Groundwater in relation to fractured till

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Introduction

Prior to the 19th century, groundwater was regarded as a part of the ground. In legal terms, groundwater was a part of the solus upon which the fee rested, being an integral part of the title to land. But with the beginning of the 19th century, economic demands upon groundwater forced a change in Anglo-American legal institutions. When something becomes worth litigating, it becomes worthy of its own definition. Initially in this process, the law was faced with a lack of physical scientific knowledge, causing judges to label groundwater "occult" (FRAZIER v. BROWN, 1861).

Groundwater science, however, did not stand still. In the 20th century, the work of such geologists as Oscar Meinzer and Harold Thomas provided lawyers access to that knowledge, initially for lawyers in administrative agencies and then for all lawyers through court decisions. Admittedly, there remained "the wide range of conditions of occurrence of ground water [that] reflect the great variations in porosity and permeability of the solid components of the earth's 'Crust'" (THOMAS, 1955), but lawyers and judges came to believe that they could make decisions in assurance of "the dramatic increase in the scientific knowledge of the nature and movement of groundwater" (NOTE, 1986). A modern court can confidently purport to define groundwater and describe its operation below ground. No vague references to the "occult" are needed, as exemplified by a more recent Ohio legal decision (VILLAGE OF PLEASANT CITY V. DIV. OF RECLAMATION, ODNR, 1993):

> Water from rain and snow infiltrates the soil and percolates down, filling pores and cracks in rocks and other materials beneath the surface of the earth. Depending on the hydraulic gradient and the rock material's permeability, the ground-water moves more or less slowly through these underground materials towards points of discharge, such as lakes or pumping wells. The permeable rock materials that the ground-water travels through are known as aquifers.

Is this wrong generally? No, but recent till fracture studies (FAUSEY et al., 2000; ALLRED, 2000) have indicated that the facts in a wide range of instances will not accord with the description in the above case. The purpose of this paper is to describe the current status of land-use decision making in Ohio as it relates to physical limitations imposed by the presence of fractures and joints in glacial tills. The paper also proposes science-based decision-making tools to protect groundwater in fractured settings.

Until recently, even among the majority of the scientific community, the presence and significance of fractured unlithified materials (especially tills) has not been well understood. Fractures in such materials have been documented in the geologic and soils literature for at least three decades. George White (1982) summed up decades of observations in northeast Ohio:

> The structure of weathered tills also differs from till to till, and the variety of fracture patterns is significant ... The variation in structure is an important factor for movement of fluids through till. Intergranular permeability is very low, but fluids may travel through the joints. This factor must be taken into account in testing for permeability of potential septic-tank and waste-disposal sites. (p. 29)

Although this document has been widely circulated in Ohio, little attention had been paid until recently to Dr White's cautions. While this lack of recognition has the appearance of negligence on the part of the environmental community, it must be remembered that at the point in time that White was working in Ohio, the environmental community was just in its infancy. Earth Day began in 1970, the U.S. Environmental Protection Agency (USEPA) was founded in 1970, and Ohio's version (OEPA) began in 1972. While there was carry-over from past work of other agencies, most experts in the responsible agencies had been engineers, who are not commonly familiar with the glacial geomorphology and soils literature in Ohio. Even ten years later, at the final White 1982 publication date, the Ohio agencies which had the combined responsibility for the protection of Ohio's waters were not staffed by individuals who had been extensively trained in glacial geomorphology and soils. Still today, they are not.

Groundwater vulnerability assessment screening tools

Given finite resources, groundwater protection efforts should focus on those aquifers most susceptible to contamination and/or most essential for sustained water supplies. Existing tools for assessing groundwater vulnerability or delineating protection zones include DRASTIC (ALLER et al., 1987), the Well Head Protection Program, USEPA Sole Source Aquifer designation, Source Water Protection (SWAP), regional water protection programs, and methods that involve map overlays (e.g., Federal Emergency Management Agency maps, wetlands maps) and/or GIS thematic coverages.

The modern version of DRASTIC provides a standardized method for quantifying and comparing the relative vulnerability of different areas to groundwater contamination. This method has been adopted by ODNR Division of Water, and many maps of groundwater vulnerability have been developed by that agency on a county by county basis. These maps were produced by combining seven input variables: depth to water, recharge, aquifer media, soil media, topographic slope, vadose zone media, and hydraulic conductivity. In preparing these maps, ODNR made certain adjustments in the original DRASTIC structure, especially in the input variable concerning the vadose zone media. The weighting of this variable is adjusted depending on increasing knowledge about the character of the till, the fractures, and the contaminant (ANGLE, 2001).

Because unfractured till is impermeable, many had regarded it as the perfect aquitard to separate surface sources of contamination from aquifers. But till is brittle as well as impermeable and fractures for many reasons, so that (when fracturing occurs) contaminants can quickly penetrate sensitive zones below the till. The adjustments in DRASTIC make the maps far more useful and scientifically up-to-date than previously had been possible in glacial till settings.

Another approach might be to provide a simplified GIS mapping overlay which may be coded red (meaning stop), where fractures are known or highly likely, yellow (meaning caution) where fractures are fairly likely, and green (meaning go) where the likelihood of fracturing is low. The purpose of the tool would be to ensure that any proposed future land uses would be compatible with ground and/or surface water resources, in addition to the more common checks of zoning compatibility and transportation availability.

ODNR has continued (and continues) county scale suitability maps, first in the Division of Geological Survey and as part of the Ohio Capability Analysis Program and, later, through the county scale Ground Water Pollution Potential maps. Through all these maps, Ohio has county scale suitability maps for the whole of Ohio and specific land suitability maps for some counties – some since 1976. Unfortunately, these maps are not part of the landfill siting criteria. Thus, in one proposed landfill straddling a county line, the pertinent maps showed the proposed site was unsuitable and should have been dropped from the proposal out of hand. Instead the applicant spent $200,000 to confirm reluctantly the unsuitability of the proposed site. Surely the money would have been better spent using the maps to locate a more promising site.

Advances in landfill technology

Since the implementation of the Resource Conservation and Recovery Act of 1976, municipal solid waste (MSW) landfills have been engineered, built and operated as dry tombs to minimize the generation and spread of hazardous leachate from the degradation of the waste. This management technique leads to a reduction in the volume of leachate produced by minimizing the moisture allowed to enter the landfill. However, the low moisture content of the landfilled waste is prohibitive to microbial activity and therefore hinders the decomposition of the degradable portion of the MSW (DEWALLE et al., 1978). Current estimates of the time required for the decomposition of waste in a dry tomb landfill range from 30 to 50 years or more.

One of the current technologies being explored to treat landfill waste in situ is the recirculation of leachate to the waste mass to raise the moisture content, thereby creating a solid state bioreactor in which microorganisms degrade many of the components of MSW (PAVEY et al., 1999). The effectiveness of bioreactor landfills has been demonstrated in several full-scale trials (PAVEY et al., 1999; REINHART and TOWNSEND, 1997). The use of bioreactor landfills decreases the time required to degrade and stabilize the MSW to projected 10 years or fewer. This shortened lifecycle of a bioreactor landfill results in rapid loss of mass and subsequent settlement of the landfill. Once the landfill has settled, more MSW may be disposed of in the landfill, extending its useful life and creating a sustainable landfill. Using this technology, landfills can be public utilities that serve much like regionalized wastewater treatment plants.

A mosaic of decision makers

Those who did understand Ohio's glacial deposits and soils, especially the staff at Ohio Department of Natural Resources (ODNR), were then and continue to be institutionally tangential to the decision-making process. Like the U.S. Geological Survey (USGS), they perform a data collection and repository function. The actual decision making for many of the various potentially soil and groundwater polluting land uses falls to the Ohio Environmental Protection Agency, the Ohio Department of Health and its county health departments, the State Fire Marshal's Office, the Ohio Department of Agriculture (ODA), the Ohio Department of Transportation (ODOT), and the Public Utilities Commission of Ohio (PUCO). These agencies, along with ODNR and USGS, comprise the State Ground Water Coordinating Committee, an outgrowth of the Interagency Ground Water Advisory Committee formed in 1987 when Ohio first certified a groundwater protection program. (See table 1 for a fairly comprehensive list of all governmental agencies of Ohio needing to be informed about till fractures).

Although these agencies participate in or influence the more obvious land-use decisions that can lead to groundwater contamination, virtually any land-use decision has the potential to affect the quality of surface and/or ground water. Therefore, the list of decision makers needs to be expanded to include local and regional entities as well.

We should remember, though, how historically recent any governmental interest is in land decisions concerning pollution. Until the 1950s, little to no interest existed in landfill siting, solid waste or otherwise. The State of Ohio is an example of this history. Local health boards exercised whatever authority was available, and any positive effect on the environment was negligible. Only in the 1960s were state siting criteria created. Any existing landfills were made "grandfathered sites," to remain free of any new controls. Siting controls were strengthened in the 1970s, creating a new set of "grandfathered sites" and strengthened again around the turn of the 1990s. Not until near the new millennium did the first dialogue in siting criteria concerning fractured till appear in Ohio.

Table 1
Ohio organizations which influence land-use decisions

Organization	Level of involvement			
	Data	Planning Collection	Rule-Making	Decision-Making
Local, Regional and State-wide Planning commissions		x		
Health departments (state and county)				x
Soil and water conservation districts (one per county)		x		
County engineers' departments				x
Local and County zoning, building, and development authorities				x
County, Regional and State Departments of Development		x		x
Solid waste management departments, authorities, districts and private firms		x		x
Local and County-wide water and sewerage (store and wastewater) agencies		x		x
Multi-county Conservancy Districts		x		
Ohio Turnpike Authority				x
State agencies: Ohio Department of Nature Resources	x			
Ohio Environmental Protection Agency – Region V			x	x
Ohio Department of Commerce: State Fire Marshall's office (Bureau of underground storage tank regulation)			x	x
Ohio Department of Agriculture (pesticides and fertilizers)			x	x
Ohio Department of Transportation (road salts)			x	x
Public Utilities Commission of Ohio (pipeline, rail, and highway transport of hazardous and toxic materials, oversight of some private sewer/water companies)				x
Ohio Department of Development (siting and funding for new and expanded manufacturing facilities)				x
Ohio Water Development Authority				
Federal agencies: US Department of Agriculture	x		x	
Natural Resources Conservation Service	x	x	x	
Agricultural Research Service	x			
Farm Services Agency				x
Farmer's Home Administration				x
US Geological Survey	x			
US Environmental Protection Agency			x	x
US Fish and Wildlife				
US Army Corps of Engineers (wetlands jurisdiction, watershed management)		x	x	x
Village and City administrations¨		x		x
Lending Institutions				x
OTHERS?				

Groundwater protection in Ohio

There is precedent in Ohio (as well as elsewhere) for full-scale groundwater protection. Beginning in the 1980s both the Miami Valley Regional Planning Commission (Darke, Preble, Miami, Montgomery, and Greene counties) and the Ohio-Kentucky-Indiana Regional Council of Governments (including Ohio's Butler, Hamilton, Clinton, Clermont, and Warren counties) instituted groundwater protection programs. These programs began by certifying portions of fourteen Southwestern Ohio counties as the Great Miami Buried Valley Sole Source Aquifer, a USEPA designation. As a follow-up, both agencies began an extensive inventory of existing and potential sources of contamination in their counties of jurisdiction.

These data bases were entered into early Geographic Information Systems (GIS) mapping programs. Funding for the programs came in part from Ohio EPA through USEPA Section 208 Clean Water Act pass-through allocations. The rest of the funds were raised locally from the member communities, business partnerships, foundations and through in-kind services. The Miami Valley Regional Planning Commission's efforts were more far-reaching. The long-range goal was to review every land-use decision as it related to groundwater protection. In addition, the Planning Commission was to assist in water-use conflict situations, helping to determine the wellhead protection for each of its member communities and the identification of critical groundwater resources. To a certain extent, the groundwater initiative currently undertaken by the Miami Conservancy District grew out of these earlier efforts.

The awareness of the importance of water has long historical meaning to southwest Ohio. The 1913 floods along the Great Miami River were devastating. While community after community rallied to insure that such destruction would never come again, even in the birth of massive engineering undertakings were the seeds of realization that natural forces, in the end, always win. Engineers design solutions which have finite life spans. It is that realization which drove the regional groundwater protection efforts in southwest Ohio. There was a grassroots understanding that some of the contaminated aquifers could not be remediated at any cost and that if the prolific groundwater reservoirs of the region were to be available in the future, they must be protected and preserved today. Groundwater protection became a daily point of discussion in the lives of average citizens. The efforts are funded with local tax dollars as part of the ongoing cost of local and regional government.

To a lesser degree, the same awareness for groundwater protection was spearheaded by the Toledo Area Regional Council of Governments in northwest Ohio and by the Northeast Four County Planning Commission in the Akron-Canton area and Northeast Ohio Area Community Council in the Greater Cleveland area. None of these programs reached the level of commitment found in the southwest Ohio effort, but groundwater protection, education and planning were undertaken through their support.

In all cases, only the most obvious contamination settings, those of fractured cavernous and karst carbonates, and buried sand and gravel aquifers, were recognized. Glacial till, on the other hand, was always considered a good, protective barrier to contaminant transport to the underlying aquifers. Even in northeast Ohio where George White worked for so many years, the connection to fracture flow in the unlithified till materials was not recognized. However, when fractured, till functions much differently than traditionally thought, no longer serving as a protective barrier.

OEPA has a wellhead protection section, but (as often the case for such programs state-wide) the program is voluntary, and few communities have participated in it due to economic and political considerations. Other states, such as New Jersey, have mandatory wellhead protection programs, and are therefore much more effective in protecting the aquifers that supply public water supply wells.

In contrast, Ohio has many designated Sole Source Aquifers. With parts or all of 20 counties contained in one of the five different Sole Source Aquifers in Ohio, Ohio has more area designated than any other state in USEPA Region V. The historical reason behind that is simple. When Ohio failed to pass legislation compelling Wellhead Protection Plans under a state-wide protection plan designating Critical Aquifer Areas in Ohio, local governments countered with the only other protection process they had – seeking Federal recognition for Sole Source Aquifers on this wide scale.

Ohio's subsurface fractures are of many kinds, depending upon the subsurface materials. Decision makers at many governmental and private levels must take them into account for protection of groundwater, surface sustenance, and prevention of volatile reactions from human actions. Emphasis is placed especially upon tools for assessing groundwater vulnerability and the legal framework for resource protection in fractured environments. Of course, case law that explains how the laws and regulations operate in confrontations is important, but not much case law exists in the case of fractures, least of all in the instance of till fractures.

All landfills eventually fail and siting criteria offer only minimal protection, at their best, from that failure. Thus, landfills placed on top of, or beside, sensitive locations (parks, public water supply aquifers, virgin forests, abandoned shaft mines, wildlife refuges, etc.) will fail to the damage or destruction of these areas allegedly protected from contamination. Maybe if we knew all the Sole Source Aquifers, 100 GPM sand and gravel aquifers, or wellhead protection areas that a growing urban industrial economy could ever need, we might just sacrifice the underlying materials to contamination. But we do not. We never shall. And so we must accept the widespread existence of fractures, and the likely continued inevitable failures of landfills.

Legal standing on till

As described earlier, the legal framework for groundwater protection had evolved in Ohio and other states from not dealing with the scientific basis for groundwater movement (the "occult" description that originated in the 1861 case of Frazier v. Brown) to using a porous media model of groundwater best applicable to sand-and-gravel aquifers (NOTE, 1986). The first opinion of a legal tribunal to formally recognize a new shift in the factual base for groundwater law in fractured till is CF/Water et al. v. Schregardus (1998).

In this case, the applicant wished to install a landfill. The commission found that beneath the site was a layer of till and, below that, aquifers. It found, also, that "the till layer would function as a barrier to vertical movement of groundwater and contaminants to aquifers" lying below the till, if the till were to function adequately as a barrier, 1998 WL 93972 1, p. 3. The presence of the aquifers required a waiver by the Director of OEPA that "deemed the siting acceptable." Id., p. 4. The applicant had to show a "thickness and lack of permeability" in the till sufficient to protect the aquifers. The Director was persuaded by the evidence offered by the applicant that the till layer was sufficient to protect the underlying aquifers.

The applicant had stated that the till was not fractured. Id., p. 6. Subsequent boring logs, however, established the existence of fractures in the till, thus allowing a "very fast time-of-travel equation" in water moving from the landfill into the aquifers sufficient to fail to meet the agency standard for an impermeable barrier. Id., p. 7. But an administrative "gap" occurred between what the record showed the agency knowing institutionally and the information upon which final decisions were made by the agency's Director.

The Director formally "deemed siting acceptable," despite what was known institutionally. The Commission, on the appeal, had developed in hearings before it that the decision makers had not known of existing fractures in the till overlying the aquifers nor had the boring logs documenting the fractures been reviewed by these decision makers. Testimony stated that if the existence of these fractures in the till had been known by these decision makers, the "effective porosity figures" of OEPA could not have been met. Id., p. 12, and the application would have been denied.

Based upon these facts, the decision of the Commission was a narrow one. The Commission found that the Director's decision had been made upon an invalid factual foundation, which rendered the decision unreasonable, requiring disaffirmance of the Director's action, ORC sec. 3745.05. Thus, the Commission returned the decision to the Director "to conduct an investigation into the application in light of the undisputed presence of fractures in the till overlying the aquifers." The factual predicate revealed in this case is that (1) the presence of till is prevalent in areas where glaciation had occurred, (2) till is a material that is impermeable, and (3) till is a material subject to frequent fracturing, facilitating rapid contamination of aquifers below the till. In the presence of till, therefore, water from surface areas does not reach aquifers by "infiltrat[ing] the soil and percolat[ing] down, filling pores and cracks in rocks and other materials beneath the surface of the earth," as asserted in *Village of Pleasant City, supra*. That's the bad news.

The good news is that, as till is both impermeable and common, fractures in the till (1) allow aquifers beneath the till to obtain recharge and (2) are common in the till. While this rapid transport insures yearly recharge of our groundwater aquifers, it is a critical point of failure when contaminants are moving with that water. Therefore, the benefit of ample recharge to sustain aquifers requires a high level of groundwater protection on the surface. This protection is to prevent water on, or near, the surface from dropping rapidly and unaltered through the fractures in the till into any underlying aquifers. Providing that protection requires revision in the current common legal views as to how water can reach aquifers.

Law cannot but help to follow science, technology, economics, and other social forces. Law scarcely can go far ahead of them, either. Even so, law can be inventive in its rules, though prematurity can render a rule academic. The Anglo-American courts in the early to mid-19th century had developed all the rules potentially (and, actually, at a later date) available to protect groundwater both qualitatively and quantitatively. The choices were not made by courts on any abstract, predetermined rules. The decisions were based, instead, upon economic grounds and upon what contemporary earth science, at that time, did – or did not – know about groundwater. "[R]ule choices were known and were varied, contradictory, credible, and difficult for judges who knew that these decisions would have important economic and social, as well as legal, consequences," (MURPHY, 1991, pp. 57-58). The same is commonly true today.

An earlier – and widely considered – case preceding C/F Water, Inc. v. Schregardus (1998) had an inkling that facts in glaciated areas might not be as they had been described under other conditions, Village of Wilsonville v. SCA Services, Inc., 86 Ill. 3d, 426 N.E.2d 824 (1981). In this earlier case, a landfill actually had been installed above a layer of till below which lay an aquifer. The landfill had leaked and a nuisance action had been brought to mandate the removal of the landfill. The testimony in the case is interesting in light of what is now being discovered about till fractures.

A USEPA task force had determined that, "the glacial till which lies under the site is quite dense and essentially massive. . .", Id., 426 N.E.2d 824, 839. In fact, the till was 40 to 65 feet thick. Permeability tests had shown repeatedly that the till was "not very permeable" and, indeed, had low permeability. Id., 828. Despite this, the experts had opinions – not supported in the Court's opinion – that the till was more permeable than any test had indicated. Id., 832. Testimony was present about "fractures;" but none seem to have been related directly to the till, probably due to the subsidence caused by an abandoned mine. Id., 829. The court was little interested in these then ambiguous facts and decided the dispute on grounds unrelated to till fractures, basically that a nuisance somehow had been caused by the pollution of an aquifer supplying water to a wide area. Yet, even so, the experts had come tantalizingly close to the role till fractures can play in a glaciated area.

One cannot put aside, of course, the painfully developed scientific bases for groundwater law developed in the United States throughout the 20th century. Professor Charles Callahan, who wrote on Ohio water law in the mid-20th century, wondered if Ohio would have a scientifically-based groundwater law by the end of the 20th century (CALLAHAN, 1959). Until 1984, Ohio common law left in place legal institutions providing landowners with "no capability or authority ... to manage ground water supplies which are in the ground – even in their own land – in the face of other demand" (COOGAN, 1975). Nor were most other Anglo-American jurisdictions better off.

No one suggests a return to such chaos. All that is required is a supplement to the knowledge which is the base for current groundwater law. Where glaciated till exists, courts and administrative agencies must recognize that another factual predicate often applies rather than the now traditionally accepted one. Greater limitation on permissible surface actions above the till is required, if pollution is not to occur in aquifers underlying fractured till – and unfractured till is not likely to exist, or at most is a function of total till thickness. Though potential actions based on different expectations would be permissible, they are not to be allowed, once the presence of till fractures, and aquifers underlying them, has been established. Standards that would deny these problems (or do not directly assume responsibility for protecting aquifers in glaciated regions) should not be adopted. Tradition is not enough. Too much is at risk for administrators to act differently.

Legal framework for groundwater protection

Our proposed process is to incorporate scientific knowledge into an institutionalized process that will be used in decision making.

- First, a risk screening tool that incorporates fracture information needs to be developed.
- Educational outreach is needed to demonstrate the importance of fractures to the general public and to the decision-making community. This is being accomplished through publications including the *Ohio Journal of Science,* vol. 100, issues 3/4, workshops, and a clearinghouse web site.
- It is essential to go beyond education, and institutionalize the process to check for fractures by creating a supportive legal framework. Such limitations can be written into state statutes or local codes (perhaps by defining fractures as a zoning hazard), but would best be served by a statewide standard for fractured till areas to support local zoning laws.

Why is it necessary to institutionalize the process? Because without that, it will not matter what is academically known about the fractures, and our planning and decision making will continue to ignore their existence and larger implications. True, wise use of the surface will lead those wise users to educate themselves about the best location for landfills or other uses with the potential to contaminate. The law must level the playing field with mandatory regulations and the final step for these regulations will be to meet challenges in court, for there will be challenges. The new processes need these changes in law.

While developing a new legal framework for till areas in order to protect underground conditions or interfaces with them, certain matters must be kept in mind. We must beware of making and applying rules without full knowledge of site specific conditions. Currently we are struggling with land-use decisions made 25 to over 100 years ago. Some were made indifferently, but many were made with best available knowledge of the time (though varying site specific knowledge). As a society, which must live with such events for protracted periods, decisions require the most careful drafting of laws and their application in the field, seeking as much foresight as humanly possible.

Regulations should be extremely conservative in providing exemptions, waivers, and variances. How wide should a setback zone be within which a certain activity is forbidden beyond which an exemption is extended to that activity? Should the setback or protective zone for a federal or state park, or a recreational or virgin land area, be 500 feet, 1,000 feet, 2,000 feet? Or should it be determined on an individual site basis with even more potentially generous setback terms? Many of the fixed setback terms have proven pitiably inadequate to provide protection. How far should the up-gradient water supply setback be to protect a well field? Contaminants from landfill gas can be carried far greater distances than previously thought. Regulation needs to document cases concerning up-gradient gas migration in different settings and develop a scientifically-based buffer zone that can be applied to the characteristics of each site, rather than rely on an arbitrary fixed distance.

Underground geologic pathways include both primary porosity and secondary fracture flow. The latter need to be monitored, or maybe remediated, while both situations need to be calculated and continuously monitored. As much needs to be learned in advance of permanent action as possible and certainly needs follow-up monitoring. Some models do not work on other than primary porosity, so models need to be used that are not so confined in their purposes. Expensive? Time consuming? Yes, but important. We have exchanged the occult for the complex.

Many maps exist as resources and need to be employed on a larger scale than is now the case. One is the digital USGS 7.5 minute topographic quadrangle, with the scale corrected to one inch = one mile. Its use requires basic understanding of Geographic Information Systems (GIS) available for any particular state and the software to process it. All county soil maps should be put into GIS form, so that surveyors and soil scientists will be familiar with the system. Indeed, one of the problems is the great number of specialists who are involved in providing information or analyzing information being provided by other specialists, such as geologists, geological scientists, soil scientists, pedologists, as well as surveyors and professional engineers. Specialists cannot venture far from their disciplines because educations do not cross over and the ignorance of a specialist in one field can be as great in another field as that of any layman. Teams – including, at a minimum, stratigraphers, glacial geomorphologists, structural geologists, and soil scientists – should be used. Descriptions of material that can be commonly used by these various disciplines are also needed – even if they have not been developed as yet.

Deposits should never be simply investigated on a grid basis. While a grid can serve as a beginning, the information gathered from one boring dictates the direction and distance needed to set the next boring, but it is not a sufficient investigation in itself. Traditional borings are often not the best investigative method for unconsolidated materials. Often pits are needed, as well as angled borings, to identify accurately the conditions present in unconsolidated materials (CHRISTY et al., 2000). The same is true of picking a single depth for tests because depths in humid areas of the saturated zone may extend only into the annually recharged vadose zone if a fixed depth has been preset by regulation. There are no short cuts in gathering needed information if the information sought is to be sufficiently accurate.

Reflections

While developing a legal framework for groundwater protection in fractured environments, several things should be kept in mind. We must beware of applying rules and assuming protection is thereby achieved when those rules were not promulgated with full knowledge of the site-specific conditions, especially in the case of fractures. We should recognize that we currently are struggling with the bad effects of land-use decisions made 25 to 200 years ago (e.g. Superfund); let us learn from our history.

Given the tools already available for assessing groundwater vulnerability, and the research-based knowledge of fractures already in place, taking fractures into account in the decision-making process is not difficult. It involves looking at site-specific information, reviewing all available documentation (including the fracture web page) and performing any additional on-site tests. Taking fractures into account is important for good decision making, as is taking the long-term point of view. Our recommendations are threefold:

- Require that any site being considered for development be screened for fractures.
- Educate local decision makers who ultimately make the final decisions or, if not made locally, then at whatever level the ultimate decision must be made. But even when the decision is made at some higher level, local people must live with the consequences of the decision and need the education to know what the consequences of the decision will be so, at the least, they can oppose or seek to modify that decision.
- Recognize that decision making is as fractured as the fractured geologic space itself.

Much site-specific information is now available, while more site-specific knowledge can be obtained as needed, including on-site tests. Expensive? Yes. But costs paid by permittees and applicants for permits are already high, without guaranteeing certainty or providing protection from imposition of heavy future costs. Politically burdensome? Yes. But under the present operations, how successful is avoidance of political risk? Not very, even in the not-too-long run. This approach offers protection to wide ranges of the environment, avoidance of damage sometimes uncorrectable or correctable only in geologic time, and an avenue to such technical improvements as the sustainable bioreactor landfill. These would be substantial improvements, in economic, political, and scientific terms. They need not be foregone.

We, as a society, have to make decisions looking at the longer term, because that's the scale at which we should want the benefits to exceed the initial costs. Political office holders may be thinking only of their terms of office, but a community as a whole must think longer-term. People who live in the area need to become educated about issues and be encouraged to participate in the decision-making process. Ultimately, most land-use decisions are site-specific and are often made – certainly heavily influenced – by local governments and private citizens.

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