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Special issue : fate of phosphorus in septic tanks (autonomous waste water treatment systems)

This is a review of a number of papers covering research knowledge and needs regarding nutrient contamination from septic tanks and other decentralised sewage treatment systems.

The Scope Newsletter

The SCOPE Newsletter is produced by the Centre Européen d'Etudes des Polyphosphates, the phosphate industry's research association and a sector group of CEFIC (the European Chemical Industry Council).

The SCOPE Newsletter seeks to promote the sustainable use of phosphates through recovery and recycling and a better understanding of the role of phosphates in the environment.

The SCOPE Newsletter is open to input from its readers and we welcome all comments or information. Contributions from readers are invited on all subjects concerning phosphates, detergents, sewage treatment and the environment. You are invited to submit scientific papers for review.

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Septic tanks

Review of research into nutrient release from autonomous sewage treatment systems

An overview of existing knowledge regarding nitrogen and phosphorus releases from septic tanks and autonomous sewage treatment systems shows the significant differences between the behaviours of these two nutrients. Nitrogen is only retained in septic tanks to a small extent, and once tank effluent is infiltrated into soil will tend to be converted to nitrates which are then very mobile and move with underground waters. Phosphorus, on the other hand, is significantly retained in septic tanks (up to 48%) and then precipitated or adsorbed in soil, so that significant contamination rarely moves more than a few metres from septic tank infiltration.

The authors assess available research regarding the operation of different types of autonomous or decentralised sewage systems, including conventional septic tank / soil absorption systems, but also innovative new systems such as grey/toilet water separate management systems, soil based and wetland systems.

Nitrogen contamination

Raw human sewage contains 2 – 8 kg total N/year. Traditional septic tanks are estimated to achieve 40% reductions in sludge volume, 60% reduction in biological oxygen demand (BOD), 70% retention of suspended solids, and 48% (Pell and Nyberg 1989) – 57% (Tetra tech 2002) which will in time need to be pumped for disposal. Settling and periodic pumping however is estimated to only remove 5 – 15% in inflow total nitrogen.

Soil adsorption can then remove a further 20% of total nitrogen, as ammonium, but this may be reversible when aerobic conditions occur and the ammonium is converted to soluble and water transportable nitrate.

Nitrogen from septic tank outflows can thus move to groundwater in a matter of days, and may tend to move mainly through shallow aquifers, posing an immediate risk to shallow wells and to surface waters.

Phosphorus from septic tanks

Phosphorus in septic tanks and in their outflow behaves completely differently from nitrogen. Firstly, a significant proportion of inflow phosphorus in septic tanks is effectively removed by settling and subsequent pumping of septic tanks (48% - 57%, see above).

Phosphorus in septic tank outflow is 85% soluble orthophosphate, with some organic and inorganic particulate phosphorus attached to suspended solids. The latter will be retained in soil. The soluble orthophosphate can be retained in soils both by precipitation to mineral phases by ions present either in the septic tank effluent or in the soil (iron, aluminium, calcium …), or can be adsorbed to soil colloids (formation of a strong chemical bond between orthophosphate and clay minerals).

Typical mass balance studies have shown that 65% - 95% of the septic tank effluent phosphorus is found in soils within a few metres of the outflow point, even after years of septic tank operation. The "plume" of phosphorus concentrations downstream of septic tank outflow is estimated by several studies to develop 10x – 100x more slowly than the general plume of contamination.

Aulenbach et al. 1981, estimated 85% overall removal of phosphorus from sewage in septic tank systems (including soil retention, and assuming 5% of systems failing) around Lake George, New York State.

Previous research

Several authors, many cited by Gold in this review, or elsewhere, have previously confirmed that the risks of phosphorus contamination of wells or surface waters from septic tank outflow are very limited.

* **Johnson & Atwater 1988** used 3m long experimental channels of different soil materials to test removal of different components of raw sewage, showing 96-99% removal of soluble phosphate with different soil types (3 loamy sands, 3 sands), whereas certain of the soil types tested removed only ¼ of the inflow inorganic nitrogen.

* **Robertson (2000, see SCOPE Newsletter n° 44)**, in 2-year field experiment using a lysimeter containing natural sandy soils, showed that septic tank effluent soluble phosphate levels were brought down below the detection limit (< 0.05 mgP/l). Only around 0.2% of soil iron had been used, forming stable coatings on the soil particles, suggesting that the system would remain effective for many years.

* **Harman et al 1996 and Robertson & Harmann 1999** studied the effluent plumes of 3 septic tank systems which had served a 200-pupil school (Langton) for nearly 50 years and a seasonal 200-person campsite for 5 and for 25 years (2 outflows), in Ontario, Canada. They reported that even after these long operational periods for large septic systems, around 85% of phosphate was being retained in the first 30 cm of soil around the outflows (vadose layer). Phosphate above background levels was detectable up to 75m away from the older system in a situation with mobile groundwater, but not beyond. They concluded that over long periods of use of septic tanks, long-term migration of phosphorus in the ground water zone may occur.

* **Zanini, Robertson et al. 1998** reported results from monitoring of the Langton school plume (as above) and of three domestic septic tank systems also in Ontario: Cambridge operational for around 20 years, Muskoka ten years, Harp Lake 30 years. They again found high phosphorus removal within the first 10-30 cm of soil around septic tank outflow infiltration pipes. Based on soil iron contents, they

estimated that it would take around 35 years to saturate the first 25 cm around a septic tank outflow, coherent with the 85% phosphorus retention in the 30 cm vadose zone observed for the Langton school site above.

* **Robertson et al. 1991** had reported analyses of the plumes of the Cambridge and Muskoka domestic septic tanks cited above. The plume at the Cambridge site was 130m long and 10m wide, for soluble contaminants such as nitrate and sodium ions, but phosphate was observed only immediately beneath the infiltration field. The plume at Muskoka was 20m long, reaching nearby surface water, but again phosphate was not detectable in the ground water below the infiltration field, nor at any significant horizontal distance away from the infiltration zone.

* **Robertson 1995** reported further monitoring results from the Cambridge domestic septic tank site, Ontario, Canada, operational for around 20 years, indicating a pattern of slow but pervasive expansion, with a migration velocity of about 1m/year. This represents a reatrding factor of around 20, probably as a result of soil particle sorption of phosphate. Phosphate levels then stabilise at around 1 mgP/l in the plume. Analysis of dilution factors led to the conclusion that around 25% of septic tank effluent P continued to be attenuated in the valdose zone, whilst throughout the rest of the plume soil capacity for phosphate sorption is progressively saturated thereby allowing slow extension of the phosphate plume. It is suggested that the attenuation in the valdose zone is probably the result of mineral precipitation, most probably of calcium phosphates. Comparisons with work at other sites suggest that higher attenuation values are obtained at lower pH levels (acidic waste water or soil conditions).The extension rate of the phosphate plume at the Cambridge site meant that it has already reached piezometers situated 20m from the tank infiltration bed, the separation distance locally required between septic tank infiltrations and sensitive surface waters, indicating that this distance is inadequate where the soil offers poor P retention.

* **Robertson & Blowes 1995**, studied a septic tanks system serving a seasonal cottage for four years after installation, at Sudbury, Ontario. In this situation, on poorly buffered silt earth, an acid contamination plume developed in the ground, but with limited phosphate mobility (retardation factor > 10) and no phosphate migration significantly beyond the infiltration bed gravel layer over the study period.

* **Robertson et al. 1998** looked at 10 mature septic tank systems in Ontario, including the 6 cited above, plus in addition another campsite (Camp Henry, 18 year old system), a resort (Delawana, 10 years) and 2 further houses (Paradise, 25 years and Killarney, 10 years). They concluded that phosphate migration is 20 – 100 times slower than the extension of the plume for other soluble contaminants, such as nitrates, but may reach around 1 m/year. Six phosphate plumes of over 10m were identified in sandy soils, but phosphate plumes <3m long on acidic silt or clay rich soils. Ground water phosphate concentrations immediately below the septic tank outflows were significantly lower than septic tank effluent levels, suggesting 23-99% phosphorus retention in the vadose zone within 1m of outflow pipes.

* **Ptacek 1998** studied the plume from the Camp Henry campsite septic tank (see above), Ontario, situated on sand alongside the coast. He found phosphate concentrations higher than background (but low at < 0.02 mgP/l) up to 60m away from the septic tank in part of the soil ground water (non-surface groundwater with low oxygen levels). This shows that septic tank outflows can contribute phosphate to surface waters where septic tanks are relatively close to surface waters (< 100m) and in sand substrate (rather than soil) over an impermeable layer.

* **Jones and Lee 1979** stated for Wisconsin, USA, found no detectable phosphate contamination at 15 sampling points situated 10 – 100 m distant from a septic tank tile field, 4 years after starting its operation, concluding “No evidence for phosphate transport fro septic tank effluent was found in any of the monitoring wells”.

* **Gilliom and Parmont 1983**, for eight 20-40 year old septic systems close to Pine Lake, Puget Sound, Washington, concluded: “movement of more than 1% of effluent P to the lake was rare” (despite

movement of diluted effluent commonly occurring). Chen 1988, New York concluded that all of 17 septic systems examined showed "good removal of orthophosphate".

* **Wieskel and Howes 1992** looked at nutrients from four different 10-75 year old septic tank systems situated close to Buttermilk Bay, Massachusetts, and concluded that approx. 61% of septic tank effluent nitrogen would reach the Bay water (10 – 100m down gradient from the septic tanks), but that only approx 0.3% of the effluent phosphorus would reach the Bay.

* **Reneau and Pettry 1976**, studied phosphorus movement in sandy loam coastal plain sols in Virginia, from two septic systems aged 4 and 15 years. They detected no soluble phosphorus in a slowly moving water table below the septic tank outflows (seasonally perched water table) and orthophosphate concentrations < 0.2 µg/l at points 3m distant from the outflows.

* **Reneau 1979**, in the Virginia coastal plain, studied transfer of contamination from 10 domestic septic tank systems (all > 12 years old) to an agricultural tile drain situated 11 – 19 metres from the tank outlflows. Also, sampling wells were drilled 1.5 – 17 m away from three of the septic tank systems. Variation in the soil phosphorus abatement capacity was found, with 99% of phosphorus being removed within 8m for two of the septic tank outflows, but only at 30m for the third. Mean phosphorus concentrations were lower in the sampling wells 13 – 17m away from the septic tank outflows than in the surface water receiving the tile drain outfall, and phosphorus was not detectable in the tile drain outflow (lower concentration than in the receiving water).

* **Reneau, Hagedorn and Degen 1989**, reviewing available literature, concluded that "the limited movement of P away from on site wastewater disposal systems (OSWDS) is well-documented" and that "Most field studies indicate that P contamination is limited shallow groundwaters adjacent to OSWDS and that P sorption continues under saturated conditions". The risk of phosphorus movement to surface waters is thus minimal.

* **Viraraghaven & Warnock 1976**, in Ottowa, Canada, analysed contaminants in groundwater samples immediately below a septic tank drainfield for a system which had been operating for three years. Most samples (14 out of 18) showed phosphate concentrations lower than the background groundwater, but some were 3-4 x higher.

* **Sawhney and Starr 1977**, used sampling tubles installed 15 – 120 cm below and 20 – 120 cm horizontally distant from a secptic tank outflow trench system. They concluded that soil 15-30 cm below the trench was continuing to remove most of the outflow phosphate after 6 years of septic tank operation, and that 60 cm of soil should "effectively remove phosphorus from septic system drainfields for a number of years and should allow only minimal additions to the groundwater". They also showed through alternate operation of 2 outflow trenches from the septic tank that the soil" regenerated" its phosphorus removal capacity: this is conform to laboratory experiments which show that soil phosphorus fixing capacity is increased by wetting – drying cycles.

* **Chen 1988** analysed contamination in groundwater samples at various distances from 17 different septic tanks systems situated near the shores of lakes in Northern and Eastern New York State. Of 45 sampling points, situated 0 – 3m below the surface and up to 100m distant from the septic tank outflows, only 4 showed phosphate concentrations > 0.1 mgP/l and the ten points > 40m distant all showed concentrations < 0.04 mgP/l. The author noted that several sites showed groundwater contamination near enough the lake edge for transfer to surface water to be possible and indicates that problems of nutrient and coliform bacteria transfer from septic tanks where their outflow is situated in rocky or sandy substrate over an impermeable layer.

* **Alhajjar et al. 1989**, compared nitrogen and phosphorus contamination of ground water for two sets of respectively 8 and 9 domestic septic tank systems, with households using in one case phosphate-based and in the other carbonate-based laundry detergents. They concluded that there was zero probability of more than 5% of phosphate reaching ground water in all cases with mean

phosphate transfer < 0.1 mgP/l in all cases. However, they found total nitrogen concentrations reaching groundwater of 39 and 69 mgN/l for the phosphate- and carbonate-detergent households respectively, concluding that the use of phosphate-based detergents led to substantially lower levels of nitrogen contamination. They conclude that the use of carbonate-built (P-free) detergent "exacerbates nitrogen leachate to ground water" with human health and environmental implications.

* **Alhajjar et al. 1990**, compared phosphate and nitrogen removal in lab-scale soil-filled columns simulating mound, new conventional and mature conventional septic tank soil drainfields, fed with septic tank effluents from households using phosphate-built or phosphate-free (zeolite built) laundry detergents. The columns fed with P-detergent effluent showed higher outflow phosphate levels, but on the other hand lower outflow nitrogen levels. The authors concluded that P-built detergents used in households served by septic tanks reduce nitrogen leaching to groundwater by a factor of 1.8 (new systems) to 2.1 (mature systems), and "slightly" increase phosphate leaching compared to households using zeolite based detergents. They suggest that this may be the result of precipitation of struvite (magnesium ammonium phosphate) or similar minerals because of higher available phosphate in the drainfield soil.

* **Woods, 1993**, studied the fate of phosphorus in a context where soil absorption of phosphorus was susceptible to be problematic, around Harp Lake, Ontario (180 km North-East of Toronto, see Zanini, et al. 1998 above): a thin heterogeneous till soil over acidic Precambrian shield bedrock. For one typical domestic septic tank dating from 1962, most of the phosphorus from 30 years use was found in the 14 cm soil layer below the tile-bed outflow. Phosphorus in the aquatic sediments at this and four other septic tank sites around Harp Lake showed mean phosphorus concentrations in the zone contaminated by the outflows with means 0.5 – 13x and maximums 0.3 – 38x background levels (see p155). The author concludes that septic tank phosphorus could be reaching the lake in 3 out of 5 cases, but in only in one case were mean contaminated zone phosphorus concentrations >20 µgP/l.

Conclusions

It thus appears clear that phosphorus contamination from septic tanks is limited, because much of the phosphorus is retained in the septic tanks, and because that released in the outflow is then retained in soil, often in the soil immediately around the discharge infiltration, thus resulting in only a very low proportion (<1%) of phosphorus in septic tank inflow being susceptible to reach surface waters. There may however be concern where septic tanks are situated close to (< 10m) surface waters or water courses in areas of calcareous sandy soil.

"Research needs in decentralized wastewater treatment and management: a risk-based approach to nutrient contamination"
http://www.ndwrcdp.org/userfiles/RESEARCH_NEEDS_PROCEEDINGS_CD.PDF

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See also:

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