GROUNDWATER IN THE PURPLE VALLEY
The Lingering Influence of Glacier Ice

Paul Bierman '85

In many areas of New England, sediment deposited during the retreat of the continental ice sheets is an important factor controlling the distribution and quality of ground water. This statement certainly rings true in Williamstown — a town with copious and clean ground water resources. The information I present in this paper was gathered during the preparation of my senior thesis at Williams and during the six months I served as project manager for the Williamstown landfill study. The Town of Williamstown and Williams College funded the landfill study for which the main contractors were Alliance Technologies and Hydro Group. The interpretations presented here are the result not only of my work, but of extensive discussions with David Dethier (Williams College Geology Department), Blake Martin (Williams '84), and Linda Marler (Hydro Group).

Review of Relevant Geologic Processes

Observation of present-day glaciers and theoretical models of ice flow have increasingly constrained the geologist's interpretation of sediment left by now-vanished ice sheets. To provide the background necessary for understanding the hypotheses presented in this paper, I will briefly review some relevant geologic concepts. The interested reader may wish to consult Drewry (1986) for a more thorough discussion of glacial processes.

Behavior of Glaciers. A glacier may be understood as a gravity-driven conveyor of ice and sediment. If sufficiently thick, ice flows and slips under its own weight. Maintenance of an active glacier margin is a balancing act. If more ice melts than flows to the margin, the glacier retreats; if more ice flows to the margin than melts, the glacier advances. As long as the glacier continues to flow, ice and sediment are delivered to the active margin (Figure 1).

Sediment Deposition. Except at the base of the glacier, most glacial ice contains little sediment; however, large volumes of sediment are carried by meltwater streams

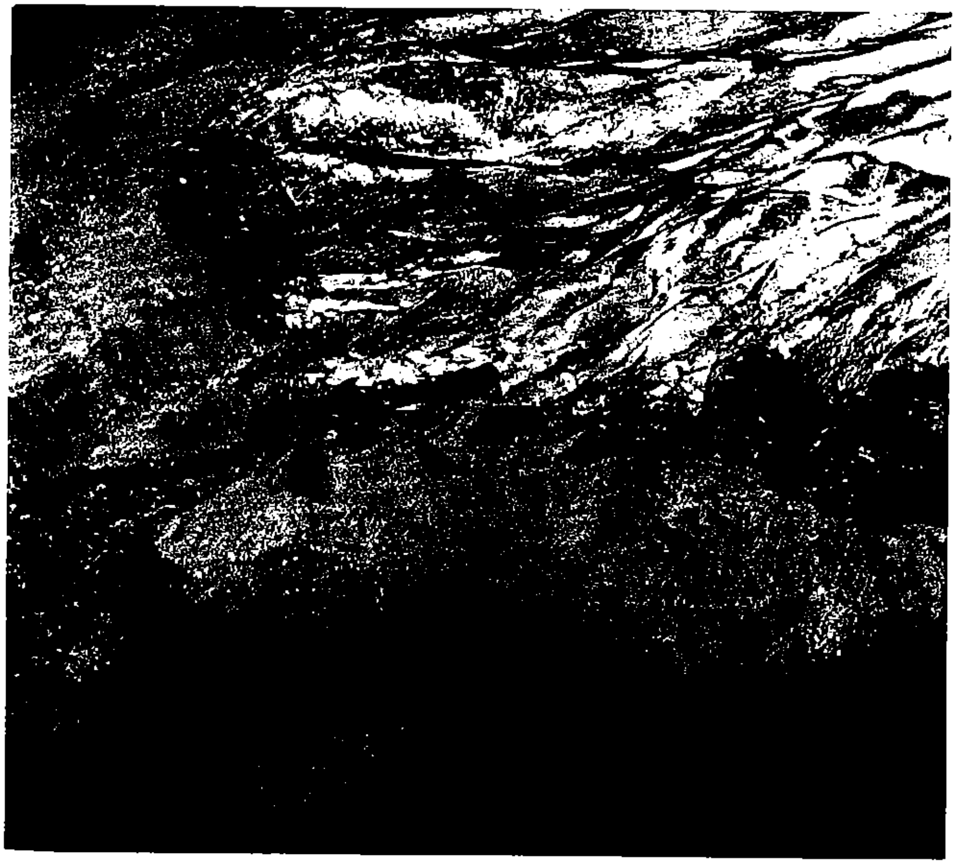


Figure 1.
The glacial ice is situated behind a glacial moraine (till). An outwash stream, with associated glaciofluvial deposits, is also visible (Juneau Ice Field, Alaska).

running within the glacier and in a layer of fluidized material below the ice. Glacial *till*, deposited directly from the base of the ice, is poorly sorted, compact, and not layered. The term *glaciofluvial* is used to describe coarse grain sediment which originated from the ice, but was deposited by moving water, perhaps at some distance from the active glacier margin. Because it has been washed by moving water, *glaciofluvial* sediment is better sorted and more stratified (layered) than till. Glaciofluvial sediment is commonly found along valley walls, where meltwater streams once flowed next to the glacier, or on the valley floor downstream from the former ice margin. If a glacial lake borders the ice margin, glaciofluvial sediment may be deposited underwater.

Glaciers or accumulations of glacial debris commonly block surface drainage and impound temporary lakes. Sediment enters the lake from the glacier and from adjacent hill slopes. In the quiet lake water, silt, clay, and fine sand settle out in a series of thin layers. Clay-rich *glaciolacustrine* sediment is deposited preferentially in the deepest part of the lake farthest from lake margin sediment sources.

As ice continues to melt back, glacial lakes empty and rivers and their floodplains once again occupy the valleys; erosion begins to modify deposits of glacial sediment. Sometimes rivers will deposit sediment over the glacial debris, in other times and places, the rivers may cut channels eroding the glacial sediment.

Setting

Previously collected data indicate that up to 90m (300 feet) of unconsolidated sediment overlie marble in the Hoosic River Valley (Hansen et al., 1973, 1974). In other words, the Hoosic River may have once flowed in a deep canyon now filled with sediment. Bierman and Dethier (1986) report that the character and thickness of unconsolidated sediment vary greatly within the Hoosic River Valley. Where bedrock is not exposed, glacial till covers much of the uplands. The largest volume of water-washed glacial sediment is found on or near the lower valley walls, below 380m (1245 feet). Most glacial lake sediment is found below 290m (950 feet). Extensive older and modern river deposits cover much of the valley floor.

As the glacier retreated from the Berkshires 15,000 years ago, it dammed the north-flowing Hoosic River, creating glacial Lake Bascom (Dale, 1906) (Figure 2); Bierman and Dethier (1986) identified several levels of Lake Bascom. Near Williamstown, Lake Bascom was up to 150m (490 feet) deep.

Methods

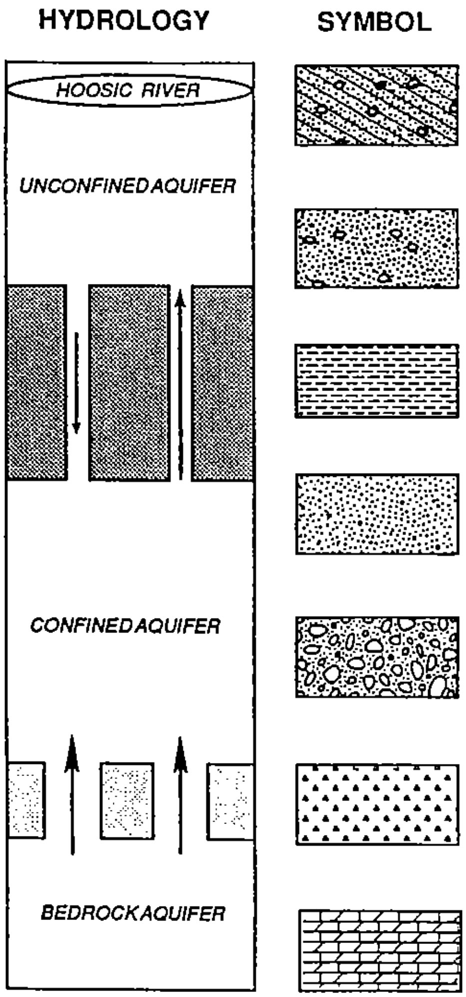
As part of the landfill study, I oversaw the installation of 27 groundwater monitoring wells. During installation of the wells, I collected sediment samples which allowed me to better understand the subsurface geology of the Williamstown area. I, along with other Alliance employees and several Williams College geology students, measured water levels in these wells and collected samples for water quality analysis. During the study we conducted a pumping test. For a six-day period, we changed the pumping rate of the town well and observed changes in water levels in other Williamstown wells. During the study, Alliance employees collected numerous samples of soil, ground water, surface water, and biota; these samples were analyzed for a wide range of compounds including: metals, volatile organics, nutrients, chloride, and pesticides.

Data

Geology. The landfill study indicated that the subsurface geology in the Hoosic River Valley has a predictable series of layers or strata (Figures 3 and 4). I have categorized these geologic units according to the processes which probably formed them.

> Alluvium — Many of the soil borings advanced during the landfill investigation encountered sand, gravel, and silt deposited by the Hoosic River or its tributaries. The alluvium is predominately sand with lesser amounts of silt and gravel. The

Figure 2. Sketch by H. Cleland (Williams Geology) of glacial Lake Bascom.



DESIGNATION	DESCRIPTION
ARTIFICIAL FILL (0 - 14 m)	UNSTRATIFIED, LOOSE GREY TO TAN GRAVEL, SAND, SILT, AND REFUSE. LOWER SECTIONS ARE BLACK AND ASHY. DEPOSITED IN FORMER AND ACTIVE LANDFILLS. SOME FILL IS WATER SATURATED. WATER QUALITY IS POOR.
ALLUVIUM (0 - 12 m)	STRATIFIED, LOOSE BROWN AND TAN SAND WITH LESSER AMOUNTS OF SILT AND GRAVEL. LOWER PART OF THE UNIT IS GREY, SILTIER, AND MORE COMPACT. CROPS OUT NEAR HOOSIC RIVER. DEPOSITED DURING AND AFTER THE DRAINING OF LAKE BASCOM. PROVIDES WATER OF VARIABLE QUALITY IN SMALL QUANTITIES (UP TO 110 M^3/DAY).
GLACIOLACUSTRINE SILT AND CLAY (16 - 37 m)	THIN BEDDED AND LAMINATED, COHESIVE GREY SILT, CLAY, AND FINE SAND. EXPOSED IN THE VALLEY BOTTOM AND ALONG LOWER VALLEY WALLS. DEPOSITED IN DEEPER SECTIONS OF GLACIAL LAKE BASCOM. RETARDS MOVEMENT OF WATER ($K=10^{-4}$ TO 10^{-5} M/DAY).
GLACIOLACUSTRINE SAND (0 - 14 m)	THIN BEDDED, LOOSE GREY SAND AND SILT. NOT EXPOSED. DEPOSITED IN DISTAL PORTIONS OF SUBAQUEOUS FANS OR DELTAS WHICH PROGRADED INTO LAKE BASCOM. PROVIDES SMALL QUANTITY OF WATER (UP TO 30 M^3/DAY).
GLACIOFLUVIAL SAND AND GRAVEL (7 - 10 m)	LAYERS OF LOOSE BLACK, GREY, AND WHITE GRAVEL AND SAND WITH GREY SILT. NOT EXPOSED. DEPOSITED SUBAQUEOUSLY BY MELTWATER STREAMS. PROVIDES LARGE QUANTITIES OF POTABLE WATER (UP TO 6500 M^3/DAY).
TILL	UNSTRATIFIED, COMPACT, GREY/GREEN SILT, SAND, AND GRAVEL. EXPOSED ON VALLEY WALLS AND IN UPLANDS, DEPOSITED AT THE BASE OF THE GLACIER. RETARDS MOVEMENT OF WATER.
BEDROCK	WHITE, CRYSTALLINE DOLOMITIC MARBLE WITH SMALL AMOUNTS OF QUARTZITE AND PHYLLITE. WEATHERED MARBLE IS SOFT AND RED. FLOWING WELLS IN VALLEY BOTTOM PROVIDE LARGE QUANTITY OF WATER (UP TO 3800 M^3/DAY).

Figure 3. This is an idealized representation and description of the geology and ground water hydrology below Williamstown.

with lesser amounts of silt and gravel. The thickness of alluvium varies greatly. In some areas, the Hoosic eroded some of the underlying glaciolacustrine silt and clay and deposited almost 12m (40 feet) of alluvium. In other areas there is no alluvium and the glacial lake sediment is exposed at the surface. This alluvium allows rapid passage of ground water.

Glacial lake silt and clay — The alluvium is underlain by fine grained glaciolacustrine material: silt, clay, and fine sand. This lake sediment is irregularly stratified — layers of fine sand alternate with layers of silt and clay. This silt and clay layer impedes the passage of ground water.

Glaciofluvial sand and gravel — At six spots in the valley deep well borings encountered a layer of coarse gravel. This gravel contains rounded clasts of marble, phyllite, and quartz, resembling rocks which crop out in western Massachusetts and southern Vermont. Ground water passes rapidly through this material.

Bedrock and till — Dolomitic marble underlies unconsolidated sediment in the Hoosic River Valley near Williamstown. One well terminated at 57m (186 feet) below ground surface in white, crystalline marble. In some places, glacial till probably overlies bedrock and underlies the glaciofluvial sand and gravel. One monitoring well terminated in till; however, another well, which was advanced into the bedrock, did not encounter till. Water passes easily through the fractured bedrock and the discontinuous blanket of till.

Groundwater Hydrology. Hydrologists refer to a body of sediment which is relatively permeable as an aquifer; relatively impermeable sediment is termed an aquitard. The landfill investigation identified two aquifers (the alluvium and the glaciofluvial sand and gravel) and one aquitard (the glaciolacustrine sediment). Data, gathered during the pumping test, suggest that the glaciolacustrine aquitard serves to confine the gravel aquifer below it. As a result of this confinement, ground water in the lower aquifer is under pressure and wells drilled into this aquifer will flow without pumping (Figure 5). The town of Williamstown and several industries draw water from the confined aquifer. Landfill units are in contact with the unconfined aquifer.

Unconfined aquifer — The unconfined aquifer is located in alluvium of the Hoosic River and its tributaries. Depth to the water table is about 3m (10 feet) in most areas. Groundwater in the unconfined aquifer is recharged episodically by precipitation and continuously by several ponds. Except during floods, groundwater in the unconfined aquifer flows toward the Hoosic River. Water quality in the unconfined aquifer has been impacted by human activities. The average chloride content is 23 ppm, twenty times higher than the average value in the confined aquifer. Water samples from several wells in the alluvium exceeded the drinking water standards for arsenic, barium, chromium, and lead.

Confined aquifer — The confined aquifer occurs in glaciofluvial gravel. Wells screened in this gravel, with the exception of those in the northern part of the study area, flow with up to 9m of head, or 15.5 psi of pressure, at the ground surface. The confined aquifer is recharged through exposures of permeable sediment on the lower valley walls and through fractured bedrock in the highlands. Water quality in the confined aquifer is excellent. Average chloride content is less than 2 ppm. Water from the confined aquifer meets all drinking water standards.

Aquitard — An aquitard of glaciolacustrine clay, slit, and fine sand dramatically limits the flow of ground water between the confined and unconfined aquifers. The thickness of the aquitard varies from 4.5m (15 feet) to 37m (120 feet). The aquitard coarsens to the north and west; it generally thins in the northern part of the study area and near the valley margins.

Implications

The spatial and textural distribution of glacial sediment controls the occurrence, flow, and quality of groundwater in the Hoosic River Valley. As the continental glacier retreated from the Hoosic River Valley, the ice was bordered directly by glacial Lake Bascom. Glacial till, deposited at the base of the glacier, is overlain by glaciofluvial gravel. This gravel was probably deposited by meltwater streams issuing from the glacier and directly discharging into the lake. This coarse, permeable gravel is overlain by fine grained, relatively impermeable, glacial lake sediment which was deposited in Lake Bascom as the glacier margin retreated into Vermont.

During the landfill study, we identified two sand and gravel aquifers, separated over most of the study area by a

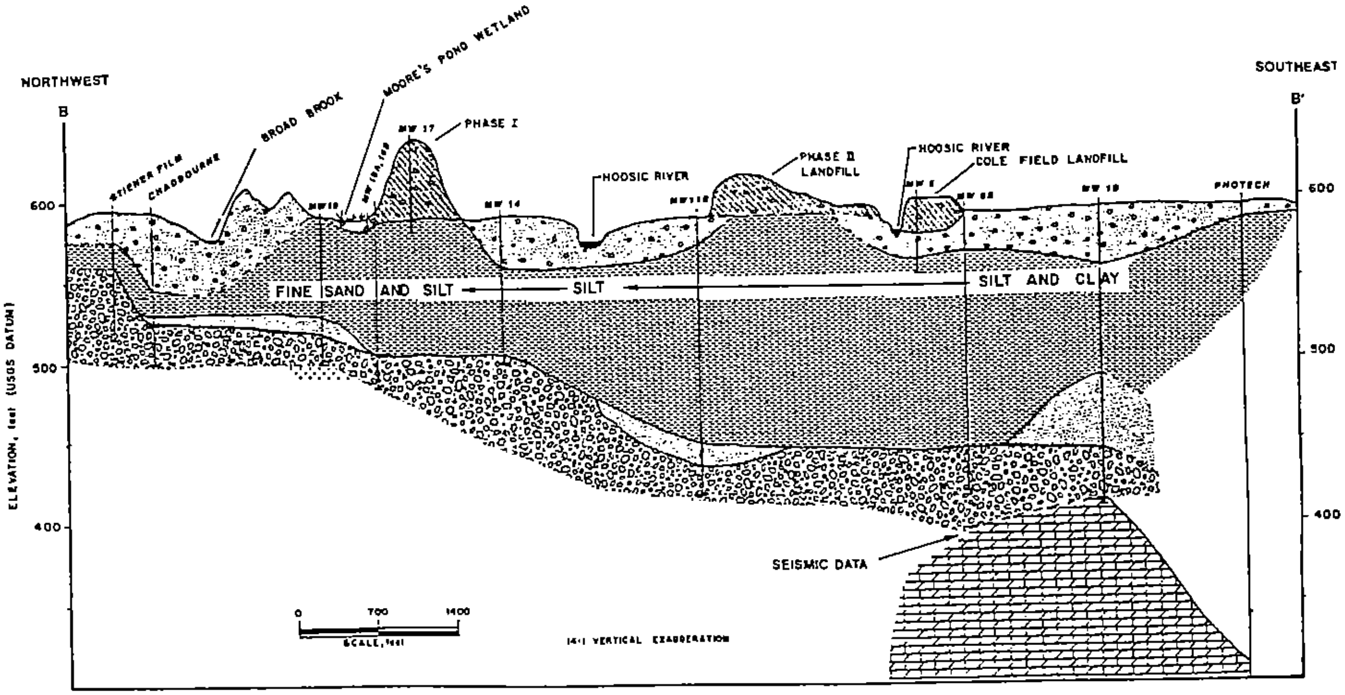


Figure 4. This geologic cross-section was generated with data collected during the landfill study. Geologic units shown on this figure correspond to those described in Figure 3.

Figure 5. This well was drilled into the confined or lower aquifer. The water, because it is under pressure, is flowing from the well without pumping.

silt and clay aquitard. Williamstown's drinking water supply is clean and ample because this aquitard separates the locally polluted upper alluvial aquifer from the extensive and permeable confined aquifer from which the town draws its water. The confined aquifer is recharged by precipitation falling on the surrounding mountainsides. Water in the confined aquifer will remain clean as long as these recharge zones are protected from pollution. If Lake Bascom had not filled the Hoosic River Valley 15,000 years ago, leaching landfills, leaking gas stations, and road salting might well have impacted Williamstown's drinking water supply.

After two years of work for Alliance Technologies, Paul Bierman is in his third year as a geology graduate student at the University of Washington, Seattle. His research now takes him to the Owens Valley and high Sierra of eastern California, where he continues to study glacial sediments. However, one thing's changed; it never, well almost never, rains on his field work anymore.

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THE ARIZONA GROUNDWATER CODE
The Public Good Redefined

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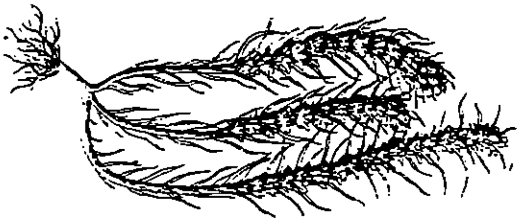
Western water law has always recognized that water is a "public good," placing certain limits on private rights to water unique among natural resources. The only problem is that the law arose in an era when there wasn't much public. Those few who would undertake the substantial investment necessary to develop scarce waters into usable quantities had to be given some assurance that their efforts would pay, and those who wished to see the sparsely settled areas develop were loathe to add any further obstacles to those already imposed by the harsh environment. Though the amount of a person's water right was generally limited to that which could be put to "reasonable and beneficial use" (a nod to the status of water as a scarce public resource) in practice these terms were read broadly, and the widely held goal was to make the desert bloom.



Although courts and state governments busied themselves from an early date with water allocation, protecting senior users in time of shortage, water conservation was not a central theme of regulatory efforts (though a court did once hold that the use of groundwater to flood out an irksome prairie dog village was *not* a beneficial use of water). The concept of beneficial use remained somewhat loose, and major disputes over rights to pump groundwater appear to have been relatively rare. Wells which had run dry could always be deepened a little to fix the problem.

The result in Arizona, not surprisingly, was the gradual development of a serious groundwater "overdraft" problem as irrigated farming and urban population both grew tremendously from World War II on. Overdraft, in simple terms, is the pumping of water at a faster rate than the natural rate of recharge of an aquifer through percolation from the surface. In Central and Southern Arizona, the long-term average overdraft of groundwater exceeds 2,000,000 acre feet per year, enough water to fill roughly 12,000 tankers the size of the Exxon Valdez. Total annual recharge is in the range of only 300,000 acre feet. The Phoenix metropolitan area is fortunate enough to receive substantial surface water supplies from the Salt and Verde rivers, and is now receiving Colorado River water through the Central Arizona Project (CAP) canal, but Tucson has been entirely dependent on groundwater, and the CAP canal has not yet been opened that far.

The consequences of overdraft are several. In a few areas of the state, the water table has declined as much as 600 feet. Not only is pumping at such depths difficult and expensive, but deep water is often contaminated with naturally occurring minerals. Land subsidence, though not as severe in Arizona as in some other areas with overdraft problems, is also a concern. As aquifers are depleted, the water-bearing strata tend to compact, reducing storage capacity and limiting natural and artificial recharge potential. In the short run, the groundwater depletion problem has obviously had little or no effect on the growth and development of the two main metropolitan areas. Arizona is perhaps one of the most "urbanized" states in the nation, with over 80% of the population living in its two main metro areas. By the mid-1970's, however, with the state's population growth reaching its peak rates, a broad spectrum of interests were acknowledging that the long-term outlook was not good, and that close regulation of the "mining" of groundwater was necessary. The 1980 Arizona Groundwater Management Act was thus forged, an ambitious attempt to reach "safe yield," or the balancing of pumping and recharge, by 2025 while still protecting, to the extent feasible, existing, long-vested interests in water.

A number of factors pushed the different water-using sectors to the negotiating table. Some of the pressure came from Washington, because of the billions in funding needed for the CAP. Congress wanted some assurance that CAP water would be used to solve part of the overdraft problem, rather than becoming a pure, heavily-subsidized, "bonus" which would only expand the state's water use. Major water users wanted to confirm the extent of their pumping rights, until then governed by the somewhat vague (at least as to amount) concept of beneficial use, in advance of further growth and change. The Code was thus hammered out over a roughly two-year period by a subcommittee of the Groundwater Management Study Commission, a body presided over by then-Governor Bruce Babbitt.

The subcommittee was essentially tripartite, with representatives of the cities, the mining industry and agriculture. Municipalities sought to protect their ability to meet the water needs of growing populations, and were leery of competition from private water suppliers and