On-site Septic Systems: The Sustainable Removal of Excess Nutrients

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Sewage is usually treated in large, centralised facilities or local on-site septic systems. The latter can involve lower costs and energy requirements, although we must ensure that on-site options such as septic systems do not negatively impact the surrounding ecosystem. **Dr William Robertson** from the University of Waterloo, Canada, investigates the removal of polluting nutrients from wastewater before it is released into the environment. He has shown that a conventional septic system can provide long-term and sustainable contaminant removal from wastewater.

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Centralised to Local

In an increasing global population, the question of how best to treat domestic sewage – wastewater –has become a hot topic. Wastewater is often treated in large, specialised facilities, although connecting a rural or remote community to a centralised plant can be costly and impractical compared to localised on-site septic systems. For this reason, about one-quarter of Americans rely on on-site wastewater treatment, mostly situated in rural or suburban areas.

Local Sewage Treatment

On-site septic systems are designed to clean wastewater before it is released into the environment, using physical, chemical, and biological tools. First, sewage is fed to a septic tank (underground container made of concrete, fibreglass, or plastic) for digesting organic matter and separating floating fats and solids from the wastewater.

This wastewater is then discharged into a shallow trench called a drainfield for further treatment. Drainfields can contain rows of perforated underground pipes, from which wastewater is slowly released into the surrounding soil. Other systems use pumps or gravity to ensure the wastewater slowly trickles through sand or organic materials in the drainfield that remove or neutralise pathogens and pollutants.

The treated wastewater is eventually accepted and dispersed by the soil before discharging to the surrounding groundwater (saturated zones of water moving slowly underground). Concentrated streams of liquid contaminants known as groundwater plumes flow in the same direction as the surrounding groundwater.

Avoiding Water Contamination

Although properly maintained on-site septic systems can be relatively low-energy, low-cost and no more polluting than centralised facilities, nearby surface water (such as lakes, rivers and streams) and groundwater resources must be safeguarded.

Dr William Robertson from the University of Waterloo, Canada, studies the ways in which contaminants can be removed from on-site wastewater treatment systems. Septic systems can cause soil and water system contamination, with phosphorus, nitrate, and nitrogen compounds such as ammonium leaching into the groundwater and affecting local ecosystems. The discharge of excessive amounts of nutrients like nitrogen and phosphorus, which act as fertilisers for bacteria and algae, could lower water quality and damage aquatic lifeforms in nearby water bodies.

Other local environmental effects of septic tanks can include surface water and groundwater contamination with pathogens. As groundwater pollution caused by nearby septic systems can affect water bodies and drinking water wells used by local residents, the contaminant profile of groundwater is key.

Dr Robertson is working to determine how best to reduce this type of environmental impact, and has even presented possible options for harvesting the phosphorus in wastewater as a sustainable, locally available fertiliser source.

Long-term Performance

Researchers previously showed septic systems can benefit from subsurface treatment reactions that attenuate nutrient levels, although it is still unclear how sustainable these are over long timescales. To gain a clear idea of the sustainability of key nutrient removal processes in the long term, Dr Robertson and his colleagues studied a standard septic system with a monitoring record spanning over thirty years.

The selected system comprised a septic tank and drainfield with discharge managed via gravity flow, used for the on-site wastewater treatment of a seasonal family cottage in woodland near Sudbury, Ontario. The drainfield was originally constructed in a small pocket of sandy dust-like sediment extending over granitic bedrock, where the sediment was excavated to a depth of 1 metre and replaced with imported, coarse filter sand.

Over a year, during 2021/22, when the system had been in operation for more than 30 years, the team extracted groundwater samples from a network of monitoring wells in the drainfield, placed along the flowpath of the groundwater plume. Dr Robertson analysed these samples using modern laboratory techniques and compared them to those he obtained from the same site over thirty years earlier. This allowed him to investigate any changes in nutrient removal while also determining which removal mechanisms were dominant in this case.

Sustainable Phosphorus Removal

A major concern in terms of groundwater contamination is soluble reactive phosphate (SRP). When phosphorus in wastewater is mineralised to produce SRP, it is reactive and can be absorbed onto surface particles or subject to mineral crystallisation. Too much SRP in the water can lead to an overabundance of algae, which affects other aquatic life.

Dr Robertson found that although SRP levels had increased slightly compared to thirty years earlier, the SRP concentration was still 99% less than in untreated sewage. The team determined that mineral precipitation, rather than surface adsorption, was the dominant removal process, and that most SRP removal happened near the groundwater plume, within about 1 m of the infiltration pipes. Dr Robertson found that, in this case, SRP removal was sustainable partly due to an excess of available metals like iron and aluminium in the drainfield sediments, which support phosphorus mineral crystallisation.

The migration of SRP in groundwater plumes is usually slowed by adsorption, although a sufficiently high plume flow rate could lead to SRP migration rates of metres a year. Nutrient migration rates on that scale could impact local ecosystems.

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How to Remove Nitrogen

Nitrogen and nitrogen compounds, such as ammonia, are also key wastewater contaminants. On measuring the total inorganic nitrogen (TIN) levels at the site, Dr Robertson found values not significantly higher than those taken thirty years before, which represented an 80% removal of TIN from the wastewater.

The team also investigated the mechanism of TIN removal and whether this deteriorated over time. Nitrate removal by denitrification (converting nitrogen into its gaseous form) can be driven by certain compounds in the subsurface sediments which donate electrons to the nitrogen, but these exist in low levels and their presence depletes over time.

As levels of compounds that donate electrons become depleted, denitrification reaction fronts (the division between a reacted and mostly unreacted material) can migrate quickly, from a few centimetres per year at low groundwater velocities to several meters per year in higher groundwater velocities. Similar to SRP migration, a high level of nutrient migration would be a cause for concern in terms of long-term on-site wastewater treatment.

Anaerobic ammonium oxidation (anammox) is another nitrogen removal mechanism that occurs in groundwater plumes and is driven by components of the wastewater itself. In this reaction, ammonium and nitrate from the wastewater are converted into N2 gas, thus simultaneously removing two pollutants from the wastewater. Dr Robertson's work suggests that anammox contributes to the robust TIN removal in the analysed septic system.

While mineral crystallisation was the dominant SRP removal mechanism, both denitrification and anammox processes appeared to contribute to the robust TIN removal observed by Dr Robertson and his team, which exceeded nutrient removal levels measured at many municipal wastewater treatment plants in Ontario.

Sustainable Wastewater Treatment

On-site septic systems can provide low-cost, low-energy wastewater treatment compared to centralised wastewater management plants. Dr Robertson's long-term study of a domestic septic system shows that key nutrient removal mechanisms can still be active after decades.

This research provides key insights into the sustainability of subsurface treatment reactions that remove and neutralise nutrients over time. Dr Robertson's decade-spanning research shows that wastewater can be safely processed in conventional on-site septic systems, highlighting the sustainability of localised wastewater treatment.

MEET THE RESEARCHER

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Dr William Robertson obtained his MSc in Earth Science at the University of Waterloo in 1977 and then completed a PhD in the same faculty. In 1992, he was appointed as Research Assistant Professor, and in 1998, he was promoted to Research Associate Professor. Dr Robertson is now Professor Emeritus in Earth Science at the same institution where he studies the migration and dissolution mechanisms of nutrients in the groundwater plumes of septic systems. As an active researcher in the field of on-site wastewater treatment for both domestic and agricultural uses, Dr Robertson holds patents for various approaches to removing excess nutrients from wastewater, which have been licenced to private companies for commercialisation. Dr Robertson has supervised multiple research students and taught a range of laboratory and field-based courses. He has published over 60 academic papers on the mechanisms and factors underpinning modern on-site wastewater treatment.

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FURTHER READING

WD Robertson, RJ Elgood, DR Van Stempvoort, *et al.*, Nitrogen and Phosphorus Treatment Can Be Sustainable During on-Site Wastewater Disposal, *Groundwater*, 2023, 61(4), 586–598. DOI: 10.1111/gwat.13316