Jo Holbert
5/13/94
ES 102

Broad Brook as a Source of Aquifer Recharge

Introduction

While it is commonly believed that streams are continually gaining water as they join with tributaries and are replenished by throughflow, recent evidence suggests that streams in some areas may simultaneously lose water to the subsurface and serve as sources of groundwater recharge. My project's purpose is to determine if Broad Brook is losing water to the subsurface, and if so, where and why the water is lost. A similar project was conducted along the same stretch of Broad Brook in 1993 by Maria Berger, also an Environmental Studies 102 student, and part of my purpose was to expand on the information she gathered and compare her data with my own observations. I also analyzed the concentrations of Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+} of Broad Brook in order to obtain a better understanding of the local rock types and to look for possible human effects on the cation concentrations in this area.

Information About the Area of Study

Broad Brook begins in the Green Mountains of Stamford, Vermont at an elevation of approximately 2360 ft. It flows through the town of Pownal, Vermont and into Williamstown, Massachusetts, where it joins the Hoosic River at a 570 ft. elevation. My study was conducted on the stretch flowing through the 590-1020 ft. range of elevation draining the Mason Hill area. The Hoosic River flows northwest through a valley underlain by "glaciolacustrine, glaciofluvial, and fluvial deposits in low-lying areas" and "unsorted glacial deposits at higher elevations" (Berger 1). The bedrock progresses from Cheshire Quartzite to limestone and dolomite at an elevation of approximately 1030 ft, becoming schist and phyllite as it enters the Hoosic Valley and finally returning to limestone and dolomite as the brook approaches and enters the Hoosic River (Ratcliffe, et. al.).

The history of Williamstown's geologic deposits is dominated by the presence of glacial Lake Bascom. "Continuing ice retreat to the north and west dammed the north-flowing Hoosic River system, forming a series of larger lakes that gradually coalesced to form Lake Bascom, which covered all of Williamstown to an elevation of 1050 to 1075 feet at about 15,500 years ago" (Dethier et. al. 19).[1] As the Laurentide Ice Sheet retreated, it uncovered spillways and caused the lake to suddenly drop to elevations of 900, 700, and 665 feet (Small and DeSimone 189).

Methods and Materials

I measured the discharge of Broad Brook at ten sites, seven of which were roughly the same sites as those measured by Maria Berger in the spring of 1993 (see Figure 1 for site locations). Three of these sites were along first-order tributaries to Broad Brook, and the remaining seven were along second-order Broad Brook. I visited the stream on four separate occasions and took measurements at each site. The dates of these measurements were 4/19/94,

[1] The 1015 foot level was first reported in Taylor 1903, which is included in the bibliography at the end of this report.

4/26/94, 4/28/94, and 4/30/94. Because of weather and time constraints, measurements were not taken at sites 2, 9, and 10 on 4/19/94 and at site 1 on 4/30/94. Ingrid Lundin, Jenny Schumi, Tessy Seward, and Sandy Brown gave generously of their time to help in the data gathering process. Dave DeSimone assisted greatly in the data analysis.

The discharge was calculated using the formula:

discharge = width x depth x velocity

After measuring the total width of the stream with a tape measure, I broke each cross-section into smaller segments of uniform width and measured the depth and velocity of each segment using a meter stick and a current meter. I then added the discharge of each segment in order to obtain a total discharge calculation for each cross-section.

For my chemical analysis, I sampled the stream water at seven of the ten sites. These samples were then filtered and diluted by a factor of 10. I combined 4 mL of each sample with 1 mL of cesium chloride for the sodium and calcium analyses, and for the magnesium and potassium, I combined 4 mL of sample with 1 mL of lanthanum chloride. These solutions were then analyzed by Sandy Brown using atomic absorption spectrophotometry.

Results

- See Figures 1-6 for data analysis.
- See pages D1-D10 for a site by site analysis.

Discuss results in text. Explain what point is being made by each figure. Then use Discussion to interpret patterns.

Discussion

Figure 2 illustrates the general trend of the discharge along this stretch of Broad Brook. The data from all days suggest that there is a gradual increase in discharge as tributaries marked by sites 2 and 5 join the brook and as groundwater flows into the stream as well. This increase peaks at site 7 in all cases except that of 4/28/94. I am convinced that there must have been an error in this measurement, for I see no reason for the stream to suddenly lose water at this location when it has demonstrated a gain on all other days. This transect was taken across an especially rocky area on this particular day, and so this probably interfered with the accuracy of this measurement as the incremental readings were often taken over rocks and had depth measurements of zero as a result. Another questionable point was the data for site 4 on 4/19/94, which I threw out because it was more than twice the sum of sites 2 and 3. This would be nearly impossible because no tributaries join the stream between these sites, and it is unrealistic as demonstrated by the data for site 4 on the other 3 days.

After site 7, the discharge drops off suddenly and hits a low at site 9, then increasing again to site 10. These data suggest that the brook is actually experiencing downward seepage of water into the subsurface in this area. We can not be sure whether or not this water is recharging the deep aquifer in this area.

The discharge of 4/19/94 is extremely higher than those measured over the following week. The combination of a high-intensity period of rainfall during the few days preceding our measurements for 4/19/94 and the melting of the remaining snow during this rain produced these elevated discharge measurements. One local resident I talked with estimated that the brook was at it's seasonal peak in the few days surrounding 4/19/94. In the following week, discharge dropped regularly after a period of slight rainfall.

Overall, it appears that the brook gains and loses water in the same areas during both high and low levels of discharge. Without data for sites 9 and 10 on 4/19/94, we cannot determine the rate of water loss during extremely high levels of discharge; however, the loss demonstrated on this day between sites 7 and 8 suggests that during periods of high flow the rate of water loss is less than during periods of lower flow. This could be due to a higher velocity hindering downward seepage and the higher saturation of the shallow aquifer at this time. However, the high level of water is insufficient to reverse the hydraulic gradient; net seepage is still downward into the subsurface during periods of high flow.

My data compare favorably with those gathered last spring by Maria Berger (Figure 3) She too noticed a peak at her transect closest to my site 7 followed by a drop-off in discharge until the brook joins the Hoosic River. The main difference is that my data shows an increase in discharge between sites 9 and 10 where her data showed a decrease. Her final point for this interval was much further downstream than mine, so perhaps there is an increase and then a decrease as the stream approaches the Hoosic River.

The principle factor determining whether the net seepage of a stream at any given spot will be into the stream or into the subsurface is the geology underlying the area. In its upper reaches, Broad Brook flows over modern alluvial deposits underlain by a thick layer of highly impermeable glacial till (Dethier, et. al.). This till is composed primarily of Cheshire Quartzite and is therefore sandier and has a slightly higher hydraulic conductivity than dolomitic till (pers. com. David DeSimone). However, the presence of this till between sites 1 and 7 prevents downward seepage of the brook and channels the flow of the water in the shallow aquifer into Broad Brook. The combination of the water entering the brook from this throughflow and from the tributaries, such as the two marked by sites 1 and 2 and site 5, produces the continual increase in discharge in the upper reach of my study area.

Somewhere in the vicinity of the 700 ft. level, between sites 7 and 8, the discharge begins to drop quickly and continuously. This region is underlain by modern alluvial fan deposits and probably deltaic deposits left from the 700 ft. level of Lake Bascom, as well as deltaic sediments of the higher lake levels that were eroded and washed downstream after the lake level dropped from their original deposition sites at higher locations. Such sediments consist of primarily sand and gravel and are thus highly permeable. The increase in the width of the brook at site 8 suggests the presence of glaciofluvial sediments (see Figure 4). Although the discharge decreases substantially, the brook's width increases between 50 and 60 percent. This suggests that the brook originally flowed through a more erodable material at site 8, consistent with the assertion that the underlying deposits have moved from a cemented till to a looser and easily eroded sand and gravel in this region. This increase in width may be partially due to the decreasing slope at this site, which lowers the velocity of the river and increases the width. However, this alone probably does not account for such a large increase when the discharge has dropped simultaneously.

It has been estimated that the thickness of the sand and gravel in the area around site 8 lies between 40 and 80 feet (pers. com. Dave DeSimone). The existence of this thick layer of permeable sediment could explain the decrease in discharge at site 8. Because the brook loses no water in the form of overland flow between sites 7 and 8, it must be feeding into this layer of sand and gravel and into the shallow aquifer, which flows primarily towards the Hoosic River.

It is quite possible that the decrease in discharge indicates the recharge of the deep aquifer by Broad Brook. As Figure 5 illustrates, streams have the potential to serve as sources of recharge to the deep aquifer in the absence of a confining aquiclude (Morrissey, et. al. 20). Till appears to be present in the vicinity of site 8, for boulders too large to have "floated" downstream or have been used as riprap were found in the streambed. These boulders are of definite till origin because they possess the crescent-shaped scars indicative of the collisions between ~~chunks~~ clasts beneath ice ~~of till~~. If present, the till lies far below the surface; it's quite possible, however, that it was partially or completely eroded away by the turbulent water flowing into Lake Bascom, and these boulders may be remainders of what was once a layer of till. In addition, the till is likely to be thinner beneath the lower reaches of the brook because much of the till was deposited as the ice sheet rose above Mason Hill and dropped it (till?) into the Broad Brook valley, and Lake Bascom and the tongue of ice that held it kept the till from being deposited as heavily in the lower regions which they covered. Therefore, the layer of till could be thin or discontinuous in this area, allowing stream water to seep into the deep aquifer.

This area also has great potential for recharge because the fine sand, silt, and clay sediments present in the Hoosic Valley are not present here. The inflow of Broad Brook into Lake Bascom created an environment too turbulent to allow these fine glaciolacustrine sediments to settle out. They were deposited further away from the turbulent edges of the lake. "Where sediment-rich water entered the lake, deposits of sand and gravel formed, and finer sand, silt, and clay rained to the lake bottom in areas more distant from the ice or tributary deltas. Till previously deposited beneath the ice was eroded away in some places, covered locally with coarse deposits and in many areas with fine-grained lacustrine material" (Dethier, et. al. 19). ? date? page number?

When the lake level dropped to 665 feet, it is probable that whatever lacustrine sediments had been deposited beyond the 700 foot delta were then eroded away in the turbulent water while glaciofluvial sediments were deposited. Therefore, a long stretch of sand and gravel glaciofluvial deposits probably ranges from just above the 700 foot level to the bottom of the delta corresponding to the 665 foot lake level, somewhere between 625 and 650. This stretch would lack a layer of glaciolacustrine sediments and be underlain by either a thin or discontinuous or possibly absent layer of till. It is roughly between the above elevations that the discharge of Broad Brook has shown to be decreasing continually; thus, if the above conditions do exist, Broad Brook is almost certainly recharging the deep aquifer.

Hmmmm.

According to my data, the discharge increases suddenly as it passes through the 620 - 610 ft. range of elevation. Because the brook is flowing into the Hoosic Valley within this range and the slope of the brook has decreased, it actually gains this water over a much larger stretch of land than would appear on the graph. As illustrated by Maria Berger's data in Figure 3, there appears to be a net loss in discharge between the 620 and 570 ft. elevations. I trust this final measurement for the 570 ft. elevation because a qualitative observation of the brook where it flows into the Hoosic River made it clear to me that a substantial loss had occurred between the above elevations. Perhaps the brook regains some of the lost groundwater and then loses it again to the subsurface. This is possible, for the sand and gravel deposits are covered by a glaciolacustrine layer which increases in thickness as one moves away from the former edges of Lake Bascom. However, once the brook approaches the Hoosic River, it flows over modern alluvial deposits from the Hoosic which could be fairly thick, and thus it could lose water in this region of thicker sand and gravel. The well log for Boring 30, which is located about 1/4 miles southwest of Site 10 at an elevation of approximately 590 ft., shows that the sediments from this location include (top to bottom) a layer of sand and gravel fill about 10 ft. thick, a layer of glaciolacustrine fine sand and silt about 80 ft. thick, and then a layer of glaciofluvial sand and gravel about 30 ft. thick (Dethiers et. al.). The thick layer of glaciolacustrine sediment probably extends up to and beyond Site 10, hindering any transfer of water into the deep aquifer which may have been occurring and covering the layer of permeable sand and gravel which lay beneath the river at higher elevations where the discharge dropped so rapidly. The combination of these factors reverses the hydraulic gradient at Site 10.

For my chemical analysis, I examined the concentrations of Mg^{+2}, Ca^{+2}, Na^{+}, and K^{+} at sites along Broad Brook. K^{+} concentrations were fairly consistent and less than 1 mg/L at all sites. Figures 6 demonstrates the results of my analyses. Trends aren't obvious here. Because the concentrations of these cations are relatively small, we cannot interpret them too critically except to recognize that they **are** small. I expected to see an increase in Ca^{+2}, Mg^{+2}, and possibly Na^{+} as the bedrock transformed from quartzite to limestone and dolomitic marble; however, no such increase occurred. Perhaps the bedrock is far beneath the surface in all locations; there are no known exposures anywhere in the vicinity of stream along the stretch I chemically analyzed. Therefore, any cations are derived from the clay through which the groundwater feeding the stream has passed and from the sediments in the streambed, which are overwhelmingly quartzite throughout this reach of the brook (pers. com. David DeSimone).

As briefly mentioned earlier, a few measurements were likely to have been made in error, most noticeably the measurements for Site 4 on 4/19/94 and Site 7 on 4/28/94. I quantified my error by qualitatively considering how much discharge I may have added or missed as a result of the location of my points of measurement across the stream and the rocks and other obstacles which prevented accurate measurements. In general, I don't believe the total discharge measurements could be off by more than 0.1 m^3/s in either the positive or negative direction.

Conclusion

In summary, the data collected in this project shows that Broad Brook is losing water to the subsurface and is potentially recharging the deep aquifer. The brook flows through impermeable glacial till in the higher elevations (750+ ft.), alluvial and deltaic sand and gravel deposits (which may or may not be completely underlain by till) as it approaches the Hoosic River Valley (620 - 750 ft.), and alluvial sediments underlain by glaciolacustrine deposits with glaciofluvial sand and gravel below as it flows through the valley and into the Hoosic River (570 - 620 ft.). The brook is definitely losing water in the middle region. Where this lost water ends up is uncertain; however, the probability that it recharges the deep aquifer is fairly high.

The area of my study is not regulated as an area of aquifer recharge as "previous models of stratified-drift aquifers may have underestimated the magnitude of upland recharge" (Morrissey, et. al. 33). I found a disturbing amount of trash along the riverbanks as I conducted my study, most of it old metal parts and white goods. One resident informed me that areas along White Oaks Road have been used as dumping grounds for some time, and I observed several "no dumping" signs posted along the road. Near the landfill and the Steinerfilm company, I found old hubcaps in the streambed as well as pieces of scrap metal protruding from the banks. The houses along White Oaks and Sand Springs Roads may have septic systems close to the stream, and "the use of lawn fertilizers is probably common practice" (Berger 6). Such conditions should be avoided in any area, but when next to a stream that is very probably recharging the source of drinking water for a community, these conditions are hazardous.

"Land-use regulations will protect water quality in stratified-drift aquifers more effectively if they are applied not only to land surface above the aquifer, but also to adjacent upland hillsides and to watersheds of tributary streams that cross the aquifer, from which a large percentage of recharge is derived" (Morrissey, et. al. 35).

This is why research of streams as a source of aquifer recharge is important and essential in the future.

Bibliography

Berger, Maria. "Groundwater Recharge from Broad Brook." Williams College, Environmental Studies 102, May, 1993.

Dethier, D.P., DeSimone, D.J., and Oelkers, E. "The Surficial Deposits and Hydrogeology of Williamstown, MA", Volumes I and II, 1989.

Morrissey, Daniel J., Randall, Allan D., and Williams, John H. "Upland Runoff as a Major Source of Recharge to Stratified Drift in the Glaciated Northeast", American Water Resources Association. Year?

Ratcliffe, Nicholas M., Potter, Donald B., and Stanley, Rolfe E. "Bedrock Geologic Map of the Williamstown and North Adams Quadrangles, Massachusetts and Vermont, and Part of the Cheshire Quadrangle, Massachusetts", USGS, 1993.

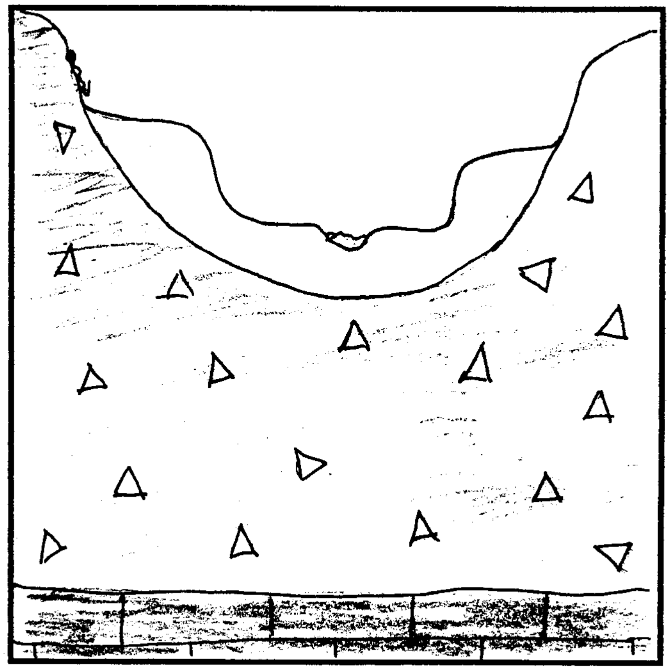
Small, Eric, and DeSimone, David ~~D.~~ J. "Asynchronous Ice Lobe Retreat: Deglaciation of the Hoosic and Vermont Valleys, Southwestern Vermont". GSA Abstracts with Programs, Northeastern Sectional Meeting, 1993, pp 79-80, in Saffer, Demian, and Madera, Edwin P. "The Flood Channel History of Glacial Lake Bascom: A Miniature Scablands", presented at The Seventh Keck Research Symposium in Geology, April 1994.

Taylor, F.B. "The Correlation and Reconstruction of Recessional Ice Borders In Berkshire County, MA", Journal of Geology, University of Chicago Press, Chicago, IL, 1903, pp 323-364, in Saffer, Demian, and Madera, Edwin P. "The Flood Channel History of Glacial Lake Bascom: A Miniature Scablands", presented at the Seventh Keck Research Symposium in Geology, April 1994.

...Well organized & nicely presented study
...The tie into Morrissey et al. is effective.

Site	1
Elevation (ft.)	1010
Width (m)	3.3
Discharge 4/19/94 (m^3/s)	0.637
Discharge 4/26/94 (m^3/s)	0.251
Discharge 4/28/94 (m^3/s)	0.147
Discharge 4/30/94 (m^3/s)	N/A

Cross-section Site 1



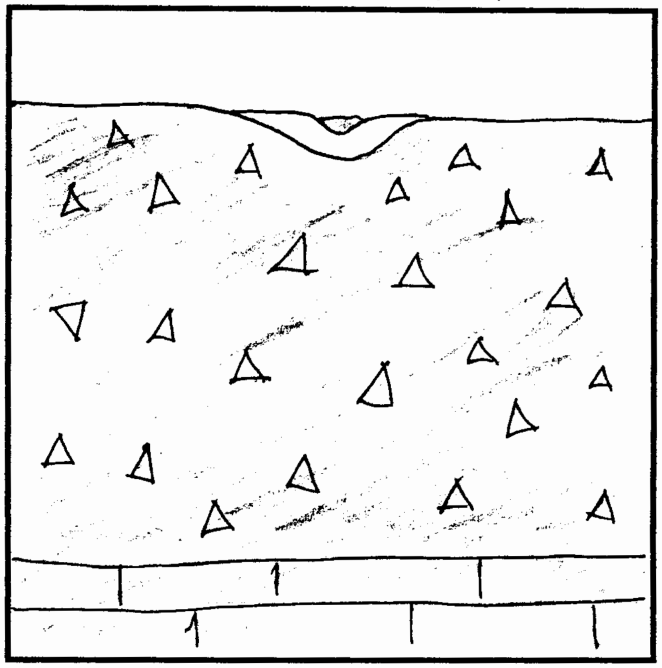
Alluvial Deposits
Till
Cheshire Quartz
Seepage

Notes:

- Northern tributary to Broad Brook
- Developed terraces
- Seepage out of till occurring in several places on vertical slopes
- Till exposed on hillsides (Cheshire Quartz)

photo taken 4/19/94

Cross-section Site 2



Site	2
Elevation (ft.)	920
Width (m)	2.5
Discharge 4/19/94 (m^3/s)	N/A
Discharge 4/26/94 (m^3/s)	0.159
Discharge 4/28/94 (m^3/s)	0.141
Discharge 4/30/94 (m^3/s)	0.101

Alluvial Deposits

Till

Limestone and Dolomite

Notes:

- Just before convergence with Main Branch Broad Brook
- North Branch has passed through an old dam between Site 1 and Site 2; dam appears to be out of use.
- Floodplain has widened

Photo

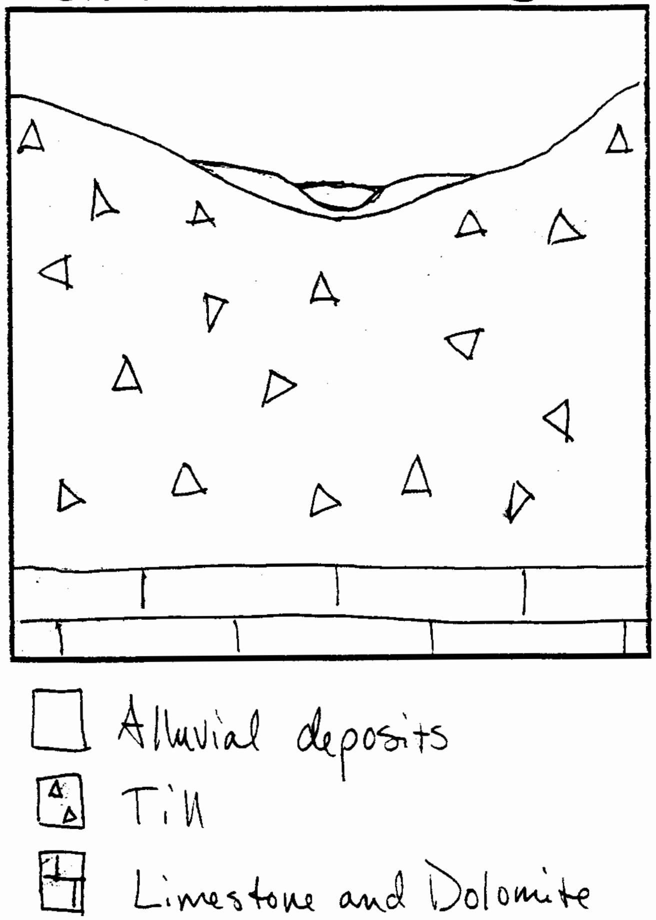
Not Available

Site	3
Elevation (ft.)	920
Width (m)	4.7
Discharge 4/19/94 (m^3/s)	1.587
Discharge 4/26/94 (m^3/s)	0.659
Discharge 4/28/94 (m^3/s)	0.624
Discharge 4/30/94 (m^3/s)	0.506

Notes:

- Just before convergence with Northern Branch

Cross-section Site 3



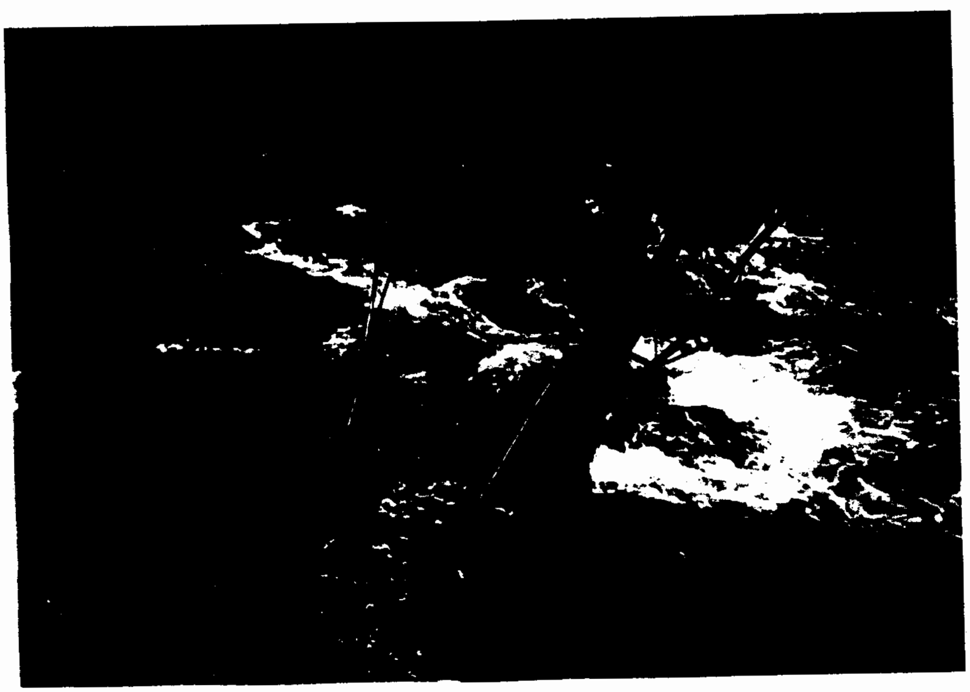


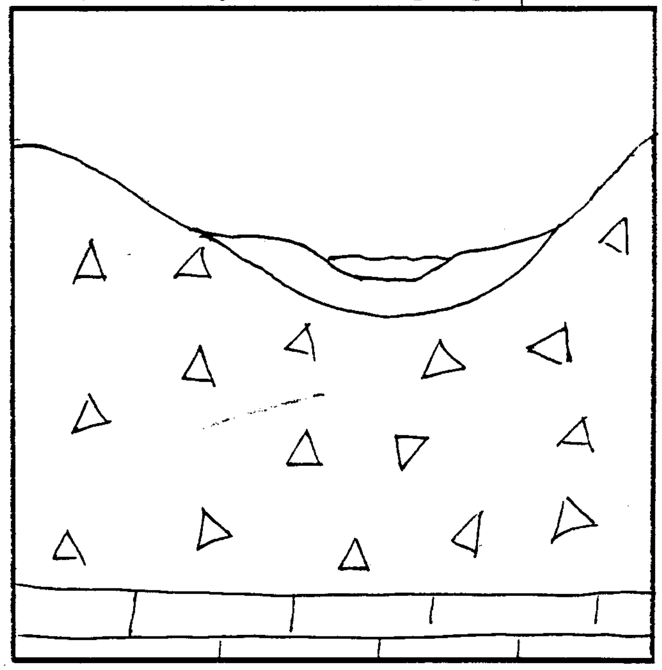
Photo taken 4/19/94

Site	4
Elevation (ft.)	900
Width (m)	7.7
Discharge 4/19/94 (m^3/s)	3.616 (?)
Discharge 4/26/94 (m^3/s)	1.007
Discharge 4/28/94 (m^3/s)	0.866
Discharge 4/30/94 (m^3/s)	0.631

Notes:

- Just after convergence with Northern Branch
- Lots of trash on western bank: mainly scrap metal

Cross-section Site 4



Alluvial Deposits

Till

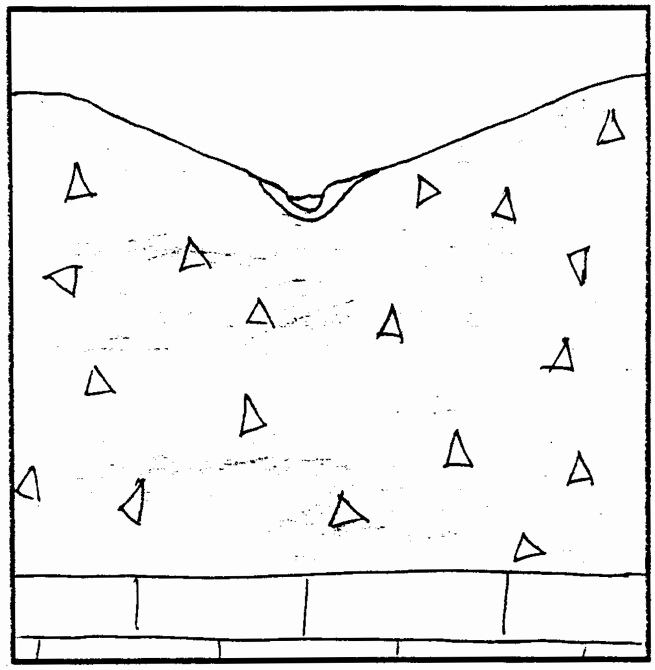
Limestone and Dolomite

Photo taken 4/19/94

Site	5
Elevation (ft.)	900
Width (m)	2.0
Discharge 4/19/94 (m^3/s)	0.155
Discharge 4/26/94 (m^3/s)	0.042
Discharge 4/28/94 (m^3/s)	0.052
Discharge 4/30/94 (m^3/s)	0.339

Notes:

- small tributary to Broad Brook



Alluvial Deposits

Till

Limestone and Dolomite

Photo taken 4/19/94

Cross-section Site 6

Site	6
Elevation (ft.)	818
Width (m)	10.8
Discharge 4/19/94 (m^3/s)	2.326
Discharge 4/26/94 (m^3/s)	1.621
Discharge 4/28/94 (m^3/s)	1.342
Discharge 4/30/94 (m^3/s)	0.749

Notes

- Till still mainly composed of Cheshire Quartz

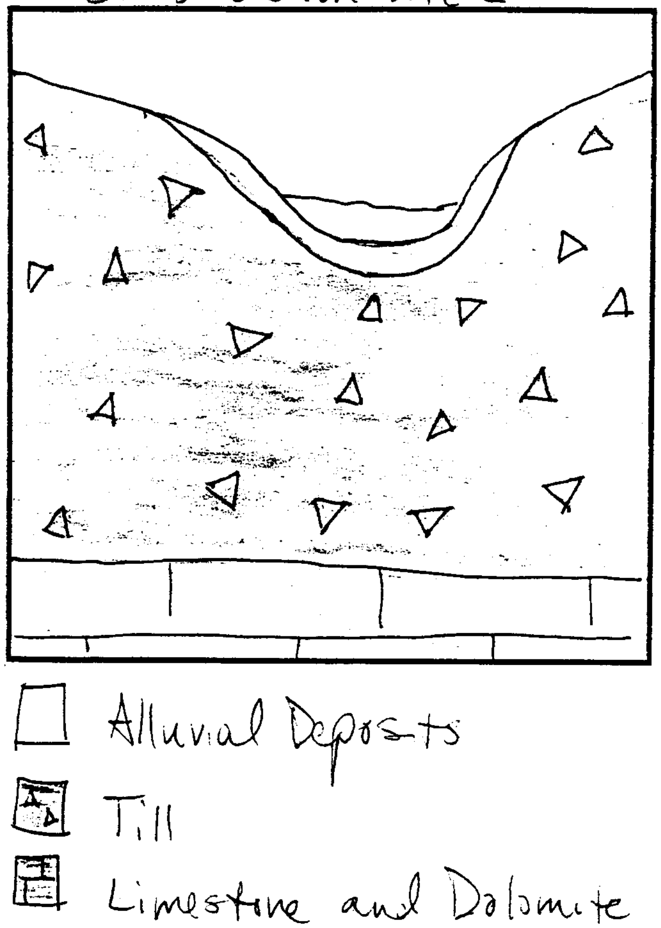


Photo taken 4/19/94

Site	7
Elevation (ft.)	740
Width (m)	9.0
Discharge 4/19/94 (m^3/s)	3.236
Discharge 4/26/94 (m^3/s)	1.748
Discharge 4/28/94 (m^3/s)	(?) 1.081
Discharge 4/30/94 (m^3/s)	1.366

Notes:

- Tiny tributary joins Broad Brook between Site 6 and Site 7

Cross-section Site 7

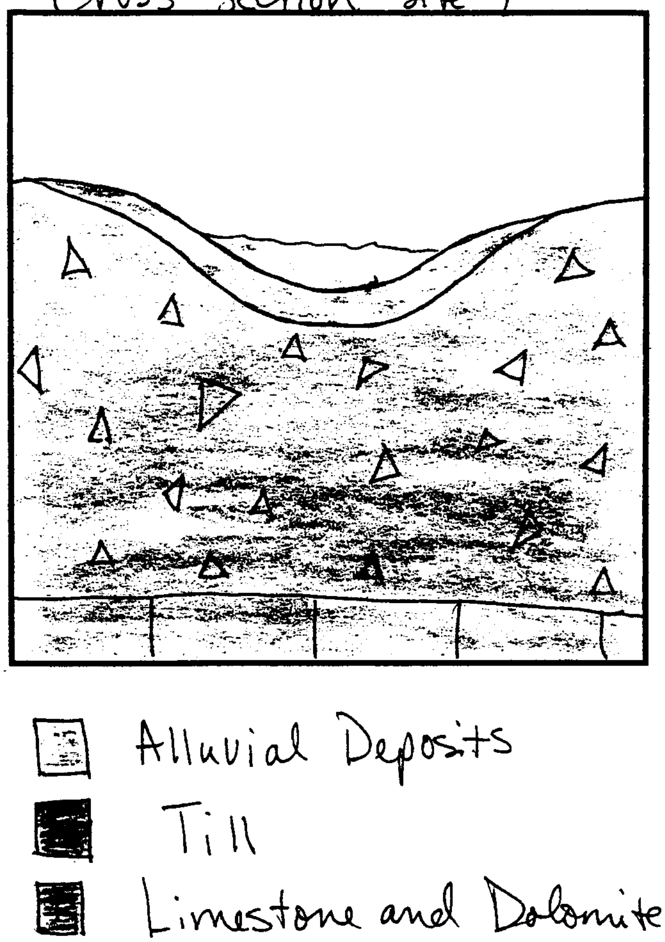


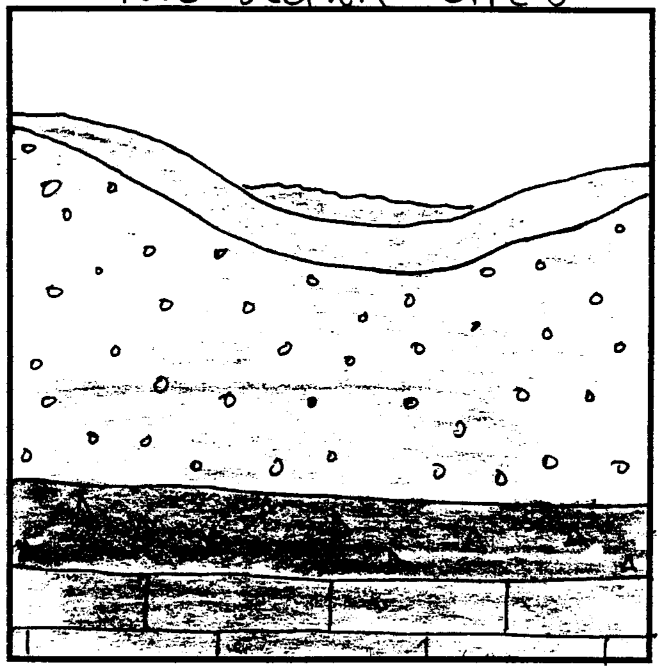
Photo taken 4/19/94

Site	8
Elevation (ft.)	665
Width (m)	13.93
Discharge 4/19/94 (m^3/s)	3.142
Discharge 4/26/94 (m^3/s)	1.267
Discharge 4/28/94 (m^3/s)	1.265
Discharge 4/30/94 (m^3/s)	0.876

Notes:

- Width has increased greatly
- Alluvial deposits thicker (part of Alluvial fan)
- Note size of boulders - till seems to be present
- Till could be discontinuous

Cross-section Site 8



- Alluvial Deposits
- Glaciofluvial and Deltaic Deposits
- Till
- Limestone and Dolomite

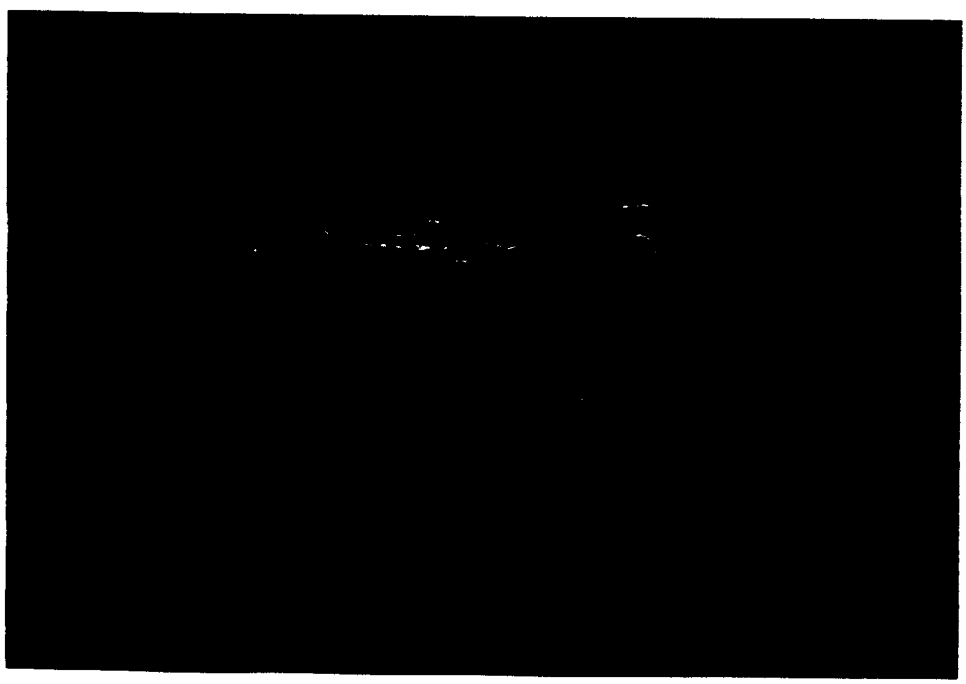
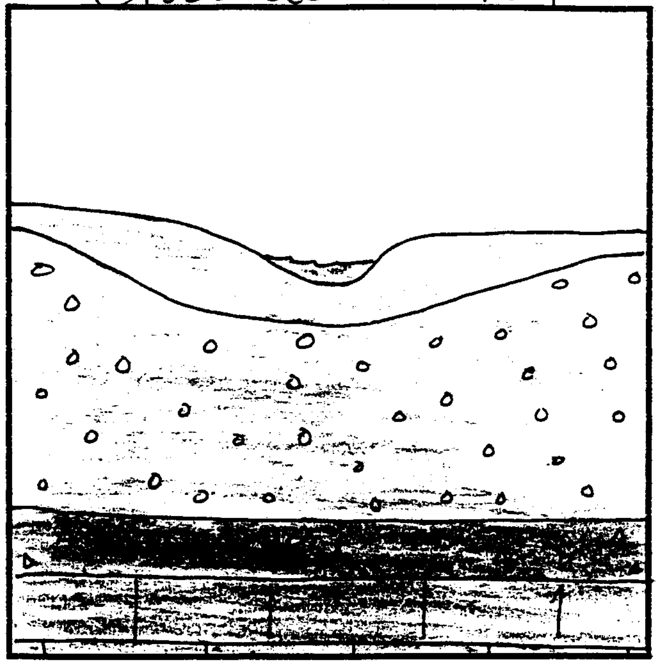


Photo taken 4/19/94

Cross-section Site 9

Site	9
Elevation (ft.)	620
Width (m)	8.3
Discharge 4/19/94 (m^3/s)	N/A
Discharge 4/26/94 (m^3/s)	1.140
Discharge 4/28/94 (m^3/s)	0.888
Discharge 4/30/94 (m^3/s)	0.693



Notes:

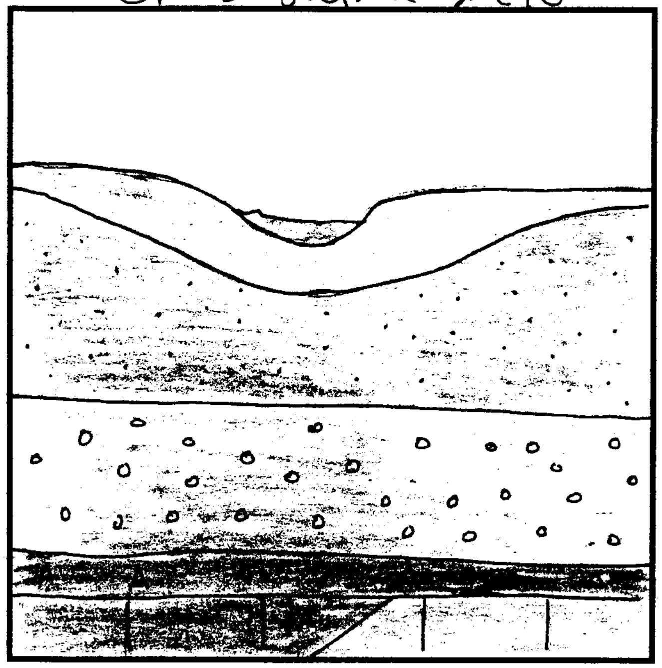
- Size of till has decreased; these boulders could have been transported downstream in high flow
- Just before Broad Brook crosses Rte. 7
- Till layer is thinning

Alluvial Deposits
Glaciofluvial and Deltaic Deposits
Till
Schist and Phyllite

Photo taken 4/28/94

Cross-section Site 10

Site	10
Elevation (ft.)	610
Width (m)	9.3
Discharge 4/19/94 (m^3/s)	N/A
Discharge 4/26/94 (m^3/s)	1.347
Discharge 4/28/94 (m^3/s)	1.177
Discharge 4/30/94 (m^3/s)	0.975



Notes:

- Boulders have become cobbles
- Till layer has become thin or disappeared completely
- Old landfill nearby has left trash in streambed and on banks; mostly scrap metal & appliances

□ Alluvial Deposits
▩ Glaciolacustrine Silt and Clay
▩ Glaciofluvial and Deltaic Deposits
▩ Till
▩ Schist and Phyllite switch to Limestone and Dolomite in vicinity of this site

Photo taken 4/28/94

13

- Site 1
- Site 2
- Site 3
- Site 4
- Site 5
- Site 6
- Site 7
- Site 8
- Site 9
- Site 10

Figure 1

COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

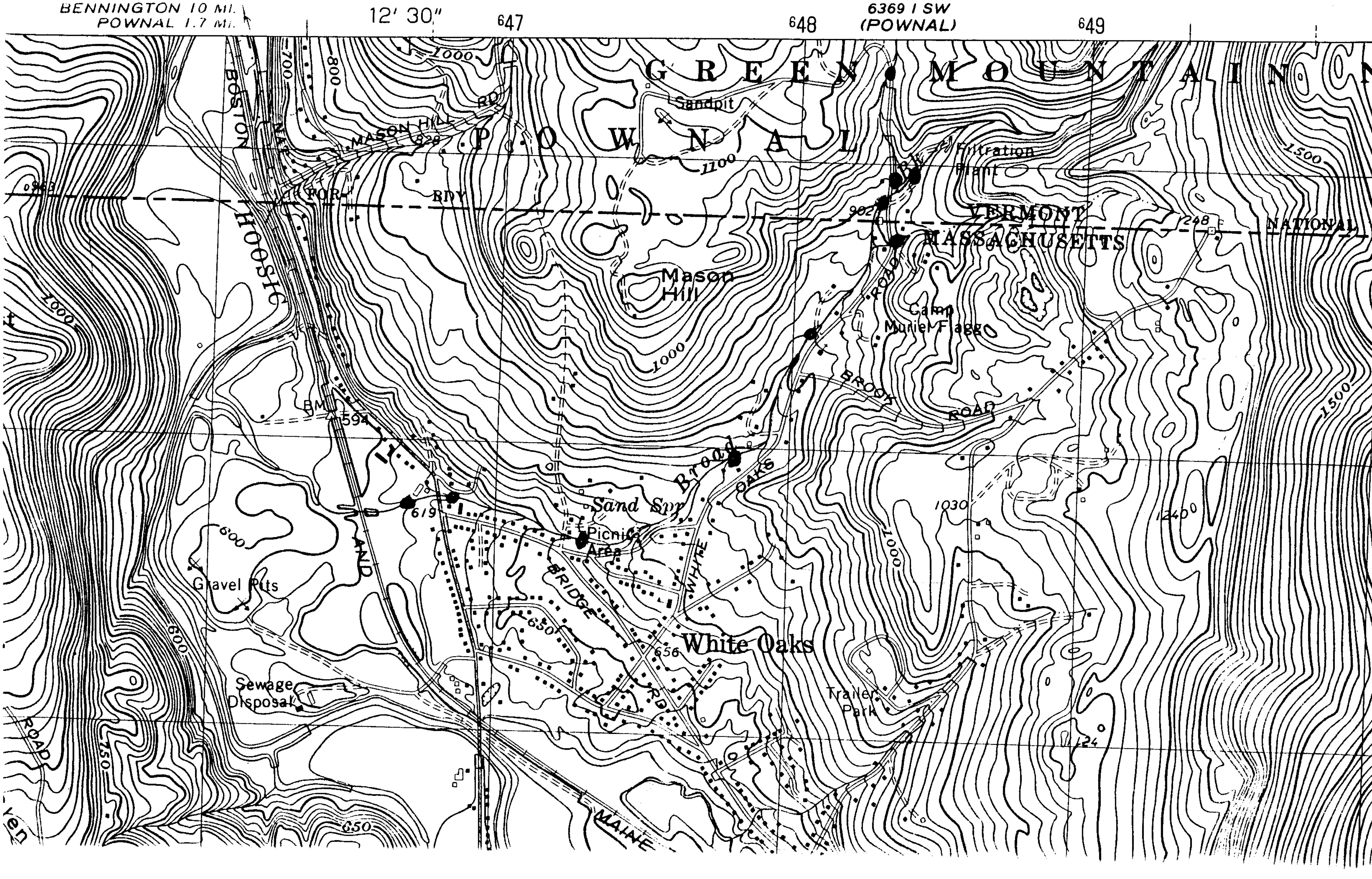


Figure 2:

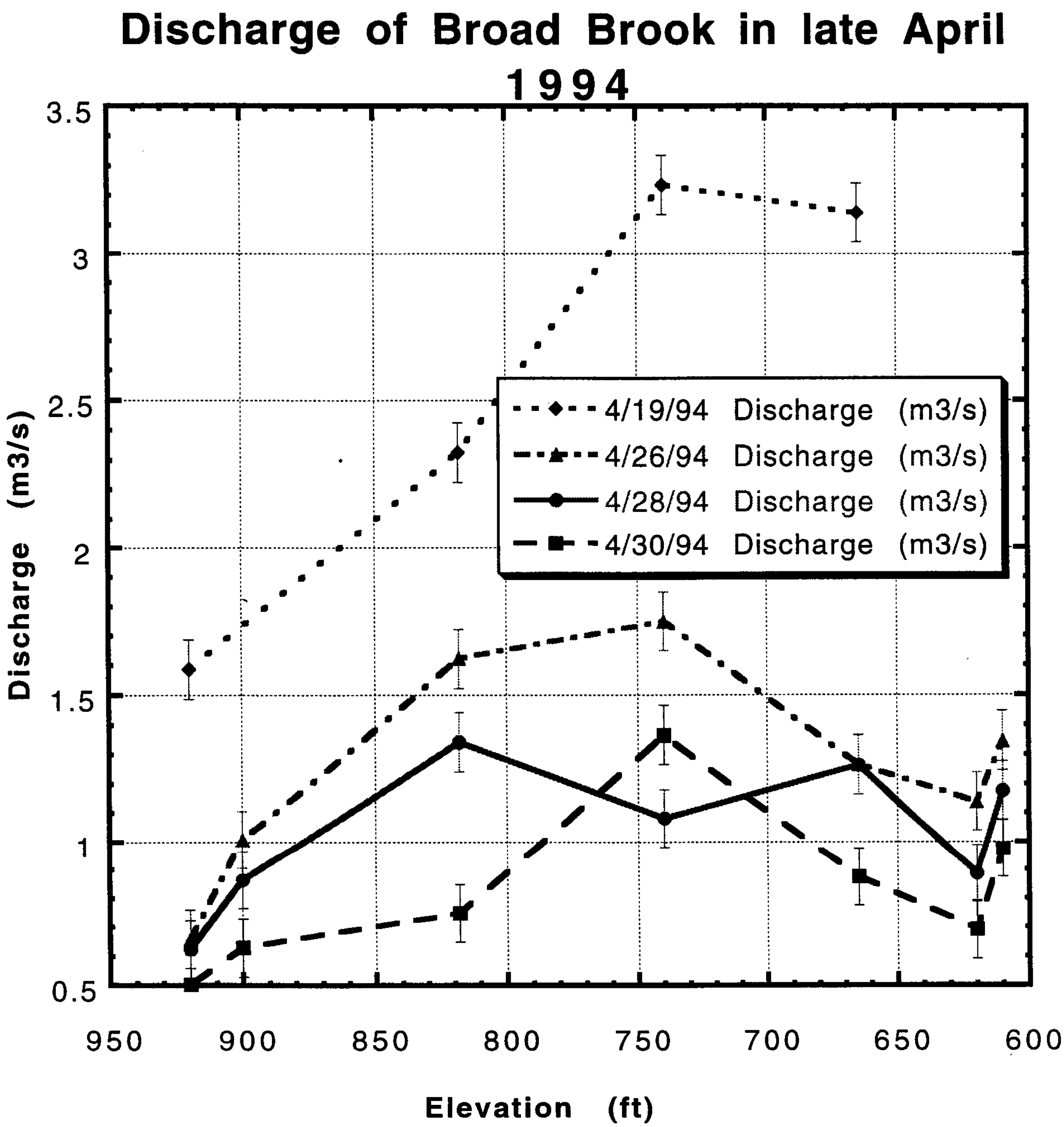

Discharge of Broad Brook in late April 1994
3.5
3
2.5
2
1.5
1
0.5
950
900
850
800
750
700
650
600
Elevation (ft)
Discharge (m3/s)
4/19/94 Discharge (m3/s)
4/26/94 Discharge (m3/s)
4/28/94 Discharge (m3/s)
4/30/94 Discharge (m3/s)

Figure 3

Comparison of Discharge Along Broad Brook 1993 and 1994

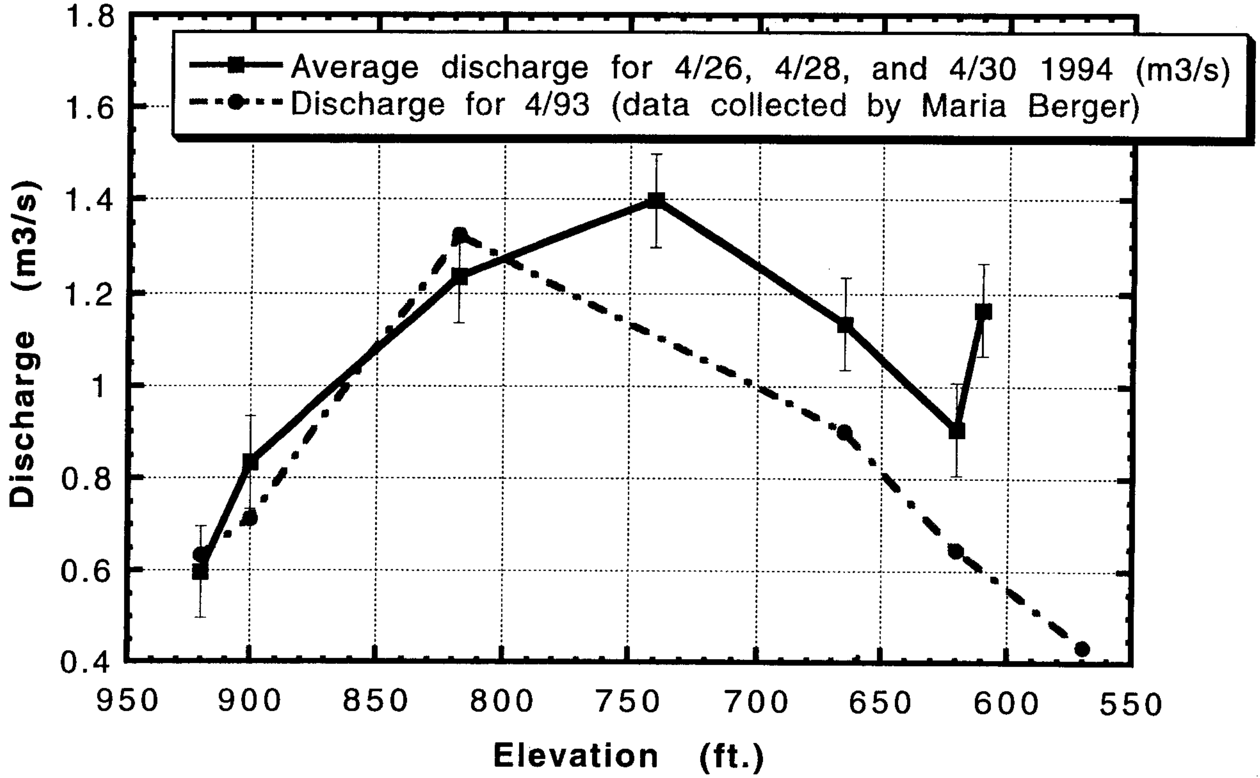


Figure 4:

Width increases while discharge decreases over region of thicker alluvial and deltaic deposits

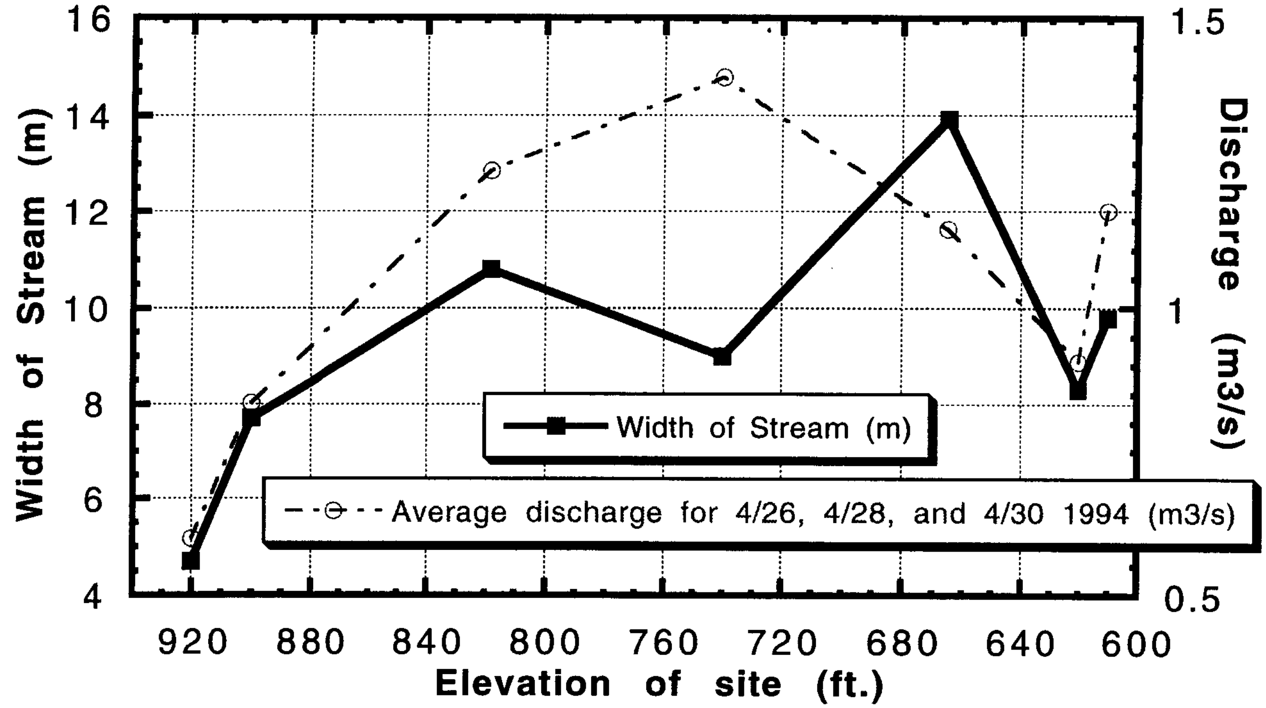
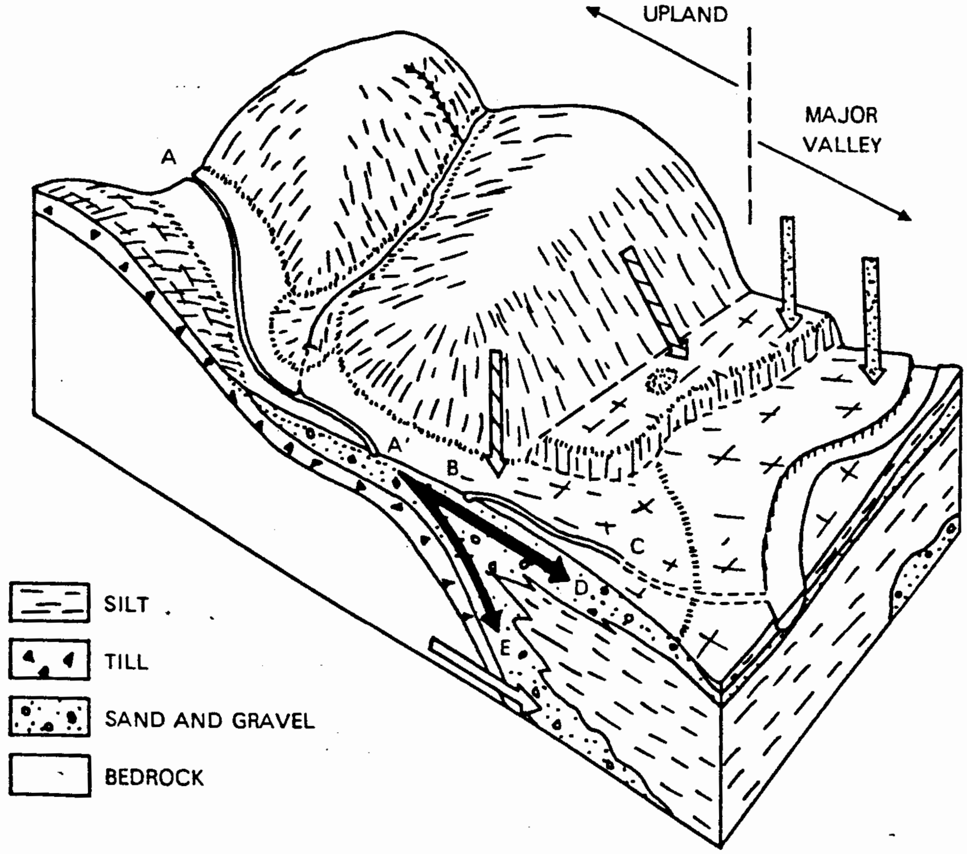


Figure 5:
Sources of Recharge to Stratified Drift in Valleys in ~~the~~ Glaciated Northeast



SOURCES OF RECHARGE TO SAND AND GRAVEL IN MAJOR VALLEYS

Unchanneled storm runoff and (or) ground-water flow from upland hillsides

Regional ground-water flow through bedrock

Precipitation on the valley floor

Tributary-stream infiltration (see letters A - E)

A═A' Tributary reach that gains water from ground-water discharge

B Edge of major valley, where wider, thicker sand and gravel deposits transmit more water than alluvium in tributary valley, so that water table drops below tributary channel and tributary loses water to the underlying aquifer

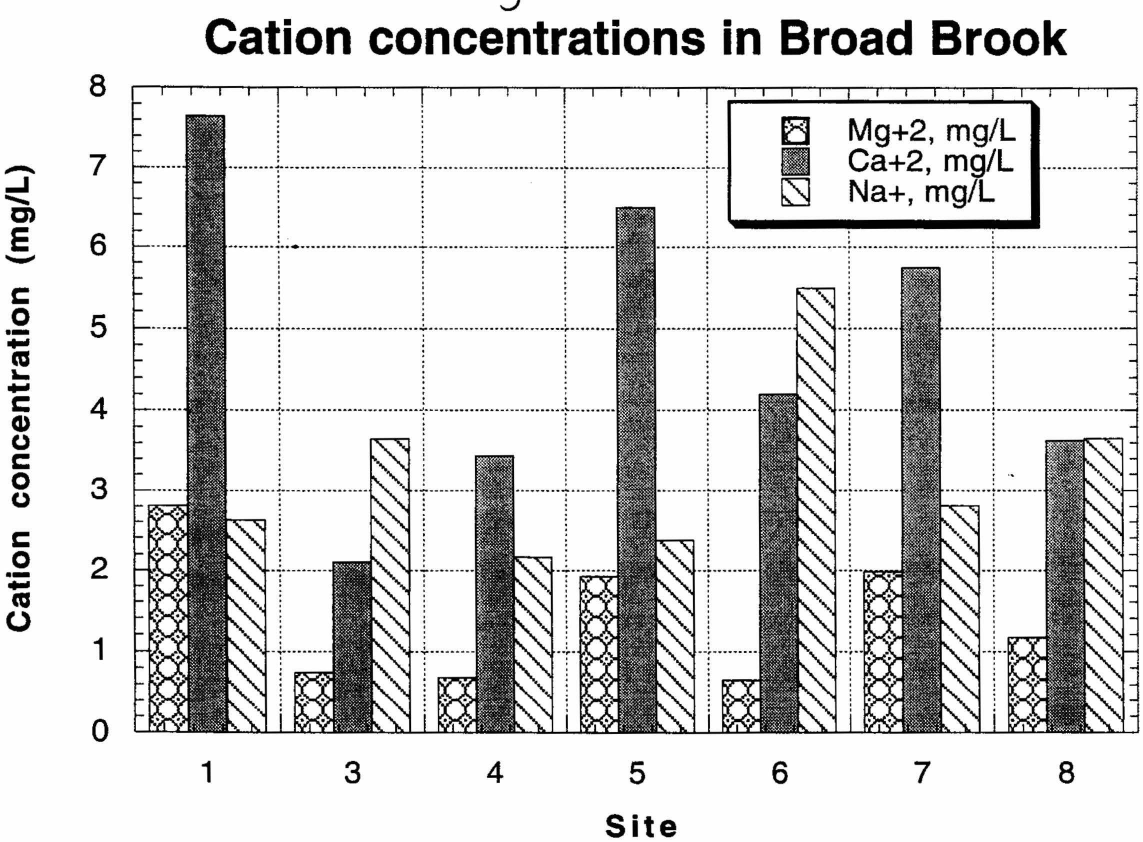
C Tributary goes dry here, where cumulative seepage loss equals streamflow at A'

D Recharge that moves laterally to river

E Recharge that moves downward to deeper aquifers

Source: Morrissey, et. al. 20

Figure 6


Cation concentrations in Broad Brook
Mg+2, mg/L
Ca+2, mg/L
Na+, mg/L
Cation concentration (mg/L)
0
1
2
3
4
5
6
7
8
1
3
4
5
6
7
8
Site