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Groundwater Management and the Causes of Confined Space Hypoxia

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London's Lower Aquifer was under artesian pressure until the early 1800s, when significant abstraction was started to supply the demands of growing population and industry. A reduction in piezometric levels was noticed as early as 1840 and by 1900 water levels in Central London had fallen by up to 40 m. Drawdown peaked in the 1960s, with water levels 70 m below normal in the cone of depression under Central London. Economic decline and abstraction controls allowed water levels to recover after the 1960s, with water levels rising 20 m by 1988, when the GARDIT (General Aquifer Research Development and Investigation Team) strategy was launched to control rising groundwater by controlled abstraction. An unexpected consequence of the drawdown and later recovery of the Lower Aquifer is the presence of deoxygenated air at depth, often under pressure. Deoxygenated air poses a serious, life-threatening hazard (confined space hypoxia) for engineering projects in London, particularly within the Upnor Formation of the Lambeth Group, where the gas appears to be trapped below impermeable clay layers in the Lower Mottled Clay of the Lambeth Group. Here we discuss the physical, chemical and geological reasons for the presence of this trapped deoxygenated air, and its implications for groundwater management in London and elsewhere, as other cities transition towards sustainable water management.

Physically, drawdown reduced the pressure in the Lower Aquifer, potentially resulting in cavitation and the release of air dissolved in the groundwater. Experimental studies demonstrate that this air can become trapped below fine-grained sediments, such as the Lower Mottled Clay. Because the water recharging the aquifer is fully aerated, the trapped air cannot redissolve and is pressurised by rising piezometric levels. Geological structure appears to control the location of the trapped air, while the presence of reducing sediments is the cause of the loss of oxygen. Historically, glauconite has been considered to be the mineral most likely to remove oxygen from the trapped air, but it lacks potency as a reducing agent and is found unaltered in many oxidised sediments. Pyrite and organic carbon are both plausible, but rare in these sediments. Green rust, a mixed Fe(II) and Fe(III) layered double hydroxide, is more likely, since it oxidises rapidly on contact with air and is only briefly observed in fresh core samples.

The implications are that groundwater management systems, on both short (ground engineering) and long (reservoir management) timescales, should be aware of the possibility for cavitation and the presence of trapped air, and of its possible interaction with natural sediments, especially where the possibility exists for oxidation of those sediments. Of particular concern are those regions in which aquifer drawdown has in the past been uncontrolled. In London, the lack of such an awareness led to two fatalities, and prompted this research.