SUITABILITY OF NON-HYDRIC SOILS FOR WETLAND MITIGATION

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16. Abstract

ABSTRACT

This project looked at the suitability of non-hydric soils for wetland mitigation by reviewing the literature, and by investigating sites at which non-hydric soils were successfully used in wetland mitigation projects. Five sites were selected for field study. They included the Pine Road Wetland Mitigation Site in Brentwood, NH; the Bangor Hydroelectric Graham Lake Dam remediation wetland mitigation site in Ellsworth, ME; the Maine Department of Transportation wetland mitigation site at the old Maine Turnpike southbound exit 6 in Scarborough, ME; the cloverleaf exit from I-691 to Route 10 in Cheshire, CT; and the Michelle Memorial Park wetland mitigation in Salem, NH. Each site was visited, and characterizations were made of the soils and hydrologic conditions.

Conclusions were drawn from the data analyses and the information gathered in the first phase of the project. The literature indicated hydrologic conditions are the controlling factor governing the formation of hydric soils. The soils should be saturated for at least 7-21 days of the growing season in order to form the characteristic hydric morphological features. Organic matter also influences the formation of redoximorphic features characteristic of wetlands. Redoximorphic features did not form in soils with less than 1.5% organics, while soils with 3% or greater were most effective in producing redox depletion in flooded plots. A small laboratory experiment using upland site soils indicated that the site soils supported this conclusion. Each site was considered a functioning site, and the soils used in the construction of all but one site were classified as hydric. The site investigations corroborated the findings of literature review. Guidelines were developed to match appropriate soils to the wetland type and the site hydrology.

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Table of Contents

List of Tables

List of Figures

Suitability of Non-Hydric Soils for Wetland Mitigation

I. Introduction

A successful wetland creation or restoration requires a hydric soil base. This is defined as a soil, which in its undrained condition, is saturated or ponded long enough to develop anaerobic conditions which favor the growth and regeneration of hydrophytic vegetation. The mitigation site is often a degraded or despoiled site that does not have a hydric soil base. In such instances hydric soils have been imported to the site. The soils used come from impacted wetlands and may include seeds from nuisance plant species which are undesirable in the mitigation site. In cases where prevention of nuisance plants is critical, or in cases where hydric soils are not available in a timely manner, non-hydric soils have been used in mitigation efforts. Guidelines are needed to establish selection criteria for non-hydric soils, and for evaluating site suitability for the development of a suitable hydric soil base for a wetland mitigation project.

II. Project objectives

The objectives of this research are three-fold. Specifically they include the following:

- Identify the characteristics and properties of non-hydric soils which have been successfully used in existing wetland mitigation projects.
- Describe the site conditions that will influence the success of using non-hydric soils for wetlands mitigation.
- Develop recommendations for the selection of non-hydric soils or non-hydric soil amendments for mitigation purposes based on existing site conditions.

The project was performed in three phases. The first phase was a detailed literature review to search for data relating to the first two objectives. The first phase of the project also included an investigation into past wetland mitigation projects both through the literature, and through direct contacts with New England agencies which in some way regulate such projects. The second phase involved locating five sites across New England where non-hydric soils had been used for wetland mitigation. Field studies were instituted at these sites to evaluate the hydrologic and soil conditions of the projects, if hydric indicators have been developed, and whether the project was successful. The third phase of the project involved combining the information gathered in the first two phases, and synthesizing the information to develop guidelines for the use of non-hydric soils for wetland mitigation.

III. Phase I Literature Review

The literature review concentrated on the hydrology of natural wetlands and mitigation projects, and on the soils found in each of these wetlands. The hydrologic conditions and soils information are described separately.

A. *Hydrologic conditions*

A wetland constitutes the transition zone between upland terrestrial environments and deep water aquatic systems, such as lakes or rivers. As such, the hydrologic conditions change from one environment into a transition zone and finally into the other environment as a continuous transition. This smooth transition presents a problem when defining at what point a wetland exists. Wetlands have been defined in terms of hydric soil conditions, plant species, and hydrology. The three components that are contained in the definition of a wetland are listed by Mitsch and Gosselink (1986) as:

1. Wetlands are distinguished by the presence of water (hydrology).
2. Wetlands are characterized by unique soils that differ from adjacent uplands (hydric soils).
3. Wetlands are populated by hydrophyte (vegetation) which are adapted to anaerobic soils, and are conspicuously devoid of flooding-intolerant vegetation.

The definition has evolved to the point where the current definition is balanced is terms of all three elements. Kadlec and Knight (1996) summarized the definition used by the U.S. Army Corps of Engineers as "areas in which the soil is saturated or inundated for a relatively long period of time during the growing season, and is characterized by the absence of plant species which thrive only in aerobic soil conditions". Perhaps the most important element defining a wetland is the hydrology of the site.

The long term success of any wetland restoration or creation project is to a large part dependent on the establishment and management of appropriate hydrologic conditions. Hydrologic conditions for wetlands are typically described with respect to a water balance equation. In this case, the change in water storage of the wetland is a result of the difference between the hydrologic inputs to the wetland system and the hydrologic output. Hammer (1996) lists the hydrologic inputs as surface and subsurface flows along with direct precipitation. Direct precipitation in this instance includes rainfall, snowfall, and ice. Surface flows include stream flow and surface runoff into the wetland. Hydrologic output includes groundwater flow out of the wetland area, surface overland flow from the wetland, and evapotranspiration. Few wetlands can be supported on direct precipitation alone. The hydrology must be supplemented by surface flow including overland surface runoff, and flow from channels or streams. In addition, groundwater discharge into the wetland can either supplement the surface flow or replace it as the primary source of water into the wetland. Surface water is important to the sustenance of wetlands due to the minerals, nutrients, and sources of fixed energy that enhance the productivity of the wetlands. In the case of groundwater, minerals and some nutrients may be transported into and out of the wetlands, but typically not in the same quantity as with surface waters.

Hydrology modifies or controls the functions and structure of the wetlands by controlling the nutrient cycling, and the composition of the plant communities. The hydrology is responsible for the import and export of the nutrients and fixed energy supplies, and their availability. For instance, nutrients tied up under reducing conditions in substrate which is inundated, are returned to active portions of the water cycles as the substrate periodically dries out. Such is the case where the groundwater table fluctuates during the course of the growing season. The saturated conditions limit decomposition. Anaerobic decomposition rates are approximately 10% of aerobic rates, resulting in a build-up of partially decomposed organic material (Hammer, 1996). Willis and Mitsch (1995) showed that the emergence of seedlings for both natural and created wetlands are affected more by the hydrologic conditions than by the amount of nutrient additions. The nutrient additions do, however, affect the development of biomass growth once emergence occurred.

Plant community composition is defined by the hydrology, as different plant species have different adaptations to the frequency and duration of saturation. Frequency and duration of saturated conditions, known as the hydroperiod, is a product of both the hydrologic conditions and the surface topography of the site. The more varied the site topography, the broader the diversity of vegetation which can be supported. (Kadlec and Knight, 1996). In the same way, shallow groundwater table systems support a more diversified plant community than a deeper, continually flooded hydrologic conditions.

Water quality influences the survival and growth rate of a wetland. The parameters cited in Hammer (1996) include water clarity, pH, dissolved oxygen, dissolved nutrients, salt concentration, and flow velocity. Of these parameters, perhaps salt concentration has the largest influence on the survival rate of the vegetation. The salt concentration affects the osmotic balance, and consequently the passage of solutes across cell membranes. Many plant species are tolerant of wide ranges of pH but rather limited ranges of salt concentration. For example, sedges and nutsedges have a tolerance range of 0-0.4 parts per trillion (ppt) salinity (Hammer, 1996).

Other chemical properties are discussed by Kadlec and Knight (1996). Organic nitrogen is formed as a by-product of biomass decomposition. It is ultimately degraded into ammonium nitrogen which is the preferred form for vegetation growth. Ammonium nitrogen is not microbialy converted to nitrate in the absence of oxygen, and is therefore utilized in the formation of biomass. During the winter when utilization is low, concentrations may build up to as high as 4 mg/l. During the growing season, levels may be as low as 0.05 mg/l. At these levels, the plant growth will not reach its full potential without additional nitrogen input from surface water flow.

Carbon compounds are prevalent in a wetland environment due to large amounts of partially decomposed biomass. Atmospheric carbon fixation provides the basis for plant growth. Typical values for total organic carbon (TOC) in wetlands is 40 mg/l.

Common metals content of wetlands reflect the concentrations of inflowing waters. With a wealth of calcium (Ca), sodium (Na), and magnesium (Mg), the wetlands are classified as minerotropic. In wetlands that are solely dependent on precipitation, classified as ombrotrophic, these common metals are typically scarce. The metals content may have an influence on the pH of the wetlands.

The pH of natural wetlands are typically circumneutral, from 6-8. Ombrotrophic wetlands can have a very low pH due to the absence of metal, and the ion exchange of metal ions for the hydrogen (H) ion by plants. Algae can raise the pH during bloom conditions to as high as 9. High concentrations of Ca in the inflowing water tend to buffer pH to neutral levels.

Dissolved oxygen (DO) and redox potential (Eh) measure the oxidation potential of the water and the sediments. The DO can range from zero to twice the theoretical solubility in water depending on many variables. It is not uncommon to have zones of different DO concentrations along vertical sections, and heterogeneity within a wetland, especially in areas of ponding. The DO levels are typically below 2 mg/l due to microbial action on the biomass.

Sulfates are often present in wetland environments as a by-product of anaerobic (oxygen deficient) processes in the wetland. Most are either precipitated by divalent metals or released as hydrogen sulfide (H_2S). Chloride (Cl^-) has been found to be conservative (nonreactive) within a wetland, and consequently moves directly with the water flow.

A created wetland is defined by Hammer (1996) as a wetland constructed for the purpose of creating a wildlife habitat as a replacement for habitat lost in a wetland disturbance. The distinction is made with regards to the term "constructed wetlands" denoting wetlands built for the purpose of water treatment. Kadlec and Knight (1996) break down "constructed wetlands" as being wetlands constructed for habitat, wetlands constructed for water treatment, wetlands constructed for flood control, or wetlands constructed for aquaculture. Typically, the resulting wetlands serve multiple functions, for instance, a flood control wetland also provides additional habitat, but has flood control as its primary purpose. The results of this study would apply to any of the aforementioned definitions of man-made wetland.

To sustain a wetland community, the water balance must come out even, or the hydrologic inputs must outweigh the hydrologic depletions. The difficulty in wetland creation design is deciding the proper hydrologic criteria to use in determining what constitutes a wetland. The definition of the hydrologic criteria is centered about the depth of saturated conditions, and the duration at which these conditions occur during the growing season. The definition has undergone successive changes. The U.S. Army Corps of Engineers defined wetland hydrology as saturated conditions existing at a depth of less than 30 cm below ground surface for 14 consecutive days during the growing season (U.S. Army Corps of Engineers, 1987). The criteria as defined in the 1989 Federal Manual for Identifying and Delineating Jurisdictional Wetlands (U.S. Army Corps of Engineers, 1989) was that saturated conditions must be maintained less than 45 cm below ground surface for 7 consecutive days. This is known as the 45/07 criteria (Skaggs et al., 1994). In the 1991 proposed revisions to the Federal Manual, saturated conditions must exist at the surface for at least 15 consecutive days. The Soil Conservation Service (SCS) definition(U.S. Soil Conservation Service, 1987) includes saturated conditions at a depth of 45 cm for 14 consecutive days during the growing season. These criteria among others were evaluated by Skaggs et al. (1994). The criterion evaluated were grouped into two categories, based on the saturation depths. The first criteria group (45/07, 45/14, 30/14) resulted in relatively well drained soils which were predicted to produce a good crop of corn. The other criterion evaluated, (5/15, 00/15, 15/21, 00/21) described poorly drained soils which was considerably wetter than the soils in the previous group, and would not support a corn crop. The latter group of criteria are suggested as the better group for delineating hydric soils.

Guidelines for engineering the proper hydrologic conditions for a wetland creation project are provided by Holman and Childres (1995), Kadlec and Knight (1996), and Hammer (1996). There are numerous articles in the literature describing the creation and success of wetlands. Examples are Turner et al. (1994), describing coastal wetland restoration in Louisiana, USA; Syphax and Hammerschlag (1995) with respect to a tidal marsh in Washington, D.C.; Bijlmakers and de Swart (1995) describing a large-scale restoration project in the Netherlands; Haberl et al. (1995) discussing constructed wetlands in Europe, and Vymaza,(1995) looking at the state of the art in water treatment constructed wetlands in the Czech Republic. The evaluation of the created wetlands can be done using the Habitat Evaluation Procedure (Duel et al., 1995) or through more complicated procedures using several hydrologic models and a decision support system (Vadas et al., 1995). Both Brown (1991) and Confer and Niering (1992) evaluated constructed wetlands by direct comparisons to natural wetlands by comparing how biomass, diversity of vegetation, and the utility of wildlife match the natural counterpart wetlands.

None of the literature searched discussed wetland creation projects using non-hydric soils. Almost all the described projects were constructed using wetland soils salvaged from disturbed sites as a top dressing. Some of the literature describing the construction of treatment wetlands mention the use of coarse sand and gravel to provide a substrate for rooting of wetland species, in particular *phragmites australis,* a common reed (Green and Upton, 1995; Kadlec and Knight, 1996)

When creating a wetland, attempts can be made to either engineer the hydrology to accommodate the conditions necessary for the desired vegetation, or to select plantings of species which are suited for the hydrologic conditions. The soils which may be used include a wide variety of soil types. Hammer (1996) discussed the substrate choices for wetland creation. Fertile loam soils are the best for wetlands. Sandy loam soils are friable and consequently provide for easy rhizome and root penetration. Heavy clay soils and dense gravels may restrict root penetration, thereby limiting vegetative growth. They may also be so impermeable so as to deprive the roots of moisture. Sands and gravels desiccate more quickly and may kill off the vegetation if they are allowed to dry out for extended periods.

Hammer (1996) notes that soil amendments are usually not necessary since wetland plants thrive in a wide variety of soils. Acid soils may be treated with lime prior to flooding. Nutrients may be added if the soil is nutrient poor prior to placement and flooding. Fertilizers applied after the soils are in place are typically used up by algae. Sandy loam and clayey loam soils usually have sufficient nutrients to support new vegetation. All of the soils mentioned above would, under appropriate hydrologic conditions, become hydric. In fact, the "definition of hydric soils indicates that any upland soil utilized for the construction of a wetland treatment system will become a hydric soil following a short to long period of flooding and continuous anaerobiosis" (Kadlec and Knight, 1996).

B. *Soils*

Hydric soils are an important indicator of wetlands, usually constituting a key element in a triad of wetland criteria: hydrology, hydrophytic vegetation, and hydric soils. Despite the wide usage of hydric soils, however, understanding of their genesis is limited, and, in many cases, identification of hydric soils remains problematic. Part of the difficulty may stem from the confusion that practitioners encounter in sorting out the differences among field indicators of hydric soils, technical criteria for hydric soils, and the definition of hydric soils. These three categories are not equivalent, and the relationship among them is often unclear. Most practitioners, especially wetland scientists who are not soil scientists, will be most familiar with one or more versions of the Field Indicators. The chronology of Field Indicator development has been complex and controversial. For example, the Northeast Experiment Station Representatives to the National Cooperative Soil Survey (NEC-50) objected to the lack of support from scientific literature demonstrating a clear correlation between Field Indicator properties and actual soil conditions. In 1994, this group of university soil scientists resolved unanimously to "…..

> 1) object to the process whereby the Field Indicators have been developed, embraced, and utilized by SCS,
>
> 2) disagree with the fundamental philosophy and approach of the Field Indicators, and
>
> 3) oppose their use as the basis for identifying and delineating hydric soils."

Despite these objections, however, a consortium of federal agencies--the Natural Resource Conservation Service, the Environmental Protection Agency, the U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers--have continued to rework, revise, and re-publish national versions of the Field Indicators, all based on interpretations, rather than on correlations to soil conditions. Regional groups have also been at work establishing regional field indicators. This plethora of versions makes it difficult to produce a timely commentary on the status of field indicators.

In the most recent (June, 1995) version of Field Indicators of Hydric Soils in the United States the field indicators include:

- a mucky surface;
- gleyed matrix--hues of 5GY, 10GY, 5G, 10G, 10BG, 5B, 10B, 5BP;
- depleted matrix--value ≥ 4, chroma 2 with redoximorphic features (Vepraskas, 1992); or
- value 5, chroma ≤ 1 without redoximorphic features.

The NEIWPCC Wetlands Work Group in New England (1995), has also produced a set of field indicators specific to New England. The New England indicators include those above, except that they require only a Munsell value ≥ 4, and Munsell chroma ≤ 1 if no redoximorphic features are present. Key to all Field Indicators, however, is the notion that they are " . . . designed to meet the requirements contained in the definition and criteria of hydric soils." (p.1, NEIWPCC Wetlands Work Group, 1995.)

In contrast to the multiplicity of agencies and versions involved in Field Indicators, the Technical Criteria for hydric soils have remained relatively consistent, and have been primarily defined by the Natural Resources Conservation Service (formerly the Soil Conservation Service). These are listed in the Federal Manual for Identifying and Delineating Wetlands (U.S. Army Corps of Engineers, 1987), as follows:

1. All Histosols except Folists; or

2. Soils in Aquic suborders, Aquic subgroups, Albolls suborder, Salorthids great group, or Pell great groups of Vertisols that are:

    a. somewhat poorly drained and have water table less than 0.5 feet from the surface for a significant period (usually a week or more) during the growing season, or

    b. poorly drained or very poorly drained and have either:

        1) water table at less than 1.0 feet from the surface for a significant period (usually a week or more) during the growing season if permeability is equal to or greater than 6.0 inches/hour in all layers within 20 inches, or

        2) water table at less than 1.5 feet from the surface for a significant period (usually a week or more) during the growing season if permeability is equal to or greater than 6.0 inches/hour in all layers within 20 inches; or

3. Soils that are ponded for long duration or very long duration during the growing season; or

4. Soils that are frequently flooded for long duration or very long duration during the growing season.

Again, the Field Indicators are accessory information, but " The technical criteria are mandatory and must be satisfied in making a . . . determination. . . . Field indicators and other information provide direct and indirect evidence for determining whether or not . . . criteria are met. . . . It must be kept in mind that exceptional and rare cases are possibilities that may call any generally sound principle into question." (U.S. Army Corps of Engineers, 1987)

It is important to note, however, that the hydric soil criteria are not identical to either the Field Indicators or to the definition of hydric soils. In 1985, this definition was, "A hydric soil is a soil that in its undrained condition is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation." (p. 74 National Research Council, 1995). This definition has been changed three times since 1985, however. The second edition deleted the words, "in its undrained condition"; the third version omitted the reference to hydrophytic vegetation, and added that anaerobic conditions must occur in the upper part of the soil. The fourth edition specified that the soil must form under conditions of ponding, flooding, or saturation (NRC, 1995). In a comparison of three versions of the Federal Manual (1987, 1989, and 1991) plus the National Food Security Act Manual (NFSAM), the National Research Council (1995) also points out that required evidence for hydric soils has varied considerably over a short time span. In the 1987 and 1989 manuals, hydric soils may be inferred from vegetation. In all three Federal manuals, hydric soils can be inferred from hydrologic observations. Although general co-occurrence of wetlands and hydric soils is well-established, the period of saturation required to produce hydric soils is more problematic. For example, among the three versions of the Federal manual, hydric soils have been variously confirmed by seven days' flooding, 15 days' inundation, or 21 days' saturation. While the NRC concedes that "...the presence of hydric soil is the most common and useful general indicator to support the substrate criterion for wetlands, . . . several scientific and technical issues require further study and refinement." Among these issues is enhanced clarification of the conditions required to form hydric soils.

Indeed, the literature in this area is sparse, particularly that literature which addresses the time frame and conditions needed for development of redoximorphic features. Only five papers have been located so far which provide specific information. Two of these papers (Veneman et al., Vepraskas and Bouma) were published in 1976. Veneman et al. monitored annual groundwater levels and matric potential (unsaturated soil suction)--but not redox potential--in a drainage sequence of soils, and compared these conditions to detailed descriptions of soil color patterns. They found that annual short periods of saturation (one day or less) produced coatings of manganese and iron on faces of peds, but soil matrix colors retained a chroma of 3 or greater. When saturation duration extended to a few days, matrix chroma decreased to 2. Several months' of continuous saturation was required to reduce matrix chroma to 1. Vepraskas and Bouma conducted laboratory experiments to simulate water table fluctuations and their effect on development of redoximorphic features. Soil cores were intermittently saturated with a buffered sugar solution with a high biological oxygen demand (BOD) to increase soil microbial activity. Cores that were kept moist, but unsaturated, developed redox concentrations (Vepraskas, 1992) on large soil aggregate (known as ped) faces. Cores that were periodically (three weeks) saturated and drained (one week) developed both redox depletions and concentrations (as defined in Soil Survey Staff, 1994) in the soil matrix. The experiment was conducted over a five-month period. In more recent work, Vepraskas and Guertal (1992) calculated that a redox depletion zone rhizosphere 2 mm wide around a root channel would require 16 years to develop if the soil was saturated for 149 days each year.

Organic matter content appears to have an important effect on development of redoximorphic features, as the nutrients found in the organic matter provides energy to the microbes that effect reduction of iron. Dobos et al. (1990) conducted laboratory experiments in which simulated saturation was accompanied by additions of varying quantities of organic matter. They found that, within seven weeks, soils with as little as 3.2% organic matter developed mottled areas of 0.03%, and that half of those mottles had chroma of 1 or 2. In general, mottled areas increased and mottle chroma decreased with increasing organic matter. After 35 weeks, mottled area had increased to more than 1%. Individual mottle size was larger in soils with highest organic matter content (15.4%), and virtually all mottles had chroma of 1 or 2 in low organic matter and high organic matter treatments. Vepraskas (1994) also determined that organic matter percentages of 3% or greater were most effective in producing redox depletions in flooded plots. In this study, redox depletions began to form after a single seven-day flood event. After a series of nine inundations, which lasted between 4 and 44 days, depletions occupied from 15 to 27% of the surface horizons in some plots. Redoximorphic features did not appear to form in materials with less than 1.5% organic matter, however.

IV. **Phase II Site Investigation**

The Phase II site investigation included the site selection process, and the site investigation methodology. Both are described below.

A. *Site selection*

The sites that were selected for this study were found by contacting persons in the academic community. These contacts, from all across New England, eventually led to consulting firms and government agencies which had either designed or reviewed wetland construction efforts using upland (non-hydric) soils. Two sites were located through a meeting with Mr. Phillip Morrison of the U.S. Fish and Wildlife Service and conversations with Mr. Frank Smigelski of the U.S. Army Corps of Engineers. A site in Scarborough, ME was brought to our attention by Ms. Sylvia Michaud of the Maine Department of Transportation. A site in Salem, NH was chosen from several sites which used non-hydric soils in New Hampshire that were suggested by Mr. Mark West of Gove Environmental Services, Inc.

The criteria used for the selection of the sites was that the construction of the site must have included non-hydric soil placed over the natural soils. Several sites were rejected that were simply excavated to, or below the water table, as those particular soils may have had existing hydric characteristics for which this investigation was testing. Sites were also selected that had background data available on the construction and hydrologic conditions of the site. Long term hydrologic data could not have been collected in the time frame of this study.

Five sites were used in this study. The first was the Bangor Hydro-Electric Company Graham Lake Remediation Wetland Mitigation Sites, located in Ellsworth, ME. A detailed location is shown in Figure 1. This project included a remediation site and a wetland construction site. The wetland construction met the selection criteria very well, and was the only site at Ellsworth used in this study. The second site was the Pine Road Wetland Mitigation Site in Brentwood, NH. The location of this site is shown in Figure 2. This site is part of a large wetland creation project serving as a mitigation area for the improvement of Route 101 in New Hampshire. The third site visited was a created wetland site where the Old Exit 6 of the Maine Turnpike (I-95) in Scarborough, ME was located. This site, shown in Figure 3, was a Maine Department of Transportation site, and was one of several sites associated with the construction of a new, permanent exit. The fourth site is at Michelle Memorial Park in Salem, NH, shown in Figure 4. This site included a created wetland and a restored wetland. Only the created site was included in this study. The fifth site investigated was one of the Connecticut

Department of Transportation wetland creation sites in the Hartford area, specifically at the exit ramp infield of the Highway 10 Exit off of I-690, shown in Figure 5.

B. *Site Investigation Methodology*

A field investigation was performed at each selected study site. Each site was visited at least once. During this visit field tests and sampling activities were performed to characterize the hydrologic conditions at the time of the visit, and the soil morphological features.

1. Hydrologic Investigation

Eighteen small diameter stainless steel wells were installed as part of the investigative program. Each well consisted of 1/2-in nominal diameter 304 stainless steel pipe. The wells were in 10-ft sections. Each well had a 0.5-foot section of blank pipe at the well bottom to act as sump for soil particles. Above the sump was a three-foot length of screen, which consisted of four rows of two-inch long slots, 0.10 in. wide, cut into opposite sides of the pipe with a laser. One well at each of the Bangor Hydro-electric, Maine Turnpike, and Connecticut sites had a five-foot length of screen. The slots were positioned 1/4-inch apart along the one -foot length and aligned such that the gaps were offset between the two rows to maintain strength. The remaining length of the 10-ft pipe was blank riser. Prior to installation, a stainless steel drive point was inserted into the sump end of the well, held in place by a rubber o-ring. No wells were installed of length greater than 10 ft.

The wells were installed using a slide hammer. The wells were installed so the screens were at, or less than three feet below, the water table. The water levels were measured using an electric sounder. The wells were developed using a 1/2-in. OD. polyethylene tube with a Delrin check valve on the bottom to create an inertial bailer. Once developed, the wells were allowed to come to equilibrium, and the depth to water was checked to make sure the well was installed to a sufficient depth. The wells were protected by inserting a plastic cap or a rubber stopper in the top of the well. No wells were flush mounted during this investigation.

Slug tests were performed in the majority of the microwells installed. Slug tests provide a means of evaluating the hydraulic conductivity of the soil in the immediate vicinity of the well. The tests are performed by creating an instantaneous deflection in the water level in the well bore, and monitoring the aquifer response as the water recovers to its original static level.

The water level deflections were created using a mechanical slug. The mechanical slugs consisted of a metal bar attached to the end of a Druck PDCR-35/D miniature submersible pressure transducer by a fine brass wire. The slug and transducer were dropped into the well to a pre-determined depth below the water table. The metal rod displaced the water in the well bore, instantaneously raising the level. The subsequent recovery of the water level in the well bore to the static level was monitored at regular intervals with the pressure transducer and a lap-top computer. This test was called a falling head slug test.

In several wells, the slugs had difficulty passing through the well bore to the water surface. In such instances, a metal rod of smaller diameter was tried. If still unsuccessful, a rod of shorter length was used. The metal rods that were used for most of the tests were 3 ft. long and either 7/16 inch or 3/8 inch diameter galvanized steel. Two wells required the use of a 2 ft long rod. More frequently, there was insufficient water in the well to use the larger length slugs, and the 12-inch slug was used. A one foot segment of 7/16 inch rod will theoretically produce a 0.77-ft rise in the water column of the well. Similarly, the 3/8 inch rods produce a 0.56-ft rise in the water level per foot of submerged rod. The response of the aquifer was so rapid, however, that the full theoretical displacement depth was rarely measured. The response times for the recovery of the water column to normal (static) conditions were measured in terms of seconds. Typical response durations were 15-30 seconds, but some wells had a response duration up to 15 minutes.

The values of hydraulic conductivity obtained from these tests are point values representing the aquifer properties in the near vicinity of each well. In formations with high values of hydraulic conductivity, the inertial effects of the aquifer can be significant, causing oscillatory responses of the piezometric level in the well. This phenomenon was not observed in the shallow wells at any of the sites tested.

The test data was analyzed according the Hvorslev method (Hvorslev, 1951). The height of the water column above the transducer was normalized with respect to the maximum observed deflection. The normalized deflections were plotted on a log scale of a semi-log plot versus the respective elapsed time values on the arithmetic scale. The plot resulting from a slug test on well UNH-1 at the Pine Road site is shown in Figure 6. The time value (T_0) when the straight-line data plot had a normalized drawdown value of 0.37 was used in the following equation to compute the hydraulic conductivity based on the natural log of the ratio of the screen length to the well bore radius:

$$K = \frac{r^2 \ln\left(\frac{L}{R}\right)}{2LT} \tag{1}$$

where:

K = hydraulic conductivity in ft/s,
r = radius of well screen in ft,
R = radius of the well bore in ft,
L = length of well screen in ft,
T_0 = intercept time in seconds.

Average values of hydraulic conductivity were calculated using the geometric means of the test values.

Sites which had ponded water were evaluated as to whether the ponded area was acting as a groundwater discharge zone or a recharge area. The evaluations were performed using miniature piezometers, or "mini-P's". The mini-p consisted of six-foot long, clear 0.25 in.-diameter acrylic tube which were installed two feet into the bottom soils of the ponded area. The tubes had a 2-in. length at the bottom that was slotted and wrapped with a filter material. Once installed, the relative piezometric level was measured in the tube with respect to the water level of the pond. If the water in the tube was lower than pond level, water from the pond was recharging the groundwater system. If the converse were true, groundwater was discharging into the pond. Typically these mini-p's were installed around the perimeter of the standing water to profile the hydrologic groundwater regime (discharging or recharging). It is not uncommon to have areas of each regime in the same water body.

2. Soils Investigation

Soils were sampled in the field, and described briefly according to prescribed format (Soil Survey Staff, 1994). More detailed descriptions were completed in the laboratory. Morphological features were analyzed in two ways. First, horizons and color patterns were compared to the Field Indicators for Identifying Hydric Soils in New England (NEIWPCC Wetlands Work Group, 1995) to determine whether or not they would be considered hydric. Secondly, Munsell color notations were condensed to produce a color index (Evans and Franzmeier, 1988) for each horizon, based on hue and chroma of matrix colors and proportion of redoximorphic features. Index values have been highly correlated to soil aeration. Well-aerated (non-hydric) soils generally have higher index values, whereas soils that are extensively saturated and reduced will have lower index values.

Organic carbon content was determined by loss-on-ignition (Schulte et al., 1991). Soil textural class was determined in the field, and particle size distribution was determined by sieve and pipette methods (Gee and Bauder, 1986). All horizons were also tested for reaction with α, α' dipyridyl, which is a test for ferrous iron (Childs, 1981). A positive reaction satisfies requirements in Soil Taxonomy (Soil Survey Staff, 1994) for aquic conditions. Aquic conditions are among the criteria for hydric soils as specified by the Federal Manual for Identifying and Delineating Jurisdictional Wetlands (USACE, 1987).

V. Results of Phase II Investigations

The results of the Phase II investigations are split into three parts for the purposes of discussion. The first part is a brief summary of the background information on the site construction and past hydrologic and soil monitoring performed at the site. The second part details the hydrologic conditions assessed during the field investigations. The third part details the results of the soils investigation for each site.

A. *Site Backgrounds and construction history*

1. Bangor Hydroelectric Graham Lake Mitigation Site

This site was the best documented site of those selected for study. Bangor Hydro-Electric Company provided copies of their Final Wetland Mitigation Plan of July 1993, the 1994 and 1995 Annual

Wetland Monitoring Report Graham Lake Dam Remediation Wetland Mitigation Sites. The following synopsis of background information was taken in a large part from these reports.

The Bangor Hydro-Electric Graham Lake Mitigation Site was created in conjunction with the U.S. Army Corps of Engineers (Corps) and the Maine Department of Environmental Protection (MEDEP). The project was constructed as a 1.0 acre mitigation wetland to replace 1.0 acre of wetlands destroyed in the modifications to the Graham Lake Dam. The final mitigation plans were submitted to the review agencies in July, 1993. Construction was completed in the fall of 1993. Final planting was completed in the spring 1994. The site is located in what was an old upland field in Ellsworth, ME west of Maine State Route 179 and 180, north of Shackford Brook. It is adjacent to a scrub-shrub wetland that is contiguous to the Shackford Brook floodplain. The original site consisted of upland soils, dominated by Lamoine series soils overlying compacted glacial till. The original vegetation was predominantly pasture grasses such as timothy (Phleum pratense), orchard grass (Dactylis glomerata), Canada bluegrass (Poa compressa), and small shrubs such as meadowsweet (Spiraea latifolia). The adjacent areas to the selected site consist of vegetatively diverse wetlands, upland scrubland, and hardwood forest. The seasonal high water table of the adjacent wetlands were evaluated prior to the mitigation design by monitoring five 2-in PVC monitoring wells installed in shallow hand-auger borings. In addition, five soil test pits were dug to a depth of eight feet to investigate the geomorphology of the site.

The upper soil layers were classified as a Lamoine series, which typically form over silty clay soils where the water table is usually deep, but the underlying silts and clays serve to support a perched water table fed by runoff infiltration in the upper fissured soil layers. The Lamoine upper horizons were underlain by silty clay of the Presumpscot Formation, which were deposited in a marine environment along coastal lowlands during the last glacial recession. The original site was excavated from an existing elevation of between 102 and 98 feet MSL to a graded elevation between 100 and 96 feet MSL, illustrated in Figure 7. Six to twelve inches of soil mixture was placed on the excavated area to establish the final elevations which correspond to the seasonal high groundwater table (between 101 and 97 feet MSL). The soil mixture was comprised of the excavated Lamoine Series loam and organic topsoil mixed with native wood chips.

The hydrogeological investigation prior to construction found that at this site, groundwater responded directly to local rainfall. As an example, one-inch of rainfall in June 1993 resulted in a rise of the shallow groundwater table of between 0.4 to 0.75 ft. During a subsequent dry period, the groundwater levels dropped to a depth of 2 ft below the ground surface. A similar drop was observed in the adjacent natural wetlands. The hydrology within the created wetland is supplied from surface runoff. A small berm was constructed at the center of the site to retain the runoff. The underlying clays have served to maintain a perched water table which is sufficiently high to create hydric conditions necessary for wetland functions. Groundwater levels have been monitored by means of ten 2-in diameter PVC wells installed across the site after construction was completed. The location of these wells are shown in Figure 8. These wells were monitored during the growing season (April through September) once every two weeks for the first year after construction, and on a monthly basis for the following two years. A record of the groundwater fluctuations for 1994 and 1995 are shown in Figures 9 and 10. The water levels demonstrate a uniform drop in water level across the site to approximately 2 - 2.5 feet below the ground surface during the months of July and August. It should be noted that precipitation for those two years was significantly below the 30-year average.

Presently the site has two areas (see Figure 8) in which there is 2-8 inches of standing water for the majority of the year. These are the northern arm and the central area. These areas retain standing water typically from September through July, based on two years of monitoring where rainfall has been more than 3 inches below the 30-year average of 6.3 inches for July and August. A narrow swale down the center of the site leading to the northern arm has been reported to retain standing water throughout at least part of the year.

2. Pine Road Wetland Creation Site

The Pine Road site in Brentwood, NH was originally an abandoned gravel pit, which has been transformed into a created wetland site. The site location is shown in Figure 2. Information on this site was provided by the New Hampshire Department of Transportation and Normandeau Associate, Inc. The site is also featured in Hammer's book, (pp. 179, Hammer, 1996) showing before and after photos of the conversion of the abandoned gravel pit to a flourishing early stage wetland. The creation site is part of the Rural Access Demonstration Project NHS-DPR-0048(001) for NH Route 101/51 improvements, and provides mitigation for wetlands disturbed during the course of the route improvements. The project involved three adjacent sites, of which the selected site is the first to be constructed, designated as the "south pit" site. This site is unique in that it utilized both hydric and non-hydric soils in its construction. The site has an area of approximately 37.9 acres, of which 3 acres are open water. At the center of the excavated site, there is a 15.5-foot deep water habitat. The site was excavated in the fall of 1994, and the first growing season was in 1995. An irrigation system was set-up for the first year to maintain proper moisture conditions for the initial plantings. The final grading plan is shown in Figures 11 and 12 which also illustrates the distribution of the various soils used to achieve the finish grade.

The original site soils were excavated to 12 in. below final grade. Both upland humus and wetland humus were brought in and spread over top of the graded site soils to final grade. The two types of soil were spread over different zones of the project area, according to the plan depicted in Figures 11 and 12. The low elevation areas depicted in the figures received an amendment of approximately 2 to 3 inches of upland humus which was incorporated with existing soils. The hydric amendment soils included wetland humus soils which had been stockpiled from disturbed highway right-of-way wetland areas. The upland humus originated from both from the project site and also from upland forest soils along disturbed highway right-of-ways. Both the upland and the wetland humus came from red maple and white pine habitat areas. The soils as described by the analyses in Table 1 are very similar, both having originated from very similar sites. In both cases, the soil can be described as a fine sandy loam, with acidic pH and low nutrient quality. Of particular note was the organic content of the soils. The pre-existing site soils had a very low organic content, while the supplemental upland and wetland soils used in the wetland construction had organic contents of 3.4 to 4%. A low phosphorus, slow dissolving fertilizer was applied in August, 1995 which improved the nutrient quality as shown in Table 1, although the nutrient levels were still not at optimal levels.

The areal distribution of each of the spread soils is shown in Figures 11 and 12. The application thickness of the two soils was from 8 to 12 inches. The wetland humus soils were spread primarily between elevation contours 127 and 130 ft. Mound and pool micro-topography was used over much of the wetland humus area. The upland humus soils were typically spread between elevation contours 123 and 127 ft. Below elevation 123 ft, a thin layer of upland humus soil amendment was used. The open water shoreline, at the time of this study, roughly followed the 125 ft contour indicated on Figures 11 and 12 by a bold contour line. Several small islands were created in the open water, and soil placement on these islands followed the same convention. In several test zones, the deposited soils were interchanged as an experiment to evaluate the effect of the soil material on the growth of the vegetation. The seeding and planting patterns remained unchanged over these zones. No difference in vegetation was observed, however no conclusions can be drawn due to the similar nature of the upland and wetland soils.

The upland humus areas next to the open water were typically seeded with emergent marsh species including cattail, three-squared bulrush, tussock sedge, pickeral weed, and arrowhead; and the upland humus above elevation 130 ft was seeded with upland plant species. Most of the hydric soils were seeded with scrub/shrub plants, such as blueberry, chokeberry, willow, elderberry, and silky dogwood. In zone along the eastern edge of the project, an area spread with non-hydric soils was planted with wet meadow vegetation, including switch grass, red top grass, and manna grass.

The hydrology of the wetland depends on groundwater to maintain the proper moisture conditions. An adjacent wetland has open water which is between one and three feet above the water level in the South Pit wetland. The water levels in both the south pit wetland and the adjacent wetland have been monitored since the South Pit wetland was created. The resulting record is shown in Figure 13.

3. Maine Turnpike Wetland Restoration Site

The background site information for the Maine Turnpike Wetland Restoration Site was provided by Northrop, Devine, and Tarbell, Inc. The old Exit 6 was a seasonal facility that was abandoned in favor of the new exit. The old ramps are located north of the new Exit 6, and are accessed from Holmes Road. The project involved three sites (see Figure 3), the Interchange Loop wetland creation site located in the cloverleaf infield of the new Exit 6, the old Northbound Ramp wetland restoration site, and the old Southbound Ramp wetland restoration. The restoration sites are at the location of the old Exit 6, no longer in existence. During the process of selecting a site to study, there was some question as to the amount of hydric soils used in the construction of the interchange loop. At the Northbound Ramp restoration site, upland soils were used only in some portions, for the construction of the microtopography. Only upland soils were used in the finish construction of the Southbound Ramp restoration site. This latter site was selected for this study, partially because of the certainty of the use of upland soils, and partially because it represented a slightly different wetland than other selected sites. The layout of the site is shown in Figure 14. The site restoration was completed in the summer/fall of 1993.

The site was originally part of a forest wetland, but had apparently been disturbed for the construction of the old Southbound Ramp. Restoration involved the removal of the roadway gravel bed. Due to compaction, it was necessary to bring in soil to restore the surface elevation of the ramp area to match the surface elevation of the adjacent wetlands. A depth of 6 to 12 inches was applied to the area, using salvaged upland soil. In some areas, microtopograhic mounds were constructed. These mounds were created by first depositing a 4 to 8 in. mound of clean road fill on top of the native soils. The mound area was then topdressed with the salvaged upland topsoil.

The salvaged soils used in this site originated from the alignment of the new Route 1 connector road (Haigis Parkway) which was constructed in conjunction with the new Exit 6. Apparently, this was not by design. The original design called for the stockpiling of hydric soils from the alignment of the Route 1 connector, to be used in the restoration projects. The contractor was diligent about salvaging the hydric soils, but chose his stockpile location poorly. The stockpile was on top of an old dump. Consequently, the hydric soils became mixed with old refuse from the dump, rendering the soil unacceptable for use in the restoration projects. There were ample untainted upland soils available from the alignment project, so these were screened to remove the large debris such as stumps and large stones. Organic material such as fallen wood, roots, branches, and uprooted scrubs were left in the upland soils.

The site hydrology is maintained primarily by the shallow groundwater table beneath the site. There is limited surface water runoff entering the site. There were seven 2-in. monitoring wells on site. Water levels in these wells were monitored during the growing season of 1995, with the resulting record of fluctuations shown in Figure 15. The maximum seasonal fluctuation in 1995 was approximately 2.5 ft.

4. Michelle Memorial Park Wetland Creation Site

The Michelle Memorial Park wetland creation site is located in the south side of the community of Salem, NH. Documentation on this site was provided by Eric Mitchell and Associates, Inc. And Gove Environmental Services, Inc. The site was constructed in the fall of 1993.

The Michelle Memorial Park wetland creation site is one of two sites created in the park to mitigate the loss of 3.72 acres of wetlands during the construction of new ballfields over the period from 1981 to 1988. The selected site is indicated as site "A" on Figure 16, and represents an area of 1.76 acres. This site originally consisted of a combination of 1.35 acres of forested upland, and 0.41 acres of former wetlands. The site is part of an overall plan which includes a second site of 1.36 acres to the north of the ballfields, designated as site "B". The total combined construction and restoration area was 3.73 acres.

The original site soils were classified as Deerfield fine sandy loam, and the site was bordered by Pipestone sand. The wetland mitigation area was constructed by first clearing the vegetation from the site, and then excavating the upland soils to an elevation of roughly 112 ft. The excavated upland topsoil was screened and stockpiled on a near-by area. An existing ditch connecting to a forested wetland to the northeast of the site bisects the mitigation site. This ditch was dredged and widened. Following the subgrade establishment, surface soils were scarified, and the stockpiled topsoil was spread over the site to a depth of at least four inches. The topsoil was amended with lime and fertilizer, to improve the nutrient quality of the soil. Two types of wetland cover were planted at this site, including scrub-sapling community designed to revert to a forested-sapling wetland, and emergent vegetation in the widened ditch running through the site. In addition, an evergreen buffer was planted along the northern and eastern boundaries. The intent is to establish a sapling-forested wetland within 10-20 years. The site was monitored with respect to the planted vegetation for three years. The approval criteria specified an 80% required vegetative coverage to be considered successful. The site was evaluated in 1996, and found to have 100% vegetative cover.

The hydrology of the site depends on a shallow water table and surface runoff from the ballfield and adjacent wetlands. The constructed wetland also serves the function of flood control.

5. Connecticut DOT I-691 Wetland Mitigation Site

The documentation on this site was obtained from a thesis and a publication copied and sent by Dr. William Niering of Connecticut College in New London, CT and from information provided by Mr. Steven Ladd of the Connecticut DOT. The thesis was by Sheri R. Confer (1990), Comparison of Created and Natural Freshwater Palustrine-Emergent Wetlands in Connecticut.

This site is located in the infield created by the exit 3 off-ramp of I-691 to Highway 10 in Cheshire, CT. It was created during the construction of the off-ramps in the fall of 1983, as part of a mitigation effort to make-up for 11.8 acres of wetland destroyed during the construction of I-691. It was part of the first wetland replacement required by the Connecticut Department of Environmental Protection, which provided approximately 13.8 total acres of compensory mitigation at three sites. The first growing season was in 1984. The site as constructed, covered approximately 0.25 acres of red mineral soils with sandy texture. Underlying the red soils are clastic sedimentary rocks including conglomerate, sandstone, and shale of Early Jurassic to Late Triassic age. The wetland is made up of 15-20% open water. The site receives surface runoff from the highway system and acts as a detention pond for a small stream which is routed through the basin by an inlet and an outlet culvert pipe. The layout of the site is illustrated in Figure 17. The inlet is in the southwestern portion of the wetland, and the outlet is in the northeast.

The site is described in Confer(1990) as littoral emergent wetland which completely borders the open water. The wetland is surrounded by mown lawn. As part of the study, a 4 - in. (10 cm) diameter PVC piezometer pipe was inserted approximately 1.6 ft (0.5 m) into the ground below the water surface. Water level measurements were taken at this piezometer with respect to the ground surface. The water level remained fairly constant averaging 0.72 ft (22 cm) above the ground surface at the piezometer. Recorded depth fluctuations were in the range of 0.6 - 0.95 ft (18 - 29 cm). The record of water level fluctuations over the period from 9/88 to 2/90 is shown in Figure 18.

The soils were classified as of the Weathersfield association, characterized by medium sandy texture and dark reddish brown color. No mottling was observed in the top 1 ft, nor was any rotten-egg smell noted associated with reducing conditions and sulfur development. The soils were classified as non-hydric soils.

B. *Field Investigation Results*

The results of the field investigation performed as part of this study are discussed below by site. The discussions for each site address the results of the hydrologic investigations followed by the soils investigative results.

1. Bangor Hydroelectric Graham Lake Mitigation Site

The hydrology of the Graham Lake Wetland Creation Site has been described as a perched groundwater system. Inflow to the system is primarily from surface water runoff. The topography and the low-conductivity soils create surface storage which provides the saturated conditions necessary to maintain the wetland vegetation. The native soils are underlain by a stiff brown silty clay which have a very low hydraulic conductivity. Soils which have been placed on top of the clay have a higher hydraulic conductivity, on the order of 0.57 ft/day (2 x 10^{-4} cm/s). This value is based on the slug test results of only one well, installed on the edge of the constructed wetland. The other wells which were installed in the site did not fill with water within the time frame of the field investigation. Groundwater piezometric contours were drawn based on the measured water levels in the ten existing monitoring wells. This data is presented in Table 3. The wells were surveyed to a common reference point so that a relative contour map could be made. The resulting map of the groundwater contours is shown in Figure 19. This figure shows that the shallow groundwater below the site flows from north-northeast to south-southwest. The flow originates from the adjacent wetlands just north of the created site. In contrast, the surface topography serves to channel water into the northwest end of the site where ponded conditions persist for most of the year. The estimated groundwater velocity across the north edge of the site is 0.02 ft/day (0.58 cm/day).

Three mini-piezometers were installed along the edge of the ponded water at the northwest end of the creation site. Their locations are indicated on Figure 8. A groundwater hydraulic gradient is defined as the change in the piezometric (groundwater pressure) head divided by the distance between measuring points. For the mini-piezometers, the change in the piezometric head is measured between the water level in the piezometer tube and the surface of the ponded water of the wetland. The distance between the measuring points is actually the distance between the pond bottom and the elevation of the filter cloth screen of the piezometer tube, typically two feet. In this instance, the gradients measured by the mini-piezometers were inconclusive. Only one mini-piezometer was responsive enough to measure a gradient. The gradient at PZ-1 was +1.25 in./ 24 in., or +0.052, indicating that groundwater was flowing into the ponded area at that point. The groundwater flow in a perched system can be described as a localized flow system, implying that the ponded area may act as a discharge zone for the shallow local groundwater flow. Since the flow direction is from the north, if shallow groundwater is discharging to the ponded area of the wetland, the water level in a mini-piezometer at the "leading edge of the ponded area" would be expected to be higher than the pond level. This is what was measured at PZ-1. The other two mini-piezometers were not responsive, and so no conclusion can be drawn as to whether the ponded area is a flow-through cell for groundwater (gradient would be reversed at the opposite end of the pond), or if it is a discharge point for groundwater on all sides (all gradients the same). The latter case may indicate that the ponded water originates primarily from surface water, and is therefore not controlled by groundwater. Judging from the tight soils below the site, it is our opinion that this wetland is dominated by surface water hydrology, which sustains a perched groundwater table. The fluctuations illustrated by Figures 9 and 10 indicate that there is a period of approximately one month in the spring of inundation or saturation, and the levels drop as much as 2.6 feet below ground surface. Hydrologic conditions are suited for the development of hydric soils, but may limit the diversity of vegetative species.

Six pedons were excavated at this site. Two samples were taken near existing monitoring wells, P10 and P5. A third pedon was excavated near the boundary of the former natural wetland and the newly-created wetland. A three-pedon transect was also completed from the upland into the currently submerged area. Pedon descriptions are below.

<u>Bangor P10</u>

A	0-10 in.	10YR 5/3 silty clay loam; common 10YR 6/2 redox depletions and 10YR 5/8 redox concentrations; massive; firm; pH 5.78; 28.8% clay.
Bg	10-16 in.	10YR 6/2 silt loam; many 10YR 6/1 redox depletions and 10YR 6/8 redox concentrations; massive; firm; pH 6.18; 8.0% clay.

Bw	16-20 in.	10YR 5/3 silty clay loam; many 10YR 6/1 redox depletions and 10YR 5/8 redox concentrations; massive; firm; pH 5.97; 28.8% clay.

<u>Bangor P5</u>

A	0-5 in.	10YR 5/3 silt loam; common 10YR 6/1 redox depletions and few 7.5YR 5/6 redox concentrations; subangular blocky structure; very friable; pH 5.30; 9.6% clay.
Bw	5-11 in.	10YR 6/3 silt loam; common 2.5Y 7/1 redox depletions and 5YR 5/8 redox concentrations; massive; friable; pH 5.24; 4.8% clay.
Bg	11-? in.	10YR 5/2 silt loam; common 10YR 7/1 redox depletions and 10YR 6/8 redox concentrations; angular blocky structure; very firm; pH 4.73; 24% clay.

<u>Bangor Old-New Boundary</u>

A	0-8 in.	10YR 5/3 silt loam; common 2.5Y 7/0 redox depletions and few 10YR 6/6 redox concentrations; massive; firm; pH 5.42; 14.4% clay.
Bw1	8-14 in.	10YR 6/4 silt loam; many 10YR 6/1 redox depletions and 7.5YR 5/8 redox concentrations; massive; firm; pH 5.72; 24% clay.
Bw2	14-24 in.	10YR 5/3 silty clay loam; many 2.5Y 7/1 redox depletions and 7.5YR 5/8 redox concentrations; massive; very firm; pH 5.99; 30.4% clay.

<u>Bangor Upland</u>

A	0-10 in.	10YR 4/3 silt loam; subangular blocky structure; very friable; pH 5.34; 9.6% clay.
Bw1	10-18 in.	10YR 6/3 silt loam; few 2.5Y 7/3 redox depletions and 10YR 5/8 redox concentrations; subangular blocky structure; friable; pH 5.22; 11.2% clay.
Bw2	18-25 in.	2.5Y 6/3 silt loam; few 2.5Y 7/2 redox depletions and 7.5YR 5/6 redox concentrations; subangular blocky structure; very firm; pH 5.55; 14.4% clay.

<u>Bangor Transitional</u>

A	0-4 in.	10YR 5/3 silt loam; common 10YR 6/1 redox depletions and 10YR 5/8 redox concentrations; massive; firm; pH 5.57; 9.6% clay.

Bw1	4-14 in.	10YR 6/3 silt loam; common 10YR 7/1 redox depletions and 10YR 5/8 redox concentrations; massive; friable; pH 5.27; 22.4% clay.
Bw2	14-? in.	10YR 6/3 silty clay loam; common 2.5Y 7/1 redox depletions and many 10YR 6/6 redox concentrations; massive; friable; pH 5.51; 30.4% clay.

Bangor Submerged

A	0-5 in.	10YR 5/2 silt loam; massive; friable; pH 5.80; 9.6% clay.
Bw	5-18 in.	10YR 5/3 silt loam; common 10YR 7/2 and 10YR 6/1 redox depletions; massive; friable; pH 5.62; 16% clay.

2. Pine Road Wetland Creation Site

The Pine Road mitigation site had standing water at and below the 125 ft contour, as shown in Figures 11 and 12. Four SDWs were installed around the outer perimeter of the mitigation site. Details of the installation are summarized in Table 2. The water levels were measured three times over the course of the summer and fall of 1996, with the results listed in Table 3 and plotted on Figure 20. The results indicate that groundwater flow beneath the site is from the west to the east. The groundwater piezometric levels of October 15, 1996 intersect the surface level of the ponded water on along a line which runs to the west of the islands. This fictional line delineates the boundary of groundwater flow into and out of the ponded area. To the west of the 125-ft piezometric contour line, groundwater was discharging into the pond. To the east of the 125 ft piezometric contour line, groundwater is being recharged from the ponded water of the wetland. This line of equilibrium with the pond will shift as the ponded water level changes over the course of the year. Surveyed water levels were provided by the NHDOT and are shown in Figure 13. The levels show that in 1995, which was an unusually dry summer, the level of the pond dropped to a minimum level of 122.4. Water levels on the eastern side of the site could be expected to reflect the low levels in the wetland. The adjacent wetland to the northeast dropped as low as 125.7 ft. The higher level in this wetland would have kept the water table higher on the west side of the South Pit wetland. The water table below the large island, where upland soils were placed about the perimeter, ranged from being inundated for at least two weeks, to approximately five feet below the ground surface. This saturation over part of the year is a necessary condition for the development of hydric conditions. As will be described below, the island soils that were sampled had redox features in the uppermost mineral horizon and were classified as hydric soils.

Six mini-piezometers were installed in the shallow ponded area round the perimeter of the ponded area, as indicated on Figure 20. The results of the measured piezometric levels in the "mini-p" tubes are consistent with the piezometric contour map. The mini-p furthest west showed a positive level, indicating groundwater was discharging into the ponded area. The remaining mini-p's indicated the pond was recharging the local groundwater system.

Slug tests were successfully completed on three of the four wells installed. The response at UNH-1 was either too rapid to measure (less than one second) or it was installed in a clay lens where the water levels had no significant response for over 30 minutes. The results of the hydraulic conductivity testing are contained in Table 4. The average hydraulic conductivity was similar for the other three wells tested, and was 11.6 ft/day (4.1×10^{-3} cm/s). This value is also consistent with the texture of sandy loam soil. Using this average hydraulic conductivity, an estimate of the Darcy groundwater velocity can be made. The average flow per unit area of aquifer beneath the site is 0.04 ft/day (1.2 cm/day).

Four pedons were described and sampled at the Pine Road site in Brentwood, New Hampshire. The first profile was from an exposed cut into the upland soil. Two pedons were excavated within the wetland—one in an area where upland topsoil had been used for mitigation, and the other in an area where wetland topsoil had been used for mitigation. A pedon was also excavated on the island near the center of the wetland. Results are below.

<u>Pine Road Upland Cut</u>

A	0-3 in.	10YR 4/3 fine sandy loam; few 10YR 3/1 organic stains and 7.5YR 5/6 mixing from underlying horizon; subangular blocky structure; friable; pH 4.51.
Bw1	3-12 in.	7.5YR 5/6 sandy loam; massive; very friable; pH 5.07; 24% clay.
Bw2	12-19 in.	10YR 6/8 loamy sand; subangular blocky structure; very friable; pH 5.02; 9.6% clay.

Bw3	19-30 in.	2.5Y 6/6 coarse sandy loam; massive; very friable; pH 5.09; 8% clay.
Bw4	30-49 in.	2.5Y 5/4 sandy loam; 10YR 5/3 silt coats in channels; massive; very firm; pH 6.22; 9.6% clay. Pockets of 2.5Y 6/4 sand with pH 5.46 and 19.2% clay.
Bw5	49-52 in.	2.5Y 5/3 sandy loam; massive; firm; pH 5.44; 4.8% clay.
Bw6	52-54 in.	2.5Y 5/4 sandy loam; massive; firm; pH 4.87; 19.2% clay.
Bw7	54-60 in.	2.5Y 6/3 loamy very fine sand; massive; friable; pH 5.65; 6.4% clay.

<u>Pine Road Upland Topsoil</u>

A1	0-5 in.	10YR 3/1 loamy fine sand; few 10YR 6/1 redox depletions and 10YR 6/8 redox concentrations; massive; friable; pH 5.8; 4.8% clay.
A2	5-12 in.	10YR 4/2 loamy fine sand; common 10YR 5/3 redox concentrations; massive; friable; pH 5.50; 3.2% clay.
A3	12-24 in.	10YR 4/2 loamy fine sand; few 10YR 6/2 redox depletions; massive; friable; pH 5.94; 8% clay.

<u>Pine Road Wetland Topsoil</u>

A1	0-8 in.	10YR 5/1 fine sandy loam; massive; friable; pH 6.18; 14.4% clay.
A2	8-18 in.	10YR 3/2 loamy fine sand; massive; friable; pH 6.16; 6.4% clay.
A3	18-25 in.	10YR 2/2 loamy fine sand; few 10YR 6/1 redox depletions and 10YR 5/8 redox concentrations; massive; friable; pH 5.86; 4.8% clay.
Bw	25-? in.	10YR 4/6 fine sandy loam; single grain; loose; pH 6.49; 8% clay.

<u>Pine Road Island</u>

A1	0-4 in.	10YR 2/1 fine sandy loam; subangular blocky structure; very friable; pH 5.81; 8% clay.
A2	4-14 in.	10YR 3/2 fine sandy loam; common 7.5YR 5/8 and 2.5Y 6/6 redox concentrations; massive; friable; pH 6.24; 6.4% clay.
Bw	14-20 in.	2.5Y 4/4 fine sandy loam; subangular blocky structure; friable; pH 6.60; 11.2% clay.

3. Maine Turnpike Wetland Restoration Site

The Southbound Old Exit 6 ramp site in Scarborough, ME had no ponded water. The site was constructed where originally there had been a coniferous and shrub wetland, prior to the construction of the old exit ramp. Four SDWs were installed to complement the existing seven 2-inch PVC monitoring wells. The SDWs were slug tested to obtain estimates of the hydraulic conductivity of the site soils. All the wells on site were surveyed, tied into a benchmark established during construction identified as Benchmark 43. From the survey and measurements of the water levels in each of the wells (Table 3), a piezometric map was created for groundwater flow beneath the site.

The piezometric contours shown in Figure 21 indicate that groundwater movement beneath the site is from west to east. Other than direct precipitation, input of water into the site was from overland flow from the adjacent wetlands. There were no channels constructed to route surface water into this site.

The groundwater hydrology is predominantly responsible for maintaining the hydric conditions found at this site. The record of the groundwater levels during the relatively dry growing season of 1995, shown in Figure 15, indicates that the water table was within four inches of the ground surface. Taking into account the capillary fringe above the piezometric surface, the figure indicates that surface soils were saturated for a period of not less than one month out of the growing season. The hydrologic conditions, therefore, are appropriate for the formation of hydric soil characteristics. These conditions were found to exist at each location sampled at this site.

The results of the slug tests performed in each of the SDWs installed at this site are shown in Table 4. The average hydraulic conductivity for the four wells ranged from 2.55 ft/day (9×10^{-4} cm/s) for SDW UNH-2 to 34.0 ft/day (1.2×10^{-2} cm/s) for UNH-4, the SDW installed along the power company easement line (labeled CMP easement line on Figure 21. The average hydraulic conductivity across the site was 6.24 ft/day (2.2×10^{-3} cm/s). From the piezometric contours shown in Figure 21, the hydraulic gradient was measured as 0.0093. The average groundwater flow velocity across the site was estimated to be approximately 0.06 ft/day (1.79 cm/day).

Three pedons were excavated at the Maine Turnpike site along an east-west transect. Pedon sites correspond to monitoring wells 5, 6, and 7. This was the only site at which soils had substantial amounts of organic matter (O horizons). The description of the pedons are provided as follows:

Maine Turnpike West

Oe1	0-5 in.	10YR 2/1 moderately decomposed organic matter; pH 4.90.
Oe2	5-10 in.	10YR 2/2 moderately decomposed organic matter; pH 4.77.
Oa	10-14 in.	10YR 2/1 well decomposed organic matter (muck); pH 4.99
C	14-? in.	10YR 5/2 sand; single grain; loose; pH 5.71; 6.4% clay.

Maine Turnpike Center

A	0-4 in.	10YR 3/3 sandy loam; massive; very friable; pH 6.15; 4.8% clay.
Oe1	4-6 in.	10YR 2/1 moderately decomposed organic matter; pH 5.72.
Oe2	6-16 in.	10YR 2/1 moderately decomposed organic matter; pH 5.60.
C	16-? in.	2.5Y 6/3 sand; massive; very friable; pH 5.88; 6.4% clay.

Maine Turnpike East

Oe	0-12 in.	10YR 2/1 moderately decomposed organic matter; pH 5.28.
Oa	12-15 in.	10YR 3/2 well decomposed organic matter (muck); pH 5.60.
C	15-? in.	10YR 6/2 loamy sand; massive; very friable; pH 6.11; 8.0% clay.

4. **Michelle Memorial Park Wetland Creation Site**

The hydrologic conditions at the Michelle Memorial Park are a result of the groundwater table being near the surface, with some additional input via surface runoff from the adjacent wetland area and the ballfield to the north of the site. There is a drainage ditch which carries surface water through the wetland area and ultimately to the Spicket River. Three SDWs were installed and surveyed at this site. The survey, along with the measured static water levels in the wells (Table 3) formed the basis for a piezometric surface map which is shown in Figure 22. The map identifies the principal direction of groundwater flow, which is to the south. Each well was tested to obtain estimates of the hydraulic conductivity of the site. The hydraulic conductivity appears to decrease as one moves farther away from the ballfield in Figure 22. Well UNH-1 had an average hydraulic conductivity of 1.6 x 10^{-3} cm/s; UNH-2 had an average hydraulic conductivity of 1.3 x 10^{-4} cm/s; and the last well, UNH-3, had a hydraulic conductivity of 9 x 10^{-5} cm/s. The groundwater piezometric contours shown in Figure 22 where derived from the piezometric levels measured in the three wells installed on the site. The flow directions and the contours indicate only a general trend, since a more refined interpretation cannot be made without more measurement points. In view of the results of the hydraulic conductivity testing, it would be expected that the actual groundwater contours would shift more to the south at the eastern side of the site. The flow velocity was calculated using the properties measured at UNH-2, where the hydraulic gradient measured from Figure 22 was 0.0083. The average groundwater velocity was calculated as approximately 0.0031 ft/day (0.09 cm/day). The groundwater movement at UNH-2 was much slower than the other sites that were investigated. The water table in August, 1996 was on the average 2.3 ft below the ground surface. This site had no long term water table data available. It should be note, however, that at the sites investigated where long term monitoring data was available, the lowest piezometric water levels were observed in the late summer. This would imply that the measured water table level for this site represents the seasonal low. Typical fluctuations at the other sites were 2.5 feet or more, therefore it is conceivable that the site soils could become saturated for several weeks in the spring, thus creating necessary conditions for the formation of hydric soil indicators.

Two pedons were excavated at the Michelle Park site in Salem, New Hampshire. One pit was dug in the upland to examine the presumed precursor soil. The second pedon was sampled in the created wetland area.

<u>Michelle Park Upland</u>

A	0-10 in.	10YR 4/3 fine sandy loam; massive; very friable; pH 6.17; 0% clay.
Bw1	10-22 in.	2.5Y 7/3 sand; few 10YR 6/8 concentrations; massive; very friable; pH 6.00; 3.2% clay.
Bw2	22-? in.	2.5Y 7/4 sand; few 10YR 6/8 concentrations; massive; very friable; pH 6.02; 1.6% clay.

Michelle Park Wetland

A	0-9 in.	2.5Y 2/1 sandy loam; angular blocky structure; very friable; pH 6.00; 8% clay.
Bw1	9-16 in.	2.5Y 7/6 loamy sand; common 7.5YR 5/8 redox concentrations; massive; very friable; pH 6.10; 4.8% clay.
Bw2	16-? in.	2.5Y 6/3 loamy sand; few 10YR 7/8 redox concentrations; single grain; loose; pH 6.10; 6.4% clay.

5. Connecticut DOT I-691 Wetland Mitigation Site

The site located in the exit infield of I-691 at the Highway 10 exit contained about 15-20% open water, which was replenished by an small stream which flowed into the wetland from a pipe at the southeast corner of the wetland. The wetland creation site provides approximately 21.0 ac-ft of flood storage, thereby functioning as a large detention pond to minimize the potential for downstream flooding. The outlet of water from the pond was via a second culvert in the northeast end of the site. Records are available for the period 1988-89 for the fluctuations of the piezometric groundwater level beneath the ponded area, shown in Figure 18. These records are from a single 3-in. PVC well driven approximately 2 feet into the bottom soils of the pond.

Three SDWs were installed at this site. The wells were surveyed, the water levels were measured, and hydraulic conductivity tests were performed. The survey is relative to an assumed datum. Consequently the water level elevations of Table 3 are relative to the same assumed datum. The piezometric contours are plotted on Figure 23. The contours demonstrate that groundwater at this site flows from the direction of the stream inlet to the outlet culvert. Four mini-piezometers were installed around the outer perimeter of the pond, as shown in Figure 23. Both PZ-1 and PZ-2 had positive heads slightly greater than 0.3 ft. These were located near the stream inlet. The mini-p's farthest from the spring, PZ-3 and PZ-4, still maintained positive gradients, but the magnitude of the positive upward groundwater pressure was only 0.05 ft. The conclusion here is that the entire pond acts as discharge for groundwater. The level of the ponded water is regulated by the elevation of the outlet culvert.

The slug tests yielded results which were an order of magnitude different between UNH-1 next to the stream inlet, and UNH-2. The hydraulic conductivity of the soils near the inlet was 62.4 ft/day (2.2×10^{-2} cm/s). The average hydraulic conductivity at UNH-2 was 1/36 ft/day (4.8×10^{-3} cm/s), and that at UNH-3 near the outlet culvert was 2.1 ft/day (7.4×10^{-4} cm/s). An average hydraulic gradient of 0.0063 was estimated based on the contours shown in Figure 23. Using an average value for the hydraulic conductivity of 1.36 ft/day (4.3×10^{-3} cm/s), the average horizontal groundwater velocity was estimated at 0.08 ft/day (2.3 cm/day).

It should be noted from Table 3 that the measured groundwater elevations are all greater than the surveyed level of the ponded water. This implies that the pond acts as a groundwater discharge area. The greatest groundwater inflow will be in the area with the highest hydraulic conductivity, near the stream inlet. A rough estimate of the upward groundwater velocity was made based on a hydraulic gradient measured between the center point of the well screen and the pond surface, and the hydraulic conductivity at UNH-1. The estimated vertical upward velocity was 27.6 ft/day (842 cm/day). This indicates that the pond is receiving a significant amount of groundwater influx. At the time of the study, there was a steady flow of water out of the wetland, which appeared to be more than the inflow, although quantitative measurements were not made.

Two pedons were excavated at the Connecticut I-691 site. One pit was dug in the upland area above the wetland, and a second pit was dug in the shallow wetland area in which cattails were the dominant vegetation. Even soil samples taken from below the water table in the cattail vegetation did not evidence hydric soil features.

<u>Connecticut Upland</u>

A	0-7.5 in.	2.5YR 4/6 sandy loam; subangular blocky structure; friable; pH 7.13; 4.8% clay.
Bw	7.5-17 in.	2.5YR 3/4 sandy loam; subangular blocky structure; very friable; pH 6.97; 8% clay.

<u>Connecticut Cattails</u>

A	0-4.5 in.	10R 3/4 loamy sand; massive; friable; pH 6.92; 1.6% clay.
Bw	4.5-15 in.	10R 4/4 sandy loam; massive; friable; pH 7.30; 3.2% clay.

C. *Soils Investigation Results*

Soil properties for the five sites are summarized in Table 5. With few exceptions, soils in the created wetlands had hydric characteristics, and soils in the adjacent uplands did not. Soils at the Connecticut site were derived from red (7.5 YR to 2.5 YR Munsell notation) sediments, and thus do not develop hydric characteristics as quickly as soils with yellower Munsell hues. They can, however, develop these features in time, provided that conditions of oxygen depletion occur at the site. As this site is fed by an active stream, it is likely that oxygenated water is generally in plentiful supply. Therefore, the requisite oxygen depletion may not occur, although no measurements of dissolved oxygen were made in this study. At the Pine Road site, the wetland soil used as top-dressing did not possess morphological characteristics consistent with hydric field indicators. That soil did, however, react positively with α, α' dipyridyl, indicating the presence of reduced (ferrous) iron. This positive reaction meets the requirements in Soil Taxonomy (Soil Survey Staff, 1994) for aquic conditions. Therefore, this soil would meet the requirements of the Hydric Soil Criteria, if not the Field Indicators. This is a good example of the lack of correlation among the hydric soil definition, which was met at this site; the hydric soil criteria, which were also met at this site, and the field indicators, which were not met at this site. Thus, in terms of the development of hydric soil characteristics, the Bangor, Maine Turnpike, Pine Road, and Michelle Park sites could be considered functioning mitigations. The Connecticut site, judging from records of inundation and vegetation, is also a functioning site, but is probably more aerobic than the other four wetlands.

Based on field observations of Munsell color patterns, a morphological index value was calculated for each profile. The index used (Evans and Franzmeier, 1988) has been successfully correlated to soil aeration regime, as determined from saturation duration during the growing season, and dissolved oxygen levels of the groundwater. It should be emphasized that this index is not synonymous with the Field Indicators. One important difference is that the index is based upon and has been correlated to actual data for saturation duration and dissolved oxygen content, whereas the Field Indicators are based on interpretations (i.e., opinion). In general, soils that are better aerated (less saturated) have higher index values than soils that are more frequently saturated and depleted of oxygen. Soils that met field indicator requirements for hydric designation had a mean index of 12.75. Soils which did not meet field indicator requirements for hydric designation had a mean index value of 17.37. Differences between these means are significant at $p = 0.006$ (Statsoft, Inc., 1995). This means that there is a very low probability (i.e. 0.6%) that the hydric and non-hydric soils are members of the same population (i.e. the same). Among the hydric soils, the morphological index was poorly correlated to texture. The correlation coefficient, $r = -0.015$. Thus, texture does not appear to be an important factor in the development of hydric soil characteristics. If textures are ranked from coarsest to finest, the order would be sand > loamy sand > sandy loam > silt loam >silty clay loam. In this study, only the sandy loam, silt loam, and silty clay loam soils provided a positive reaction to the α, α' dipyridyl test. A positive reaction indicates the presence of reduced iron on the broken soil surface. The lack of such a reaction on the loamy sand and sandy soils probably reflects the increased hydraulic conductivity of those soils. Under conditions of rapid permeability and conductivity, the soluble ferrous iron (Fe^{2+}) may be easily removed in solution, and is not present to react. Thus, the absence of reaction to α, α' dipyridyl test may not be due to a lack of iron reduction, but due the coupling of reduction and loss of iron. Among the finer-textured soils, which reacted positively to the α, α' dipyridyl test, two explanations are possible. One is that the lower hydraulic conductivity of these soils resulted in less rapid loss of the reduced iron. Alternatively, as finer-textured soils are associated with higher cation-exchange capacity, it may be that the reduced iron was retained by cation exchange sites on clay particles.

Only the very sandy soils at the Maine Turnpike site had significant surficial thickness of organic materials (peat and muck). Although sandy soils may often be droughty because of excessive permeability, it appears that the endosaturation produced by hydrologic conditions at this site prevented subsoil drying and subsequent oxidation of the histic epipedon, which is an organic layer at least 10 inches thick. Although none of the other soils had histic epipedons, organic content, as measured by weight loss on ignition (LOI) was significantly ($p = 0.0003$) higher in hydric soils than in non-hydric soils. Weighted mean profile values were 11.2% and 1.70%, respectively, for the hydric and non-hydric soils. LOI was also strongly correlated ($r = -0.71$) to the morphological index. The negative correlation is reasonable, because the morphological index values decrease as soils become wetter, while organic matter content tends to increase with increasing wetness. Thus, findings reported earlier that linked hydric morphology to organic matter levels also seem to apply to the soils in this study.

Among the hydric soils, age was only weakly—but positively—correlated to the morphological index (r = 0.34). Thus, it appeared that hydric characteristics were established rather quickly, and that increasing age of the mitigation sites did not produce significant changes in soil color patterns. We conclude, therefore, that provided hydrologic conditions—including oxygen depletion—are maintained, the likelihood of hydric soil development is primarily related to sufficient soil organic matter to feed microbial reduction processes. As stated in the literature review, the exact organic matter content which qualifies as "sufficient" may vary, but the consensus seemed to favor a minimal value of about 3% organic matter.

In order to examine this problem further, an experiment was carried out to examine the respective roles of saturation, organic matter content, and biological activity in the production of redoximorphic features. Samples of upland soils were collected from four of the sites. There was no upland soil available at the Maine Turnpike site. Samples were air-dried, mixed, and crushed. Each soil was partitioned into 4 samples of approximately 25 grams air-dry mass, and each of the 16 samples was placed in a beaker. Four treatments were devised for each soil type: no organic matter, 1% organic matter, 3.5% organic matter, and 3.5% organic matter plus sugar. Organic matter was mixed into three of the four samples. In one sample, sufficient organic matter was added so as to constitute one percent by weight. In two of the samples, organic matter was added so as to constitute 3.5% by weight. Organic matter was mixed into the soil thoroughly, and all soils were submerged in distilled water. Sugar was added to one of the samples with 3.5% organic matter. Munsell color was determined for each sample. All beakers were covered with Parafilm to prevent evaporation or oxygenation and were left undisturbed for 90 days. At the end of 90 days, the contents of all beakers were stirred for homogenization, and Munsell color was determined again. Results of the experiment are presented in Table 6.

Simple submergence had the least effect on soil color. Note that soils from the Bangor and Pine Road sites remained the same color. The Bangor soil had the highest initial organic matter content of the four soils, 4.6% LOI, and was also the only one of the four soils that had a Munsell chroma of 2 or less. The Bangor soil was thus the only one of the four samples that would initially be characterized as having a reduced matrix. The other three soils had initial Munsell chroma of 4 or 6, commonly indicative of oxidized iron. Munsell chroma of the Michelle Park soil actually increased when that soil was submerged without additional organic matter. The Connecticut soil color response affected both chroma and hue, although chroma remained well above 2, which is the diagnostic Munsell chroma for redox depletions. The hue, however, became yellower, changing from 2.5YR to 5YR. The 5YR hue page contains colors that are still considered quite red—redder, in fact, than the 7.5YR hue at the Pine Road site. This soil had the least amount of initial organic matter, 0.12% LOI, so it seems unlikely that reduction of iron took place. Due to the extremely red colors of this soil, it is likely that at least a portion of the iron oxide is present as hematite. It is possible that hydration may have transformed some of the hematite to goethite, which typically has a somewhat yellower color. Iron oxide mineralogy was not determined on these samples, however.

When organic matter, or organic matter and sugar, were added to the soils the Bangor site showed the most notable color changes. With the low organic matter (1%) treatment, the hue became yellower. Although the chroma increased from 2 to 3, it is important to note that the value also increased—i.e., the soil became more pale. It is also noteworthy that several soil scientists have suggested that a chroma of three may indicate reduction of iron, although the specific Munsell chroma for redox depletions or reduced matrix is 2 or less. When the addition of organic matter was increased to 3.5%, the Munsell chroma of the Bangor soil decreased to 2. This shift is even more noteworthy because, prior to submersion, the value and chroma of that sample were 4 and 3. It is also interesting to note that, initially, when organic matter was first added, the Munsell value was decreased to 4, compared to the untreated, pre-submerged value of 6. A decrease in value represents a darkening of color, so is a normal response to an addition of organic matter. Reductive processes, however, were sufficient in this sample to return the soil color to its initial, paler, value and chroma. Then, when sugar was added to "jump start" microbial processes, the color transformation was even more pronounced. Munsell chroma was reduced to 1, accompanied by a change to a yellower hue (2.5Y vs. the initial 10YR).

Samples from the Pine Road site showed very little change in color, other than development of a yellower hue with addition of organic matter. In all three samples to which organic matter was added, Munsell hue changed from 7.5YR to 10YR. Apparently, the 90-day submergence was not sufficient to produce intense reduction of iron in this soil. The initial color, however, does indicate that considerable iron is present in this soil, although the quantity of iron was not measured. Therefore, it is most likely that, given a relatively high iron concentration, a greater proportion of that iron would need to be reduced in order to impact the Munsell colors. Although 90 days was insufficient to transform chroma of this soil in the lab, it is apparent from the site itself that 2 years was sufficient time to develop low chroma matrices and redox depletions in the more organic rich wetland and island soils.

The likelihood of a high level of iron that requires intensely reductive processes to effect soil color is even more apparent in the soil from the Connecticut site. These soils had a redder hue (2.5YR) than the Pine Road soils which had Munsell hue of 7.5YR. The expectation, then, is that the Connecticut soils were the most iron-rich of all the soils sampled. Furthermore, the high Munsell chroma (6) indicates that the iron is well-oxidized. Again, a high proportion of that iron would need to be reduced in order to impact the soil color substantially. The laboratory experiment seems to have provided insufficient time to effect that reduction. In the field, however, time has been sufficient (10 years) but reduction of iron has apparently not occurred. As noted earlier, this is probably due to a well-oxygenated water source. At the scale of this experiment, then, there does seem to be some relationship between time, iron content, initial oxidation status of the iron, and development of redox depletions.

Finally, the soil samples from Michelle Park showed a nearly idealized response to the additions of organic matter and nutrient source. All three of the organically enriched samples had an initial color of 2.5Y 5/6, which facilitates comparisons. The first response, in the sample with a low (1%) organic matter addition, was an increase of Munsell value from 5 to 6, indicating that the soil became more pale during submergence. With 3.5% organic matter, value again increased from 5 to 6. In addition, Munsell chroma decreased (i.e., moved in the direction of grayness) from 6 to 4. With the addition of sugar, chroma decreased from 6 to 3, only one Munsell chip from the chroma of 2 that is used to identify reduction of iron.

Although degree of response differed among the soils, it is clear from this brief experiment that all four of the soils examined have the potential to develop soil color features associated with reduced iron. Each of the soils moved in that direction, if only slightly in some cases, by developing a yellower Munsell hue, a higher Munsell value and/or a lower Munsell chroma during submergence—provided that at least some organic matter was added. Soils with presumed higher iron content (redder Munsell hues) may require more time to develop redox depletions and/or reduced matrices. The two yellower soils—Bangor and Michelle Park—responded in nearly linear fashion to increase in organic matter and addition of nutritive substrate.

VI. Phase III Formulation of Guidelines to the Use of Non-Hydric Soils for Wetland Mitigation

The guidelines for the use of non-hydric soils were developed based on the results from the first two phases of the project. The overriding requirement for the use of non-hydric soils for wetland construction is that the hydrological conditions must be appropriate. The hydroperiod and depth of groundwater fluctuations must be such that the surficial soil profile is saturated for 7-30 days of the growing season, and sufficient moisture is maintained throughout the growing season to sustain hydrophytic vegetation. The non-hydric soils to be used for wetland construction should have at least 3% organic matter.

With the above requirements met, almost any soil will become hydric. Below are some further guidelines to match the non-hydric soil selected for the wetland construction to the type of wetland and the hydrology of the site:

1. Sandy loam soils are recommended for the construction of wetlands in almost any appropriate hydrological condition. These soils are soft and friable, making it easy for root and rhizome penetration and growth. These soils also typically have nutrients available for initial plant growth.
2. Sands and loose or uniform gravels are appropriate for ponded conditions, or hydrologic conditions with long hydroperiods at very shallow depths. Deep fluctuations in groundwater levels may allow these soils to dry out, which will kill the vegetation.
3. Peaty soils are recommended for constructing bogs. These soils would not be recommended for other types of wetlands, since they do not have the structure to physically support the roots of taller plants.
4. Soils with a high clay content (clayey loam, clayey sand), or soils with a very low hydraulic conductivity (10^{-5} - 10^{-7} cm/s), may be more suited to conditions where the constructed wetland

hydrology is dominated by surface water, or there are significant groundwater fluctuations. These soils have a low vertical conductivity and would more readily retain the surface water.

5. Clays and dense gravels should be avoided. These soils are too tight or dense to allow for easy root and rhizome penetration; consequently, plant growth may be severely inhibited.

VII. Project Summary, Conclusions, and Recommendations

The literature reviewed in the first phase of the project suggests that essentially any soil, given the appropriate hydrologic conditions, may become hydric. The appropriate hydrologic conditions are those which saturate the surficial soil profile for at least 15 to 30 consecutive days of the growing season, and maintain sufficient moisture at other times during the growing season to sustain hydrophytic vegetation. This hydrologic condition may be maintained by either surface waters or groundwaters or a combination. Depletion of oxygen is an important condition in the development of redoximorphic features; therefore, saturation alone is not sufficient for development of many of the hydric soil Field Indicators. The results of the phase two investigation confirmed that non-hydric soils may be successfully used for wetland construction if all of these conditions are met, and that hydric conditions are formed relatively rapidly, at least within two years. Thus, the Connecticut soils most probably failed to develop gray colors indicative of iron reduction because the water source contained too much oxygen, and the because the oxygen source was regularly replenished. Although this site appeared to meet the conditions of saturation, reduction of iron did not occur in sufficient intensity to produce redoximorphic features. Soils at the Bangor, Pine Road, and Michelle Park sites developed redox depletions (low chroma features) sufficiently close to the soil surface to qualify as hydric soils according to the Field indicators. At the Maine Turnpike site, thick organic-rich surface horizons (histic epipedons) qualified those soils as hydric, again according to the Field Indicators.

The field investigation evaluated soils from four different textural classes, including sands, loamy sands, sandy loams, and silty clays. Hydraulic conductivities spanned two orders of magnitude, from 10^{-4} to 10^{-2} cm/s for the entire study, sometimes for a single site. No consistent correlation was noted with soil texture.

Hydrologic conditions ranged from a wetland mitigation site dependent primarily on surface water to a system strongly influenced by groundwater flow. In each case, the hydrology of the wetland had a hydroperiod of sufficient duration to create hydric soil conditions. Each site had soils which were characterized as hydric, except for the Connecticut site where the color of the soil may have masked the tell-tale hydric features. Soil texture was not found to be an important factor in the development of hydric conditions. Texture-based recommendations were made with regard to vegetative growth rather than morphological considerations. Morphological features were strongly correlated to organic content, indicating that the organic content has an significant role in the formation of hydric conditions. The age of the wetlands, which varied from 2 to 10 years, had a weak positive correlation to the morphological index. The weak correlation indicated that there were notable differences in the morphological index only weakly among the wetlands that had been in existence for a short time. This indicates that the hydric characteristics developed rather quickly, and increasing age did not provide stronger soil color changes.

The conclusions which may be drawn are:

- There are two factors which affect the development of hydric conditions, hydrology and organic content.
- The hydrology must create saturated conditions over the surficial soil profile for at least 7-30 days during the growing season. There must be sufficient moisture at other times in the growing season to sustain plant growth.
- The organic content of the non-hydric soils used for wetland construction must be above 1.5% (according to the literature), with the optimum value at approximately 3%.
- Hydrologic conditions of the planned mitigation site may be used as a guide in selecting appropriate non-hydric soils for wetland mitigation.

Nutrient requirements depend on the requirements of the particular vegetative species. Typically nutrients are derived from both incoming waters and from the soils. As organic material builds up on the soil surface, many species are able to utilize nutrients from the breakdown of the organic materials. Consequently, soils with low levels of nutrients may require fertilization until the organic buildup is sufficient to maintain the required nutrient levels. This study did not investigate the nutrient requirements of the soils, since the majority of the sites selected had no nutrient data available for the upland soils at the time of construction.

To further refine the dependence of hydric soil development on organic content, and hydrology, it is suggested that a controlled experiment be set up on a wetland creation site that has a variety of hydrologic conditions. Frequent monitoring and sampling of plots with different organic contents, nutrients, and hydrologic conditions would provide more definition to the relationships

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Table 1. Summary of soils analyses for the Pine Road Wetland Mitigation Site

Property	Pre-const	Post Construction		After Fertilizing	
	Southern Pit Sand	Southern Pit Upland	Southern Pit Wetland	Southern Pit Upland	Southern Pit Wetland
Texture	Sand	Loam	Sandy Loam	Loam	Loam
Sand (%)	87	50	63	50	50
Silt (%)	7	40	23	33	37
Clay (%)	6	10	13	17	13
Organic Matter (%)	1.0	3.7	4.4	n/a	3.4
Cation Exchange (meq/100g)	n/a	6.5	6.1	11.4	10.1
pH	6.0	5.7	5.2	5.0	4.9
Nutrients					
Magnesium (ppm)	36	54	22	48	46
Calcium (ppm)	302	580	154	372	306
Potassium (ppm)	22	54	42	66	66
Phosphorus (ppm)	16	37	19	22	35
Base Saturation (%)	n/a	53.8	17.5	21.3	20.7
Calcium Saturation (%)	n/a	44.7	12.7	16.3	15.2
Magnesium Saturation (%)	n/a	6.9	33.0	3.5	3.8
Potassium Saturation (%)	n/a	2.1	1.8	1.5	1.7

Table 2. Wetland Well Statistics Summary

Well	Current TOC* Elevation (ft)	Current Stick-up** (in)	Total Well Depth BGS† (ft)	Screened Interval Depths BGS† Top (ft)	Bottom (ft)
Site:	Bangor Hydroelectric Ellsworth, ME				
UNH-1	101.69	3.50	6.50	3.00	6.00
UNH-2	104.67	4.30	5.70	0.20	5.20
UNH-3	105.31	3.45	6.55	3.05	6.05
UNH-4	106.02	5.15	4.85	1.35	4.35
Site:	Pine Road Brentwood, NH				
UNH-1	130.22	2.33	7.67	4.17	7.17
UNH-2	129.77	2.52	7.48	3.98	6.98
UNH-3	130.57	2.25	7.75	4.25	7.25
UNH-4	131.95	2.25	7.75	4.25	7.25
Site:	Maine Turnpike (I-95) Old Exit 6 Scarborough, ME				
UNH-1	101.69	2.67	7.33	3.83	6.83
UNH-2	104.67	2.50	7.50	2.00	7.00
UNH-3	105.31	2.54	7.46	3.96	6.96
UNH-4	106.02	3.60	6.40	2.90	5.90
Site:	Michelle Memorial Park Salem, NH				
UNH-1	98.31	2.17	7.83	4.33	7.33
UNH-2	98.34	2.50	7.50	4.00	7.00
UNH-3	99.46	2.83	7.17	3.67	6.67
Site:	Connecticut DOT I-691 & Rt. 10 Cheshire, CT				
UNH-1	103.63	3.05	6.95	1.45	6.45
UNH-2	102.83	3.10	6.90	3.40	6.40
UNH-3	103.03	3.14	6.86	3.36	6.36

Key: * TOC: Top of Casing ** Stick-up: distance from TOC to ground surface
† BGS: Below Ground Surface

Table 3. Summary of Piezometric Levels at Wetland Sites

Well	Elevation Top of Casing (TOC)	Static Water Level (TOC)	Groundwater Elevation (ft)	TOC Stickup (FGS)*	Ground Surface Elevation (ft)	Water Table Depth (bgs)**
Site:	Bangor Hydroelectric Ellsworth, Me					
UNH-1	101.69	9.59	92.10	3.50	98.19	6.09
UNH-2	104.67	3.94	100.73	4.30	100.37	-0.36
UNH-3	105.31	9.34	95.97	3.45	101.86	5.89
UNH-4	106.02	8.87	97.15	5.15	100.87	3.72
P1	101.04	2.84	98.20	2.50	98.54	0.34
P2	102.99	3.71	99.28	2.60	100.39	1.11
P3	99.19	3.58	95.61	2.70	96.49	0.88
P4	100.77	3.60	97.17	2.80	97.97	0.80
P5	103.64	4.53	99.11	2.92	100.72	1.61
P6	105.47	3.36	102.11	2.56	102.91	0.80
P7	103.73	3.53	100.20	2.90	100.83	0.63
P8	105.70	3.51	102.19	3.00	102.70	0.51
P9	103.50	4.20	99.30	2.95	100.55	1.25
P10	100.42	3.51	96.91	2.68	97.74	0.83
WATER	100.82	0.00	100.82			
Site:	Pine Road Brentwood, NH					
UNH-1	130.32	5.21	125.11	2.33	127.98	2.88
UNH-2	129.77	4.59	125.18	2.52	127.25	2.07
UNH-3	130.57	5.04	125.53	2.25	128.32	2.79
UNH-4	131.95	6.13	125.82	2.25	129.70	3.88
Well 1	133.80	7.97	125.83			
SITE:	Maine Turnpike I-95 Old Exit 6 Southbound Scarborough, Me					
UNH-1	63.29	3.47	59.82	2.67	60.62	0.80
UNH-2	63.58	3.60	59.98	2.50	61.08	1.10
UNH-3	63.96	3.16	60.80	2.54	61.42	0.62
UNH-4	63.86	5.23	58.63	3.60	60.26	1.63
SBR1	61.55	2.01	59.54	1.08	60.47	0.93
SBR2	62.13	1.71	60.42	1.15	60.98	0.56
SBR3	62.66	2.81	59.85	1.96	60.70	0.85
SBR4	61.12	1.87	59.25	0.79	60.33	1.08
SBR5	64.14	3.42	60.72	2.69	61.45	0.73
SBR6	63.91	3.51	60.40	2.50	61.41	1.01
SBR7	63.73	3.58	60.15	2.60	61.13	0.98
SITE:	Michelle Memorial Park Salem, NH					
UNH-1	98.31	4.57	93.74	2.17	96.14	2.40
UNH-2	98.34	4.67	93.67	2.50	95.84	2.17
UNH-3	99.46	5.17	94.29	2.83	96.63	2.34
SITE:	Connecticut DOT I-691 & Rt. 10 Cheshire, CT					
UNH-1	103.63	3.16	100.47	3.05	100.58	0.11
UNH-2	102.83	3.60	99.23	3.10	99.73	0.50
UNH-3	103.03	3.88	99.15	3.14	99.89	0.74
Sherry-1	100.00	1.10	98.90	NA	NA	NA
Pond	98.72	0.00	98.72	NA	NA	NA

Key: * FGS: From Ground Surface ** BGS: Below Ground Surface

Table 4. Summary of Slug Test Results for All Wetland Sites

Well ID	Notes	Test #	To (sec)	K (in/s)	K (cm/s)	Avg K (cm/s)
Bangor UNH-2	5 ft screen	1	58.33	6.756E-05	1.716E-04	2.068E-04
		2	58.33	6.756E-05	1.716E-04	
		3	33.33	1.182E-04	3.003E-04	
UNH-2 Pine Road	3 ft screen	1	3.72	1.582E-03	4.019E-03	4.555E-03
		2	3.19	1.845E-03	4.687E-03	
		3	2.98	1.975E-03	5.017E-03	
UNH-3 Pine Road	3 ft screen	1	4.88	1.206E-03	3.064E-03	3.017E-03
		2	5.04	1.168E-03	2.967E-03	
		3	4.79	1.229E-03	3.121E-03	
		4	5.12	1.150E-03	2.920E-03	
UNH-4 Pine Road	3 ft screen	1	3.09	1.905E-03	4.839E-03	5.088E-03
		2	2.93	2.009E-03	5.103E-03	
		3	2.87	2.051E-03	5.210E-03	
		4	2.87	2.051E-03	5.210E-03	
UNH-1 Maine Turnpike	3 ft screen	1	2.00	2.943E-03	7.476E-03	2.057E-03
		2	12.00	4.905E-04	1.246E-03	
		3	16.00	3.679E-04	9.345E-04	
UNH-2 Maine Turnpike	5 ft screen	1	19.00	2.074E-04	5.268E-04	8.725E-04
		2	16.00	2.463E-04	6.256E-04	
		3	3.00	1.314E-03	3.337E-03	
		4	19.00	2.074E-04	5.268E-04	
UNH-3 Maine Turnpike	3 ft screen	1	2.50	2.355E-03	5.981E-03	5.773E-03
		2	3.00	1.962E-03	4.984E-03	
		3	2.00	2.943E-03	7.476E-03	
		4	3.00	1.962E-03	4.984E-03	
UNH-4 Maine Turnpike	3 ft screen	1	2.50	2.355E-03	5.981E-03	1.189E-02
		2	0.50	1.177E-02	2.990E-02	
		3	1.00	5.886E-03	1.495E-02	
		4	2.00	2.943E-03	7.476E-03	
UNH-1 Michelle Memorial Park	3 ft screen	1	8.80	6.689E-04	1.699E-03	1.556E-03
		2	9.60	6.132E-04	1.557E-03	
		3	10.50	5.606E-04	1.424E-03	
UNH-2 Michelle Memorial Park	3 ft screen	1	148.40	3.967E-05	1.008E-04	1.308E-04
		2	91.60	6.426E-05	1.632E-04	
		3	109.90	5.356E-05	1.360E-04	
UNH-3 Michelle Memorial Park	3 ft screen	1	179.50	3.279E-05	8.329E-05	8.979E-05
		2	170.10	3.461E-05	8.790E-05	
		3	151.20	3.893E-05	9.889E-05	
UNH-1 Connecticut	5 ft screen	1	0.30	1.314E-02	3.337E-02	2.209E-02
		2	0.57	6.914E-03	1.756E-02	
		3	0.41	9.612E-03	2.441E-02	
		4	0.60	6.568E-03	1.668E-02	
		5	0.49	8.043E-03	2.043E-02	
		6	0.42	9.383E-03	2.383E-02	
UNH-2 Connecticut	3 ft screen	1	2.00	2.943E-03	7.476E-03	4.815E-03
		2	5.00	1.177E-03	2.990E-03	
		3	3.00	1.962E-03	4.984E-03	
		4	3.10	1.899E-03	4.823E-03	
UNH-3 Connecticut	3 ft screen	1	24.50	2.403E-04	6.103E-04	7.427E-04
		2	17.90	3.288E-04	8.353E-04	
		3	18.60	3.165E-04	8.038E-04	

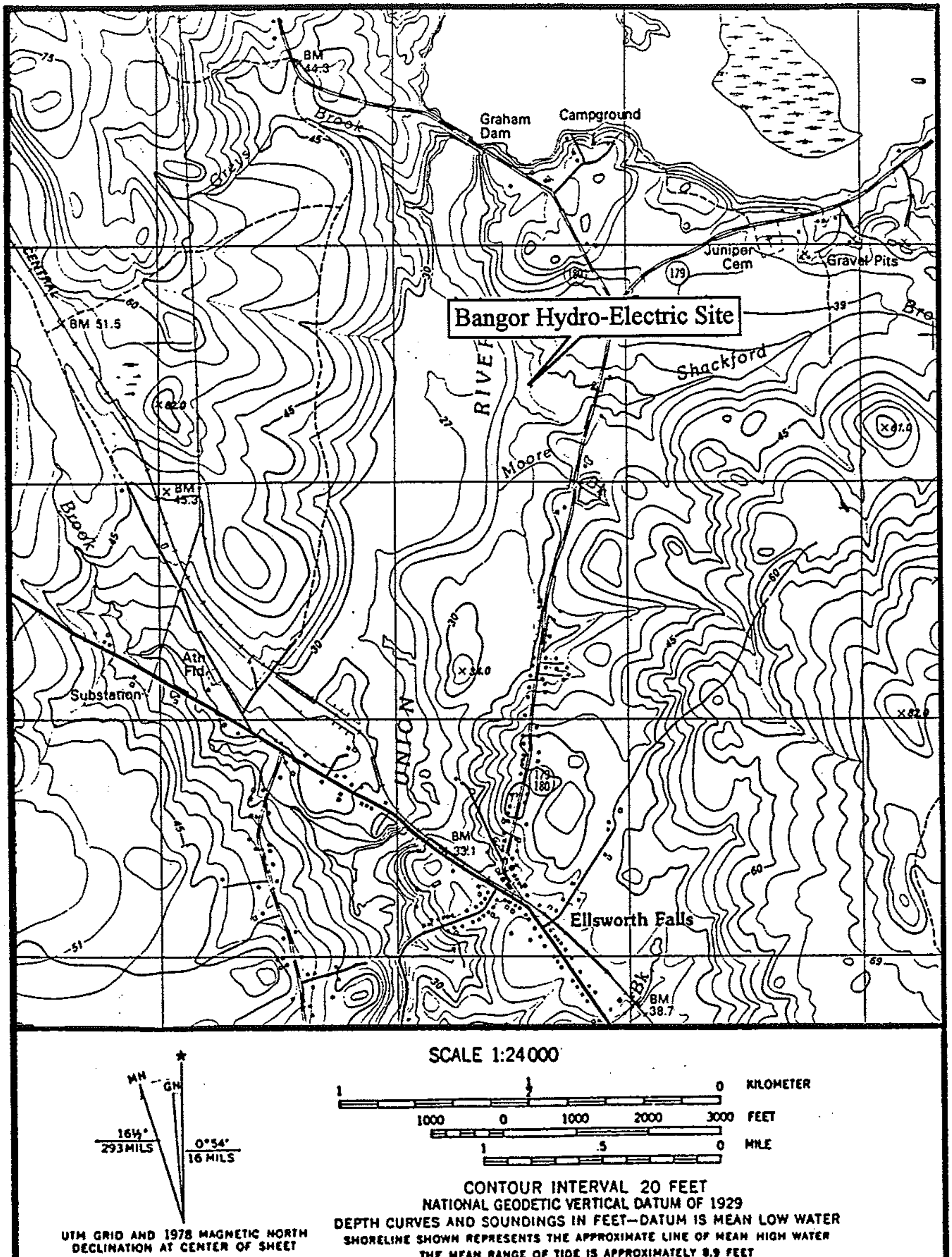
Table 5. Summary of Soil Properties

Site	Hydric?	O* (cm)	Index	Dipyridyl Reaction?	LOI (%)	Age (yrs)	Textural Class
Bangor							
Upland	no	0	11.82	no	5.86	NA	sil
Transition	yes	0	13.465	yes	4.64	3	sicl
Submerged	yes	0	12.574	yes	7.12	3	sil
Boundary	yes	0	13.534	yes	4.33	3	sicl
P5	yes	0	12.890	no	3.95	3	sil
P10	yes	0	13.824	yes	4.01	3	sicl
Pine Road							
Upland	no	0	13.70	no	1.63	NA	sl
Island	yes	0	15.03	yes	4.01	2	sl
Upland topsoil	yes	0	11.90	yes	6.09	2	ls
Wetland topsoil	yes	0	12.90	yes	3.02	2	ls
Maine Turnpike							
East	yes	14	11.74	no	31.64	2	ls
Center	yes	12	10.96	no	32.14	2	s
West	yes	14	11.74	no	26.60	2	s
Michelle Park							
Upland	no	0	15.17	no	1.75	NA	ls
Wetland	yes	0	13.46	no	1.70	5	ls
Connecticut DOT							
Upland	no	0	24.0	no	0.12	10	sl
Cattails	no	0	21.1	no	1.99	10	sl

KEY:
*O = O horizon thickness
**Textural class: sil = silt loam; sicl = silty clay loam; sl = sandy loam; ls = loamy sand; s = sand

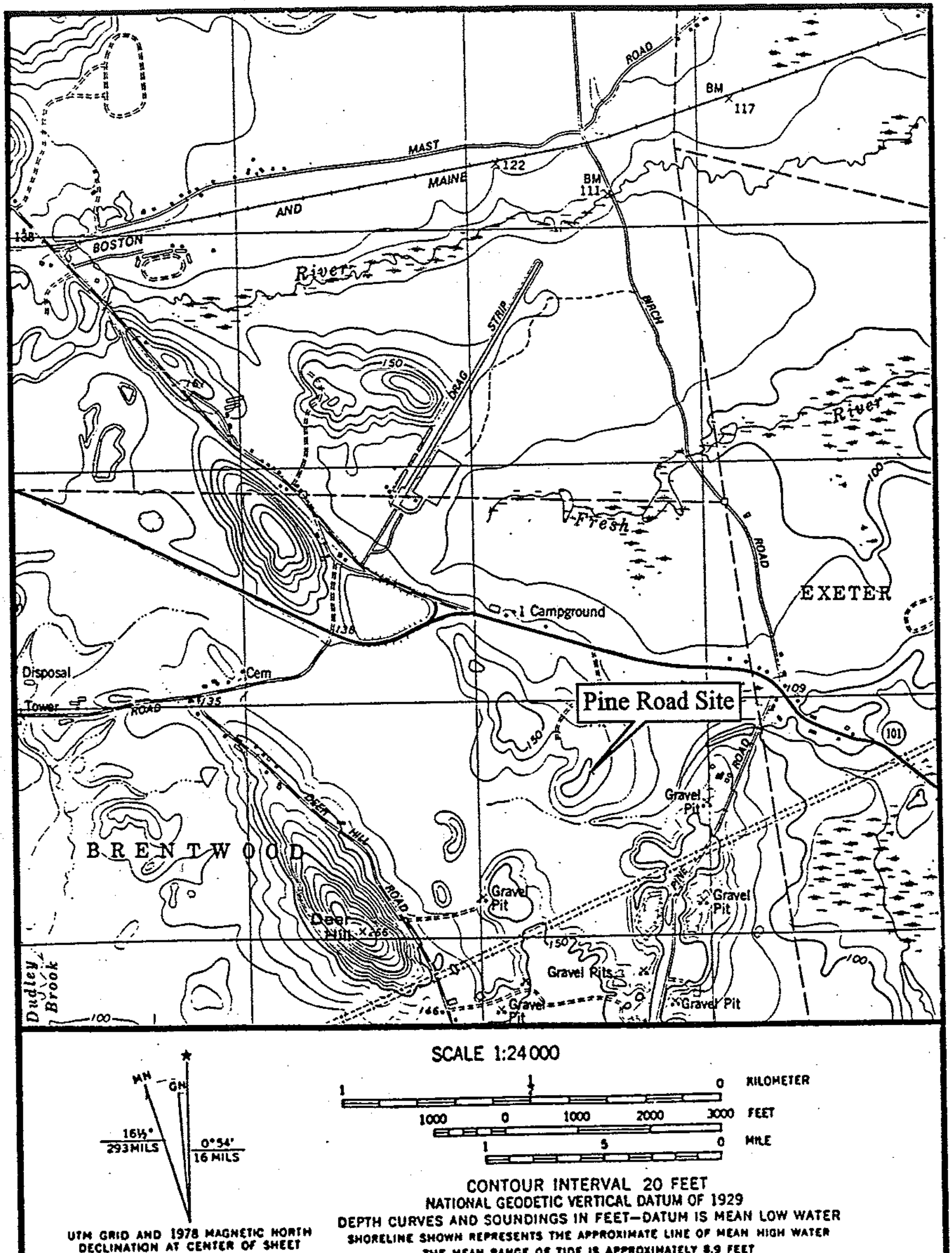
Table 6. Munsell color notation before and after 90-day submersion.

Site	Time	No Added Organic Matter	1% Organic Matter	3.5% Organic Matter	Sugar + 3.5% Organic Matter
Bangor	Start	10YR 6/2	10YR 5/2	10YR 4/3	10YR 4/3
Bangor	End	10YR 6/2	2.5Y 6/3	10YR 6/2	2.5Y 5/1
Pine Road	Start	7.5YR 5/6	10YR 4/6	10YR 4/6	10YR 4/6
Pine Road	End	7.5YR 5/6	10YR 5/6	10YR 5/6	10YR 3/6
Michelle Park	Start	2.5Y 7/4	2.5Y 5/6	2.5Y 5/6	2.5Y 5/6
Michelle Park	End	2.5Y 7/6	2.5Y 6/6	2.5Y 6/4	2.5Y 6/3
Connecticut DOT	Start	2.5YR 4/6	2.5YR 3/4	5YR 3/4	5YR 3/4
Connecticut DOT	End	5YR 4/4	5YR 4/3	5YR 4/3	5YR 4/3



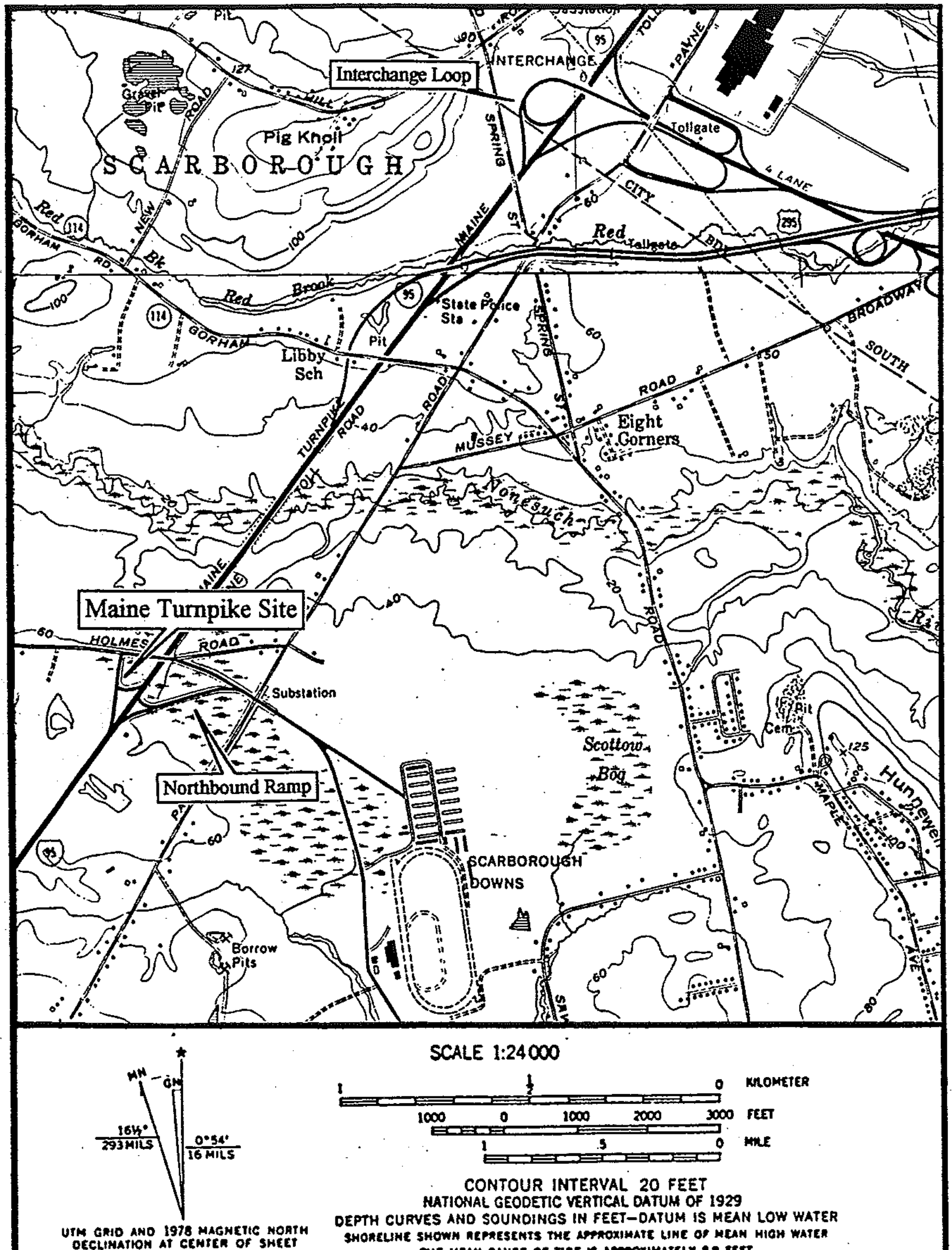
Location of Bangor Hydro-electric Wetland Mitigation Site

Figure 1.



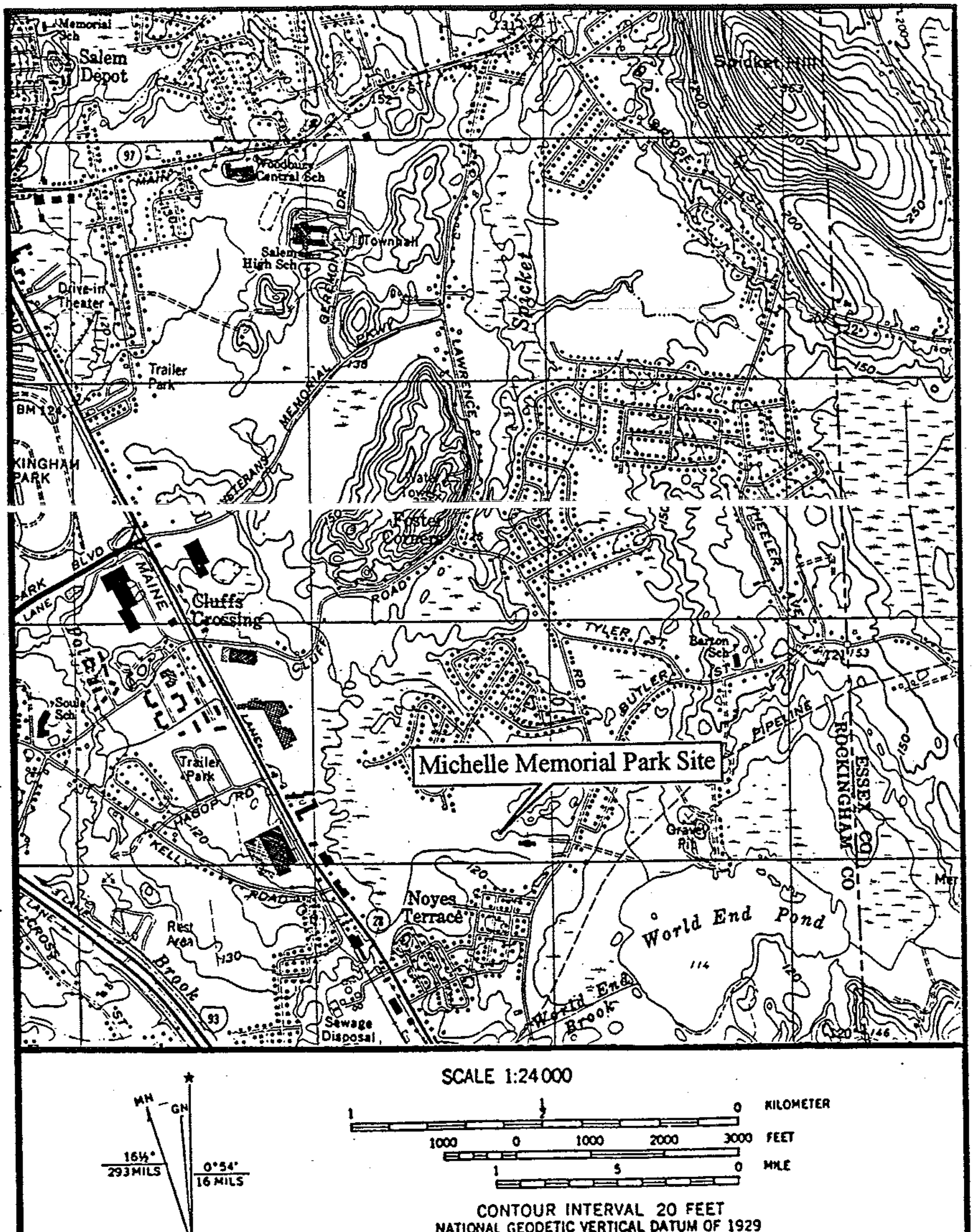
Location of Pine Road Wetland Mitigation Site

Figure 2.



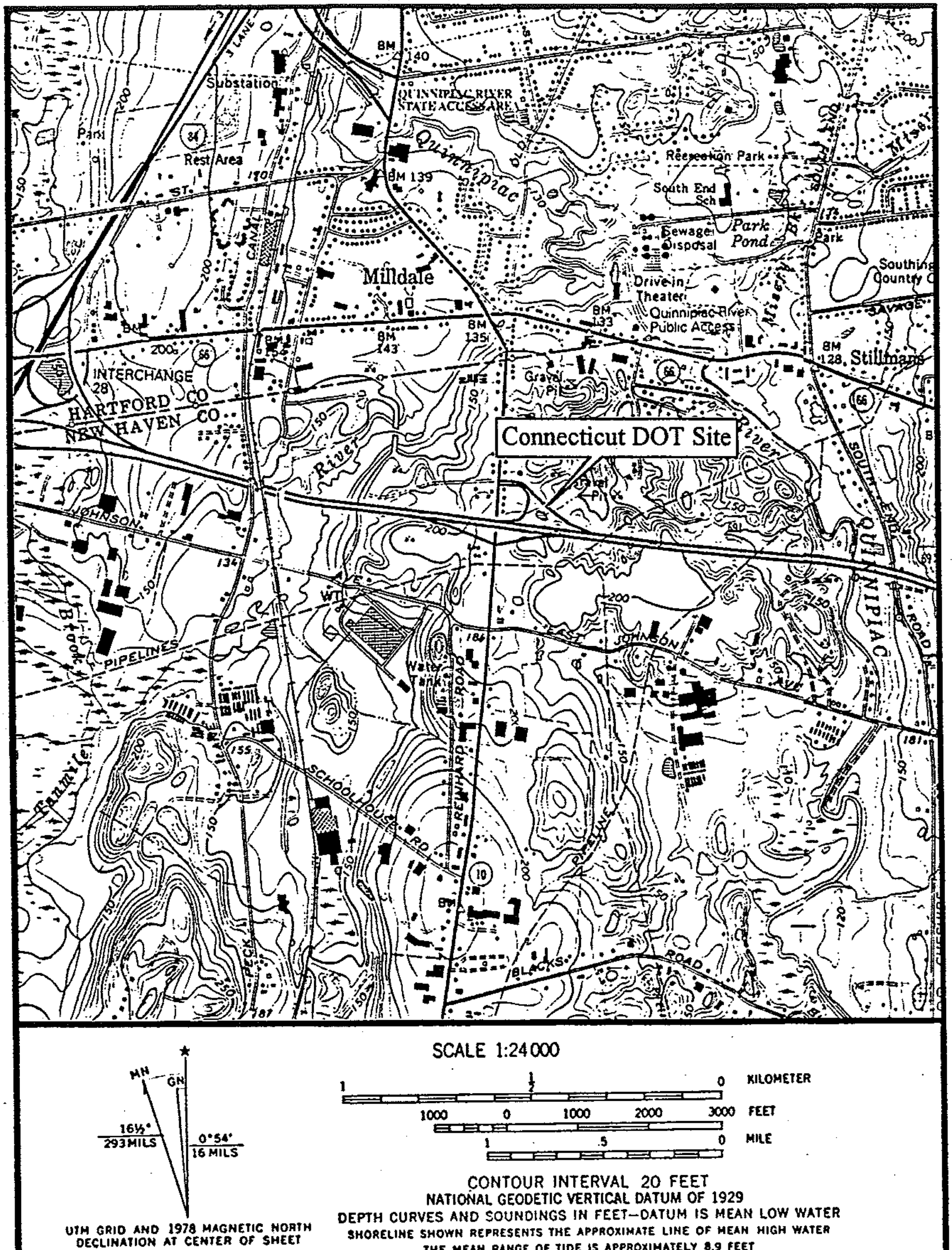
Location of Maine Turnpike Old Exit 6 Mitigation Site

Figure 3.



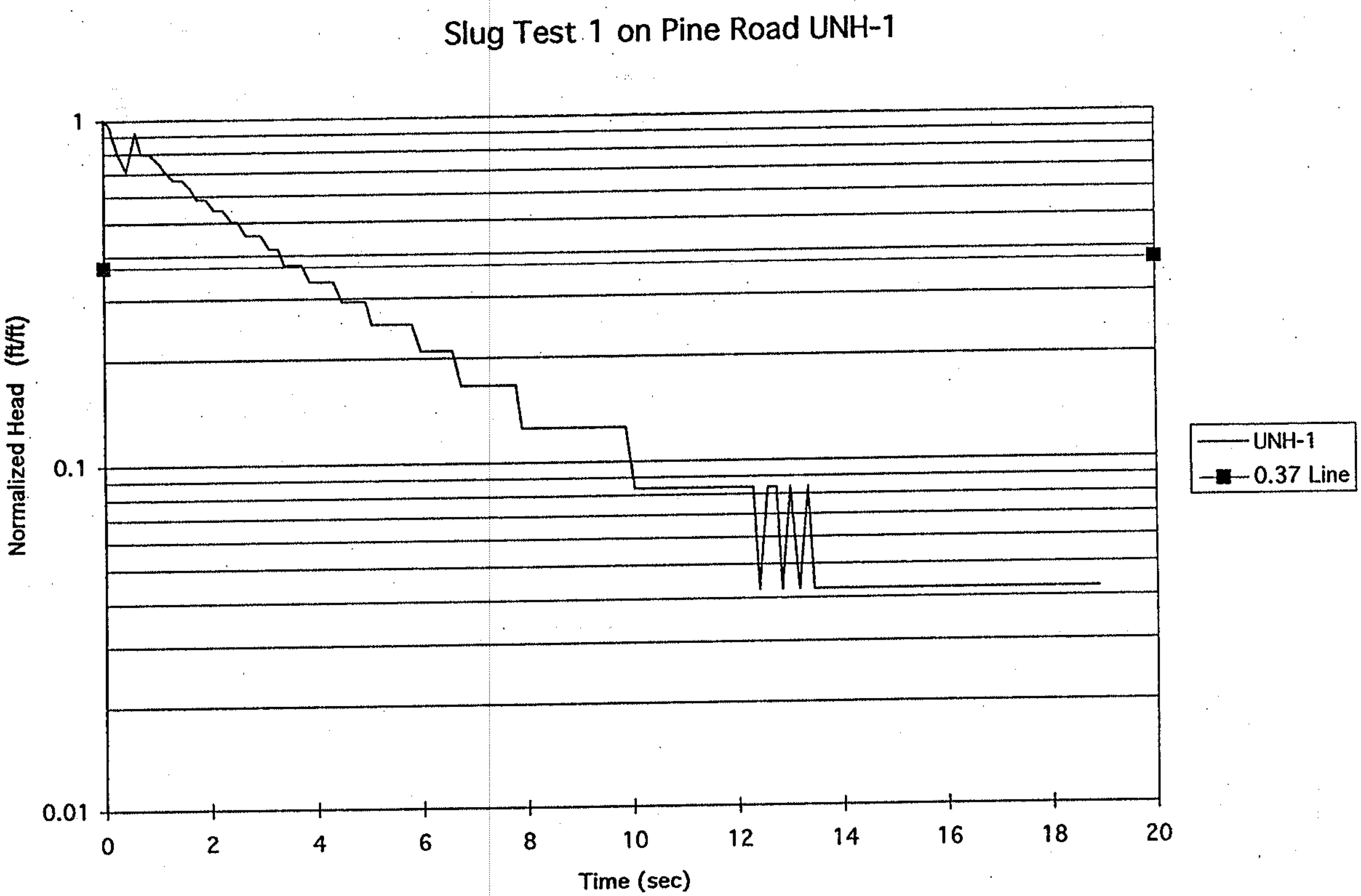
Location of Michelle Memorial Park Mitigation Site

Figure 4.



Location of Connecticut I-691 Wetland Mitigation Site

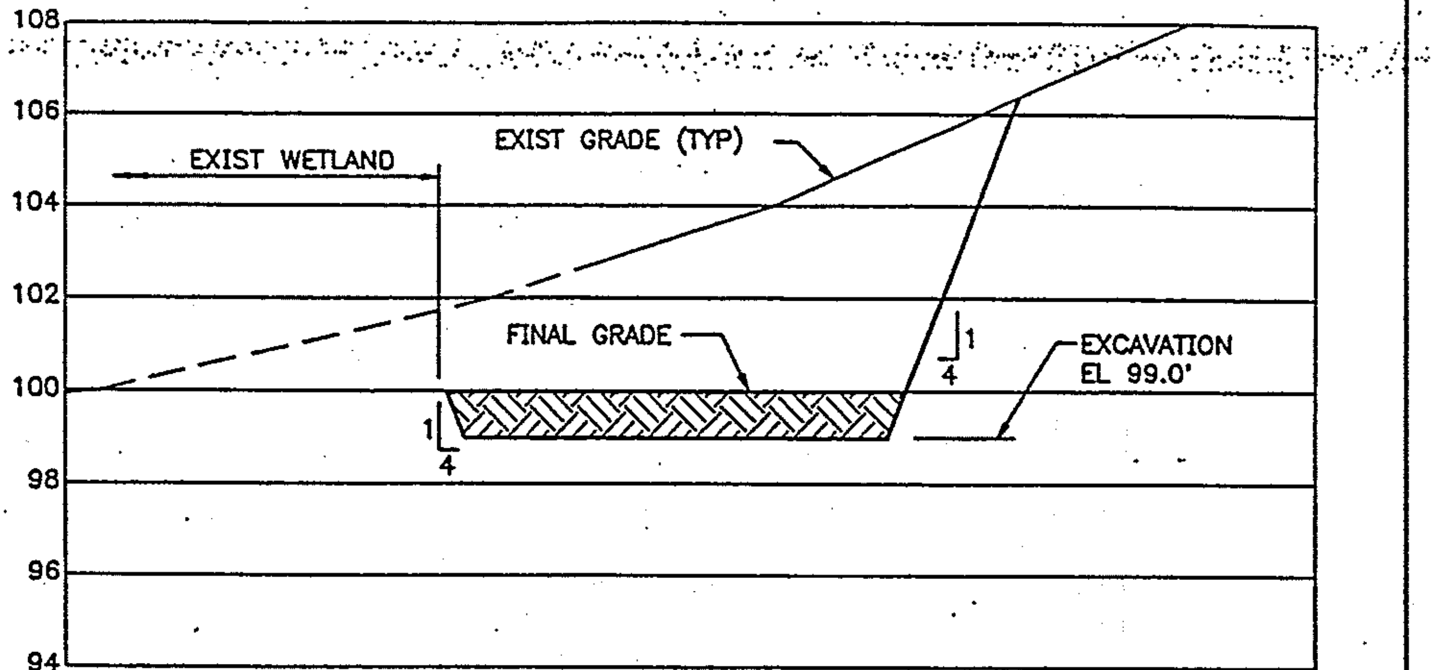
Figure 5.



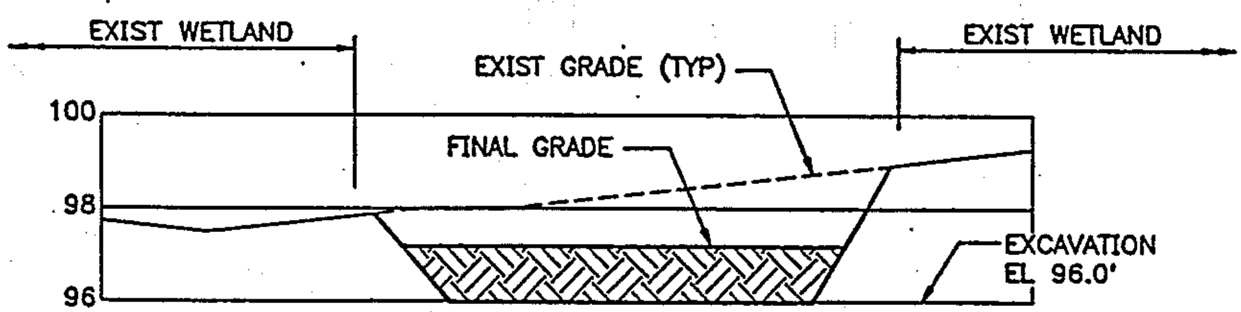
Example of Slug Test Analysis Plot

Figure 6.

ND&T



1–1 (30C–203, B3; 30C–204, G–2)



2–2 (30C–203, E–8; 30C–204, H–4)

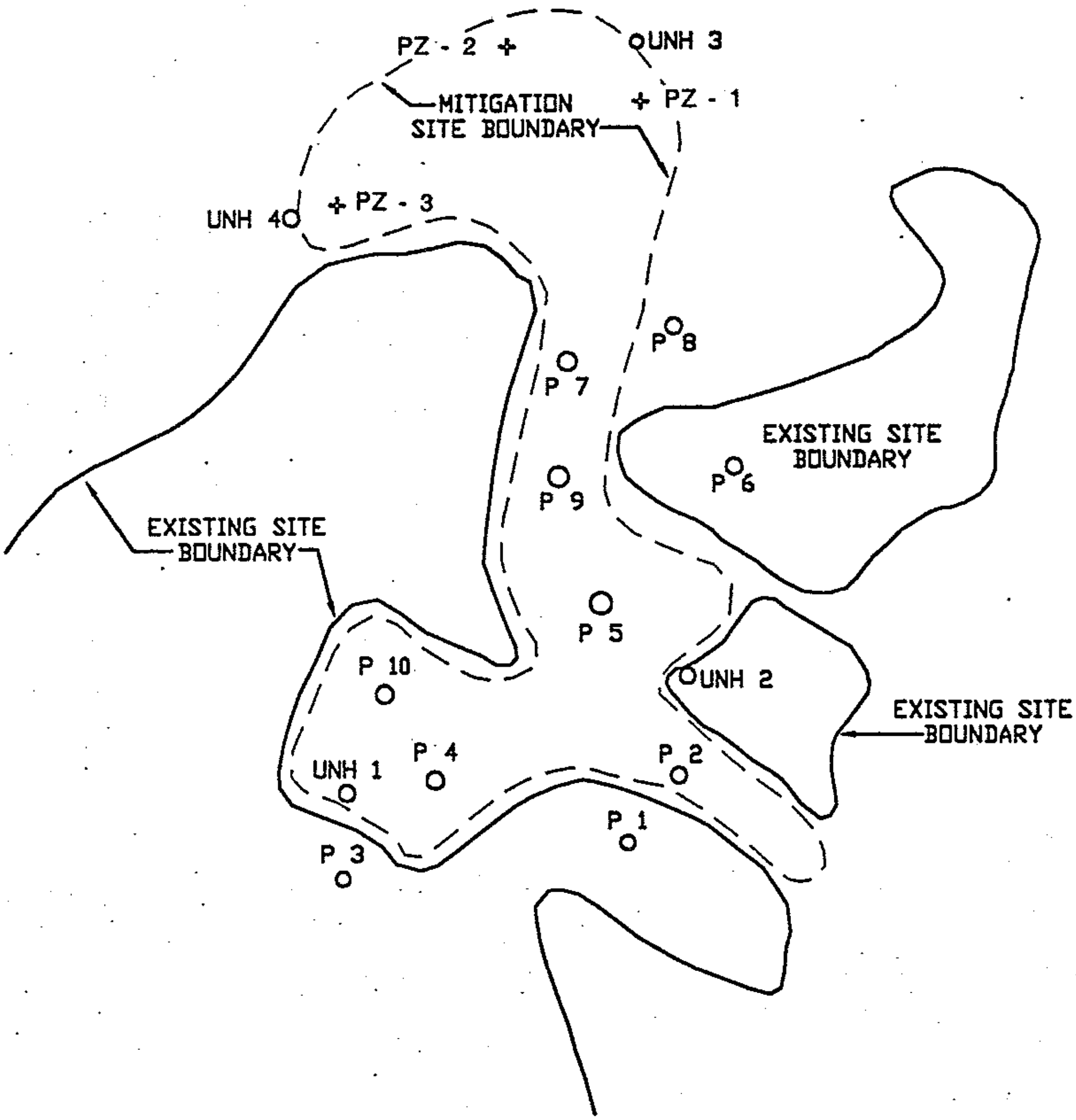
Typical Profiles of the Bangor Hydroelectric Creation Site

ADAPTED FROM DRAWING 30C-205, SUBMITTED JULY 1993

Taken from Northrop, Devine, and Tarbell, Inc., 1993.

APPLICATION BY: BANGOR HYDRO-ELECTRIC CO. 33 STATE STREET BANGOR, MAINE 04402 PURPOSE: GRAHAM LAKE DAM REMEDIATION WETLAND CREATION DATUM: NGVD 1929	WETLAND MITIGATION SECTIONS APPROXIMATE SCALE 0 30 60 FEET	PROJECT: PROPOSED FINAL WETLAND MITIGATION AT: ELLSWORTH, HANCOCK COUNTY, MAINE DATE: JULY 1993

Figure 7.



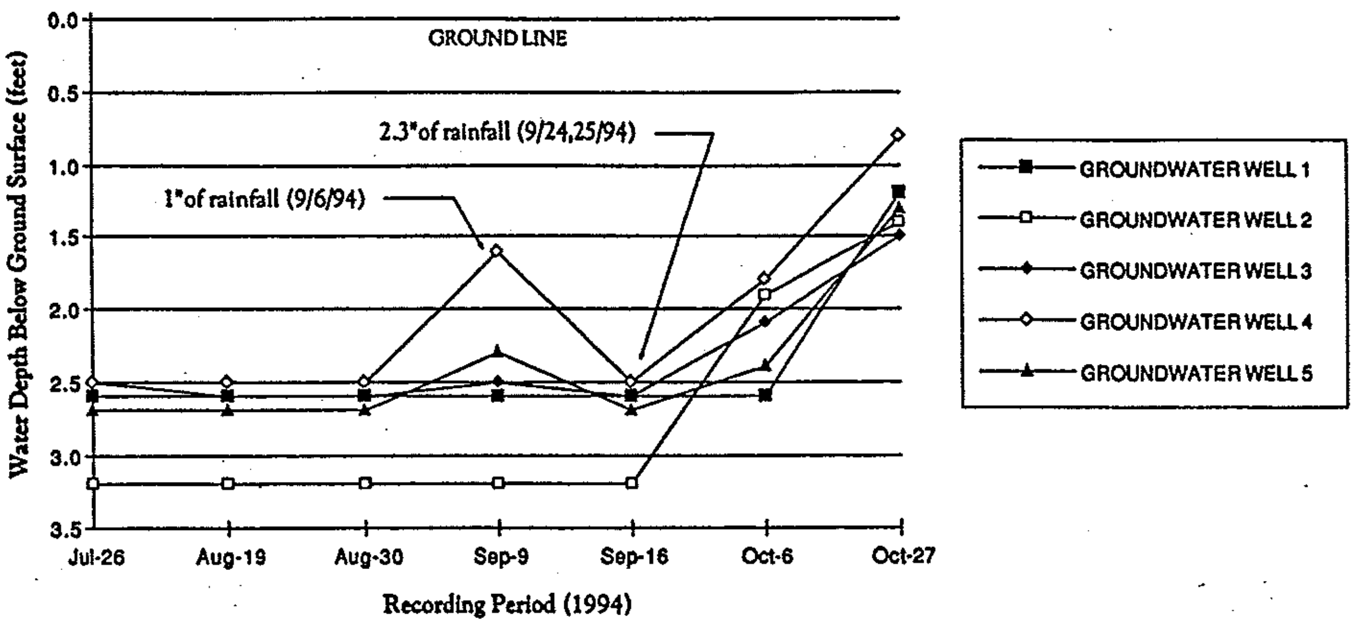
MONITORING WELL LOCATIONS AT THE BANGOR HYDRO-ELECTRIC SITE

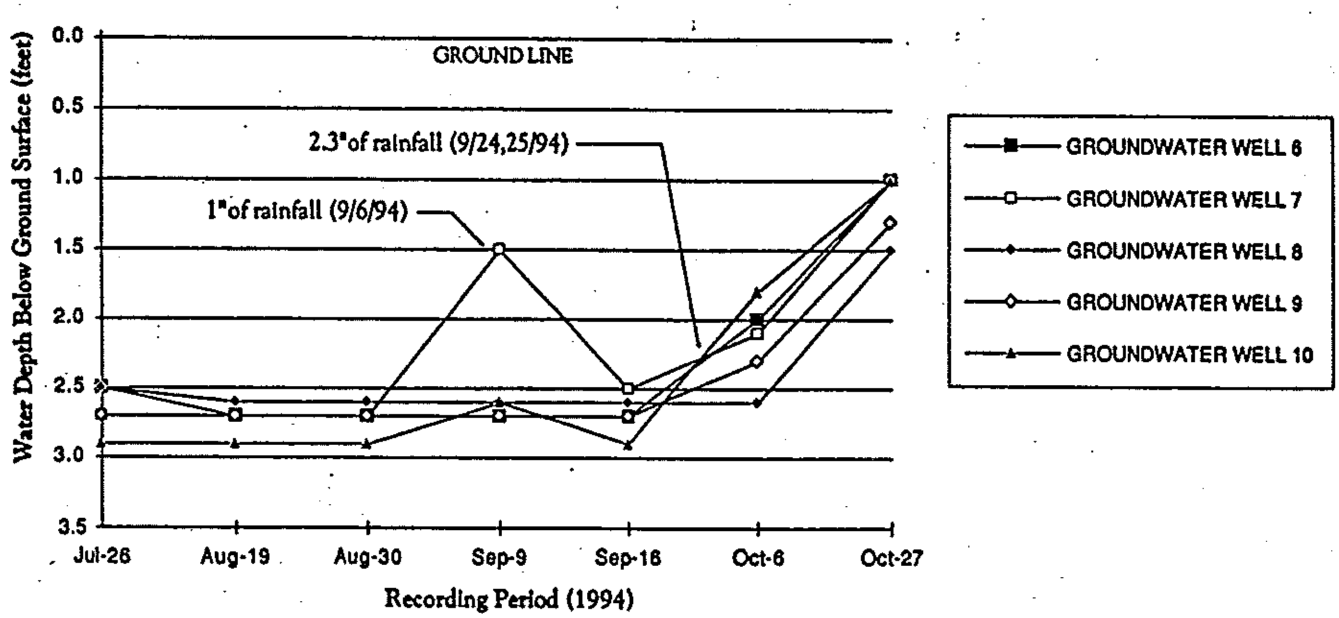
PROVIDED BY:
ND&T
NORTHROP, DEVINE, & TARBELL, INC.

SCALE: 1" = APPROX. 60'

Figure 8

GRAHAM LAKE DAM CREATION SITE
GROUNDWATER MONITORING WELL DATA (POST-CONSTRUCTION)



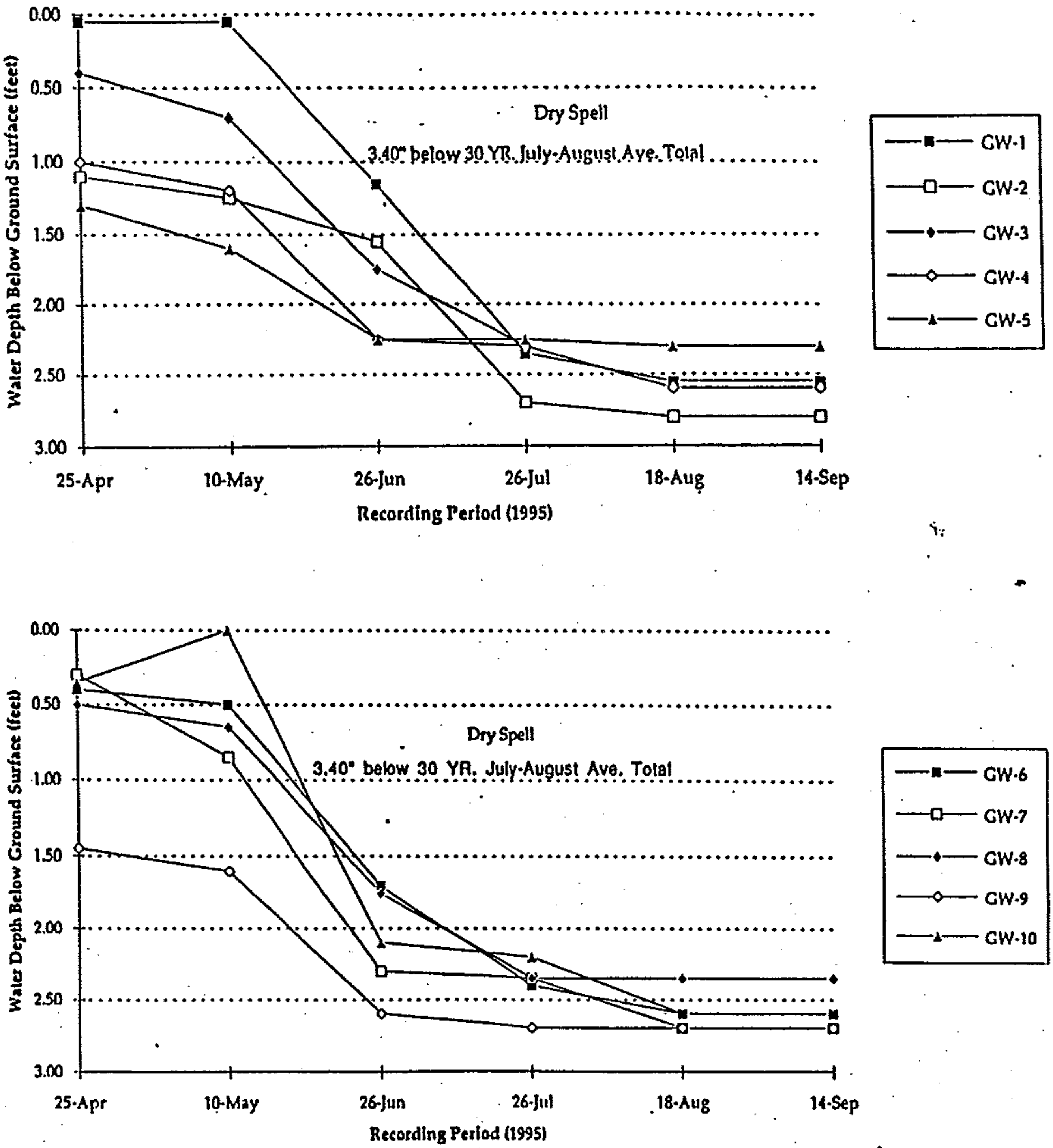


Taken from Bangor Hydro-electric Company, 1994

Groundwater Fluctuations at the Bangor Hydro-electric Site in 1994

Figure 9.

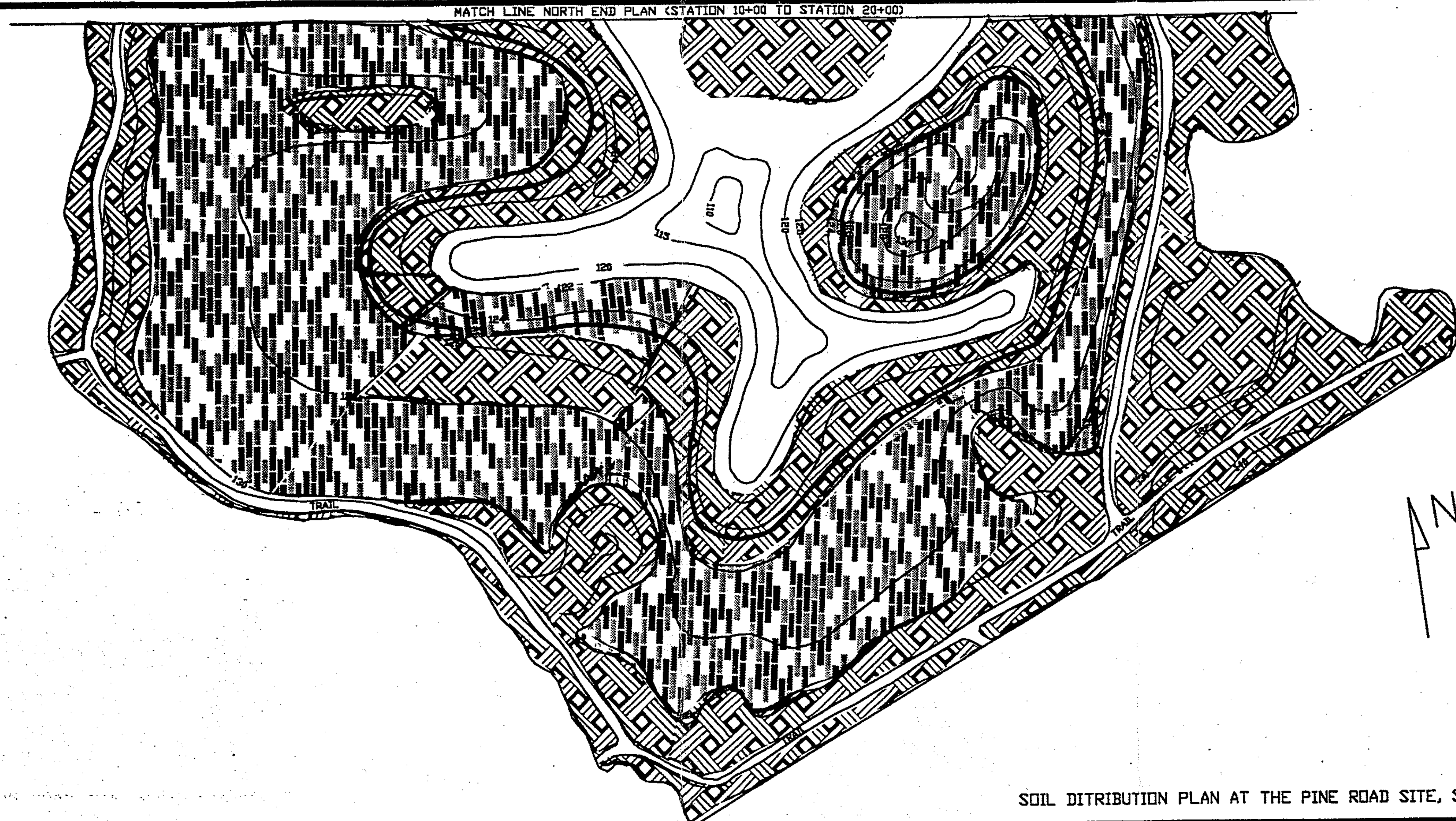
GRAHAM LAKE DAM WETLAND CREATION SITE
GROUNDWATER MONITORING WELL DATA (POST-CONSTRUCTION)



Taken from Bangor Hydro-electric Company, 1995

Groundwater Fluctuations at the Bangor Hydro-electric Site in 1995

Figure 10.



SOIL DITRIBUTION PLAN AT THE PINE ROAD SITE, SOUTH END

WETLAND HUMUS

UPLAND HUMUS

— 120 — SURFACE CONTOUR

— 125 — STANDING WATER LEVEL AT TIME OF STUDY

White areas within map denote thin layer of upland soil incorporated in existing soils.

PROVIDED BY:
NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
NORMANDEAU ASSOCIATES, INC.

PINE ROAD WETLAND MITIGATION SITE
NH ROUTE 101/51

SCALE: 1" = APPROX. 120'

Figure 11.

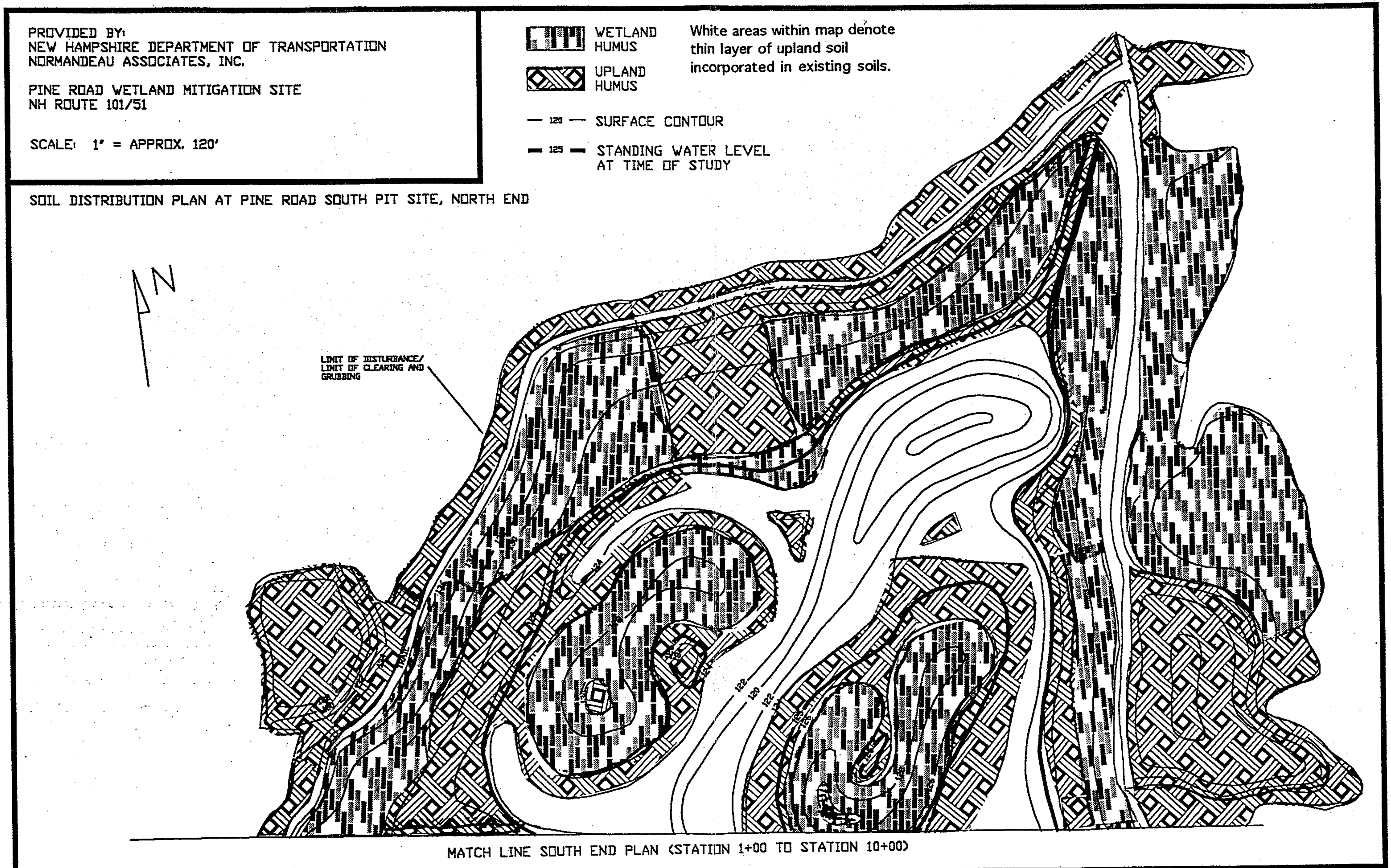
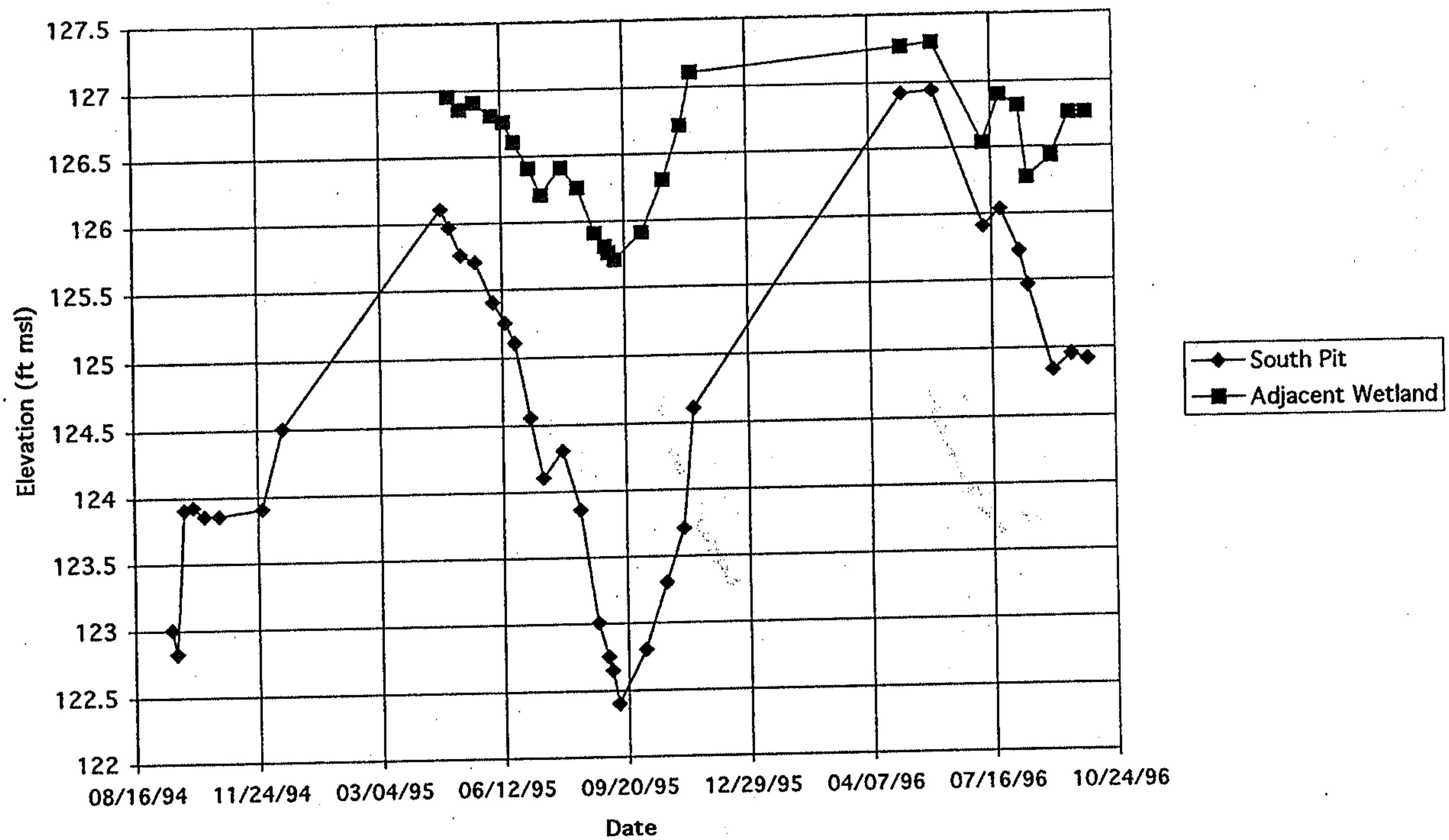

PROVIDED BY:
NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
NORMANDEAU ASSOCIATES, INC.
PINE ROAD WETLAND MITIGATION SITE
NH ROUTE 101/51
SCALE: 1" = APPROX. 120'
WETLAND HUMUS
UPLAND HUMUS
White areas within map denote thin layer of upland soil incorporated in existing soils.
120 SURFACE CONTOUR
125 STANDING WATER LEVEL AT TIME OF STUDY
SOIL DISTRIBUTION PLAN AT PINE ROAD SOUTH PIT SITE, NORTH END
N
LIMIT OF DISTURBANCE/ LIMIT OF CLEARING AND GRUBBING
122
120
122
MATCH LINE SOUTH END PLAN (STATION 1+00 TO STATION 10+00)

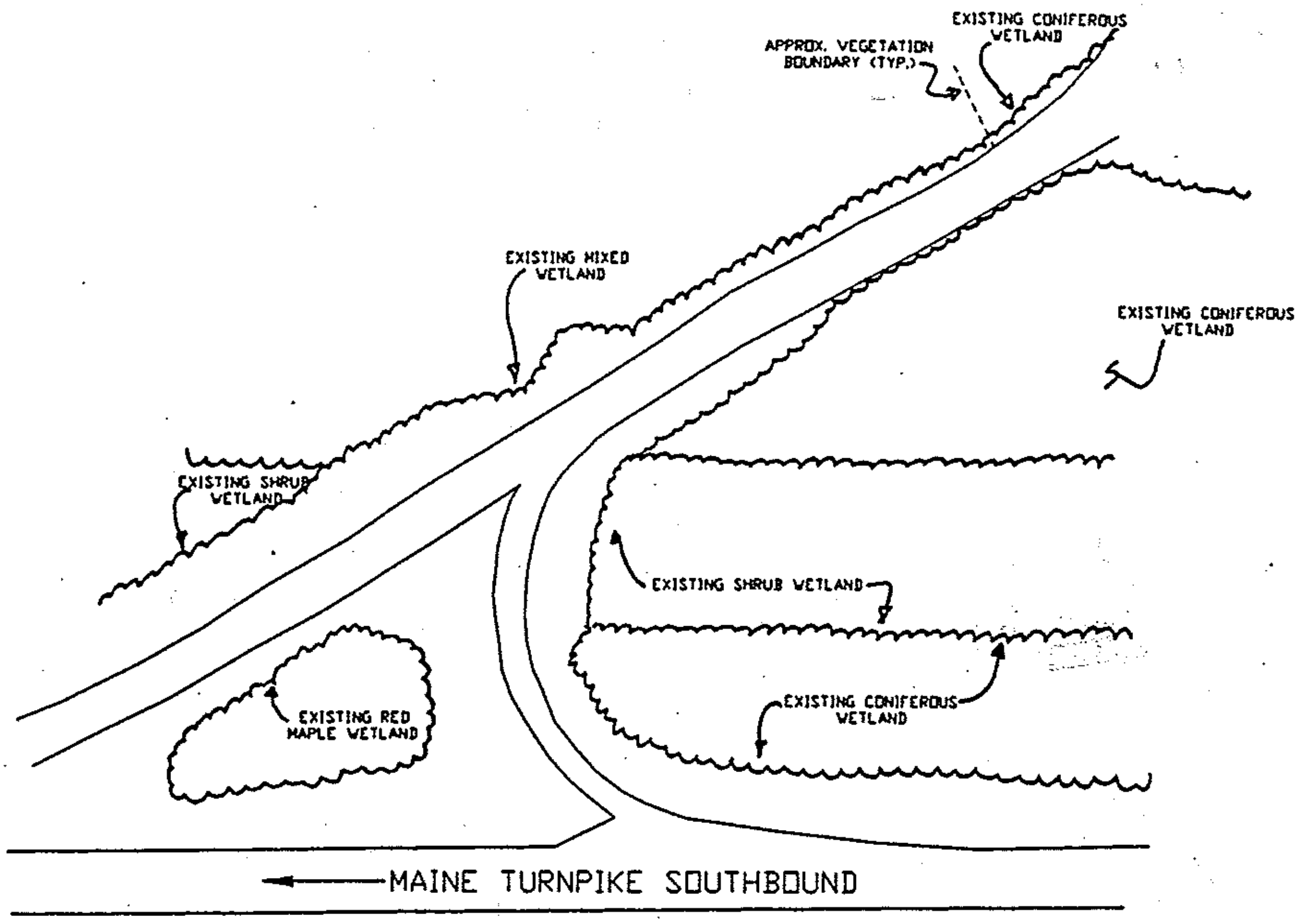
Figure 12.

Water Elevations at Pine Road Brentwood, NH



Ponded Water Level Fluctuations at Pine Road South Pit Site

Figure 13.

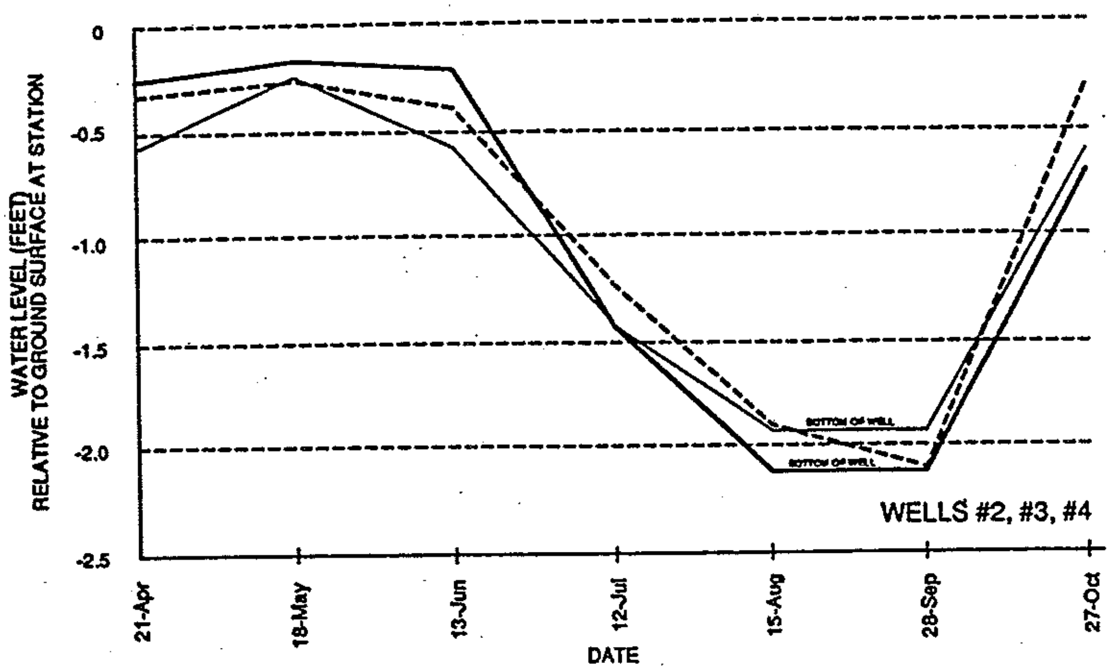


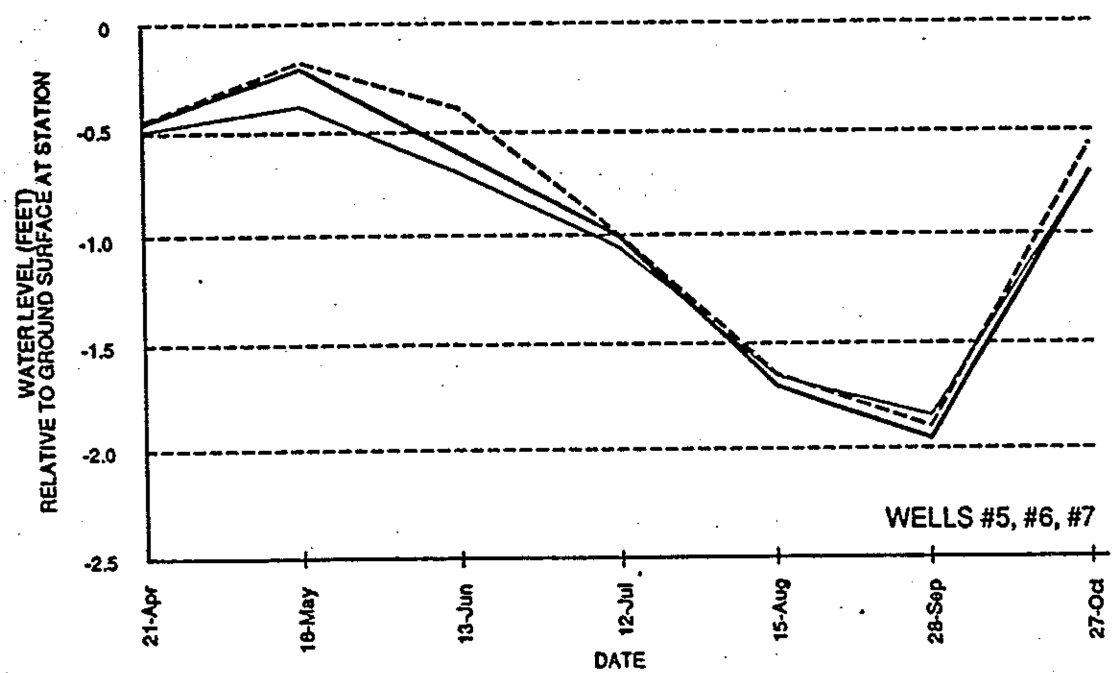
SITE MAP PRIOR TO CONSTRUCTION AT
MAINE TURNPIKE OLD EXIT 6

PROVIDED BY:
MAINE DEPARTMENT OF TRANSPORTATION
AUGUSTA, ME 04333
AND
NORMANDEAU ASSOCIATES, INC.
YARMOUTH, ME 04096

SCALE: 1" = APPROX. 100'

Figure 14.





Water Level Fluctuations at Maine Turnpike Old Exit 6

LEGEND

WELL #2 — WELL #5
WELL #3 — WELL #6
WELL #4 — WELL #7

Solid line = Well in adjacent wetlands
Dashed line = Well in restoration site

SOUTHBOUND RAMP WATER LEVELS (1995)	
MAINE DEPARTMENT OF TRANSPORTATION STATE HOUSE STATION 16 AUGUSTA, MAINE 04333	SOUTHBOUND RAMP SITE TOWN OF SCARBOROUGH CUMBERLAND COUNTY, MAINE APRIL 1996

Figure 15

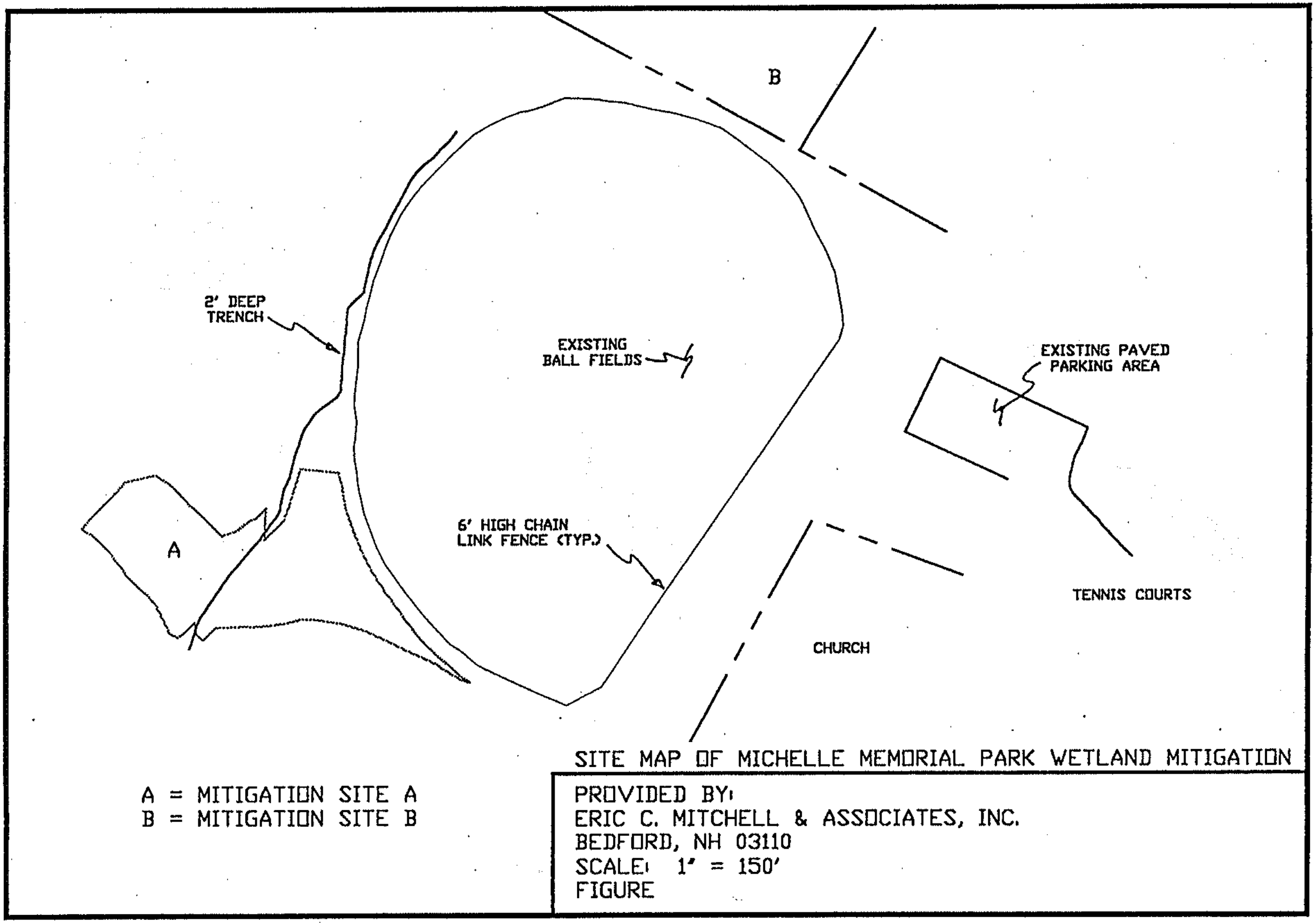
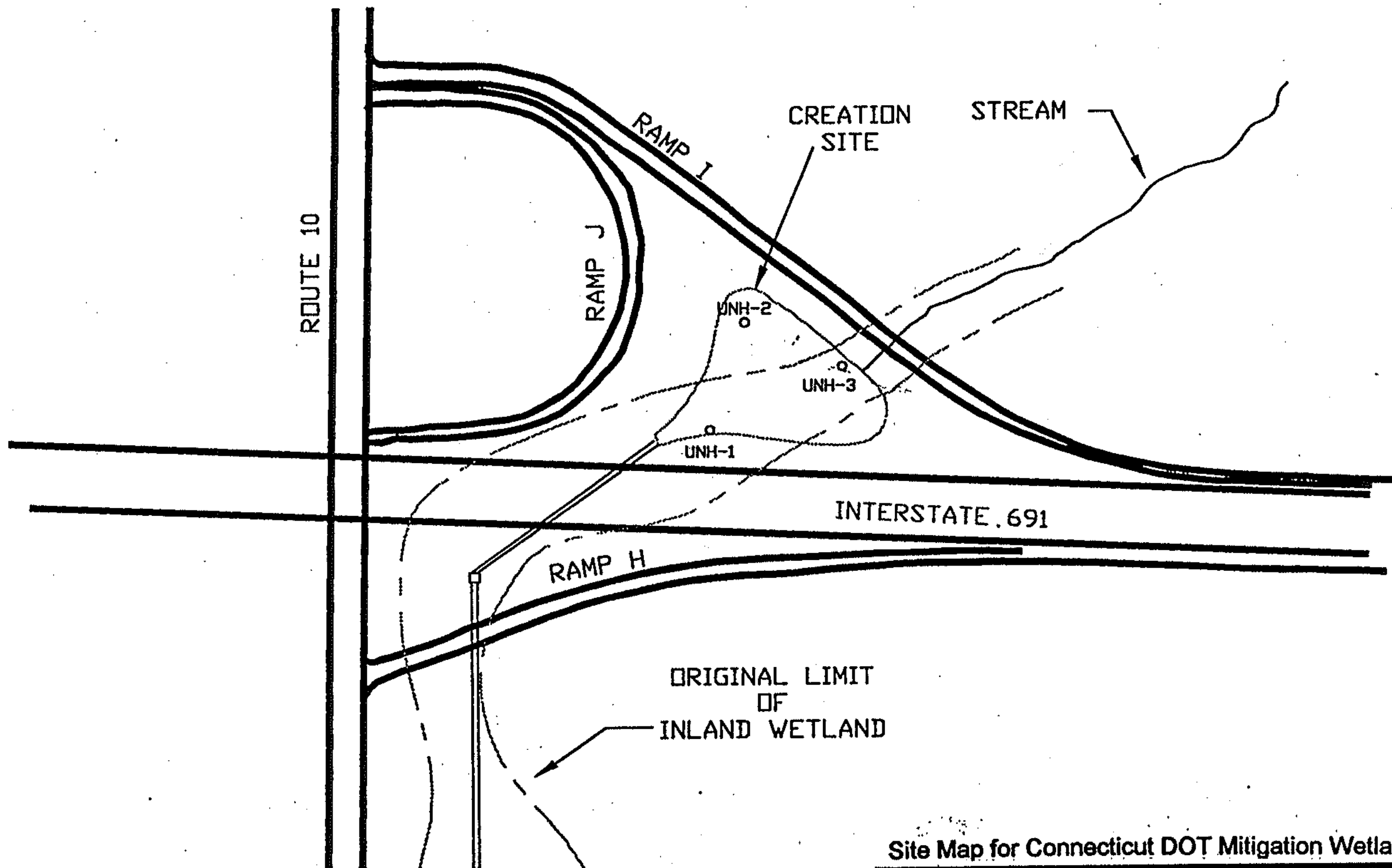

B
2' DEEP TRENCH
EXISTING BALL FIELDS
EXISTING PAVED PARKING AREA
A
6' HIGH CHAIN LINK FENCE (TYP.)
TENNIS COURTS
CHURCH
SITE MAP OF MICHELLE MEMORIAL PARK WETLAND MITIGATION
A = MITIGATION SITE A
B = MITIGATION SITE B
PROVIDED BY:
ERIC C. MITCHELL & ASSOCIATES, INC.
BEDFORD, NH 03110
SCALE: 1" = 150'
FIGURE

Figure 16.



GROUNDWATER CONTOUR

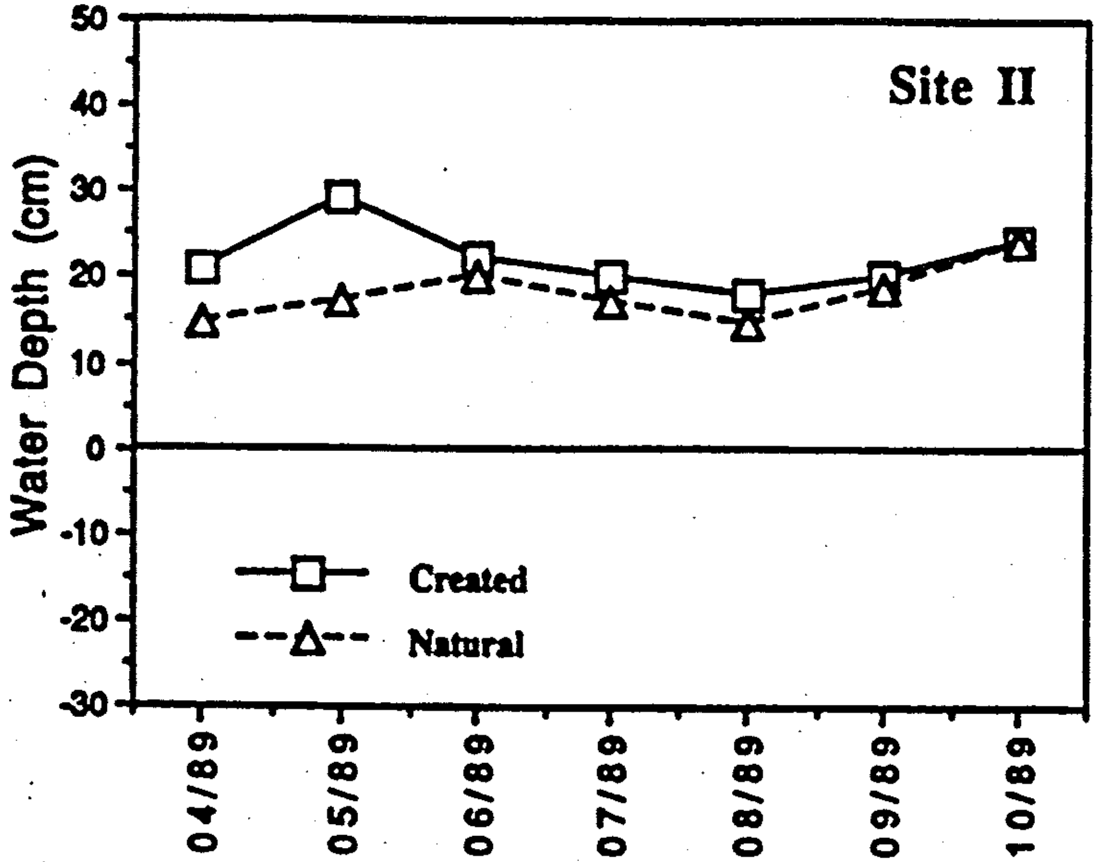
GROUNDWATER FLOW

GROUNDWATER MONITORING WELL

Site Map for Connecticut DOT Mitigation Wetland

PROVIDED BY:
STATE OF CONNECTICUT DEPARTMENT OF TRANSPORTATION

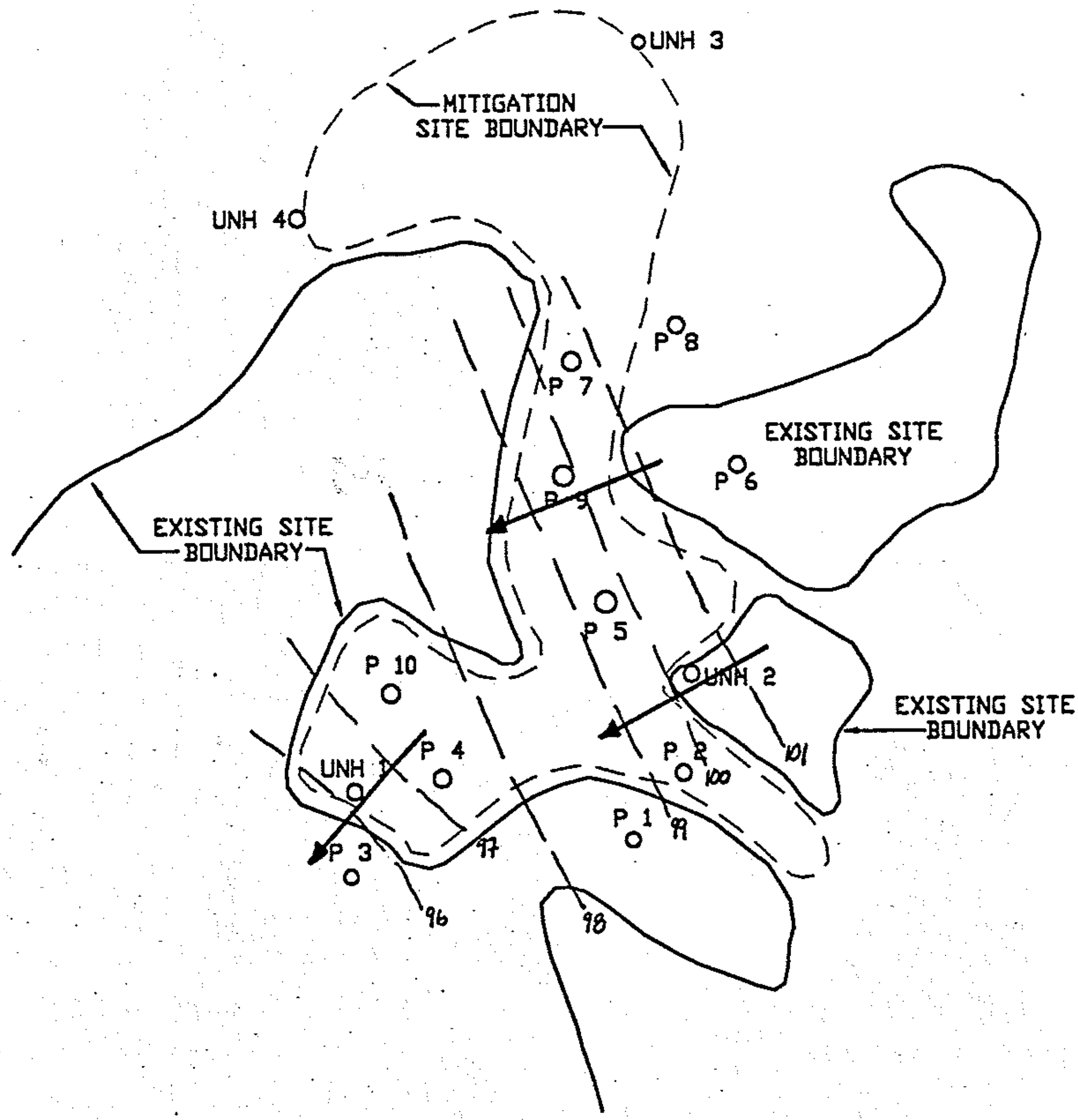
DRAWING NOT TO SCALE



Taken from Confer and Niering, 1992.

Water Level Fluctuations at Connecticut I-691 Site

Figure 18.



GROUNDWATER CONTOURS AT BANGOR HYDRO-ELECTRIC SITE

UNH-1
○ GROUNDWATER MONITORING WELL

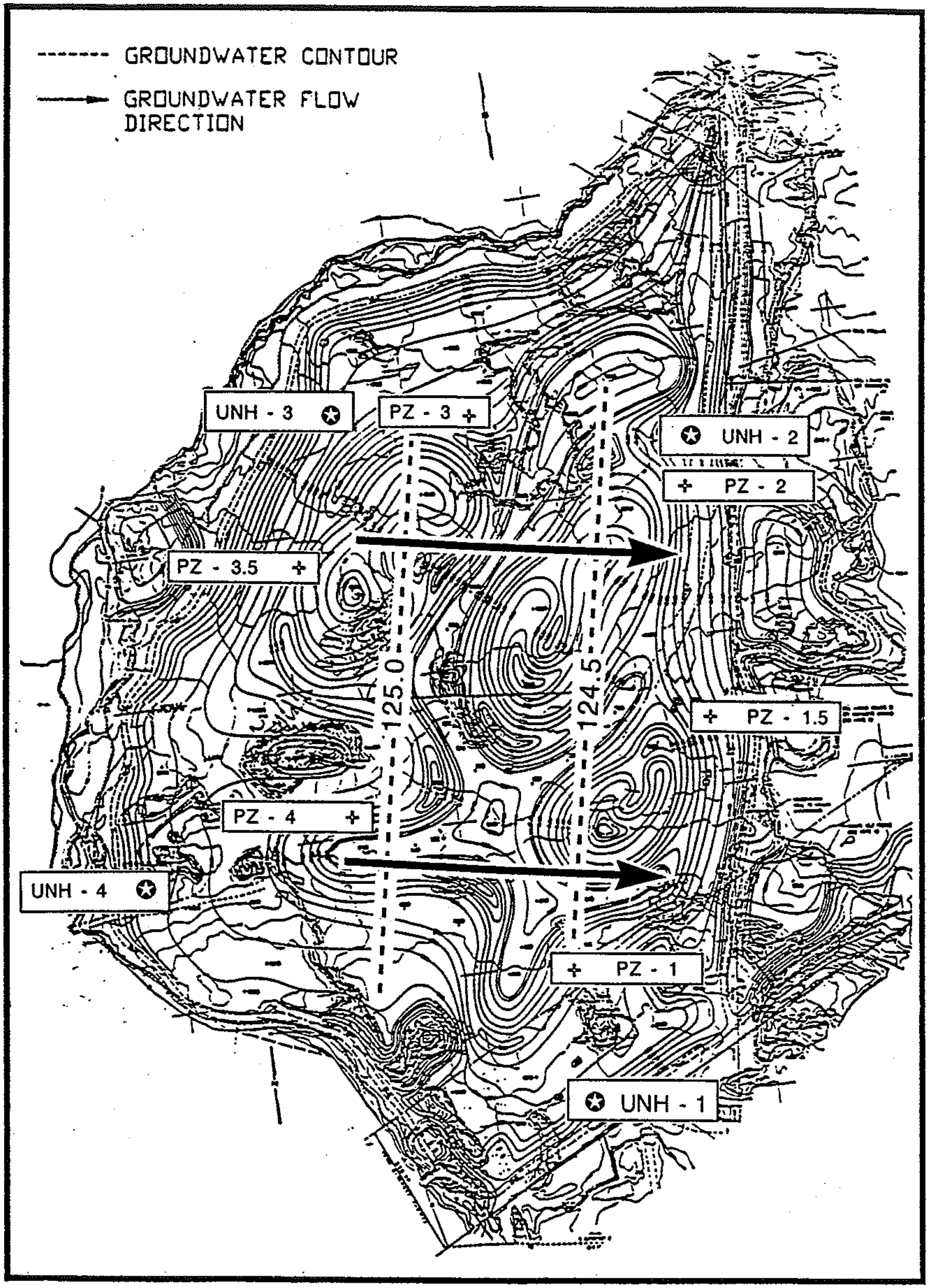
——▶ GROUNDWATER FLOW DIRECTION

------ GROUNDWATER CONTOUR

PROVIDED BY:
ND&T
NORTHROP, DEVINE, & TARBELL, INC.

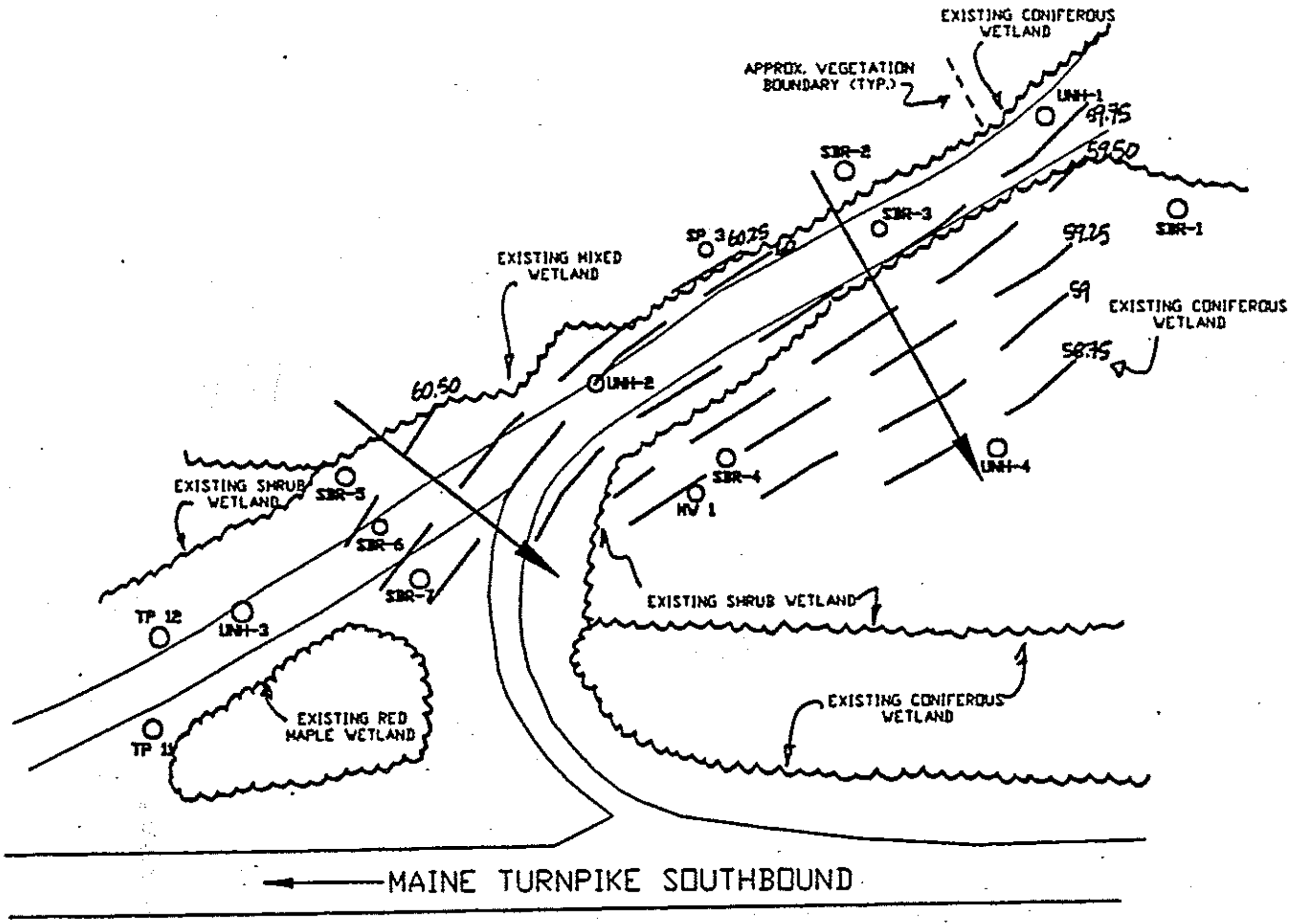
SCALE: 1" = APPROX. 60'

Figure 19.



Groundwater Contour Map at Pine Road South Pit Site

Figure 20.



GROUNDWATER CONTOUR MAP OF MAINE TURNPIKE OLD EXIT 6 SITE

PROVIDED BY:
MAINE DEPARTMENT OF TRANSPORTATION
AUGUSTA, ME 04333
AND
NORMANDEAU ASSOCIATES, INC.
YARMOUTH, ME 04096

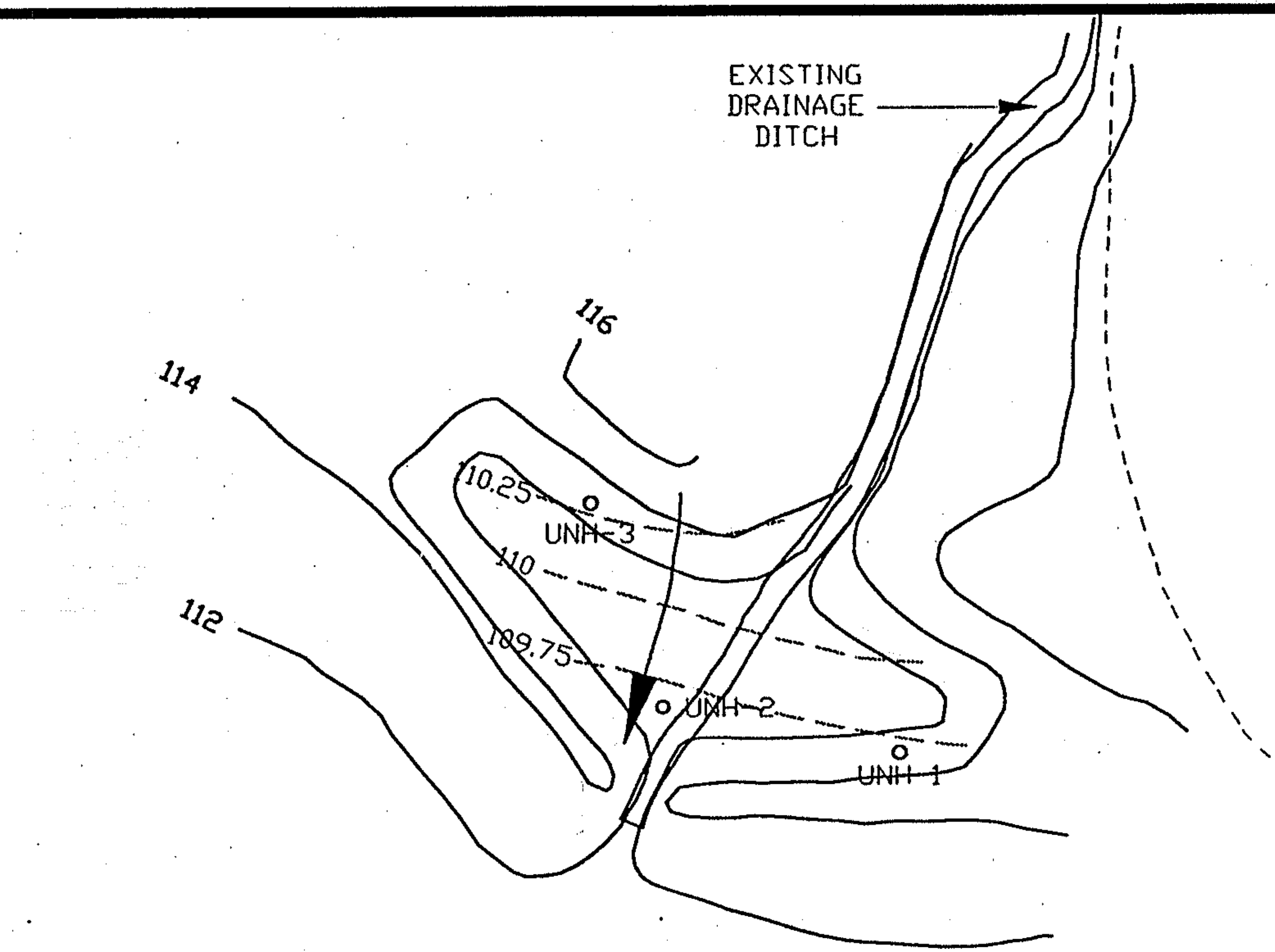
SCALE: 1" = APPROX. 100'

○ GROUNDWATER MONITORING WELL

------- GROUNDWATER CONTOUR

——► GROUNDWATER FLOW DIRECTION

Figure 21.



GROUNDWATER CONTOUR MAP OF THE MICHELLE MEMORIAL PARK SITE

- - - - - GROUNDWATER CONTOUR

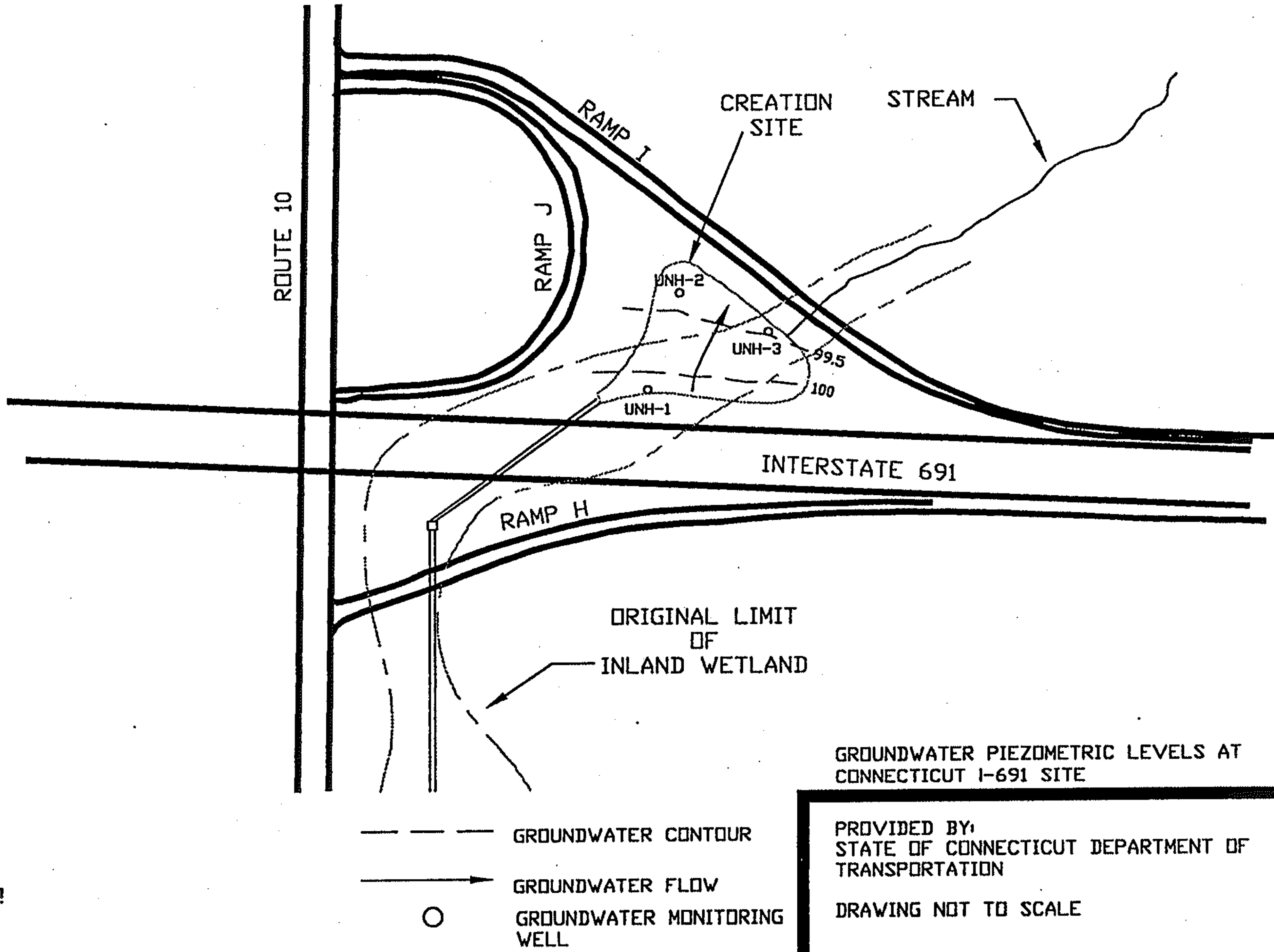
——→ GROUNDWATER FLOW DIRECTION

○ GROUNDWATER MONITORING WELL

PROVIDED BY:
ERIC C. MITCHELL & ASSOCIATES, INC.
BEDFORD, NH 03110

MICHELLE MEMORIAL PARK
SALEM, NH

Figure 22.



GROUNDWATER PIEZOMETRIC LEVELS AT CONNECTICUT I-691 SITE

PROVIDED BY:
STATE OF CONNECTICUT DEPARTMENT OF TRANSPORTATION

DRAWING NOT TO SCALE

Figure 23.