Use of GIS to rationalise pressure in water supply systems

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Abstract

Water is a valuable resource needing conservation. Excessive water pressure in water distribution systems causes leakages leading to substantial losses of treated water. It also places additional strain on networks reducing their efficiency and increasing annual maintenance costs. Conversely, too low a water pressure can be an inconvenient annoyance to the user and, more importantly, mean inadequate conditions to meet fire fighting requirements. The North Shore City Council (NSCC) in Auckland, is not free from the aforementioned pressure-related problems.

This paper summarises the outcome of a study undertaken, using GIS technology, to identify areas with potential pressure problems and suggest options for consideration to resolve pressure issues with the intension of (a) reducing water losses, (b) providing customer satisfaction, (c) ensuring fire-fighting readiness, and (d) making long term savings by strategic capital investment in the water supply network of the NSCC.

First, the clusters of properties with potential pressure problems were identified. A sensitivity analysis was carried out to determine the optimum pressure for the key zones to minimise the number of properties affected by either low or high pressure issues. Then, the optimum pressure for each user was determined while ensuring (a) a minimum supply head of 30m for each property, (b) a maximum static head of 90m, (b) no property experiences a reduction in pressure exceeding 30m as a result of the implementation of the remedial measures suggested, and (c) a minimum residual pressure of 10m at fire hydrants during fire-fighting. Finally, a range of suggestions ranging from pressure zone boundary adjustments to sample designs that can eventually lead to potential capital expenditure are made.

Introduction

Excessive as well as low pressures are recognised internationally as a problem in supply networks. Losses of up to 20% are common in NZ water supply networks and in some towns, losses as high as 70 % have been reported.

The North Shore City is the 4th largest city in New Zealand with a population of 219,300 (as at June 2006) and an area of 12,979 ha. Each year the North Shore City Council (NSCC) purchases about 20 million cubic metres of treated water from the bulk regional supplier Watercare Services Limited (WSL), and supplies to 72,000 households and commercial users throughout the city via a series of reservoirs, pumps and trunks. The city has 29 separate pressure zones (See Figure 1) and elevations of habitable areas ranging from sea level to 145m above MSL. The elevation of the hydraulic grade line (HGL) in the NSCC's water supply zones vary from 80m to 135m, the latter attained in the zones where booster pumps are used.

The driver of this investigation was to consider the possibility of using global data derived from LIDAR information to identify areas of potential issues in the reticulation system. While the determination of the capital expenditure programmes in the NSCC involves more rigorous investigation, a preliminary investigation such as the work presented in this paper can pave the way to identify areas for further investigation in the zone management plan and to recognise opportunities to rationalise pressure to reduce water losses.

Figure 1: Water supply zones in the North Shore City Council

Design Criteria

The NSCC's responsibilities related to supply of water to its domestic, commercial, recreation and fire-fighting needs are stipulated in various documents. These include the Asset Management Plan (AMP) of the NSCC (NSCC, 2005), Infrastructure Design Standards (NSCC, 2006), and New Zealand Fire Service Fire Fighting Water Supplies Code of Practice (NZ Fire Service, 2003).

According to the AMP, the performance of water supply services is monitored through key performance indicators measured against agreed levels of services. The key service criteria for which expected levels of service are defined are Capacity of service, Water Quality, Service sustainability, Legislative compliance, Quality of service (responsiveness), Cost effectiveness and Customer satisfaction. Of these, the level of service with regard to water pressure agreed with customers, which this study aims to meet, in summary are: (a) The Level of Service condition 14 (LoS14) states that 80% of the supplies installed prior to 1 July 2000 should meet the agreed standards of flow greater than 25L/min and static pressure greater than 200kpa by end of 2006, and (b) The LoS 16 states that the entire water supply network must comply with the Fire Fighting code of Practice by 2010.

Two relevant requirements stated in the Infrastructure Design Standards (NSCC, 2005) regarding water pressure are that (a) the supply system shall conform to NZ PAS 4509:2003 New Zealand Fire Service Fire Fighting Water Supplies Code of Practice, (b) the minimum water pressure during the peak domestic demand and taken at the ground level at the proposed property platform shall be 300 kPa and (c) the maximum static pressure at ground level for each lot shall be limited to 800 kPa.

According to the above requirements, the water pressure rationalisation must follow and meet the following design criteria:

1. For planning purposes, the minimum water pressure at point of supply must be 30m for each property;
2. Properties with a water pressure at point of supply of 20m must meet LoS 14;
3. For hydrants, a residual pressure of 10m is required in operation;
4. The maximum water pressure at point of supply must be 80m; and
5. Prioritisation of capital and renewal projects is to be driven by the performance and capacity factors only.

Of these, the requirement of the maximum pressure at point of supply to be 80m was relaxed to 90m for this preliminary investigation.

Use of GIS to identify properties with pressure problems

The GIS data were queried to extract clusters of properties depending on the type of the potential pressure issue. The following clusters were identified in the first instance, where CSP: Current static pressure.

1. Properties with potential inadequate water pressure, i.e., CSP<20m
2. Properties with potential inadequate water pressure, i.e., CSP <30m
3. Properties with potential excessive water pressure, i.e., CSP >90m

Closer inspection of the extracted results indicated that it will be beneficial from a cost/benefit perspective to consider properties very close to the 30m static pressure mark. The tables below summarise the numbers of properties with potential pressure issues, derived from the GIS data analysis. It should be noted that there are no properties with CSP <10m in the NSCC. Furthermore, maps were produced in MapInfo® to illustrate the spatial distribution of these properties.

Table 1: Properties with inadequate pressure (CSP: Current static pressure.)

Name of pressure zone	No. of Properties			
	CSP<20m	20m≤CSP<28m	28m≤CSP<30m	CSP<30m
Albany Low 80m	6	67	37	110
Beachhaven 80m		4	4	8
Birkenhead 110m	92	186	95	373
Birkenhead Boosted 130m	-	33	28	61
Cuthill 110m	-	-	15	15
Cuthill Boosted 130m	-	8	8	16
Devonport 80m	2	3	1	6
Glenfield 110m	9	87	94	190
Glenvar 110m	2	52	0	54
Glenvar Boosted 135m	4	7	0	11
Greenhithe 80m	1	63	12	76
Kowhai 80m	-	10	22	32
Northcote 80m	-	36	28	64
Pinehill Boosted 130m	-	9	4	13
Takapuna 80m	-	17	15	32
Torbay 80m	8	61	27	96

Table 2: Properties with excessive pressure (CSP: Current static pressure)

Name of pressure zone	No. of Properties with CSP > 90m
Birkenhead 110m	125
Birkenhead Boosted 130m	24
Cuthill 110m	2
Cuthill Boosted 130m	1
Glenfield 110m	344
Glenfield Boosted 135m	135
Pinehill 110m	104

The ability to visualise the location of the clusters of properties with potential pressure issues with respect to the zone boundaries is a significant benefit of using a GIS platform for the analysis. For example, if a cluster of properties with excessive pressure is located in the middle of a certain pressure zone, that local issue can be dealt with by pressure reduction valves (PRVs). Similarly, inadequacies in pressure can be rectified by boosting the pressure in a specific area. If the clusters are located near the boundary of the pressure zone, the excessive pressure issue may be rectified by disconnecting the properties from the current pressure zone and re-connecting to an adjacent low pressure zone, or by PRVs. Similarly, the inadequate pressure issues can be remedied by disconnecting clusters from the current low pressure zone and re-connecting them to an adjacent high pressure zone if they are near the boundary.

If the issues in a certain pressure zone are confined to clusters of properties having one type of an issue, i.e. either too high a pressure or too low a pressure in the entire zone, a potential solution can be suggested with relative ease. It is clear that a forced reduction in the pressure in a given zone can satisfy customers who currently have excessive pressure. However, this may cause other customers who currently have adequate pressure to begin experiencing low pressure. The reverse is also true; a forced boost to the pressure in a given zone can satisfy customers who currently have inadequate pressure but may generate new issues of excessive pressure to others. Therefore, in those pressure zones where there are several clusters of properties with each experiencing different type of a pressure issue, the potential solutions are not straight forward. Such zones need to be dealt with using an integrated approach.

A sensitivity analysis which can be used to determine how the changes in zone pressures affect the static pressure (SP) is vital for these pressure zones. Two pressure zones which revealed clusters of properties with mixed pressure issues are Glenfield 110m and Birkenhead 110m. A GIS query analysis was carried out to enumerate the properties with the potential to get affected and thereby the sensitivity of the pressure variation due to boosting/reducing the zone pressure in each of these two areas. Figure 2 shows the results of this sensitivity analysis for these two pressure zones.

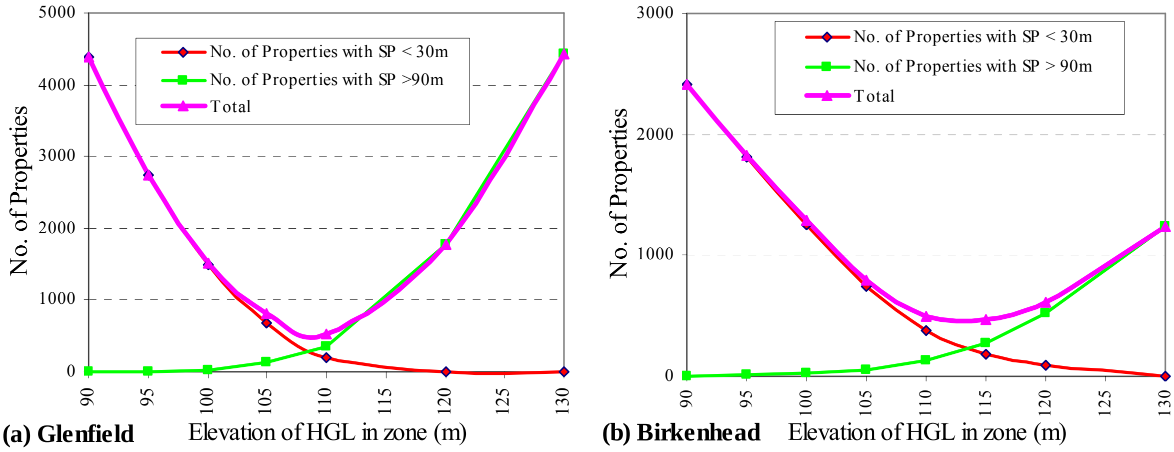

Figure 2a: Sensitivity analysis for Glenfield zone (HGL is currently at 110m)
Figure 2b: Sensitivity analysis for Birkenhead zone (HGL is currently at 110m)

For the Glenfield 110m pressure zone, the ideal elevation of HGL would be 109m while for Birkenhead 110m zone, it is approximately 113m. From this analysis it becomes clear that the current supply pressure in the zones, although not ideal, is very close to that giving rise to the minimum number of total pressure issues. Thus it can be concluded that a zone pressure adjustment is not a significant potential solution for these two zones.

Prioritisation of remedial measures

Although it is ideal to be able to rectify all potential pressure issues in the NSCC, from a point of view of implementation of solutions, it is necessary to take into account the geographical scatter of the affected properties. As such, the following reasoning was adopted to assist in the prioritisation of the areas to continue further investigation.

(a) Properties having CSP<30m, and geographically in close proximity to each other forming a bigger cluster, will be prioritised. If, however, a smaller cluster is formed by a few properties with 28m≤CSP<30m, and this is far from another prioritised cluster, no solution will be sought for these few properties.
(b) All properties with 20m≤CSP<28m will be prioritised, unless these properties are very loosely scattered geographically.
(c) All properties with CSP<20m will be prioritised even if isolated.
(d) Properties with CSP > 90m will be prioritised. However, a reduction in pressure of more than 30m is avoided as such a drop can be felt by the consumer and perceived as a deterioration of quality or comfort.

Based on the above reasoning, five types of clusters were identified using GIS data analysis to be prioritised for further investigation to rectify pressure issues. The GIS analysis makes it possible to examine closely the geographical location of these clusters and suggest potential approaches to rectify the potential issue. The following paragraphs and tables summarise the findings of the GIS analysis and the suggestions.

<u>Type 1:</u> Properties of this type potentially have inadequate pressure (CSP<30m) and are located near the boundary of pressure zones. The general suggestion for these clusters is to disconnect them from the current pressure zone and re-connect to the nearest higher pressure zone. Table 3 summarises the potential issues and the suggestions for potential solutions.

Type 2: These properties also have inadequate pressure (CSP<30m) and usually are located in the middle part of pressure zones or in the periphery of the NSCC boundary. Table 4 details the outcome of the preliminary analysis.
Type 3: The properties in this category potentially have excessive pressure (CSP >90m) and are located near the boundary of pressure zones. The clusters and the possible resolutions from the preliminary analysis are summarised in Table 5.
Type 4: These clusters with potential excessive pressure (CSP>90m) lie in the central part of the pressure zones or close to the beach. Table 6 gives the outcome of the analysis.
Type 5: These properties may have inadequate pressure (CSP <20m) and form small clusters or are located very far from a higher pressure zone making it difficult to provide an economically feasible solution. This category of clusters summarised in Table 7 with the issues.

Table 3: Type 1 property clusters with inadequate Pressure (CSP<30m)

Cluster	**Current pressure zone**	Nearest zone	No. of properties that can be disconnected and re-connected
Cluster 1	Torbay 80m	Glenvar 110m	46
Cluster 2	Torbay 80m	Pinehill 110m	61
Cluster 3	Glenvar 110m	Glenvar Boosted 135m	47
Cluster 4	Albany Low 80m	Cuthill 110m	61
Cluster 5	Glenfield 110m	Pinehill Boosted 130m	31
Cluster 6	Glenfield 110m	Glenfield Boosted 130m	65
Cluster 7	Takepuna 80m	Glenfield 110m	49
Cluster 8	Northcote 80m	Birkenhead 110m	23
Cluster 9	Birkenhead 110m	Birkenhead Boosted 130m	80

Table 4: Type 2 property clusters with Inadequate Pressure (CSP<30m)

Cluster	**Current Location**	**Identified potential remedial measure**
Cluster 10	Near the boundary of Albany low 80m zone but close to other council's territory.	Provide pressure boost for the 19 properties.
Cluster 11	In the middle of Greenhithe 80m zone.	Provide pressure boost for 76 properties.
Cluster 12	In the middle of Pinehill Boosted 130m zone.	Provide pressure boost for 12 properties.
Cluster 13	In the middle part of the Birkenhead Boosted 130m zone.	Provide pressure boost for 61 properties.

Table 5: Type 3 property clusters with Excessive Pressure (CSP >90m)

Cluster	**Location**	**Suggestion 1**	**Suggestion 2**
Cluster 14	Near the boundary of Birkenhead 110m zone but close to the beach.	Install PRVs for 14 properties.	Reduce zone pressure. New issues of inadequate pressure will have to be addressed.
Cluster 15	Near the boundary of Glenfield 110m zone but close to beach.	Install PRVs for 136 properties.	Reduce zone pressure. New issues of inadequate pressure will have to be addressed.

Table 6: Type 4 property clusters with excessive pressure (CSP >90m)

Cluster	Location	Potential remedial measure to be investigated
Cluster 16	Near the boundary of Pinehill 110m zone and close to Kowhai 80m zone.	Disconnect 94 Properties from Pinehill 110m zone and re-connect to Kowhai 80m zone.
Cluster 17	Near the boundary of the Birkenhead Boosted 130m zone and close to Birkenhead 110m zone.	Disconnect 24 properties from Birkenhead Boosted 130m zone and re-connect to Birkenhead 110m zone or install PRVs.
Cluster 18	Near the boundary of Glenfield Boosted 135m zone and close to Glenfield 110m zone.	Disconnect 110 properties from Glenfield Boosted 135m zone and re-connect to Glenfield 110m zone.

Table 7 : Type 5 property clusters with inadequate pressure (CSP <20m)

Cluster	Location	Identified potential remedial measure
Cluster 19	In the middle of Birkenhead 110m zone.	Disconnect 17 properties from Birkenhead 110m zone and re-connect to Birkenhead Boosted 130m zone.
Cluster 20	A very small cluster located near the boundary of the Cuthill Boosted 130m zone.	Do nothing at this stage.
Cluster 21	A very small cluster located near the boundary of the Glenvar Boosted 135m zone.	Do nothing at this stage.

These clusters were further split in to sub-clusters depending on the location of the properties. The GIS was extremely useful in this data management as well as visualisation. Although not provided here due to space constraints, graphical illustrations of the clusters and sub-clusters, a sample of which is shown in Figure 3, were prepared. These preliminary maps will provide a good basis to narrow down the further investigation.

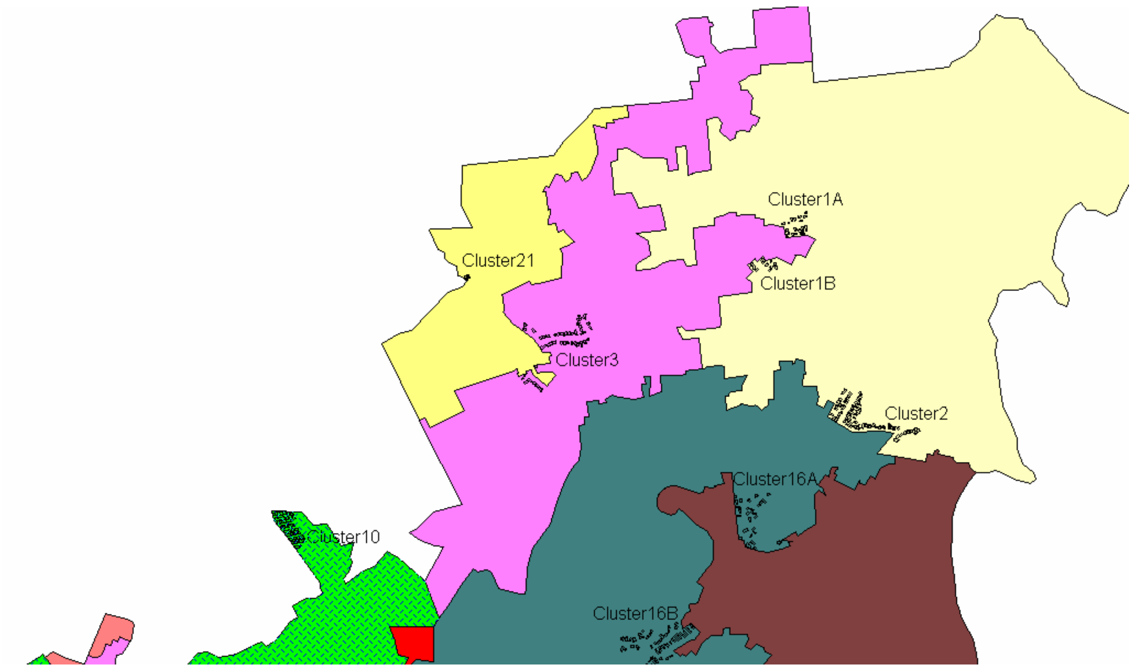

Figure 4: A sample illustrating identified clusters of properties with potential pressure issues

Suggested remedies for preliminarily identified issues

In order to evaluate the suggested remedial measures to rectify the pressure issues for each cluster of properties, a careful and close examination was made of the sub-clusters and their physical locations along with the GIS data of existing reticulation, auxiliaries, and other service and infrastructure to examine the feasibility of solutions. This scrutiny included an evaluation of the site constraints and potential environmental and social impacts associated with implementing the suggestions.

As the last step of this preliminary study, sample templates for potential designs were prepared for some key areas. These included following elements:

(a) Abandonment of existing connections;
(b) Extensions of existing rider mains;
(c) New connections;
(d) Installation of new sluice valves;
(e) Installation of new pumps;
(f) Relocation of zone boundaries by adjusting valve operations;
(g) Installation of pressure reducing valves (PRVs);
(h) Relocation of fire hydrants; and
(i) Replacement of motors in existing variable speed pumps.

GIS was extremely helpful in preparing maps to illustrate the templates of proposed suggestions, samples of which will be presented at the conference.

Conclusions

If the relevant data are available, GIS can be a powerful tool to evaluate static water pressure distribution and thereby determine areas of potential high/low pressure issues in a reticulation system. This study showed how GIS can be utilised to carry out a sensitivity analysis to determine the ideal pressures in pressure zones to minimise the pressure related problems. Analysis with GIS also allows easy visualisation of the query results which helps the engineer in determining appropriate solutions subject to other constraints by incorporating into the analysis the GIS information of property elevations, reticulation system and auxiliaries, conflict with other utilities and infrastructure. A desk-top GIS study such as this enables identification of potential problem areas that deserve further investigation to rationalise the water pressure to save the valuable resource of water while satisfying the customer needs.

References

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