SECTION 1 - INTRODUCTION

1.1 PROBLEM STATEMENT

Homeowner reports of foundation-related problems and structural damage in Amherst, New York, increased in the late 1990s and peaked in 2003. Of the estimated 31,000 residential structures with basements, about 1,095 homeowners have contacted the Town of Amherst (Town) to request a foundation repair permit, make a foundation inquiry, or have their property value assessments lowered because of foundation-related damages. However, many homeowners are concerned about stigmatizing their neighborhood or adversely affecting their property value, thus the actual number of repaired and damaged houses, their age, and repair cost is somewhat uncertain and disputed.

The majority of damaged houses are located north of Main Street, in the lowland, and on fine-grained lacustrine soils. The geographic pattern and severity of the damage is irregular, akin to earthquake damage, and can affect none, one, or a cluster of houses in close proximity.

Damage symptoms commonly include cracked and bowed basement walls and slabs, and/or uneven settlement across the foundation. Lateral pressures and differential settlement have been recognized as causative factors. However, there is much speculation about specific hydrologic, geotechnical, and structural factors behind these causes.

Most homeowners with damages are seeking simple, immediate, and economical solutions and, in some cases, restitution and adjudication. To be sure, the financial and emotional distress for some homeowners is substantial. Property owners without damages are seeking unambiguous advice about preventative maintenance, monitoring, and even predictions about the future occurrence and location of problems. Town officials seek simple engineering remedies that translate into policy and/or ordinances. Practicing engineers seek new data for design and repair of houses. Builders and contractors seek confirmation of their methods and consistent planning and policy-making.

These expectations, however well intentioned, must be subordinated to an initial investigation into the (1) scope and extent of the problem and (2) its causative factors. This preliminary, one-year, cooperative investigation between the U.S. Army Corps of Engineers (Corps) and the Town, represents this first step toward developing a basic foundation of understanding. These findings will be applied by engineers and Town officials and assist homeowners and building professionals in the future design/construction and evaluation/repair of Amherst houses. This study, then, is the beginning of a process rather than the end, and additional work will be needed to verify and advance these preliminary findings.

1.2 STUDY OBJECTIVES

The study objectives were negotiated in a Letter of Agreement and the Project Management Plan (PMP, 2004) between the Town and Corps and include the following:

- Better define the extent and scope of the foundation-related damages;
- Determine potential causative factors;
- Provide recommendations to the Town and homeowners regarding new construction and existing residential structures.

1.3 APPROACH

The study approach is a synthesis of existing literature and local investigations. The literature sources include Town databases, government and consultant reports, and peer-reviewed articles. The local investigations include a phone survey, home inspections, and field inspections. Four Town departments, the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), and the geology department at the State University of New York at Buffalo (University at Buffalo or UB) contributed to this report.

1.4 LITERATURE REVIEW

This literature review is an introductory bibliography for homeowners, Town officials and building professionals. The topics are wide ranging and reference general to technical publications.

There are three excellent guides for homeowners or homebuyers: (1) *Has your House got Cracks* (Freeman et al.,1994); (2) *A Guide to Swelling Soils for Colorado Homebuyers and Homeowners* (Noe et al., 1997), and (3) *So Your Home is Built on Expansive Soils* (ASCE, 1995). In addition, online guidance from Virginia (DPWES, 2002) and Canada (CHMC, 2004) is informative. It must be stressed that all of these guides reflect their geographic region and climate; therefore, some problems and recommendations are not applicable to Amherst.

Erie County's soils have been mapped and their characteristics described by the National Resource Conservation Service (NRCS, formerly Soil Conservation Service, or SCS) since the early 1970's (USDA, 1986). An excellent summary entitled, *Soil Inventory and Interpretive Study for Town of Amherst, Erie County, New York*, was prepared for the Town regarding the suitability of soils for such uses as foundations, utilities, streets, etc. (ECSWCD, 1972).

Regional hydrogeology and hydrology is the focus of several government reports. A comprehensive analysis of groundwater resources in the Erie-Niagara basin was written by La Sala (1968). Bedrock aquifers in Erie and Niagara County have been described by the U.S. Geological Survey (Kappel and Miller, 1996; Miller and Staubitz, 1985; Staubitz and Miller, 1987). The Corps did an extensive geotechnical investigation along Ellicott Creek for a flood control project (USACE, 1979).

Several reports present geologic and geotechnical data about the unconsolidated deposits in Amherst or the surrounding region. For example, Ward (1971, 1973) conducted sequential geotechnical investigations of soils at the District 16 Sewage Treatment Plant, located in northwest Amherst. Hodge et al. (1973) used geophysical surveys to describe the geologic and hydrogeologic zones surrounding the University at Buffalo (north campus). The Corps (USACE, 1979) developed a geologic cross section from about 35 boreholes along the 1.7 mile corridor of Ellicott Creek, between Niagara Falls and Maple Road. Two technical papers describe the extensive subsoil investigation and embankment instability along the Lockport Expressway (McGuffey et al., 1981; Kyfor and Gemme, 1994). The Corps (USACE, 1973) investigated subsoil conditions in North Tonawanda (also glacio-lacustrine sediments) as part of the Lake Erie-Lake Ontario Waterway project.

Clays are associated with the subsidence of many major cities around the world (Waltham, 2002). Expansive soils have been mapped in many parts of the world and the United States (FHA, 1975). Classification of expansive soils is reviewed by Sridharan and Prakash (2000). Meehan and Karp (1994) summarize 30 years of lessons learned with expansive soils and housing damage in California; they recommend, that buildings on expansive soils must be engineered, a comprehensive pre-building design and geotechnical investigation of the site is needed, and the construction should be performed with architect's observation and engineer's inspection. Simons (1991) describes damage caused by expansive soils as probably the least publicized of natural hazards, but it ties with hurricanes for second place amongst economic loss to buildings. Simons summarizes that due to the uniqueness of each type of structure, one set of assumptions, design criteria and subsequent repairs, cannot provide a solution for every problem encountered. Numerous authors cite the Jones and Holtz (1973) article entitled, *Expansive soils – the hidden disaster*. A Corps technical manual for engineers entitled, *Foundations in Expansive Soils*, is published online (USDOA, 1983). The Texas Section of the American Society of Civil Engineers (Texas ASCE) promulgated two useful expansive soils-related guidelines entitled, *Recommended Practice for the Design of Residential Foundations* and *Guidelines for the Evaluation and Repair of Residential Foundations* (Texas ASCE, 2002, 2002a).

Numerous articles and reports describe the causes/damages of settlement and lateral pressures on residential structures. Wahls (1981) reviews the current concepts and practices for establishing tolerable settlements for buildings. Settlement caused by groundwater withdrawal is discussed by Preene (2000). Damage caused by tree root extraction of moisture is discussed by Day (1992), Silvestri and Tabib (1994), Vipulanandan et al. (2001). Methods of engineering for settlement cases, often on marginal lands, is described by Adid and Paratore (1994), Moore and Chryssafopoulos (1972), and Whitlock and Moosa (1996). Diaz et al. (1994) describes basement failure as one of the most common problems in residential buildings in Ohio.

Anumba and Scott (2001) described a knowledge-based system intended to provide guidance for engineers dealing with subsidence cases. Their system covers diagnosis to remedial measures and was in response to the large number of buildings in

England being subjected to remedial underpinning (foundation damage in the UK is covered by insurance); they concluded the underpinning was not always justified.

Alternative methods of design and construction are described by Senapathy et al. (2000) and Sealy and Brandimere (1987).

Literature on the geotechnical and mineralogical properties of various clays is discussed in Murray and Quirk (1980) and Ghably (1998). Lytton (1994) presents an in-depth discussion of the mechanics and theory of moisture-related volume change in expansive soils.

1.5 SITE DESCRIPTION

1.5.1 General

The town of Amherst is located northeast of the city of Buffalo in extreme western New York State, USA (Figure 1). The Town incorporates 54 square miles and had a population of 116,510 in the 2000 census (Amherst IDA, 2005). Amherst includes the village of Williamsville with a population of 5,573. Approximately 45 percent of the land area is developed in residential uses. In January 2000, there were an estimated 33,000 single-family residences and 14,000 multi-family residences. Approximately 13% of the land area is currently designated for recreation and open-spaces. Most of the town is sewered, with the exception of 43,000 acres in the northern area near Millersport Highway and I-990. Where sewer is not available, soil conditions generally constrain development and limit residential development to one unit per ¾ acre. Nearly 50 percent of Amherst is in the 500-year flood plain, with approximately 24 percent in the regulated 100-year floodplain.

1.5.2 Physiography/Topography

Erie County is located in the western portion of the Erie-Ontario physiographic province of New York, which is in the northeastern portion of the Central Lowlands physiographic province of the Interior Plains physiographic division (USACE, 1979). The region is bordered on the north by Lake Ontario, on the west by Lake Erie and the Niagara River, and on the south by the Allegheny Plateau. Within the region are three plains, Ontario, Huron, and Erie, separated by the east-west striking Niagara, Onondaga, and Portage escarpments. Amherst is located within the Salina Lowland of the east-west trending Huron plain. This lowland area is bounded by the Onondaga and Niagara Escarpments, which are composed of more resistant rock.

A digital elevation model (DEM) of the town shows the major topographic features in Amherst (Figure 2). Topographic relief in Amherst is due to pre-glacial erosion of the bedrock and subsequent topographic modification by glaciation (La Sala, 1968). The Town generally slopes north-northwest, which promotes surface and subsurface drainage toward Tonawanda Creek and the Niagara River. Between the major drainages of Ellicott and Ransom Creeks, the topography is nearly flat, with Tonawanda Creek dropping only three feet per mile across northern Amherst.

1.5.3 Geologic History

Lake Tonawanda is a remnant of Lake Dana-Lundy resulting from the final northward retreat of the Ontario ice lobe of the Wisconsin glacial ice sheet when the ice front was located between the Niagara escarpment and Lake Ontario (section after D'Agostino, 1958). The lobes position near the Niagara escarpment prevented the northward drainage of Lake Dana-Lundy, forcing the lake to drain eastward through the Marcellus Spillway. However, when the ice lobe had retreated further northward toward the present Lake Ontario, lower outlets of eastern Lake Dana-Lundy, now uncovered by glacial ice, caused a rapid lowering of the lake level (Figure 3). When the level of Lake Dana-Lundy was lowered to the elevation of the Niagara Escarpment, the water sought various drainage outlets over the Niagara Escarpment. These drainage outlets terminated the existence of Lake Dana-Lundy and brought into existence Lake Ontario, Lake Erie, and the large river-lake called Lake Tonawanda. From the descriptions provided by D'Agostino (1958), it is the older lacustrine deposits, more so than the Lake Tonawanda deposits, that has cohesive and varved clays (Photo 1). More detailed accounts about the evolution of Lake Tonawanda are found in NYSGA (1966), NYSGA (1982), and D'Agostino (1958).

1.5.4 Bedrock Geology

The Erie-Niagara basin is underlain by bedrock that is largely covered by unconsolidated deposits (section after La Sala, 1968). The bedrock consists mainly of shale, limestone, and dolomite. All bedrock units were built up from fine-grained sediments deposited in ancient seas during the Silurian and Devonian periods and, therefore, are bedded or layered. The dip of the rocks (inclination of the bedding planes) is gently southward at 20 to 60 feet per mile, but the dip is so gentle that it is hardly perceptible in outcrops.

The Camillus Shale underlies most of Amherst (Figure 4). The Camillus contains a large amount of interbedded gypsum with beds up to 5 feet thick, but most gypsum occurs as thin lenses and veins. Underground gypsum mining in east Amherst is described briefly below. Groundwater in shale is likely to follow fractures and openings formed by dissolution of gypsum. Groundwater that enters the formation discharges mainly to Tonawanda Creek (La Sala, 1968). In Clarence, Staubitz and Miller (1987) describe the top 3 to 10 feet of the Camillus as moderately weathered and fractured, and, where overlain by dolomite, extremely fractured and weathered, such that it resembles coarse gravel. Boring logs reviewed in this study and reports by the Corps (USACE, 1979) and Kappel and Miller (1996) also suggest the upper surface can be weathered and have degraded rock quality.

Further south but stratigraphically above the shale is the "limestone unit" that includes the Bertie Limestone at the base, the Akron Dolomite, and the Onondaga Limestone at the top (La Sala, 1968; Kappel and Miller, 1996). Both limestone and gypsifferous shale can be dissolved by circulating groundwater, thus, dissolution of rock may be a causative factor for settling houses on or near the escarpment.

1.5.4.1 Gypsum Mining

Underground gypsum mining in Amherst occurred beneath a one mile-square area near the southeastern boundary of the Town, approximately between Klein, Maple, Ayer and Transit roads. As development of that area progressed, the Town acquired additional information that further defined the mining area. The refined information was based upon borings into bedrock and electrical resistivity analysis. The vast majority of the mined-out area is now known to be located east of Covent Garden Lane, south of Renaissance Drive, north of Maple Road, and west of Transit Road.

The mining operation commenced in 1925 and ended in 1976. The impure gypsum was removed (mined) from a layer approximately 70 feet below ground level. The bedrock is overlain by 10 to 40 feet of unconsolidated glacial deposits. The layer of gypsum varied in thickness but was typically 36 to 42 inches in height. The room and pillar method used in mining leaves intact pillars of bedrock within excavated "rooms" of gypsum and rock. According to various reports, the size of the pillars ranged from 10' by 10' to 24' by 24'. Measurements of the pillar spacing have been described as 33 feet from center to center with a roof span of approximately 24 feet. The haulage ways were excavated to a height of 6 feet with a width of 18 feet. Main haulage ways may have had some spans of 40 feet and a height of 8 feet.

With the cessation of mining in 1976, the dewatering operation (pumping) discontinued and the water table returned to its natural level. While in operation the pumping rate was estimated to be 500 to 1,000 gallons per minute (gpm, or 1.44 million gallons per day) during the summer and up to 5,000 gpm during the spring.

Details of the mining operation can be found in various reports contained in the Town's rezoning files associated with the DRT, Tesmer, and Cimato parcels. The master file for these reports is obtainable from the Planning Department. It is the policy of the Town Building Department to assume that all properties in the Maple-Ayer-Klein-Transit roads area are located above a mine unless determined otherwise through appropriate engineering or scientific analysis.

1.5.5 Surficial Geology

The overlying unconsolidated deposits are mostly glacial or glacial lacustrine in origin and were formed during the Pleistocene time about 10,000 to 15,000 years ago, when the ice sheet covered the region (section after La Sala, 1968). The glacial deposits consist of: (1) till, which is a non-sorted mixture of clay, silt, and, stones deposited directly from the ice sheet; (2) lake deposits, which are bedded clay, silt, and sand that settled out in lakes fed by the melting ice; and (3) sand and gravel deposits, which were laid down in glacial streams. In Amherst, the typical thickness of unconsolidated material is about 40 feet but ranges from less than one to more than 70 feet. The lacustrine or lake deposits are a primary focus in this report and will be discussed below. Other unconsolidated deposits are alluvium formed by streams in recent times and swamp deposits created by the accumulation of decayed plant matter in poorly drained areas.

The surficial geology map of western New York shows lacustrine deposits in northern Amherst and till in the south (Figure 4). This mapping scale does not adequately identify lacustrine deposits in the south-central portions of Amherst (see below).

Appendix 6.1 shows a geologic cross section prepared by the Corps for the Ellicott Creek Flood Control Project (USACE, 1979). The section illustrates several characteristics about the overburden which are consistent with our findings. The cross section is composed of several segments that parallel Ellicott Creek from Niagara Falls Boulevard (Plate D5) to Maple Road (Plate D6). The dominant geologic units in descending stratigraphic order are: (1) Lacustrine (Qlt) – stratified, sorted, sandy silt and sandy clay of low plasticity, associated with Lake Tonawanda; (2) Lacustrine (Ql) – well sorted, thin bedded to massive, red-brown to gray clayey silt of high plasticity, associated with proglacial Great Lakes, and (3) Glacial Till (Qt) – compact, non-stratified, red-brown to gray, pebble, clay silt till of low plasticity. The cross section suggests:

- The overburden thickness above the shale ranges from 10 to 75 feet;
- The northern section (1) has a "layer-cake" stratigraphy;
- The southern section (2) shows lacustrine deposits lapping onto till;
- All three units (Qlt, Ql and Qt) are exposed at the ground surface;
- Qlt is more heterogeneous (SM, SC, ML, CL, OL, CH) than Ql (CH, CL);
- Stratified gravel deposits occasionally overlie or are embedded in the till.

1.5.6 Soils

Soil texture is an expression of the proportion of sand, silt and clay in the soil. Common regional descriptions of soils as "clay" are often simplifications or misinterpretations of the true soil texture. South of the escarpment, soils are mainly silt loam in texture, meaning the soils consist of roughly equal proportions of sand, silt and clay within the surface layer or horizon. North of the escarpment, while often described as "clay," surface textures would more accurately be described as silty clay or silty clay loam, although there are still large areas of silt loam and smaller pockets and bands of sandy loam and other textural groups.

Silt (0.074 to 0.002 mm) and clay (less than 0.002 mm) are described as "fine particles" (meaning smaller). Sand-size particles represent a range of particle sizes from fine sand (0.25 mm to 0.1 mm) to very course sand (2.0 to 1.0 mm). The properties and characteristics of soil are heavily influenced by soil texture. Drainage, permeability, infiltration and percolation, rooting depth, moisture holding capacity, and seasonal high water table or zone of saturation are some of the properties most influenced by soil texture. Textural variation with the soil profile can be significant. Particularly in lacustrine soils, it is not uncommon to find layers of fine to coarse sand bounded by silty clay or clay layers.

Deeper horizons often do not have the same texture as the surface layer. Below the surface soils, including the formal subsoil or "B" horizon, the deep, unconsolidated subsoil can be similar to or may vary significantly from the overlying surface soil. In this region, subsoil may be associated with older geological events and time periods. This can result in some unexpected conditions with somewhat unpredictable consequences when relying solely on mapped soil data for planning and engineering decisions. The inaccuracy of National Cooperative Soil Survey maps has been evaluated in several studies (see Brevik et al., 2003).

1.5.6.1 Regional Soils

The Soil Survey of Erie County, New York, and prior published soil maps describe the surface soils generally to a depth of 60 inches (USDA, 1986). The characteristics of the deep subsoil can sometimes be inferred from the mapped soil data but, typically, *on-site site investigations* would be required to properly characterize the unmapped subsoil. Surface geology maps are not detailed enough for site-specific evaluations.

Soil properties are an important planning, design and engineering consideration. The fine-grained lacustrine soils which dominate the landscape of the study area are recognized has having serious limitations for a variety of engineering activities and land uses (see ECSWCD, 1972; USDA, 1986). Agricultural uses are limited because of generally poor drainage characteristics without artificial drainage, usually surface drainage. Large areas of hydric soils, often indicative of historic or current wetlands, are common. Seasonal high water tables (zones of saturation) are recognized as serious limitations. High potential frost action, low permeability (except in sandy soils and sandy layers within lacustrine deposits), high plasticity indices and high liquid limits are common limitations for most urban uses of these soils. North of the escarpment, slow permeability combines with the flat slopes to contribute to ponding and localized drainage problems. These problems are exacerbated in areas prone to localized or regional flooding.

The Soil Survey describes the stratified, fine-grained deposits common throughout the study area as "difficult to use for engineering works" and suggests that "sites proposed for embankments and heavy structures or buildings must be investigated for soil strength, settlement characteristics, and the effects of ground water" (USDA, 1986). The same section of the Soil Survey reads:

> Because of their fine texture and high moisture content, these deposits have relatively low strength. They are generally highly compressible and tend to settle over long periods.

Other deposits including stratified, coarse-grained deposits formed in lacustrine sands, shallow-to-rock deposits along the escarpment and small areas of organic deposits, occur in the study area. Coarse-grained materials generally have high strength but may settle when vibrated (USDA, 1986). Long-term settlement is also of concern if organic soils are filled over.

1.5.6.2 Amherst Soils

The Onondaga Escarpment, which parallels Route 5 through the Town, marks the approximate boundary between surface soils which are predominantly lacustrine in origin (to the north) and predominantly glacial till soils (south). Soils are more typically shallow to bedrock along and just south of the escarpment. North of the escarpment, soils are generally deeper, with depth to bedrock greater than 10 to 20 feet in most areas.

There are approximately 55 mapped soil units within the town of Amherst (ECSWCD, 1972). Five soil units are described as fine-grained lacustrine soils and include Cheektowaga, Cosad, Lakemont, Niagara, and Odessa. These soils cover about 42 percent of Amherst and account for 48 percent of the foundations (Figure 5). These cohesive soils generally show high porosities, low permeabilities, and a natural moisture content associated with low strength, low bearing capacity, and high settlement characteristics. Often increasing values of moisture content tend to be associated with decreasingly favorable foundation conditions (Watson and Burnett, 1995).

1.5.6.3 Soil Boring Data

To investigate subsurface conditions across Amherst, data from 371 boring logs were entered into the Town's Geographic Information System (GIS). A boring log is a geotechnical/geologic description of the subsurface materials encountered by a driller, and a GIS is specialized computer system capable of analyzing and displaying layers of spatial data. The majority of the boring logs came from recent building department permits, but about one-third are from the installation of intercepting sewers in the early 1970s.

The primary purpose for analyzing these data is to determine the extent and depth of an exceptionally soft silty clay layer, locally described as the "peanut butter" or "gumbo" layer (Dolan, 2004). Similar soils have been implicated in bank failures along creeks, ponds, and roadways in other parts of Erie County.

The data entered into the GIS included surface elevation (if available) and the depths (below ground) to the bottom of fill, top of soft layer (if present), bottom of soft layer (if present), bottom of bore hole, reason for termination (end-of-bore, refusal, rock), and groundwater depth. The consistency of the soft layer was classified as "*soft*" if the N-value (sum of middle blow counts) was less than 4, or "*semi-soft*" if the N-value was greater than or equal to 4 but less than 8. Some boreholes did not encounter a soft stratum (N = 8) and are termed "*not soft*." The soft stratum of interest consists of silty clay, however, other soft horizons were sometimes present elsewhere in the profile (e.g. organics or wet sand). The water level measurement from the open borehole was entered for the longest interval after borehole completion, which ranged from 0 to 72 hours.

Figure 6 shows the location of borings and whether a soft, semi-soft, or not soft horizon was encountered. The soft stratum is present in most boreholes in central and northern Amherst. However, semi-soft and not soft strata are also found in these areas. Conversely, the subdivision near Transit Road and Maple Road is underlain by till that is mostly not soft, except for one boring that has soft strata. Figure 6 illustrates the heterogeneity in a soft stratum area at the parcel-scale (see inset). These data suggest that in most areas (1) site specific borings are generally needed to determine subsurface conditions, but (2) in some areas, that requirement could be excessive.

1.5.6.4 Geotechnical/Geologic Cross Section

Figure 7 is geotechnical/geologic cross section across central Amherst that follows the 5.8 mile former New York Central Railroad, known locally as the "Peanut Line." The section shows the depth to the soft (lighter/red stippling), semi-soft (darker/blue stippling), or not soft stratum. (The geotechnical significance of the soft stratum is discussed in Section 3.4.3.2). These data were collected in May to June, 1973, from 61 equally spaced soil borings (record 55 missing). The section line is located entirely within lacustrine surficial geologic units (Figure 4). Figure 7 also illustrates (and exaggerates) the extremely shallow grade from east to west (0.06%).

Most borings intersect the soft (78%) or semi-soft (12%) stratum. The soft stratum appears to gradually pinch out toward the east, which may explain, in part, the relatively low occurrence of foundation-related damages in neighboring Clarence. The surface of the bedrock when intercepted varies from 571 to 545 feet above mean sea level (AMSL). Figure 7 suggests that bedrock-controlled topographically higher areas have stiffer soils, perhaps because micro-topography influences runoff, ponding, infiltration, and groundwater hydrology.

Figure 8 shows a generalized stratigraphic/soil profile for central and northern Amherst. The generally coarser sandy silt soil transitions downward to a moderately stiff silty clay that grades to a plastic soft clay (USCS classification CL/CH). The clay consistency decreases from stiff/hard to soft/very soft. The depth of the transition to soft clay varies from 3 to 35 feet across Amherst, but along the Peanut Line it averages 12.3 ± 2.0 (1s) feet below the ground surface. The transition is marked by a gradual to sudden drop in blow counts (sometimes weight of rods), an increase in natural water content (Figure 9), and a general increase in plasticity of the clay. Above the transition is the stiff stratum and below the soft stratum. Many residential footings rest on this stiff stratum, that is, the foundation footings are only a few feet above the soft stratum. In other locations, the footings rest directly on the soft stratum or till (see Appendix 6.1). The upper till boundary sometimes can include dense, wet, compacted fine sand with a little silt or coarse gravel. The dense glacial till rests on shale.

1.5.6.5 Expansive Soils

Lacustrine soils in Amherst are moderate to highly expansive (Section 3.2.3). This section provides some general information about expansive soils. Swelling or expansive soils are found in 40 of 50 United States and in all the world's continents except the polar ones (Steinberg, 1999). The first conference on expansive soils was held at Texas A&M in 1965. The need for proper construction of buildings on expansive soil was identified at least 35 years ago, was mandated by the State of California, and is required by the UBC (Meehan and Karp, 1994). Studies spanning decades have determined that the change in swelling soils' moisture content results in damaging volumetric changes. These soils are described in relation to the prevailing climate, that is, in arid climates they are known as "swelling soils" and "heaving soils," and in the temperate climate of the United Kingdom, these soils are known as "shrinkable" soils (ASCE, 1995; Freeman et al., 1994). Previous predictive mapping of expansive soils did not recognize the lacustrine deposits in western New York as having expansive soils (Figure 10).

Most clay soils swell, to varying degrees, with increased moisture and shrink with drying. There are many factors that control how much a soil can swell, including the type of and concentration of minerals, soil density, the capacity for moisture change, and the restraining pressure of the surrounding soil (Noe, 1997). The degree of shrink/swell is often related to its clay mineralogy. Kaolinite, illite, and smectite are the most common clay minerals. In rain-soaked western New York, the initial concern is for removing soil moisture. Desiccation of clay soils causes them to be hard and cracked (Photo 2).

Two commonly used indexes to characterize an expansive soil are the plasticity index (PI) and the expansion index (EI). PI is a geotechnical engineering term that is the difference between the soil's plastic limit and liquid limit, two common soil tests performed in a laboratory. If the soil's PI is between 20 and 40, the soil is considered to have moderate expansive properties (see Freeman et al., 1994), although Sridharan and Prakash (2000) suggest PI and related properties cannot satisfactorily predict a soil's expansivity. A soil with an EI of 50 or less is considered to have low expansion potential, moderate potential between 51 to 90, and an EI of 91 or greater indicates a soil with high or very high (> 121) potential.

Expansion Index testing has been required by the Amherst Building Department since January 2003. We reviewed approximately 15 Amherst projects with geotechnical reports (in 2004) that had EI values considered moderate to high. One local laboratory that has performed 75 or more EI tests reports that nearly all Amherst soils have been in the range from 60 to 120 (pers. Comm., Jeanne Asquith, 3rd Rock LLC, 2004).

Prior to EI testing, McGuffey et al. (1981) showed the average PI of 66 samples along the Lockport Expressway was 22.2 ± 3.0 (1σ). The Corps (USACE, 1979) had numerous samples along Ellicott Creek with an average PI ranging from 26.3 to 29.8 (Table 1). The Corps (USACE, 1973) collected 15 clayey soil samples from two boreholes north of Tonawanda Creek, but within the lacustrine sediments, that yielded PI's of 22.0 ± 3.3 and 24.4 ± 3.3 (Table 1). Ward (1973) soil samples form north Amherst had a PI of 24.1 ± 4.3.

1.5.6.5.1 Soil Moisture Variation

House and field inspections reveal that a fairly constant but large number of factors at various scales, both natural and man-made, are potentially affecting the soil moisture conditions in the active soil zone around a typical Amherst foundation (Table 2). Many man-made factors often result from the conversion from undeveloped to developed land (suburbanization). The net effect of these factors on soil moisture can be determined with careful measurement but is not easily anticipated by homeowners. The term "active zone" has taken on several different meanings over the past two or three decades (Nelson et al., 2001). In this study, it refers to the zone of soil that is contributing to heave and settlement at any particular time and includes material below the elevation of the foundation footing, not just simply material surrounding the basement.

1.5.6.5.2 Quantitative Mineralogy

The Corps contracted the University of Buffalo's Geology Department to investigate the amount and nature of soil minerals, particularly clays, present in the samples gathered for geotechnical analysis. All samples were analyzed using X-ray diffraction and quantitative mineralogical analysis software (Giese and Juul, 2005). When analyzed, specially prepared samples reveal characteristic diffraction patterns that are matched with an internal standard to identify and quantify the minerals in the sample.

Appendix 6.2 shows the results for three sample strata -- backfill, stiff stratum, and upper soft stratum (see Figure 8). Two samples of till (Corps No. 13 and 27) are not used in the statistical summaries because they differ significantly from the lacustrine samples. The total of clay minerals average 31.8%, 35.9% and 36.6% by weight for the three sample stratum, respectively (i.e., the clay content increases with depth). The dominant minerals are illite and quartz, followed by calcite, chlorite (a clay mineral), and feldspar.

The dominance of illite (with chlorite), both non-swelling clays, suggests the mechanism of soil swell is *not* the classically understood interlayer swelling, which occurs with smectite clays. Interlayer swelling is the process where water enters directly into the clay structure and can expand the mineral volume by 100% or more. Smectite clays are found in western states with well known expansive soil problems. In Amherst, the lacustrine soils are swelling by another mechanism, perhaps intra-layer swelling and/or by a process involving an organic coating on quartz and other mineral grains. This conclusion is interesting and not simply academic because potential cutting edge remedial options involving soil amendments will be predicated on our understanding of this swelling behavior.

1.5.7 Hydrology

Amherst hydrography is shown in Figure 11. Ellicott Creek is the largest tributary of Tonawanda Creek. Ellicott Creek drops precipitously some 60 feet in Williamsville, then flows northwesterly before discharging into the channelized section of Tonawanda Creek at an elevation of approximately 564 feet (USACE, 1979). The slope in the flatlands is about two feet per mile. Before the Ellicott Creek flood control project, peak discharge during flood events was considerably less downstream at Niagara Falls Boulevard than upstream in Williamsville, indicating abundant overbank storage. The Corps' project was designed to keep flow in the channel and lower the 100-year flood stage by an average 1.5 feet between Maple Road and Niagara Falls Boulevard. It is plausible that areas near the creek receive less groundwater recharge as a result of the project.

Amherst's growth and development (Section 1.6.1) converted farmland to residential subdivisions. Development generally alters the hydrologic budget of an area and leads to less infiltration and more surface water runoff (NJDEP, 1999). Downspout collection systems, yard drainage, footing drain tiles, sump pumps, maturing trees, positively sloped yards, and impervious roofs, walks, patios, and driveways route water away from a parcel and reduce recharge to the water table (see Table 2). A typical ½-acre house lot, for example, has 25 percent impervious cover. Groundwater and diverted surface water runoff enters Amherst's stormwater system comprised of underground storm sewer pipes, ditches, retention ponds, and dry wells. Sometimes this drying trend is offset by landscaping, leaky plumbing (e.g., sprinkler, sewer, water, pool), snow storage and retention ponds. In either case, net soil moisture changes can be incremental and may take several years. We inspected some houses whose settlement might be caused or aggravated by long-term localized desiccation.

The New York State Department of Environmental Conservation (NYSDEC) has identified approximately 1,565 acres of regulated wetlands in Amherst, and an additional 250 acres of wetlands are protected by Federal wetland protection. Wetlands provide many important functions, not the least of which is temporary storage for flood waters.

Consulting engineers sometimes provide water balances with proposals for residential development. For comparison, an estimated average water budget for nearby Ohio is provided in Appendix 6.3. Calculating an actual water balance at the house-lot scale, however, is challenging because many of the inflows and outflows listed above are simply unknown or have significant temporal and spatial variability (e.g., canopy cover, infiltration rate, sump pump withdrawal). In addition, homeowners landscape to route surface water from their yards in what we termed as Amherst's "topography war." Newer subdivisions are often elevated and flow into older neighborhoods. In short, careful site inspection and measurement may be needed to produce an accurate water balance.

Minor flooding occurs periodically in many Amherst neighborhoods and affects soil moisture conditions. Historically, much of Ransom Oaks, Audubon and SUNY-Buffalo experienced flooding and were even declared flood hazard areas in the 1970s (MacClennan, 1974). During inspections, many homeowners recounted minor flooding in their neighborhood. Local flooding observed during this study appeared to be caused by overflow of storm water conveyances, which are sized for the 10-year storm event, rather than the overtopping of streams banks.

1.5.7.1 Climate/Precipitation

The Niagara Frontier, including Buffalo and vicinity, experiences a fairly humid, continental-type climate, but with a definite "maritime" flavor due to strong modification from the Great Lakes (NWS, 2005). The average annual temperature is about 48 degrees

Fahrenheit (Table 3). The average annual precipitation at the first-order Buffalo Airport (1971-2000) station is about 40.5 inches, which is uniformly distributed throughout the year. The average annual snowfall for Buffalo is 97.0 inches. During the summer growing season, the potential evaporation is about 24.4 inches, thus evapotranspiration exceeds precipitation and a deficiency of soil moisture generally develops (La Sala, 1968).

Figure 12 shows historical trends in precipitation in the Buffalo area as inferred from the Palmer Drought Index (PDI) and precipitation record. Many homeowners first noticed foundation damage during drier years. The Palmer Drought index uses precipitation and temperature information in a formula to determine dryness, where 0 represents normal and drought is shown in terms of negative numbers: for example –2 is moderate drought, –3 is severe drought, and –4 is extreme drought (NRCC, 2005). The PDI suggests that 1988-89, 1991, 1995, 1998, and 2001 were dry years. Less than average annual precipitation occurred in 1980-81, 1983-84, 1986, 1988, 1994-95, 1998-99, and 2001-03. Prolonged summer dry periods occurred during 1982-86, 1989, 1991, 1994-95, 1998-99, and 2001-02. Periods with two or more months of severe or extreme drought last occurred in the Great Lakes Climate Division in January 1961 (NRCC, 2005)

1.5.8 Hydrogeology

Groundwater geology, or hydrogeology, investigates the origin, occurrence and movement of groundwater, and is potentially associated with foundation damage

Unfortunately, long-term groundwater monitoring data from overburden wells in Amherst are generally absent. Therefore, we present available data that is incomplete and preliminary. These data generally suggest that groundwater levels fluctuate periodically at the footing level and less frequently in the soft stratum. The amplitude of these fluctuations diminishes with depth and there is vertical gradient through the soft stratum. For this discussion, the overburden is subdivided into three zones – upper, middle, and lower.

1.5.8.1 Upper Soil Zone

The upper soil zone extends from the ground surface to about six to eight feet below ground surface, or approximately the depth of a typical foundation footing (Figure 8). Under natural conditions, shallow soils beneath the surface of the ground alternately become wetter and drier as a result of seasonal moisture and temperature changes. That is, groundwater storage normally undergoes seasonal changes because the rates of recharge and discharge are rarely equal. Geophysical, soil boring and monitoring well data provide evidence of these seasonal fluctuations.

Hodge et al. (1973) used geophysics (seismic and resistivity) and hand-auger borings to investigate the overburden near the University of Buffalo's north campus. The study area was bounded by the major roads of French, Sweet Home, North Forest and Campbell Boulevard. The late fall seismic survey identified three and sometimes four distinct layers. Universally, there was a top layer that represented unconsolidated sediment composed of either *unsaturated* sand or clay. Beneath the top layer in most locations was a second layer that represented the water interface. The depth to the *saturated zone* varied considerably throughout the area, but ranged from one to eight feet below the ground surface. Hand-auger borings revealed saturated sand was overlying a sand-clay interface. At several seismic sites, however, the second layer was *stiff clay* described as "unsaturated."

A perched water table typically exists where a more permeable stratum (e.g., sandy loam) overlies a less permeable stratum (e.g., silty clay). About half of the 60 soil borings along the Peanut Line (Figure 7) identified a "wet" sandy horizon overlying a clayey horizon, with some logs explicitly noting "water encountered." Many water level measurements on Figure 7 are shallow and postulated to represent the elevation of the perched water table.

Desiccation cracks and mottling also indicate a fluctuating water content. Both features are commonly recorded in boring logs to depths of 7 to 10 feet below ground surface. Soil mottling (discoloration) reflects the natural depth to a seasonally high water table (Earth Dimensions, 1981). Oily contaminants have migrated along vertical cracks in the Tonawanda landfill to depths of 20 to 25 feet (pers. comm., Glen May, NYSDEC). Contractors who repair foundations have observed "bone dry" conditions at the footing level at many repair sites (pers. comm., ABS, 2003). Desiccation cracks near foundations (Photo 2) greatly increase infiltration rates and the vertical movement of groundwater. Desiccated soils that pitch toward the foundation wall explain, in part, why many homeowners report sump pump cycling shortly after a rainstorm.

The seasonal fluctuations of the water table in some soils may mimic the hydrograph (water level vs. time) of a Ransomville well, located northeast of Buffalo, NY (Figure 13). Approximately weekly water level readings have been gathered by the U.S. Geologic Survey (USGS) from 1972-95 at a farmer's dug well estimated to be 25 feet deep. Two subsurface borings (ARC-66509, AUC-67511) about one mile west of the site show a fairly homogenous sandy clay over a sandy clay with some gravel that is underlain by bedrock at 30 to 50 feet (USACE, 1973). Well use could not be determined. The 1990 to 1994 period was selected to illustrate a contrasting dry (1991) and wet year (1992), with the latter being comparable to the 2004 study year.

Figure 14 illustrates qualitatively the annual change in groundwater storage between February and September, which averages about 4.6 ft. If the upper groundwater zone in parts of Amherst fluctuates to the extent of the Ransomville well, then the active soil zone could experience some dramatic soil moisture changes in some years.

There are approximately 30 shallow to deep monitoring wells located around the former Tonawanda landfill and Spaulding sites (Appendix 6.4). The subsurface material is a uniform, red-brown, silt and clay, with some sand and fine gravel, with faint bedding that transitions to gray-brown clay in deeper wells. This monotonous sequence overlies sand with trace gravel, which overlies weathered clay-filled shale. The depth to rock is typically 60 to 95 feet below ground surface. The blow counts are generally between 10 and 30. This material is different from the typical lacustrine deposits in north-central Amherst and is presumed a till sequence; nonetheless, it may mimic groundwater behavior in south-central Amherst or, more broadly, a impervious formation overlying fractured bedrock.

Figure 15 shows the depth to groundwater at several observation wells along the perimeter of the Spaulding site. The 10-foot well screens have sand packs with a midpoint that is uniformly about 14 feet below the ground surface. The ground elevation at the wells varies from about 591 to 603 feet AMSL. These data show the temporal and spatial variability of the water table across a comparatively small site. For example, the water table fluctuated nearly nine feet at OW-1, and the range of concurrent measurements was nearly 4 to 6 feet.

In summary, geophysical readings, desiccation cracks, mottling, and groundwater measurements from across the region suggest that groundwater in the upper soil zone fluctuates seasonally and likely affects soil moisture conditions near the footing.

1.5.8.2 Middle Soil Zone

The middle zone, unlike the upper zone, appears to be less affected by seasonal fluctuations. In lacustrine deposits, the middle zone corresponds to the soft stratum. The middle zone may be within the capillary fringe during certain periods. Only a few wells have been constructed to monitor groundwater levels in the soft clay stratum, and most of these have extremely short records.

Daigler (2004a) determined the hydraulic head in the soft stratum in northern Amherst for two weeks during August 2004. He placed vibrating wire piezometers in a single borehole at 13, 18, and 25 feet below the ground surface. The soft stratum overlies till (27') and bedrock (33'). These data showed a downward vertical hydraulic gradient (I) of about 0.26 ft/ft (I = ? H/L = 3 ft/11.8 ft). That is, the 13 and 25 foot probes registered heads equivalent to about 7 and 10 feet below ground surface. This snapshot suggests some recharge to the soft silty clay comes from the upper soil zone. The rate of recharge can be estimated using laboratory vertical permeability data (two samples) on the silty clay. Considering groundwater flow through a 1ft^2 area, the flux can be computed as Q = K x I x A: where Q is discharge (gals/year), K is hydraulic conductivity (2.7 gals/ft^2/yr or 6.9 x 10^{-7} ft/min), I is the gradient of 0.26 ft/ft, and A is area 1 ft^2. The discharge is equal to 0.7 gals/year (= 1.1 inches = 2.8 % of total precipitation). This suggests that a meager 1.1 inches is available for bedrock recharge per year (c.f., Kappel and Miller (1996) chose 10 in/yr rate).

Daigler (2004a) showed that the hydraulic head being measured 18 feet below ground actually rose about *three feet* while the head in the till actually dropped about two feet during a two week period. The golf course maintenance department does irrigate from a pond and a bedrock well, but both sources are located several hundred yards away on the first hole. Daigler concluded, "groundwater conditions at the undeveloped site were not steady state and appear to vary from one location to the next."

Ward (1973) installed a *piezometer* (B-9) in soft varved clay near the Amherst Sewage Treatment Plant and measured the head for about four weeks during March 1973. The piezometer opening was at 22.4 feet and the hydraulic head was 9.6 feet below ground surface. As in many boreholes, the hydraulic head in the soft stratum about coincides with the top of the stratum.

A third well was installed at the Amherst Senior Center (Barron and Associates, 1999). The bottom 18 feet of the 24 foot well was constructed with slotted screen. The well casing was sealed with bentonite in the soft lacustrine brown clay. During the initial boring, they encountered water at silt seam about 20 feet below grade. Three days after installing the well, the water level was 20 feet below grade (elevation 558.1 ft msl). Bailing the well dry three days later, they returned after 11 days and the elevation was similarly 20.5 feet below ground surface (elevation 557.6 msl). Grain size analysis from the 18 to 20 foot depth showed the sample that was 81% clay and 17% silt. One plausible explanation for the well behavior may be dewatering of a silt seam and extremely slow recharge due to low hydraulic conductivity.

The Tonawanda landfill has two pair of side-by-side wells (BM-13 & BM-14) comprised of a shallow (S) and moderately deep (D) well (Appendix 6.4). The sandpack midpoints are approximately 15 and 40 feet below the ground surface, respectively. Figure 16 shows there is clearly some hydraulic relationship at BM-13 as well as a fairly constant downward component to the gradient most of the time. Note, these data are not continuous (as illustrated) and span several years. Also, the head is not static but varies about 35 feet in BM-13D. Figure 17 shows similar behavior at BM-14. These well pairs also demonstrate a lateral flow component.

In summary, these few middle zone data from lacustrine and till deposits suggest that (1) the hydraulic head in the zone is not static and (2) that a downward gradient is normally present. We speculate that these groundwater level changes are felt by the upper soil zone and underlying compressible clays.

1.5.8.3 Deep Soil Zone

The deep soil zone occurs from the upper till to bedrock interface. Several wells have been completed in this zone.

Ward (1971, 1973) installed eight *piezometers* during a soils investigation for the Amherst sewage treatment plant. The site is nearly flat and located 1,500 feet south of Tonawanda Creek. All borings encountered the typical lacustrine stratigraphy (Fig. 8) except B-17, which was predominantly till. PS-2 cored through 27 feet of shale and noted 100% water loss. The piezometer openings were completed at the till/rock interface and ranged in depth from 53 to 17 feet below ground. Figure 18 shows the hydraulic heads in 1971 and 1973 (depth annotated on legend). The 1971 data may reflect summer conditions or the somewhat deeper construction. The 1973 data may represent spring conditions; B-17 and B-12 appear to be influenced by the rising river stage in Tonawanda Creek. The discharge in the creek, as measured at Batavia, increased significantly during that period. B-17 would likely have an upward gradient during this period. These data reveal some dynamic conditions in the deeper stratum.

Earth Dimensions collected groundwater data in the fall 1982 from two observation wells (1B-30 and 1B-40) at two sites along Young's Road, north of Sheridan Drive. Both wells bored through lacustrine deposits but eventually placed sandpacks that intercept groundwater from the wet compact sand/till. Figure 19 shows the fluctuation observed in those wells.

Tonawanda landfill has several monitoring wells both north and south of the landfill that are screened in till or at the bedrock interface. Figure 20 shows groundwater elevations during several measurement periods. With the exception of DW-1, most wells show comparatively modest or steady change.

1.5.8.4 Bedrock Aquifers

Groundwater in bedrock in western New York is described in detail by Kappel and Miller (1996), La Sala (1968), Staubitz and Miller (1987), and in less detail in USACE (1979), USACE (1973), Hodge et al. (1973), Ward (1971, 1973), Earth Dimensions (1981), Barron (1999), and Daigler (2004).

The Onondaga Limestone and Camillus Shale are generally regarded as high-yield aquifers (La Sala, 1968; Kappel and Miller, 1996). In Amherst, artesian conditions exist along the base of the escarpment. North of the escarpment, groundwater movement likely mimics the topography and moves from higher to lower parts of the basin. Boreholes that cored several feet into the underlying shale generally did not intercept groundwater but rather lost water. The upper weathered bedrock probably acts variably as an aquitard or groundwater sink; that is, the bedrock surface may channel groundwater flow along uneven topography or allow it to percolate deeper into the rock.

1.5.8.5 Summary

Long-term groundwater data from clustered wells in Amherst was not available for this report, nonetheless, the cited studies provide a starting point for future investigations.

In general, the upper soil zone undergoes seasonal changes in groundwater storage that are typical of the northeastern United States (La Sala, 1968). Flat terrain, relatively impervious soils, and few incised features suggest lateral movement of groundwater could be quite limited. The well data suggests groundwater moves vertically downward with an accompanying head loss. The amplitude of fluctuations in the groundwater levels becomes more subdued with depth. However, a few till wells respond quickly to phenomenon such as river stage or possibly groundwater pumping. The fate of groundwater reaching the till or bedrock is unknown, but may follow the bedrock topography or enter the deeper bedrock aquifer. Importantly, fluctuating groundwater levels in the upper and middle soil zones suggest that soil moisture conditions could change periodically in the stiff stratum and perhaps less frequently in the soft stratum.

1.6 HISTORICAL PERSPECTIVE

1.6.1 Amherst Growth and Land-Use

During the past fifty years, the town of Amherst has experienced significant growth, increasing from a population of 33,744 in 1950 to 116,510 in 2000 (Table 4). Amherst's share of Erie County's total population has also increased, from less than 4% in 1950 to over 12% in 2000. The Town saw its greatest growth and largest percentage increase, 46%, in the 1950's and 1960's. The growth rate in the 1990's was approximately 4%. According to population growth estimates, the Town can expect to grow by about 11,000 to 22,000 people over the next 20 years, to a total of 127,264 to 138,839.

By 2020, approximately 5,000 to 10,000 additional housing units could be built in Amherst to accommodate new residents and future growth. The number of building permits for single-family dwellings (multi-family not included) during 1990–2004 averaged 194 ± 68 (1s).

Significant land use changes have occurred since 1972. Approximately 55% of vacant and agricultural land in the Town has converted to other uses (Table 5). During the 1980's and 1990's, the non-residential uses increased, and Amherst has become a major employment center.

1.6.2 Special Flood Hazard Areas

Property owners within the town of Amherst became eligible to purchase flood insurance through the National Flood Insurance Program (NFIP) on August 9, 1974. From 1974 to December 17, 1984, the flood insurance program was regulated under the provisions of the emergency program of the NFIP. On December 18, 1984, the regular program of the NFIP became effective and continues to the present date.

Under the emergency program, the Town adopted its first official floodplain map on February 27, 1978. The floodplain maps depict the Special Flood Hazard Area (SFHA) which is commonly known as the 100-year floodplain (Figure 21). Updated Flood Insurance Rate Maps (FIRM's) were adopted in association with the regular program in 1984. Since then, there have been two major revisions to the FIRM's on September 28, 1990 and October 16, 1992. The FIRM's from 1992 are still in effect. The current 100-year floodplain covers approximately 24% of the town of Amherst.

Within the regulated SFHA, certain structures, including dwellings, must be built in accordance with floodplain regulations so that flood insurance can be obtained. The conventional floodplain regulations require the lowest floor of a structure, including the basement floor, to be constructed above the 100-year flood elevation (also known as the base flood elevation - BFE). However, the town of Amherst obtained an exception to the conventional regulations in 1978. The Federal Insurance Administrator of the Department of Housing and Urban Development approved the exception on November 20, 1978.

The so-called basement exception allows for the construction of residential basements where the basement floor is located at a lower elevation than the base flood elevation. The basement exception permits the basement floor elevation to be no more than five feet below the BFE and the building must comply with other structural and elevation requirements. When using the basement exception option, the first floor elevation (not including the basement floor) must be elevated to at least one foot above the BFE and the structure must be flood-proofed to one foot above the BFE.

1.6.3 Building Codes for NYS and Amherst

Table 6 provides a chronology of important building codes that have been adopted in the town of Amherst. From 1936 through end of 2002, the building codes for one- and two-family dwellings under 40-feet in height allowed the bearing capacity of soil to be based upon the presumptive bearing value for that soil. The presumptive bearing value is determined by identifying the soil type and then obtaining a bearing value as listed in a table contained in various design manuals, building codes, or engineering books. This methodology does not involve any geotechnical analysis.

For one- and two-family dwellings, the relevant code sections for soil bearing values associated with the building codes are listed in chronological order below:

1) Building Code of the Town of Amherst (1936-77, known as Building Ordinance):

Subdivision 8.4 – Bearing Value of Soils – The bearing power of the soil on the maximum of live and dead loads combined, in tons per square foot of bearing surface on the ground, shall not exceed the following:

Soft Clay	1
Wet Sand	2
Ordinary clay and sand together in wet and springy layers	2
Loam, clay or fine sand; firm, clean and dry	3
Hard, dry clay	4
Very firm, coarse sand or stiff gravel	5

Where the bearing power of the soil is doubtful or undetermined, the Inspector may direct that borings or soil tests be made. Such tests shall be made under his supervision and he shall keep a record of their results.

2) The "State Building Construction Code" (1977-83):

Section A 302-2(a) – For buildings 40 feet or less in height, the allowable bearing value of the soil upon which the building rests shall be the presumptive bearing value or shall be determined by field loading tests in conformity with generally accepted standards.

3) State Uniform Fire Prevention and Building Code (1984-02):

Section 801.2(a)(1) - For buildings 40 feet or less in height, the allowable bearing value of the soil upon which the building rests shall be the presumptive bearing value, or shall be determined by field loading tests in conformity with generally accepted good engineering practice.

4) Residential Code of New York State (2003 to present):

Section R401.4 Soil tests. In areas likely to have *expansive, compressible, shifting or other unknown soil characteristics*, a soil test shall be performed to determine the soil's characteristics at a particular location. This test shall be made by an approved agency using an approved method.

Until the Residential Code of New York State became effective in 2003, soil analysis was based on the "presumptive bearing value" method. Furthermore, architects and professional engineers were relied upon to exercise good engineering practice in the preparation of construction plans.

It is the current practice of the town of Amherst Building Department to require soil testing and geotechnical analysis prior to the issuance of a building permit for any proposed dwelling located north of the Onondaga Escarpment. At the discretion of the Commissioner of Building, soil testing may be required for proposed buildings located on the Onondaga Escarpment.

The design and construction of a dwelling must take into account the soil conditions for each specific site. The construction drawings and specifications must include the design recommendations of the geotechnical engineer.

In addition to the more detailed soil analysis, the Building Department has adopted a policy to require compressive strength tests for concrete that is used for footings and foundation walls. The compressive strength test results must be submitted to the Building Department prior to the issuance of a Certificate of Occupancy. Minimum compressive strength requirements are specified in the Residential Code of New York State. This testing addresses defective concrete concerns.

In accordance with New York State Education Law, plans, specifications and reports relating to residence buildings of gross floor area of fifteen hundred square feet or less, not including garages, carports, porches, cellars, or uninhabitable basements or attics are not required to be prepared by a licensed architect or professional engineer. Unless exempt from NYS Education Law, all other buildings, plans, specifications, and reports relating to the construction of buildings shall be stamped and signed by a professional engineer, architect or land surveyor. Regardless of any exemption from the NYS Education Law, the Building Department currently requires reasonable soil testing and geotechnical analysis prior to the issuance of a building permit.

Since the adoption of the first building code in 1936, the Town has conducted plan reviews in association with each building permit application. Plan reviews were based upon the adopted building code at the time of the permit application. Subsequent to the issuance of a building permit, town of Amherst Building Inspectors conduct appropriate construction inspections. From 1936 through 1951, the town's Building Inspectors were assigned to the Engineering Department. The Building Department was created in 1951 and now employs approximately 27 inspectors in various job titles.

Upon the adoption of the State Uniform Fire Prevention and Building Code on January 1, 1984, the state also established minimum standards for the administration and enforcement of that code. The minimum standards included (among other items) provisions for construction inspections, such as observation of the foundation, structural elements, electrical systems, plumbing systems, heating, ventilation and air conditioning systems, fire protection systems and exit features. The Town conducted inspections and continues to conduct inspections as established by state standards.

The information contained in this section is just a brief overview of the codes, inspections, and building permit process. Further detailed information regarding these topics can be obtained from the Town of Amherst Building Department.

1.7 Figures, Table, Photos

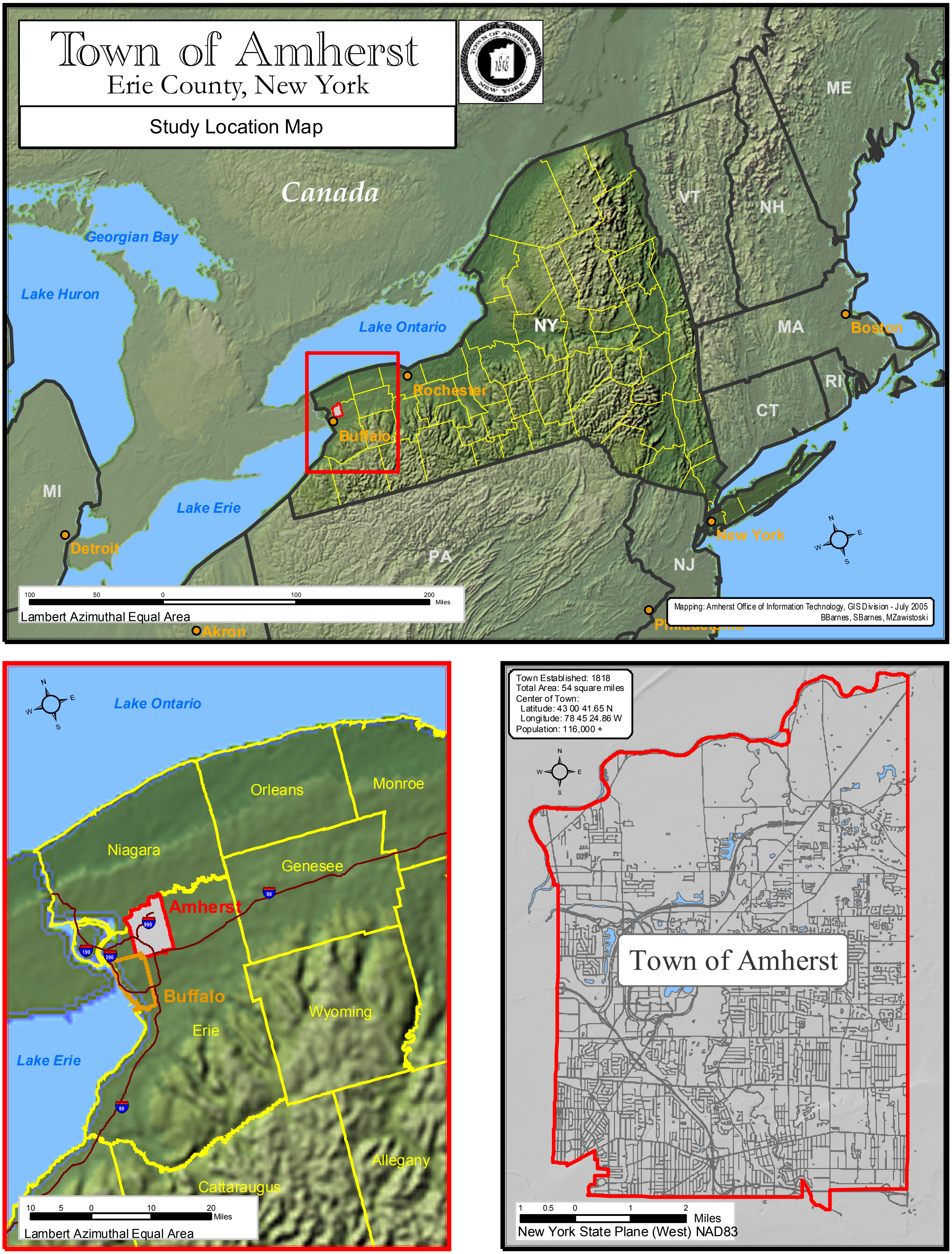

Figure 1. Study location maps of Town of Amherst, Erie County, and western New York.

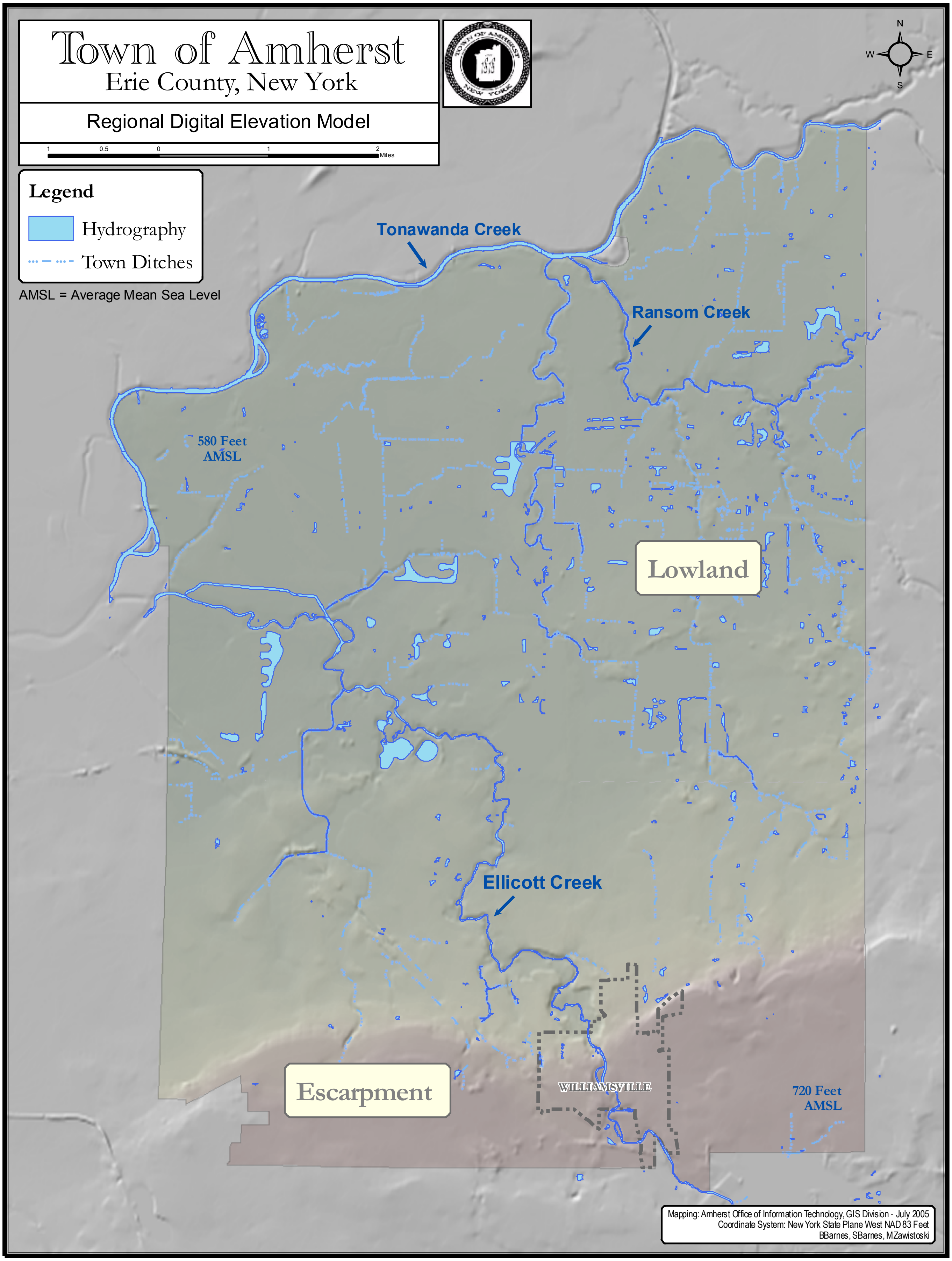

Figure 2: Digital elevation model (DEM) of Amherst, NY, showing change in relief from escarpment to lowland areas.

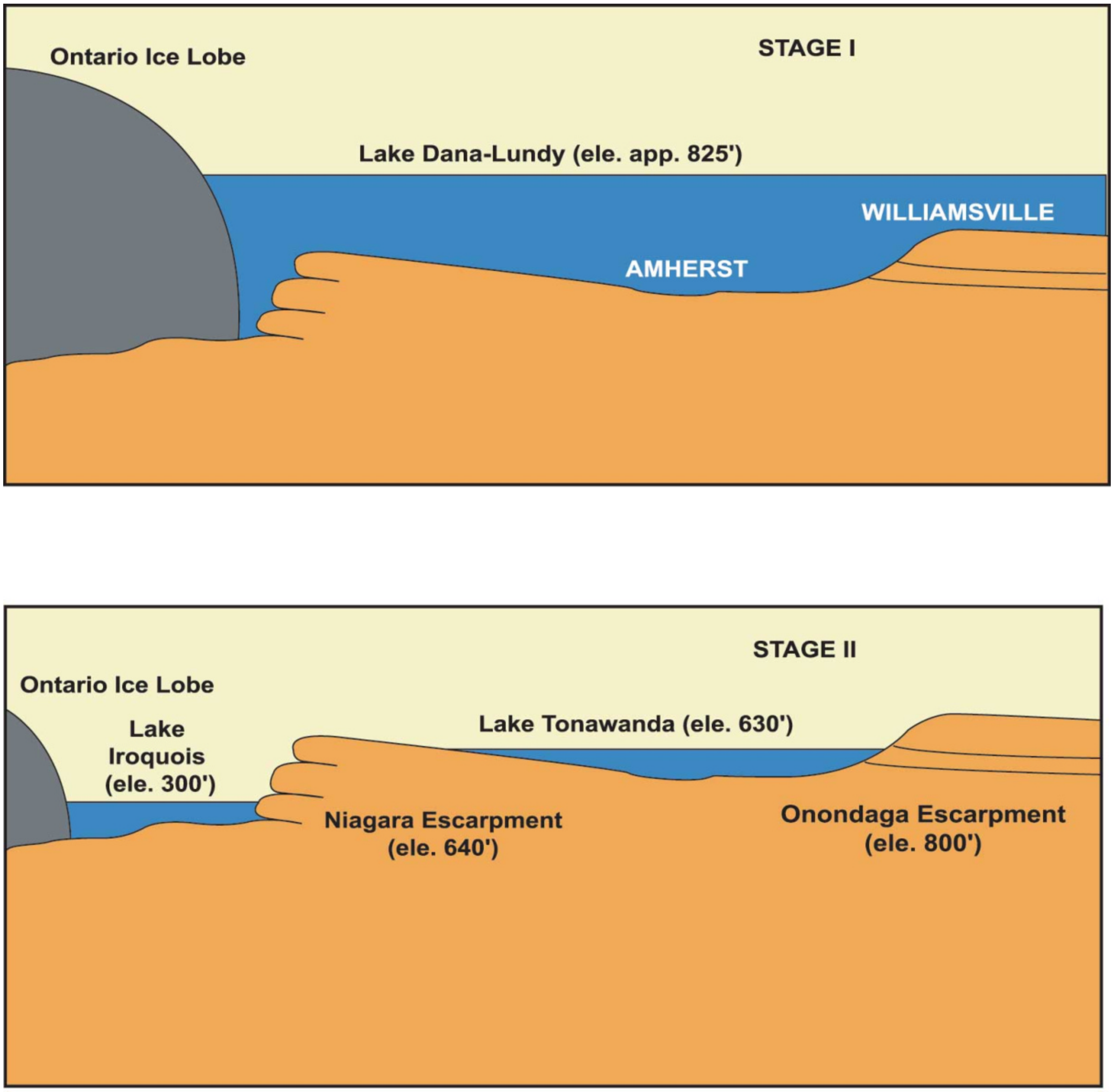

Figure 3. Lake Tonawanda is a remnant of Lake Dana-Lundy resulting from the final northward retreat of the Ontario ice lobe of the Wisconsin glacial ice sheet when the ice front was located between the Niagara escarpment and Lake Ontario (from D'Agostino, 1958).

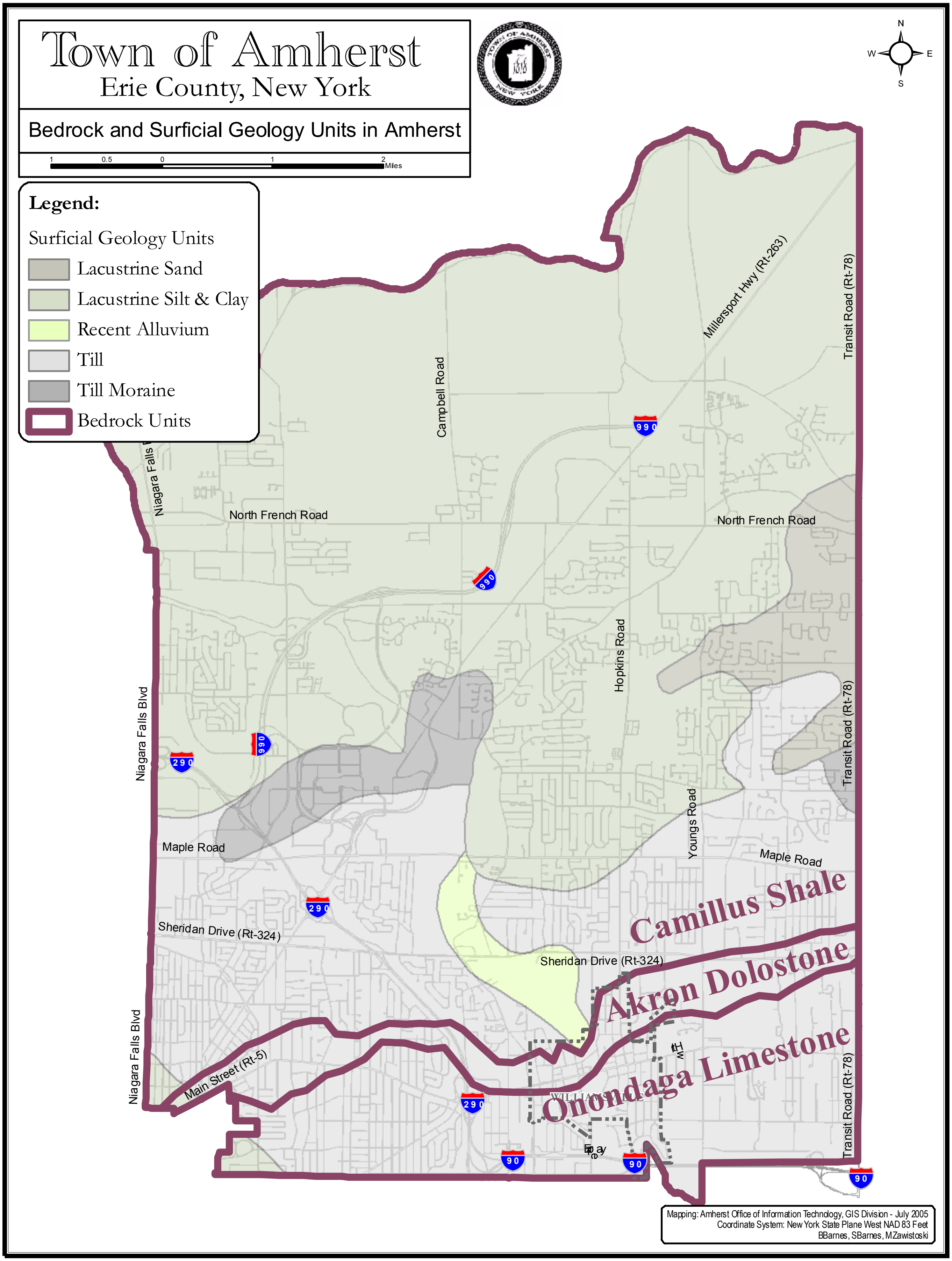

Figure 4: Surficial and bedrock geology of Amherst, NY. Lacustrine deposits (north) and till (south) overly gypsiferrous shale and calcarious rocks (dolostone and limestone) respectively (Source: NYSGS, 2005).

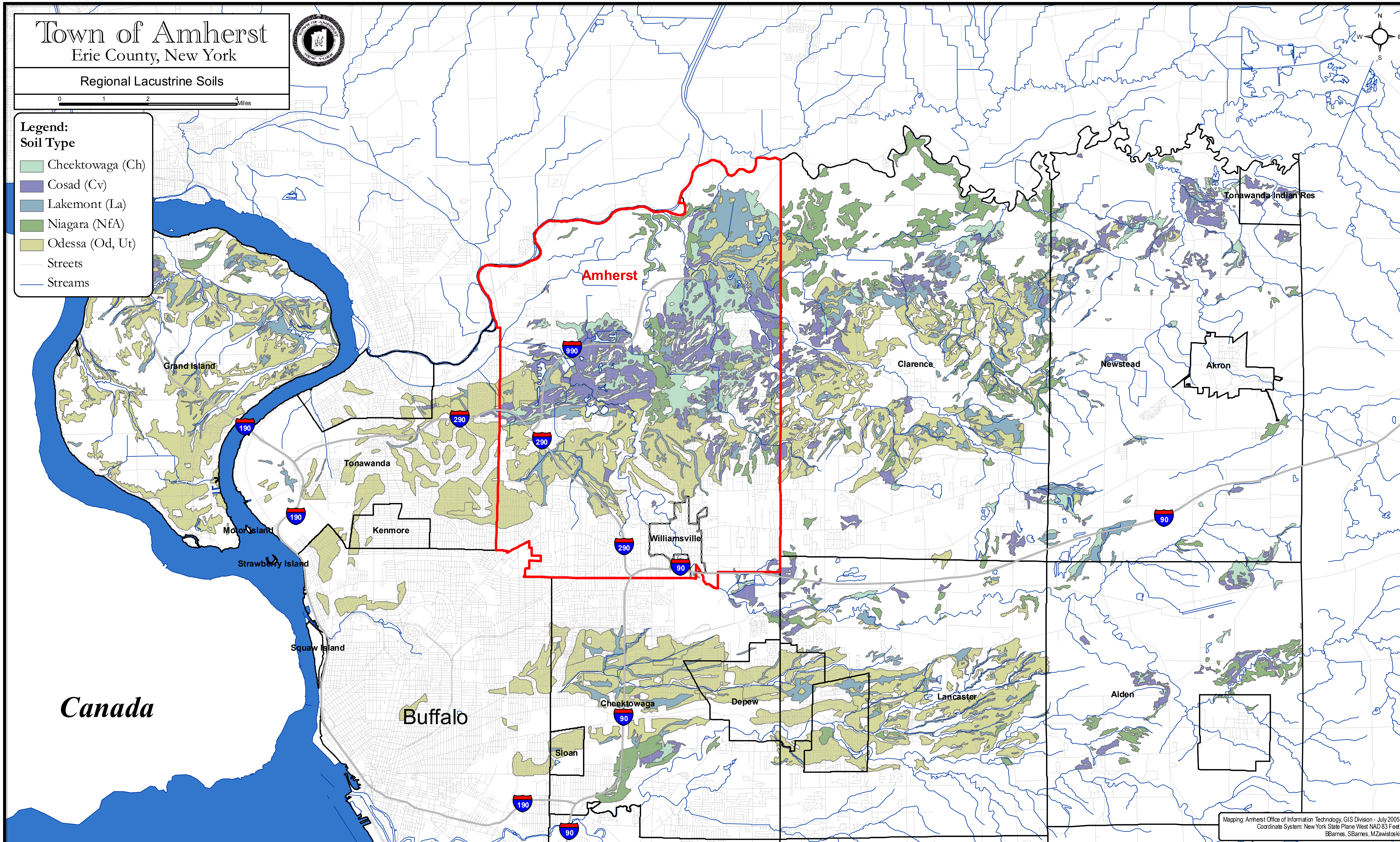

Figure 5: Distribution of five lacustrine surface soil types in Amherst, NY.

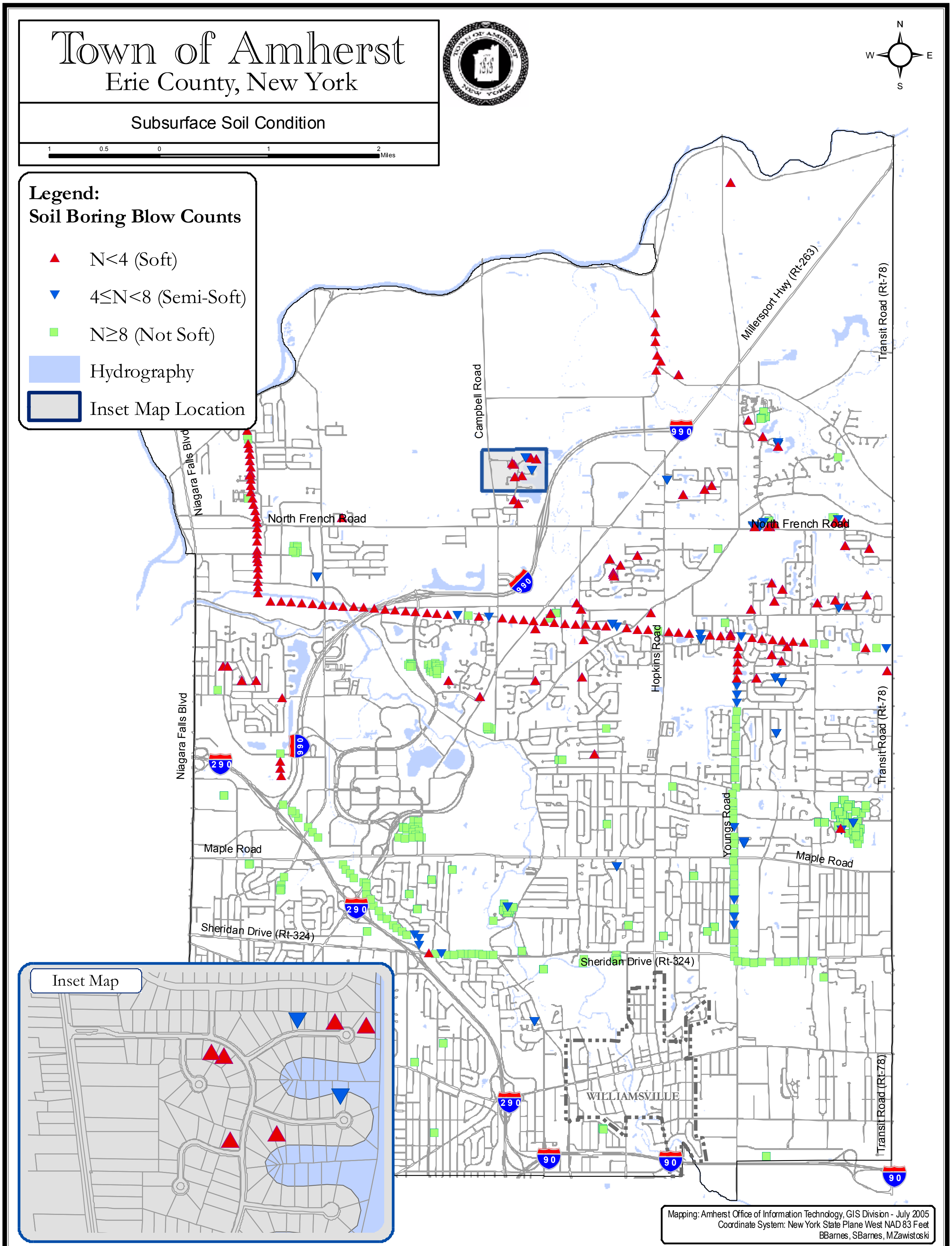

Figure 6: Location of boreholes and the presence of "soft," "semi-soft," or "not soft" strata. These designations are based on the N-values (blow counts). The soft stratum generally consists of silty clay. In general, the northern portion of Amherst is underlain by the soft stratum, but the inset shows variability at parcel level.

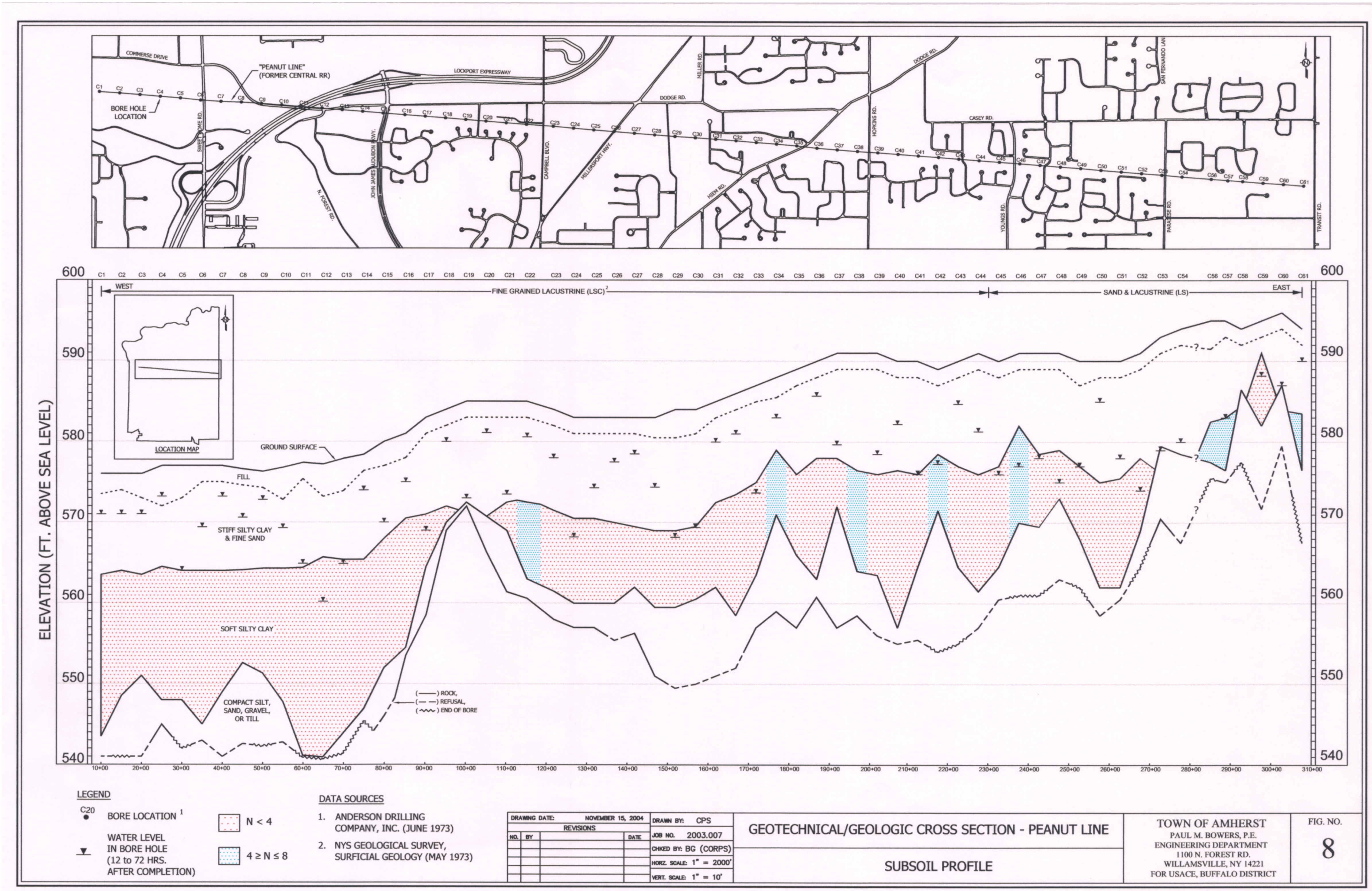

Figure 7. Geotechnical/geologic cross-section through central Amherst along former New York Railroad, or "Peanut Line." Upper section shows aerial view of borehole locations. Cross-section shows elevation of ground surface and depths of fill, soft stratum (if present), till, and borehole termination (end-of-borehole, refusal, or rock). Stipling shows thickness of soft stratum (red) and semi-soft stratum (blue), generally silty clay. Micro-topography of the bedrock and surface appear to influence the location of softer stratum. Subsurface condition becomes more heterogeneous in east towards Clarence.

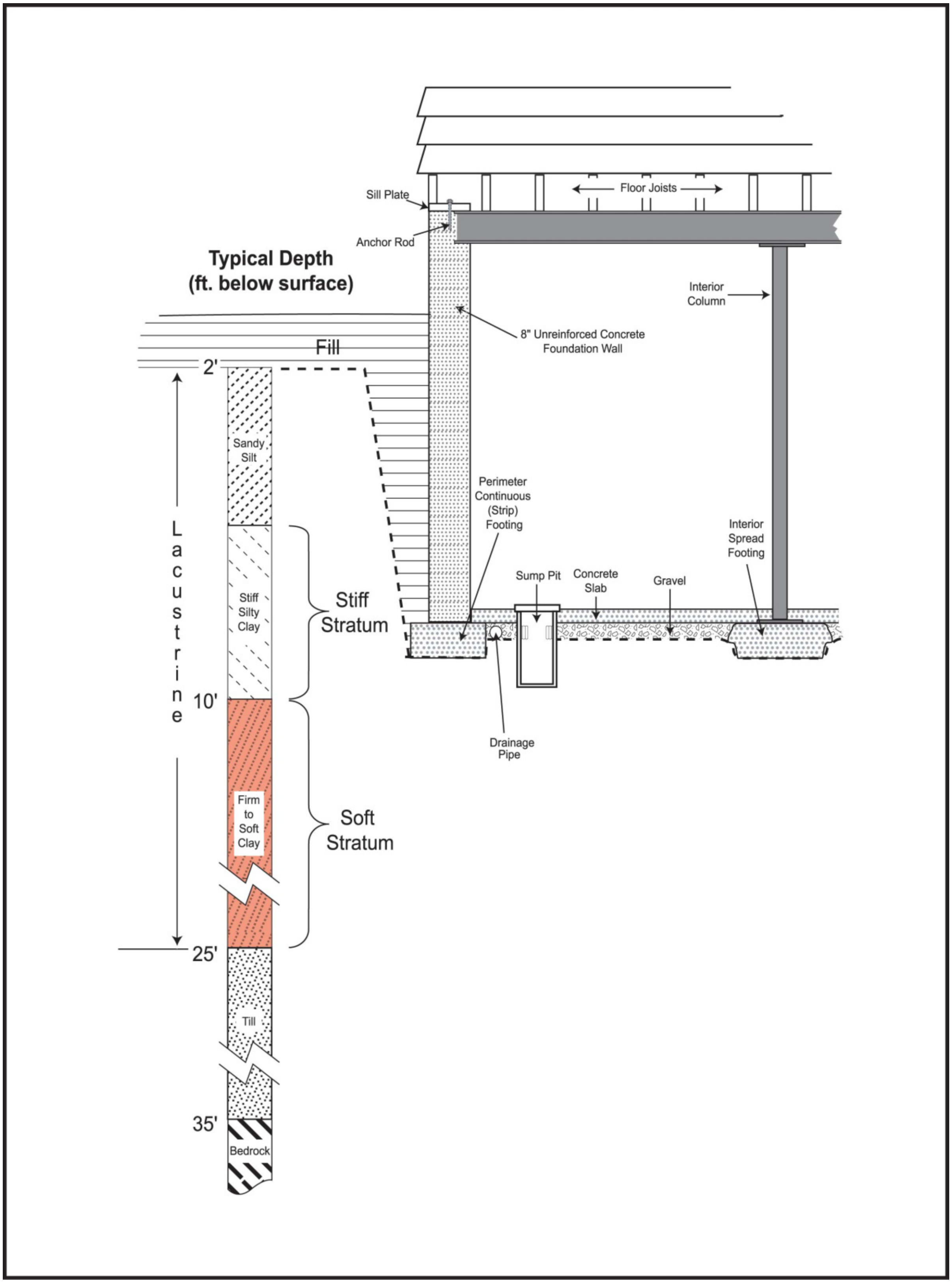

Figure 8. Schematic stratigraphic soil profile in central and northern Amherst showing typical construction of older houses. Many footings rest on a stiff stratum that overlies a soft stratum. Fill consists of remolded native material.

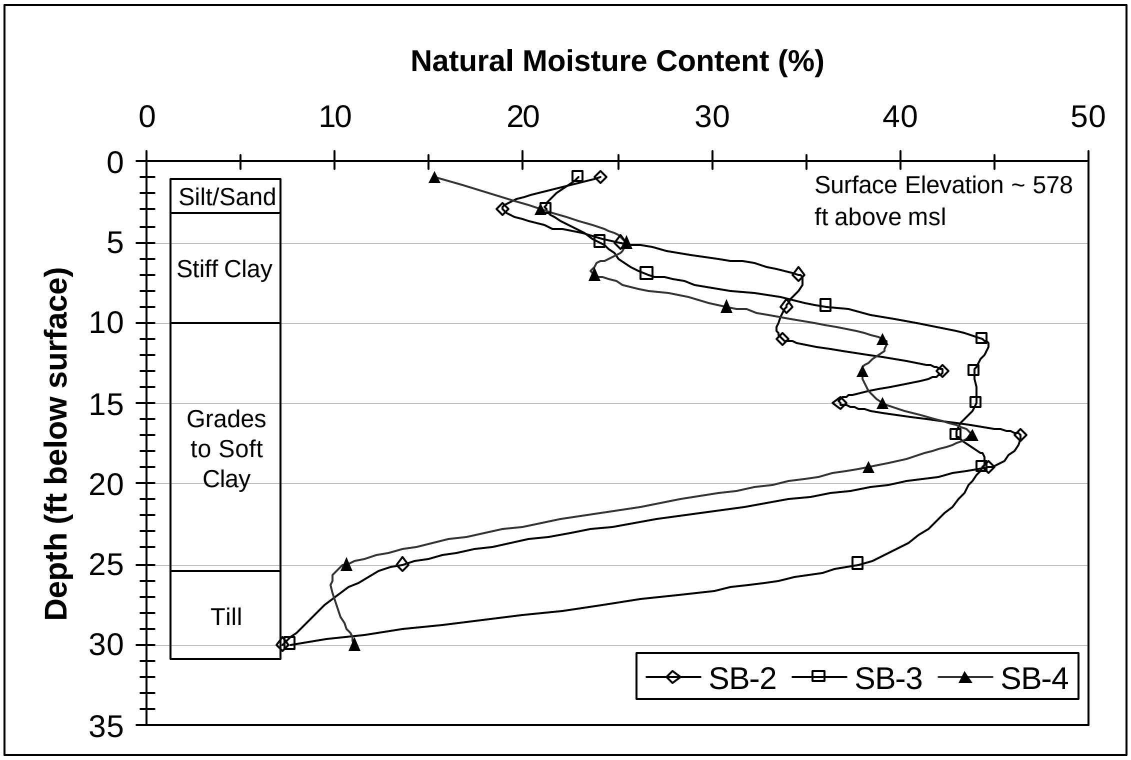

Figure 9. Typical soil moisture content profile from three soil borings at sewage treatment plant in northwestern Amherst. Data from Ward (1973).

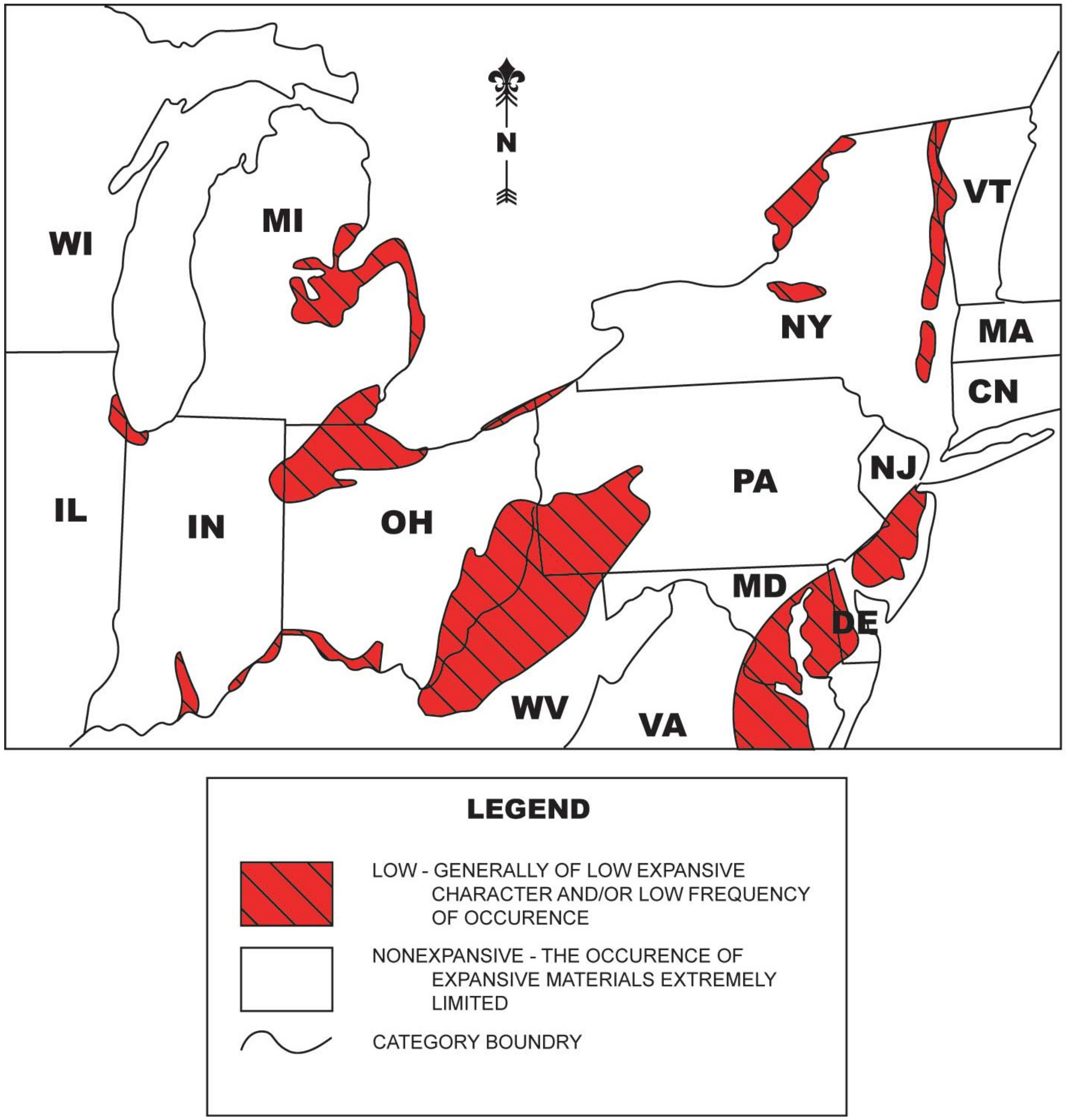

Figure 10. Distribution of potentially expansive soils in the Great Lakes and Northeastern United States (modified from FHWA, 1975).

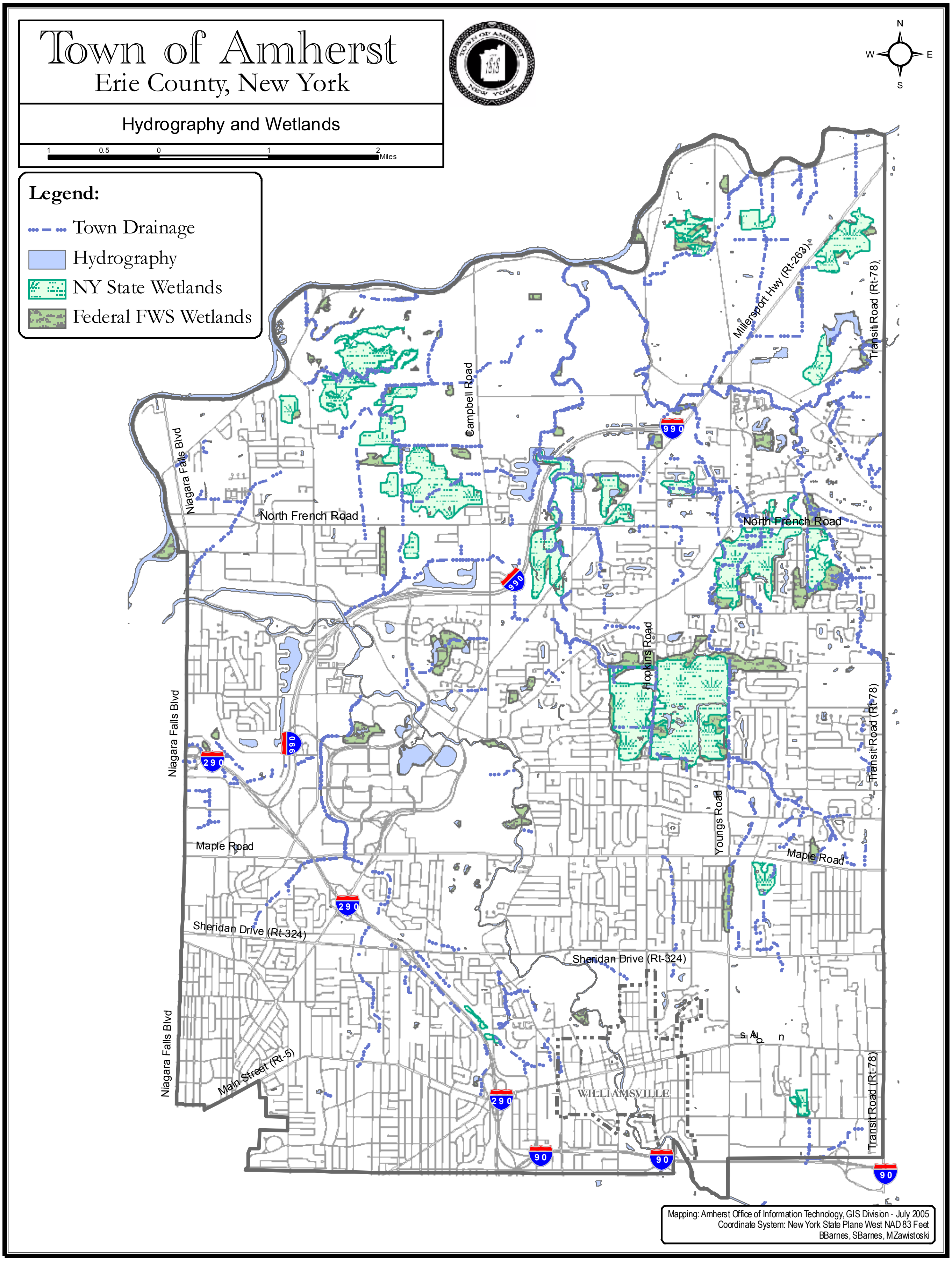

Figure 11: Hydrography and wetlands of Amherst, NY.

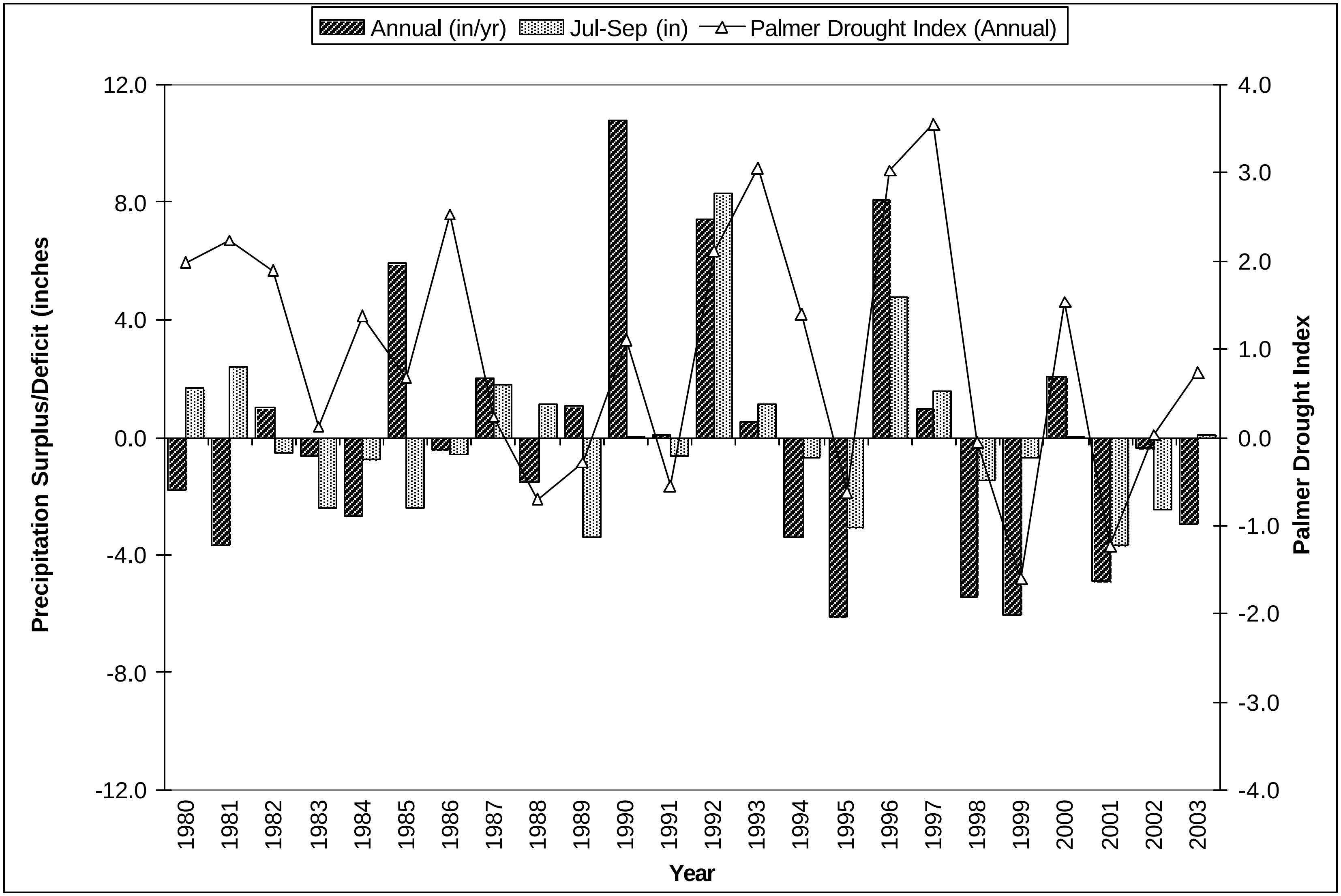

Figure 12. Annual and summer precipitation deficit and surplus (inches from normal) and the annual Palmer Drought Index. For example, in 1996 the summer and year was wetter than normal, while 2001 was drier than normal.

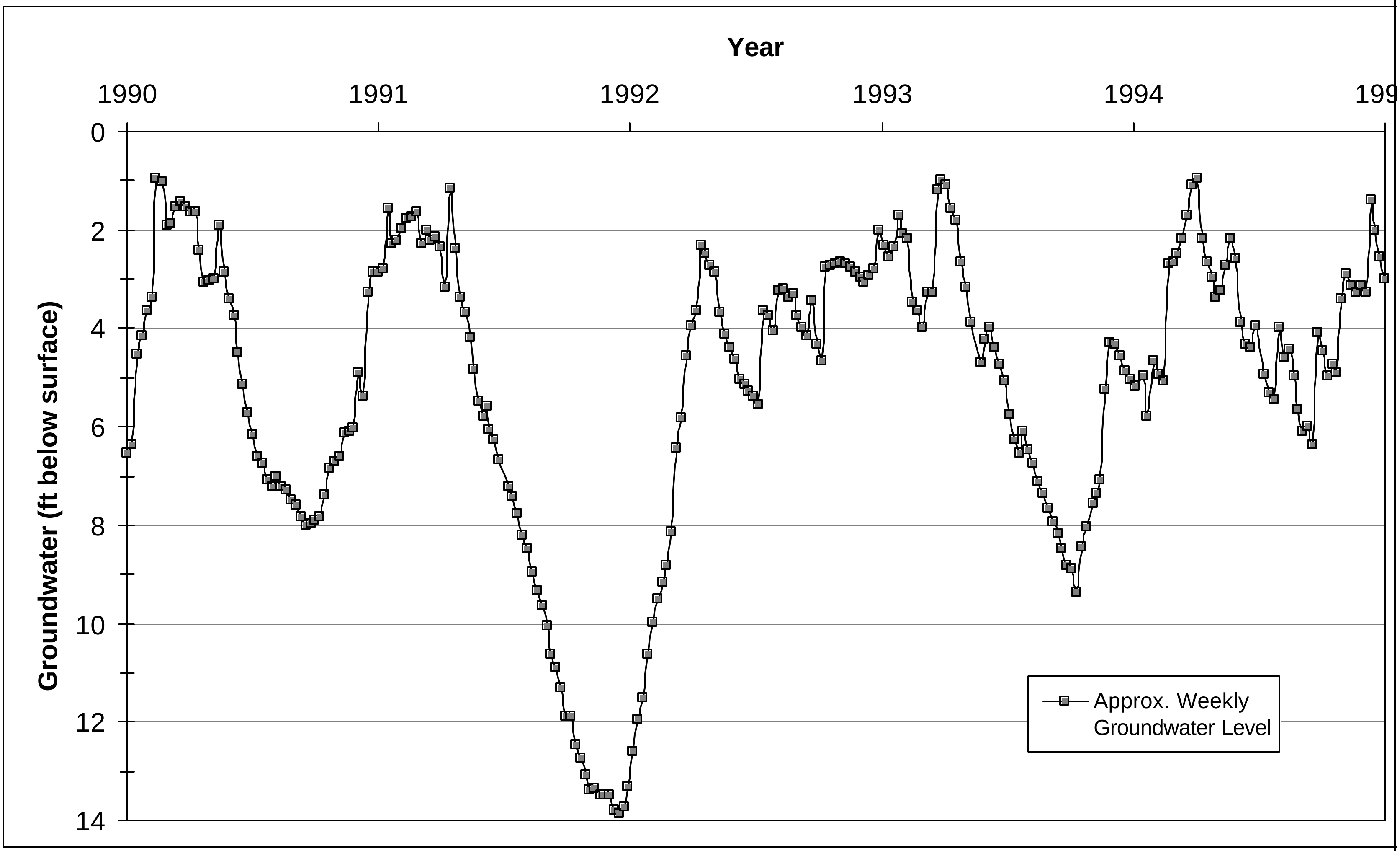

Figure 13. Hydrograph of Ransomville well, near Buffalo, NY, showing weekly groundwater levels in dug well (~25 ft deep) in possible sandy clay stratum. Dry and wet years correspond to 1991 and 1992. Data collected by the USGS (Well No. NI-70).

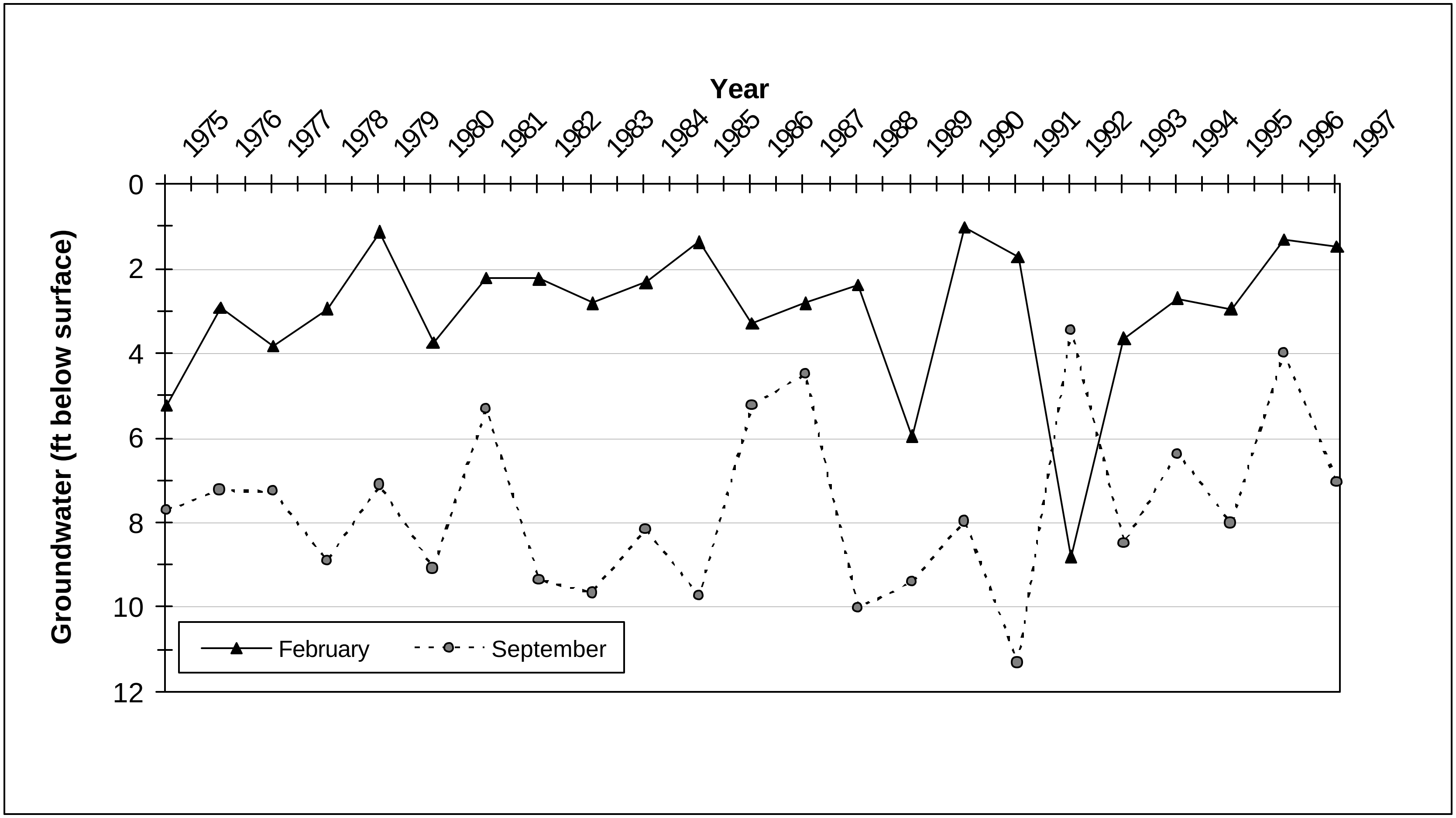

Figure 14. Hydrograph of Ransomville well, near Buffalo, NY, shows qualitatively the annual change in storage from late-February to late-September (1975-96). The dug well is 25 foot-deep and the subsurface may be sandy clay. Data collected by the US GS (Well No. NI-70).

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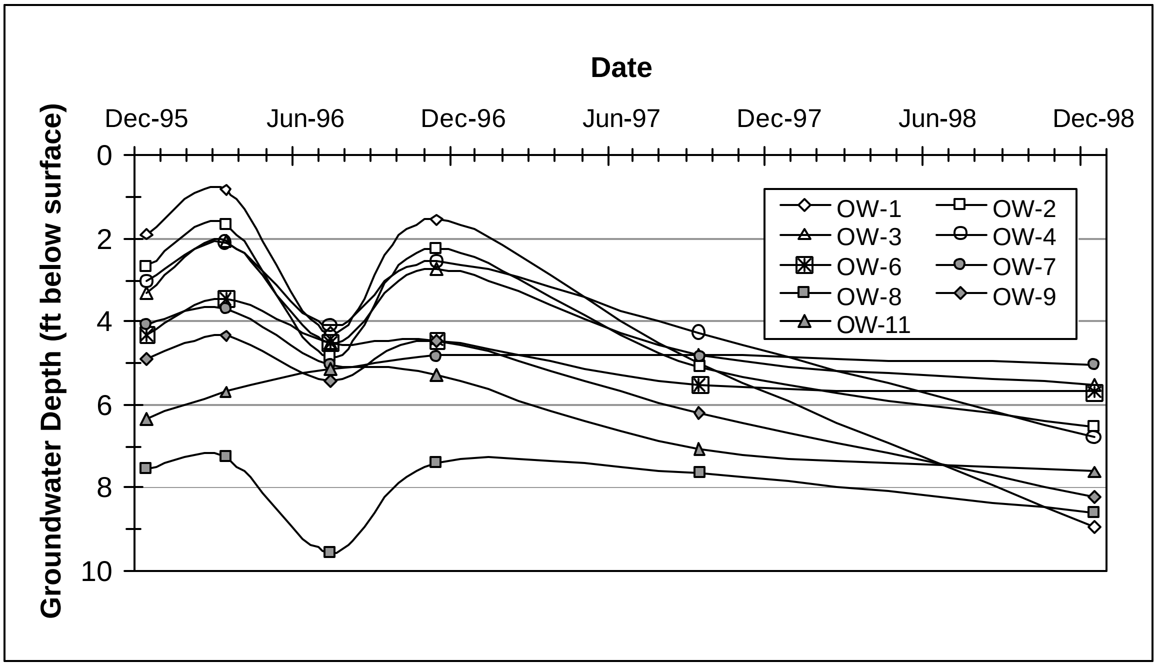

Figure 15. Groundwater levels in shallow wells at Spaulding Site, north of former Tonawanda Landfill (see Appendix 6.1.4). The midpoint of the sandpack for all wells is about 14 feet below ground surface in silty clay (probably till). Data shows spatial and temporal variability in shallow groundwater level. (Data source: Glen May, NYSDEC, 2005)

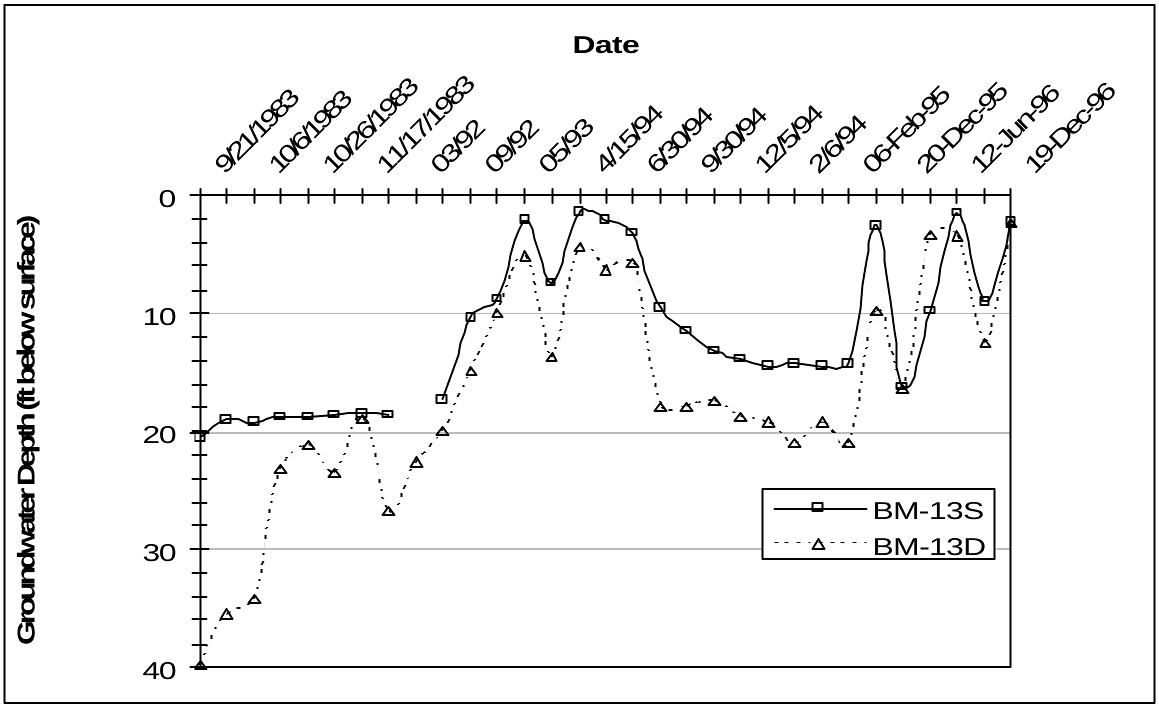

Figure 16. Tonawanda landfill wells BM-13 shallow (S) and deep (D). Sandpack midpoints are approximately 15 and 40 feet below ground surface. Note discontinuous dates. (Data source: Glen May, NYSDEC, 2005).

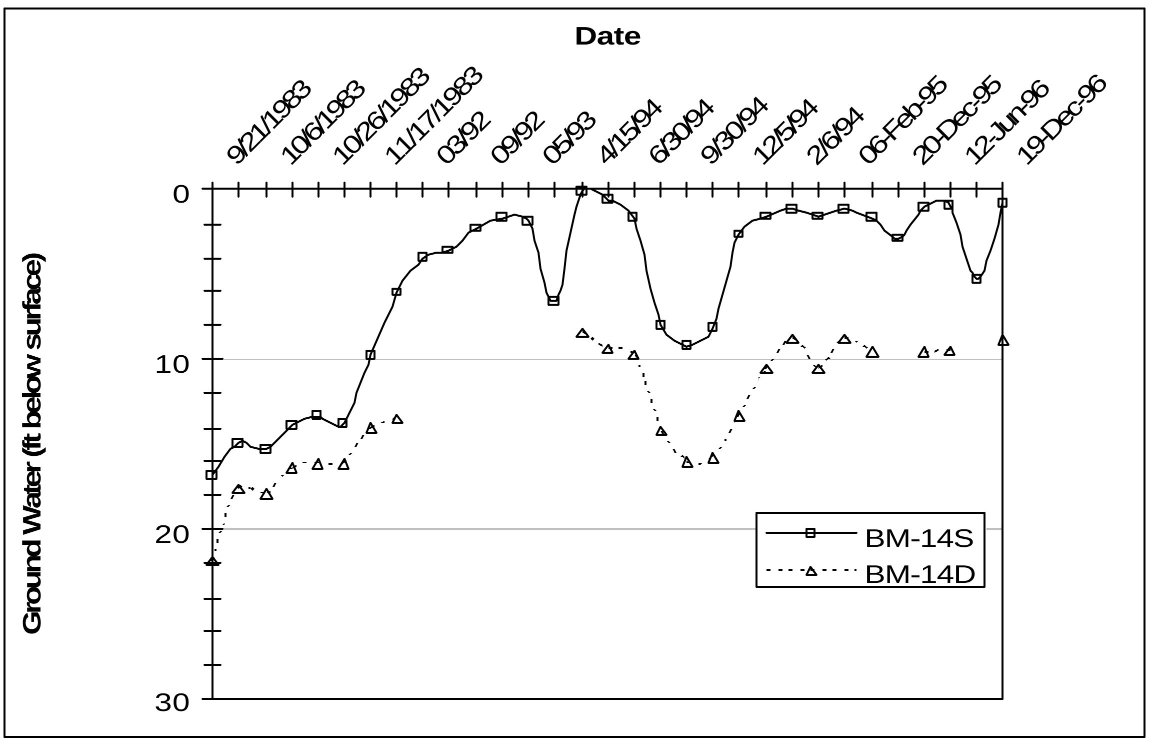

Figure 17. Tonawanda landfill wells BM-14 shallow (S) and deep (D). Sandpack midpoints are approximately 15 and 40 feet below ground surface. Note discontinuous dates. (Data source: Glen May, NYSDEC, 2005).

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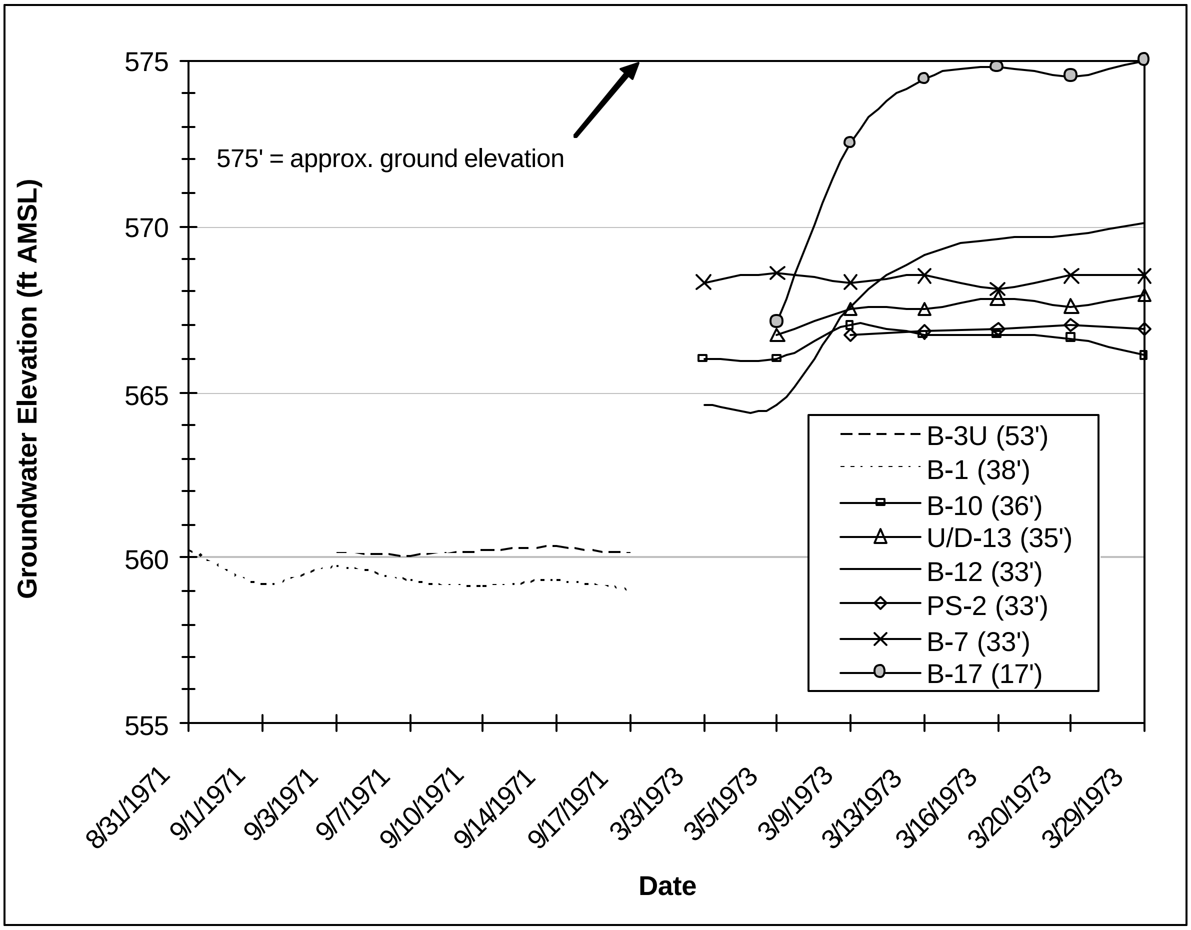

Figure 18. Groundwater elevation at piezometers in till or rock in northwest Amherst, near sewage treatment plant. Note hiatus in dates. Legend shows depth of opening below ground surface. Site is nearly flat with ground elevation ~ 575 ft AMSL. (Data source: Ward, 1971 & 1973).

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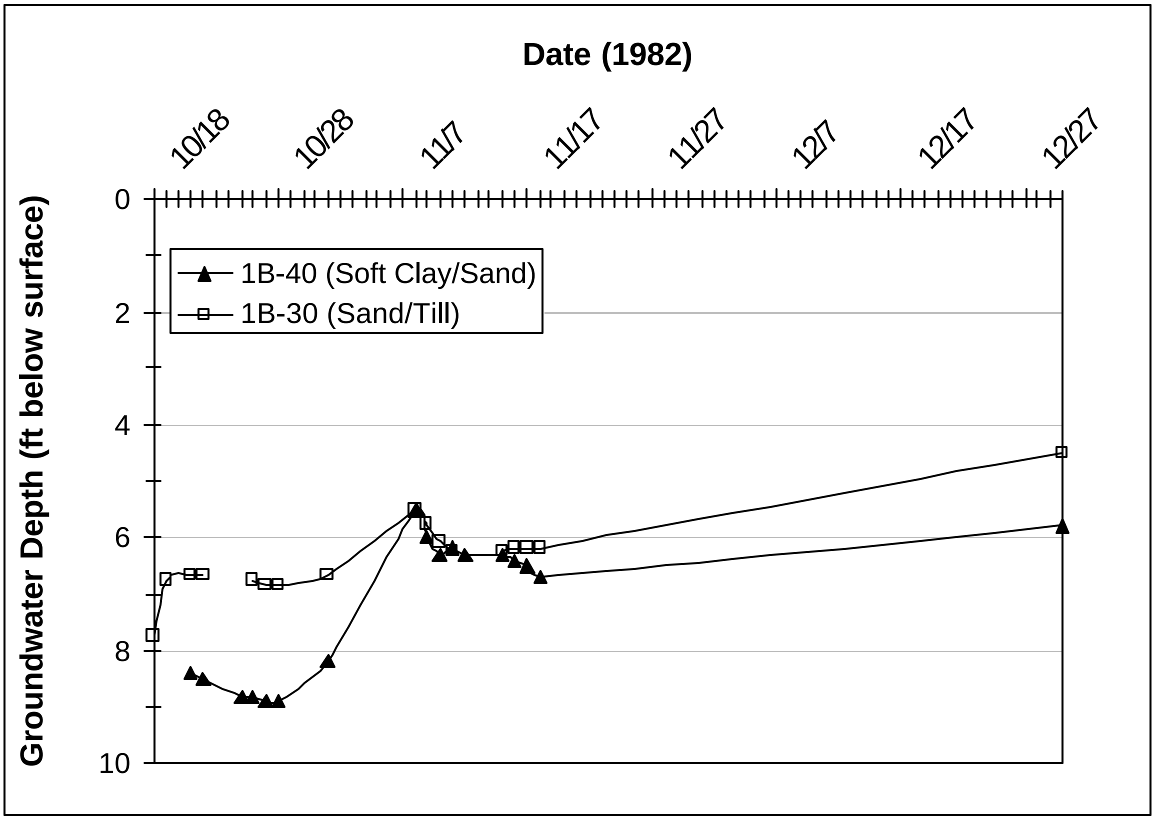

Figure 19. Groundwater elevations at two observation wells along Youngs Road, north of Sheridan Drive (1982). 1B-40 is screened in soft clay stratum transitioning to sand (12 to 20'), and 1B-30 is screened in sand/till (12-20'); both have a total depth of 20 ft. (Data source: Earth Dimensions, 1982).

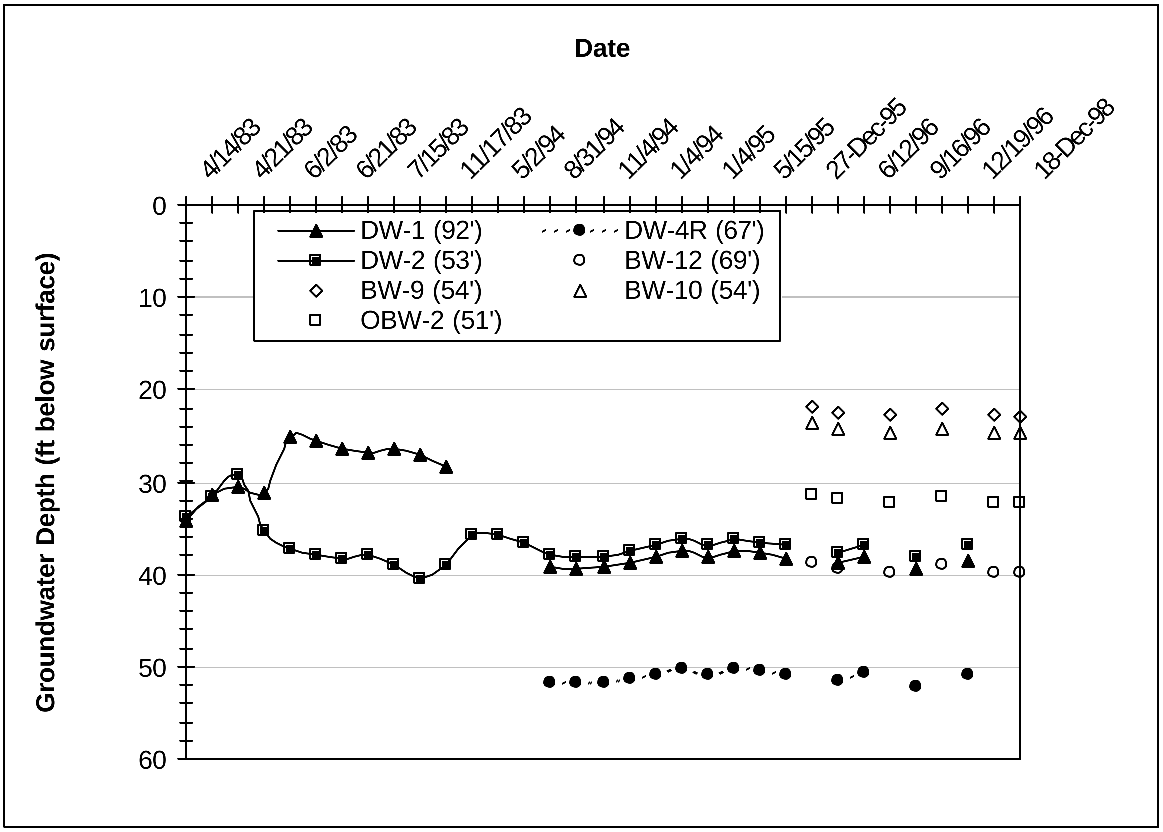

Figure 20. Hydrograph of till (open) and shale (solid) monitoring wells at the Tonawanda landfill. NY. Legend indicates midpoint depth of screened interval (see Appendix 6.4). Note hiatus in dates. (Data source: Glen May, NYSDEC, 2004)

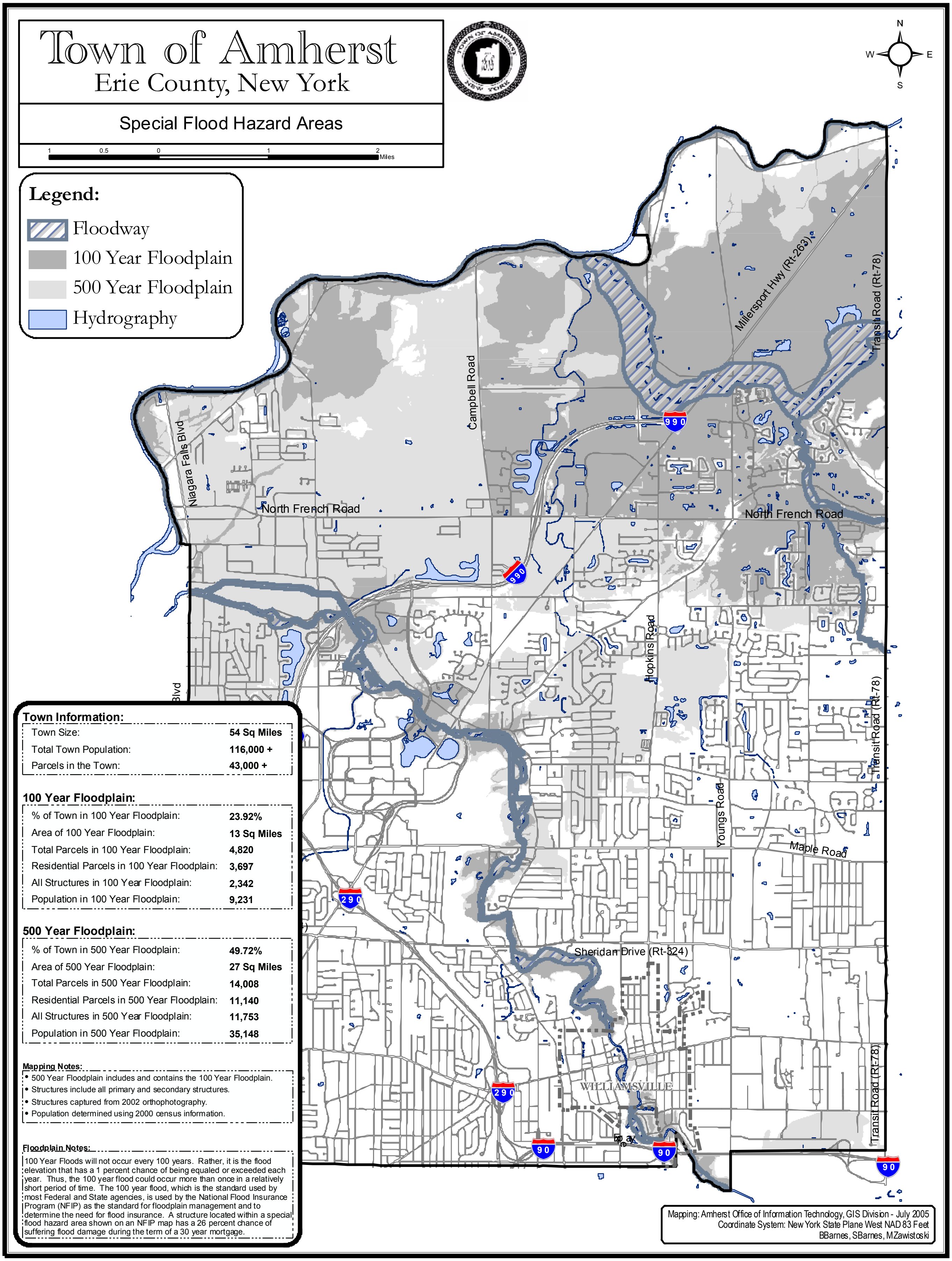

Figure 21: Special flood hazard areas in Amherst, NY (2004).

Table 1. Historical plasticity index data for Amherst and surrounding area.

Location	Data Source	Geologic Material	Sample Depth (feet below surface)	No. of Samples	Average PI	Standard Deviation	Max. PI	Min. PI
Lockport Expressway	McGuffey et al. (1982)	Firm-Soft Silty Clay	---	66	22.2	± 3.0	---	---
Ellicott Creek Flood Control Project	USACE (1979)	Lacustrine Deposit (Ql)[1]	0 – 9	13	27.2	± 6.6	36	13
			10 – 19	33	29.8	± 3.3	33	20
			20 – 25	10	27.8	± 3.9	34	21
		Lacustrine Deposit (Qlt)[2]	0 – 20	10	26.3	± 6.5	34	11
Tonawanda Creek area North	USACE (1973)	---	---	5	22.0	± 3.3	25	17
		---	---	10	24.4	± 3.3	33	20
Amherst Sewage Treatment Plant	Ward & Associates (1971,73)	Silt and Clay (A & B)[3]	5 – 17	16	24.1	± 4.3	29	17

[1] Ql = Well sorted, thin-bedded to massive, red-brown to gray clayey-silt of high plasticity, associated with post-glacio Great Lake (includes CH or CL)

[2] Qlt = Stratified, sorted, sandy silt and sandy clay of low plasticity, associated with Lake Tonawanda (includes CH or CL)

[3] Samples represented are predominantly varved gray brown silty clay or clay and silt, less than 20 ft in depth, and have blow counts between 0-4 (A Clays) or 5-8 (B Clay).

Table 2. Natural and man-made factors affecting soil moisture content

<table>
<tr><th colspan="3">Factors Affecting Soil Moisture Variation in the Subsurface</th></tr>
<tr><th>Natural/Undeveloped</th><th colspan="2">Man-made/Developed</th></tr>
<tr><th colspan="3">Scale of Observation</th></tr>
<tr><th>Regional</th><th>Neighborhood</th><th>House-lot</th></tr>
<tr><td>Preciptation
Evapotranspiration
Temperature
Wind
Soils
Wetlands
Floodplain
Flood control</td><td>Impervious Surfaces (roofs, roads, parking lots)
Evapotranspiration
Stormwater conveyances (storm drains, ditches)
Ponds (detention, retention, recreational)
Sewer main (infiltration or leakage)
Water main
Snow storage
Mining
Groundwater (withdrawal & injection)</td><td>Impervious Surfaces (roofs, driveway, patios, walkway)
Trees and schrubs
Sump pump
Downspouts/storm drain
Footing drain
Leaky plumbing (water, sewer, garden hose)
Yard drainage
Lawn irrigation
Landscaping/ground slope
Dehumidifier
Neighbor’s runoff
Pools
French Drain
Utility trenches
Storage under slab
Desiccation cracks
Backfill settlement
Sun exposure (N-S)</td></tr>
</table>

Table 3. Climate data for Buffalo, New York

	Period	Month												Annual Average
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Temperature[1] (°F)	1971-00	25	26	34	45	57	66	71	69	62	51	40	30	48
ETo[2] (inches)	1987	0.46	0.43	0.89	1.69	3.13	4.26	5.31	4.32	2.55	1.51	0.71	0.48	25.7
Precipitation[1] (inches)	1971-00	3.2	2.4	3.0	3.0	3.4	3.8	3.1	3.9	3.8	3.2	3.9	3.8	40.5 ± 5.4
Snowfall[1] (inches)	1884-04	26.1	17.8	12.4	3.6	0.3	---	---	---	0.0	0.3	11.0	25.5	97.0

Data Sources:[1] National Weather Service Buffalo; temperature and precipitation data available for 1940-2004; temperature value rounded to nearest whole number; precipitation values rounded to nearest one-tenth; snowfall maximum 199.4 inches (1976-77) and minimum 22.4 inches (1889-90). [2] ETo (potential evapotranspiration) values for Clarence from Staubitz and Miller (1987), but similar to La Sala (1968) = 24.4 inches for Buffalo.

Table 4. Population growth in Town of Amherst (1950–2000)

	Total Population	10-Year Change (%)	Erie County Population (%)
1950	33,744	--	3.8%
1960	62,837	+46.3%	5.9%
1970	93,929	+33.1%	8.4%
1980	108,706	+13.6%	10.7%
1990	111,711	+2.7%	11.5%
2000	116,510	+4.1%	12.3%

Source: United States Census Bureau

Table 5. Land use changes in Town of Amherst (1972– 2000)

Land-Use Category	1972		1985		2000	
	Acreage	Percentage	Acreage	Percentage	Acreage	Percentage
Residential	7,229	21.2%	8,840	25.9%	12,492	36.6%
Commercial	885	2.6%	1,160	3.4%	1,367	4.0%
Office	65	0.2%	224	0.7%	818	2.4%
Industrial	127	0.4%	453	1.3%	335	1.0%
Public and Semi-public	2,390	7.0%	2,533	7.4%	2,578	7.6%
Recreation and Open Space	2,146	6.3%	2,319	6.8%	3,678	10.8%
Transportation, Utilities, Communications	4,149	12.2%	5,012	14.7%	5,112	15%
Vacant and Agricultural	17,017	49.9%	13,559	39.8%		
Agricultural					1,226	3.6%
Vacant					6,484	19.0%

Source: Town of Amherst, Planning Department

Table 6. Chronology of important building code changes in Amherst, NY.

CODE NAME	EFFECTIVE DATES OF CODE	NOTES
None	Before 5/11/36	
Building Code of the Town of Amherst (also known as the Building Ordinance)	5/11/36 to 7/4/77	This Building Code was supplemented by "The Fifth Edition of the Building Codes recommended by the Board of Fire Underwriters". The Fire Underwriter's code was deemed to be the generally accepted good practice for conditions, details and subjects not covered in the Building Ordinance.
The "State Building Construction Code"	7/5/77 to 12/31/83	This was a non-mandated New York State Building Code. The adoption of the code was voluntary.
State Uniform Fire Prevention and Building Code	1/1/84 to 12/31/02	The adoption of this code was mandatory for all municipalities throughout New York State with the exception of New York City
1) Building Code of New York State (NYS); 2) Residential Code of NYS; 3) Fire Code of NYS; 4) Plumbing Code of NYS; 5) Mechanical Code of NYS; 6) Fuel Gas Code of NYS; and 7) Property Maintenance Code of NYS.	1/1/03 to present	The adoption of these codes was mandatory. They are based upon the International Codes and are modified with New York State Enhancements.

Photo 1. Varved clay from excavation near Millersport and Transit Roads. Sample characteristic of lacustrine material in Lake Dana-Lundy (D'Agostino, 1958). Laminated bands thought to indicate annual cycles of deposition from summer (pink) to winter (gray).

Photo 1. Desiccation cracks in backfill near basement wall in central Amherst, NY, in July 2004.