GIS-BASED RISK ASSESSMENT FOR CATCHMENT SCALE ON-SITE WASTEWATER MANAGEMENT

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Abstract

Geographic Information System (GIS)-based risk models have been developed for use in improved on-site wastewater management in the USA and more recently in Australia.

This paper outlines the application of a GIS-based risk assessment to a catchment at Dodges Ferry, Tasmania and demonstrates how it can effectively integrate on-site wastewater and catchment data to assist with future planning in the catchment.

Ongoing development to extend the capacity of GIS-based risk assessment is outlined.

Keywords

Catchment scale impacts, Dodges Ferry, Geographic Information System, on-site wastewater management system, risk-based model.

1 Introduction

Council records of on-site wastewater management systems and catchment-scale studies of on-site wastewater management systems and their related impacts result in the accumulation of substantial data sets of on-site systems, their performance, and the range and variation of physical parameters that determine both their performance and impact. Such data sets lend themselves to collation and interpretation using relational databases and GIS-based models.

A number of catchment-scale studies of on-site wastewater systems have been undertaken in Australia (Martens & Geary 1999, Geary *et al*. 1999, Cromer 2001, Whitehead *et al*. 2001). GIS has been used to display the physical parameters of significance in determining the performance of on-site systems (Martens & Geary 1999; Kenway, Irvine & Moorhead 2001).

Furthermore, a number of Australian catchment scale studies have investigated possible impacts of on-site systems on groundwater (Hoxley & Dudding 1994, Ivkovic *et al*. 1998, Whitehead & Associates 1998) and more recent studies have demonstrated (Cromer 2001, Whitehead *et al*. 2001) that even at quite high densities of development (> 500 systems per square kilometre) with on-site wastewater systems there need not necessarily be adverse impacts on groundwater quality. Sustainable lot density and minimum lot size have been explored by Jelliffe & Hillier (2001).

Whilst the above approaches offer much in interpretation of existing systems and in developing some predictive tools for various aspects of on-site wastewater work, there is potential to further improve the growing understanding of catchment scale impacts of on-site wastewater systems by developing risk-based models and using them as planning tools. GIS-based risk models have been used for such purposes in the United States (Joubert *et al*. 1996, Kellogg *et al*. 1997) and have now been developed in Australia with the NSW Department of

Local Government On-site Sewage Risk Assessment System (OSRAS) (Kenway *et al*. 2001). Such approaches offer planners the opportunity to predict the likely impacts of on-site wastewater systems in future development areas and also to predict possible further impacts in already partially developed catchments if they are subject to additional development.

The OSRAS handbook (NSW DLG 2001) presents two case studies to show how the system might be applied. These studies were of the Katoomba area in the Blue Mountains and the Tuross estuary in Eurobodalla Shire, both in New South Wales. This study applies the broad approach adopted by the OSRAS to a coastal catchment in Tasmania.

2 Dodges Ferry, Tasmania Study

Since 1998, a catchment management and groundwater monitoring program has been proceeding in and around Dodges Ferry, some 35 kilometres from Hobart, Tasmania (Geary *et al*. 1999). This study has been undertaken in a coastal catchment contiguous with several sensitive bathing beaches. It is located on predominantly sandy soils within which clay rich horizons support a number of perched water table aquifers that are accessed by bores for domestic but non-potable use. The area is subject to increasing development on generally small lots (< 800 m^2). The area is not sewered and does not have reticulated water supply but Council is under pressure from the community to provide reticulated water. Details of the groundwater monitoring study have been described by Geary & Whitehead (2001) showing evidence of a localised nitrate plume migrating towards the coast and localised contamination of perched water table aquifers near poorly performing on-site wastewater systems.

The area has been subdivided but many lots remain to be developed. In addition many of the older and commonly only occasionally or seasonally occupied holiday homes are now being extended or redeveloped for permanent occupancy. Thus council is concerned that increased system density will have an adverse effect on surface water and groundwater quality.

Whilst there are some small clusters of on-site wastewater systems which perform poorly due to locational factors and result in off-site and cumulative impacts on a localised sub-catchment scale, much of the area supports a high density of development (in excess of 800 systems per square kilometre) without showing any adverse impact on groundwater quality in both the shallow unconfined perched water table aquifers and deeper aquifers in the underlying bedrock (Whitehead *et al*. 2001).

This study has brought together data available from council and other government agencies' sources and data derived as part of the study in a series of GIS data layers.

Natural hazards have been identified, classified and overlaid to assign an on-site natural hazard class. Built hazards have been identified, classified and overlaid to assign an on-site sewage export hazard class. Environmental receptor sensitivity has been identified and classified to assign an environmental receptor sensitivity class. Catchments and drainage lines have been mapped. The three data sets, export hazard, receptor sensitivity and catchment and drainage were then integrated to identify risk.

Data layers generated include:

- Soil type
- Slope class
- Allotment size class
- Drainage analysis
- Drainage hazard - flooding
- Buffer analysis - properties within 50 metres of a drainage line
- Drainage buffer analysis - lots intersecting the 50 metre buffer

High-risk areas determined by the model show good correlation with areas of system failures and poor system performance identified by council inspections and the investigations carried out as part of the recent catchment management and groundwater monitoring program.

The model can be applied with "*what if?*" scenarios of increasing lot density to full build-out of all lots and potential impacts determined. The risk maps can then be used to prioritise management action and determine the increased risk should further development take place. This enables council to determine sustainable system density under different development scenarios and provide guidance on on-site wastewater management system selection and sizing. The risk model will enable council to identify areas where additional development is not sustainable and to identify areas where additional land might be required for off-lot land application of wastewater where current systems cannot be sustained on the existing lots.

3 Further Development of OSRAS

To date, OSRAS has been successfully applied to trial catchments at Katoomba and Eurobodalla in New South Wales and in this study at Dodges Ferry in Tasmania. Typically, these catchments have ranged in areal coverage up to a maximum of approximately 200 square kilometres. At this scale, the semi-manual manipulation of the appropriate GIS layers and OSRAS outputs required to make an assessment of the risk posed to downstream sensitive receptors from failing on-site systems is generally feasible. Further, whilst able to be addressed to some extent by quasi-manual buffer analyses, the natural attenuation and decay during travel of exported hazards such as pathogens is not of first order importance in catchments of this size. This is in contrast to the application of OSRAS to larger catchments such as the Hawkesbury Lower Nepean (HLN) in NSW, which is approximately 12,700 square kilometres in area and contains some 50,000 on-site systems. In such larger catchments, manual analysis and interpretation of the relationship between all on-site systems and all downstream receptors is prohibitively complex and time-consuming. In addition, travel paths for exported pollutants can be in the order of hundreds of kilometres, and as such, pollutants should be readily subjected to natural attenuation and decay processes, potentially reducing their impact on sensitive downstream receptors. Clearly, an alternative, automated, approach to applying OSRAS in such catchments is required.

3.1 Development of an 'OSRAS Engine'

The NSW Department of Local Government, through a joint consultancy between WBM Oceanics Australia and Whitehead & Associates Environmental Consultants, is currently developing an automated 'engine' to apply a slightly modified OSRAS process to the HLN catchment. The modifications to the OSRAS methodology included in this engine are not discussed here, but are largely motivated by access to more comprehensive and improved data sets than were previously available during the development of the original OSRAS process. The primary features of the new OSRAS engine are discussed here.

3.2 Full Automation of the Application of the Entire OSRAS Risk Assignment Process

The OSRAS automation includes the use of information such as system type, reticulated water usage, rainfall and evapotranspiration data, system age and maintenance frequency data (not currently used) and soil type and landscape data to automatically compute the Sewage Export Hazard Class (SEHC) for each system. User input logic matrices are used by the engine to generate the SEHC from the required input data. The user is required to supply the above input data to the engine in the form of a GIS layer containing a series of points. Each point represents an on-site system (which is correctly geographically located) and has the information listed above. The engine then employs the user defined logic matrices to compute the SEHC for each system.

3.3 Particle Tracking

Once the engine has computed the SEHC for each system, each SEHC is treated as a particle and tracked downwards through a digital elevation model (DEM) specified by the user. This tracking process is executed for every particle (i.e. system SEHC) and the coordinates of every point along every track stored in memory for further use. In addition, the particle tracks are written to a GIS layer, for easy importation to a GIS package as a vector data set. This data set can then be interrogated at any DEM cell location using standard GIS information tools. For instance, a given cell (point) may correspond to six on-site system tracks that have exported SEHC units through that cell. Further to this vector data set, the engine also creates a single ASCII grid, also for importation to a GIS package. This grid contains the total (i.e. summed) SEHC units at every grid cell within the DEM. This is useful for assessing global, cumulative, impacts of on-site systems, and can be interrogated using standard grid information tools.

3.4 Decay of SEHC Units During Tracking

In addition to tracking all SEHC units through a user-specified DEM, the OSRAS engine also decays these units as they travel to represent natural attenuation of hazard due to environmental assimilation. This decay is a simple linear decay (specified as a percentage SEHC decay per unit travel length), and decay rates are input by the user. If no decay is required, decay rates of 0.0 can be set. We recognise that this linear decay algorithm is a simplification of some complex natural attenuation processes that are likely to occur (e.g. non-linear bacterial decay). The engine, however, has been designed so that the decay algorithm is easily updateable, given sufficient scientific basis, and we envisage that in future applications of OSRAS, this may indeed occur.

3.5 Automated Hazard Assessment Tool

The most recent addition to the OSRAS engine, and perhaps the most powerful from a user's point of view, is the inclusion of a facility to automatically assess and report the incursion of SEHC units into pre-defined regions containing sensitive receptors such as groundwater bores, oyster leases, natural swimming holes and the like. Prior to running the OSRAS engine, the user can optionally nominate a GIS layer with regions, representing sensitive receptors. Each such region is designated a sensitivity class that represents the perceived sensitivity of the region. For instance, an oyster lease might be given a high sensitivity class if the export of pathogens is being considered. When tracked SEHC units enter such regions, the OSRAS engine uses a user-defined logic matrix to determine the overall risk posed by the particular combination of SEHC and sensitive receptor. This information can be imported by, and interrogated within, a standard GIS system. It is envisaged that this facility can be tailored to meet the needs of any particular risk analysis.

3.6 Graphical User Interface (GUI)

The OSRAS engine has been constructed so that it operates in conjunction with, but under the control of, a graphical user interface (GUI). This GUI allows the user to interact with the engine in a typical Windows environment. The current form of the GUI is shown below.

An example of the typical output from the engine (for a demonstration catchment) is shown in Figure 2. The stars represent on-site systems, and the lines are the corresponding grid-based

SEHC particle tracks, which coalesce (and sum) at junctions, and decay as particles proceed through the catchment. The outline of the corresponding demonstration DEM is also shown.

Figure 1. OSRAS Engine - Illustration

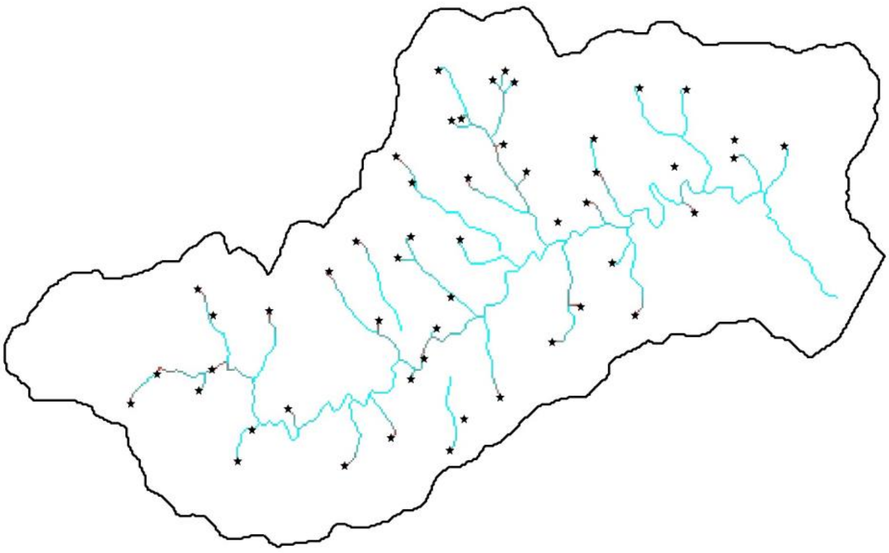

Figure 2. Typical Output from the OSRAS Engine

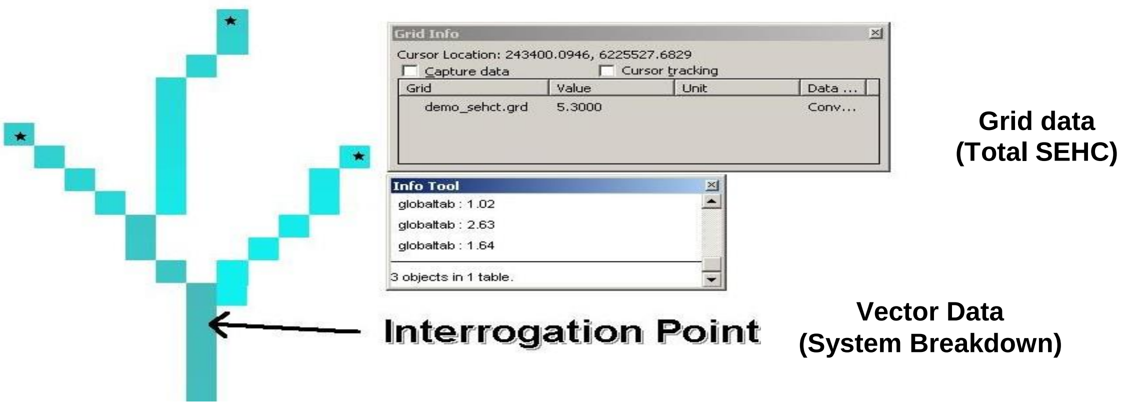

Figure 3. Simultaneous Interrogation of Vector and Grid Data

Figure 3 shows an example of how the vector and grid data can be simultaneously interrogated to examine both total SEHC counts at a point (grid data), and the corresponding breakdown into constituent systems of origin.

It is intended that this OSRAS engine will be made available as a management tool for use by appropriate stakeholders, government and regulatory authorities.

4 References

Cromer, W.C. 2001. Treating Domestic Wastewater in a Shallow Coastal Sand Aquifer near Hobart. ***In***: Patterson, R.A. and Jones, M.J. (eds.) *Proceedings of On-site '01 Conference: Advancing On-site Wastewater Systems*, Armidale, pp 113-120. Lanfax Laboratories, Armidale, NSW.

Geary, P.M., Robertson, G. & Whitehead, J.H. 1999. On-site Systems and Catchment Management. ***In***: Patterson, R.A. ed. *Proceedings of On-site '99 Conference: Making on-site wastewater systems work*, Armidale, pp 125-132. Lanfax Laboratories, Armidale, NSW.

Geary, P.M. & Whitehead, J.H. 2001. Groundwater Contamination from On-site Domestic Wastewater Management Systems in a Coastal Catchment. ***In****: Proceedings of 9th International Symposium on Individual and Small Community Sewage Systems*. pp 479-487. American Society of Agricultural Engineers, St. Joseph, Michigan.

Hoxley, G. & Dudding, M. 1994. Groundwater contamination by septic tank effluent: two case studies in Victoria, Australia. ***In***: Water Down Under '94, *Proceedings of 25th Congress of International Association of Hydrogeologists*, Adelaide, pp 145-152. Institution of Engineers, Sydney.

Ivkovic, K.M., Watkins, K.L., Cresswell, R.G. & Bauld, J. 1998. *A groundwater quality assessment of the fractured rock aquifers of the Piccadilly Valley, South Australia*. Australian Geological Survey Organisation Record 1998/16.

Jelliffe, P. & Hillier, H. 2001. Prediction of Sustainable Allotment Size and Critical Development Densities in Unsewered Areas. ***In***: *Ozwater Conference Proceedings*. Australian Water Association, Artarmon, NSW. April.

Joubert, L., Kellogg, D.Q. and Gold, A. 1996. Watershed Nonpoint Assessment and Nutrient Loading Using the Geographic Information System-Based MANAGE Method. *Proceedings, Watershed '96*. Water Environment Foundation. Baltimore, MD.

Kellogg DQ, Joubert L and Mandeville A. 1997. Hunt-Potowomut Watershed Assessment: Results and Management Options. Watershed Pollution Risk Assessment and Nutrient Loading Using the MANAGE Method. Summary Report & Technical Appdx. URI Cooperative Extension. Kingston RI.

Kenway, S., Irvine, R. & Moorhead, R. 2001. The On-site Sewage Risk Assessment System. ***In***: Patterson, R.A. and Jones, M.J. (eds.), *Proceedings of On-site '01 Conference: Advancing On-site Wastewater Systems*, Armidale, pp 227-233. Lanfax Laboratories, Armidale, NSW.

Martens, D.M. & Geary, P.M. 1999. Australian on-site wastewater strategies: a case study of Scotland Island, Sydney, Australia. ***In***: Patterson, R.A. ed. *Proceedings of On-site '99 Conference: Making on-site wastewater systems work*, Armidale, pp 255-263. Lanfax Laboratories, Armidale, NSW.

NSW Department of Local Government, 2001. *On-site Sewage Risk Assessment System Handbook*, NSW Department of Local Government, Bankstown.

Whitehead & Associates Environmental Consultants. 1998. *Dodges Ferry Catchment Management and Groundwater Monitoring Programme*. Report prepared for Sorell Council, Tasmania (unpubl.).

Whitehead, J.H., Geary, P.M. & Saunders, M. 2001. Towards a Better Understanding of Sustainable Lot Density - Evidence from Five Australian Case Studies. ***In***: Patterson, R.A. and Jones, M.J. (eds.) *Proceedings of On-site '01 Conference: Advancing On-site Wastewater Systems, Armidale*, pp 383-390. Lanfax Laboratories, Armidale, NSW.