Preliminary Development of a Sewerage Infrastructure Buffer Assessment Tool for Engineering Risk and Strategic Land Use Planning

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Abstract

Urban expansion continues to encroach on once isolated sewerage infrastructure. In this context, legislation and guidelines provide limited direction to the amenity allocation of appropriate buffer distances for land use planners and infrastructure providers. Topography, wind speed and direction, temperature, humidity, existing land uses and vegetation profiles are some of the factors that require investigation in analytically determining a basis for buffer separations. This paper discusses the compilation and analysis of six years of Logan sewerage odour complaint data. Graphically, relationships between the complaints, topographical features and meteorological data are presented. Application of a buffer sizing process could assist planners and infrastructure designers alike, whilst automatically providing extra green spaces. Establishing a justifiable criterion for buffer zone allocations can only assist in promoting manageable growth for healthier and more sustainable communities.

Key Words
buffer sizing, separation distance, sewage, sewerage, odour complaint, topography

1. Introduction

The Queensland University of Technology in partnership with Allconnex Water is currently performing a scientific review of these issues against Logan City's existing sewerage infrastructure

Sewer systems are a series of pipes, designed for the most part to run downhill, taking human waste to treatment plants. The systems use both gravity and a series of pump stations which bring sewerage from low points back up to higher points so that gravity may continue to do most of the work. A great deal of planning goes into the design of these systems, which generally speaking, follow the natural contours of the land, similar to natural water systems and also storm water systems. Allowing adequate space for dilution of odours in the past was not so difficult, due to treatment plants being located in more remote locations and relatively low density development. Until more recently, guidelines and legislation requirements only went as far as to mention that buffer distances needed to be of an 'adequate' or 'appropriate' distance [1].

Due to fast expansion of cities and newer concepts such as nodal centres and more high density living, the need for planned buffer spaces has escalated into an important issue due to awareness of sewer odours within proximity of pump stations and discharge manholes (the highest point that a sewerage pump station brings the effluent to). One might assume that catering for these needs is the developer's issue, but it is also necessary to consider the potential for catastrophe due to natural causes and lack of maintenance as well as access complications for later maintenance. Ironically, pump stations that handle higher volumes of sewerage have fewer odours due to reduced retention time, which means newly developed areas are potentially at more risk of suffering from odour problems. This evidence shows the necessity for an understanding of the need to set aside land during the planning process which would stop issues such as these arising in the first place.

Effective land use planning is integral to the appropriate growth of communities. This paper reviews the existing Logan City sewerage system, and establishes the need to introduce a process for planning and assessing the requirements for buffer systems around sewerage infrastructure.

2. Methodology

Research for existing guidelines and sewerage system attributes was undertaken as outlined in sections 2 through 6.

2.1. Buffer distances

To better define a buffer area surrounding varying sewerage infrastructures, research was undertaken, with the hope that previous studies may already exist in this area. Unfortunately most guidelines state the requirement of buffers of an 'adequate area' [1] or the like. The Queensland Environmental Protection Agency (EPA) Odour Guideline [2] refers to the Victorian EPA philosophy on buffer distances. The Victorian EPA document [3] specifies distances of 100 - 2200m which are chosen according to the equivalent population serviced by the device. Also stipulated in the Victorian document, are requirements to determine buffer distances in consultation with the EPA, considering wind regimes, topography, waste loading, treatment/disposal methods and design capacity [3].

On further studying the documentation, it was observed that existing guidelines differ greatly with regards to criteria buffers should be measured against. Potential criteria include both qualitative and quantitative elements, covering social, environmental and economical issues, deeming clear definitions of case by case circumstances extremely complex. To adequately formulate a criteria based assessment of sorts, a list of impacting criteria were assembled, using written interpretations of requirements sourced from Australia's EPA branches and their equivalents in Canada [1], the United States [4], and the Netherlands [5].

Also established through research was the realisation that although pumps may be a certain size and function at a certain capacity, they would not necessarily always be working at their full capacity (Bell, P. personal interview, December 15th 2009). Dimensionally over-designed systems could give rise to septicity due to the relatively small amounts of sewerage passing through, therefore amplifying odour issues in sewerage systems. This theory presented new issues with regards to establishing a buffer zone according to pump size, and gave rise to a new set of criterion to consider. For this reason, type of pumps, sizes, functionality, and time frames were added to the criteria list.

***2.2.** Pump stations*

The functionality and treatment types offered by treatment plants at the end of the line are another criteria that needs to be considered. Differing treatment systems cater for varying stages of septicity of the effluent, defining the characteristics required for devices up stream which in turn impacts on odorous emissions from pump stations [6][7].

***2.3.** Other considerations*

The literature review suggested that planning sewerage systems is a delicate balance between social impact constraints, environmental issues, energy efficiency and required treatment levels. The intricate web of interactions between the many variables means that designating assessment criteria for the design of buffer systems would be extremely difficult. Adding further complexity, the type of foliage used, density of the buffer, ability for the chosen foliage to absorb odours, convert nutrients and withstand storms and erosion are also issues of further contention when determining buffer dimensions [8].

Following compilations of the lists of criteria to be considered, a meeting of Allconnex Water engineers was convened to establish a hierarchy between the criteria to determine dependency and a critical path type of analysis for buffer design. It was decided that odour was the most important external impacting criteria that required further investigation to adequately assign buffer sizes.

3. Considered Impacting Criteria

3.1. External

External impacts are defined here as those that affect, first hand, the community surrounding the sewerage treatment plan site. These include:

- predicted noise levels
- odour levels/intensity
- odour release conditions
- wind patterns carrying odour
- temperature
- emission rates

3.2. Surface and Geographical

Surface and geographical considerations are those to do with contours and other variables which may impact on the velocity and quality of sewerage flow, as well as surrounding environments that would be affected in the case of leakage.

- topographical
- microclimate
- distance to nearest receptor
- distance travelled (age and septicity of sewerage)
- distance not aerated (pumped distances)
- floodplain delineation
- vegetation
- rainfall

3.3. Subsurface Geotechnical

- geotechnical aspects
- seepage speed
- depth of asset
- groundwater locations

3.4. Internal

- chemicals present
- bacteria levels

3.5. Buffer Characteristics

- types of foliage in buffer
- size of foliage in buffer
- structural attributes of buffer
- age of buffer
- understory of buffer
- ability to convert nutrients into biomass
- ability to withstand sediment deposition and inundation periods of flooding
- ability to withstand erosion
- ability to stimulate biological and chemical processes to draw deeper nutrients
- production of carbon contents to feed bacteria during nitrification

3.6. Criteria for Implementing Buffer Systems on Existing Assets

- maintenance requirements
- age of asset

4. Establishment of Hierarchy

To begin to create an assessment method by which buffer dimensions could be determined, a hierarchy within the impacting criteria, pump efficiencies, treatment methods and reuse requirements was considered. In creating the hierarchy, one expectation was that a decision making flow path may begin to emerge in the form of a critical path type of analysis for potential future buffer sizing.

4.1. Impacting Criteria

The meeting of Allconnex Water engineers established outcomes of hierarchy discussed in the following paragraphs.

For external impacting criteria, mitigation of noise in sewerage pump stations and wastewater treatment plants is relatively easier than mitigation of the odour issues. The impact of odour also depends heavily on the other external criteria, internal criteria, the buffer criteria and most of the surface and geographical criteria. For this reason, odour was singled out as the governing criteria due to its encompassing nature of so many other criteria. It also became apparent that mitigation of subsurface criteria can be engineered with foresight, provided enough space is available and appropriate geotechnical investigations have occurred. Given the large expanse of land odour considerations will require, it is not believed that space will be an issue for the subsurface criteria, although a later check of these criteria would be necessary. In the interim, subsurface criteria was also deemed less important during buffer design than odour.

The only area that odour does not encompass with regards to buffer design is the need to address possible contaminants within the odorous gases. There is the possibility, for example, that non-odorous gases carried within are far more toxic and therefore dangerous to surrounding human and natural communities. Examples of this kind of occurrence are discussed in medical literature, for example the deaths of two surveyors who fell into a sewer and died due to hydrogen sulphide (rotten egg gas) exposure [9] and the blindness of a housewife caused by exposure to a nasty cocktail of chemicals when cleaning her toilet. Her demise was caused by chronic and repeated exposure to chloramine and methyl chloride formed by a combination of sodium hypochlorite, hydrochloric acid (found in cleaning products) and urine in her toilet [10]. This evidence also brings to light the need to consider the chemicals and medicines that the community flushes into the sewer system, as well as the chemicals used to treat effluent and the impact they have on receptacle environments. Given the vast expanse of further research this perspective requires, chemical impacts on humans and the natural environment will not be investigated in this paper, except to consider their possible existence in the odorous gases emitted by sewerage infrastructure.

5. Pump Study

Functioning time, capacity and loads on pump stations can significantly change the quality and septicity of effluent in the system.

5.1. Data Collection

To classify the pumps for buffer design purposes, descriptive data about the pumps was required. To collect data for the pump hours and numbers of starts, the Telemetry department of the Logan City Council (LCC) was consulted, and were forthcoming with data outlining the numbers of starts, run-time, breakdown and overflow data for any specified pump and date range. Overlay Mapinfo data provided by the Asset Management department of the LCC, showing a list of all pumps in the area, size, volumes pumped, names, codes, addresses, the rate at which they pump, construction dates, number of pumps and much more. Although there was potential that these data sets were not identical; for this paper, it was assumed that the data obtained is correct and complete.

To make best use of the available data, the LCC Asset Management department Mapinfo overlay pump data combined with pump start and run time data from the LCC Telemetry department was collated to give a more holistic understanding of design capabilities and actual running of pumps in Logan. Understanding the limits of the telemetry pump systems was also necessary for this investigation. Some of the older pumps in the system are fitted with sensors a considerable distance from the surface, showing the well to be 100% full (overflowing) in the telemetry system, when overflow is not actually occurring (Bell, P. personal interview, December 15th, 2009). Also, pumps running below capacity due to upstream locale and low Equivalent Persons (EP) service prior to planned development can tend to cause odours due to septicity caused by higher retention times. These odours would subside once the pump is running closer to capacity.

6. Odour Principles

Given it was established that odour was the most prevalent criteria to consider, further investigation of odour constraints was undertaken. The review found that in the past, buffers for odour control were not considered, as it was believed that mitigation of odour using appropriate design methods such as slope, aeration and appropriate pump and pipe sizing were enough to mitigate odour issues [11]. As development begins to encroach upon pump stations and wastewater treatment plants, the old mitigation approaches do not seem to be enough, inviting creation of an industry of gadgets to minimise odour emissions.

Generally speaking, the types of odour that come from sewerage are created by the biological degradation of sewage due to anaerobic activity [12]. Odour may also arise due to solvents, organic compounds, petroleum derivatives and high sulphur content of the effluent [12]. Most noticeable nuisance sewerage odours constitute the gases: hydrogen sulphide (H_2S) and various forms of nitrogen, for example N_2O nitrous oxide.

The important notable dimensions of an odour are the detection threshold, intensity, hedonic tone and character. Should an odour be analysed by the human nose, the detection threshold is the concentration necessary for detection by a certain percentage (usually 50%) of the population [13]. Intensity is established with the use of a human panel, commenting on how strong the odour is. Hedonic tone measures whether the odour is pleasant or unpleasant and character is simply a description of how the odour smells [14]. Other impacts from odours that need to be considered are: duration of exposure time, frequency of odour occurrence and the tolerance of the receptor [13].

Odour measurement is a relatively subjective topic and can be approached many ways. Olfactometry [13] is a method which uses human noses and gas chromatography - utilising machines to measure volatile organic compounds [15] within gases are two such methods. Plume theory, using statistical modelling and computers to approximate dispersion is another popular method, however this study will focus on a visual analysis of odour complaint data collected from the Logan City Council over the past six years. A feasible alternative to using complaint data would be to install gas sensors or electronic noses to collect large amounts of odour data [16]. In Australia, most State governments stipulate the use of dynamic olfactometry [17] [18] to measure odours. Dynamic Olfactometry techniques are outlined in the Australian/New Zealand Standard 4323.3: 2001, Stationary source emissions. Victoria, however, uses another method stipulated by the US EPA which also relies on olfactometry [17]. The Victorian method is based around empirical formulae, behind which is extensive confidential research the Victorian EPA has undertaken (Anonymous, personal interview, January 28th 2010).

6.1. Discussion about Intensity and Concentration

When measuring odours, it is important to note that intensity - the perceived strength of an odour - is a very different parameter than concentration [19]. Whilst the two variables are linearly related using a power function, a reduction in concentration does not necessarily reduce perception of the odour. In fact, the intensity of odour depends heavily on the threshold at which the odour can be detected. The smaller the threshold, the longer it takes for intensity to reduce, even if concentration reduces dramatically [19].

6.2. Hydrogen Sulphide

Hydrogen sulphide (H_2S) is the main gas responsible for sewerage and waste odours. The gas is produced during the decay of sewerage in anaerobic circumstances. H_2S is generally the dominant odorant in sewerage, but in rare cases where it is not dominant, it is usually present and acts as a marker for other sewerage odours [12]. It should be noted, however, that some researchers believe that odour maintenance based on H_2S values alone underestimates odours, claiming that the combination of odours including nitrogen substances and skatole can cause higher levels of annoyance [20]. Contradicting this, there are many papers that draw correlations between odour complaints and H_2S levels [12] [16]. This correlation is seen as a valuable tool, should permanent monitoring be in place. Pagliuso [21] suggests that H_2S and methane (CH_4) are the two gases of most concern from sewerage due to both the odour issue of H_2S (methane is odourless) and the gases' enormous global warming potential. In high concentrations, H_2S can also harm the environment in the form of acid rain [22]. At higher temperatures, H_2S diffuses faster, meaning that more stakeholders would be affected by the odour it causes [23].

6.3. Human Detection of Hydrogen Sulphide

The hydrogen sulphide odour is detectable at 0.0047 ppm (parts per million) [24] [25] [22]. Exposure can cause nausea and loss of appetite, amongst other subtle medical problems, even at concentrations as low as 2 ppm [25]. Concentrations higher than 10 - 20 ppm cause reactions from eye irritations and blindness, through to loss of life due to failure of the nervous system [26].

For engineering design, facilities aim to produce concentrations of less than 0.18 ppm [24], although H_2S odours can become irritating at concentrations as low as 0.01 ppm - 1 ppm. This observation also clearly warrants the need to investigate dispersion of this gas and the need for buffering requirements.

7. Data Collection (Logan City)

In order to establish measurable criteria by which buffer dimensions could be determined for Logan City, data of sewerage odour complaints was collected from various departments of the LCC. Customer Service and Operations for both LCC and GC City Council provided varying levels of data. All data sources contained information about location and time of the complaint which were compiled and used for the data analysis.

It should be noted here that complaint data is highly subjective. Complaints come into councils due to a breach of the annoyance levels for a given individual. As shown in olfactometry studies, an individual's sensitivity to odour differs from person to person depending on intensity, perceived annoyance levels, frequency and duration of exposure [27]. It is for this reason that calibration of noses using a general odour occurs as part of olfactometry testing. Another factor which plays a part in the accuracy of complaint data is that residents are not at home all day every day to encounter odours. Odours may be occurring for example, when residents are at work, leaving some odour events unnoticed.

Finally, the density of developments can also have an effect on odour complaints. In Logan for example, much of the land is rural residential, which means there are less people spread across larger areas. In more dense residential developments however, there will always be more people present and therefore a higher complaint rate.

8. Data Preparation

8.1. Logan Complaint Data Preparation

Data collected was examined to establish whether there are connections between locations of complaints and their:

- correlation with pump station locations
- correlation with regards to seasons
- similarities or differences across the years
- proximity with regards to topography
- relation to wind trends

The locations of the complaints were mapped using GIS software (Mapinfo), shading properties where complaints have been filed. The map was then coded using coloured thematic maps to show the above mentioned relationships of data locations. Imported overlays for comparisons included 10m contour lines and elevations. Reduced Levels (RL's) were attributed to each odour complaint.

Data was colour coded as follows according to the season the complaint originated:

- Summer - Yellow
- Autumn - Orange

- Winter - Blue
- Spring - Green

8.2. Odour Source Data Preparation

In order to compare the complaint data with other objects, a layer on Mapinfo was created. An existing layer showing all pump stations, sewerage treatment plants and rising main discharge manholes which also have potential to emit odours. Reduced Levels were also attributed to each odour source to facilitate investigations as to whether topographical location contributes to odour complaints.

Overflow manholes and pipes were not included in this layer as these devices only come into play during extreme events - such as storms - when it is expected that dilution of sewerage is high enough to treat flows naturally using surrounding wetlands. It should be noted that although storm water flows are not meant to be plumbed into sewerage infrastructure, evidence of this was found in multiple locations of the LCC sewerage system.

9. Preliminary Data Examination – Results and Findings

On an initial glance at the complaint data, clusters of data from similar dates appear. Given the clustered nature of the complaints, it would be reasonable to assume that certain weather events or system breakdowns may have occurred at these times. An investigation of telemetry data and weather patterns was undertaken to see whether the clusters of complaints match these events.

9.1. Correlation with Pump Station Locations

Comparing pump station locations with the locations of complaints provided little evidence of any correlation, as the data appears to be randomly scattered around the Logan area (refer to Figure 1). It should be noted that in Figure 1, properties are shaded if a complaint has been generated from that property. The size of the property should not be confused with the quantity of complaints; therefore, small dots on the map are just as significant as large shaded areas.

No significant circles of complaint data appear around pump stations (maroon squares). On further investigation of separate complaints, many were described as coming from unsealed manholes rather than pump stations. One thing to note, however, is that manholes along certain trunk or branch mains have previously showed evidence of bursting in conjunction with pressure build up in the system due to pump station malfunction (Bell, P. personal interview, December 15th, 2009).

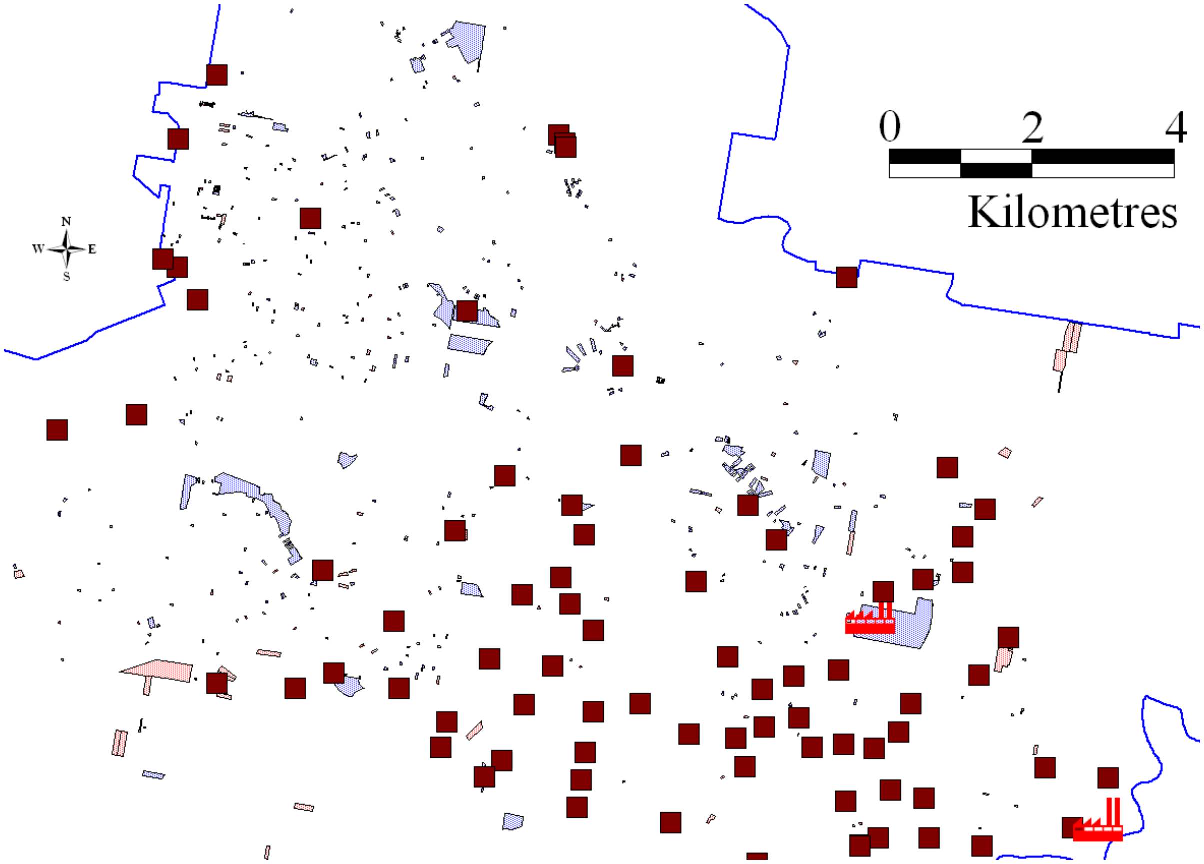

Figure 1. GIS Map of Springwood to Eagleby - an excerpt of the complaint locations (blue and red shaded properties) versus pumps (maroon squares) and treatment plants (red icons)

9.2. Correlation with regards to Years and Seasons

Displaying the data on the GIS map coded seasonally showed more interesting results. Data was prepared seasonally for each year as separate maps and also combined together in one map showing all seasonal data for the last four years. The limitation of four years was due to the software package allowing a maximum of 16 date ranges.

Yearly maps appear to show improvement with fewer complaints as the years progress in some areas, but other areas show degradation of the system with increasing complaints around the longest main trunk passing through Alfred Street towards the Loganholme treatment facility. Increasing load on the system due to population growth could be the explanation for this occurrence [28], assuming the system is functioning correctly.

Plotting all complaint data from 2006 - 2009 with slightly different variations of colour (ie: various hues of yellow for Summer) showed that seasonally, complaints are made in the same areas over the years. The seasonal segregation showed obvious clusters of complaint data. Figure 2 shows a diagonal band of orange Autumn complaints in the upper half of the figure, and a yellow band of Summer yellow complaints in the lower half. Given the shape of the bands, the implications for further investigation of both wind directions and topography were realised.

Also notable during this investigation was that around the Loganholme treatment plant was surrounded by all colours (refer to Figure 3) particularly along the Pacific Highway, suggesting a possible wind corridor or topographical phenomenon. This suggestion of natural causes (wind and topography) assumes the infrastructure is fully functional and working correctly. The section includes the Jalan Street and Konara Drive pump stations, where odour is not surprising considering the path is part of the longest drainage path in the system. Sewerage passing through this area would have just passed the colossally sized Alfred Street pump station and would be on its final route to the Loganholme Water Pollution Control Centre (WPCC).

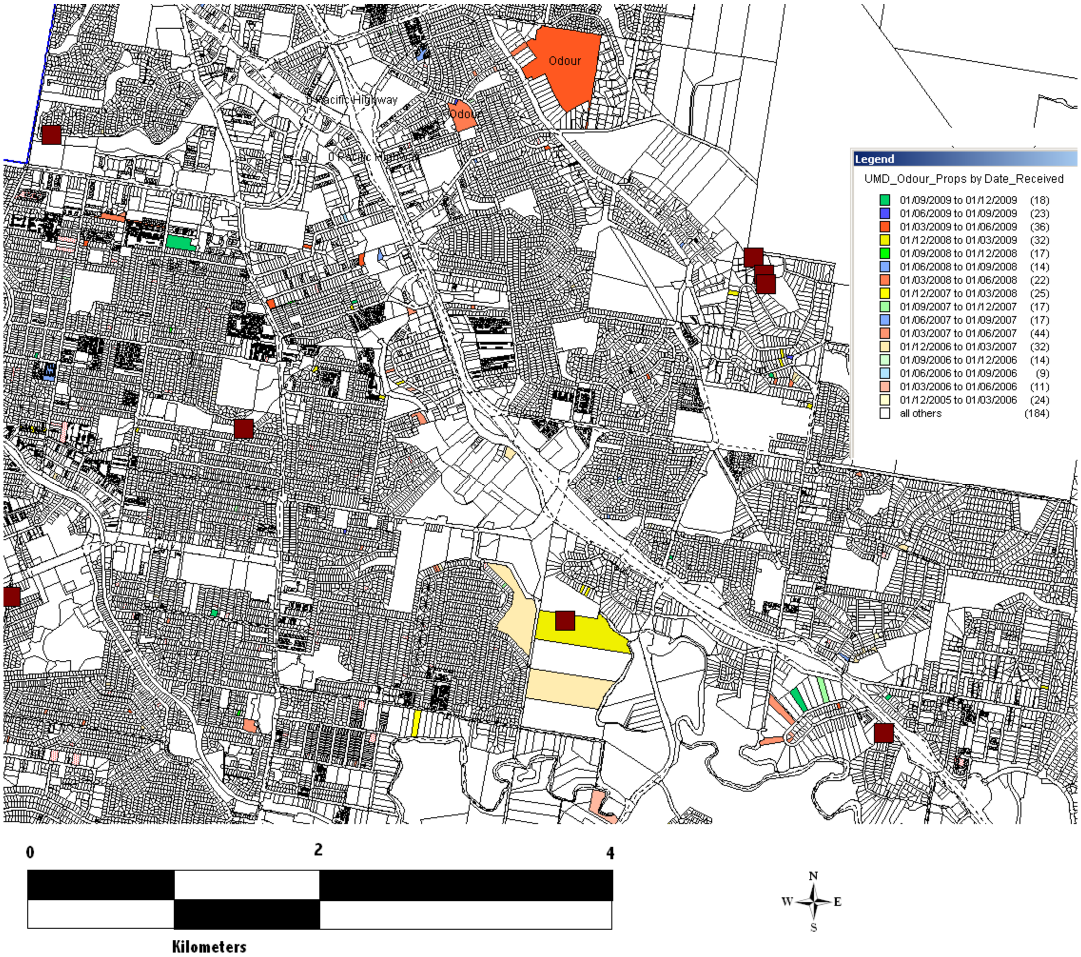

Figure 2. An example of some obvious seasonal clusters of complaints - Autumn orange complaints in the upper half and yellow Summer complaints at the bottom. Maroon squares - pumps

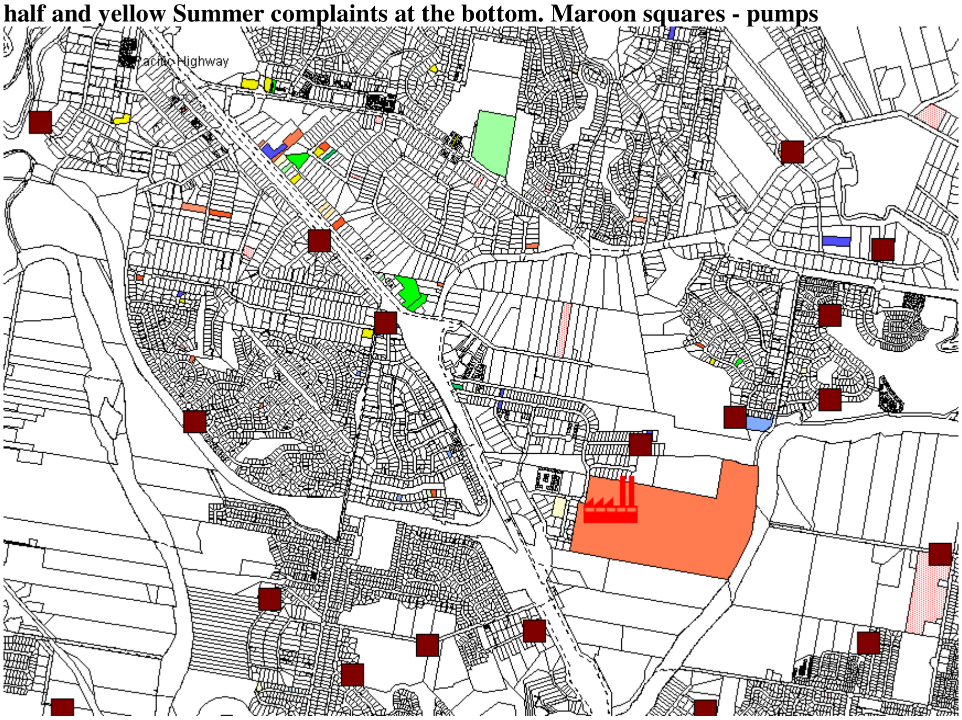

Figure 3. Loganholme WPCC (Water Pollution Control Centre) and surrounding complaints Maroon squares – pumps

9.3. Complaints with regards to Topography

To try to make sense of the random locations of complaints as well as the seasonal clumping of complaint data, a topographical investigation was undertaken. Data was plotted against an elevation diagram with very interesting results (refer to Figure 4).

Most, if not all complaints (white patches and spots) lie in blue and green areas (10 - 20 m elevation). Lower areas are susceptible to temperature inversions and encourage wind tunnels, giving some explanation to much of the data. It should also be mentioned, however, that most of the pumps also lie in these lower areas (refer to Figure 4), suggesting that perhaps more of the odour than first thought is caused by sewer pumps. These plots also suggest that wind does have a prominent effect on where odours become a problem, sparking the need for further investigation of seasonal wind directions and comparing them with the seasonal complaints.

Figure 4 also reinforces the reasons behind odour complaints around the WPCC. As can be seen in Figure 4, the line of complaints following the Pacific Motorway is clearly in a gully. Investigation of wind roses may further strengthen this theory.

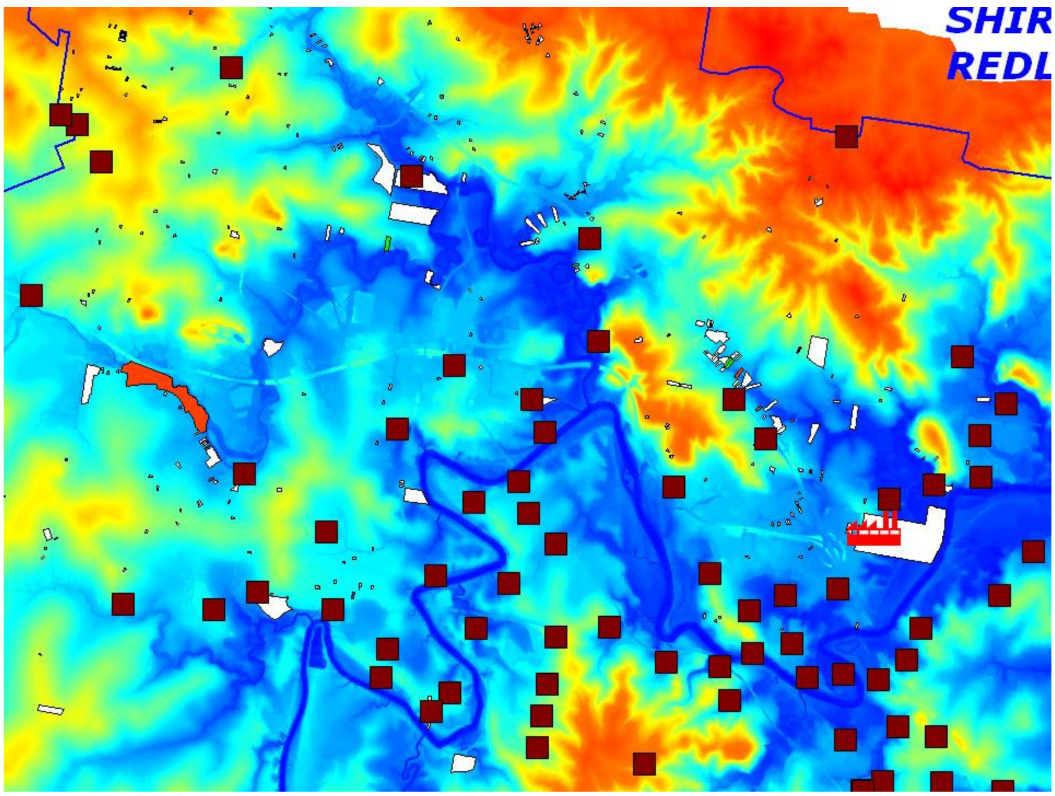

Figure 4 Elevation plot with complaints, pump stations and the WPCC

9.4. Relation to Seasonal Wind Roses

Given the strong relationship to topography that was identified, a study of seasonal wind patterns was also investigated to establish whether wind direction had an impact on the spread of odour complaints.

Examining the initial seasonal data, clumps of complaints in particular seasons were clearly visible. Average wind roses for the seasons were chosen according to seasonal trends and highest wind velocities. For example, if winds in March were similar to those in February and April winds showed marked directional changes with higher velocities, which were higher than those of May, then April winds were chosen as the 'average' for the Autumn.

The first example above of a clumped seasonal complaint was the Autumn series in Figure 2. Observing the data locations shows complaints following a roughly diagonal line in a South West direction. Pump stations nearby are the Pilbi Street pump station to the South West and the Parfrey Road, Stellaris Way and Underwood Road pumps to the North East. Looking initially at the wind roses for Autumn shows winds travelling generally from a South West or South East direction, implying that the Pilbi Street pump station would be responsible, provided the odour is definitely caused by a pump station. Some of the complaints appeared to be remedied by maintenance to nearby manholes, suggesting that it is not just the pump that is responsible. Interestingly, the inference made by the complaint and wind data was confirmed by pump logs, which show the pump operating at 99% capacity at complaint times during April and May 2009, corresponding directly with large rain events.

The second example was the Summer complaints around the Meakin Road pump station (refer to Figure 2 – yellow section at the bottom). Winds for the Summer tend to flow mostly from the East and South East, meaning that either Alfred Street or Meakin Road pump stations are implicated. Given the load that the Alfred Street pump deals with, and the over flow located at Meakin Road, it is highly likely that this is the case.

9.5. Correlation of Complaint Data with Weather Events

As can be seen from the above investigations, topography and wind direction are two main factors that affect the area exposed to odours and therefore complaint generation. As an interesting aside, it should be noted that comparison of clumped complaints to pump overflows showed direct correlation. On further investigation of weather events, it was found that some pump overflows in the Logan area consistently occur following significant rain events. The conclusion from this was that some sewerage catchment areas have stormwater plumbed into them, causing great detriment to the system, hence the complaints. This information could be used by other departments within the Logan City Council.

9.6. Current Buffer Effectiveness Discussion

When studying the existing sewerage infrastructure in Logan, it is noticeable that most sewerage pump stations tend to be in parks or near wetlands. Although this appears to be a wise choice for planning purposes, there are some cases where overflow ponds are within full view and within metres of residential properties – situations which should be rectified. Development of the proposed criteria would not only be useful for planning of new areas, but would also act as an assessment for the existing network, identifying areas which need improvement

10. Conclusion

Having reviewed existing buffer design documentation, it became apparent that many philosophies exist on the issue. Criteria for analysis include both qualitative and quantitative elements, deeming evaluation of site-specific scenarios extremely difficult. Preliminary examination of collated sewerage odour complaint data for Logan City has implied strong correlation between topographical location and some correlation with wind, rainfall and seasons. This evidence further explains the need for more detailed research to establish quantitative distances for buffers around sewerage infrastructure, particularly when urban sprawl is beginning to edge closer to once remote treatment plants and associated infrastructure. Whilst Logan has planned for most sewerage devices to exist within parks or near wetlands and has in some cases mitigated with odour treatment devices such as odour stacks; sewerage odour continues to be a problem that will only increase with time due to planned development for the area. Further study by way of plume modelling, odour data collection or statistical analysis is recommended to verify the findings of this study and to help establish criteria by which local councils could plan buffers for infrastructure, heading towards a more sustainable future.

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