

## Estimation of the Contribution of Phosphorus From On-site Sewage Disposal Systems to Lakes

### INTRODUCTION

Phosphorus is considered, in most situations, to be the nutrient most responsible for eutrophication of freshwater lakes—the process by which a lake becomes so nutrient-rich that it supports a dense plant population, which deprives the lake of oxygen.

The greatest single source of phosphorus may be on-site sewage disposal systems. Planning for control of eutrophication involves applying models that identify and quantify sources of phosphorus that originate in a watershed.

There are different methods available to estimate the phosphorus contribution from on-site sewage disposal systems to lakes.

Some methods assume that all available on-site phosphorus from the total watershed reaches the lake. Others methods assume that only a fraction of the phosphorus from the watershed reaches the lake. Yet others assume only phosphorus from within an assumed distance from the lake or its tributaries reaches the lake. Most approaches do not account directly for factors such as soil type, groundwater depth or chemical processes in the soil.

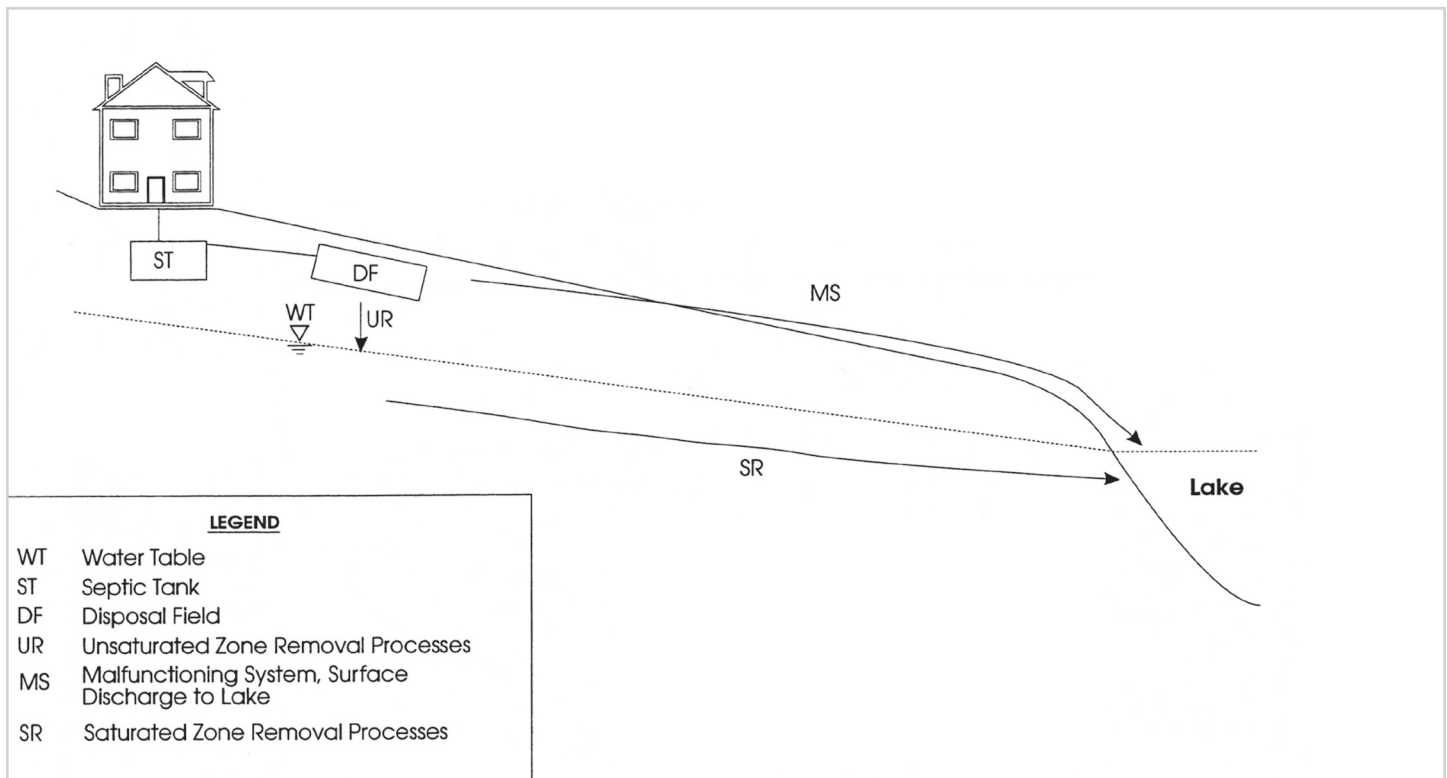
The objective of this research was to develop a modelling methodology that could more accurately estimate annual phosphorus loads to lakes from on-site sewage disposal systems.

### RESEARCH PROGRAM

The research began with a thorough literature review of different approaches that have been used to estimate phosphorus loads to lakes. These reviews led to the identification of two computer models that offered the capability of representing the factors and processes involved in phosphorus removal. Exploration of the use of these models began with sensitivity analyses based on a range of typical soil parameters. Field and laboratory studies undertaken for a separate research project provided data for calibration and verification of the computer models.

### RESULTS

The amount of phosphorus discharged from an on-site sewage disposal system depends on the phosphorus loading from the source (usually single-family dwellings), less any phosphorus removed in the septic tank and disposal field before the effluent enters the soil below the field. The literature review revealed that many different assumptions are used by different researchers to estimate potential phosphorus loads. Generally, however, removal of phosphorus by a septic tank and disposal field is considered to be insignificant.



**Figure 1** Potential pathways of phosphorous migration to lakes

Figure 1 shows the basic route for phosphorus movement from an on-site system to a lake and the opportunities for phosphorus removal. Phosphorus can be removed in the unsaturated zone below a disposal field or during passage of groundwater from the field to a lake. An alternative route for phosphorus is from a malfunctioning septic system—one that permits effluent to escape to the ground surface, a ditch or a stream, where it may flow or be carried by storm water to the lake. This research did not deal with phosphorus movement from a faulty system.

Researchers have different theories about how phosphorus attenuation in soil occurs. There is general agreement, however, that phosphorus can be removed from solutions flowing through the subsurface in two ways:

1. Adsorption, in which some of the phosphorus is quickly adsorbed onto the surface of soil particles at rates that are typically measured in hours.
2. Precipitation, in which minerals such as calcium, iron and aluminum react with the phosphorous solution to form highly insoluble phosphorus, at rates measured in weeks and months.

Some approaches assume that adsorption and precipitation occur in series while other approaches are based on simultaneous reactions.

Other methods of phosphate removal include uptake by plants and biological immobilization; however, in the case of on-site disposal systems, these two processes are believed to be insignificant because the disposal field lies underneath the biologically active upper soil region.

Much of the existing research dealing with phosphorus attenuation relates to agricultural settings and, as a result, the data and conclusions are typically for the unsaturated zone. In all likelihood, the processes responsible for phosphorus attenuation above the water table are also major processes which retain it in the saturated zone.

Many different factors affect phosphorus attenuation, including:

- Degree of oxidation of the effluent reaching the soil.
- Oxygen levels in the subsurface.
- Texture and composition of the soil beneath the disposal bed (including pH, particle size distribution and soil mineralogy).
- Depth of unsaturated soil.
- Texture and composition of the soil below the water table.
- Travel distance in the saturated zone.
- Concentration of dwellings.

- Repeated wetting and drying of the soil.
- Temperature of the soil.

The capacity of a soil to adsorb phosphorus can be described using experimentally derived isotherms, which are graphical plots of the concentration of phosphorus in solution against its adsorbed concentration for a given soil at a given pressure and temperature. Using the isotherm approach to estimating phosphorus adsorption assumes equilibrium conditions exist between the adsorbed phosphorus and the phosphorus in solution.

Precipitation reactions, on the other hand, proceed very slowly and do not reach equilibrium. Therefore, to describe precipitation reactions, a method that considers reaction kinetics must be used. Most attempts to model phosphorus movement in the subsurface are based on an equation that includes a term for attenuation due to dispersion (adsorption and precipitation) and a term for losses due to physical movement via flowing water. This velocity flow is generally considered to be the major mechanism that transports solute in the subsurface.

Many of the mathematical relationships that researchers use to represent the complex processes of phosphorus movement and removal are incorporated into computer simulation models. The movement and attenuation of phosphorus in the unsaturated zone must be modelled separately from the saturated zones due to the differences between the processes in each zone.

After reviewing several simulation models, CHEMFLO was chosen to model phosphorus removal in the unsaturated zone and MT3D to model phosphorus removal in the saturated zone. MT3D is a module designed to be used with MODFLOW, the flow model supported by the United States Environmental Protection Agency (EPA).

Sensitivity analyses were undertaken to explore the response of these models to a range of hypothetical soils, representing soils in which septic systems might be installed. The modelling supported the conclusion often reached in literature, that although the movement of phosphorus is very restricted in the unsaturated zone, there is potential for its migration to the saturated zone under appropriate conditions.

This result also reinforced the point that phosphorus removal problems are typically site-specific. The modelling revealed that precipitation is by far the more important of the two processes involved in phosphorus attenuation. Fairly modest changes in the value of the term used to describe precipitation resulted in drastic changes in the distance of phosphorus migration.

Experimental and field results of phosphorus attenuation from another ongoing applied research program were examined. Four sites were selected for review: two private homes, a provincial recreational facility and a school.

The field observations showed phosphorus attenuation in the unsaturated zone is much more effective than in the saturated zone. Samples collected during different water table elevations at one site indicated that phosphorus reduction increases exponentially with the thickness of the unsaturated zone. The results also showed that soils with low hydraulic conductivities are better suited to phosphorus removal.

A comparison of the effluent from the private homes and the recreational facility showed a marked difference. At the recreation centre, phosphorus concentrations were about one-tenth those seen at the private homes, while chloride levels were double. This suggests that most phosphorus is derived from sources such as dishwashing and that chloride is derived from the use of chemicals used to clean and disinfect washrooms.

While the field observations showed that phosphorus levels were reduced to very low levels within tens of metres of the disposal beds, the resulting concentrations were still significantly elevated over natural groundwater levels and may represent a threat to surface water supplies.

The field data was compared to the simulated results to validate the models. The field data from one of the sites was used to calibrate the computer models and the calibrated model was then applied to the other sites. It was found that CHEMFLO and MT3D could adequately represent the factors and processes that control phosphorus removal in the soil at the scale of a single property. The models could also identify and quantify controlling variables.

The research also found that most of the reported studies of phosphorus loadings have used results of phosphorus analyses based on a detection limit of 0.02 mg/L. Results of this and other studies undertaken by the Centre for Water Resources Studies, which are based on a detection limit of 0.001 mg/L, indicate that phosphorus loads may be underestimated if loads contributed by concentrations lower than 0.02 mg/L are ignored. The stannous chloride method for phosphorus analysis provided a detection limit of 0.001 mg/L and to eliminate some inconsistencies in groundwater analysis results when compared with the ascorbic acid method. This result has implications for other research conducted in this field, suggesting that future research work should be based on a detection limit of 0.001 mg/L and that the stannous chloride method should be used.

## Research Highlight

### Estimation of the Contribution of Phosphorus From On-site Sewage Disposal Systems to Lakes

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