Water system in Pig Farm

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Introduction

This study uses EPANET to model the flow for the water system in a pig farm. I have an interest in water engineering and I have been working on pig farms in Moray, so I naturally wanted to model the water flow. I have observed first hand the water systems and noticed at times pressure is zero at some nodes and at other times pressure is high at other nodes.. Water is an essential part of a pig farm. Since pigs are mammals like us, available drinking water is vital – more important than even food and shelter. Having a reliable model of the water system is therefore useful for the functioning of the farm.

Aims

My aim is to model the water pipe network in EPANET to estimate the flow through the pipes and the pressures at the water-troughs. I am building the model to be faithful to as it is in situ, rather than constructing an imaginary model. Having first-hand experience of the farm makes this possible. With the model built, I aim to see how difficult it will be to keep enough pressure at all the troughs without there being points of excessive pressure.

I will test for two scenarios that happen in the farm. A leakage and some of the troughs being emptied requiring a refill rate (see #refill rate). I will then get an acceptable range of water supply. I will select a pump that is suitable delivering in this range.

Methodology

Troughs

I am using EPANET so I will use their terminology. They refer to junctions or nodes as the points where water flows out of the system. Demand is the rate of outflow, and I have chosen the unit litres/minute (l/min). The junctions are the drinking troughs for the pigs. There are two main types of troughs. One that is placed in between two single-pig paddocks, or occasionally placed for one single-pig paddock., and one that is placed in a ‘dry paddock’ catering for around 20 pigs.

The ‘single-pig trough’ takes the form of barrel lying lengthways and cut in half so that water is accessible to the pig. This looks like figure 1

Figure 1: Trough[AgSmartTV, 2014]

These troughs on this farm are different from the one in figure 1 in that they are half covered which reduces evaporation. They are also connected to a pipe with a modulating float valve(MFV) inside the barrel. This is to stop flow once the barrel is full. The MFV looks like figure 2.

Figure 2: Modulating float valve[CLA-VAL]

The pigs in the farm are either lactating with piglets or pregnant. Lactating pigs consume more water. Though most of the pigs in the farm are sows/gilts, there is a small number of boars for serving. Table 1 summarises the different demands at the barrel troughs (see #appendix A.1).

Table 1: pig water demand

2 lactating sows	**0.037833 l/min**
1 lactating sow	0.019430 l/min
2 pregnant sows	0.017693 l/min
1 pregnant sow	0.009360 l/min
1 boar	0.014171 l/min

The second type of trough looks like figure 3.

Figure 3: drinking trough for group of pigs[Harvey,2019]

The demand is assumed to be **0.170441** l/min, see [#Appendix A.2] for how it was calculated.

Figure 4 shows the layout of the single-pig paddocks.

Figure 4: rows of 1-pig paddocks[Google Earth Pro]

You can see that the troughs on the parallel row are close to each other. Since there are many rows each with many paddocks I have simplified the model using the principal of skeletonisation[Santiago, A., 2011]. Where there are two rows running together I have added both troughs into the same node. They are close enough to each other (usually less than 5m) and have a similar elevation to make this possible. The troughs for dry paddocks are also merged two into one when they are very close. Here are the values for merged nodes:

Table 2: Node demands

Node for 4 lactating sows	0.075666 l/min
Node for 4 pregnant sows	0.035386 l/min
Node for 2 dry troughs	0.340882 l/min

The nodes in the model are named according to their purpose. C are the connector nodes with no demands, which are necessary to stay true to the pipe layout. The nodes in B stand for barrel, BR for boar and D for dry.

Elevation

Elevation makes a big difference in a water system. Delivering water to nodes at higher elevations requires more energy. A water system with a high difference in elevation is more difficult to keep running. Without reliable elevation data this study would not be very insightful. Fortunately this was available on Scottish remote sensing portal[Scot Gov, 2012]. I used a 2m-resolution digital terrtain model(DTM). I created a raster layer on QGis with the DTM to create a contour map. I then Used Google earth for a background image on EPANET, taking a note of the northings and eastings and inputting these data to EPANET. This made the pipe lengths relaible. I then manually added the elevation at the nodes in epanet by looking to and fro between epanet and contour map on Qgis. This meant that the elevations were reliable. If EPANET allowed this process to be automated it would have saved me some time!

Figure 5 shows the elevation of the nodes of nearly the whole farm.

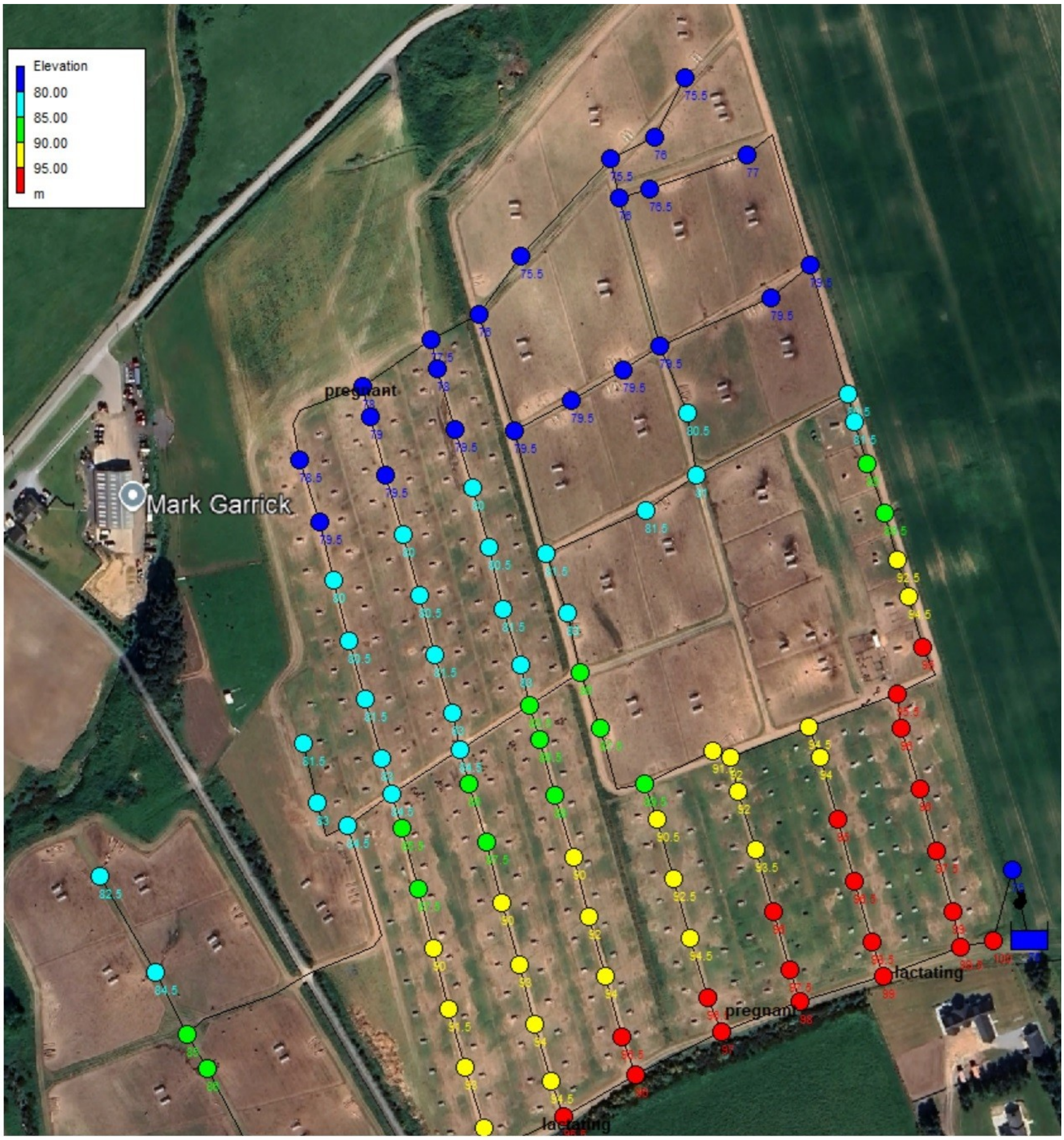

Figure 5: EPANET screenshot

The elevation ranges from 100m to 75.5m, making this farm quite hilly.

Water source

This farm draws its water from a borehole and pump. The EPANET documentation suggests modelling a groundwater well as a junction with negative demand, if the pumping rate is known[EPANET, 2020].

Since I don’t have data for the borehole and pump this is the method I will use initially. Although this study is lacking this information I do have reliable data on the other pieces of the puzzles - the pipe lengths, pipe roughness, pipe diameters, node elevations etc. I know empirically that the pressure on the farm day-to-day is not excessive (i.e. above 50m) at any node, so I can therefore alter the negative demand of the source to obtain a likely range that exists in the field. Using negative demand node is simpler than the alternative approach of a reservoir and pump and leads to the same result. Figure 7 shows the EPANET set-up.

Once I’ve found a likely pressure range, I will then change the water source model to a borehole with a submersible groundwater pump. This reflects the in situ system and allows a suitable pump to be suggested.

Figure 6 shows how the pump was set up. The reservoir(called borehole) is set at an elevation of the ground level minus the water table and the drawdown, which is 70m. The pump is attached to the node called pump, this node is set at the same elevation as the borehole. The node pump is then attached to another node (called firstnode because it is the first junction that acts like a junction) via a pipe. The diameter of this pipe is 72mm to simulate the diameter of the borehole, and the length is the groundlevel to water table distance plus the drawdown (30m). The firstnode is then attached to the rest of the system via a pipe, whose diameter reverts to the normal diameters (32mm for this pipe). I owe this set up to [Arnalich, S., 2024]’s youtube video.

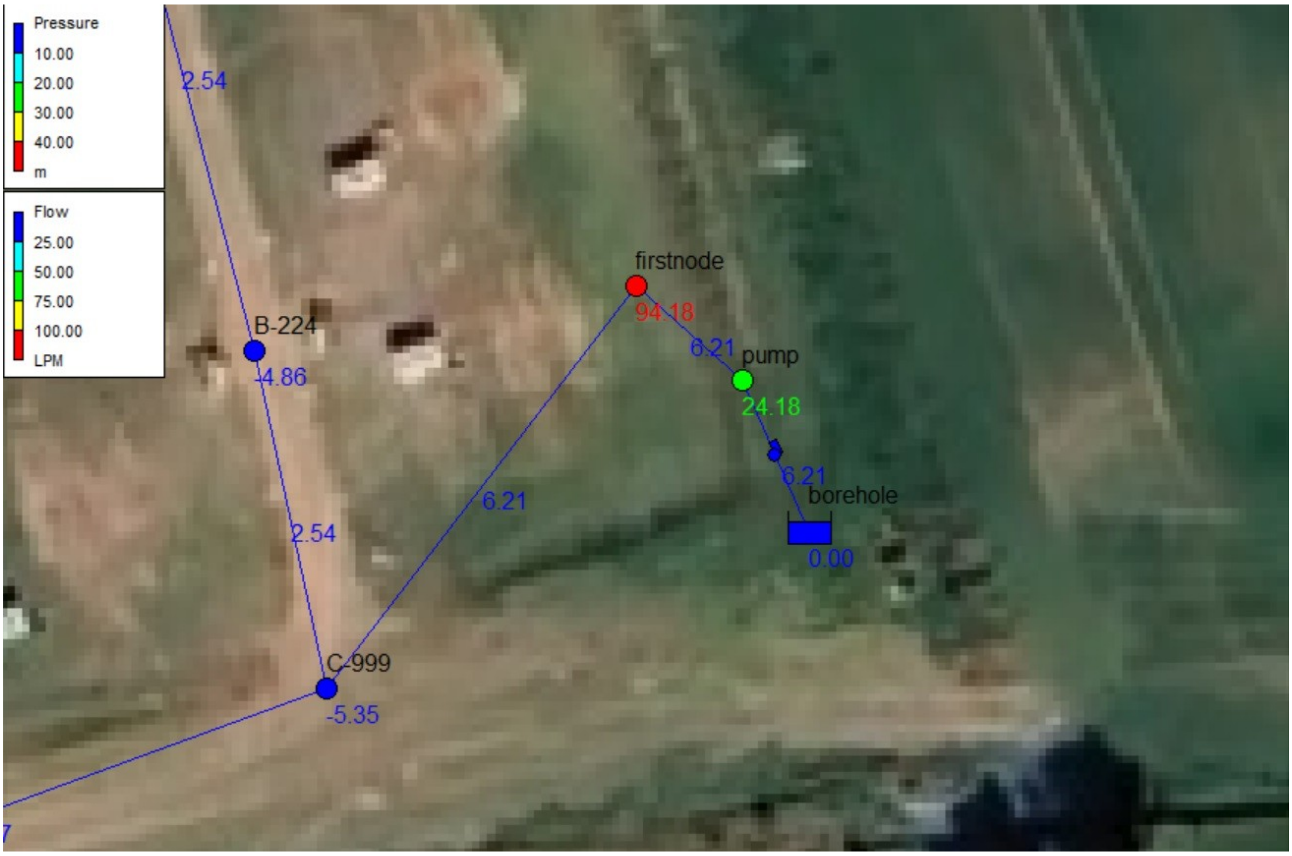

Figure 6: Epanet screenshot of pump and borehole

I have assumed the borehole is inside the farm and is at a point of the highest elevation, as this would be a logical choice of location as it would reduce the pumping power needed. A borehole at a different location would require more pumping power.

Pipes

The farm uses blue pipeat diameters of 32mm and 25mm. ,32mm pipes are laid at longer sections and 25mm are for shorter distances connecting troughs. There only a handful of 32mm pipes in the farm, one of them is the pipe connecting the firstnode to the rest of the system. I have chosen a Hazen William friction coefficient of 140. I have used Hazen Williams equation instead of Darcy Weisbach as it works well for water systems. A higher friction coefficient of 120 was chosen for the simulated vertical borehole pipe.

[Arnalich, S., 2011] suggests the velocity in the pipes should be between 0.5-2m/s and unit headloss should be below 5m/km.

I have chosen a pressure driven demand analysis rather than a demand driven one as this reflects field conditions. There are times during cleaning when many troughs are empty and there is not enough to supply water at every trough.

Leaks

There will be leakages from the pipes. One way to model this is to increase the total demand by 20% [Santiagio, A., 2011]. Table 3 shows the updated values.

Table 3: leakage factor

	Actual value	**Leakage factor added**	**Tag**
Node for 4 lactating sows	0.075666 l/min	0.090799	lactating 4
Node for 4 pregnant sows	0.035386 l/min	0.042463	pregnant 4
Node for 2 pregnant sows	0.017693 l/min	0.021232	pregnant 2
Node for 1 dry trough	**0.170441** l/min	0.204529	dry 1
Node for 2 dry troughs	0.340882 l/min	0.409058	dry 2
Node for 1 boar	0.014171 l/min	0.017005	boar 1

This ‘dispersed leakage’ method will not be used in this study. Instead a single-location leak will be simulated. This fits with what I have seen – a pipe connection coming loose due to e.g. a vehicle running over a pipe or a pig rummaging with their snout and biting the connection.

I have modelled a leak using the emitter coefficient(EC) feature. This allows the leakage to vary with the pressure. I have chosen an EC of 1, a value suggested as typical of a significant leakage on an epanet forum[openepanet,2016]. The 1-leak scenario will choose a leak to occur at a low-elevation(C-135,76m), the 2-leak scenario will choose an extra leak at a mid-elevation node(C-24,86m).

Pressure

According to [Arnalich, S., 2011] the acceptable range of pressure is 1-3 bars(10-30m). We can reduce the 10m lower limit as pigs can wait longer for their troughs to refill than humans. Also if the elevation range is too great, a choice will have to be made between increasing upper pressure or decreasing lower pressure. If pressure can be reduced while still ensuring the pig has water access it is better to use that option, making pressure safe to work with at lower elevations.

What should the new lower limit be? When the model shows the actual demand is less than the base demand, this might seem to be the right threshhold. But this would be too low, as the base demand is average water consumption over a long period of time. This would mean the trough would fill too slowly when empty. The pressure needs to be above this threshhold by a certain amount.

Finding the correct lower limit

A trial and error method was used, testing the node at the highest elevation. Figure 6 shows a screenshot of the borehole, negative demand junction and highest elevation junction(B224). In this case the pressure was 0.83m.

Figure 7: EPANET screenshot

Table 4 shows the findings. The last column is the input of the negative demand coming from the borehole.

Table 4: trial and error lower limits

Pressure at node	Base demand	With leak(EC=1)?	Bd=1.74	2 rows of bd=1.74, 8 nodes	With 2 leaks(EC=1)	Water supply(l/min)
0.32	yes	no	Bd reduced to 1.33			-285.35
0.49	Yes	No	yes	2 nodes pressure=0		-288
0.88	yes	Yes	Yes	2 nodes pressure=0	no	-290
1.63	Yes	Yes	yes	2 nodes pressure=0	no	-292
2.23	yes	Yes	Yes	1 node pressure=0	yes	-295

The lower pressure limit at the highest junction is 0.46m. However this does not allow for a leak. The lower pressure limit allowing for a leak is 0.49m. To allow 2 leaks the limit is increased to 2.23m. All pressures above 0.46m allow for 6 of 8 empty-trough nodes to be refilling at a sufficient rate, which is satisfactory.

Refill rate

The system needs to handle an increase in demand at a small number of troughs. This is when the troughs get cleaned which involves emptying the trough of all water. Usually this is done in groups, up to 32 troughs over a 4 hour period. The demand set at each node is for the water demand average over a day, if the empty barrel was refilling at this rate it would refill too slowly and leave the pig without water for too long.

Ideally a pig would have to wait no more than 4 hours before drinking water, but since cleaning water barrels only happens once every 2 or 3 weeks at most, it would be just about acceptable to make the pig wait up to 8 hours. Since several barrels are cleaned at once, there will be several empty barrels which will take longer for them all to refill. If the refill rate is chosen to refill one barrel in 4 hours, the last barrels of the group to be refilled would take too long.

I have therefore chosen a refill rate of 1 hour per trough. This means that if 8 barrels are empty at once, it would take at most 8 hours for them all to be refilled. In practice it would take less time, one barrel would be refilling at the full refilling rate but the other barrels would still be refilling although at a slower rate. This means that more than 8 barrels could be empty and still be refilled in time. I have judged that this would be sufficient for 32 barrels, using a conservative estimate.

This refill rate is calculated as 1.74 l/min (see #Append A.3). Since the junctions are for 2 troughs, I have calculated the rate to fill 2 troughs (200l) in 2 hours.

The troughs at the highest elevation were tested for a conservative estimate.

Groundwater

I made an assumption about the groundwater. Boreholes records in the surrounding area show a water table depth of around 5m[BGS]. However there is a 25m difference in elevation within the site, so it is likely that at the highest point the groundwater level is lower. I have assumed a depth of 25m with a drawdown of 5m. This is consistent with a moderately productively aquifer which this farm lies within.

Results

Borehole as reservoir with junction at negative demand

Table 5 shows the upper and lower limits for the water supply using the negative demand method.

Table 5: Upper and lower limits for water supply

	Negative demand(l/min)	**Pressure at highest node(m)**	**Pressure at lowest node(m)**	**Demand at reservoir(l/min)**	**Head at first junction(m)**
Upper limit	-315	6.36	29.75	307.92	105.38
conservative Lower limit	-295	2.23	25.63	287.84	101.24
Unconservative lower limit	-288	0.49	24.23	280.85	99.85

The pressure at the highest node (B-224) must be at least 0.49m, and at the lowest node (D-0) can't exceed 30m. 5.87,5.52. This gives a range of 5.87m at B-224, and 5.52m at D-0. A mean of 5.7m pressure range for individual nodes can be assumed. This is not a large range

Borehole as reservoir with groundwater submersible pump

After experimenting with pump-curves of different pumps, the pump that was found to supply the correct pressure was Grundfos' SP-14-6[wattuneed]. Figure 8 shows the pressures.

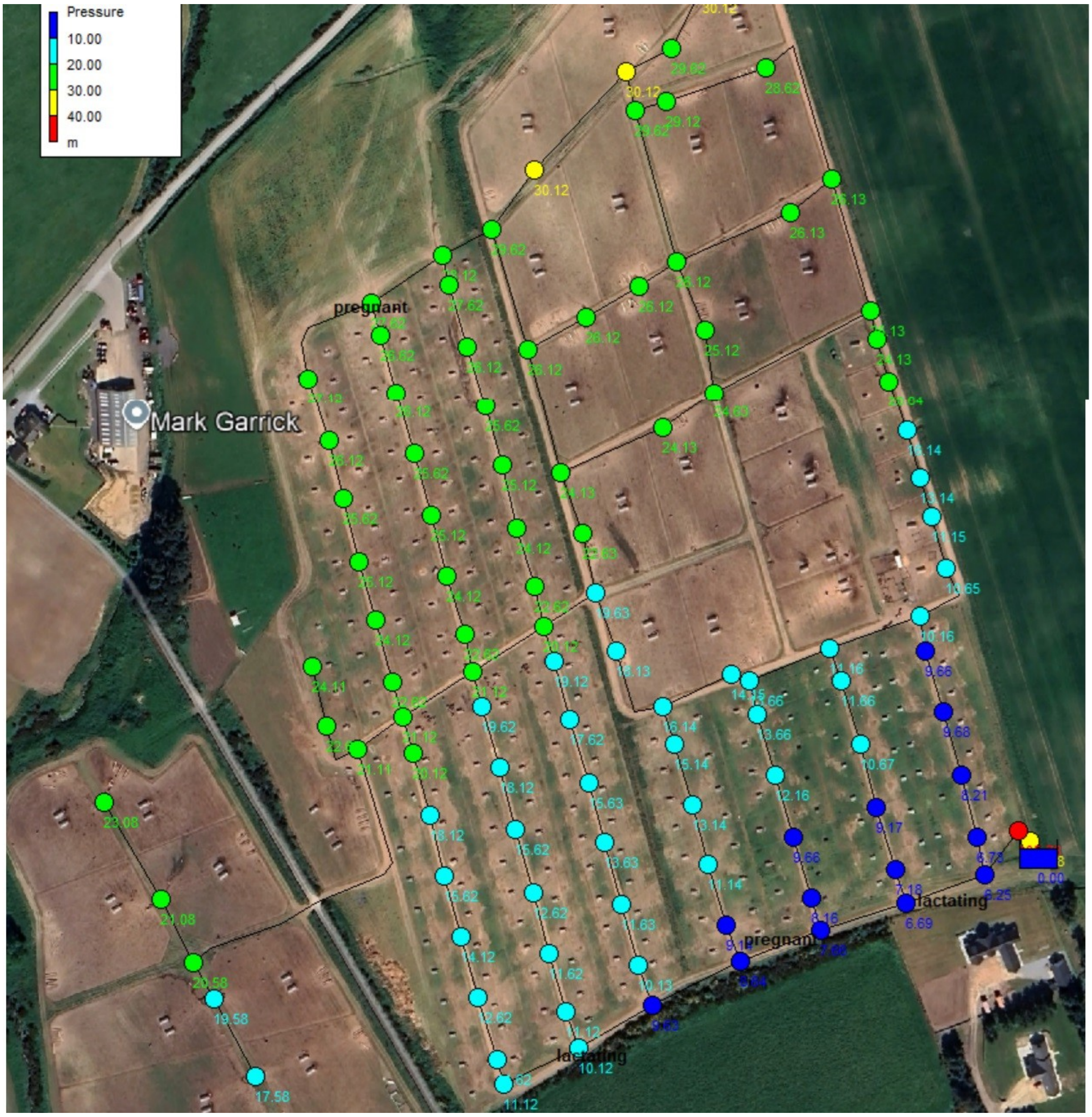

Figure 8: epanet screenshot

D-0’s pressure is 30.12m, slightly over the upper limit, and B-224’s is 6.24m, well above the lower limit.

Velocity and Unit Headloss

Table 6 shows the velocities and unit headlosses of the pipes flowing into/out of a sample of nodes.

Table 6: velocity and unit headloss into/out of selected nodes

Node ID	Elevation (m)	velocity into/out (m/s)	Unit headloss into/out (m/km)
firstnode	100	0.029/ 0.149	0.03/ 1.18
B-224	99	0.97/ 0.094	0.71/ 0.67
BR-129	85	0.063/ 0.062	0.32/ 0.31
D-21	88	0.012/ n/a	0.01/ n/a
B-18	78	0.008/ 0.007	0.01/ 0.01
D-0	75.5	0.008/ 0.002	0.01/ 0.00

The highest velocity is 0.149m/s and the lowest is 0.002m/s. This is much lower than Arnalich's suggestion. If there are suspended particles in the water this could cause the pipes to clog up. Arnalich's suggestion is for a larger network supplying humans, so we don't need to read too much into it.

All the unit headlosses are well below the recommended 5m/km. This can also be explained by the smaller scale of this water system.

Room for changes

It is possible that both the water table and drawdown could change over time. This could be due to differences in rainfall and the long-term effects of constant pumping. Two scenarios will be examined, one with the water table lowered and the drawdown increased, and the other with the water table elevated and the drawdown decreased. The node B-224 and D-0 are chosen for the highest and lowest elevation respectively.

Water table lowered and drawdown increased

The water table will be decreased by 5m and the drawdown increased by 2.5m. This will make the pump elevation 62.5m. Table 7 shows the pressures.

Table 7: head to overcome increased

Node ID	pressure(m)
B-224	-0.76
D-0	22.6

This results in below 0 pressure.

Water table elevated and drawdown decreased

The water table will be increased by 5m and the drawdown decreased by 2.5m. This will make the pump elevation 77.5m. Table 8 shows the pressures.

Table 8: head to overcome decreased

Node ID	pressure(m)
B-224	14.23
D-0	37.59

This results in a pressure above 30m by 7.59m, which is significant.

This shows that there is little wiggle room for changes in groundwater level and drawdown.

Limitations

This study is limited by incomplete knowledge of the borehole. The borehole diameter was assumed to 72mm, a typical value, but many boreholes have a larger diameter.

The groundwater data was assumed. It was also assumed that drawdown is constant which is not necessarily the case. The assumed change in groundwater and drawdown could be different, which would change the findings. For example if the water table only varied by 1m and the drawdown by 0.5m, then the water system would be more reliable and less in need of being changed.

The distribution of pigs in a pig farm is always changing, sometimes within a week. Sometimes the dry paddocks have more than 20 pigs, sometimes less. Sometimes farrowing paddocks have a pig removed, sometimes they are doubled up. This study only assumed one distribution, however a conservative estimate was chosen (larger number of pigs than the average).

As this is only a model, only so much can be gleaned from the findings. Readings of pressure and flow rate in the field to compare to the theoretical results would benefit this study.

Conclusion

Providing water to a pig farm is less challenging than to a human settlement or other more water-intensive industries, as the scale is much smaller. This farm in particular is quite compact, with the longest pipe length between 2 nodes being only around 180m.

This farm is a challenging one to provide water to because of its hilliness. There is a small range of acceptable change in pressure at the highest and lowest nodes (approx. 5m). This means small changes in groundwater depth and drawdown could hamper the system. Farm workers will have to be extra vigilant about leaks.

Although the groundwater data was assumed and may be different in reality, it still shed some useful light. A lower groundwater level would require a more powerful pump but the pressure difficulties would remain the same.

Ways to counter this are installing a pump with different power levels that can be switched to, and installing a storage tank at a mid-elevation point to reduce the pressure differences.

Appendix

A. Calculation of volume and demand

1. Barrel Trough

It is estimated that the dimensions are the same as the ones shown in figure 9 for a 200l barrel on ali express.

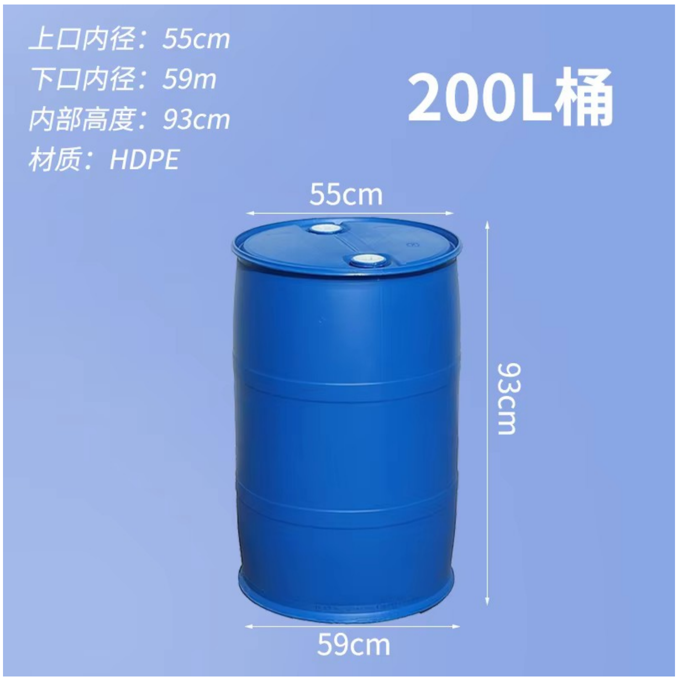

Figure 9: barrel dimensions

volume = half of full barrel volume = 100l

r = mean diameter / 2.

mean diameter = (59 + 55)/2 = 57cm

r = 28.5cm

h = 93cm

surface area of water = average diameter * length = 57 * 93 =5301 cm^2 = 0.53m^2

A corporate study conducted in the UK[VapourGuard, 2008] found the evaporation rate to be 2.79 litres/m^2/day. This means the evaporation rate,

ER = 2.79 * 0.53 = 1.479 l/day

However there are some differences to this study. The wind speed is a significant factor in increasing evaporation and this study was conducted with a wind speed range of 0-4m/s with a mean of 1.6m/s. This is much lower than the wind speeds commonly experienced in Moray. Another difference is that in this study the barrel are half covered, which will reduce evaporation. It is estimated that these two factors will cancel each other out and the ER is assumed to remain the same as the one estimated in VapourGuard's study. So ER remains at 1.479 l/day = **0.00102708 l/min**.

The water consumption for a pregnant sow 12l/day or **0.008333l/min**.

For a lactating sow it is 26.5l/day or **0.018403 l/min**[Masterfeeds] .

So for a barrel serving 2 pregnant sows,

demand = 0.008333 * 2 + 0.00102708 = 0.01769308 l/min.

For 1 pregant sow deamdn = 0.008333 + 0.00102708 = 0.00936008 l/min
For 2 lactating sows demand = 0.018403 * 2 + 0.00102708 = 0.03783308 l/min
For 1 lactating sow demand = 0.018403 + 0.00102708 = 0.01943008 l/min

The water consumption for a boar is 5 US gallons per day[National Pork Board, 2003, as cited in Guthrie,T.,2011].

Consumption = 18.9270589 l/day = 18.927059 / (24 * 60) = 0.013144 l/min

Demand = 0.013144 + 0.00102708 = **0.014171** l/min.

2. Dry paddock trough

The dimensions are estimated as 75cmx200cm, so area = 15000cm^2 = 1.5m^2

Since it is not covered, the ER is increased by a wind factor, estimated as 1.3. So

ER = 2.79 * 1.3 = 3.63 l/m^2/day.

The ER for the trough = 3.63 * 1.5 = 5.445 l/day = **0.00378125 l/min**

It serves a number of sows in a 'dry' paddock, (dry presumably because there are never lactating sows in these). The number of sows vary can between 12 and 32 but is on average 20.
Demand = 20 * 0.008333 + 0.00378125 = **0.17044125 l/min**

3. Calculation of refill rate

consumption rate(l/min)	refill rate(l/min)	trough capacity(l)	refill factor
0.075666	**1.740318**	200	23

after	1 min	water in trough is	1.664652
	2 hours		199.75824
	1 day		2397.0988

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