Spectrum

Designing lakes to control pollution

As Australia's population expands, so does its need for residential development — and for agriculture to feed a growing number of people. New residential areas have traditionally been concentrated in the fertile, well-watered coastal regions, but these have only a limited capacity to accommodate people while maintaining their agricultural productivity and protecting unique environments. And that puts greater pressure on developments inland... which means more people and more agriculture, and hence more pollution of inland streams as well as coastal rivers and oceans.

While a generation ago water pollution 'control' often consisted of little more than discharging wastes into streams, thence into rivers and the sea, such a laissez-faire approach is no longer possible. Planners are concerned to minimise pollutants at the very beginning of the disposal chain, before they can 'escape' into streams or the sea.

One method of controlling pollutant escape is by capturing water-borne chemical and sediment wastes and retaining them for appropriate periods in artificial lakes (which can also be important for recreation, for wildlife conservation and for their aesthetic value). Chemical pollutants, such as nitrates from agriculture or phosphates from domestic detergents, can be broken down over time by aquatic plants, and sediments can be trapped in deep ponds for future dredging and disposal in, for example, landfill.

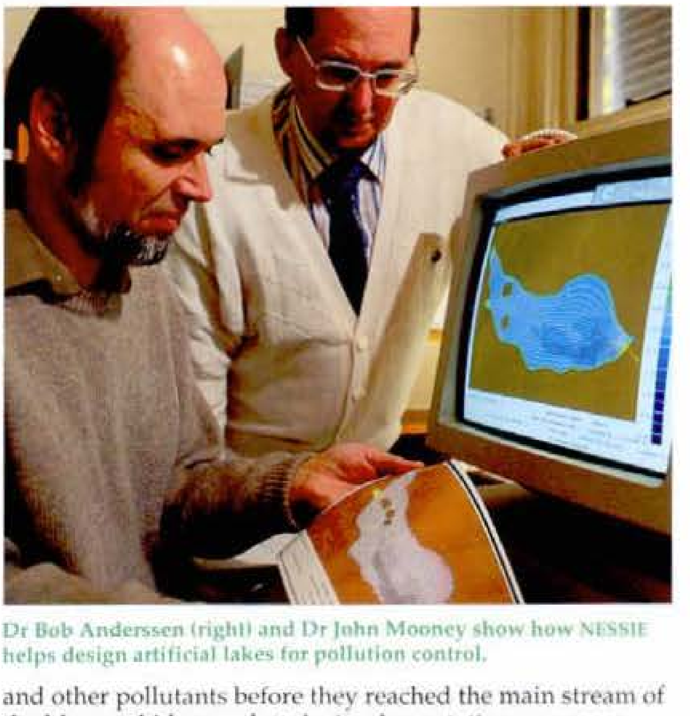
At the Yarralumla, Canberra, laboratories of the CSIRO Division of Mathematics and Statistics, Dr Bob Anderssen and Dr John Mooney have developed a potent tool to help planners design such pollution-control ponds. Called NESSIE (an affectionate name that is distinctly more accessible than 'two-dimensional vertically integrated resistive flow model'), it had its beginnings in 1988, when the then National Capital Development Commission (NCDC) asked the Division to study the design, construction and usefulness of artificial lakes as pollution-control devices, to evaluate modelling approaches to lake design on the basis of their economy, speed and ease of use and, if possible, to improve the design of such models.

Simple equation

The NCDC's approach was motivated by a simple, if problematical, equation: the Murrumbidgee River must leave the Australian Capital Territory as clean and free of pollutants (including natural pollutants such as sediment, as well as those produced by a population of some 300 000 urban residents and rural land-users) as it enters.

That means exercising some form of control over the Murrumbidgee to prevent it carrying pollutants into New South Wales, so the researchers looked first at preventing pollutants entering the river from its tributaries within the Territory.

The concept was simple enough — the construction of a series of impoundment dams at suitable locations, trapping sediment, agricultural chemical residues such as nitrates



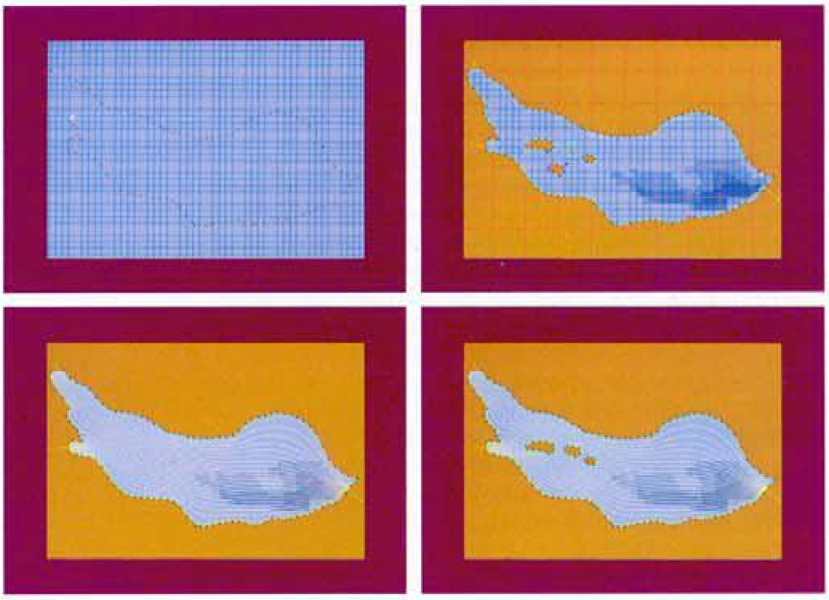
Dr Bob Anderssen (right) and Dr John Mooney show how NESSIE helps design artificial lakes for pollution control.

and other pollutants before they reached the main stream of the Murrumbidgee — but the implementation was more difficult. How, for example, could planners choose the optimum location and shape for such ponds? How could they design ponds that perform their designated functions correctly?

Two factors are central to a pollution-control pond's performance: residence time (the longer water stays in an artificial lake, the better the lake can retain chemical pollutants until they can be broken down, and the more efficiently sediment will settle) and sediment trapping (the lake's ability to accumulate silt, gravel and other sediments for long periods). Available models of water flow and sedimentation in artificial lakes were difficult to use and offered little opportunity to experiment speedily with changes in design. Nor could they answer some of the questions planners needed to pose.

Dr Claude Dietrich of the Centre for Mathematical Analysis at the Australian National University collaborated with Dr Anderssen to dissect the problem into parts that echo architect Mies van der Rohe's dictum about form following function. Form is expressed in the 'inverse' problem (for given pollution-control criteria, determine the best shape and contours for artificial lakes), while function is addressed by the 'forward' problem (for a given existing lake, determine how well it performs as a pollution-control device in terms of the amounts of sediment deposited and the amounts of chemical pollutants removed).

Working with Dr Mooney, Dr Anderssen then combined both problems into a simple, 'user-friendly' computer model that enables planners to achieve the best kind of compromise between form and function by altering a number of variables within the lakes. The main elements they can alter are: the size and shape of the lake, and its inlets and outlets, to regulate the speed and volume of water passing through the lake; the shape and number of deep areas ('subponds') to trap sediment and to slow the flow of water through the lake, and their placement to allow easy removal of sediment build-ups in future; the placement of shallow areas for aquatic plants to remove chemical pollutants; the placement of islands to regulate water speed and direction; and the positioning of outlets to regulate how long water takes to flow through the lake and therefore maximise the retention of sediments and the removal of chemical pollutants.



How NESSIE 'constructs' an artificial lake. First the designer draws the lake's physical parameters: its boundaries, shallows and depths, and islands. Then NESSIE plots the flow of water from one or more entry points, around or over obstacles, and shows residence times. A planner can assess how well a lake is 'working' by comparing flow patterns and residence times; he or she can even manipulate lake design to achieve optimum performance.

Pollution control

Planners have employed NESSIE in the design of lakes for pollution control in residential areas of the Australian Capital Territory. In one example, the engineering firm Scott and Furphy used it to refine the design of a 1-km-long, 500-m-wide and 4-m-deep run-off collection and stabilisation facility at Gungahlin, a new residential development in Canberra's northern suburbs.

Scott and Furphy engineers Mr Viet Le and Mr Geoff Henkel see NESSIE as a valuable tool for use in conjunction with other models to help planners arrive at the most efficient design in terms of function and cost. They say it not only helps planners modify and correct their designs but also lets them know when they have done their work well — when, for example, hydrological studies and engineering expertise have arrived at a design that achieves its aims.

The model works two-dimensionally, interpreting varying depth as varying resistance to water flow.

It models a lake's depths in much the same way as a topographic map that shows the land's contours. Planners first use a BUILD module to construct the lake on screen, entering information on the lake's shape, inflow and outflow points, islands and areas of deep or shallow water (the screen displays relative depths in colour, ranging from light yellowish-green for shallow water to dark blue for deep subponds). They use the same methods to 'build' on screen an existing lake when they want to assess and perhaps improve its pollution-control performance, or a planned lake designed according to the topography of a site.

The SOLVE module then calculates flow patterns — the direction water follows around obstacles, over shallows and through deeper areas — and residence times (a measure of flow speed expressed in how long a given mass of water takes to flow past a particular location), illustrating them in the DISPLAY module and providing a portrait of the lake's performance in a way that can be analysed easily and quickly. The DISPLAY module also gives users an opportunity to assess potential problems — if, for example, the residence times over a shallow area indicate the possibility of erosion of the lake-bed.

It is NESSIE's fourth function that makes it particularly valuable. The AMEND module allows planners to experiment with alterations in lake design: to discover what will happen if, say, an island is reduced, enlarged or moved or if subponds are excavated further to improve sediment storage. Or, in a lake intended to remove chemical pollutants such as nitrates, they can determine the optimum size, depth and placement of shallow areas for the growth of nitrate-absorbing aquatic plants.

As Dr Anderssen stresses, NESSIE has been designed so that planners, engineers and other users will feel comfortable with its use within 10 minutes of being introduced to the system — an essential component in making it as useful as possible, so that clients can concentrate on decision-making within a broad context rather than on learning to use an unwieldy computer system.

The model represents a significant advance in utility, economy and ease of use, as well as flexibility in application. Hydrodynamic modelling tools are under development elsewhere, but they lack NESSIE's essential ease of use and are consequently less likely to be adopted by planners: NESSIE is so flexible it can be applied to the design of marinas and artificial wetlands as well as artificial lakes, to the analysis of pollution capture and to the identification of sedimentation zones in existing lakes. More than 50 local government authorities, environmental engineers, planners and consultants around Australia have expressed serious interest in using it.

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