolved air	108.66	414.95	55.66	-	**579.27**
Rapid Sand (removing floc)	8.15	1.82	56.90	-	**66.87**
Rapid Sand (removing Mn)	4.52	0.91	21.34	-	**26.77**
Slow Sand	837.13	91.53	2,078.13	-	**3,006.78**
Ultrafiltration	388.70	581.20	-	-	**969.90**
GAC	8.15	1.82	56.90	98.96	**165.83**
UV Irradiation	13.61	71.02	-	-	**84.63**
Ozonation	11.98	22.61	-	-	**34.59**
Chlorination	-	437.68	-	-	**437.68**

Table 9: Detailing of capital costs (£000's) of individual processes

Annual Operating Costs

Process	Maintenance (Civil)	Maintenance (M&E)	Electricity	Other	Total
Floc Blanket	4.68	3.42	-	-	**8.10**
Dissolved air	1.09	12.45	23.10	-	**36.64**
Rapid Sand (removing floc)	0.08	0.05	-	-	**0.14**
Rapid Sand (removing Mn)	0.05	0.03	-	-	**0.07**
Slow Sand	8.37	2.75	-	-	**11.12**
Ultrafiltration	3.89	17.44	-	34.87	**56.20**
GAC	0.08	0.05	-	11.88	**12.01**
UV Irradiation	0.14	2.13	7.28	-	**9.55**
Ozonation	0.12	0.68	0.79	-	**1.59**
Chlorination		13.13	-	3.22	**16.35**

Table 10: Detailing of annual operating costs (£000's/year) of individual processes

APPENDIX 12: RISK ASSEMENT

Severity and Probability values apply to conditions after precautions. They are rated from 1 (minor/unlikely) to 5 (severe/very likely). Risk rating = severity value × probability value. Level of risk is LOW, MEDIUM or HIGH for rating 1-10, 11-15, 16-25.

Health & Safety of Construction

Task – Constructing New Water Treatment Plant and Laying Pipe Line

TASK/ACTIVITY	HAZARD IDENTIFICATION	CURRENT CONTROL MEASURES AND ADDITIONAL PRECAUTIONS TO BE TAKEN	SEVERITY	PROBABILITY	RISK RATING	LEVEL OF RISK
Construction of Temporary Works For Construction	Falls From height, off of the scaffolding etc	Safety harness should be worn along with hard hat and visibility jacket	5	3	15	Medium
Construction of Temporary Works For Excavations	Falls into excavations & apparatus falling into excavation	Edge project is required for safety and foot stops to stop possibility of things falling into excavations	4	2	8	Low
Excavation work for Foundations	Excavation collapse	Piles etc to be used to support edge of excavations to stop possibility of collapse	5	2	10	Low
Excavations for Foundation works	Excavation collapse	Make sure heavily construction vehicles are at a safe distance from excavations & take into account the fall angle of excavations	5	1	5	Low
Creating pipelines throughout site & route to village	Lifting & dropping pipe lines from construction vehicles and into place	Injury to persons if pipes land on them and damage to surrounding environment if pipe is dropped & problems with getting pipes out of ditches etc if dropped in wrong place	5	1	5	Low
Laying pipeline	Pipes laid out so that moving around site is done in a safe manner which will not cause injury	Trips and falls and injuries resulting thereof	4	3	12	Medium
Plant Construction – individual constructions (tanks etc)	Injuries caused by construction works to the feet	Safety Boots to be wore at all times on site	3	2	6	Low

TASK/ACTIVITY	HAZARD IDENTIFICATION	CURRENT CONTROL MEASURES AND ADDITIONAL PRECAUTIONS TO BE TAKEN	SEVERITY	PROBABILITY	RISK RATING	LEVEL OF RISK
Plant Construction – individual constructions (tanks etc)	Injuries caused by constructions works to eyes when welding and moving bars etc	Safety Goggles to be wore at all times on site when dealing in these situations	4	2	8	Low
Plant Construction – individual constructions (tanks etc)	Dust movement & inhaling of other dangerous substances	Safety masks to be wore at all times during heavy construction	4	2	8	Low
Plant layout – externally on site	Movement of humans & construction vehicles should be kept separate as much as possible	High visibility jackets to be worn at all times on site and site to be planned to keep the humans and machines separate when moving around site as much as possible	5	2	10	Low
Road construction	Movement of construction vehicles & transportation of materials interacting with humans	High visibility jackets to be worn and also planning of road construction needs to be done correct to minimise possibility of injury	5	1	5	Low
Road Excavations	Trips and falls into excavation	Edge protection to be used and care to be taken when doing road excavations	4	1	4	Low

Table 11: Risk assessment for health and safety of construction

Mechanical

TASK/ACTIVITY	HAZARD IDENTIFICATION	CURRENT CONTROL MEASURES AND ADDITIONAL PRECAUTIONS TO BE TAKEN	SEVERITY	PROBABILITY	RISK RATING	LEVEL OF RISK
Rotation of drum screens	Debris caught between ends of shaft and frame / insufficient backwashing causing blockages. Rotational moving parts & high pressure wash systems	Second route in place to provide by-pass as a back-up. Correct machine selection. Adequate guards fitted. Adequate coarse screening provided.	2	3	6	LOW
Mixing during coagulation & flocculation	Mixer fails to function causing insufficient flocculation. Fluctuating speeds of mixing.	Alternative method of mixing installed as a backup. Correct selection of mixer.	4	2	8	LOW
Removal of floc blanket	Not frequent enough – possible overflow of blanket, decrease in efficiency of blanket as a filter	Employment of 2 instruments to detect and measure the level of floc formed. Signal to alert if level exceeds specified limit.	2	2	4	LOW
Dissolved air flotation	High pressure air and water systems.	Correct selection of system	4	1	4	LOW
Cleaning of beds	Ineffective - waste not completely removed causing inefficiencies or blockages	Ensure correct choice of air rate and blower. Ensure pumps are capable of removing necessary volumes	4	1	4	LOW
Chemical dosage	Incorrect dosage supplied, causing inadequate disinfection/pH adjustment etc	Careful selection/design of peristaltic pumps. Regular inspection and testing of dosing equipment.	4	3	12	MED
Flow control *Inlet/Outlet valves for cleaning, sludge disposal etc*	Leakage of fluids through valves, seals etc	Regular inspection and maintenance program. Signal control for accurate monitoring, alarm system for alerting about unusual flow activity	2	2	4	LOW
Pump	Failure of pump	Ensure every duty pump has a standby, signalled to function as required	3	2	6	LOW

Table 12: Risk assessment for mechanical aspects of treatments

It should be noted that a maintenance program should be employed which is consistent with the procedures and frequency recommendations of the manufacturer of each individual plant part.

Chemical

TASK/ACTIVITY	HAZARD IDENTIFICATION	CURRENT CONTROL MEASURES AND ADDITIONAL PRECAUTIONS TO BE TAKEN	SEVERITY	PROBABILITY	RISK RATING	LEVEL OF RISK
Storage and Handling of Ferric Sulphate	Ferric Sulphate is a toxic substance and prolonged expose/physical contact causes health problems	Air-tight storage cylinders. Ventilated storage area.	3	2	6	LOW
Storage and Handling of Granulated Activated Carbon	Nuisance dust, reactive with oxidising agents, oxygen starved combustion produces Carbon monoxide	Storage area ventilated and stored in air tight container under water to prevent combustion.	2	2	4	LOW
Storage of Chlorine (Possible release)	Chlorine is very toxic and can cause death at low levels (1000ppm). Corrosive and will burn skin.	Toxic alarm system around process/storage units which may involve chlorine. Stored in a well ventilated area.	5	3	15	MEDIUM

Table 13: Risk assessment for chemical storage and handling

REFERENCES

Data Provided

- Scottish Infrastructure Solutions PLC

Course Notes

- *Water and Wastewater Systems 3, Course Notes*, Dr Miklas Scholz, University of Edinburgh
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Websites

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- *Water Quality and Treatment – A Handbook of Public Water Supplies (3rd Edition),* 1971, The American Water Works Association Inc
- *Water Treatment Handbook, Volume 2 (6th Edition),* 1991, Degremont
- *Water Treatment Processes and Practices,* 1992, T Hall & RA Hyde
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