



The maths of water conservation

For more than 6000 years farmers have irrigated dry land. But it was not until early this century that scientists began to understand just what happens when water soaks into the ground.

Even then, the theory of water flow through soil progressed slowly, for two reasons. First, the theorists had produced mathematical equations that were difficult to solve because of the large changes in flow properties produced by relatively small changes in the soil's water content.

Second, people who worked on the land questioned the value of these numerical exercises in any case. 'You can't reduce soil to an equation', they argued. 'As you dig down, you come across cracks and worm burrows, and a few paces to one side the earth is shallower or more sandy. How could you ascribe values to such varied material?'

In the 1950s, Dr John Philip, now director of the CSIRO Institute of Physical Sciences, developed methods for solving the mathematical problems. This work provided the theoretical basis for a rational description of water movement in soils — and indeed of liquid flow in porous materials generally.

Since then, he and other researchers at the CSIRO



Scientists using a 'rainmaker' to test the theory of water infiltration in native forest.

Division of Environmental Mechanics have shown that the basic principles governing water flow in soils can be applied in a variety of practical circumstances.

Dr Philip and Dr David Smiles extended the theory to the flow of water through swelling soils, colloidal suspensions, and slurries — materials that have traditionally been regarded as intractable. They found that the flow equations were similar to those for non-swelling porous solids.

Dr Smiles has shown that this theory can be used with nothing more than a pocket calculator to predict water and solid distributions in such industrial processes as the filtration and sedimentation of 'red mud' slurry (a waste product from the processing of bauxite), phosphate slime (a waste from phosphate extraction), and clay slurries (produced in china-clay mining and sand washing).

Recently, other members of the Division have been studying how water moves through soils while it is raining. Using a theory of rainfall infiltration that had been developed in the Division, these scientists found they could accurately describe water movement in simple porous materials under simulated rain in the laboratory.

The maths, then, has been tamed, but what about the problem of soil's heterogeneity? Researchers had suspected that, during rain, up to the time that water collected on the surface, cracks and holes made by earthworms, ants, and so on did not influence the flow of water. Dr Ian White of the Division and Dr Brent Clothier, who was on leave from the Plant Physiology Division of CSIRO's New Zealand counterpart, DSIR, confirmed that this was indeed true in the field for a sandy soil and a loam.

When rain first falls, soil soaks up water like blotting paper, and any cracks and tunnels left by animals or dead roots do not appreciably affect water movement. Once the soil has absorbed all the water it can hold, the picture radically changes: large pores and cracks then form expressways for water movement.

This means that it is easier to apply the theory of liquid flow in porous media to unsaturated soils — for example, during sprinkler or drip irrigation — than to saturated ones, as during flood or furrow irrigation.

Dr White and Dr Clothier wanted to be able to predict the answers to three important questions. How deep into the soil will rain or



A device developed by the Division of Environmental Mechanics for measuring water-conducting properties of soil in the field.

sprinkler water penetrate? How is this water distributed through the soil? And how long can somebody continue to use a sprinkler before the soil becomes saturated and water collects on the surface?

For field use, the researchers simplified the theory of water infiltration so that answers to these questions could be expressed in terms of two quickly measured properties: sorptivity, a gathering of various fundamental physical properties of the soil that would be time-consuming to measure individually; and its saturated conductivity — that is, how fast water runs through the soil once it is saturated.

You can determine the sorptivity in about a quarter of an hour. You simply push a brass or steel cylinder into the soil and place on the soil surface a small device, specially designed in the Division, that supplies water

to the soil at slightly less than atmospheric pressure in order to exclude the effect of large pores.

The second measurement can be made on the same sample after it has been excavated from the soil. Both measurements can be made rapidly, allowing many samples to be examined within a couple of days.

Researchers in the Division of Water and Land Resources are using the field apparatus to examine changes in the physical properties of soil after grazing and tree-killing in woodland. State Departments of Agriculture and overseas universities have also expressed interest in the apparatus, whose design is available to field workers from Dr White at the Division of Environmental Mechanics.

The simplified theory has already been found useful for predicting water movement in both agricultural land and native forest, and researchers are now extending the work — for example, to clay soils.

The theory could prove valuable for people using sprinklers. A simple calculation will give you the rate and length of water application for the most efficient water use.

The theory also helps to indicate the best strategy for reclaiming saline soils. Here unsaturated flow, such as that produced by the moderate use of sprinklers,

proves best at conserving water under certain conditions, like those on some heavy soils.

The mathematical expressions developed for rain infiltration can be used to estimate when the upper layers of the soil will become saturated and water will start to flow over the surface; this could provide useful information to hydrologists concerned with the supply of water to reservoirs, or with soil erosion. The theory can, furthermore, be used to predict the effect of a leaky canal on the water table beneath.

Practical applications of the Division's theoretical work are not restricted to soil, however. People are interested in the way water flows through a variety of other porous materials.

The Division has helped train scientists from both the CSIRO Division of Mineral Chemistry and Alcoa, who have been interested in learning more about water flow in clay slurries and red mud. By being able to predict the outcome of various slurry treatments, a scientist can minimize water consumption and the hazards of contaminated seepage.

The Division has also collaborated with the Australian Atomic Energy Commission in taking measurements of water flow through a uranium-mine overburden dump at Rum

Jungle, in the Northern Territory. The measurements were necessary to estimate the amount of seepage through the dump. This seepage, which was highly acid as a result of bacterial action within the dump, was leaking into a branch of the Finnis River.

The Division has worked, too, with scientists from the New South Wales Soil Conservation Service and the CSIRO Division of Plant Industry, who are interested in the effects of alternative types of land management on runoff and erosion.

Theory of infiltration. J.R. Philip. *Advances in Hydroscience*, 1969, 5, 215–96.

Sedimentation: integral behaviour. D.E. Smiles. *Chemical Engineering Science*, 1976, 31, 273–5.

Constant-rate filtration of bentonite. D.E. Smiles. *Chemical Engineering Science*, 1978, 33, 1355–6.

Pre-ponding constant-rate rainfall infiltration. I. White, B.E. Clothier, and D.E. Smiles. *Proceedings of International Symposium on Rainfall Runoff Modelling, Mississippi, May 1981* (in press).



Assessing the water-flow properties of a uranium-mine overburden dump at Rum Jungle, N.T.