DYNAMIC CATCHMENT RISK ASSESSMENT – INNOVATIVE TOOLS FOR WATER SECURITY DECISION-MAKING

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ABSTRACT

Contamination of the Havelock North drinking water supply in 2016 has prompted significant reforms to drinking water regulations in New Zealand. Within the reforms comes a strong mandate for water suppliers to intimately understand and manage risks to source water. However, this comes with significant technical challenges, as source catchments are often highly complex and dynamic. In direct response to those challenges, an automated GIS risk assessment tool has been developed. The GIS tool allows a water supplier or decision-maker to identify, prioritise and respond to source risks in real-time as they emerge. Currently, the tool represents the forefront of catchment-risk management in New Zealand. This paper presents a summary of how the tool has been developed and how it is implemented as part of broader water safety planning framework.

INTRODUCTION

In August 2016, over 2,500 people became seriously ill from an outbreak of Campylobacter within the Havelock North drinking water supply (NZ). The source of contamination was later determined to be from contaminated flood-water entering the aquifer and then the water supply bores. The outbreak was essentially the result of the alignment of numerous high-risk events that allowed a relatively large volume of surface contamination to accumulate and then migrate to the public water supply bore. The outbreak represents a classic “Swiss cheese” model, whereby an number of events (holes) align to create an outcome.

The event has been a catalyst for significant legislative reform in New Zealand and has brought about a sharp focus on drinking water protection. The outbreak also serves as a stark reminder of the importance of risk identification and management in source water catchments.

A multiple barrier approach is now globally recognised as a founding principle for delivering safe drinking water. A multiple barrier approach requires that there are “barriers” or measures in place at several steps through the catchment-to-tap process which guard against contamination or the potential for contamination. The first barrier in this process is the prevention of contaminants from entering the water source, which means that potential contaminant risks residing in a source catchment need to be identified, then managed. However, source water catchments can contain thousands of contaminant sources within highly complex and dynamic systems. Furthermore, as for the Havelock North outbreak, often a number of events (Swiss cheese holes) need to align before a contaminant source presents an actual risk to a water supply (i.e., there needs to be a viable pathway). Identifying these potential alignments of risk events within complex and dynamic catchments poses significant challenges to proactive management approaches.

Broadly, contamination risk consists of two main factors that combine to create a risk. Firstly, there must be a source of contamination, then there must be a pathway for the contamination to reach a receptor (in this case, a receptor may be a water supply bore, or water supply intake).

This paper presents an automated tool that allows for contaminant sources to be identified, assessed in terms of potential pathways and then prioritised in terms of risk to a water supply bore.

A qualitative risk score is displayed in real-time on an interactive GIS viewer. The tool is currently configured to assess risks associated with groundwater supply catchments, for which this paper focuses. However, the tool could reasonably be applied to assess risks to surface water sources also.

METHODOLOGY/ PROCESS

The tool uses "live" GIS data to identify various potential sources of contamination within a catchment, then interrogates these in terms of aquifer vulnerability and transport mechanisms from the source, to the abstraction point. This means that the tool critically relies on:

- Quality GIS data to identify contaminant sources associated with land-use activities;
- An understanding of spatial trends in the aquifer's vulnerability to surface contamination (vertical retardation of contaminants); and
- An existing understanding of groundwater flow (horizontal travel time) within the catchment.

To date, we have addressed these by completing analytical groundwater flow modelling and DRASTIC[1] aquifer vulnerability mapping as pre-cursors to developing the GIS tool.

Once this information is available, the tool considers the interaction between risk factors contained within numerous GIS layers. In New Zealand, potential sources of contamination in a catchment can be identified from numerous GIS data sources, such as:

- Contaminated land databases, managed by district and regional authorities (for example, the HAIL database)
- District and regional land-use mapping and planning
- Hazardous substance registries (for industrial land) and handling/storage licences
- Surface water mapping
- Discharge consenting GIS data, showing the location and nature of permitted discharges to land, air and water
- Wastewater infrastructure GIS data, showing the location, age and construction material of various wastewater infrastructure, such as pipes, pumping stations, treatment plants and manholes
- GIS layers showing areas of historical quarrying, mining and landfilling.

Before interrogating the GIS data above, a generic raw risk score is generated for each type of land-use activity type or potential contamination source using a relatively simple risk matrix that considers the following aspects:

- The likely nature of contamination at a particular source. This includes consideration of the likely volume, toxicity and mobility of contaminants associated with a particular activity (for example an underground fuel storage tank)

- The likelihood of a contaminant release from a particular source, considering factors such as the level of management of containment structures

- The consequence of the contaminant reaching the abstraction point. For example, pathogens represent a much higher acute risk than nitrates at comparable concentrations.

Raw risk scores are calculated by assigning a series of qualitative scores (between 1 and 3) for each of the following criteria:

a Whether the activity is currently occurring or historic (yes, no, or unknown);

b Whether bulk storage of contaminants is undertaken as part of the activity;

c Whether the activity includes existing discharges to ground;

d Whether the activity includes existing discharges to surface water;

e The level of management/regulation of the activity;

f The mobility of contaminants associated with the activity and how readily they attenuate in ground and groundwater;

g The toxicity (acute and chronic) of contaminants associated with the activity.

Raw risk scores are determined for each activity using the following calculation:

$$\text{Raw Risk Score} = (a + b + c + d + e) \times (f + g)$$

Mobility and toxicity are adopted as multipliers of raw risk as contaminants cannot present a significant risk to groundwater quality if they are either not mobile in the environment or have low toxicity.

All generic land uses share the same raw risk score, for example all landfills within a catchment are assigned the same raw risk score. The generic “raw risk score” is then built upon for an individual site/contaminant source within a catchment by considering the location of the individual activity in relation to the public water supply and the vulnerability of the aquifer beneath the activity. Using this methodology, individual activities (such as a landfill) are differentiated in terms of distance from the public water supply bore (as a proxy for groundwater travel time) and the relative vulnerability of the aquifer beneath them. In this way, each potential contaminant source in a catchment is given a final risk score that considers the risk factors that contribute to the likelihood and consequence of a contaminant release.

Final risk scores are calculated using the following formula:

$$\text{Final Risk Score} = \frac{(RRS \times AVS)}{P}$$

Where RRS represents the Raw Risk Score, AV represents Aquifer Vulnerability Score and P represents the proximity score (1-10) to the supply bore.

Because the quality and quantity of information contained with existing GIS datasets can vary widely, the raw risk matrix and final risk score must be tailored to the GIS dataset. If detailed data relating to potential sources is available (for instance, attribute data that contains precise contaminant volumes, chemical suites and concentrations), a relatively detailed risk matrix can be developed. However, if information is sparse, often relatively conservative scoring must be undertaken, then revised on a case-by case bases once final risk scoring is completed.

If additional information is available for a particular contaminant source, further multipliers can be added to the final risk score calculation to allow for more detailed ranking to be undertaken. For example, relatively detailed GIS data is often held by wastewater asset owners, such as the age, condition, depth, pipe size, pressure and material type. This information can be used to further consider the risk posed by various sections of infrastructure, because of factors that contribute to the risk of a failure, such as age, material and condition. Data such as the pipe size and operational pressure can be used to consider the consequence of a failure (in terms of likely volume of discharge). In this way, the relatively simple “final risk score” calculation can be adapted to consider additional risk factors if a greater level of data is available. For example, the final risk score for wastewater infrastructure is calculated as follows:

$$\text{Final Risk Score} = \frac{(RRS \times AVS \times age \times material \times pressure \times depth)}{P}$$

In this example, all wastewater pipes share a common raw risk score, but particular sections of wastewater pipe will have differing final risk scores based on the age, material and operating pressure of the pipe, along with its location in terms of the vulnerability of the underlying aquifer and groundwater travel time to the abstraction point.

In this way, an old section of wastewater pipe that is made from leak-prone material (e.g. earthenware), that is within a vulnerable area of the aquifer and is located a short distance from the abstraction point will have an elevated final risk score. In comparison, a section of wastewater pipe located further from the abstraction point and constructed from a more robust material (e.g. HDPE) will be identified as lower risk.

The final risk scores are calculated using Feature Manipulation Engine (FME) software and displayed as a “heat map” on an interactive GIS viewer, which displays the results and allows a user to interrogate the supporting data.

IMPLEMENTATION:

The GIS risk screening tool has largely been designed to align with New Zealand drinking water safety legislation relating to catchment risk. The tool is proposed to fit within the following catchment risk assessment process:

- Delineation of source protection zones (SPZ) for each bore field, based on 1 year groundwater travel time. SPZs provide the boundary and proximity zones within which, catchment risk assessments are undertaken.
- Development of the GIS risk screening tool to identify and prioritise land uses within the SPZ that potentially pose a risk to the drinking water supply. “Screening” results may be updated within water safety planning documents and be used to focus broad/catchment scale management objectives

- Based on results from the GIS tool, focusing of further investigations to target activities that show relatively elevated risk rankings. Incorporation of the detailed catchment risk results into water safety planning along with risk management/mitigation controls.
- As an understanding of the geological and hydrogeological dynamics improves, the tool can be updated to include more quantitative assessments of risk, such as components of fate and transport modelling.

Because the tool is built and delivered through Feature Manipulation Engine (FME) software, organisations with established GIS teams are often able to host, run, maintain and improve the tool themselves with minimal additional investment. This is particularly beneficial for ensuring that the tool benefits from continuous improvement programmes within the organisation and advances in institutional knowledge.

RESULTS/ OUTCOMES

The outcome is that potential contaminant sources are identified, then prioritised in terms of their potential to reach the abstraction point at concentrations that might pose a risk to the supply.

Because the tool is automated and the GIS input data is "live", the risk tool is able to reflect the reduction in risk when changes occur in the catchment. For instance if upgrades to wastewater infrastructure are completed (e.g. replacement of a concrete pipe with HDPE), risk score reductions are reflected in the risk tool once the GIS data source is updated. Equally, when new contaminant sources emerge within a catchment (e.g. a new contaminated site is identified or a new discharge permit is granted) the tool is able to identify and assess these. This allows a water supplier to easily maintain an up-to-date understanding of source-risks and identify new risks emerge. Once risks are identified, a water manager is able to easily prioritise resources to address the highest risks, then measure value in terms of risk reduction.

Figures 1-4 below provide working examples of the risk tool results.

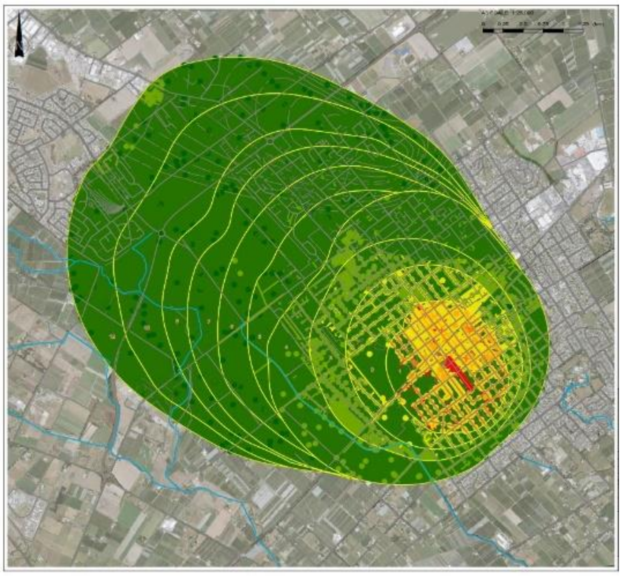

Figure 1: An example of how the tool displays relative risk at a catchment-scale. In this example, risk is primarily driven by proximity to the abstraction bores.

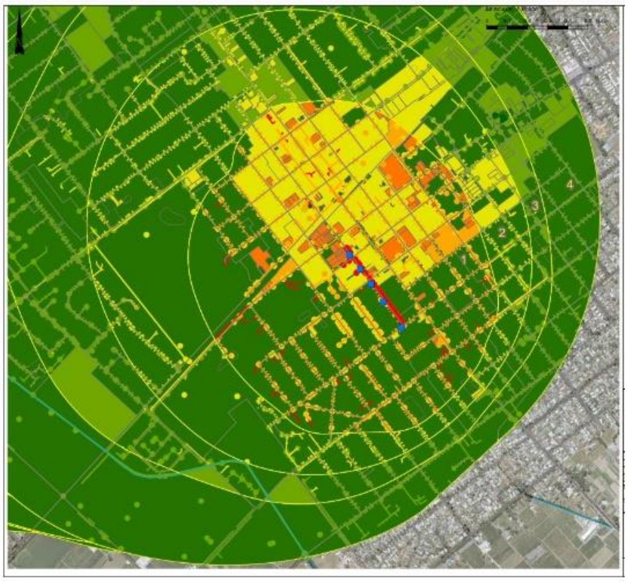

Figure 2: An example of how the tool displays relative risk at a local-scale. In this example, an alignment of abandoned former public water supply bores are assessed as presenting a very high risk to the supply (refer red symbols adjacent to the operational bores shown in blue).

Figure 4: Shows an output of wastewater infrastructure risk. Note the impact of the relatively high aquifer vulnerability zone (refer red zone) on the final risk of the wastewater infrastructure. In this example, wastewater infrastructure located relatively close to the bore is assessed as lower risk because the aquifer has a relatively low vulnerability in that area. An absence of clay overlying the aquifer further upgradient means that wastewater infrastructure in that area poses a higher risk to the bore.

CONCLUSION

A multiple barrier approach is now globally recognised as a founding principle for delivering safe drinking water. This applies to legislative requirements and statutory guidance in New Zealand. A multiple barrier approach means that there are "barriers" or measures in place at several steps through the catchment-to-tap process which guard against contamination or the potential for contamination. The first barrier in this process is the prevention of contaminants from entering the water source, which means that potential contaminant risks residing in the catchment of a drinking water supply need to be identified, then managed. However, source water catchments can contain thousands of contaminant sources within highly complex and dynamic systems. These factors pose significant challenges to proactive management approaches.

An automated GIS risk tool has been developed to address some of these challenges. Using available GIS data and an understanding of catchment processes, the tool is able to identify and prioritise potential contamination risks to public water supply bores. The input GIS data to the tool is live, and often hosted by regulatory authorities, or the water suppliers themselves. Because of this, the tool is able to respond to changes that occur in the catchment, such as the introduction of new potential contaminant sources or improvements/ risk reductions to existing contaminant sources.

Within a wider water safety framework, the tool allows water supply managers and decision makers to maintain an updated understanding of potential risks to a water supply catchment, even when catchments are seemingly highly complex and dynamic. This allows responsive and proactive decision making, which represents a significant step forward in catchment risk management tools currently available.

The tool presented here represents an early development of a dynamic catchment risk assessment tool that is expected to expand and improve with time. With the coverage and availability of GIS datasets expected to improve continually, tools such as those presented here are expected to provide greater accuracy and visibility for water suppliers wishing to understand and manage their catchment risks.

ACKNOWLEDGEMENTS

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REFERENCES

1. Aller, L., T. Bennett, J. Lehr, AND R. Petty. DRASTI; A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings: U.S. Environmental Protection Agency, Washington, D.C., EPA/600/2-85/018.