USGS

WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Improved Sampling Methods for Soil Water and Groundwater

Focus Categories: GW, WQL, MET, NPP

Descriptors: Water quality monitoring, Groundwater quality, Vadose zone, Solute transport, Field methods

Duration: March 1, 2000 - Feb. 28, 2001

FY 2000 Federal Funds: $13,000

FY 2000 Non-Federal Funds: $40,414

Principal Investigators:

Tammo S. Steenhuis, Professor
Department of Agricultural and Biological Engineering

Ellen Z. Harrison, Director,
Cornell Waste Management Institute
Cornell University

Cooperators: Brian Richards, Arik Heilig; Cornell University; Phillip Dickson; Dickson Farm

Congressional district: NY 26

Critical Water Problem

One of the critical shortcomings in the evaluation of land management practices (such as BMP's, land application of wastes, septic tanks, etc) is the lack of effective methods to evaluate impacts on groundwater quality. Groundwater sampling is also required in a number of cases (such after the detection of a spill) by NYS DEC as well as other states, but the results are difficult to interpret. For example, in some cases groundwater concentrations initially below the legal limit increased after the water table height increased in the spring as residual pollutants left in the vadose zone were mobilized by the rising groundwater. Many pollutants (trace metals, pesticides, organics) are mobilized as colloidal complexes which may be excluded from sampling devices by filtration. Research to date demonstrates that sampling methods can have a significant impact on monitoring results, especially for soils that have significant preferential flow.

Expected Benefits

We propose examine different soil and water sampling techniques for their capability to capture the transport of water and contaminants in the soil. The primary research will be carried out on a farm site where manure, fertilizer and wastewater sludge has been land applied. We are currently monitoring trace metal, nitrate and phosphorus concentrations in the soil and in soil water on fields receiving manure, sludge, fertilizers and on a forested control plot with no human activities. Soil water is collected using with passive wick lysimeters. In this proposal we will install additional water sampling devices consisting of pan samplers, porous cup samplers and shallow and deep wells in several fields and compare the metal, phosphorus and nitrogen concentrations. (Research to date suggests that several monitoring devices might give a better overall representation of the extent of the contamination than an increased number of replicates of a single sampling device.) Results from these different sampling methods will be compared, and will be compared with soil analyses and with concentrations observed in creeks and tile drains that originate on the farm. The research will lead to a better understanding in the difference in concentrations given by different sampling devices, and may lead to an early warning system for groundwater pollution. The sampling strategy will be developed in cooperation with DEC, NRCS and USGS personnel. The applicability of findings to required monitoring of best management practices and other purposes will be discussed with state and federal agency personnel.

Nature, Scope, and Objectives

We propose to examine different soil water and groundwater sampling techniques to characterize their capability to capture the transport of water and contaminants in soil. We will examine what combination of sampling devices might give the optimal sampling strategy at several cost levels. It is expected that several monitoring devices might give a better overall representation of the extent of the contamination than multiple replicates of same sampling device.

The study will be carried out on a working farm where manure, fertilizer and wastewater sludge has been land applied. We are currently monitoring trace metal, nitrate and phosphorus concentrations in the soil and in soil water on fields receiving manure, sludge, fertilizers and on a forested control plot with no human activities. Soil water is collected using with passive wick lysimeters. In this proposal we will install additional water sampling devices consisting of pan samplers, porous cup samplers and shallow and deep wells in several fields. By adding a known amount of a conservative bromide tracer, we can obtain the temporal and spatial sampling distribution for each sampler. By measuring or estimating the recharge of water we can do a mass balance for the bromide. This will enable to make statements concerning the effectiveness of each sampler. At the same time we will measure the metal, phosphorus and nitrogen concentrations from the different fields. Results from these different sampling methods will be compared. Making use of data being collected as part of a project comparing the impacts of these different soil amendments, we will also compare the water quality results with soil analyses. In addition we will measure the concentration of contaminants in water in creeks and tile drains that originate on the farm. The research will lead to a better understanding in the difference in concentrations given by different sampling devices and may lead to an early warning system for groundwater pollution.

Methods, Procedures, and Facilities

The study site will be the Dickson Farm (near Bath NY) where manure and wastewater sludge has been land applied on designated fields since 1978. Currently we are monitoring on the Dickson farm heavy metal, nitrate and phosphorus concentrations both in the soil (direct soil analysis) and in soil water with passive wick lysimeters. Sampled fields represent treatments of manure, sludge, fertilizers and from a wooded control plot with no human activities. We propose to install a number of additional water sampling devices and apply a conservative tracer (bromide or chloride, depending on the back ground levels) to examine the efficiency of the various sampling devices

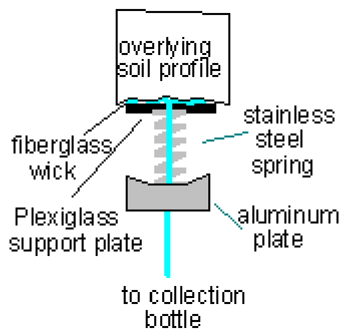

Figure 1. Detail of single wick sampler cell in contact with soil profile.

The experimental procedures are as follows: Gravity pan samplers, ceramic suction cup samplers, piezometers, and vertical wells will be installed on the manured, sludge and fertilizer field sites that have two wick samplers and a tile line already in place. The wick pan samplers were installed 1 m apart, 0.6 m below the soil surface in 0.7 m long, horizontal tunnels excavated in the side of a trench. The pan consists of a 5 by 5 grid of individually sampled compartments and was pressed upwards against the intact native soil with springs (Steenhuis et al., 1995a). The gravity pan samplers will be installed similarly. The difference between the wick and gravity pan samplers is the way water is collected. In the 32 by 32-cm gravity pan, the 2.5-cm high sampling compartments were filled with pea gravel so that water dripped into the bottles from saturated soil. The undisturbed soil above each cell of the wick pan was sampled under continuous suction applied by a 0.4 m long, 9.5 mm diameter fiberglass wick. The upper end of the wick was spread over an acrylic plate and each plate was seated on a compression spring (6.5 cm tall, 2.4 cm diameter) assuring good contact with the soil. Each wick was encased in 1.3-cm i.d. tygon tubing and was suspended above a collection bottle to prevent upward movement in the wick (Boll et al., 1991). A schematic drawing of one cell in the wick pan sampler is given in Figure 1.

Porous cup samplers consist of a ceramic cup having an outside diameter of 4.8 cm, cemented to a 70 to 100 cm long PVC pipe plugged with a stopper. Plastic tubing is installed in holes in the stopper: a short length with which to apply vacuum to the sampler, and a longer section reaching to the bottom of the cup for sample retrieval. Each sampler will be installed through vertical auger holes backfilled with a slurry of the original soil mixed with a small amount of bentonite. All holes will be sealed with a 250 mm layer of bentonite to prevent leakage from the surface. In each field six porous cup samplers will be installed at a depth of 60 cm and six at a depth of 90 cm.

The 10-cm tile lines (horizontal wells) will be installed at a depth of 90 cm surrounded by gravel. Samples can be collected at the tile line outlet. A large tank will be installed at the outlet so that integrated samples can be taken at a similar time scale as the other samples. Four horizontal wells will be installed in each of the fields to a depth of bed rock (less than 4 meter). Four piezometers will installed to a depth of 1 meter. To keep costs down, a Guiness probe from the Department of Crop & Soil Sciences will be used for the wells. Backfilling will be same as for the porous cup samplers.

All samplers will be installed in area of 10 x 15 m. A non-reactive tracer (bromide or chloride) at low concentration will be applied evenly during the early summer and later in the fall. The summer application will be followed by 4 cm irrigation daily for three weeks. (This should be sufficient to leach the tracer from the soil profile.) No irrigation water will be applied after the fall application. Nitrate, phosphorus, and metals will be measured in selected samples (at least 25% of the total). Soil samples to a depth of 1 meter will be taken at 3 days and 10 days following tracer application.

Making use of data currently being collected for another project, we will compare the water quality results with soil analyses. In addition we will measure the concentration of contaminants in water in creeks that originate on the farm. During low precipitation periods, the creek flow reflects contributions from shallow groundwater. The sampling strategy will be developed in cooperation with DEC, NRCS and USGS. Results will be shared with state agency personnel and the applicability of findings to regulatory required monitoring of best management practices and other purposes will be discussed.

The laboratory of Dr. Steenhuis in the Department of Agricultural and Biological Engineering will be available to support the field work and analytical needs of the project. An array of standard laboratory equipment is available, including a total organic carbon analyzer, ion chromatograph, spectrophotometer, chloridometer and pH/EC meter. ICP analysis will be carried out at the Cornell Nutrient Analysis Laboratory in the Department of Fruit and Vegetable Sciences on a Thermo Jarrell Ash IRIS Advantage system with duo-view capability.

Related work

It has been shown (Steenhuis et al. 1995a; Boll et al. 1997; Maeda et al. 1999) that sampling methods can have a significant impact on monitoring results. This is especially true for soils that have significant preferential flow such as occur throughout NY state. In these soils, there is usually only a perched water table during the summer, and concentrations in wells during this time vary greatly (i.e. by two orders of magnitude).

Interest in the chemical concentration in the vadose zone date as far back as the beginning of this century (e.g., Briggs and McCall, 1904). Destructive soil coring is the oldest and probably most widely used method for determining solute concentration (Everett et al., 1984). Non-destructive methods are porous cups, pan samplers, and agricultural tile lines. Porous cup samplers (Wood, 1973; Litaor, 1988) are cheap, easy to install and widely used. The disadvantage is that, in fine sandy soils, samplers (>0.5 cm diameter) may either attract the streamlines or being bypassed by the flow (Litaor, 1988; Cochran et al. 1970; van der Ploeg and Beese, 1977; Talsma et al.,1979; Steenhuis et al. 1995a) and may either over- or under-predict leaching. In coarse soils it is often difficult to obtain sufficient volume for analysis. In structured soils, the preferentially moving solutes may bypass the suction cup resulting in underestimation of the amount of solutes arriving at the groundwater (Shaffer et al., 1979; Biggar and Nielsen, 1976). Wenzel et al. (1997) found that porous ceramic cups adsorb trace metal contaminants, leading to underreporting of soil water concentrations.

Gravity pan samplers (Parizek and Lane, 1970; Barbee and Brown, 1986) are time consuming to install, sample from a known area, and give a time integrated flux and concentrations. Gravity pan samplers collect mostly gravitational water (i.e., water flowing through macropores; Holder et al., 1992) and consequently bypassing of the sampler especially in non-structured soil has been widely observed (Radulovich and Sollins, 1987; Jemison and Fox, 1992). Tension based pan samplers overcome some of the bypass flow problems of the by applying a passive suction at the soil pan interface with fiberglass wicks (Holder et al., 1992; Boll et al., 1992; Brandi-Dohrn et al., 1996a,b; Knutson and Selker, 1994; Steenhuis et al. 1995a). They can be used for finding flux distribution s in the soil (Boll et al. 1997). Most chemicals do not adsorb to the fiberglass wicks and travel time though the wicks is usually a small portion of the total travel time through the soil (Holder et al., 1992; Boll et al., 1992; Poletika et al., 1992; Rimmer et al. 1996).

Samples taken from agricultural tile lines represent spatial and temporal integrations of the solute concentrations in the recharge water. Tile lines, however, can only be used in areas where the groundwater is always within 1 to 2 m from the surface (Richard and Steenhuis, 1988; Everts and Kanwar, 1988). Piezometers, which are not limited to shallow groundwater depths, give similar concentration as tile lines but over a smaller area (Koterba et al., 1993; Spalding and Exner, 1993). In structured soils, however, there is a large variability in concentration observed and they do not represent the concentrations in tile outflow or groundwater (Steenhuis et al. 1995b)

REFERENCES

Barbee, G.C. & K.W. Brown. 1986. Comparison between suction and free-drainage soil suction samplers. Soil Sci. 141:149-154.

Biggar, J.W. & D.R. Nielsen. 1976. Spatial variability of the leaching characteristics of a field soil. Water Resour. Res. 12(1):78-84.

Boll, J., T.S. Steenhuis, & J.S. Selker. 1992. Fiberglass wicks for sampling of water and solutes in the vadose zone. Soil Sci. Soc. Am. J. 56:701-707.

Boll, J., J.S. Selker, G. Shalit, & T.S. Steenhuis. 1997. Frequency distribution of water and solute transport properties derived from pan sampler data. Water Resources Research 33(12):2655-2664.

Boll, J., Selker, J.S., Nijssen, B.M., Steenhuis, T.S., Van Winkle, J., & Jolles, E., Water quality sampling under preferential flow conditions, in *Proc. International Symposium on Lysimetry: Lysimeters for Evapotranspiration and Environmental Measurements,* Allen, R.G., Howell, T.A., Pruitt, W.O., Walter, I.A., & Jensen, M.E., Eds., American Society of Civil Engineers, New York City, NY, 290, 1991.

Brandi-Dohrn, F.M., R.P. Dick, M. Hess, & J.S. Selker. 1996a. Field evaluation of passive capillary samplers. Soil Sci. Soc. Am. J. 60:1705-1713.

Brandi-Dohrn, F.M., R.P. Dick, M. Hess, & J.S. Selker. 1996b. Suction cup sampler bias in leaching characterization of an undisturbed field soil. Water Resources Research 32:1173-1182.

Briggs, L.J. & J.R. McCall. 1904. An artificial root for inducing capillary movement of soil moisture. Science 20:566-568.

Cochran, P.H., G.M. Marison, & A.L. Leaf. 1970. Variation in tension lysimeter leachate volumes. Soil Sci. Soc. Am. J. 34:309-311.

Everett, L.G., E.W. Hoylman, L.G. Wilson, & L.G. McMillion. 1984. Constraints and categories of vadose zone monitoring devices. Groundwater Monit. Rev. 4:26-32.

Everts, C.J. & R.S. Kanwar. 1988. Quantifying preferential flow to a tile line with tracers. ASAE Paper No. 88-2635. ASAE, St Joseph, MI. 15 pp.

Holder, M., K.W. Brown, J.C. Thomas, D. Zabcik, & H.E. Murray. 1992. Design and performance of a capillary wick unsaturated zone soil pore water sampler. Soil Sci. Soc. Am. J. 55:1195-1202.

Jemison, J.M. & R.H. Fox. 1992. Estimation of zero-tension pan lysimeter collection efficiency. Soil Sci. 154:85-94.

Knutson, J.H. & J.S. Selker. 1994. Unsaturated hydraulic conductivities of fiberglass wicks in designing capillary wick pore-water samplers. Soil Sci. Soc. Am. J. 58:721-729.

Koterba, M.T., W.S.L. Banks, & R.J. Shedlock. 1993. Pesticides in Shallow Groundwater in the Delmarva Peninsula. J. Env. Qual. 22:500-518.

Litaor, M.I. 1988. Review of soil solution samplers. Water Resour. Res. 24(5):727-733.

Maeda, M., B.C. Liyanage & Y. Ozaki. 1999. Water collection efficiency of wick samplers under steady state flow conditions Soil Sci Plant Nutr 45: (2) 485 -492.

Parizek, R.R. & B.E. Lane. 1970. Soil-water sampling using pan and pressure vacuum lysimeters. J. Hydrol. 11:1-21.

Poletika, N.N., K. Roth, & W.A. Jury. 1992. Interpretation of solute transport data obtained with fiberglass wick soil solution samplers. Soil Sci. Soc. Am. J. 56:1751-1753.

Radulovich, R. & P. Sollins. 1987. Improved performance of zero-tension lysimeters. Soil Sci. Soc. Am. J. 51:1386-1388.

Richard, T.L. & T.S. Steenhuis. 1988. Tile drain sampling of preferential flow on a field scale. In: Rapid and far reaching hydrologic processes in the vadose zone, P.F. Germann (Ed.). J. Cont. Hydrol. 3:307-325.

Rimmer, A., T.S. Steenhuis, J.S. Selker, & G.J. Albrecht. 1995. Wick Samplers: An Evaluation of Solute Travel Times. Soil Science 159(4):235-243.

Shaffer, K.A., D.D. Fritton, & D.E. Baker. 1979. Drainage water sampling in a wet dual pore system. J. Env. Qual. 8:241-246.

Spalding, R.F., & M.E. Exner. 1993. Occurrence of Nitrate in Groundwater - A Review. J. Env. Qual. 22:392-402.

Steenhuis, T.S., J. Boll, E. Jolles, & J. Selker. 1995a. Field Evaluation of Wick and Gravity Pan Samplers. Chapter 34, In: Handbook of Vadose Zone Characterization & Monitoring, L. Everett, S. Cullen, and L. Wilson, Eds. Lewis Publishers, Ann Arbor, MI. pp. 629-638.

Steenhuis, T.S., J.-Y. Parlange, & S.A. Aburime. 1995b. Preferential Flow in Structured and Sandy Soils: Consequences for Modeling and Monitoring. Chapter 5, In: Handbook of Vadose Zone Characterization and Monitoring, L. Everett, S. Cullen, & L. Wilson, Eds. Lewis Publishers, Ann Arbor, MI. pp. 61-77.

Talsma, T., P.M. Hallam, & R.S. Mansell. 1979. Evaluation of porous cup soil-water extractors: Physical factors. Aust. J. Soil. Res. 17:417-422.

van der Ploeg, R.R. & F. Beese. 1977. Model calculations for the extraction of soil water by ceramic cups and plates. Soil Sci. Soc. Am. J. 41:466-470.

Wenzel, W.W., R. S. Sletten, A. Brandstetter, G. Wieshammer, & G. Stingeder. 1997. Adsorption of trace metals by tension lysimeters: nylon membrane vs. porous ceramic cup. *J. Environ. Qual.* 26:1430 1434.

Wood, W.W. 1973. A technique using porous cups for water sampling at any depth in the unsaturated zone. Water Resour. Res. 9(2):486-488.