THE USE OF MODELS TO ADVANCE ON-SITE AND DECENTRALISED WASTEWATER RISK ASSESSMENT AND PLANNING IN VICTORIA

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ABSTRACT
A wide range of models are available to assist with on-site and decentralised wastewater system planning and design. Others may be used to assist with risk assessment, operation and management. This paper will review the types of models used to date in on-site and decentralised wastewater management and will provide pointers as to the potential future use of models for improved design and management of on-site and decentralised systems in Victoria.

Case studies will illustrate the use of models for qualitative and quantitative risk assessment, servicing option selection and decentralised system design and costing in Victoria. The value of models as a cost effective means of achieving these objectives will be emphasised.

Keywords: cost effective servicing, decentralised wastewater planning, risk assessment, risk models, servicing option selection.

BACKGROUND OF MODELLING PRINCIPLES
There are several broad categories of modelling approaches which both determine and are determined by the overarching purpose that the model is designed for, and the outcomes it achieves. Essentially, modelling simulations are ‘answers’ to specific ‘questions’ that are posed by the user of the model. The ‘question’, as it were, is a formulation of data inputs and assumptions. The type and availability of data inputs determines which category of model will be most suitable for answering the question. Briefly, models can be classified into the following general groups:

Empirical Models are based on relationships between parameters that are simply determined through calibration of input and output processes. The calibrations are the result of experimental or observed processes and outcomes, without any attempt to model or explain the underlying causes of relationships between parameters.

Analytical Models use simple algorithms that can ‘solve’ a modelled process as for an equation, once all data inputs are entered into the model. ‘Mass balance’ models, which work on the principle that matter cannot be created or destroyed, also fall under this general category. Mass balance models can be used to track the fate of pollutant loads within the modelled system (such as a catchment).

Conceptual Models use more complex algorithms to describe and predict the relationships between various parameters. Generally the algorithms are determined on an empirical basis (simple conceptual models); however, they can be determined through a more detailed understanding of the underlying natural processes that occur in the field (complex conceptual models). Complex conceptual models are also known as biophysical or process-based models. In practice, the relationships between natural processes are often difficult to measure in the field, and so algorithms which approximate these relationships are typically included in complex conceptual models.

Stochastic Models use statistical distributions of data, rather than single input values, for some or all of the model parameters. This approach results in a range of output data sets derived from the different combinations of inputs, each with a certain probability of actually occurring in the field. Stochastic models are usually required to be run as many times as required by the different possible combinations.

The ‘predictive power’ or performance of a model for a given investigation is in practice a trade-off between the model complexity (the number of parameters included) and the availability of calibration data. It follows that the availability of data should be a major determining factor in model selection.

WASTEWATER MODELLING
There has been a marked increase in the number of new wastewater risk assessment and planning models that have been developed over the past five to ten years, in response to the increasing needs of industry and governments as well as advancements in on-site and decentralised wastewater technology. In addition,
many of the older models are continually being modified and improved by the original developers and other
users, and key concepts in existing models are being incorporated into novel modelling approaches.

Like all other computer based models, an immense diversity of wastewater risk assessment and planning
models have been developed. They are highly varied in terms of costs, data, resource and time
requirements, complexity, assumptions and accuracy. Models are typically either generated to meet a
specific purpose or situation, or developed as a somewhat generic program which runs on specific inputs
that relate to the situation under investigation.

In general terms, no single model can satisfy all desired outcomes in terms of broad wastewater
management at the catchment scale, because uncertainties remain about the transport and fate of specific
pollutants of concern under various environmental conditions. However, a single appropriate risk assessment
model can often be selected to meet most defined objectives for a modelling study, and a combination of
appropriate models should be able to cover all parameters under investigation.

Wastewater-specific modelling parameters
Due to the relatively predictable characteristics and processes of domestic wastewater management, there
are some common elements to most models used in wastewater planning and risk assessment, including:

- Quantification of wastewater generation rates and total loads;
- Quantification of wastewater characteristics (constituent loadings as concentrations or total masses,
  usually including nutrients and/or pathogenic indicators);
- Identification of local environmental characteristics pertinent to wastewater management, including:
  - Soil type
  - Climate
  - Geomorphology
  - Types of sensitive receptors (such as surface and groundwaters)
  - Distance and pathways to sensitive receptors
  - Land use zoning and lot sizes.
- Simulation of the status and operation of wastewater systems and the transport of specific pollutants
  through surface and subsurface water flow; and
- Tools to estimate spatial and temporal variation in risk.

These parameters (not an exhaustive or exclusive list) are analysed in varying detail depending on the model
inputs and ultimate outcomes.

Wastewater Risk Assessment Modelling
Wastewater risk assessment models use a variety of available data, in combination with empirical and/or
analytical methods, in an attempt to classify and predict the risks posed by wastewater systems within a
broad range of environmental conditions.

The continually expanding scope and flexibility of GIS has enabled this platform to be used as a framework
for creating and running risk assessment frameworks; either on a case by case, “do-it-yourself” basis with
iterative hazard stipulation, or as a principal component of proprietary models. Many of the more complex
and powerful wastewater models use GIS, but this is only of benefit where adequate GIS data for the study
area are available. Other relevant data, such as the parameters listed above, are also typically required.

The majority of wastewater risk assessment models deal with surface discharges only, as groundwater data
for a study area is often not available or inadequate. However, some predict groundwater contamination risks
through deep drainage from effluent application areas. The output of risk assessment models depends on
the complexity and structure of the model. Examples include (but are not limited to):

- Probabilities of on-site system failures
- Cumulative influence of nearby failing systems
- Pollutant export, as concentrations or mass loadings, transport pathways, etc
- Hazard maps indicating levels of risk for modelled on-site systems or lots
- Potential environmental consequences of failures
- Capacity of the site and local environment to attenuate the contaminants
- Recommended minimum lot sizes for sustainable on-site effluent management.

Wastewater Planning and Servicing Modelling
Increasingly, decision-support models are being developed to assist wastewater systems planners and
managers in government and the private sector. Often, these models are incorporated into wastewater risk
assessment models as discrete modules which use outputs from the risk assessment component as inputs. Typical parameters used in wastewater planning modelling approaches include (but are not limited to):

- Expected performance of various on-site and community wastewater servicing system technologies (e.g. typical effluent quality)
- Likely costing scenarios for implementing new wastewater technologies
- Likely timeframes required for implementing new wastewater technologies.

Often such models have an application which can allow the comparison of a range of potential servicing options for a given situation. One example of such a model is the Decentralised Sewer Model (DSM), developed jointly by Whitehead & Associates and BMT WBM (Kidd & Wainwright 2004, Bishop et al. 2005), which includes both a risk assessment component and a decision-support tool to evaluate potential on-site and decentralised servicing options.

CASE STUDIES

Domestic Wastewater Management Survey for Tarago Reservoir, Victoria

This assessment was carried out in 2006-2007 by Whitehead & Associates (Whitehead & Associates 2006a). The DSM was a major component of the project, and was used to predict the possible impacts of on-site wastewater management systems on the Tarago Reservoir, which is a drinking water supply for the region. The model was calibrated using field data collected from site assessments of 55 properties with on-site systems surrounding the Reservoir. A pollutant-decay module was developed using the soil landscape classification tags, in order to more accurately track the movement of pollutants in surface flow within the catchment.

The results of the risk assessment modelling component suggested that on-site systems are contributing some nutrients and pathogens to the Reservoir in an average rainfall year; however, the total quantity of nitrogen, phosphorus and E. coli attributable to on-site systems is very small when compared to other sources (such as agricultural activities). The decision-support component of the model was also used to compare and evaluate three different servicing scenarios for the locality based on a cost-benefit analysis. Examples of the modelling outputs are provided in Figures 1 and 2.

Domestic Wastewater Management Plan for Baw Baw Shire Council, Victoria

DSM modelling was carried out by Whitehead & Associates and BMT WBM in 2006 (Whitehead & Associates 2006b; Asquith et al. 2007). A series of towns and villages within Baw Baw Shire were selected for analysis based on a preliminary risk assessment procedure to determine general septic system failures. The DSM was primarily used to estimate the capacity for on-lot management of wastewater within the villages, and to assist in identifying the best options for improved wastewater management. The particle tracking output was used to illustrate the potential for effluent export from effluent application areas to rivers and streams. The outcomes of the modelling included recommendations for most appropriate community servicing options based on optimal performance and minimal risks to the environment. A visual example of one of the model outcomes for one of the villages is shown in Figure 3. The map shows potential for effluent re-use at the individual lot scale.

GIS-based Risk Assessment Modelling for On-site Systems in Tyers, Victoria

A GIS-based risk assessment was undertaken in order to estimate the potential for sustainable and safe on-site wastewater management in the township of Tyers in 2007 (Whitehead & Associates 2008). Each lot was assigned a ‘natural’ or land capability hazard class, based on physical characteristics relevant to on-site wastewater management system performance; and a ‘built’ hazard class, based on the capacity for sustainable long-term on-site wastewater management in light of the state of the existing system (expressed as a percentage of the average daily wastewater load). The capacity on each lot for sustainable long-term on-site wastewater management was then estimated using water balance modelling.

The hazard map was prepared using the MapInfo 7.8 Geographic Information System (GIS), using digital data supplied by Latrobe City Council and the Victorian Department of Primary Industries. The classes assigned to individual sites ranged from 1 “Low” to 4 “Very High” hazard. One hazard class was assigned for every 5 metre grid or individual lot within the study area.
Figure 1: DSM model output for potential on-site system failures in the Tarago catchment, Victoria.

Figure 2: Example of the Particle Tracking and Pollutant Decay Module in the Tarago catchment, Victoria.
Figure 3: DSM model output for potential of on-lot reuse of treated effluent in the township of Noojee, Baw Baw Shire, Victoria.
The Final Wastewater Servicing Hazard Map (Figure 4) was used to identify lots where on-site wastewater management is likely to be sustainable and where some form of community wastewater scheme is needed. It was then used to nominate a Community Wastewater Zone within Tyers. This zone then became the focus of the development of potential wastewater servicing options that include a range of technology and servicing options. Recently, Tyers’ stakeholders have elected to adopt the recommended servicing option for Tyers on the basis of the modelling.

**East Gippsland Shire and Wellington Shire Councils’ Domestic Wastewater Management Plan**

An on-site wastewater risk assessment for un-sewered towns and localities in each of the above municipalities was carried out by RM Consulting Group, van de Graaff & Associates, Ethos NRM and Geocode Mapping & Analysis in 2006.

Both Shires had previously used risk assessment analysis to identify approximately 50 towns and settlements where domestic wastewater management was perceived to be an environmental or health issue. The medium-risk and high-risk areas were further modelled using a risk analysis based on the process described in the Model Municipal Domestic Wastewater Management Plan (MAV and EPA, 2005) to enable priority ranking for future mitigation actions.

The risk assessment and follow-on economic modelling suggested that on-site wastewater management is generally appropriate for the majority of the modelled localities, and that a range of mitigation measures to improve system performance would be the most effective response. These actions include both strategic and policy responses, such as education of property owners and determination of minimum lot sizes for future development, and physical improvements to, and replacements of, existing on-site systems. The modelling also assisted in developing a priority-based time-frame for adaptive management across various towns and villages in each of the Shires, as well as for each Shire as a whole.

**THE VALUE OF MODELLING**

The value of modelling can be demonstrated in a number of ways; cost effective and rapid collation and interpretation of data, reduced costs of field inspection and auditing of on-site systems and transparent comparison of alternative servicing options.

The modelling undertaken for the Baw Baw Shire Council Domestic Wastewater Management Plan rapidly collated and evaluated large volumes of data to enable the Council to prioritise currently unsewered villages for alternative wastewater servicing and to cost those options. The use of the model has enabled Council to achieve more advanced outcomes compared to approaches employed elsewhere and to demonstrate good stewardship of Government funds provided for their Domestic Wastewater Management Plan. Council reports that this approach has received favourable review and advanced Councils case for further funding support for innovative servicing solutions which can be supported by clearly presented, detailed and independent data.

The modelling approach used in the domestic wastewater management survey for Tarago Reservoir has reduced the cost of a catchment wide inspection and auditing program by using a first-pass run of the model, populated with data derived from a desk study, to rank potentially failing systems in terms of their likelihood to contribute to the pollution load in the reservoir. A reduced inspection and auditing program, targeting the higher risk systems could then be justified to calibrate the model. In this particular case the decision was made to inspect all properties, but in the event it was only possible to inspect some 60% of properties. This modelling approach has resulted in significant potential savings in replacement and upgrading of systems which have been shown by the field data calibrated model to not be significant contributors to the pollutant load in the reservoir.

Models are also of value in the transparent comparison of alternative servicing options. The DSM assists in determining the suitability of servicing options as it identifies the potential of individual lots to manage on-lot generated wastewater and also the potential of off-lot land parcels for beneficial reuse or disposal. By modelling the reticulation needs of a servicing option in terms of routing and wastewater load, servicing options can be readily sized and costed and transparent comparative costings can be undertaken.
Final Wastewater Servicing Map - Tyers

Figure 4: Final Wastewater Servicing Map for Tyers, based on the results of the DSM
The model can assess the relative merits of servicing options and can be used to test scenarios for partial or total servicing solutions and to determine how best fixed or limited budgets can be spent in addressing problems. Historically, little innovation has been offered in servicing solutions for unsewered towns and villages. Solutions such as Modified Conventional Sewer have been presented as cost effective options whilst ignoring the higher life-cycle costs of blockages and maintenance due to reduced grades and fewer manholes. Innovative “small pipe” effluent sewer options have been over-costed by consultants and water authorities unfamiliar with these alternative technologies and many of their environmental and economic benefits downplayed.

More recently, the business cases for Modified Conventional Sewer options have been challenged by water authorities such as Gippsland Water and Yarra Valley Water (Macdonald et al. 2008) who have identified more closely with the benefits of alternative “small pipe” solutions once modelled data has enabled true and transparent comparison of the various servicing options.

FUTURE DIRECTIONS IN MODELLING

Wastewater risk assessment and planning models are continually being developed and redeveloped, commonly by environmental and engineering consultants as well as government research and regulatory agencies. Rapid advancements in computer hardware and software capacity have enabled greater complexity and shorter time-scales to be incorporated into models. One example of this is the recent modification of the DSM to include an algorithm for a daily time step in wastewater pollutant transport within a catchment serviced by on-site systems.

In the future, models which include more comprehensive economic and social parameters will become more commonplace; particularly for comparing wastewater servicing options for un-sewered villages and towns throughout rural and regional Victoria. The benefits of modelling for wastewater management through cost and time efficiencies will continue to expand as information gathering techniques and databases develop throughout Victoria, and as the models themselves become more powerful and comprehensive.

REFERENCES


Municipal Association of Victoria and Victorian Environmental Protection Agency (2005) “Model Municipal Domestic Wastewater Management Plan”.


