lines used during construction can easily be seen.

Going underground

Malta has a serious nitrate pollution problem. But where is it all coming from? **Marianne Stuart** traces the source from the underground galleries to farmer's fields.

This was going to be one of the most interesting samples to collect. The six of us donned hairnets, hard hats and overshoes and stepped into the lift. We pressed the button for Level Zero and dropped one hundred metres below a groundwater pumping station on the island of Malta.

We wanted to reach the water table to collect an untreated sample of groundwater. The pump house adds chlorine to the public supply to kill bacteria, but it was coliform bacteria we were after.

Through the lift's viewing window we could see the geological changes passing, from the damp clay-rich grey Globigerina Limestone down through the lighter-coloured Lower Coralline Limestone which contains the main aquifer.

The lift came to a halt above the water and a spiral iron ladder took us the final steps. At the water table, a series of large tunnels, known as galleries, radiate from the pumping station. The longest runs for six kilometres. Engineers designed them to skim the fresh groundwater floating on the denser seawater below.

This was one of the final samples collected for an EU-funded project led by British Geological Survey scientists with the NERC Isotope Geosciences Laboratory and the Malta Resources Authority.

We were trying to identify the principal sources of nitrate in groundwater in Malta. The two main Maltese islands, Malta and Gozo, have a serious problem with groundwater nitrate, with some of the highest concentrations in Europe.

Malta's accession to the European Union in 2003 means that the whole country has been declared a Nitrate Vulnerable Zone. Under the terms of the EU's Water Framework Directive, the Maltese government must identify and control pollutant sources, and eventually reduce groundwater concentrations to acceptable levels.

The Maltese islands are mainly made up of coralline limestones with a low-permeability mid-layer – the 'Blue Clay' – and the underlying Globigerina Limestone. This means that there are two aquifers, a shallow aquifer above the Blue Clay, up to 100m above sea level, and a deeper one at sea level.

The climate is hot and dry in the summer and surface water is scarce, so the islands are heavily dependent on groundwater. This is extracted from many boreholes and by large pumping stations, similar to the one above us. The amount of water available cannot meet demand, so desalination plants provide about half of the drinking water.

Groundwater quality in the shallow aquifer is sometimes poor with high nitrate and bacterial concentrations. The long-held view is that water seeps to the lower aquifer through fractures and fissures in the rock. But recent work by the International Atomic Energy Agency has indicated that there are two flow mechanisms operating: a fast flow through fissures, possibly taking days or weeks, and a much slower route through the small pores in the limestone, taking years or decades. This means that the full impact of pollution today may not be seen in groundwater for many years or decades.

Malta has some of the highest concentrations of groundwater nitrate in Europe.

Muck raking

Nitrate can reach groundwater from many sources. In most countries fertilised agriculture is the main way. Rainfall causes excess fertiliser – either synthetic nitrogen compounds or animal manure –

to leach through the soil into the subsurface.

About 400,000 permanent residents live on the island, but a large influx of tourists each year swells this population, creating a substantial source of waste.

The islands are almost entirely sewered, but parts of the network are old and unlined. Natural fractures must allow some sewage to escape and eventually reach groundwater.

Farming practices on the islands are peculiar to Malta. Over 50 years ago, to control a livestock disease known as 'contagious abortion', or endemic brucellosis, farmers changed from typical Mediterranean outdoor husbandry of sheep and goats to predominantly indoor rearing of pigs, cattle and poultry. Brucellosis is highly contagious and can cause a disease in humans called 'Malta fever'.

There are now over 73,000 pigs and 20,000 cattle on the islands, plus one million poultry and some farmed rabbits. We never saw a pig on our visit, but you can certainly smell them. Farmers have predominantly used cattle manure as a valuable fertiliser, but pig slurry has been frequently disposed of illicitly.

Collecting a sewage sample.

Tracking pollution

So how do you track this pollution from various sources and in its various guises as it makes its way through the rocks? Ideal markers would be chemicals or microorganisms typical of each source that we can trace from the surface through the rocks to the aquifers. Since these don't exist, we need a range of indicators to provide clues. We used nitrate-stable isotopes, dissolved organic carbon, fluorescence, and coliform bacteria, plus others. We already knew that seawater intrudes the lower aquifers. This limits the type of analysis we can do because many solutes in sewage and animal waste also exist in seawater.

We never saw a pig on our visit, but you can certainly smell them.

Nitrate-stable isotopes are expensive to analyse but invaluable tools for understanding what has happened to the nitrogen in the subsurface. Another approach is to use chlorofluorocarbons (CFCs) or sulfur hexafluoride (SF_6): young groundwaters (recharged within the past 50 years) generally contain dissolved CFCs and SF_6, telling us how long the water has been there.

Deep beneath the pump house, I filled up sample bottles from the surface of the water, which was surprisingly warm for those of us used to collecting groundwater in the UK. This concluded our extensive sampling programme including groundwater from pumping stations like the one above, boreholes and springs, and typical nitrate sources such as synthetic fertilisers, animal wastes, sewage and soils.

An illicit manure pile in the corner of a field a few metres from a public supply borehole.

The results show that, as would be expected, the groundwater system is very complex and there is no unequivocal answer. It seems that fertiliser and sewage-derived nitrogen are not major contributors to groundwater nitrate and that the most probable source is leaching of nitrate from cultivated soils and possibly from manure piles.

Soil nitrogen may itself be originally derived from spreading animal wastes or synthetic fertilisers. There was little evidence of denitrification so we think the lower concentrations of nitrate found in the Gozo aquifer must be due to the protection of the groundwater by the Blue Clay cover on the island.

These findings will allow the Maltese government to bring in effective controls on nitrate sources, reducing groundwater nitrate in the long term. They have already implemented a scheme upgrading manure stores to prevent nitrogen leaching. The government will now need to tackle the practices of the many part-time small-scale farmers.

Another significant finding for the lower aquifers was the time water spends in the aquifer. This proved and be between 15 and 40 years in the Malta aquifer and between 25 and as much as 60 years in Gozo. This is on top of the time taken by water taking the slow route from the surface to the water table. We found relatively few coliform bacteria in most samples suggesting that only a limited fraction of water takes the fast route. This slow movement has important implications for future groundwater quality since it means that even if all nitrate-producing activities could be stopped tomorrow, it would take decades to flush out nitrate to an acceptable level. ❖

MORE INFORMATION

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