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Project Summary

Evaluation of Septic Tank System Effects on Ground Water Quality

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This study summarizes literature concerning the types and mechanisms of ground-water pollution from septic tank systems and provides information on methodologies for evaluating the ground-water pollution potential. The conclusions are: (1) septic tank systems represent a significant source of ground water pollution in the United States, since many systems are exceeding their design life, the use of synthetic organic chemicals in the household is increasing, and larger-scale systems are being designed and used; (2) a key issue is related to understanding the transport and fate of system effluents in the subsurface environment; (3) no specific methodology exists for evaluating the ground-water effects of septic tank systems; however, two empirical methodologies (surface impoundment assessment (SIA) and waste-soil-site interaction matrix), adjusted for annual wastewater flow and analytical method (Hantush) for determining water table rise, and a solute-transport model (Konikow and Bredehoeft) for ground-water flow and pollutant concentrations have been applied with some success; (4) the empirical assessment methodology (adjusted SIA method) could be used in permitting or evaluating systems serving individual homes and subdivisions, as well as large-scale systems; the analytical model could be used for subdivisions and large-scale systems; and the solute-transport model could be used for large-scale systems; and (5) a specific empirical assessment methodology should be developed for septic tank system areas, with the methodology using some factors from both the SIA method and the interaction matrix, and additional factors such as wastewater flow, percolation rate, septic tank density, and average life of septic tank systems.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Septic tanks were introduced in the United States in 1884, and since then septic tank systems have become the most widely used method of on-site sewage disposal, with over 70 million people depending on them. Approximately 17 million housing units, or 1/3 of all housing units, dispose of domestic wastewater through these systems, and about 25% of all new homes being constructed are including them. The greatest densities of usage occur in the East, the Southeast, the northern tier, and the northwestern portions of the United States. A septic tank system includes both the septic tank and the subsurface soil absorption system. Approximately 800 billion gallons of wastewater is discharged annually to the soil via tile fields following the 17 million septic tanks.

Septic tank systems that have been properly designed, constructed, and maintained are efficient and economical alternatives to public sewage disposal systems. However, due to poor locations for many septic tank systems, as well as poor design, construction, and maintenance practices, septic tank systems have polluted or have the potential to pollute underlying ground waters. A major concern in many locations is that the density of the septic tanks is greater than the natural ability of the subsurface environment to receive and purify system effluents before they move into ground water and that the design life of many septic tank systems is in the order of 10 to 15 years. Due to the rapid rate of placement of septic tank systems in the 1960's, the usable life of many of the systems is being exceeded, and ground-water contamination is beginning to occur. Septic tank systems are frequently reported sources of localized ground-water pollution. Historic beginning to occur.

Septic tank systems are frequently reported sources of localized ground-water pollution. Historic concerns have focused on bacterial and nitrate pollution; more recently, synthetic organic chemicals from septic tank cleaners have been identified in ground water. Regional ground-water problems have also been recognized in areas of high septic tank system density. Within the United States there are four counties with more than 100,000 housing units served by septic tank systems and cesspools and an additional 23 counties with more than 50,000 housing units served by these systems. Densities range from as low as 2 to greater than 346 per square mile based on the assumption of an even distribution of the septic tank systems and cesspools throughout the county. If they are localized in segments of the county, the actual densities could be several times greater. An often-cited figure is that areas with more than 40 systems per square mile can be considered to have potential contamination problems.

Several types of institutional arrangements have been developed for regulating septic tank system design and installation, operation and maintenance, and failure detection and correction. Most of the regulatory activities are conducted by state and local governments. The U.S. Environmental Protection Agency (EPA) can become a participant in the regulatory process based on the provision of funding for septic tank systems. Sections 201(h) and (j) of the Clean Water Act of 1977 (P.L. 95-217) authorized construction grants funding of privately-owned treatment works serving individual housing units or groups of housing units (or small commercial establishments), provided that a public entity (which will ensure proper operation and maintenance) apply on behalf of a number of such individual systems. One of the major facets of a funding decision is the ground-water pollution potential of the proposed system or systems. This issue becomes even more important for larger systems serving several hundred housing units. To serve as an illustration of possible system size, EPA has funded a system located in the northeastern United States with a design flow of 100,000 gallons per day.

Because EPA needs to evaluate the ground-water pollution potential of septic tank systems being considered for grant funding and because engineering designers and state and local regulatory officials need similar relevant information, this study was designed to summarize existing literature about the types and mechanisms of ground-water pollution from septic tank systems and to provide information on methodologies for evaluating the ground-water pollution potential of septic tank systems. The scope of work included a survey of published literature on the identification and evaluation of ground-water pollution from septic tank systems and selection and evaluation of two empirical assessment methodologies, one numerical model, and one analytical model for their applicability to septic tank systems. The methodologies and models were selected based on their previous or potential use for septic tank systems; the availability of required input data; resource requirements in terms of general personnel and technical specialists, computational equipment, and time or ease of implementation; understandability by non-technical persons; and previous documentation for prediction of pollutant transport.

The basic septic tank system consists of a buried tank, where waterborne wastes are collected and scum, grease, and settleable solids are removed from the liquid by gravity separation and a subsurface drain system, where clarified effluent percolates into the soil. System performance is essentially a function of the design of the system components, construction techniques employed, characteristics of the wastes, rate of hydraulic loading, climate, areal geology and topography, physical and chemical composition of the soil mantle, and care given to periodic maintenance.

Septic tank design considerations include determination of the appropriate volume, a choice between single and double compartments, selection of the construction material, and placement on the site. Placement of the septic tank on the site basically involves consideration of the site slope and minimum setback distances from various natural features or existing structures. Soil absorption is accomplished using trenches or beds, seepage pits, mounds, fills and artificially drained systems. Trench and bed systems are the most commonly used methods for on-site wastewater treatment and disposal. Site criteria that must be met for septic tank system approval include a specified percolation rate, as determined by a percolation test, and a minimum 4 ft (1.2 m) separation between the bottom of the seepage system and the maximum seasonal elevation of ground water. In addition, there must be a reasonable thickness, again normally 4 ft, of relatively permeable soil between the seepage system and the top of a clay layer or impervious rock formation.

One of the key concerns associated with the design and usage of septic tank systems is the potential for inadvertently polluting ground water. This concern is increased for systems serving multiple housing units. Potential ground-water pollutants from septic tank systems are primarily those associated with domestic wastewater, unless the systems receive industrial wastes. Contaminants originating from system cleaning can also contribute to the ground-water pollution potential of septic tank systems. The typical wastewater flow from a household unit is about 150 to 170 liters/day/person. Typical sources of household wastewater, expressed on a percentage basis, are: toilet(s) -- 22 to 45%; laundry --4 to 26%; bath(s) -- 18 to 37%; kitchen --6 to 13%; and other --0 to 14%. Ground-water pollution is affected by the quality of the effluent from the septic tank portion of the system and the efficiency of constituent removal in the soil underlying the soil absorption system. Based on a number of studies, the following represent typical physical and chemical parameter effluent concentrations from septic tanks: suspended solids -- 75 mg/l; BOD_5 -- 140 mg/l; COD -- 300 mg/l; total nitrogen -- 40 mg/l; and total phosphorus -- 15 mg/l. Studies of the efficiency of soil absorption systems have indicated the following typical concentrations entering ground water:

suspended solids -- 18 to 53 mg/l; BOD -- 28-84 mg/l; COD -- 57-142 mg/l; ammonia nitrogen -- 10-78 mg/l; and total phosphates -- 6-9 mg/l. In addition, other wastewater constituents of concern include bacteria, viruses, nitrates, synthetic organic contaminants such as trichloroethylene, metals (lead, tin, zinc, copper, iron, cadmium, and arsenic), and inorganic contaminants (sodium, chlorides, potassium, calcium, magnesium, and sulfates).

Ground-water degradation, which occurs in many areas having high densities of septic tank systems, is characterized by high concentrations of nitrates and bacteria in addition to potentially significant amounts of organic contaminants. One common reason for degradation is that the capacity of the soil to absorb effluent from the tank has been exceeded, and the waste added to the system moves to the soil surface above the lateral lines. In addition, many soils with high hydraulic absorptive capacity (permeability) can be rapidly overloaded with organic and inorganic chemicals and microorganisms, thus permitting rapid movement of contaminants from the lateral field to the ground-water zone. In considering ground-water contamination from septic tank systems, attention must be directed to the transport and fate of pollutants from the soil absorption system through underlying soils and into ground water. Physical, chemical, and biological removal mechanisms may occur in both the soil and ground-water systems. The transport and fate of biological (bacterial and viral pathogens), inorganic (phosphorus, nitrogen and metals), and organic contaminants (synthetic organics and pesticides) must be considered.

Biological contaminants exhibit a variety of characteristics, including wide ranges in size, shape, surface properties, and die-away rates. The travel distance of bacteria through soil is of considerable significance, since contamination of ground supplies may present a health hazard. Many environmental factors can influence the transport rate, including rainfall, soil moisture, temperature, pH, and the availability of organic matter. The survival of enteric bacteria in soil is affected by soil moisture content and holding capacity, temperature, pH, sunlight, organic matter, and antagonism from soil microflora. The physical process of straining (chance contact) and the chemical process of adsorption (bonding and chemical interaction) appear to be the most significant mechanisms in bacterial removal from water percolating through soil. The removal efficiency of viruses by soil is influenced by flow rate, cation concentrations, clays, soluble organics concentrations, pH, isoelectric point of the viruses, and general chemical composition of the soil. The most important mechanism of virus removal in soil is by adsorption of viruses onto soil particles.

Although phosphorus can move through soils underlying soil absorption systems and reach ground water, this has not been a major concern, since phosphorus can be easily retained in the underlying soils due to chemical changes and adsorption. Phosphate ions become chemisorbed on the surfaces of Fe and Al minerals in strongly acid to neutral systems and on Ca minerals in neutral to alkaline systems. In the pH range encountered in septic tank seepage fields, hydroxyapatite is the stable calcium phosphate precipitate. However, at relatively high phosphorus concentrations similar to those found in septic tank effluents, dicalcium phosphate or octacalcium phosphate are formed initially, and this is followed by a slow conversion to hydroxyapatite. Ammonium ions can be discharged into the subsurface environment or they can be generated within the upper layers of soil from the ammonification process (conversion of organic nitrogen to ammonia nitrogen). The transport and fate of ammonium ions may involve adsorption, cation exchange, incorporation into microbial biomass, or release to the atmosphere in the gaseous form. Adsorption is probably the major mechanism of removal in the subsurface environment. Nitrate ions can also be discharged directly or generated within the upper layers of soil. The transport and fate of nitrate ions may involve movement with the water phase, uptake in plants or crops, or denitrification. Nitrates can move with ground water with minimal transformation.

Metals may react with soils by means of adsorption, ion exchange, chemical precipitation, and complexation with organic substances. Of these four reactions, adsorption appears to be the most important for the fixation of heavy metals. Ion exchange is thought to provide only a temporary or transitory mechanism for the retention of trace and heavy metals. Precipitation reactions are greatly influenced by pH and concentration, with precipitation predominately occurring at neutral to high pH values and in macroconcentrations. Organic materials in soils may immobilize metals through complexation reactions or cation exchange. Fixation of heavy metals by soils by either of these four mechanisms is dependent on a number of factors including soil composition, soil texture, pH and the oxidation-reduction potential of the soil and associated ions.

The transport and fate of organic contaminants in the subsurface environment is a relatively new area of concern; thus, the published literature is sparse. A variety of possibilities exist for the movement of organics, including transport with the water phase, volatilization and loss from the soil system, retention on the soil due to adsorption, incorporation into microbial or plant biomass, and bacterial degradation. The relative importance of these possibilities in a given situation is dependent upon the characteristics of the organic, the soil types and characteristics, and the subsurface environmental conditions. This complicated topic is being actively researched at this time. Several studies have been conducted on the movement and biodegradation of large concentrations of pesticides in soils.

Technical methodologies for evaluating the ground-water pollution potential of septic tank systems range from empirical index approaches to sophisticated mathematical models. Models can range from analytical approaches addressing ground-water flow to numerical approaches which aggregate both flow and solute transport considerations. Septic tank systems can be considered area sources of ground-water pollution, with the rectangular dimensions of the drainage field representing the source boundaries. Waste stabilization ponds (surface impoundments), and sanitary and chemical landfills also can be considered potential area sources of ground-water pollution. Empirical assessment methodologies refer to simple approaches for developing numerical indices of the ground-water pollution potential of human activities. Several methodologies have been developed for evaluating the ground-water pollution potential of wastewater ponds and sanitary and chemical landfills. Methodologies typically contain several factors for evaluation, with the number, type, and importance weighting varying from methodology to methodology.

Ground-water models can be classified as flow models and solute transport models. Analytical models and numerical models are of interest here. Analytical models include those in which the behavior of an aquifer is described by differential equations derived from basic principles such as the laws of continuity and conservation of energy. Numerical models are actually analytical models that are large enough to require the use of digital computers, capable of multiple iterations, to converge on a solution. The applicability of ground-water models has been the subject of a number of studies. Prediction of the movement of contaminants in ground-water systems through the use of models has been given increased emphasis in recent years because of the growing trend toward subsurface disposal of wastes.

Ground-water modeling can be useful for evaluating specific sites for systems or even larger geographical areas that may be served by hundreds of systems. Modeling could be used to include septic tank system location on specific sites or in larger geographical areas. In addition, modeling can be useful in planning ground-water monitoring programs for specific sites or geographical areas. Available technical methodologies for addressing the ground-water effects of septic tank systems, which range from empirical assessment approaches to ground-water flow and solute transport models, differ in their input requirements, output characteristics, and general useability. Accordingly, certain criteria were identified as basic to the selection of technical methodologies used in this study. The criteria were as follows:

1. The methodologies should have been used previously for evaluating septic tank systems.
2. They should be adaptable for use in evaluations of septic tank systems.
3. If they need to be calibrated before use, the necessary data for calibration should be readily available.
4. The input data required for the methodology should be readily available; thus its use could be easily implemented.
5. The resource requirements for use of the methodology should be minimal (resource requirements refer to personnel needs and qualifications, computer needs, and the time necessary for calibration and usage).
6. Usage of the methodology for predicting pollutant transport in the subsurface environment should have been previously documented.
7. The conceptual framework of the methodology as well as its output should be understandable by non-specialists.

Although no single methodology that met all seven criteria was identified, two empirical assessment methodologies (Surface Impoundment Assessment (SIA) and Waste-Soil-Site Interaction Matrix), one analytical model (Hantush), and one solute-transport model (Konikow and Bredehoeft) were chosen for examination. The two empirical methodologies were used to determine the ground-water pollution potential of 13 septic tank system areas in central Oklahoma. The rank order of the ground-water pollution potential of the 13 areas was determined through the use of the two methodologies, which were adjusted by considering the annual wastewater flows in the areas. The two adjusted methodologies provided similar rank orderings of the 13 septic tank system areas. Key findings from this part of the study were as follows:

(1) The final ranking of the 13 septic tank system areas was largely dependent upon the annual wastewater flow in the area, and this is directly related to the number of persons and septic tank systems in the area.

(2) Both the surface impoundment assessment method and the waste-soil-site interaction matrix can be used to develop a priority ranking of existing or planned septic tank system areas. Since the SIA method has 6 items of needed information versus 17 items in the interaction matrix, the SIA method is easier to use. However, neither methodology accounts for wastewater flow, and this is an important consideration in the use of either method for septic tank system areas.

The Hantush analytical model was developed to determine the rise and fall of the water table under circular, rectangular, or square recharge areas, but it does not address ground water quality. This model was applied to a mound-type septic tank system analogous to those used in Wisconsin, and it was determined that the rise of the water table only approaches a maximum of 8 inches; however, this could be a significant rise in view of the fact that mound systems are used in areas of high water tables. Actual loadings from septic tank systems will be intermittent and this will decrease the actual rise of the water table, but increases in loading rates (either by malfunctioning or overloaded systems) could increase the water table rise.

The Konikow-Bredehoeft (K-B) numerical model was applied to a septic tank system study area near Edmond, Oklahoma, to determine its usefulness in predicting nitrate concentrations in ground water from this source type. The K-B model is a two-dimensional solute transport model that has been used in the analysis of ground-water pollution from a variety of source types. The objective of this portion of the overall study was to determine the feasibility of modeling the effects of septic tank systems on ground-water quality by direct application of the K-B solute transport model computer package to an existing situation. The results of the Edmond study area analysis by the K-B model must be classified as disappointing and frustrating. Disappointment stems from the fact that the model was unable to be calibrated, even for ground-water flow (water levels). Frustration stems from the fact that the difficulties encountered with the model were due solely to the lack or questionable validity of input data. The only conclusion to be drawn about applying sophisticated ground-water models to the problem of septic tank systems is that the utility of the models may be outweighed by their significant data requirements. This suggests that special field studies will be necessary in order to gather the input data necessary for use of solute-transport models for evaluation of septic tank systems or system areas.

Based on the results of this study, an hierarchical structure for usage of the three types of technical methodologies has been developed. Potential usage can be considered for three types of septic tank systems: (1) a septic tank systems serving an individual home; (2) several hundred individual septic tank systems being used in a subdivision; and (3) a large-scale septic tank system serving several hundred homes, with the daily wastewater flow being upwards of 100,000 gallons. The empirical assessment methodology (adjusted SIA method) could be used as part of the permitting procedure for all three types; however, its greatest usage should probably be for the first two types. The analytical model could be used for subdivisions and large-scale systems, with the greatest usage probably associated with the former. Finally, the solute-transport model should be used for large-scale systems, since their potential for ground-water pollution could justify conducting the necessary field studies to gather appropriate input data.

Conclusions

Conclusions about the effects of septic tank systems on ground-water quality are as follows:

1. Septic tank systems represent a significant source of ground-water pollution in the United States. The significance of this source type is expected to increase since:
   - many existing systems are becoming older and exceeding their design life by several-fold;
   - the use of synthetic organic chemicals in the household and for system cleaning is increasing; and
   - larger-scale systems are being designed and used, with flows up to 100,000 gallons/day.
2. A key issue associated with septic tank systems is related to understanding the transport and fate of system effluents in the subsurface environment. There is a considerable body of knowledge relative to the transport and fate of biological and inorganic contaminants in the subsurface environment. However, much research is needed relative to the subsurface movement and disposition of many synthetic organic chemicals of current concern. For example, research is needed to:
   - Develop a classification scheme for synthetic organic chemicals in terms of their transport and fate in the subsurface environment
   - Determine the influence of aerobic and anaerobic conditions on transport and fate processes
   - Develop information on intermediate products and by-products of degradation processes which may be of greater concern to ground-water pollution than the original synthetic organic chemicals.
3. No specific technical methodology exists for evaluating the ground-water effects of septic tank systems based on the seven desirable criteria enumerated previously.
4. Application of two empirical assessment methodologies adjusted for annual wastewater flow, an analytical method for determining water table rise, and a solute-transport model for ground-water flow and pollutant concentrations has met with some success. Use of these approaches should be keyed to the following three types of septic tank systems: (1) a septic tank system serving an individual home; (2) several hundred individual septic tank systems being used in a subdivision; and (3) a large-scale septic tank system serving several hundred homes, with the daily wastewater flow being upwards of 100,000 gallons. The empirical assessment methodology (adjusted SIA method) could be used as part of the permitting or evaluation procedure for all three types; the analytical model could be used for subdivisions and large-scale systems, and the solute-transport model could be used for large-scale systems.
5. A usable type of methodology for septic tank system evaluation is the empirical assessment methodology directed toward developing an index of ground-water pollution potential. A specific methodology should be developed for septic tank sytems areas. The methodology could use some factors from both the SIA method and the interaction matrix and should include some additional factors such as wastewater flow, percolation rate, septic tank density, and average life of septic tank systems.

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The complete report, entitled "Evaluation of Septic Tank System Effects on Ground Water Quality," (Order No. PB 84-244 441; Cost: $29.50, subject to change) will be available only from:
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