IMPLEMENTING AN ON-SITE SEWAGE RISK ASSESSMENT SYSTEM (OSRAS) IN THE HAWKESBURY LOWER NEPEAN BASIN

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Abstract

Decentralised sewage management arrangements are common in regional areas of NSW where an estimated 40% of households use 'septic systems'. Well-managed septic systems provide safe and cost effective sanitation, particularly for low density housing, and modern decentralised sewage systems are appreciated for their water conservation, energy efficiency and operational benefits. However risks remain. About one third of existing septic systems, on inspection, are reported to be failing and there are ongoing eco-sanitation risks for all sewage management systems, including town sewerage. In settled catchments, the cumulative impact of effluent flows from decentralised sewage management alone may be significant. For public safety and sustainability, local councils and communities need tools to centrally manage cumulative risks to public health and the environment at least cost.

The *SepticSafe* On-site Sewage Risk Assessment System (OSRAS) integrates spatial, natural resource, infrastructure and operational data relevant to the performance of common on-site sewage management systems, providing an information framework for cumulative, spatial assessment of sanitation risks, for setting strategic sewage management goals and standards, and for land capability planning. The aim is to demonstrate an evidence based process for evaluation of sewage management hazards and assessment of risks, that will assist local councils to implement open, least cost local sanitation strategies for private sewage services. OSRAS allows diffuse source pollution to be ranked and roughly quantified, permitting comparative risk assessments for diffuse and point sources of pollution. OSRAS method can be applied, with appropriate data sets, for risk assessment of leaky drains, sewer overflows, intensive agriculture, industrial land uses and other diffuse pollution hazards.

In partnership with relevant local councils, OSRAS is being used in a pilot study across the Hawkesbury Lower Nepean Basin. This paper discusses new functions to enable cost effective OSRAS hazard identification and cumulative risk assessment in a 12,700 square kilometre catchment with over 50,000 septic systems.

Key words

Septic systems, sewage pollution, risk assessment, geographic information systems, settlement planning, environmental health, sanitation, catchment management.

The power of mapping

John Snow (1813-1858), an English physician provided a classic example of mapping used for sanitation assessment in his paper On the Mode of Communication of Cholera, London, 1849. John Snow mapped the residence of people with cholera to identify the water source responsible. Geographic information systems (GIS) combining mapping and information are now widely used. By tracking the movement of pollution in the landscape, communities can identify threats and can take action to minimise risks with effective, well targeted management interventions.

1 An Outline of the OSRAS Process

1.1 Failure, hazard and risk

Risk analysis involves consideration of potential hazards and their consequences. The principal hazards of on-site sewage relate to leakages, surcharge and seepage from effluent application areas. Failure is a hazard for downstream areas and groundwater.

1.2 Natural hazard

Natural site characteristics determine the capability of an effluent application area (EAA) to assimilate effluent without transmitting pollutants to surface or groundwater. Data describing natural landscape characteristics such as soil, landform and slope are used to classify and map the Sewage Natural Hazard Class. This class reflects the difficulty of assimilating sewage effluent within the EAA. Chapman *et al.* (2001) describes mapping soil-related hazards. Performance-based soil hazard assessment in a regional OSRAS is discussed below.

1.3 Export hazard

The likelihood of sewage effluent being exported from an EAA is influenced by siting, operational and infrastructure factors including housing density, occupancy levels, available water supply and other factors. Sewage Export Hazard is mapped by overlaying natural hazard maps with relevant infrastructure and system operation hazard characteristics.

1.4 Environmental health sensitivity and receptor risk

Sensitivity analysis and mapping help determine the possible consequences of on-site sewage pollution in a catchment and are precursors to assessing off-site risks. Pathogen contamination of drinking water constitutes significant risk, particularly if a large population is serviced by the storage. Sewage pollution is a particular threat to the safety of aquatic foods. Groundwater is sensitive to impacts from on-site sewage pollution.

1.5 Cumulative effects in catchments

Catchment form influences the flow, accumulation and die-off of pollutants, and catchment uses and functions influence the human values attributed to them. These in turn affect receptor risk. The 'cumulative' drainage risk is mapped by 'hydrological' (flow-direction) tracking of emitted pollutants using a Digital Elevation Model (DEM). OSRAS can assess the risk that valued receptors may be contaminated, and the likely source of pollution.

OSRAS hazard class assignment and risk assessment tools are being refined and automated to allow efficient catchment regional scale processing of data. Techniques proposed for the pilot implementation of OSRAS in the Hawkesbury Lower Nepean Basin are discussed below.

1.6 Application and use

OSRAS integrates natural resources, infrastructure and on-site sewage systems information. Maps, data bases and logic matrixes identify and classify sewage pollution hazards. Spatial and cumulative analyses track the flow and accumulation of potential pollutants in drainage lines. The *Onsite Sewage Risk Assessment System Handbook* (DLG 2001) includes small area case studies for Katoomba (Blue Mountains) and Tuross estuary (Eurobodalla).

OSRAS is not a "black box" decision-making system. Rather, it helps collate and present complex environmental health data for operational and strategic management assessment. It is for settlement or catchment scale, with data management and geographic information systems.

2 OSRAS Hawkesbury Lower Nepean (HLN) Regional Pilot Study

2.1 Background

The NSW Department of Local Government (DLG), through a joint consultancy with Whitehead & Associates and WBM Oceanics Australia, is conducting a pilot study of the implementation of the OSRAS in the HLN catchment. Use of OSRAS at the catchment scale requires automation systems for cumulative analysis, incorporation of new natural hazard data and some modifications to the OSRAS methodology, including new assessment processes for 'operational hazard' variables such as system type and maintenance frequency. These process modifications are not finalised and are not discussed here. The actions taken to incorporate soil performance criteria and to refine soil landscape data are discussed in section 3. The OSRAS engine developed to automate the regional implementation is discussed in section 4.

2.2 The Hawkesbury River Drainage Basin

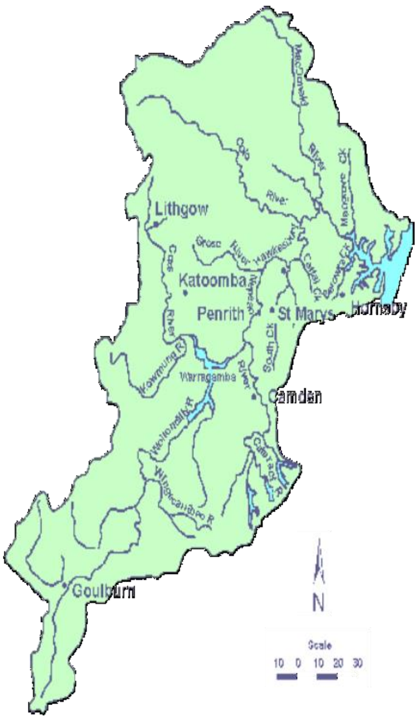

Figure 1 The Hawkesbury Drainage Basin

At its estuary the Hawkesbury River receives surface waters directly and through a radial network of major tributary rivers across a catchment of almost 22,000 square kilometres in the hinterland of the Sydney metropolitan area. The catchment is generally constrained to the west by the Great Dividing Range. Flows from the southern and south western sub-catchments (Sydney Water Catchment) are impounded at the Warragamba Dam to provide water supply for Sydney.

Unregulated tributaries, including the Hawkesbury, drain 12,700 square kilometres. The Hawkesbury Lower Nepean Basin includes extensive National Parks and State Forests and urban areas of Camden, Campbelltown, Liverpool, Fairfield, Penrith, Blacktown, Hawkesbury, Baulkham Hills, Hornsby, Pittwater and Gosford.

The Hawkesbury Lower Nepean Basin (below the dam) is the study area selected for the regional OSRAS pilot, a coastal catchment where sewage management is a high priority for river health and where local councils supervise over 50,000 on-site or decentralised systems of sewage management.

3 Performance-Based Soil Hazard Classification

3.1 Soil hazard classification

OSRAS Soil Hazard Class is based on the soil capacity of at a site to sustainably assimilate sewage effluent from septic tanks and small treatment plants. The OSRAS regional pilot study uses a performance-based soil hazard classification for small-scale effluent application areas that typically involve soak-a-way trenches or near-surface irrigation. The most limiting soil and landscape parameter determines hazard class. Some 12 700 square km of the Hawkesbury Lower Nepean Basin was classified using 1:100 000 soil landscape mapping. Unmapped soil landscape facets were disaggregated using a DEM-derived topographic wetness parameter to produce 1:25 000 hazard maps and a certainty ranking for classification of landscape facets.

3.2 Effluent application area field types

For each type of 'effluent application area' (EAA), naturally occurring processes strongly influence variation in outcomes for a given load. The main principles of operation relate to:

- stability of the EAA field from erosion and settlement;
- water balance risks of overtopping;
- soil-effluent residence time - the longer it is in contact with soil the more likely pathogen die-off and nutrient transformation will occur prior to reaching ground water; and,
- soil transformative capacity - the ability of the soil to transform nutrients and pathogens.

OSRAS specifies soil hazard class tables for two types of effluent application areas (EAA): (A) 600mm deep trench injection fields; and (B) surface/near surface vegetation irrigation fields. Criteria for other EAA (e.g. composting heaps, modified earth, mounds, transpiration beds, filter systems, ponds and lagoons) can be incorporated into OSRAS when justified.

3.3 Selection of criteria

A UN Food and Agriculture Organisation (FAO 1976) land evaluation table was prepared for each EAA. Performance is ranked to one of five classes based on assessed soil hazard for each criterion. The Soil Hazard Class is based on the most limiting of the specified criteria. Control sections are used to specify the soil profile depth ranges at which effluent is in contact with the soil. Trenches generally have deeper control sections than irrigation systems. The certainty of the effect of each criterion on actual system performance has been specified using a four class allocation (after Smith, *pers comm*, 2002). Certainty ratings serve to indicate gaps in knowledge of the relationship of performance to soil and land attributes.

3.4 Landscape performance criteria

Performance criteria were selected by review of existing land capability and land suitability tables and documents such as Standards Australia (AS/NZS 1547:2000), Department of Local Government (1998) and (2001), US Dept of Agriculture (1993), van Gool and Moore (1998). The review examined conditions, technical errors and availability of mapped soil and landscape attributes across NSW. Class ranges were determined following literature review and ratification by a panel of experts. The following performance criteria were determined:

- Erosion Hazard: stability of soil against erosion
- Slope: probability of lateral seepage, runoff and erosion, difficulty with even distribution
- Flooding frequency: surface water contamination
- Terrain Unit/Wetness Index: increased run-on, pathogen movement in saturated soils
- Mass Movement: Increase of slope failure, uneven distribution of effluent
- Drainage/ seasonal waterlogging: limits soil absorption, speeds pathogen movement
- Water table depth: groundwater contamination
- Rock Outcrop: variable soil depth, seepage, surface topping
- Soil permeability 600mm below surface: Limits soil residence time & ability to absorb effluent.
- Available water holding capacity (surface irrigation only); limits loading/ frequency of application
- Effective soil depth (to impermeable layer): Limits residence time, ability to absorb effluent, drainage.
- Coarse fragments: (Gravels, cobbles and stones); Limits soil volume, reduces soil residence time.
- Relative Soil Phosphorus sorption capacity within 600mm of application depth; nutrient retention
- Cation Exchange Capacity within 600mm of application depth; nutrient and pathogen retention
- Surface Soil pH; Effectiveness of evapotranspiration and plant growth
- Salinity Hazard; contribution to regional salinity.
- Soil Sodicity reduction of permeability
- Soil Reactivity (Shrink-swell on change of moisture)- uneven distribution of effluent

3.5 Overview of soil landscapes

Soil Landscapes are areas of land that 'have recognisable and specifiable topographies and soils, that are capable of presentation on maps, and can be described by concise statements' (Northcote, 1978). The NSW Soil Landscape mapping program of eastern and central NSW in published, draft or reconnaissance format is underway or completed for over 75% of the target area. Land Systems Mapping in the Western Division was completed in the 1980s (Walker, 1991). Soil Landscape reports contain descriptive and analytic soil information for each soil landscape mapping unit, as well as a range of details concerning features of the land.

3.6 Mapping soil landscape facets

Distinctive landform areas (facets) within soil landscapes typically repeat in a pattern across the parent landscape. If a map can be made of facets in a soil landscape, say hill crests, then the attributes of the soil on the crests can be used to determine soil hazard for all crests in that soil landscape. Whilst mapping facets can be a slow process, it is often possible to map individual facets using DEMs.

3.7 Wetness index

The Wetness Index (Wilson & Gallant, 2000) (or Compound Topographic Index) was used to discriminate hill slope segments to map Soil Landscape facets. This is an indicator of likely soil moisture: when applied to a digital elevation grid, crests have lesser values than lower slopes and depressions. (Figure 2 shows a 3D image of wetness index across a landscape.)

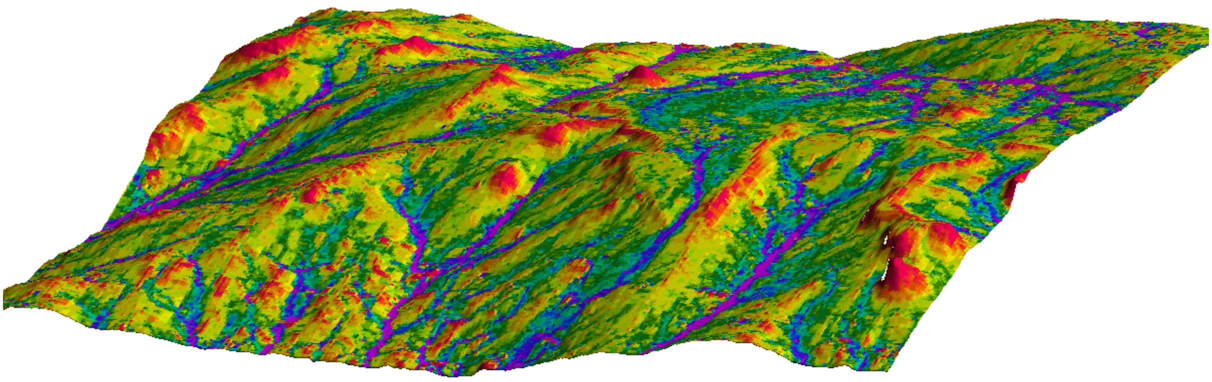

Figure 2 - Wetness Index draped on a Digital Elevation Model (after Caccetta, P (1999))

3.8 Facet generation, mapping and outputs

By determining the cumulative frequency distribution of Wetness Index across any particular soil landscape it is possible to determine wetness index ranges which indicate crests and other hill slope morphological types. A cumulative frequency wetness index has been prepared for each Soil Landscape with wetness index values based on areal estimates in Soil Landscape reports, to generate a map of landscape facets. Where facets are not able to be mapped, estimates of the percentage area of each facet within each soil landscape can be used to provide a weighted average of soil hazard. To address inherent uncertainties a confidence rating has been used to rank the overall predictive accuracy of each soil hazard assessment.

3.9 OSRAS soil facet hazard mapping – preliminary indications and some cautions

OSRAS soil hazard mapping is a single consistent process for classifying, across very large regions, the landscape areas that are most and least suited for sustainable assimilation of domestic effluent when applied by one of the two small area effluent application systems in most common use, by combining soil map information with performance based tables.

Such applications, once sufficiently validated, may be appropriate for regional scale modelling processes which examine cumulative impacts of sewage management on a catchment basis. Caution and judgement must be used when soil hazard facet maps are applied on a lot by lot basis. Soil hazard class does not take account of other relevant factors such as climate variation and water balance and so cannot be used in isolation for the design or sizing of effluent application fields for particular locations. However, soil results from regional landscape mapping, applied through the OSRAS system, can be used with a degree of known confidence as a surrogate for expensive individual site inspection and testing.

There are uncertainties about sustainable application of effluent to land, including processes, impacts and offsite effects. The soil hazard class assessment method highlights some of the areas where knowledge gaps require ongoing practical research.

4 The OSRAS Engine: Flow Tracking and Risk Assessment

4.1 Background

The OSRAS uses information about the operation of OSM systems, including natural, infrastructure and system operation hazards, to compute the composite Sewage Export Hazard Class (SEHC) for each system. The user supplies input data to the OSRAS engine in the form of a GIS layer containing a series of points. Each point represents an OSM system correctly geographically located, linked to the above information. The OSRAS engine coordinates inputs, implements key calculations, then computes the SEHC for each system taking account of values input from user-defined logic matrices.

Figure 3: OSRAS engine - GUI & output map

4.2 Particle tracking

Once the OSRAS engine has computed the SEHC for each OSM system, each SEHC is treated as a particle and tracked through a DEM specified by the user for the purpose. This tracking process and the coordinates of every point along every track are stored in memory for further use. These particle tracks are also written to a GIS layer, for easy export to a GIS as a vector data set. Data can be interrogated at any DEM cell location using a standard GIS. For instance, a cell may correspond to six system tracks exporting SEHC through that cell. The engine also creates a single ASCII grid for export to a GIS, containing the total (i.e. summed) SEHC units at every grid cell within the DEM. This is useful for assessing global, cumulative impacts of OSM systems, and can be interrogated using standard grid information tools.

4.3 Decay of SEHC units during tracking

In addition to tracking all SEHC units through a DEM, the OSRAS engine also decays these units as they travel to represent natural attenuation due to environmental assimilation. This is a simple linear decay specified by the user as a percentage SEHC decay per unit travel. If no decay is required it can be turned off.

4.4 Automation of receptor risk assessment

The OSRAS engine allows the user to map and report on the risk of incursion of SEHC units into pre-defined regions such as water supply sources, swimming holes, sea food harvesting areas and other sensitive receptors specified as a region in a GIS layer. Each such region is designated a sensitivity class for the particular receptor. For instance, a swimming hole might be given a high sensitivity class if the export of pathogens is being considered. When tracked SEHC units enter defined receptor regions the OSRAS engine employs a user-specified logic matrix to model 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.

4.5 Operation of the OSRAS engine

The OSRAS engine operates through a graphical user interface (GUI), allowing the user to interact with the engine in a typical Windows environment. Typical output from the OSRAS is shown in Figure 3. 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 demonstration DEM has been shown as partially translucent. The vector data are transparent. The vector and grid data can be simultaneously interrogated to examine total SEHC counts at a point (grid data) and the corresponding data breakdown relating to the constituent OSM systems of origin (land parcel, system type, etc.).

5 Using the OSRAS

The OSRAS is a conceptual model available for anyone to use and is concerned with the relationship between hazards and cumulative impacts. While useful for 'front desk' advice for developers, it does not preclude the need for site specific surveys for performance monitoring or development/re-zoning applications. It relies substantially on practical application of public health and catchment management knowledge and spatial data and analysis. The results depend on the quality of those sources of information.

The OSRAS is an aid for central management of decentralised sewage effluent disposal, particularly for identifying and tracking eco-sanitation hazards and for assessing cumulative downstream risks. The graphical output provides a visual aid for analysis and for communication of catchment-related sanitation issues. The output is relevant for prioritising catchment management, land capability planning and environmental monitoring strategies.

The Hawkesbury Lower Nepean OSRAS regional pilot project addressed key technical issues relating to regional-scale natural hazard assignment, sewage export hazard tracking, risk assignment and cumulative risk reporting. Current tasks include reviewing risk assessment options for infrastructure and operations, conducting natural hazard assignment processes for target areas, and working with councils and Sydney Water Corporation to coordinate local data collection. The project is expected to report in April 2004.

The OSRAS Handbook, with a range of other *SepticSafe* management tools, including the Easy Septic Guide and the OSM Information Management Handbook, is for local government use. *SepticSafe* publications, including the draft OSRAS Handbook, are available on CD from

the NSW Department of Local Government, Nowra. The *SepticSafe* Publications may also be downloaded from the *SepticSafe* web site:
http://www.dlg.nsw.gov.au/dlg/dlghome/dlg_InformationIndex.asp?areaindex=SEPTIC&index=152 .

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