A Large Scale Pilot Study of a GIS Based Risk Assessment System for On-site Wastewater Management in New South Wales, Australia.

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Abstract

Following an outbreak of *Hepatitis A* disease associated with consumption of oysters from Wallis Lake, New South Wales (NSW), Australia in 1996, the NSW Government has invested A$3.8M over the past four years (1998-2002) in a SepticSafe program to assist local government authorities (local councils) to implement systematic management of sanitation risks related to on-site wastewater management. Part of this investment was directed to the development of an integrated system of sewage risk assessment in coastal areas, particularly oyster growing areas and drinking water catchments (watersheds).

An On-site Risk Assessment System (OSRAS) has been developed to bring together information held by local councils and State Government agencies. The OSRAS uses GIS layering techniques and transparent logic matrices to model the fate of sewage pollution from decentralised sewage management facilities, in relation to identified disease vectors and sensitive environmental receptors, and to generate risk "maps". The output will enable councils and State Government agencies to assess the likely scale of impact and relative risk of sewage pollution in unsewered residential areas. The OSRAS is currently being trialed in the Hawkesbury Lower Nepean catchment, covering 20 Local Government Areas in the Sydney hinterland with approximately 50,000 on-site wastewater management systems.

The large scale pilot study involves the development of a data management system, data integrity review, application of the OSRAS methodology to the Hawkesbury Lower Nepean catchment, consultation with local councils and State Government agencies and field validation, prior to the release of the OSRAS for use in other areas of coastal NSW.

KEYWORDS. Sanitation, GIS based risk assessment, on-site and decentralized wastewater management, Hawkesbury Lower Nepean Catchment, New South Wales, Australia.

Introduction

There are currently about 300,000 small-scale, mostly single lot domestic, on-site wastewater management systems in the State of New South Wales. Five State Government agencies, responsible for environment protection, public health, land and water resource management, development planning and local government have participated in the development of Environment & Health Protection Guidelines for On-site Sewage Management for Single Households (NSW Department of Local Government 1998). The installation and safe operation of these on-site wastewater management systems is the responsibility of some 170 local councils across NSW.

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A number of surveys (Geary, 1992) and local council studies have indicated that a significant proportion of existing on-site systems fail or perform poorly though the criteria by which failure has been judged have varied considerably from one study to the next. It is clear, however, that failing on-site systems and inadequate effluent disposal areas can have serious environmental health implications and can contribute to nutrient-related water management problems (Whitehead & Geary, 2000). The public health and environmental implications of on-site system failure were brought into the public eye with growing concerns over nutrient loadings and algal blooms in NSW coastal lakes and estuaries in the early 1990s. In 1996 there was an outbreak of *Hepatitis A* associated with consumption of oysters from in Wallis Lake, NSW (Brooker, 1999) and in 1998 unacceptable levels of *Cryptosporidium* and *Giardia* pathogens in the Sydney drinking water-supply resulted in the city's population of approximately four million having to boil their drinking water for a period of several weeks. Whilst failing on-site wastewater management systems were not identified as the cause of either of these incidents, the general performance of on-site wastewater systems and the possibility of failing systems contributing to such environmental and public health scares was enough to prompt the NSW Government to develop regulatory reforms and guidelines to enable more effective council regulation and performance supervision of on-site and decentralised sewage management systems (Irvine et al., 1999). To this end, the NSW government committed A$3.8M, over the period 1998 to 2002, to a range of measures designed to assist local councils to improve on-site wastewater management arrangements (Irvine & Hood, 2001). These measures included the introduction of a system of operating permits and the publication of Environment & Health Protection Guidelines (NSW DLG, 1998) and supporting technical sheets, a communications strategy with posters and brochures, a plain language Easy Septic Guide (NSW DLG, 2000), an Information Management Handbook (NSW DLG, 2000) for local councils, a small program of research and development grants, the development of an On-site Sewage Risk Assessment System (OSRAS) (Kenway et al., 2001) and an independent program evaluation.

CATCHMENT SCALE STUDIES, GIS AND RISK ASSESSMENT

Prior to the development of the NSW Government's SepticSafe program, there was little in the Australian literature to link the performance of on-site wastewater management systems and specific incidence of contamination of receiving waters (Whitehead & Geary, 2000). Catchment scale impacts of on-site wastewater management systems had been demonstrated in other States (Hoxley & Dudding, 1994, Ivkovic et al., 1998 and Whitehead & Associates, 1998). More recently detailed linkages of system performance and receiving water quality have been demonstrated in Tasmania (Geary & Whitehead, 2001 and Cromer, 2001) and in four further studies at Allworth, Coomba Park, North Arm Cove and Pindimar in NSW (Whitehead et al., 2001). These latter studies have shed further light on the determination of sustainable lot sizes (without off-lot discharge) and development densities for dwellings with on-site wastewater management systems in sensitive coastal lake and estuarine catchments. They offer much in interpretation of existing systems and in developing some predictive tools for various aspects of on-site wastewater work but 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 and management tools.

GIS based risk assessment 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 an opportunity to predict the likely impacts of on-site wastewater systems in future residential development areas and the possible further impacts in partially developed catchments if they are subject to additional development.

The OSRAS handbook (NSW DLG, 2001) presents two small area (about 70 square miles) case studies. These studies are Katoomba in the Blue Mountains council area and Tuross estuary in the Eurobodalla council area, both in New South Wales. A further study has applied the methodology at Dodges Ferry and Carlton, Tasmania (Whitehead et al., 2003).

HAWKESBURY LOWER NEPEAN OSRAS SOFTWARE

To date, the OSRAS process has been applied to catchments that have ranged in areal coverage up to a maximum of approximately 200 square kilometres. At this scale, the use of standard GIS tools (e.g. manipulation of hazard layers and cell based flow accumulation) to make an assessment of the cumulative risk posed to downstream sensitive receptors from failing on-site systems is generally feasible. Further, the natural attenuation and decay during travel of exported hazards such as pathogens and nutrients 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), which is approximately 12,700 square kilometres in area and contains some 50,000 on-site systems. In such 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 such pollutants are subjected to natural attenuation and decay processes, reducing their potential impact on sensitive downstream receptors. An automated OSRAS is required in such catchment areas.

DEVELOPMENT OF A MODIFIED 'OSRAS ENGINE'

The New South Wales Department of Local Government (DLG) is currently developing an automated and modified OSRAS process, including a 'software engine', for the HLN catchment.

Development of Modified OSRAS Logic

The modified OSRAS process has been developed in conjunction with key personnel, including those primarily responsible for the development of the original OSRAS logic. These modifications have been 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 changes to the OSRAS logic include:

- Refinement of inputs to On-site Natural Hazard Class, particularly for soil landscape units;
- Moving from a whole allotment base to a point base for allocation of wastewater facilities to a Sewage Export Hazard Class (SEHC);
- Inclusion of design and maintenance characteristics (such as system age and maintenance frequency) in the computation of SEHC, through calculation of a Design and Maintenance Hazard Class (DMHC).
- Inclusion of a System Operation Hazard Class (SOHC) to account for the impact of climatic conditions on system performance. The following figures show the original and revised OSRAS logic processes.

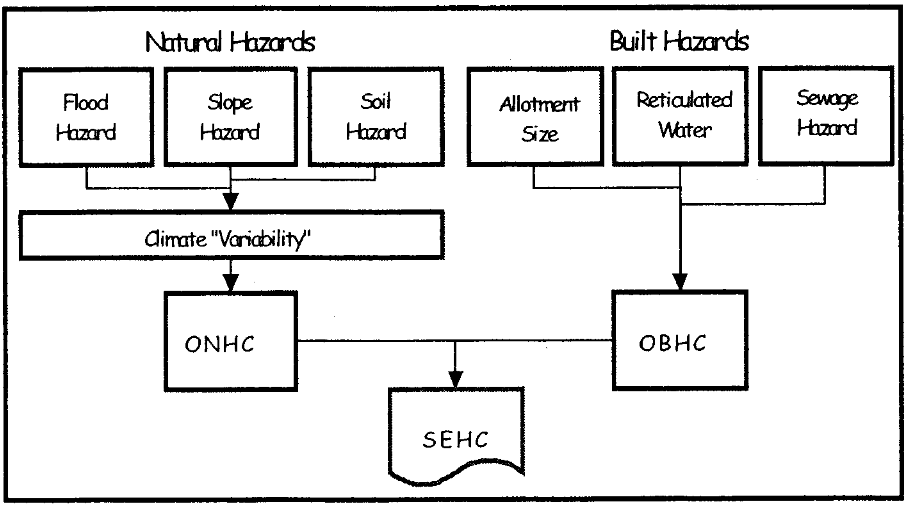

Figure 1. Original OSRAS Logic (Simplified)

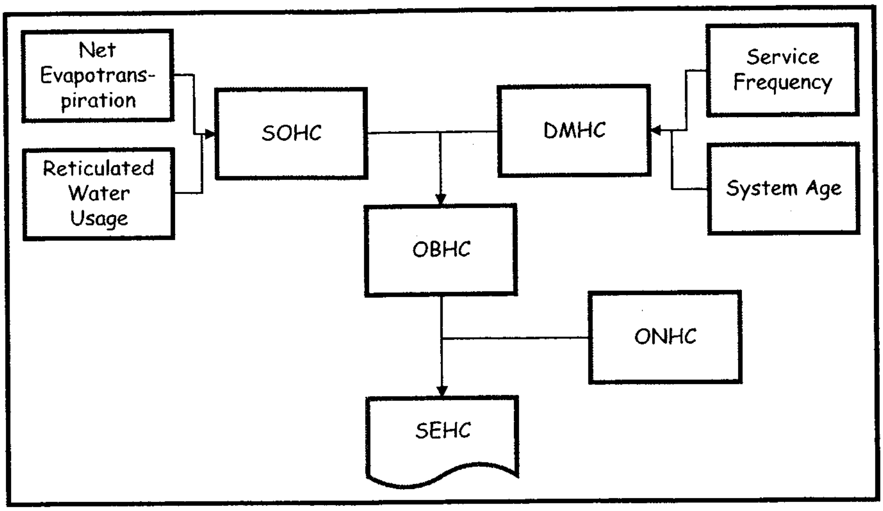

Figure 2. Modified OSRAS Logic.
ONHC = On-site Natural Hazard Class (separate to the engine); OBHC = On-site Built Hazard Class; SOHC = System Operation Hazard Class

We note that some simplifications have been made in presenting the original logic. The primary features of the new 'OSRAS engine' are discussed in the following sections.

FULL AUTOMATION OF THE OSRAS RISK ASSIGNMENT PROCESS

The revised OSRAS (Revision 2) incorporates new hazard identification data including system type, reticulated (mains) water usage, rainfall and evapotranspiration, system age and maintenance frequency and refined soil landscape maps and tables and allows the automatic computation of the Sewage Export Hazard Class (SEHC) for each on-site system. User determined logic matrices are employed by the OSRAS engine to generate the SEHC from the required input data. The user supplies the input data to the engine in the form of a GIS layer containing points that represent existing on-site systems. Each point is geographically located, with the information and hazard classification listed above as attribute data.

Particle Tracking

Once the engine has computed 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 each particle (i.e. system SEHC) and the coordinates of every point along every track are stored in memory for further use. In addition, the particle tracks are written to a GIS layer, for easy importation to a standard GIS as a point data set. This data set can then be interrogated at any DEM cell location using standard GIS information tools. For instance, a given DEM cell may correspond to six on-site system tracks that have exported SEHC units through that cell. Further to this point 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.

Decay of SEHC Units during Tracking

In addition to tracking all SEHC units through a user-specified DEM, the OSRAS engine can also decay these units as they travel to represent natural attenuation of hazard due to pathogen decay and nutrient assimilation. This decay is a simple linear decay (specified as a percentage SEHC decay per 100 meters travel length), and decay rates are input by the user to meet specific risk assessment requirements. If no decay is required decay rates of 0.0 can be set.

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 representing 'sensitive receptors' such as oyster harvesting areas, swimming areas, sensitive ecosystem areas, and the like. Prior to running the OSRAS engine, the user can nominate a GIS layer with one or more defined sensitive receptor regions. Each such region is pre-designated a sensitivity class that represents the assessed sensitivity of the subject receptor. For instance, an oyster harvesting area might be given a high sensitivity classification if the export of pathogens is being considered. When tracked SEHC units enter such designated regions, the OSRAS engine employs a user-defined logic matrix to determine the overall risk posed by the particular combination of SEHC and sensitivity. This information can be imported by, and interrogated within, a standard GIS. This function can be tailored to meet the needs of specific risk assessment tasks.

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 in Figure 3.

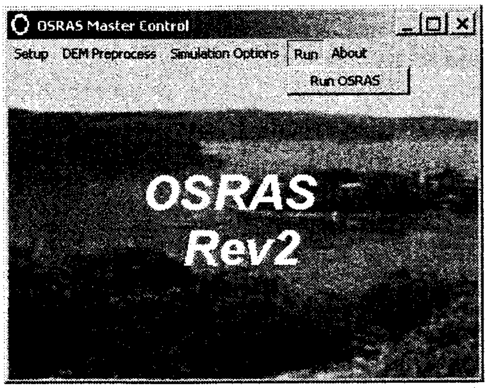

Figure 3. Graphical User Interface.

OSRAS Engine Illustration

An example of the typical output from the engine (for a hypothetical catchment) is shown in Figure 4. The stars (points) represent on-site sewage systems and the emergent lines represent the corresponding grid-based SEHC particle tracks, which coalesce and sum at junctions, and decay as SEHC particles proceed through the catchment.

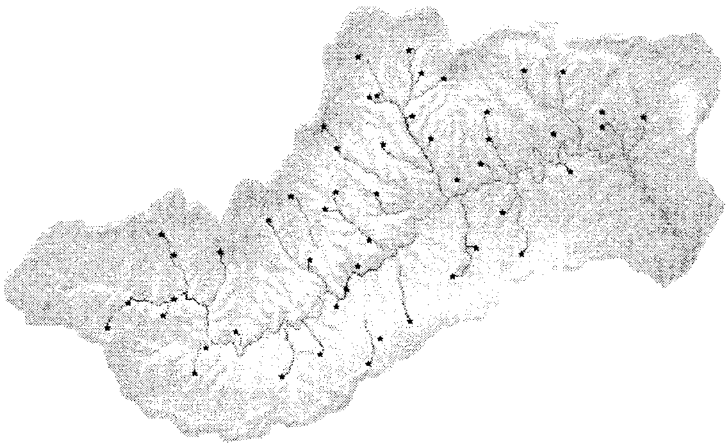

Figure 4. Typical output from the engine (for a demonstration catchment).

Figure 5 shows an example of how the point 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.

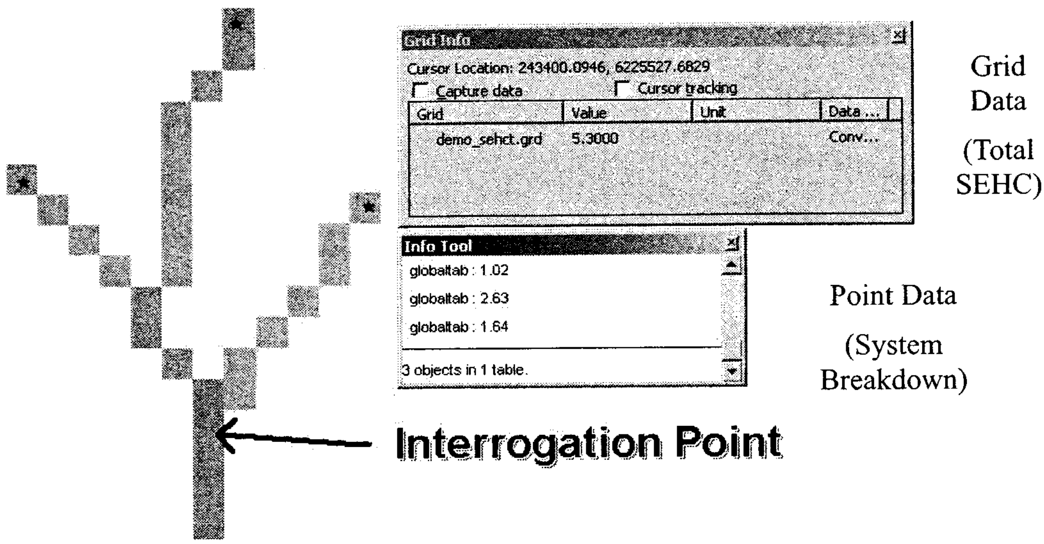

Figure 5. Simultaneous interrogation of the vector and grid data.

Application

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

In addition to the above features, some demonstration GIS platform specific code (MapBasic/MapInfo) has been written to illustrate the additional features of the engine output that can be exploited by individual OSRAS users. In this example, we have written code to allow the user to click on a particular particle track and execute a program that 'backtracks' from the selected point to each on-site system that contributes SEHC units to that point. Figure 6 demonstrates this feature.

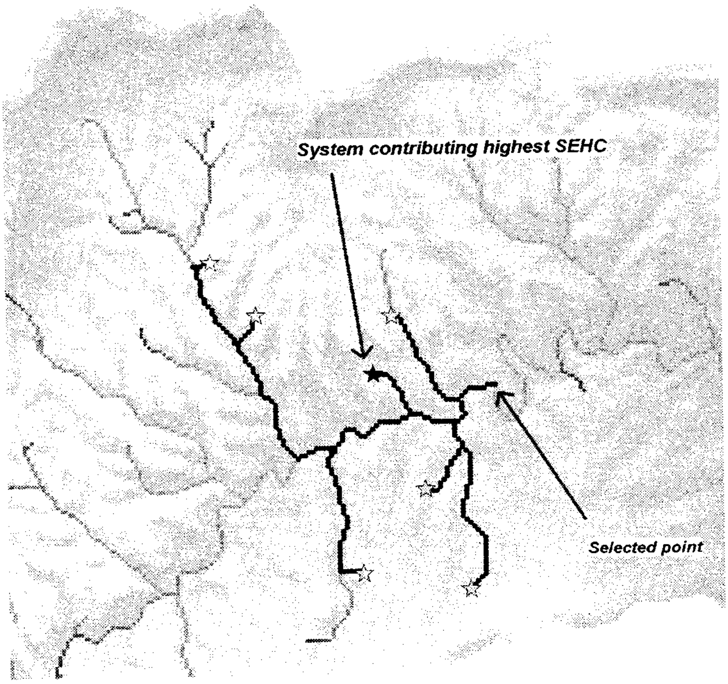

Figure 6. 'Backtracking' from the selected point to each on-site system that contributes SEHC units.

CALIBRATION OF THE OSRAS ENGINE

An important component of the application of the OSRAS Rev.2 process to the HLN catchment has been the 'calibration' of the software engine. This calibration has been undertaken as a quasi-quantitative assessment that examined the engine's ability to identify 'hotspots', i.e. high-risk areas, and background regions (i.e. low risk areas). In particular, one subcatchment of the HLN catchment was selected as a trial area with which to apply and calibrate the engine. The area chosen was the Hawkesbury Local Government Area. The calibration was undertaken as an iterative process, with the engine outputs used to provide an initial indication of where 'hotspots' might occur. Quasi-quantitative 'ground-truthing' was then undertaken at these hotspots. This involved sampling of hotspot surface waters and subjecting these samples to fecal sterol analyses. Fecal sterols enable distinction to be drawn between different animal sources of fecal material. These analyses were then compared to fecal sterol analyses from typical 'background' (i.e. low risk) areas and used to assess the engine's ability to predict hotspots. This process was repeated in an iterative fashion adjusting the engine decay rates, which are the primary free parameters within the engine. After several iterations the model was successfully 'calibrated' to the Hawkesbury area. We stress that this calibration is only quasi-quantitative, and sought only to test the engine's ability in predicting the *relative* risk posed to downstream sensitive receptors.

CONCLUSION

It has been possible to draw together a substantial amount of physical, catchment scale data and integrate this with on-site wastewater management system performance data, gathered by local councils, using GIS layering techniques and transparent logic matrices processed through the OSRAS to provide a sanitation management and development planning tool for local government. This will assist local councils in NSW to implement systematic sanitation, catchment management and planning arrangements for safe and sustainable on-site wastewater management activities.

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