PINPOINTING UNKNOWN ON-SITE WASTEWATER SYSTEMS IN CANTERBURY REGION

Weaver L[1], Orsi A[1], Humphries B[1], Pearson A[1], Wills M[2], Qiu R[1]

[1] Institute of Environment Science and Research (ESR)
27 Creyke Road, Ilam, Christchurch 8041

[2] Environment Canterbury
200 Tuam Street Christchurch 8011

ABSTRACT

Throughout Aotearoa the locations of decentralised on-site wastewater systems are largely unknown if they were installed prior to the year 1998, because installing an on-site wastewater system did not require a resource consent before that time. Those systems are presumed to be primary treatment systems which sometimes date back to the 1950s or older. Their performance and risks to environmental and public health are poorly understood. Even for more recently installed secondary treatment systems, their risks are also poorly understood and require further research.

This paper investigates the application of Geographical Information Systems (GIS) to create a pipeline of methods to estimate the locations and number of unknown on-site wastewater systems on a regional scale based on rating units (property), building outlines, rating information alongside information of consented on-site wastewater systems. A case study of the Canterbury Region, which contains 10 districts, shows how geospatial data can assist in pinpointing the locations of on-site wastewater systems. The investigation revealed that approximately 34,265 rating units are serviced by on-site wastewater systems. Out of these, only 23.61% have active wastewater discharge consents. Around 76.39% of rating units which potentially have on-site wastewater systems were unknown to the Canterbury regional council before the investigation. The findings also revealed that on-site wastewater systems are not only located in communities without reticulated wastewater service, but also within town boundaries where reticulated wastewater infrastructure exists. Additionally, the research uncovered 862 previously unknown on-site wastewater systems in drinking-water protection zones.

The locations and number of the unknown on-site wastewater systems is vital to inform potential future locations where reticulated wastewater infrastructure investment may be required. It also provides insights into those locations which may be at risk from on-site wastewater contamination, particularly drinking water protection zones and those environments that are sensitive to changes in our climate (e.g., shallow groundwater and coastal environments).

KEYWORDS

On-site wastewater systems, septic tanks, wastewater, GIS

PRESENTER PROFILE

Rachel Qiu is a data scientist at ESR. She holds a master's degree in applied data science. Rachel has passion in Geospatial Analysis and Deep Learning. She is also keen to combine GIS and Deep Learning methods to solve real world problems.

INTRODUCTION

On-site wastewater management systems (OWMS), also crudely known as septic tanks, are systems that receive and treat wastewater from specific properties before distributing the treated wastewater to a Land Application System (LAS) within the same property boundary (Environment Canterbury, 2018). These systems are typically used in areas where municipal reticulated sewage infrastructure is not available, such as rural or urban fringe areas. It is estimated that approximately 20%-25% of New Zealand's population rely on on-site wastewater system for their wastewater disposal needs (GHD, 2021). The settings serviced by on-site wastewater systems not only include private residential dwellings, but also include rural schools, holiday homes, campsites, and commercial establishments.

On-site wastewater systems with different designs and components provide variable wastewater treatment. Whether the systems are serviced regularly also has great effect on the performance of the systems (Water New Zealand, 2017). Well-designed and properly functioning on-site wastewater systems can provide a high degree of domestic waste treatment (Robertson et al., 2019). However, their discharges contain nutrients and microbial contaminants which can contribute to groundwater and surface water degradation (Weaver et al 2013, Yang et al., 2017, Spoelstra et al., 2020, Rakhimbekova et al., 2021). Poorly functioning (often aging) systems may provide inadequate treatment, discharge to unsuitable land application systems, be irregularly serviced, and be poorly maintained. Effluent discharged from on-site wastewater systems contains amongst other nutrients nitrogen and phosphorus, which can contribute to the degradation of groundwater and surface water quality. Further, the effluent contains microbial contaminants which can impact the quality of groundwater used for drinking water (Bremer and Harter, 2012, Clemens et al 2020, Murphy et al., 2020). Risks to human health are exacerbated in areas with high densities of on-site wastewater systems and shallow private-supply wells (which, unlike public-supply wells are not monitored frequently), and following periods of heavy rainfall (Murphy et al., 2020).

Prior the year 1998, human effluent discharge via an on-site wastewater system was considered a permitted activity in New Zealand. The rules for on-site wastewater regulation vary in different regions and are subject to change (Ministry for Environment, 2008). With the concern of the impact of on-site wastewater on environment and public health growing, the unknown number and locations of the systems become a management challenge facing the regional or district councils throughout New Zealand. This paper investigates the application of Geographical Information Systems (GIS) in estimating the locations and number of unknown on-site wastewater systems in Canterbury region, leveraging geospatial data from Canterbury Maps (Environment Canterbury, 2023). The aim is to show the locations where on-site wastewater systems are estimated to be present on a Canterbury regional map, and to assist Environment Canterbury in aspects of its management of its groundwater and surface water resources and improve assessments of risks to drinking-water wells.

A geographic information system (GIS) is a computer-based system that integrates location data with all types of descriptive information in the form of a map (Environmental Systems Research Institute, n.d.). There has been extensive research on the field of on-site wastewater employing GIS. The most related studies in estimating the locations and number of on-site wastewater systems are the studies of Environment Southland (2014), Otago Regional Council (2015), and Krista et al (2020). To estimate the risk of groundwater contamination sourced from on-site wastewater systems, Environment Southland (2014) used 2013 census data of resident population and occupied dwellings in a mesh block scale by overlaying reticulated sewage systems to estimate the number of on-site systems. The limitation of the approach was that aggregated data in a mesh block does not have individual data points for dwellings. Also, it did not include locations like schools, business premises, and halls, which potentially have an on-site wastewater system because the census data only includes residential dwellings. Otago Regional Council (2015) developed a risk-based model to assess the potential contamination of groundwater by leachates. They calculated the number of septic tanks in Otago region by using properties addresses, excluding properties that were known to have wastewater reticulation, lack address points and have an area greater than 6.7 hectares. This approach may have overestimated the number of on-site wastewater systems because it included addresses without dwellings and undeveloped sections. Krista et al (2020) developed a framework to assess the potential environmental risk and environmental justice concerns associated with on-site wastewater systems with a case study in Athens Clarke County, Georgia in the south-eastern United States. To achieve the goal, they utilised datasets with known on-site wastewater system locations, addresses of sewer connection, sewer lines, tax parcels, and building information to determine the distribution of parcels with sewer, with registered on-site wastewater systems, or with unknown on-site wastewater systems. The study achieved a higher level of accuracy in determining the number of on-site wastewater systems comparing to the methods of Environment Southland and Otago Regional Council. The limitation of this approach was that it assumed all on-site wastewater systems are situated at the centre of the parcels, resulting in reduced location accuracy of the on-site wastewater systems in parcels with large land areas.

Unlike the above GIS-based studies, this paper focused on estimating the point locations of the unknown on-site wastewater systems which operate under permitted activity, not the impact of them. The methods used in the paper are pertinent to the ones used by Krista et al (2020), but with notable discrepancy in how to locate a system within a property. Krista et al (2020) assumed all systems were located in the centre of a parcel while this paper pinpointed the unknown systems as the centre of the largest building in a property, which achieved a much higher accuracy in location estimation.

MATERIALS AND METHODS

DATA SOURCE AND DESCRIPTION

The data used in estimating the locations of unknow OWMS are “Rating Units”, “Building Outlines”, “Wastewater Pipelines”, “Human Effluent Discharge Consents”, and “Rating units on reticulated wastewater systems”. Most of the data were sourced from Canterbury Maps (Environment Canterbury, 2023) as map layers (Figure 1), except “Rating units on reticulated wastewater systems”, which are CSV files or shapefiles sourced from local councils (either directly provided by local councils or extracted from their websites or approximated by wastewater pipelines).

Figure 1: Map layers in Canterbury maps used in pinpointing unknown on-site wastewater systems (The map shows southeast of Ashburton town centre)

“Rating units” are defined and maintained by city councils for the purpose of rate collection. Other regions like Otago refer to rating units as “properties”. They overlap with land parcels on many occasions, but they are not identical to land parcels. There are “Land Use”, “Category” and “Improvement Value” columns in the attribute table among other information, which provides details of a rating unit including the category of the property, the status of a property (whether it is vacant) with Rating Valuations Rules from Land Information New Zealand (LINZ, 2008). These attributes can help distinguish whether a property is occupied in subsequent analysis. The “Building Outlines” map layer is roof outlines of buildings extracted from Land Information New Zealand (LINZ) aerial imagery, which contains building outlines no less than 10 square meters. Building outlines were used to exclude rating units without buildings in the analysis. The dates on which the aerial imageries were taken range from January 2010 to March 2021. Thus, the building outline dataset derived from the aerial imageries is not up to date. The "Human Effluent Discharge Consents" are the records of resource consents to discharge human effluent onto land or into water in Environment Canterbury's Resource Management Act Database. The "Wastewater Pipelines" are the maps of the pipelines of reticulated wastewater systems. The "Rating Units on Reticulated Wastewater Systems" are CSV files or shapefiles containing information on the rating units within Canterbury region that are connected to reticulated wastewater systems. The sources of the data are either directly provided by district councils (Timaru, Waimate, Mackenzie, Waitaki), or extracted from the website of district councils (Ashburton, Selwyn, Waimakariri, Hurunui, Kaikōura), or estimated by the wastewater pipes (Christchurch and Banks Peninsula).

METHODS

The location of on-site wastewater systems was estimated at the level of rating units. As described in section 2, a rating unit is defined and maintained by local councils for the purpose of calculating and collecting rates. The methods were built upon the assumption that if a rating unit has occupied buildings (the rating unit has buildings and it is not vacant) and is not connected to a reticulated wastewater system, it would need to be serviced by some form of on-site wastewater system. The method can be succinctly expressed as: rating units with unknown systems corresponds to all occupied rating units that are not reticulated or with active discharge consents. Hence, the way to find the unknown systems is to answer the following questions: 1) How to locate occupied rating units? 2)How to obtain the data of rating units connected to reticulated wastewater systems? 3) How to identify rating units with consented on-site wastewater systems (i.e., with active human effluent discharge consents)?

LOCATING OCCUPIED RATING UNITS

Two map layers, "Rating Units" and "Building Outlines" were used to locate the occupied rating units (Figure 2). An occupied rating unit was located by the largest building in the rating unit, which has great advantage in location accuracy over using the centre of the rating unit. On-site wastewater systems are normally installed near dwellings and most of them are in rural areas or the urban fringe, where the rating units tends to have larger land area. In such cases, the centre of a rating unit and the dwelling may be far away. This is why building outlines are important in estimating the locations of on-site wastewater systems.

In the Canterbury Maps datasets, Rating Units and Building Outlines cannot be related by their attributes. Instead, they can only be related by their spatial relationship. In other words, if a rating unit polygon contains a building outline polygon, it is considered belonging to the rating unit. If they overlap, the intersect area of the building outline is considered as part of the rating unit. If a building outline is neither inside nor overlap with a rating unit, it is considered that there is no relation between the two. To exclude the buildings too small to be dwellings and the vacant dwellings, the rating unit with building outlines less than 30 m^2, the rating units which are denoted as vacant in "land use" and "category" columns and rating units with improvement value less than $20,000 were removed. The left rating units were considered as occupied rating units.

OBTAINING RETICULATION DATA

There are two methods to identify which rating units are connected to the municipal reticulated wastewater systems. One is to use rating information from the local councils (Figure 3), the other is to use the distance of a rating unit from the wastewater pipes. Reticulated rating units of all districts were identified by rating information except Christchurch and Banks Peninsula. In this case, if a rating unit is charged for wastewater connection, it is considered reticulated. For Christchurch and Banks Peninsula, if a rating unit is within 200 meters of the nearest wastewater pipeline, it is considered reticulated. This method is not as accurate as the first method.

Figure 2: A rating unit with two building outlines

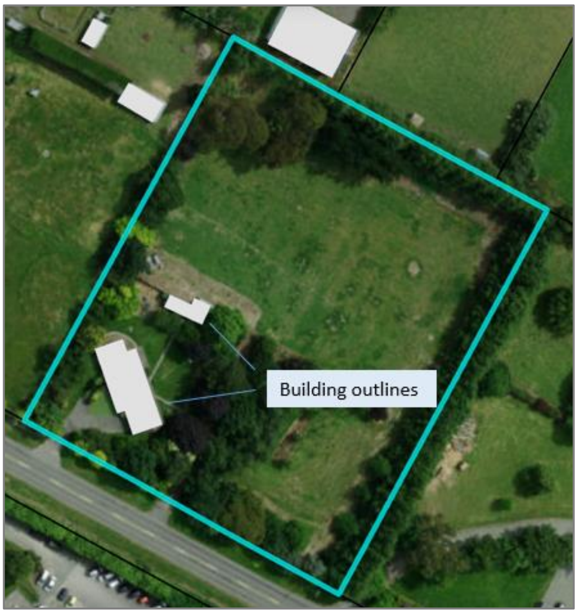


Figure 3: Rating information from Ashburton District Council

Rating Information Current District

Description	Factor	Rate/Charge	Amount
Ashburton Urban Amenity	400000	0.0007450000	$298.00
Ashburton Waste Collection	1	235.3000000000	$235.30
Ashburton Wastewater Connected	1	484.8000000000	$484.80
Ashburton Water Supply Connected	1	514.2000000000	$514.20
General Rate	400000	0.0004040000	$161.60
Roading Rate	400000	0.0004330000	$173.20
Uniform Annual General Charge	1	697.0000000000	$697.00
Total			**$2,564.10**

Rating Information Current Regional

Description	Factor	Rate/Charge	Amount
Ashburton River E Catchment Works	400000	0.00003755	$15.02
Catchment Works and Services	400000	0.0000120400	$4.82
Civil Defence Emergency Management	1	13.8600000000	$13.86
Clean Heat Incentive	400000	0.0000093300	$3.73
Regional General Rate	400000	0.0003324900	$133.00
Regional Uniform Annual General Charge	1	46.1000000000	$46.10
Total Mobility Rate	400000	0.0000080300	$3.21
Total			**$219.74**

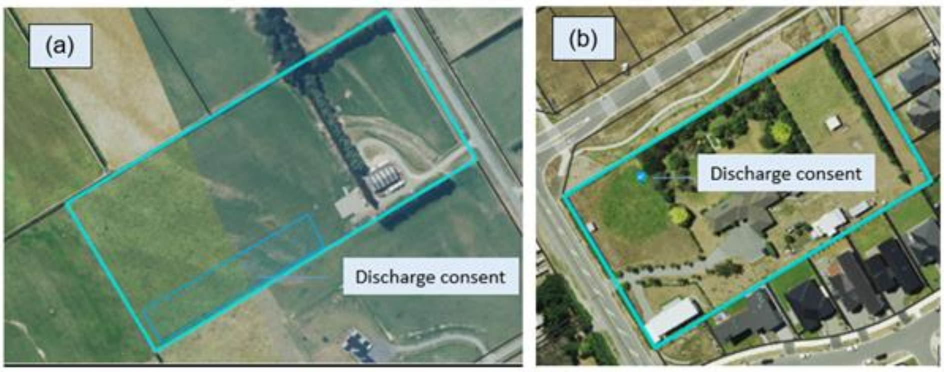
IDENTIFYING RATING UNITS WITH ACTIVE DISCHARGE CONSENTS

"Rating units" and "Human Effluent discharge Consents" map layers were utilised to identify rating units with active consented on-site wastewater systems. The rationale was that if a rating unit contained an active discharge consent, it should have an on-site wastewater system installed within the rating unit. Most of the discharge consents were marked as points in Canterbury Maps, a few others were marked as areas (Figure 4).

Initially, it was attempted to join two attribute tables Rating Units and Human Effluent discharge Consents according to their common attributes which is "street address" in Rating Units and "location" in Human Effluent discharge Consents, for they both represent addresses. However, this was not feasible because some addresses had missing values for suburb or locality. Moreover, the records of the location column in discharge consents were not uniformed, with the random presence or absence of property number, suburb, district, or postcode. In some cases, the locations were just descriptions of the corner of two roads. The huge difference in the two columns of the attribute tables rules out the possibility of direct match or fuzzy match by address. The second attempt was to geocode the addresses in ArcMap using address locator created from NZ Street Address and locator from Environment Canterbury. However, the match rates were under 20% with both address locators, which was not good enough for joining the two tables.

The alternative solution, which was adopted in this research, is to perform a spatial join in GIS software. With the geometry of attributes (points, lines, or polygons) and their locations on the map, it is convenient to use spatial functions to determine the relation between the geometries. According to consents (polygons/points) and rating units (polygons) locations, if a discharge consent polygon/point lays inside a rating unit polygon, the consent record is considered belonging to the rating unit. If not, it does not belong to the rating unit.

Figure 4: (a) Discharge consent as an area (b)Discharge consent as a point



IDENTIFYING RATING UNITS WITH UNKNOWN ON-SITE SYSTEMS

With the occupied rating units map layer derived from Section 4.2.1, joined by reticulation data from Section 4.2.2, and rating units with active discharge consents from Section 4.2.3, the rating units with unknown OWMS can be identified.

RESULTS AND DISCUSSIONS

OWMS IN CANTERBURY BY DISTRICTS

The result shows that in Canterbury, approximately 34,265 (13.94%) rating units with occupied dwellings are serviced by on-site wastewater systems, of which 8,089 (23.61%) have active wastewater discharge consents for their on-site wastewater systems. There are approximately 26,176 (76.39%) rating units which potentially have on-site wastewater systems that do not have their systems consented and were previously unknown by regional council. The number of on-site systems and the rates of consented on-site wastewater systems vary among districts. The largest number of on-site systems can be found in Selwyn district (2,716 consented, 6,689 previously unknown), followed by Waimakariri district (2,081 consented, 4,668 previously unknown). Among the 10 districts in Canterbury, Waimakariri district has the highest rate of consented systems (30.83%), closely followed by Selwyn (28.88%) and Kaikōura (26.02%). In contrast, Waitaki and Waimate district have the lowest rates of consented systems at 14.93% and15.22% respectively (Table 1).

Table 1: The number of on-site wastewater systems in Canterbury by district

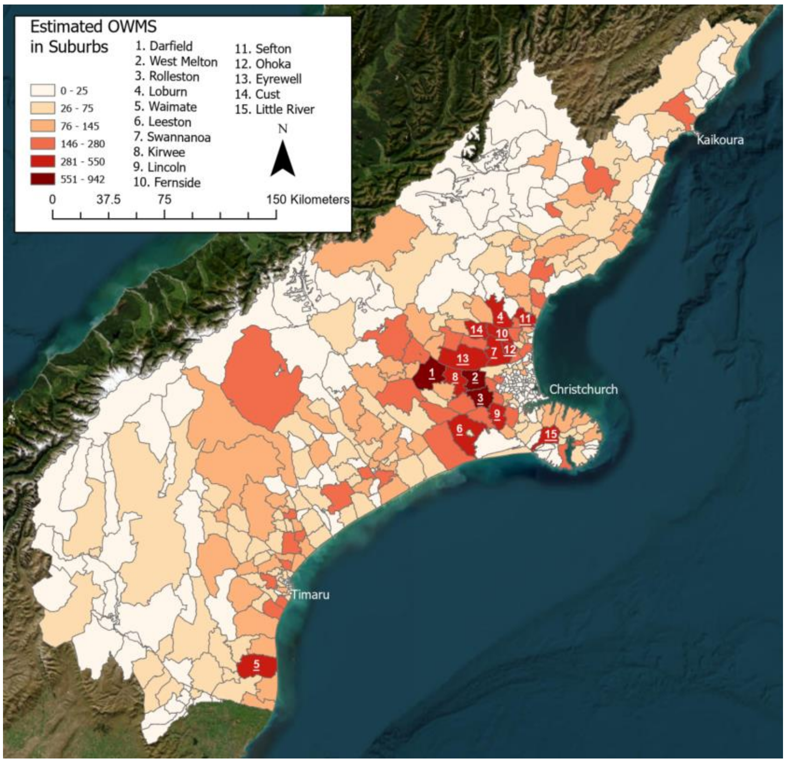
District	Total OWMS	Consented OWMS	%Consented OWMS	Estimated OWMS	%Estimated OWMS
Selwyn	9,405	2,716	28.88%	6,689	71.12%
Waimakariri	6,749	2,081	30.83%	4,668	69.17%
Timaru	4,367	725	16.60%	3,642	83.40%
Ashburton	3,819	723	18.93%	3,096	81.07%
Hurunui	3,226	614	19.03%	2,612	80.97%
Christchurch*	3,028	552	18.23%	2,476	81.77%
Waimate	1,781	271	15.22%	1,510	84.78%
Kaikōura	757	197	26.02%	560	73.98%
Mackenzie	711	147	20.68%	564	79.32%
Waitaki**	422	63	14.93%	359	85.07%
Total	34,265	8,089	28.88%	26,176	71.12%

*Greater Christchurch, including Banks Peninsula.
**Only the part of Waitaki district which is under jurisdiction of Canterbury was included.

ESTIMATED OWMS IN CANTERBURY BY SUBURBS/LOCALITIES

There are 553 suburbs or localities in Canterbury. Top three of them with the largest number of unknown on-site wastewater systems is Darfield (942), West Melton (683) and Rolleston (652), all of which are in Selwyn district. Darfield is the largest non-reticulated community in Canterbury. Of the top 15 suburbs or localities with the largest number of on-site wastewater systems, 7 are in Waimakariri, 6 are in Selwyn, 1 in Waimate, and 1 is Little River in Greater Christchurch (Figure 5).

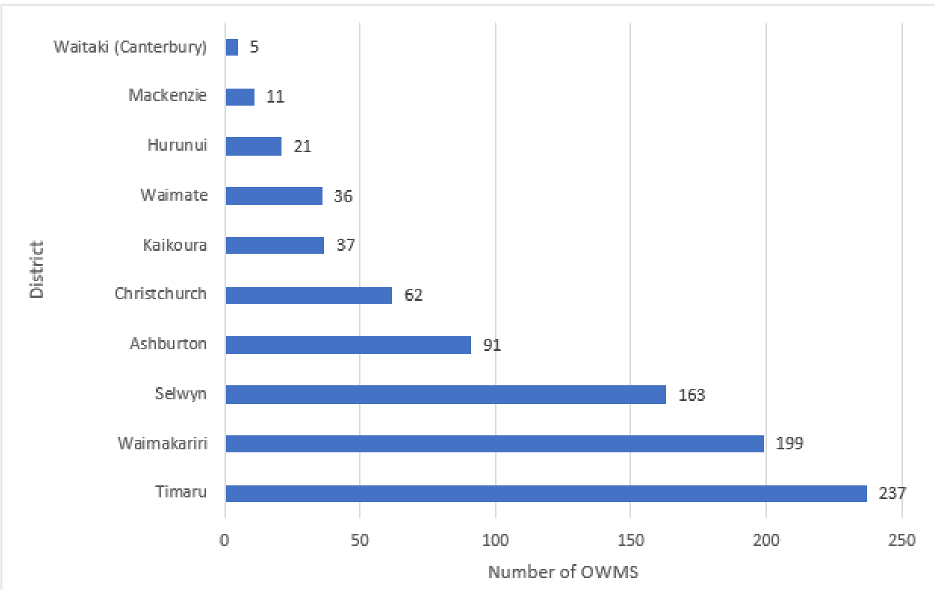
Figure 5: Suburbs with the largest number of OWMS in Canterbury.



UNKNOWN OWMS IN DRINKING WATER PROTECTION ZONES

This investigation identified 862 previously unknown on-site wastewater systems in drinking-water protection zones. Timaru district has the most on-site wastewater systems (237) near their public or community drinking-water sources, followed by Waimakariri district (199) and Selwyn district (163) (Figure 6).

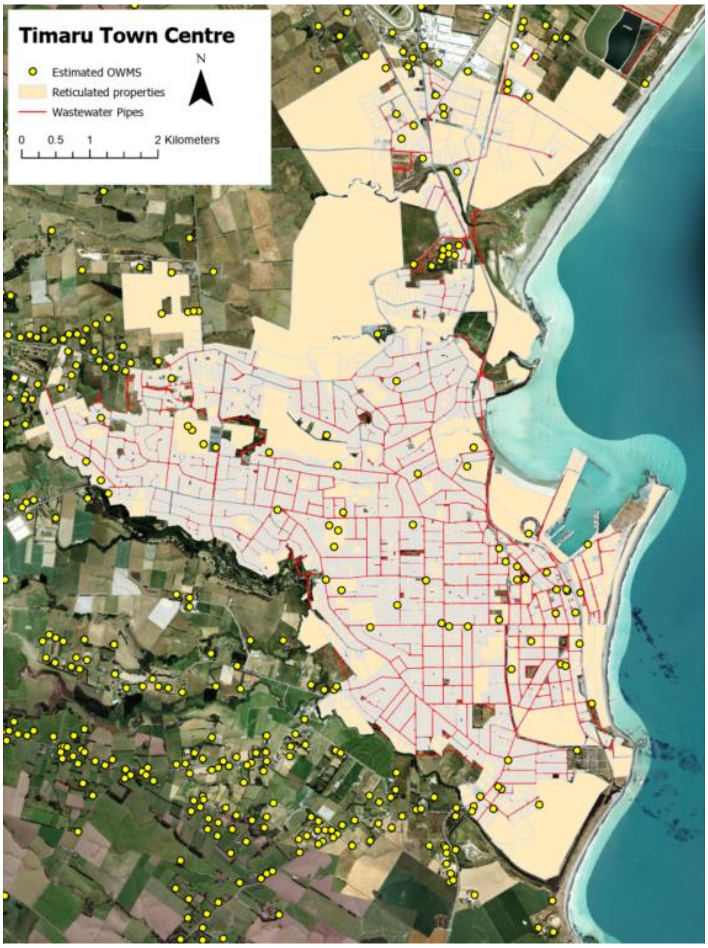
Figure 6: Unknown OWMS in Drinking Water Protection Zones in Canterbury.



UNKNOWN OWMS IN RETICULATED AREAS

There are some properties in urban areas near reticulated wastewater pipes that have no record of paying for reticulation service (e.g., in Timaru (Figure 7)). These properties are flagged as "not reticulated" in the mapping result. It is possible that some of these properties are in fact reticulated. It is also possible that some of these properties have on-site wastewater systems installed reticulated systems extending to the properties and the property owners may have decided not to connect their property to the systems.

Figure 7: Unknown on-site wastewater systems in reticulated area (The map shows Timaru town center and the fringe area).



LIMITATIONS

The approach used to identify the unknown OWMS has certain limitations. One significant limitation is that when a rating unit contains multiple dwellings, the approach can only identify one of them, specifically the largest building within the rating unit, potentially overlooking other dwellings on the same property. The datasets used in the study also impose limitations. Firstly, the aerial imageries from which the building outlines were derived were captured between January 2010 and March 2021, making them not entirely up to date and possibly missing recent changes or developments in the area. Secondly, the "rating units" dataset presents a challenge due to some rating units sharing the same geometry. This issue can lead to the incorrect identification of buildings for certain rating units, compromising the accuracy and reliability of the results.

These limitations should be taken into consideration when interpreting the study's findings, and efforts should be made to address and mitigate their potential impact on the overall conclusions. Future studies might benefit from using more recent aerial imageries and improving the accuracy and resolution of the "rating units" dataset to enhance the precision of on-site wastewater systems identification.

CONCLUSIONS

Mapping the estimated location of on-site wastewater systems can assist decision makers in managing groundwater and surface water resources and protecting groundwater-derived drinking water sources. Utilising the 'building outlines' dataset and using the largest building in a rating unit to represent the possible OWMS, has a great advantage in location accuracy compared with using the centre of the rating unit. The other advantage is that not only OWMS serving domestic dwellings can be captured, but also other unreticulated settings and locations like rural schools, marae, holiday parks and commercial buildings. OWMS in these locations may service hundreds of people and include additional issues such as seasonal and variable wastewater loading and are not usually included in OWMS studies.

By leveraging GIS and spatial analysis techniques, this methodology provides a scalable and adaptable framework that can be applied to other regions in New Zealand. The biggest challenges are data availability and data quality. Obtaining comprehensive and up-to-date data on rating units (property records), building outlines and reticulated wastewater infrastructure is crucial for accurate analysis.

ACKNOWLEDGEMENTS

This project was funded by Environment Canterbury.

REFERENCES

Bremer, J. & Harter, T. 2012. Domestic wells have high probability of pumping septic tank leachate. Hydrology and Earth System Sciences, 16, 2453-2467.

Clemens, H., Pang, L., Morgan, L.K. and Weaver, L., 2020. Attenuation of rotavirus, MS2 bacteriophage and biomolecule-modified silica nanoparticles in undisturbed silt loam over gravels dosed with onsite wastewater. Water Research, 169, p.115272.

Environment Canterbury, 2018, Canterbury Land and Water Regional Plan, <https://www.ecan.govt.nz/your-region/plans-strategies-and-bylaws/canterbury-land-and-water-regional-plan/>

Environmental Systems Research Institute, n.d., What is GIS, accessed 15th, July 2023, <https://www.esri.com/en-us/what-is-gis/overview>

Land Information New Zealand, n.d. data dictionary for NZ Building outlines data, accessed 12th, April 2023,

<https://nz-buildings.readthedocs.io/en/latest/introduction.html>

Land Information New Zealand, 2008, Rating Valuation Rules,

<https://www.linz.govt.nz/resources/regulatory/rating-valuations-rules-2008-version-date-1-october-2010-linzs30300>

Ministry for the Environment, 2008, Proposed National Environment Standard for on-site wastewater systems, <https://environment.govt.nz/assets/Publications/Files/nes-onsite-wastewater-systems-discussion-jul08.pdf>

Murphy, H. M., McGinnis, S., Blunt, R., Stokdyk, J., Wu, J., Cagle, A., Denno, D. M., Spencer, S., Firnstahl, A. & Borchardt, M. A. 2020. Septic systems and rainfall influence human fecal marker and indicator organism occurrence in private wells in southeastern Pennsylvania. Environmental Science & Technology, 54, 3159-3168.

Rakhimbekova, S., O'Carroll, D. M., Oldfield, L. E., Ptacek, C. J. & Robinson, C. E. 2021.

Spatiotemporal controls on septic system derived nutrients in a nearshore aquifer and their discharge to a large lake. Science of the Total Environment, 752, 141262.

Richards, S., Withers, P.J., Paterson, E., McRoberts, C.W. and Stutter, M., 2017. Potential tracers for tracking septic tank effluent discharges in watercourses. Environmental Pollution, 228, pp.245-255.

Robertson, W. D., Van Stempvoort, D. R. & Schiff, S. L. 2019. Review of phosphorus attenuation in groundwater plumes from 24 septic systems. Science of the Total Environment, 692, 640-652.

Spoelstra, J., Schiff, S. L. & Brown, S. J. 2020. Septic systems contribute artificial sweeteners to streams through groundwater. Journal of Hydrology X, 7, 100050.

Weaver, L., Sinton, L.W., Pang, L., Dann, R. and Close, M.E. 2013. Transport of microbial tracers in clean and organically contaminated silica sand in laboratory columns compared with their transport in the field. Science of the Total Environment, 443, 55–64.

Yang, Y.-Y., Toor, G. S., Wilson, P. C. & Williams, C. F. 2017. Micropollutants in groundwater from septic systems: Transformations, transport mechanisms, and human health risk assessment. Water Research, 123, 258-267.