CTE / NCDOT
Joint Environmental Research Program

*Final Report*

# Determination of Lateral Effects of Borrow Pits on Hydrology of Adjacent Wetlands


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September 28, 2007

## Technical Report Documentation Page

| | | |
|---|---|---|
| 1. Report No. **FHWA/NC/2006-50** | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle **Determination of lateral effects of borrow pits on hydrology of adjacent wetlands** | | 5. Report Date **September 28, 2007** |
| | | 6. Performing Organization Code |
| 7. Author(s) **R.W. Skaggs, G.M. Chescheir, B.D. Phillips** | | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address **Department of Biological and Agricultural Engineering North Carolina State University Raleigh, NC 27695-7625** | | 10. Work Unit No. (TRAIS) |
| | | 11. Contract or Grant No. |
| 12. Sponsoring Agency Name and Address **U.S. Department of Transportation Research and Innovative Technology Administration 400 7th Street, SW Washington, DC 20590-0001** | | 13. Type of Report and Period Covered **Final Report September 2004 - August 2007** |
| | | 14. Sponsoring Agency Code **2005-24** |

15. Supplementary Notes:

This project was supported by a grant from the U.S. Department of Transportation and the North Carolina Department of Transportation, through the Center for Transportation and the Environment, NC State University.

16. Abstract

A three year research project was conducted to develop and test a method to predict the distance borrow pits should be set back from adjacent wetlands to avoid detrimental impacts on wetland hydrology. The method is based on the Boussinesq equation. Knowledge of soil hydraulic properties and the time, $T_{25}$, required for characteristic water table drawdown is necessary to calculate the setback. DRAINMOD simulations were conducted to determine the $T_{25}$ values for all 100 North Carolina counties. A survey of 27 borrow pits indicated seepage from the wetland to the pit in 42% of the pits, pit to the wetland in 31% and sometimes in one direction and vice versa in 27% of the pits. Eight borrow pits were instrumented to determine the response of the water level in the pit, and the water table in adjacent wetlands, to rainfall, evapotranspiration and seepage. The time required after closure for the water level in pits to rise to equilibrium varied from 10 to 23 months with an average of 17 months. The equilibrium water level is a critical factor affecting the impact of the pit on hydrology of adjacent wetlands. This depth depends primarily on the elevation of surface water outlets, the depths of adjacent drainage ditches or other subsurface drainage sinks in close proximity to the pit, and the natural depth of the water table prior to the construction of the pit. Equilibrium water levels in 5 of the 8 instrumented pits were lower than the surface of adjacent wetlands, with seepage from the wetland to the pit. The average water levels in the 5 pits ranged from 1.0 to 4.1 ft. below the surface of adjacent wetlands. Water level elevations in the other 3 pits were equal to or above the elevation of adjacent wetlands. The method developed herein was used to predict setback requirements for the 5 instrumented borrow pits having seepage from wetlands to the pit. Results were compared to the potential lateral impacts determined from measured water table data. The setback distances predicted using the measured pit water levels were about 60% greater than the measured impacts on average. The method is based on conservative assumptions so the overestimation was not unexpected. Use of a constant 2 ft. depth of water in the pit predicted setback requirements within 16% of measured potential impacts for 3 of the 5 cases; the setback was overestimated by more than a factor of 2 for the other two pits. However, the projected lateral impacts were less than 50 ft. in both cases. It was concluded that the proposed method will provide conservative but reasonable estimates of the setback necessary to avoid impacts on the hydrology of wetlands adjacent to borrow pits.

| | | | |
|---|---|---|---|
| 17. Key Words DRAINMOD, Lateral effect, Wetland drainage, Water table, Wetlands, Drainage, Hydric soils | | 18. Distribution Statement …… | |
| 19. Security Classif. (of this report) Unclassified | 20. Security Classif. (of this page) Unclassified | 21. No. of Pages 85 | 22. Price …… |

**Form DOT F 1700.7** (8-72) **Reproduction of completed page authorized**

## ACKNOWLEDGEMENTS

The work reported herein is a product of the North Carolina Agricultural Research Service, N.C. State University, Raleigh. Support was provided by the Center for Transportation and the Environment in cooperation with the U.S. Department of Transportation and North Carolina Department of Transportation through the Institute for Transportation Research and Education, North Carolina State University.

## DISCLAIMER



## EXECUTIVE SUMMARY

A three year research project was conducted to develop and test a method to predict the distance borrow pits should be set back from adjacent wetlands to avoid detrimental impacts on wetland hydrology. Because of the relatively flat topography, borrow pits in eastern North Carolina are often constructed close to wetlands. There is concern that the pits will create a drainage sink that will promote seepage from adjacent wetlands with detrimental effects on their hydrology. A method, originally developed to predict the lateral effect of drainage ditches on wetland hydrology, was modified to determine the potential effect of borrow pits. The method is based on solutions to the nonlinear Boussinesq equation. Knowledge of soil properties (hydraulic conductivity and drainable porosity) and the time, $T_{25}$, required for a characteristic water table drawdown is necessary to calculate the setback needed to avoid detrimental impacts to the wetland. $T_{25}$ values depend on location and on depressional surface storage. Multiple DRAINMOD simulations were conducted to determine the $T_{25}$ values for all 100 North Carolina counties. Values were determined for surface storages of 1.0 and 2.0 inches and are tabulated in this report.

A survey was conducted on 27 borrow pits to characterize the pits in terms of factors affecting their impact on nearby wetlands. Results indicated that borrow pits could be classified by three types according to direction of seepage with respect to nearby wetlands, and factors controlling the water level elevation in the pit. Type 1 borrow pits have surface water elevations that are lower than the surface of adjacent wetlands; the prevailing direction of seepage is from the wetland toward the pit. Type 2 pits have water surface elevations that are higher than the water in adjacent wetlands with the prevailing seepage direction from the pit to the wetland. Type 3 borrow pits are flow through pits with seepage from the wetland to the pit on one side and from the pit to wetlands on the other side. Seepage was from the wetland to the pit in 42% of the pits surveyed, from the pit to the wetland in 31% of the pits. In the remaining 27% of the pits, the direction of seepage was either unclear, or from the wetland to the pit during

some periods and in the opposite direction during other periods. Potential detrimental effects of borrow pits are mostly confined to pit Type 1 and to the wetlands on the side where seepage is into Type 3 pits. Impacts of pits in which seepage is from the pit to the wetland tend to make the wetlands wetter during some periods. These impacts are difficult to assess, and are considered minimal in most cases.

Eight borrow pits were instrumented to determine the response of the water level in the pit, and the water table in adjacent wetlands, to rainfall, evapotranspiration and seepage. Water level and water table measurements were recorded continuously for a period of 2 to 2.5 years for 7 of the pits and for 1.5 years in the 8$^{th}$ pit. Four of the pits were instrumented prior to closing for the purpose of determining the time required for the pits to fill after the mining of borrow materials ceases and the pits are closed. Water level data from all 8 pits were analyzed to determine the equilibrium water surface elevation, the factors that control that level, and its relationship to water table elevations in adjacent wetlands.

The time required for the water level in pits to rise to equilibrium varied from 10 to 23 months with an average of 17 months. While time to equilibrium is expected to vary depending on spatial and temporal rainfall patterns, the observed times are considered typical for eastern North Carolina.

A critical factor affecting the potential impact of borrow pits on adjacent wetlands, and in predicting those impacts using the methods developed in this study, is the water level elevation in the pit. Analysis of data collected from the survey of 27 borrow pits, with particular attention to the 8 instrumented pits of this study, indicated that the equilibrium water level in the pit depends primarily on the elevation of surface water outlets and the depths of adjacent drainage ditches or other subsurface drainage sinks in close proximity to the pit. On average, annual precipitation exceeds potential evapotranspiration in eastern North Carolina by 10 to 17 inches, depending on location. This means that, in the absence of seepage into or out of the pit, the pit water level will rise until it either spills over the top of the pit or reaches the elevation of a weir, pipe, spillway or other structure that serves as a surface water outlet. In some cases, the water level in the pit is controlled by seepage to nearby drainage ditches or streams. In those cases the equilibrium water level in the pit may be close to the elevation of the bottom of the ditch, depending on its location. In other cases the water level in the pit may be controlled by seepage down slope where it ultimately enters a stream or a wetland. In those cases the water level in the pit will likely approach the water table elevation that existed at the site prior to the construction of the pit. Equilibrium water levels in 5 of the 8 instrumented pits were lower than the surface of adjacent wetlands with seepage from the wetland to the pit. The average water levels in those 5 pits ranged from 1.0 to 4.1 ft. below the surface of adjacent wetlands. Water level elevations in 2 of the other 3 pits were above the elevation of adjacent wetlands and seepage was from the pit to the wetland. There was no discernable surface or subsurface outlet for the 8$^{th}$ pit, which had seepage into the pit during wet periods and out of the pit to adjacent wetlands during dry periods.

Water table data from the 5 instrumented sites having seepage from the wetland to the borrow pit were analyzed to determine the potential lateral impact of the pit on wetland hydrology. The maximum duration that the water table remained above the 1 ft. depth for each of the observation wells was compared to the time predicted for a threshold wetland. Since the water table was monitored at only two locations for most sites, this "measured" lateral impact was determined by interpolation. In most cases the potential lateral impact was less than the distance to the first observation well. The potential lateral impacts determined from measured data were used to test the reliability of the method developed to predict the setback requirements for borrow pits.

The method developed herein was used to predict setback requirements for the 5 instrumented borrow pits for which seepage was from adjacent wetlands to the pit. Results were compared to the potential lateral impacts determined from measured water table data. Predictions were made for three different values for the depth of the water level in the pit below the surface of the adjacent wetland: (1) the average measured depth; (2) a depth of 2 ft. (the depth that has been recommended for use in the application of the method on an interim basis subject to the completion of this research), and (3) a constant depth of 1.0 ft. The setback distances predicted using the measured pit water levels were about 60% greater than the measured impacts for all pits. The method is based on conservative assumptions so the overestimation was not unexpected. Use of a constant water level depth of 1 ft. below the surface of the wetland resulted in substantially underestimating the potential impact for 3 of the 5 pits. Use of a constant 2 ft. depth predicted setback requirements within 16% of measured potential impacts for 3 of the 5 cases while overestimating the requirements by more than a factor of 2 for the other two pits. The overestimations occurred for pits where the measured potential impacts were less than 50 ft.

An input to the proposed method that is sometimes difficult to determine is the drainable porosity. Predicted results based on a constant drainable porosity of $f = 0.035$ were compared with measured potential lateral impacts. On average, the results were in good agreement with measured lateral impacts and with results predicted with the measured drainable porosity values.

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# INTRODUCTION

The construction of highways often requires soil to fill low areas and to build overpasses and ramps. When the required fill is unavailable from cuts made during construction, it is usually obtained from borrow pits located in the vicinity of the highway. Due to the relatively low elevations and flat topography, borrow pits in eastern North Carolina are often near or adjacent to wetlands. There is concern that the borrow pit may serve as a long-term drainage sink and that after closure of the pit, the hydrology of wetlands close to the pit will be affected.

The water level in a borrow pit may be relatively deep during the time that it is open and soil is being actively mined. In order to keep the pit dry and suitable for mining, ground water is typically pumped from a rim ditch constructed at an elevation somewhat lower than the bottom of the pit. Pit depths range from about 10 feet to over 25 feet with depths in excess of 20 feet relatively common in eastern North Carolina. Seepage from adjacent or neighboring wetlands to the pit will be at a maximum during the mining period when water is being pumped from the rim ditch. However, the effect on wetland hydrology is mitigated by two factors. 1. Water pumped from the pit is nearly always released back into the wetlands; and 2. The pit is only open and actively pumped for a limited period of time. Once mining operations are complete, pumping ceases and the water level in the pit rises to an equilibrium level. A schematic diagram of a pit, an adjacent wetland, and relative water levels and water table elevations is shown in Figure 1. The rise of the water level in the pit to an equilibrium elevation, d, reduces the hydraulic gradient (compared to its value when the water in the pit is being pumped during mining) and the effect of the pit on wetlands in the vicinity. The equilibrium water level is defined as the long-term average water level in the pit after pumping ceases.

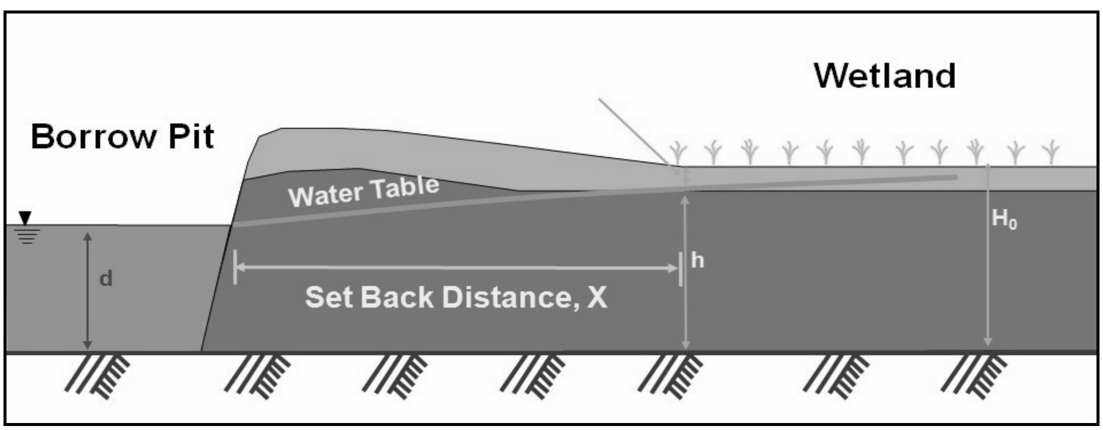


**Figure 1. Schematic of Borrow pit in relation to nearby wetlands.**

It is recognized that the actual pit water level will rise and fall in response to rainfall, ET, and seepage, but these fluctuations will be small in most cases, and the water level is expected to remain relatively constant after if rises in the pit following closure. Both the equilibrium water level and the time required after closure for the water in the pit to rise to the equilibrium level are important variables. If the time is relatively short (months), impacts during the active mining phase when the water level in the pit is deep, may be considered temporary and lateral effects can be calculated based on the equilibrium water level. If the time required for the water level to rise to equilibrium is long (several years) impacts of deeper water levels in the pit on seepage and the hydrology of adjacent wetlands would have to be considered. Thus, the effect of borrow pits on the hydrology of adjacent wetlands is dependent on several factors. What is the equilibrium water level in the pit after mining is complete, pumping ceases and the pit is "closed"? How long is required for the water level in the pit to reach "equilibrium" status? What is the lateral distance from the pit that water tables and wetland hydrology will be affected? How does this distance depend on soil properties, depth of the pit, weather, and other topographic and site dependent factors? This study was designed to answer these and related questions.

## BACKGROUND

An approximate method was developed in a previous North Carolina Department of Transportation (NCDOT) sponsored research project to estimate the lateral effect of a roadside drainage ditch on adjacent wetland hydrology (Skaggs et al., 2005; Phillips, 2006; Phillips et al., 2006). It seems reasonable to apply these same methods to predict the lateral effects of borrow pits. In this case we would use the method to determine the distance the borrow pit should be set back from the wetland such that the hydrology at the edge of the wetland would not be significantly modified by the presence of the pit. In this study it was assumed that conditions at the edge of the wetland would, in the absence of the pit, satisfy minimum requirements for wetland hydrology as specified in the U.S. Army Corps of Engineers 1987 wetland delineation manual (USACOE, 1987). Even wetter conditions might exist in the interior of the wetland. But at the edge of the wetland, it is reasonable to assume that minimal conditions for wetland hydrology are satisfied. It follows that a setback distance equal to the lateral effect of the pit on wetlands that are immediately adjacent would insure that the pit would have negligible effect on the wetland. That is, the edge of the wetland would satisfy minimum hydrologic requirements for wetlands before the pit is constructed. And by setting the pit back from the wetland by a distance equal to the potential lateral effect, minimal conditions for wetland hydrology would still exist at the edge of the wetland after the pit is constructed. This study was conducted to modify the methods developed for drainage ditches for application to borrow pits, to determine factors necessary to apply the methods throughout North Carolina, and to test the reliability of the methods for conditions in the NC coastal plains.

A key input to the method developed for determining the effect of a drainage sink (ditch or borrow pit) on wetland hydrology is the $T_{25}$ value. The value represents the time required for the water table to be drawn down by drainage from the surface to a depth of 10 inches (25 cm) at the location on the landscape that represents the divide between upland and wetland conditions (i.e., at the edge of wetland). The following provides a summary of the development of the $T_{25}$ value and a further clarification of the concept. More details can be found in the final report of NCDOT project HWY – 0751.

Wetland hydrology exists on a site if the wetland hydrologic criterion is satisfied during the growing season. The hydrology criterion specifies that the water table be within one foot of the soil surface for a consecutive time period of at least five percent of the growing season in at least one-half of the years (e.g. 20 out of 40 years). For example, if the growing season is 240 days, the criterion is satisfied if the water table remains within one foot of the soil surface for at least 12 consecutive days during the growing season in at least 50% of the years. Water table fluctuations due to rainfall, drainage, and a number of other factors can be predicted on a continuous basis with the DRAINMOD model (Skaggs, 1978, 1999). The model was developed to describe the performance of agricultural drainage systems, and can be used to predict the day-to-day water table depths in wetlands for a long period of climatological record.

Long-term DRAINMOD simulations were conducted to determine the drain spacing that would just barely satisfy the wetland hydrologic criterion for drain depths of 1, 2, 3, 4, 5, and 6 feet. This threshold drain spacing (Skaggs et al. 1994; Hunt et al., 2001) was determined for each drain depth for each of the following five North Carolina hydric soils: Arapahoe (Coarse-loamy, mixed, nonacid, thermic Typic Humaquepts), Coxville (Clayey, kaolinitic, thermic Typic Paleaquults), Portsmouth (Fine-loamy, mixed, thermic Typic Umbraquults), Rains (Fine-loamy siliceous, thermic Typic Paleaquults), and Wasda (Fine-loamy, mixed, acid, thermic Typic Humaquepts). These five soils represent a wide range of hydraulic conductivities and drainage response times. Table 1 summarizes the threshold drain spacing for 50-year (1951- 2000) simulations conducted at Wilmington, North Carolina for surface depressional storage conditions of 1 inch (2.5 cm).

**Table 1. Threshold ditch spacings, Lt, (in m and ft) as a function of soil and ditch depth for a surface depressional storage of 2.5 cm (1 inch) at Wilmington, NC. The determinations are based on DRAINMOD simulations for a 50-year period of climatological record (1951-2000).**

| | Ditch Depth | | |
|---|---|---|---|
| **Soil** | **60 cm** | **90 cm** | **120 cm** |
| **Arapahoe loamy sand** | **153 m** | **198** | **226** |
| **Coxville sandy loam** | **35** | **43** | **48** |
| **Portsmouth sandy loam** | **85** | **105** | **121** |
| **Rains sandy loam** | **36** | **46** | **51** |
| **Wasda muck** | **38** | **50** | **57** |

Results from Table 1 represent threshold drain spacings such that the land midway between the two parallel drains would just barely satisfy the wetland hydrologic criterion. How can this information be used to predict the lateral effect of a single ditch or a borrow pit? One method would be to assume the lateral effect would be one-half of the threshold spacing. This would result in an over prediction of the lateral effect, albeit a conservative prediction. Drainage theory indicates that the drawdown due to a single drain is less than that of two parallel drains. This is shown graphically in Figure 2 where $L_t$ represents the threshold drain spacing.

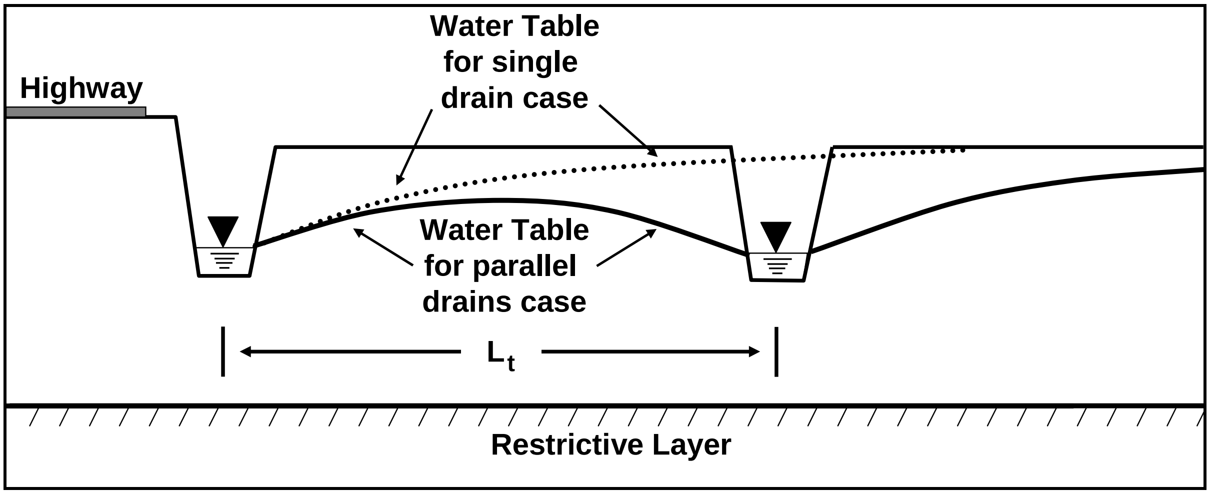


**Figure 2. Schematic of parallel ditches showing the effect of a second ditch on the water table depth.**

Consider the case in Figure 2 when the ditch on the right side is not present and drainage is due solely to the single ditch adjacent to the highway. The water table will be represented by the broken curve in Figure 2. In the absence of the second ditch, drainage is reduced, resulting in a shallower water table profile (broken curve for water table in Figure 2), all other parameters being equal, and the lateral effect due to the single ditch would be less than the $L_t/2$.

The question still remains as to how the lateral effect of a single ditch can be predicted. A means of calculating this effect was developed based on the time required for water table drawdown midway between parallel ditches. A method developed by Bouwer and van Schilfgaarde (1963) and modified by Skaggs (2005) uses the Hooghoudt equation to calculate drainage rates and a water balance to determine the time required for incremental water table drawdown midway between drains. That is, the times required for the water table to be drawn down from a depth of 0 to 10 cm, 10 to 20 cm, etc. were calculated based on the drain spacing and depth, and soil parameters. Results for Wilmington, North Carolina are plotted in Figure 3 for a ditch depth of 120 cm (4 ft) and surface storage conditions of 1 inch (2.5 cm) for the threshold drain spacings of the five soils listed in Table 1. Predicted water table drawdown is plotted as a function of time for all five soils in Figure 3.

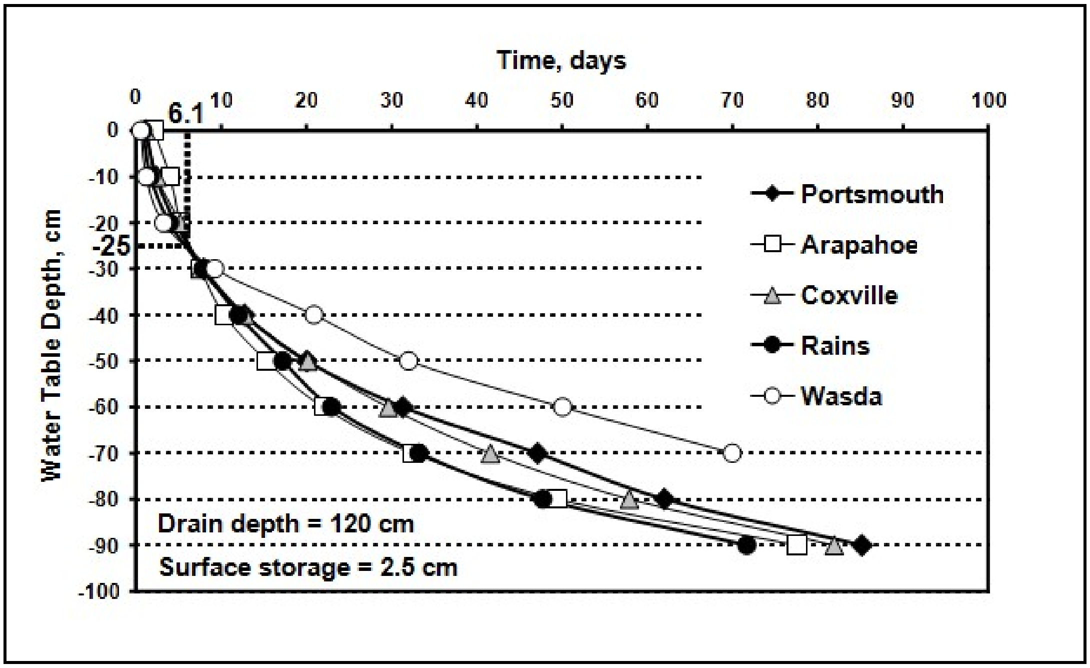


**Figure 3. Predicted midpoint water table drawdown for threshold ditch spacings of 5 North Carolina soils. Results are for a ditch depth of 120 cm and surface storage of S = 2.5 cm. Time for water table drawdown of 25 cm ($T_{25}$) is approximately 6.1 days for all soils.**

Note that the water table recession curves for the threshold ditch spacings for all five soils are similar, especially when the water table is in the upper part of the profile, and that they intersect at a water table depth of about 25 cm. That is, the ditch spacings that would result in midpoint conditions that satisfy the wetland hydrologic criterion in 25 of 50 years, would, if the water table were initially coincident with the surface, provide a midpoint drawdown of 25 cm in 6.1 days. This is the drawdown that would occur in the absence of ET and rainfall (i.e., due to drainage alone). Results for the 60 cm and 90 cm drain depths listed in Table 1 showed similar coincidental drawdown intersection points at a depth of 25 cm (5.2 days at a depth of 60 cm and 5.7 days at a depth of 90 cm). Similar results were also obtained using threshold drain spacings predicted for other North Carolina counties.

Therefore, for a given location, drain depth and surface depressional storage, sites that marginally satisfy the wetland hydrologic criterion have a nearly unique water table drawdown rate. This threshold drawdown rate can be characterized by the time, $T_{25}$, required for water table drawdown from the soil surface to a depth of 25 cm. That is, $T_{25}$ is defined as the time required for the water table, in a site that marginally satisfies the wetland hydrologic criterion, to be drawn down, by drainage alone, from the surface to a depth of 25 cm. Based on an analysis of five soils having a wide range of properties, $T_{25}$ depends on location (because of differences in weather) and surface depressional storage, but not soil type. The fact that the rate of water table drawdown in the field is dependent on both drainage and ET has been well understood for a long time (e.g., Skaggs, 1975). The effect of ET is considered in DRAINMOD and is reflected in the threshold ditch spacings, $L_t$, (Table 1), and, consequently, in the $T_{25}$ values. The $T_{25}$ values characterize threshold drawdown rates that would occur in the absence of ET for a site barely satisfying the wetland hydrologic criterion.

Methods published several years ago by Skaggs (1976), and more recently by Cooke et al. (2001), can be used to predict the effect of a single drainage ditch on water table drawdown in a semi-infinite medium (inset, Figure 4). The water table elevations, h, at any time, t, and distance from the ditch, x, were obtained from numerical solutions to the Boussinesq equation, and are plotted in nondimensional form in Figure 5. In addition to $h_0$, x and t, the solution depends on the vertical distance from the water level in the ditch to the restrictive layer, d, the effective lateral hydraulic conductivity, $K_e$, and the drainable porosity, f. Solutions plotted in Figure 4 can be used directly to determine the distance from the ditch, x, where water table drawdown will be 25 cm in time t = $T_{25}$. From results presented in Figures 3 we know that a site having these drainage characteristics will marginally satisfy the wetland hydrologic criteria. Thus the x value calculated in this way may be used to represent the lateral effect of a single ditch, or a borrow pit, on wetland status.

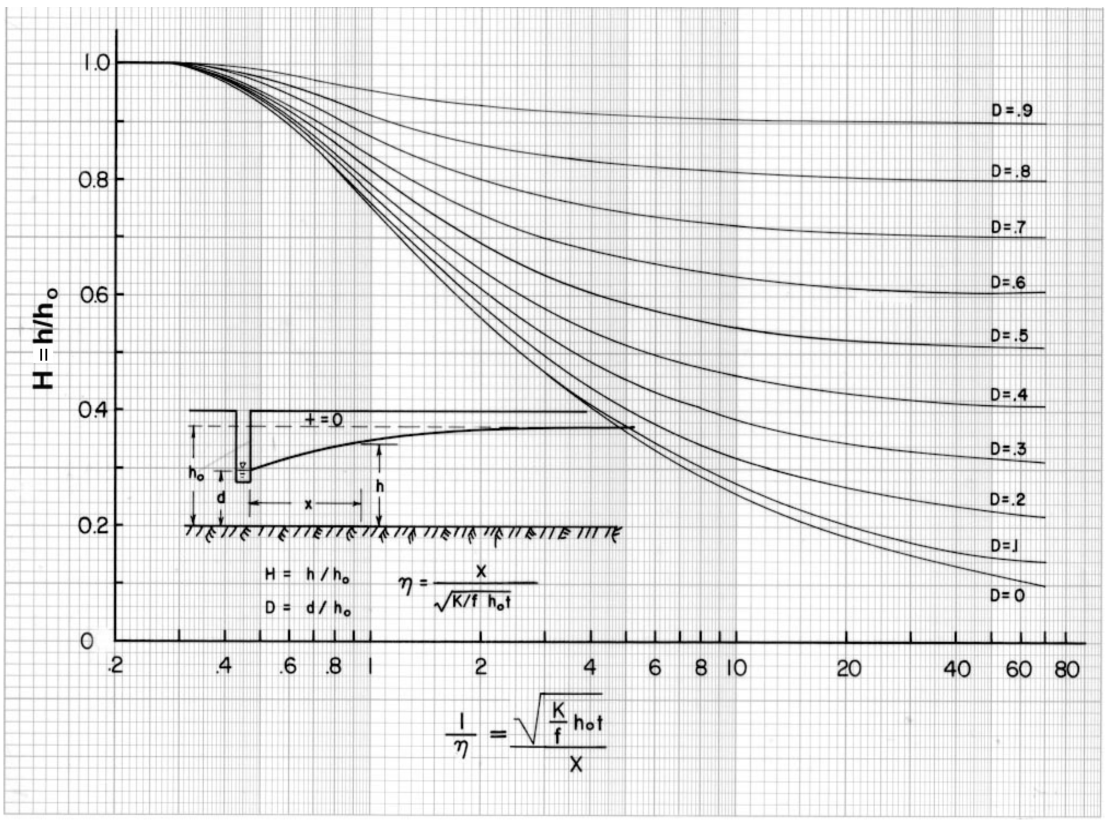


**Figure 4. Nondimensional solutions to the Boussinesq equation for water table drawdown due to drainage to a single ditch (after Skaggs, 1976).**

It is important to note that the lateral effect of a drainage ditch or other drainage sink on wetland hydrology depends very much on its definition. We have chosen to define the "lateral effect" as being the width of that strip of land adjacent to the ditch that has had its hydrology modified such that it no longer satisfies wetland hydrologic criteria. Since the edge of the wetland, under natural conditions, should satisfy the minimum requirements for wetland hydrology, a setback equal to the lateral effect as defined above will insure a negligible effect of the pit on the wetland

Location affects two factors important to wetland hydrology. First, it affects the numerical values in the criterion. The beginning and ending dates of the growing season vary from county to county, so both the window of time, and the duration (5% of the growing season) over which the water table must satisfy the criterion are affected by location. Second, rainfall and ET vary with location, so it is logical that a threshold drainage intensity sufficient to prevent the wetland criterion from being satisfied at one location would not necessarily prevent the criterion from being satisfied at another location where precipitation is greater or ET is lower.

Surface storage is an important factor affecting wetland hydrology. It is defined for this analysis as the average depth of water that can be stored in depressions on the site before runoff will occur. The capacity to store water on the surface depends on surface roughness and the average depth and distribution of surface depressions. Other factors remaining equal, the wetness of a site increases with increasing surface storage. Heavy rainfall the depressions will be full and water will remain ponded on the surface. It follows that $T_{25}$ values decrease with increased surface depressional storage.

## EXAMPLE APPLICATION

An example application of the approximate method for determining a setback requirement for a borrow pit is presented below. A pit located in New Hanover County, North Carolina is to be excavated in a Goldsboro soil adjacent to a wetland. The depth of the pit will be 20 ft with the bottom 22 ft below the surface of the wetland (Figure 5). The effective lateral hydraulic conductivity, K, of the soil is 2in/hr, the drainable porosity, f, is 0.035, and the average surface storage depth in the wetland is 2 in. It is assumed that sandy soil in the borrow pit will be excavated down to a clayey impermeable layer. After closure, the water level in the pit is assumed to be 2 ft below the surface of the wetland.

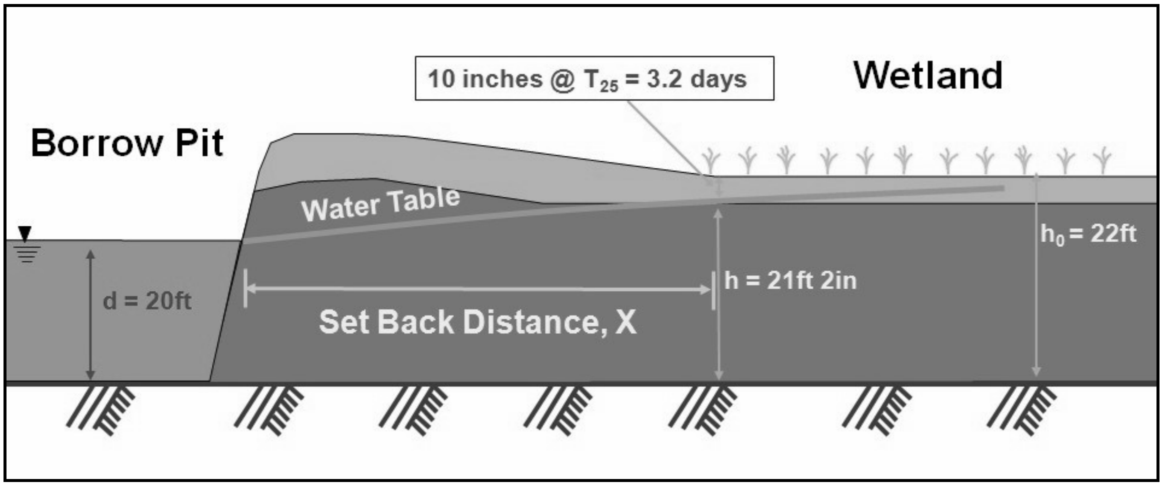


**Figure 5. Schematic of borrow pit showing the required set back distance of the pit.**

Two values are required to determine the Boussinesq parameter. Those values are $H = h/h_o$, where h is the water table elevation above the impermeable layer in the wetland at the $T_{25}$ time (i.e. the value of h representing a water table depth of 10 in. $h=h_o$-10), $h_o$ is the depth to the impermeable layer in the wetland, and $D = d/h_o$, where d is the elevation of the water level in the pit above the impermeable layer.
For this example h = 21.2 ft., ho = 22 ft. and d=20, so

$$H = \frac{21\,ft\;\;2in}{22\,ft} = 0.96 \qquad\qquad D = \frac{20}{22} = 0.91$$

From the nondimensional solution plot, Figure 4, with these values of H and D, the value for the Boussinesq parameter, 1/ ή, is approximately **0.96**.
As shown in Table 4, the $T_{25}$ value, for a pit located in Beaufort County with surface storage 2 in and a depth of the water in the pit 2 ft below the surface of the wetland, is $T_{25}$ = 3.7 days.

The lateral effect, x, is then solved as,

$$x = \frac{\sqrt{[\frac{K}{f}] * h_o * \mathrm{T}_{25}}}{\frac{1}{\eta}}$$

Substituting in the given soil properties, the lateral effect is calculated as follows.

$$x = \frac{\sqrt{[(4\,ft/day)/0.035] * 22\,ft * 3.2 days}}{0.96} = \mathbf{93\ ft}$$

The required setback for the example pit is 93 ft from the wetland.

There are differences and additional unknowns that must be resolved before the methods developed for highway drainage ditches can be used for determining the lateral impacts of borrow pits. One of the main differences concerns the water level in the borrow pit relative to the water table elevation in the wetland. After the borrow material has been removed and the pit is "closed", the elevation of the water level in the pit will control the hydraulic gradient and determine whether the pit serves as a sink or a source for seepage to or from adjacent wetlands. One goal of this study is to determine the "equilibrium" water level elevation in a number of pits and to develop methods of estimating that level. Once this elevation is known, the methods developed in previous research can be applied to estimate the distance the pit should be set back from adjacent wetlands to avoid detrimental hydrologic effects.

### OBJECTIVES

1. Develop information necessary to estimate the lateral effect of borrow pits on wetland hydrology using methods developed for drainage ditches.
2. Survey existing (closed) borrow pits to determine characteristics of the pit, water levels in pit, and their relation to adjacent wetlands
3. Determine time required for the water level in the pit to attain equilibrium after pumping ceases and the pit is closed.
4. Develop methods for predicting the equilibrium water level in the pit.
5. Conduct workshops to teach DOT personnel and consultants how to use the methods for determining setback distances for borrow pits.

# PROCEDURES

**Objective 1. Develop information necessary to estimate the lateral effect of borrow pits on wetland hydrology using methods developed for drainage ditches.**

Application of the method for borrow pits requires knowledge of $T_{25}$ values. These values vary with location due to differences in precipitation, potential evapotranspiration, and growing season. The $T_{25}$ values essentially quantify threshold drawdown rates, which are needed for each county in which the methods are to be applied. Values were determined for all 100 counties in North Carolina in the previous project (Phillips et al., 2006) for ditch depths of 2, 3, and 4 feet using methods explained in the Background section of this report. This project required a wider range of depths, so we determined $T_{25}$ values for 1, 5, and 6 feet for all 100 counties. Values were determined, as discussed earlier, for 5 hydric soils and averaged to give a base $T_{25}$ value for each county. Each location required 30 determinations of $T_{25}$ (5 soils X 3 depths X 2 surface storages) with up to 20 simulations for a 50 year weather record for each determination. Values were determined for surface depressional storage conditions of 1 and 2 inches.

**Objective 2. Survey existing (closed) borrow pits to determine characteristics of the pit, water levels in pit, and their relation to adjacent wetlands**

We worked with DOT Roadside Environmental to identify borrow pits that had been closed for sufficient time to attain "equilibrium" conditions. Our original goal was to survey about 50 of those pits to determine equilibrium water levels, distance from wetlands, water table elevations in wetlands, hydraulic gradients, soil series in the pit area and in the wetland and other information concerning the potential long lasting effect of the pit on nearby wetlands. We visited and collected data on 27 sites. Many additional sites were considered but were not appropriate for the study because there were no wetlands close to the pit, or because, in a few cases, we were unable to get the owners permission to access the site. Our initial objective was to obtain the required information for each pit during a single visit to the site. Example applications of the method and discussions with the COE highlighted the critical nature of one parameter in determining the setback distance. That variable is the difference between the water level elevation in the pit and the water table elevation in the wetland. Because both of those elevations change with time (due to rainfall and ET, primarily) it became apparent that additional information was needed on the pit water levels and the hydraulic gradient between pits and nearby wetlands. Four closed pits were instrumented to record water levels in the pit and water table elevations on transects from the pit to the wetland. Locations and dates of instrumentation of the pits are given in Table 2. The methods for measuring and recording the water levels were the same as used for the closed pits discussed under objective 3 below.

**Objective 3. Determine time required for the water level in the pit to attain equilibrium after pumping ceases and the pit is closed.**

Four pits were instrumented to measure the water level rise in the pit after closure and to determine water table depths between the pit and adjacent wetlands as the pit water level rose to an equilibrium position. Methods used to instrument the pits for addressing both objectives 2 and 3 are discussed below.

## LOCATION OF STUDY SITES

Altogether, eight study sites were instrumented (four to address objective 2 and four to address objective 3). The sites were either still under the control and being maintained by the NCDOT, or permission was received from the land owner to install monitoring equipment. The study sites were located in five North Carolina coastal plain counties: Edgecombe, Pitt, Washington, Tyrrell, and New Hanover. These five counties represent areas within three major North Carolina watersheds: Pasquotank, Tar-Pamlico, and Cape Fear. Four of the study site pits had been closed for more than four years and four were closed near the time of instrumentation (recently closed pits). Table 2 summarizes the study site locations and closure information. Figure 6 shows the location for each study site.

**Table 2. Summary of study sites. [1]Recorders in wetlands installed prior to closure.**

| Pit Name | County | Coordinates | Date of Closure | Date Instrumented |
|---|---|---|---|---|
| **Closed Pits** | | | | |
| Mildred Woods | Edgecombe | 35°51'59.53"N, 77°29'49.30"W | Prior to 2000 | April 2005 |
| Hardy | Pitt | 35°46'6.17"N, 77°23'9.06"W | Prior to 2000 | June 2005 |
| Stallings | Washington | 35°51'44.71"N, 76°36'52.63"W | Prior to 2000 | February 2005 |
| Twiddy | Washington | 35°55'33.83"N, 76°23'44.13"W | Prior to 2000 | November 2005 |
| **Recently Closed** | | | | |
| Davis | Tyrrell | 35°53'20.40"N, 76°21'2.41"W | July 2005 | January 2005[1] |
| Spruill | Tyrrell | 35°55'9.59"N, 76°20'52.69"W | April 2005 | February 2005[1] |
| Vann | New Hanover | 34°18'19.80"N, 77°47'13.09"W | October 2004 | December 2004 |
| Prime Ridge | New Hanover | 34°18'23.87"N, 77°47'36.35"W | October 2004 | December 2004 |

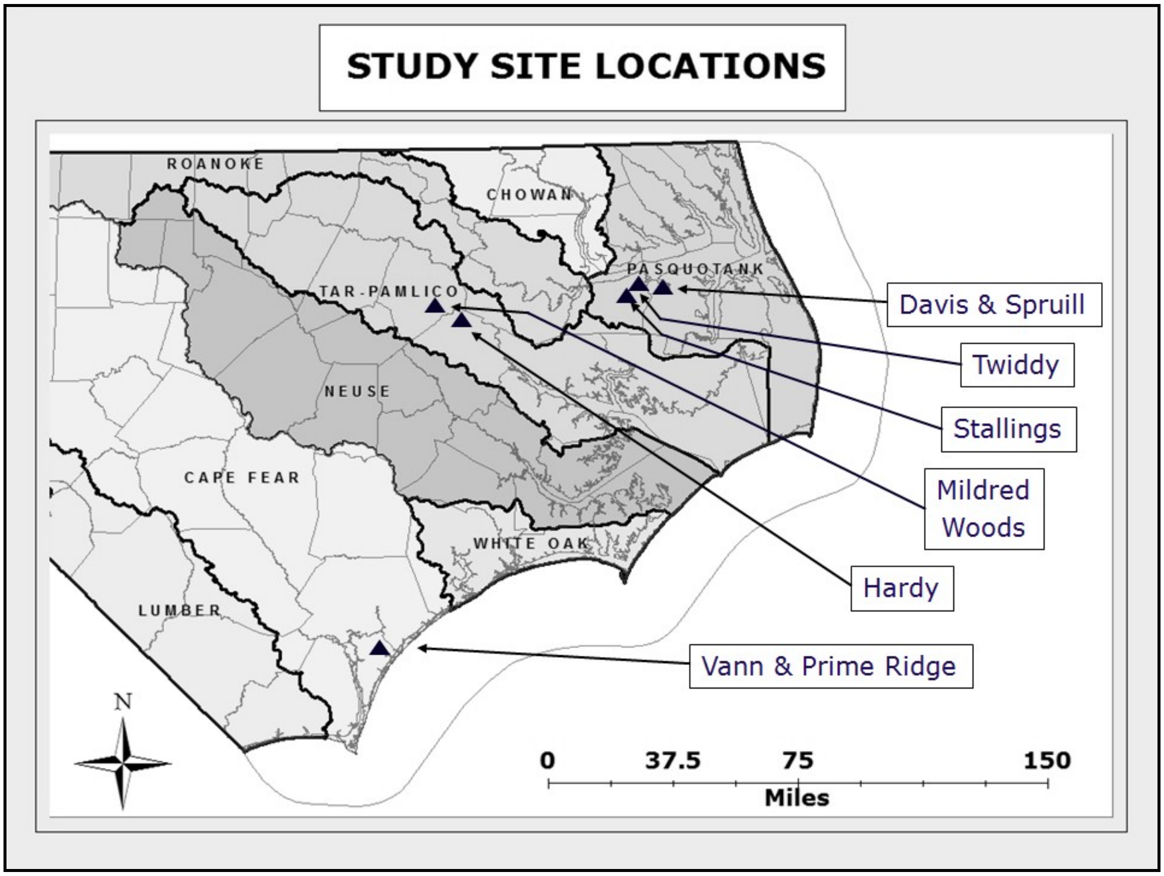


**Figure 6. Location of study sites.**

## INSTRUMENTATION OF PITS

A continuous water level recorder and staff gauge were installed in each pit. The instrument is a pressure sensor type (Infinities USA, Inc., Figure 7) which records water level readings at hourly intervals. A calibration relationship between the water level reading and observed staff reading was used to accurately determine water levels on an hourly basis.

Transects of two or three wells were installed leading from the pits to adjacent wetlands. The wells consisted of slotted 4-inch diameter PVC pipe installed to a depth of 4.5 to 6.0 feet. Weatherproof instrument boxes were placed atop recording wells. The recording mechanisms consist of a float/counterweight pulley system coupled to a potentiometer (Figure 7). Voltages through the potentiometer were monitored and recorded by a data logger (Onset Computer Corporation HOBO U12 Logger) on an hourly basis. Water table depth was determined by a calibrated relationship between water table depth and voltage.

**Figure 7. Image of pulley/float recording system showing the pulley, potentiometer, and the data logger on the left. Image of pit recorder and staff on right.**

Surveys were conducted at each study site during the time of equipment installation. By defining an arbitrary datum several feet below the ground surface, the water levels in the pit and in the transect well could be related in reference to the datum. In pits that were recently closed, installation of equipment occurred shortly before or close to the time the pits were closed in order to measure the response of the water level in each pit as it rose to a steady state or "equilibrium" position.

A manual rain gage and a recording rain gage were located at or in close proximity to each study site. The six inch diameter recording tipping bucket rain gage (Onset Computer Corporation) was calibrated to 0.01 inch depth of precipitation per tip. The time of each tip of the bucket was recorded by a logger (Onset Computer Corporation HOBO Event Logger). During each field visit, the manual rain gage was read and then reset and the data from the automatic recording rain gage downloaded. The reading from the manual rain gage was compared to the total rainfall recorded by the automatic rain gage and the data adjusted as necessary.

Collection of data from the field involved visiting each site on a regular basis, usually two to four weeks, depending on weather conditions. The pit staff water level was recorded and used to check calibration of the instruments. Depth to the water table was measured manually and recorded at each transect well. Water level readings from the pit recorder and voltage data from the wells were downloaded to a computer. Paired values for the pit staff and the water level reading as well as the manually measured water table depth and the voltage at the time of the download were recorded. These data for each visit were entered into a spreadsheet and a linear regression line fitted to the updated set of data pairs to develop an equation for the relationship between pit staff and pit water level as well as the voltage and measured water table depth for each recording water table well. These calibration equations were then used to convert the hourly measured pit water levels to actual water levels and the voltage data to hourly water table depths. Water levels in the pits and water tables in the adjacent wetlands, were continuously measured and recorded from the time the equipment was installed (Table 2) until June or early July, 2007.

### SOIL PROPERTIES

Soil data were collected at each study site. Lateral hydraulic conductivity was measured with the auger hole method (van Beers, 1970). Soil cores were collected to determine soil-water characteristics (soil water retention curves) and vertical hydraulic conductivity (Klute, 1986). Drainable porosity for the soil on each site was calculated from the soil water characteristics using methods presented by Skaggs et al. (1978). Pre-construction soil boring logs were provided by the NCDOT resident engineers for some of the pits. These logs provide descriptions and textural information for the soil profile prior to pit construction. The depth to the restrictive layer was estimated from this information

### WATER DEPTHS IN THE PITS

A remote controlled model boat (2 feet in length) equipped with a sonar/GPS device was used to map the bottom of several of the study pits. Information from the boat sonar log provided depths to the bottom of the pit. As expected the depths recorded were spatially variable and the pit bottom was somewhat uneven. It was assumed that, in most cases, material was excavated down to a layer with clay contents that were too high for road construction. This layer would logically be very slowly permeable, so the depth of the pit recorded by the sonar log provides an approximation of the depth to the restrictive layer. These results were used in combination with boring logs to determine depth of the restrictive layer for the purposes of calculating lateral effects of borrow pits. Figure 8 shows an image of the sonar equipped boat in use and being controlled from the shore. The inset in Figure 8 shows a closer image of the boat.

**Figure 8. Sonar equipped model boat used to measure the depth to the restrictive layer in several study site borrow pits. Inset shows closer image of boat belonging to the Animal Waste Management extension program in BAE, NCSU**

# RESULTS AND DISCUSSION

## $T_{25}$ VALUES FOR NORTH CAROLINA

$T_{25}$ values for all counties in North Carolina are given in Tables **3** and **4**. These values are based on the wetland criterion given in the COE wetlands delineation manual assuming the minimum duration of wet conditions of 5% of the growing season (as published in the county soil survey).

**Table 3. Summary of $T_{25}$ values (in days) for all North Carolina counties for surface depressional storage of 1 inch (2.5 cm).**

| Depth of water in ditch | 1 ft | 2 ft | 3 ft | 4 ft | 5 ft | 6 ft |
|---|---|---|---|---|---|---|
| Alamance | 9.4 | 9.0 | 9.7 | 10.7 | 11.8 | 12.6 |
| Alexander | 5.0 | 5.6 | 6.3 | 7.0 | 7.5 | 8.0 |
| Alleghany | 5.4 | 5.7 | 6.7 | 7.2 | 7.7 | 8.2 |
| Anson | 8.6 | 8.5 | 9.1 | 9.9 | 10.4 | 10.9 |
| Ashe | 2.5 | 2.9 | 3.3 | 4.0 | 4.8 | 5.2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Avery | 2.3 | 3.0 | 3.7 | 4.4 | 5.2 | 5.6 |
| Bertie | 10.3 | 8.7 | 9.3 | 10.7 | 11.9 | 13.1 |
| Beaufort | 6.6 | 6.2 | 7.0 | 7.6 | 8.1 | 8.7 |
| Bladen | 11.8 | 10.3 | 10.5 | 10.9 | 11.3 | 12.4 |
| Brunswick | 4.2 | 4.6 | 5.1 | 5.4 | 5.8 | 5.9 |
| Buncombe | 4.0 | 4.0 | 4.1 | 5.1 | 5.4 | 6.2 |
| Burke | 4.7 | 5.6 | 6.4 | 6.8 | 7.3 | 7.6 |
| Cabarrus | 6.5 | 6.7 | 7.2 | 7.6 | 8.0 | 8.4 |
| Caldwell | 4.8 | 5.1 | 5.7 | 5.9 | 6.1 | 6.6 |
| Camden | 6.5 | 6.0 | 6.7 | 7.4 | 8.1 | 8.8 |
| Carteret | 4.8 | 5.0 | 5.4 | 5.9 | 6.3 | 6.6 |
| Caswell | 9.2 | 8.2 | 8.9 | 9.3 | 10.5 | 10.8 |
| Catawba | 5.0 | 5.6 | 6.3 | 7.0 | 7.5 | 8.0 |
| Chatham | 5.6 | 5.4 | 6.2 | 6.9 | 7.6 | 8.6 |
| Cherokee | 3.3 | 4.0 | 4.5 | 5.0 | 5.4 | 5.7 |
| Chowan | 7.9 | 7.1 | 8.1 | 8.6 | 9.2 | 9.7 |
| Clay | 2.4 | 2.8 | 3.3 | 3.5 | 3.9 | 4.2 |
| Cleveland | 5.3 | 5.2 | 5.7 | 6.3 | 6.7 | 6.8 |
| Columbus | 9.7 | 9.2 | 10.2 | 11.0 | 11.6 | 12.2 |
| Craven | 5.1 | 5.2 | 6.0 | 6.9 | 7.5 | 8.1 |
| Cumberland | 6.3 | 6.3 | 7.4 | 8.6 | 9.1 | 9.7 |
| Currituck | 6.5 | 6.0 | 6.7 | 7.4 | 8.1 | 8.8 |
| Dare | 5.4 | 5.7 | 6.2 | 6.9 | 7.3 | 7.6 |
| Davidson | 7.8 | 8.6 | 9.4 | 10.3 | 10.4 | 10.8 |
| Davie | 7.6 | 6.9 | 8.5 | 10.2 | 11.1 | 11.7 |
| Duplin | 6.1 | 5.5 | 6.4 | 7.1 | 7.8 | 8.6 |
| Durham | 7.0 | 7.1 | 7.6 | 8.1 | 8.8 | 9.8 |
| Edgecombe | 10.7 | 9.5 | 10.2 | 11.0 | 11.8 | 12.4 |
| Forsyth | 7.0 | 7.1 | 7.6 | 8.7 | 9.6 | 10.3 |
| Franklin | 12.4 | 10.5 | 11.9 | 13.1 | 14.8 | 16.1 |
| Gaston | 7.5 | 7.0 | 7.6 | 8.1 | 8.7 | 9.0 |
| Gates | 7.3 | 6.2 | 7.3 | 8.2 | 9.0 | 9.5 |
| Graham | 4.0 | 4.8 | 5.6 | 6.1 | 6.7 | 7.2 |
| Granville | 12.0 | 9.7 | 10.9 | 11.4 | 12.2 | 12.7 |
| Greene | 10.5 | 8.6 | 9.4 | 10.9 | 11.7 | 12.6 |
| Guilford | 5.5 | 6.2 | 6.9 | 7.6 | 8.1 | 8.8 |
| Halifax | 8.3 | 7.9 | 8.7 | 9.9 | 10.9 | 11.3 |
| Harnett | 10.5 | 8.9 | 9.6 | 11.1 | 12.2 | 13.0 |
| Haywood | 7.4 | 10.4 | 12.1 | 13.5 | 15.9 | 16.5 |
| Henderson | 3.2 | 3.3 | 4.2 | 4.4 | 4.9 | 5.1 |
| Hertford | 7.3 | 6.2 | 7.3 | 8.2 | 9.0 | 9.5 |
| Hoke | 6.3 | 6.3 | 7.4 | 8.6 | 9.1 | 9.7 |
| Hyde | 7.8 | 7.2 | 7.6 | 7.8 | 8.7 | 8.9 |
| Iredell | 5.0 | 5.6 | 6.3 | 7.0 | 7.5 | 8.0 |
| Jackson | 6.2 | 6.4 | 7.4 | 8.9 | 11.4 | 12.7 |
| Johnston | 11.2 | 9.8 | 10.8 | 12.2 | 10.3 | 13.6 |
| Jones | 7.7 | 6.2 | 6.6 | 7.6 | 7.9 | 9.0 |
| Lee | 11.9 | 9.5 | 10.2 | 10.9 | 12.5 | 13.8 |
| Lenoir | 9.8 | 8.4 | 9.1 | 10.4 | 11.2 | 12.1 |
| Lincoln | 6.0 | 5.7 | 6.3 | 7.0 | 7.2 | 7.4 |
| Macon | 2.4 | 2.8 | 3.3 | 3.5 | 3.9 | 4.2 |
| Madison | 4.0 | 4.0 | 4.1 | 5.1 | 5.4 | 6.2 |
| Martin | 7.0 | 6.2 | 6.9 | 7.8 | 8.2 | 8.8 |

| | | | | | | |
|---|---|---|---|---|---|---|
| McDowell | 7.3 | 7.1 | 7.9 | 8.9 | 9.5 | 10.1 |
| Mecklenburg | 6.6 | 6.6 | 7.5 | 8.3 | 8.6 | 9.0 |
| Mitchell | 2.1 | 2.9 | 3.4 | 4.0 | 4.2 | 4.7 |
| Montgomery | 7.3 | 7.2 | 8.5 | 10.4 | 11.1 | 11.6 |
| Moore | 9.7 | 8.1 | 8.5 | 9.8 | 10.4 | 10.7 |
| Nash | 10.0 | 9.3 | 10.4 | 11.1 | 11.7 | 12.2 |
| New Hanover | 4.5 | 5.5 | 5.9 | 6.3 | 6.6 | 6.9 |
| Northampton | 11.8 | 8.6 | 9.5 | 11.0 | 12.1 | 12.9 |
| Onslow | 6.8 | 6.2 | 7.4 | 8.8 | 9.2 | 9.5 |
| Orange | 10.2 | 8.2 | 8.9 | 10.0 | 10.6 | 11.6 |
| Pamlico | 5.1 | 5.7 | 6.1 | 7.0 | 7.5 | 8.0 |
| Pasquotank | 6.5 | 6.0 | 6.7 | 7.4 | 8.1 | 8.8 |
| Pender | 6.5 | 6.2 | 7.2 | 8.2 | 8.8 | 9.3 |
| Perquimans | 9.0 | 8.9 | 9.9 | 10.3 | 10.7 | 11.3 |
| Person | 8.0 | 7.4 | 8.3 | 9.3 | 10.0 | 11.4 |
| Pitt | 10.5 | 8.6 | 9.4 | 10.9 | 11.7 | 12.6 |
| Polk | 3.2 | 3.7 | 4.0 | 4.2 | 4.5 | 4.7 |
| Randolph | 8.3 | 7.6 | 8.6 | 9.5 | 10.8 | 11.6 |
| Richmond | 8.8 | 8.6 | 10.3 | 11.5 | 12.3 | 12.8 |
| Robeson | 10.4 | 9.1 | 9.6 | 10.9 | 11.6 | 12.7 |
| Rockingham | 8.9 | 6.6 | 7.6 | 8.3 | 8.7 | 9.0 |
| Rowan | 7.1 | 7.1 | 7.6 | 8.2 | 9.1 | 9.7 |
| Rutherford | 6.3 | 6.0 | 6.6 | 7.6 | 8.0 | 8.4 |
| Sampson | 7.4 | 6.6 | 7.4 | 7.6 | 8.1 | 8.4 |
| Scotland | 10.7 | 10.9 | 11.9 | 12.7 | 15.0 | 15.7 |
| Stanly | 4.9 | 5.5 | 6.6 | 7.6 | 8.3 | 8.4 |
| Stokes | 4.2 | 4.9 | 5.4 | 6.8 | 7.9 | 8.7 |
| Surry | 6.2 | 6.0 | 6.7 | 7.3 | 7.8 | 8.1 |
| Swain | 3.2 | 4.2 | 5.0 | 5.9 | 6.2 | 6.4 |
| Transylvania | 2.2 | 2.6 | 3 | 3.3 | 3.6 | 3.9 |
| Tyrrell | 9.1 | 7.9 | 8.1 | 8.9 | 9.6 | 10.2 |
| Union | 8.3 | 8.5 | 10.5 | 11.4 | 12.3 | 12.8 |
| Vance | 6.8 | 6.7 | 7.6 | 8.4 | 9.1 | 9.5 |
| Wake | 9.6 | 7.7 | 8.4 | 9.6 | 10.3 | 10.7 |
| Warren | 8.8 | 7.6 | 9.1 | 9.5 | 10.0 | 10.6 |
| Washington | 9.1 | 7.9 | 8.1 | 8.9 | 9.6 | 10.2 |
| Watauga | 3.0 | 3.7 | 4.3 | 4.7 | 5.5 | 5.6 |
| Wayne | 14.0 | 11.1 | 11.4 | 12.3 | 12.9 | 13.4 |
| Wilkes | 4.5 | 4.3 | 5.4 | 6.7 | 7.5 | 7.7 |
| Wilson | 11.0 | 11.2 | 11.4 | 12.0 | 12.0 | 12.8 |
| Yadkin | 7.6 | 6.9 | 8.5 | 10.2 | 11.1 | 11.7 |
| Yancey | 2.1 | 2.9 | 3.4 | 4.0 | 4.2 | 4.7 |

**Table 4. Summary of $T_{25}$ values (in days) for all North Carolina counties for surface depressional storage of 2 inches (5.0 cm).**

| Depth of water in ditch | 1 ft | 2 ft | 3 ft | 4 ft | 5 ft | 6 ft |
|---|---|---|---|---|---|---|
| Alamance | 5.3 | 4.6 | 5.3 | 5.8 | 6.6 | 7.0 |
| Alexander | 3.4 | 3.5 | 3.8 | 4.1 | 4.3 | 4.5 |
| Alleghany | 3.5 | 3.5 | 3.8 | 4.2 | 4.6 | 4.9 |
| Anson | 5.4 | 4.6 | 4.7 | 5.1 | 5.7 | 6.0 |
| Ashe | 1.7 | 1.9 | 2.3 | 3.0 | 3.5 | 3.7 |
| Avery | 1.7 | 2.2 | 2.7 | 3.4 | 4.1 | 4.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Bertie | 4.5 | 4.1 | 5.0 | 5.4 | 6.0 | 6.3 |
| Beaufort | 3.9 | 3.7 | 4.1 | 4.6 | 4.9 | 5.2 |
| Bladen | 5.6 | 4.8 | 5.3 | 5.9 | 6.4 | 6.7 |
| Brunswick | 2.8 | 3.0 | 3.2 | 3.5 | 3.6 | 3.8 |
| Buncombe | 2.7 | 2.8 | 3.3 | 3.6 | 3.8 | 4.0 |
| Burke | 3.2 | 3.3 | 3.6 | 3.9 | 4.0 | 4.5 |
| Cabarrus | 4.5 | 3.9 | 4.2 | 4.7 | 5.0 | 5.4 |
| Caldwell | 3.0 | 2.9 | 3.1 | 3.6 | 4.0 | 4.1 |
| Camden | 3.7 | 3.8 | 4.2 | 4.5 | 4.8 | 5.1 |
| Carteret | 3.3 | 3.2 | 3.6 | 3.9 | 4.0 | 4.2 |
| Caswell | 4.9 | 4.5 | 5.0 | 5.3 | 5.9 | 6.3 |
| Catawba | 3.4 | 3.5 | 3.8 | 4.1 | 4.3 | 4.5 |
| Chatham | 3.4 | 3.6 | 3.9 | 4.5 | 5.0 | 5.5 |
| Cherokee | 2.2 | 2.5 | 3.1 | 3.6 | 4.0 | 4.2 |
| Chowan | 4.4 | 4.0 | 4.1 | 4.4 | 4.8 | 5.0 |
| Clay | 1.5 | 1.7 | 2.0 | 2.3 | 2.5 | 2.7 |
| Cleveland | 3.3 | 3.2 | 3.3 | 3.7 | 4.4 | 4.9 |
| Columbus | 4.9 | 4.6 | 5.0 | 5.5 | 5.8 | 6.3 |
| Craven | 3.1 | 3.2 | 3.8 | 4.4 | 4.9 | 5.3 |
| Cumberland | 4.9 | 4.6 | 5.1 | 5.5 | 5.8 | 6.0 |
| Currituck | 3.7 | 3.8 | 4.2 | 4.5 | 4.8 | 5.1 |
| Dare | 3.3 | 3.2 | 3.6 | 4.0 | 4.2 | 4.4 |
| Davidson | 5.4 | 4.8 | 5.1 | 5.6 | 5.9 | 6.5 |
| Davie | 5.2 | 4.4 | 5.2 | 6.1 | 6.3 | 6.9 |
| Duplin | 3.6 | 3.4 | 4.2 | 4.8 | 5.3 | 5.6 |
| Durham | 4.1 | 4.0 | 4.2 | 4.9 | 5.5 | 5.8 |
| Edgecombe | 5.5 | 4.7 | 5.3 | 5.6 | 6.1 | 6.3 |
| Forsyth | 4.5 | 4.1 | 4.8 | 5.4 | 5.6 | 6.0 |
| Franklin | 5.9 | 5.5 | 5.7 | 6.0 | 6.5 | 7.0 |
| Gaston | 3.9 | 3.7 | 4.2 | 4.9 | 5.1 | 5.7 |
| Gates | 3.7 | 3.7 | 4.3 | 4.7 | 5.3 | 5.7 |
| Graham | 3.0 | 3.1 | 3.7 | 4.1 | 4.6 | 5.0 |
| Granville | 6.0 | 4.6 | 5.0 | 5.7 | 6.5 | 6.8 |
| Greene | 4.7 | 4.0 | 4.5 | 4.9 | 5.6 | 6.0 |
| Guilford | 3.4 | 3.9 | 4.3 | 4.9 | 5.6 | 6.1 |
| Halifax | 4.8 | 4.6 | 5.1 | 5.6 | 5.9 | 6.2 |
| Harnett | 5.6 | 4.7 | 5.1 | 5.5 | 6.0 | 6.5 |
| Haywood | 4.0 | 5.7 | 6.8 | 7.4 | 7.7 | 8.3 |
| Henderson | 2.2 | 2.4 | 2.5 | 2.8 | 3.2 | 3.4 |
| Hertford | 3.7 | 3.7 | 4.3 | 4.7 | 5.3 | 5.7 |
| Hoke | 4.9 | 4.6 | 5.1 | 5.5 | 5.8 | 6.0 |
| Hyde | 3.6 | 3.6 | 4.0 | 4.4 | 4.7 | 5.1 |
| Iredell | 3.4 | 3.5 | 3.8 | 4.1 | 4.3 | 4.5 |
| Jackson | 4.1 | 4.2 | 5.0 | 6.1 | 6.6 | 7.3 |
| Johnston | 6.3 | 5.2 | 5.9 | 6.6 | 7.1 | 7.4 |
| Jones | 4.6 | 3.9 | 4.2 | 4.6 | 5.5 | 5.5[1] |
| Lee | 4.5 | 4.0 | 4.6 | 5.1 | 5.5 | 6.2 |
| Lenoir | 4.9 | 4.4 | 5.1 | 5.5 | 5.9 | 6.2 |
| Lincoln | 3.4 | 3.4 | 4.0 | 4.4 | 4.6 | 4.7 |
| Macon | 1.5 | 1.7 | 2.0 | 2.3 | 2.5 | 2.7 |
| Madison | 2.7 | 2.8 | 3.3 | 3.6 | 3.8 | 4.0 |
| Martin | 4.3 | 3.8 | 4.1 | 4.6 | 5.1 | 5.4 |
| McDowell | 4.0 | 4.1 | 4.4 | 4.9 | 5.2 | 5.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Mecklenburg | 5.1 | 4.6 | 5.2 | 5.6 | 6.3 | 6.5 |
| Mitchell | 1.6 | 2.0 | 2.4 | 2.7 | 3.0 | 3.3 |
| Montgomery | 4.6 | 4.8 | 4.8 | 5.2 | 5.5 | 6.0 |
| Moore | 4.5 | 4.0 | 4.3 | 4.8 | 5.2 | 5.6 |
| Nash | 5.7 | 5.1 | 5.7 | 6.2 | 6.4 | 6.6 |
| New Hanover | 2.9 | 3.2 | 3.4 | 3.7 | 3.9 | 4.1 |
| Northampton | 6.1 | 4.7 | 5.4 | 6.1 | 6.7 | 7.0 |
| Onslow | 3.4 | 3.2 | 3.7 | 4.1 | 4.3 | 4.5 |
| Orange | 4.2 | 4.1 | 4.6 | 5.5 | 6.3 | 6.6 |
| Pamlico | 3.3 | 3.2 | 3.8 | 4.2 | 4.5 | 4.8 |
| Pasquotank | 3.7 | 3.8 | 4.2 | 4.5 | 4.8 | 5.1 |
| Pender | 3.6 | 3.5 | 3.9 | 4.5 | 4.9 | 5.2 |
| Perquimans | 5.2 | 4.1 | 4.7 | 5.1 | 5.6 | 6.3 |
| Person | 4.8 | 4.6 | 4.9 | 5.6 | 5.9 | 6.6 |
| Pitt | 4.7 | 4.0 | 4.5 | 4.9 | 5.6 | 6.0 |
| Polk | 2.4 | 2.4 | 2.5 | 2.6 | 2.8 | 3.0 |
| Randolph | 4.9 | 4.3 | 4.9 | 5.2 | 6.1 | 6.7 |
| Richmond | 5.3 | 4.6 | 5.0 | 5.6 | 6.2 | 6.7 |
| Robeson | 5.0 | 4.7 | 5.4 | 6.1 | 6.6 | 7.2 |
| Rockingham | 3.8 | 3.8 | 4.1 | 4.5 | 4.8 | 5.5 |
| Rowan | 4.7 | 4.6 | 5.5 | 5.8 | 6.6 | 7.1 |
| Rutherford | 3.4 | 3.2 | 3.8 | 4.2 | 4.6 | 4.9 |
| Sampson | 4.7 | 4.2 | 4.6 | 5.0 | 5.3 | 5.7 |
| Scotland | 6.2 | 5.1 | 5.4 | 5.9 | 6.4 | 6.8 |
| Stanly | 3.5 | 3.4 | 3.7 | 3.9 | 4.3 | 4.8 |
| Stokes | 3.1 | 3.2 | 3.7 | 4.2 | 4.6 | 5.0 |
| Surry | 3.8 | 3.9 | 4.2 | 4.6 | 5.3 | 5.9 |
| Swain | 2.9 | 3.0 | 3.6 | 3.9 | 4.4 | 4.7 |
| Transylvania | 1.5 | 1.9 | 2.1 | 2.4 | 2.9 | 3.1 |
| Tyrrell | 4.0 | 4.0 | 4.4 | 4.7 | 5.1 | 5.3 |
| Union | 5.4 | 4.9 | 5.2 | 5.9 | 6.6 | 7.3 |
| Vance | 4.2 | 3.8 | 4.2 | 4.8 | 5.3 | 5.5 |
| Wake | 4.6 | 4.3 | 4.7 | 5.1 | 5.5 | 5.9 |
| Warren | 4.5 | 4.2 | 4.5 | 4.8 | 5.6 | 6.0 |
| Washington | 4.0 | 4.0 | 4.4 | 4.7 | 5.1 | 5.3 |
| Watauga | 2.1 | 2.4 | 2.8 | 3.2 | 3.5 | 3.7 |
| Wayne | 6.2 | 5.3 | 5.7 | 6.4 | 6.9 | 7.3 |
| Wilkes | 3.0 | 3.0 | 3.7 | 4.2 | 4.5 | 4.8 |
| Wilson | 6.4 | 6.2 | 6.7 | 7.1 | 7.4 | 7.9 |
| Yadkin | 5.2 | 4.4 | 5.2 | 6.1 | 6.3 | 6.9 |
| Yancey | 1.6 | 2.0 | 2.4 | 2.7 | 3.0 | 3.3 |

1. Values for the 5 and 6 ft depths are equal.

## CHARACTERISTICS OF CLOSED BORROW PITS

The first step in determining potential impacts of borrow pits is to evaluate the factors affecting the equilibrium water level in the pit and its relationship to wetlands in the immediate vicinity. Consider the Mildred Woods borrow pit shown schematically in Figure 9. If we conduct a simple water balance on the pit for any period of time, say one year, we could write the following equation,

$$\mathbf{P = E + O} \quad \textbf{[1]}$$

where **P** is annual precipitation (in.), **E** is annual evaporation from the pit (in.) and **O** is net annual outflow from the pit (in). The net outflow, **O**, may be made up of several components, each of which would be positive for flow out of the pit and negative for flow into the pit. For example the outflow could be written as,

$$\mathbf{O = F_o + S_o - S_i} \quad \textbf{[2]}$$

Where $\mathbf{F_o}$ is net annual flow out through surface outlets (in), $\mathbf{S_o}$ is annual seepage out of the pit (in), and $\mathbf{S_i}$ is net annual seepage into the pit (in). In eastern North Carolina annual rainfall varies from about 48 to 55 inches(1220 to 1400 mm) and evaporation from a free water surface (lake, river, borrow pit) is about 36 to 40 inches (900 to 1000 mm). From equation 1 above, **O = P – E**. Since P is always greater than E in eastern NC on a long-term basis, average annual flow out of the pit is always greater than average annual flow into the pit. That means that $\mathbf{F_o + S_o}$ in equation 2 is greater than $\mathbf{S_i}$ on average. The major concern justifying the need for this project was that seepage into the borrow pits from adjacent wetlands could detrimentally impact the hydrology of the wetland. The rate of seepage into and out of the borrow pit is directly dependent on the water level elevation or stage in the pit. Generally, after the pit is closed the water level will rise until the net outflow, **O**, is equal to **P – E**. The factors affecting the net outflow are the factors affecting the components in equation 2. For example, if a pit has an outlet weir at a fixed elevation, water will be released from the pit by surface flow when it rises to the elevation of the weir. The rate of release will depend on the stage, but, depending on the length of the weir, the water surface elevation may not rise much above the weir except during and shortly following large storms. In other case there may not be a surface outlet and the water surface elevation may be controlled by seepage from the pit to nearby drainage ditches or streams. The point is that the first step in determining the potential effect of borrow pits on the hydrology of wetlands is to characterize the pit in terms of the factors affecting the equilibrium water levels, as well as those factors controlling seepage between the wetland and the pit.

During the course of the study, we surveyed 26 borrow pits to determine characteristics of the pit that affect water balances and the hydrology of nearby wetlands. The greatest concern was that pits constructed adjacent to wetlands would result in seepage from the wetland to the pit resulting in detrimental effects on wetland hydrology. The survey of existing pits revealed a wide range of topographic settings, conditions, and factors affecting seepage to or from the pit with respect to adjacent wetlands. Our field investigations showed that in 31% of the cases seepage was from the pit to the wetland. In some cases seepage was from the wetland to the pit during some periods and in the reverse direction (from the pit to the wetland during drier periods). In order to facilitate analysis and discussion, the pits were divided into three general types.

**Type 1: Wetland Upslope of the Pit**. The ground surface of the wetland adjacent to a pit of this type is higher than the equilibrium water level in the pit. Concern about detrimental effects of borrow pits on wetland hydrology is greatest for this type as water could seep from the wetland to the borrow pit potentially decreasing water levels in the wetland. It should be noted that the natural direction of seepage prior to construction may well have been from the wetland to the site that is now the borrow pit. In that case it is not the seepage direction that is the question or potential problem, but whether or not the presence of the pit increases seepage rates such that detrimental effects result. The equilibrium water level in the pit is an important factor in these types of pits, since it determines the gradient from the wetland to the pit. We observed two conditions that would limit the water level in the pit and further classified those pits as **Type 1a** and **Type 1b**. The water level in **Type 1a** pits is controlled by the elevation of a weir or spillway at the outlet of the pit. Examples are the Mildred Woods pit and the Hardy pit shown schematically in Figures 9 and 10. **Type 1b** pits did not have surface outlets but the water levels were controlled by seepage to nearby drainage ditches or other sinks. Examples of **Type 1b** pits are the Davis pit and the Spruill pit (Figures 11 and 12). These pits are located in a drained agricultural field where field ditches are sinks receiving lateral seepage from the pit.

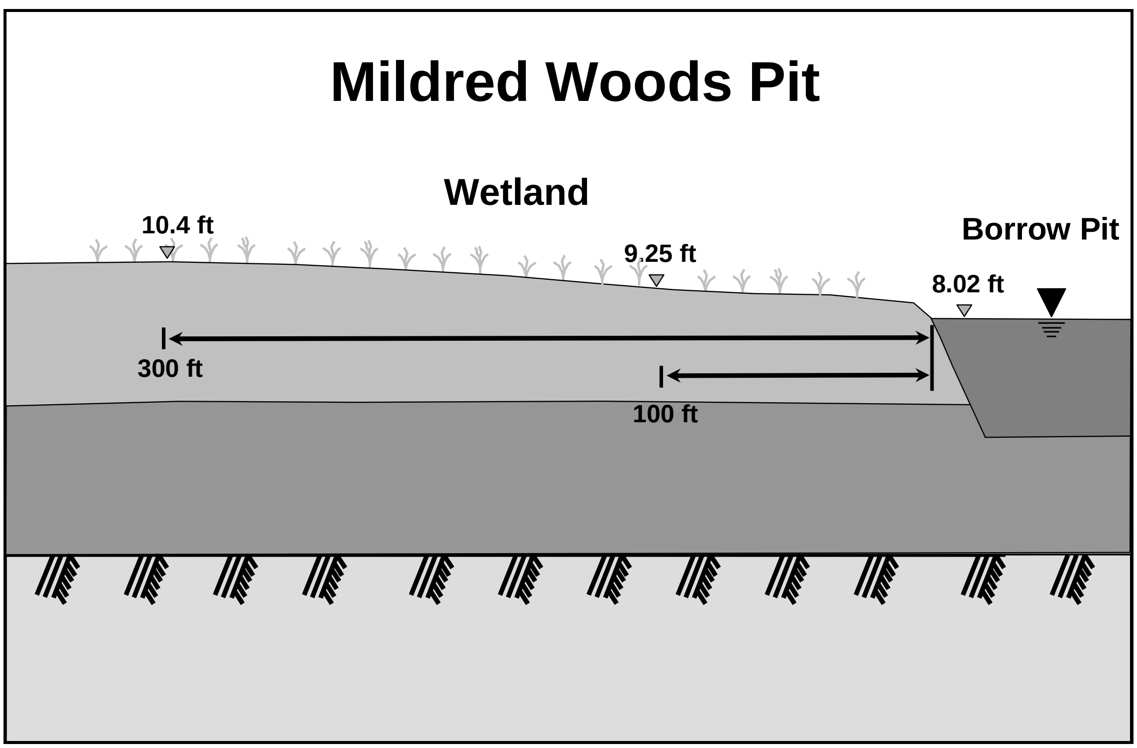


**Figure 9. Type 1a – Wetland upslope of pit. Mildred Woods Pit. Ground surface of wetland at higher elevation than pit water level. Water level of pit controlled by elevation of outlet.**

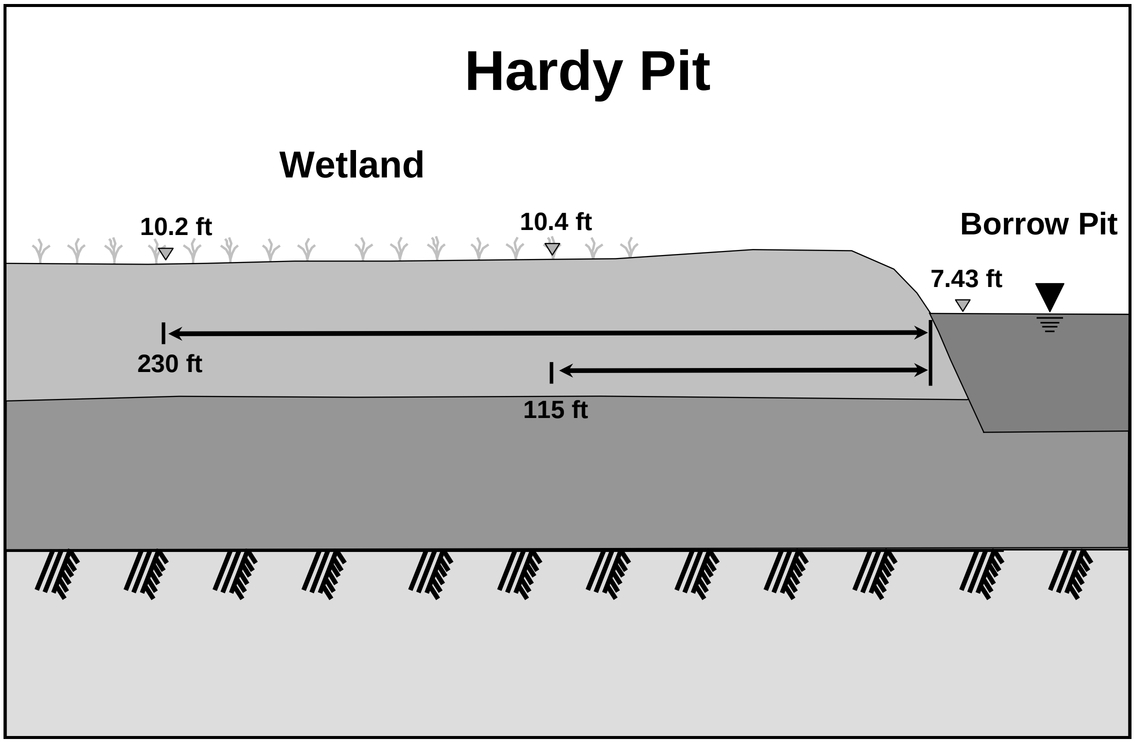


**Figure 10. Type 1a – Hardy Pit. Ground surface of wetland at higher elevation than pit water level, which is controlled by weir elevation in outlet control structure.**

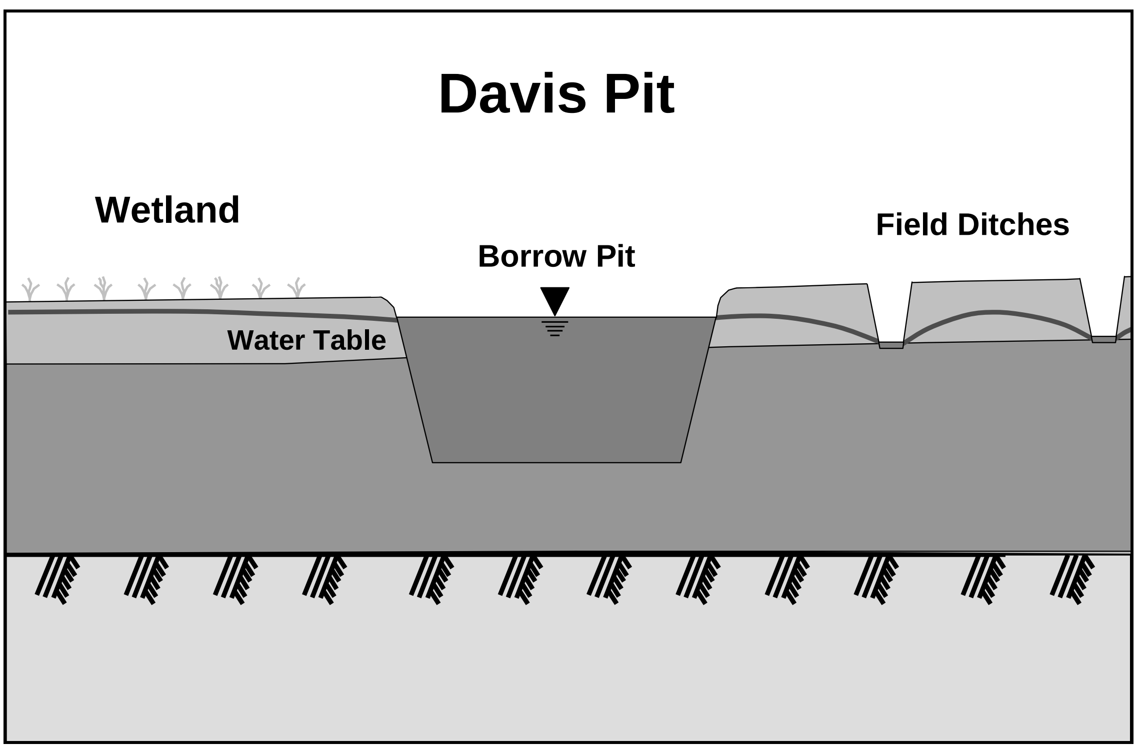


**Figure 11. Type 1b. Davis Pit. Wetland upslope of pit. Ground surface of wetland at higher elevation than pit water level. Water level of pit controlled by seepage to field ditches.**

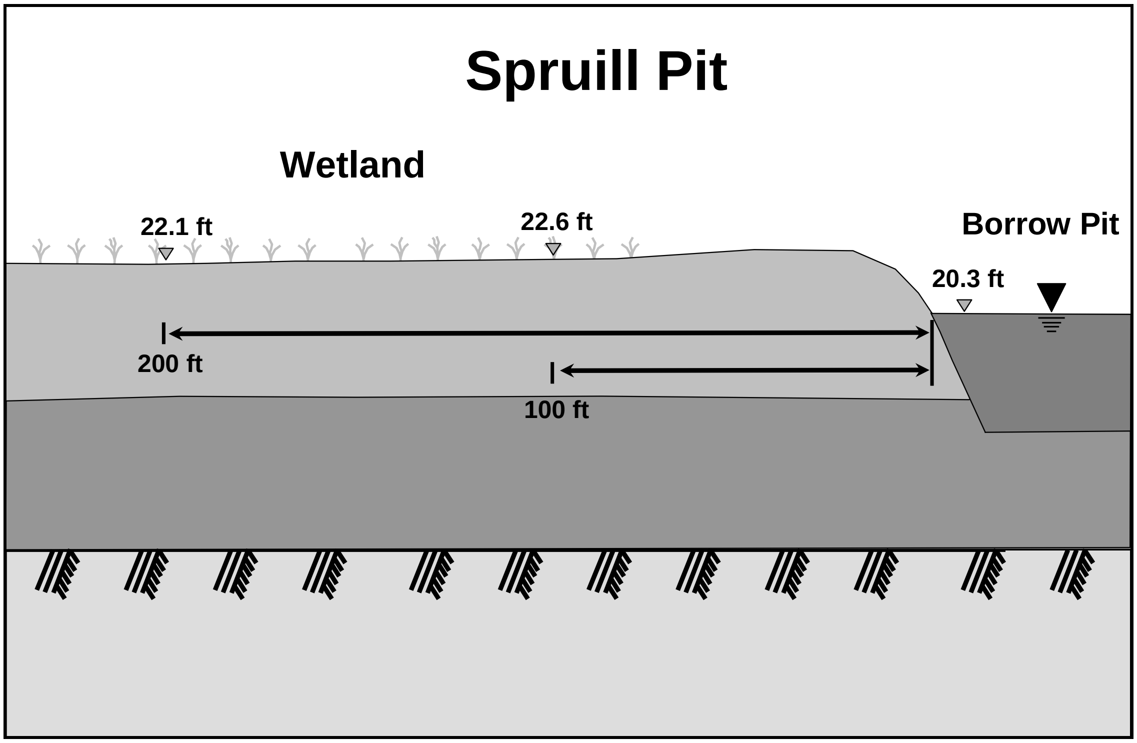


**Figure 12. Type 1b. Spruill Pit. Water level of pit limited by seepage to sink. Ground surface of wetland at higher elevation than pit water level. Water level of pit limited by seepage to field ditches (not shown).**

Two different scenarios of Type 1b borrow pits are demonstrated by the Alexander pit (Figure 13) and the Borden East pit (Figure 14). The water level in the Alexander pit was most likely controlled by the ditch located between the pit and the wetland. In this case there was minimal, if any, impact of the pit on the wetland, because the wetland was affected by the pre-existing ditch before construction of the borrow pit. The ground elevation of the wetland near the Borden East pit was higher than the water level in the pit. Elevation measurements were made at this site during a wet period when the stage of stream next to the wetland was higher than normal and higher than the elevation of the water in the pit. Under drier conditions the stage of the stream would be lower than the water level in the both the wetland and the pit, with seepage from the wetland and the borrow pit to the steam. The water level in the pit could also be affected by seepage to undocumented sinks. Other examples of Type 1b pits are the Callie Road pit and the Bullard 6 pit (Figures 15 and 16). The water levels in these pits were apparently controlled by seepage to undocumented sinks. The standing water near the wetland in the Bullard 6 pit was not part of a stream.

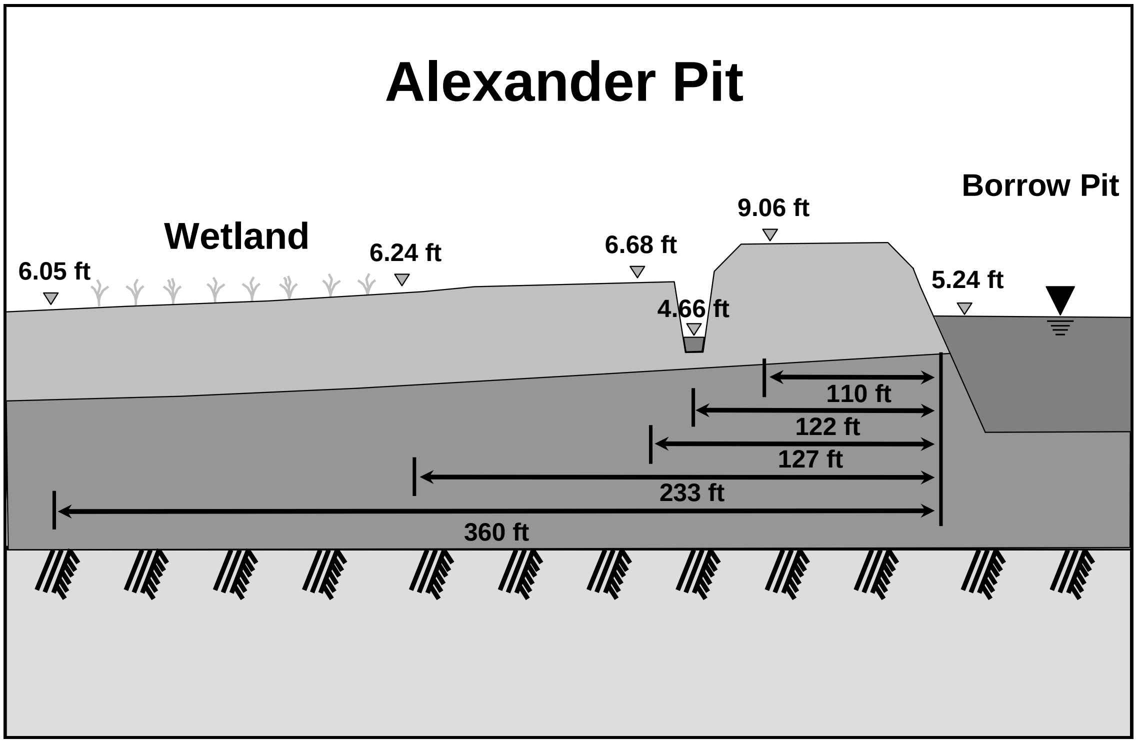


**Figure 13. Type 1b - Wetland upslope of pit. Alexander Pit. Ground surface of wetland at higher elevation than pit water level. Water level of pit limited by seepage to ditch. Note that the ditch between the wetland and the pit.**

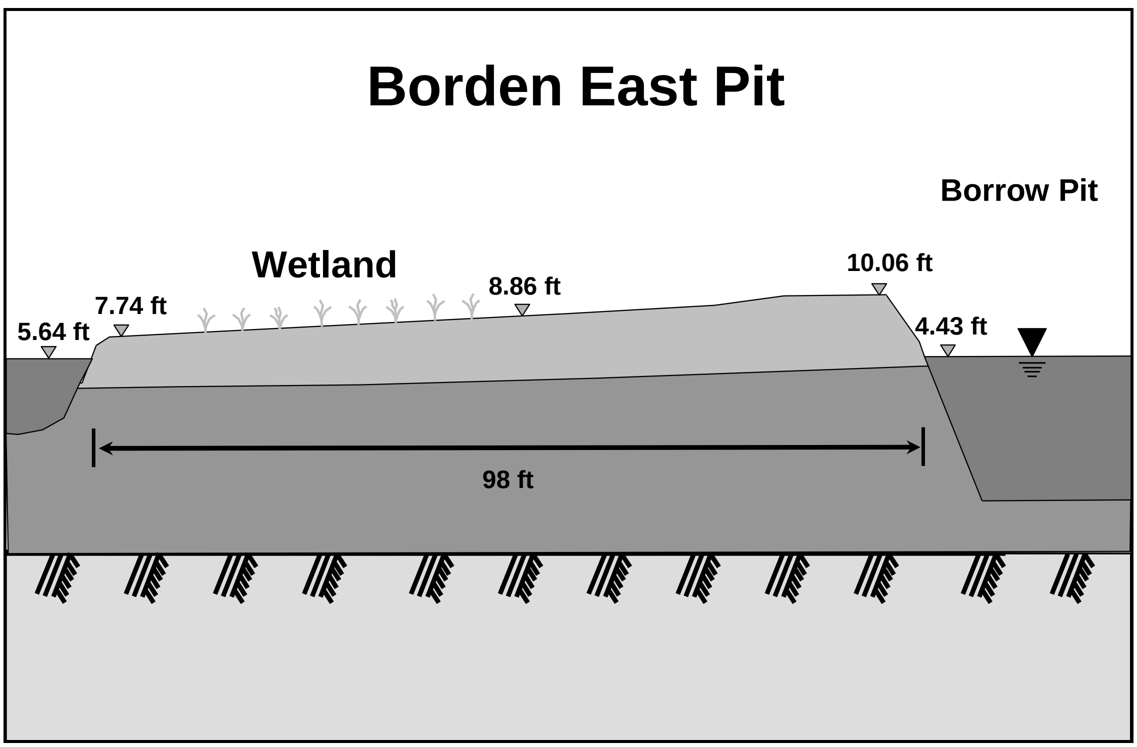


**Figure 14. Type 1b - Water level of pit limited by seepage to sink. Borden East Pit. Ground surface of wetland at higher elevation than pit water level. Water level of pit limited by seepage to stream. The stream level was high during this measurement.**

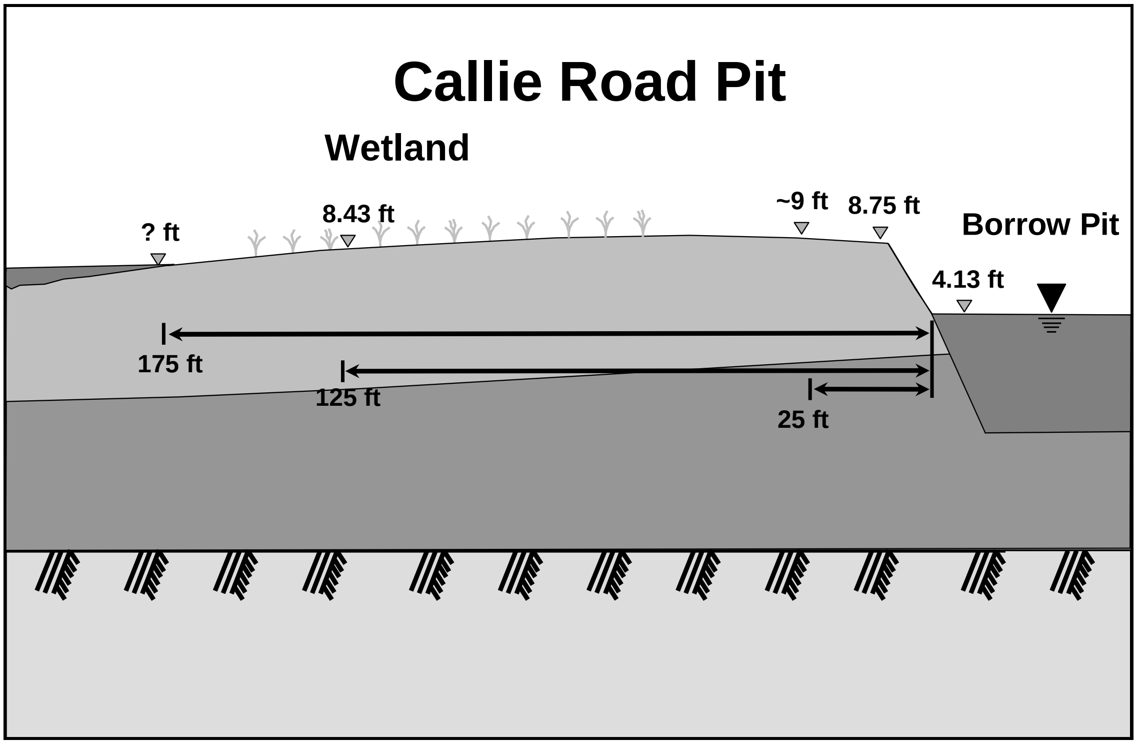


**Figure 15. Type 1 - Wetland upslope of pit. Callie Road Pit. Ground surface of wetland at higher elevation than pit water level. Limit of pit water level not determined.**

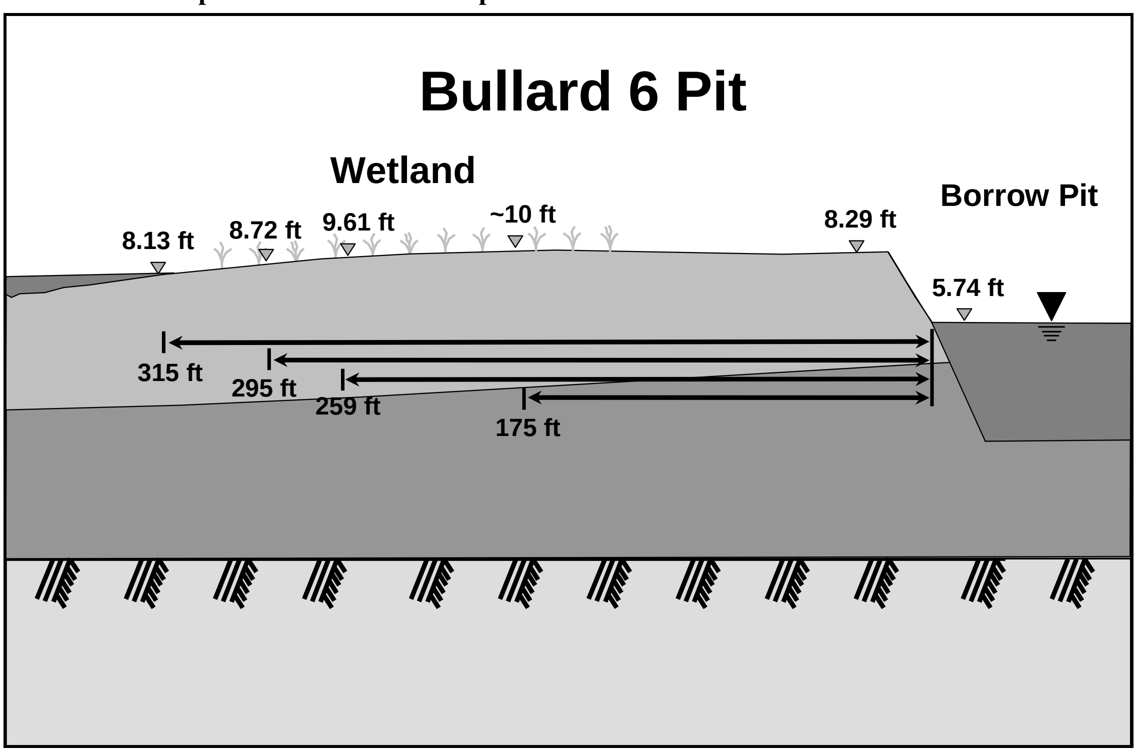


**Figure 16. Type 1 - Water level limit unknown. Bullard 6 Pit. Ground surface of wetland at higher elevation than pit water level. Limit of pit water level not determined.**

**Type 2: Wetland Down Slope From The Pit.** The **Type 2** borrow pit represents the condition where the wetland is down slope from the pit. The ground surface of the wetland is at an elevation lower than the average water level of the borrow pit. This situation usually occurs when the pit is constructed near a stream and the wetland is located on the floodplain between the pit and the stream. Examples of these pits are the Stallings pit, the Vail pit, the Nance pit, and the Borden South pit (Figures 17 to 20). The Pierce pit (Figure 21) was located on a ridge between two streams with wetlands on the floodplain. Type 2 pits also occur if the wetland is located on a slope away from the pit. The Tart pit (Figure 22) is an example where the wetland is on a slope. Our observation is that the equilibrium water levels in Type 2 borrow pits are close to seasonal high water table elevations prior to construction. The volume of water stored in the pit provides a continuous source of seepage so the pit may cause the wetland to be somewhat wetter during the summer months rather than drier. However these effects are not expected to be large and would be difficult to detect in most years.

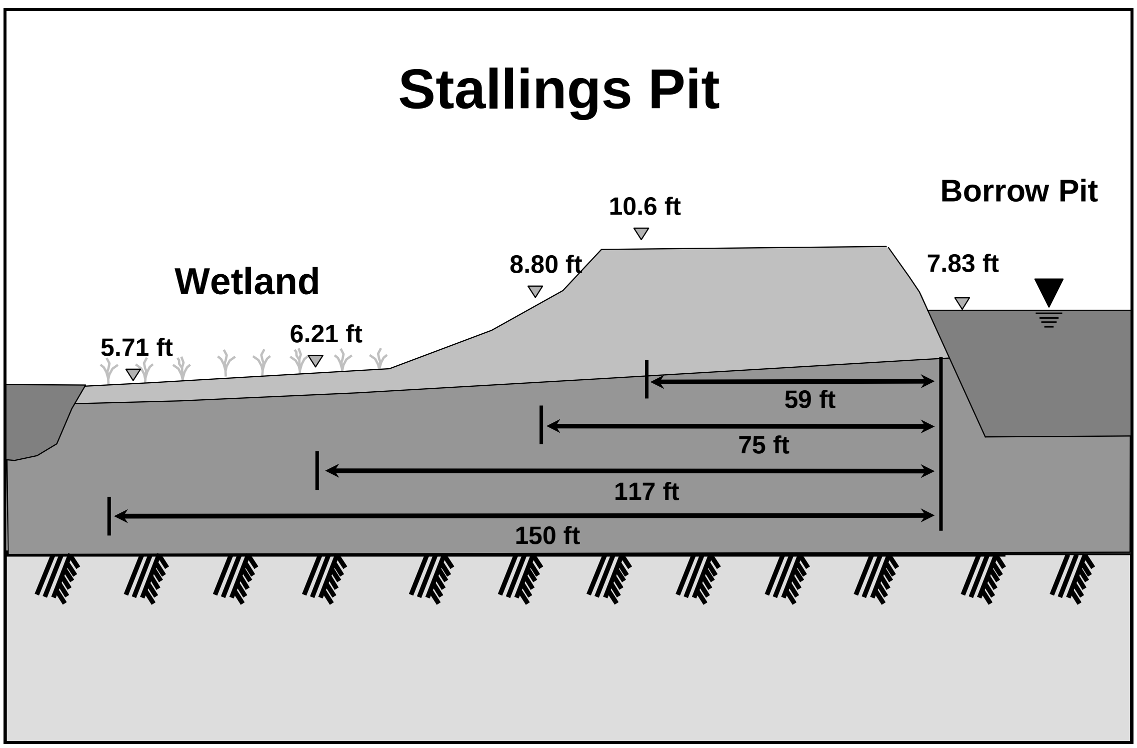


**Figure 17. Type 2 Stallings Pit. Wetland down slope of pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the stream.**

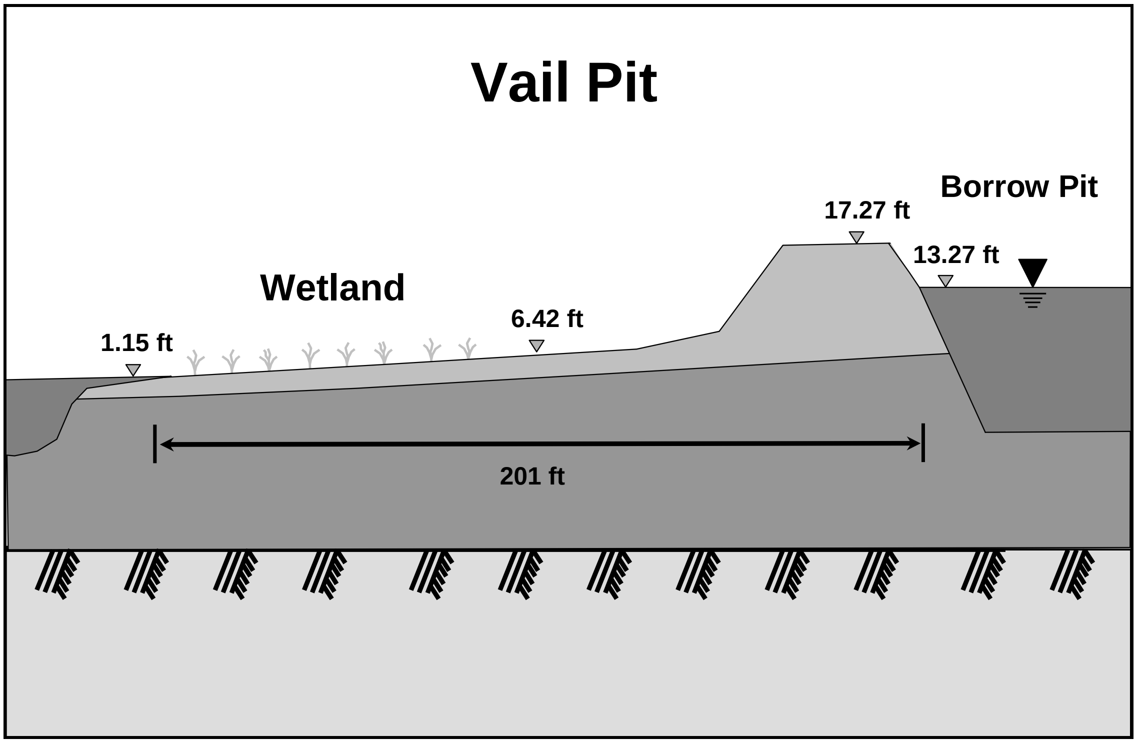


**Figure 18. Type 2 - Wetland down slope of pit. Vail Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the stream.**

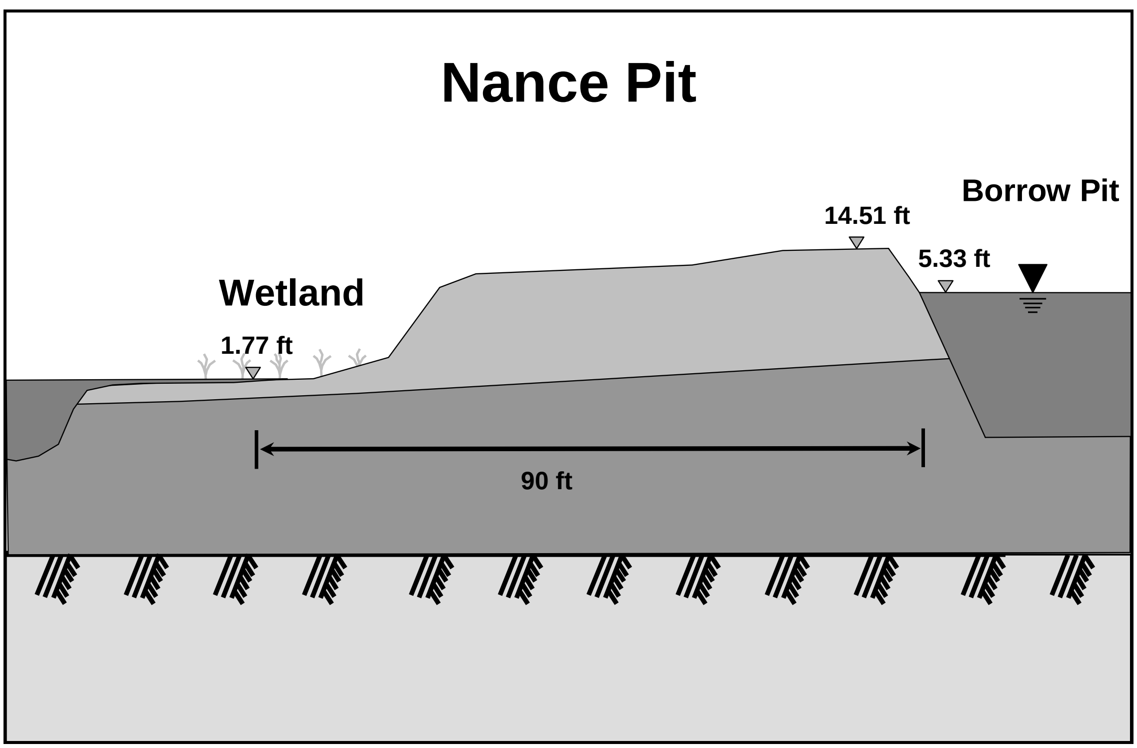


**Figure 19. Type 2 - Wetland down slope of pit. Nance Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the stream.**

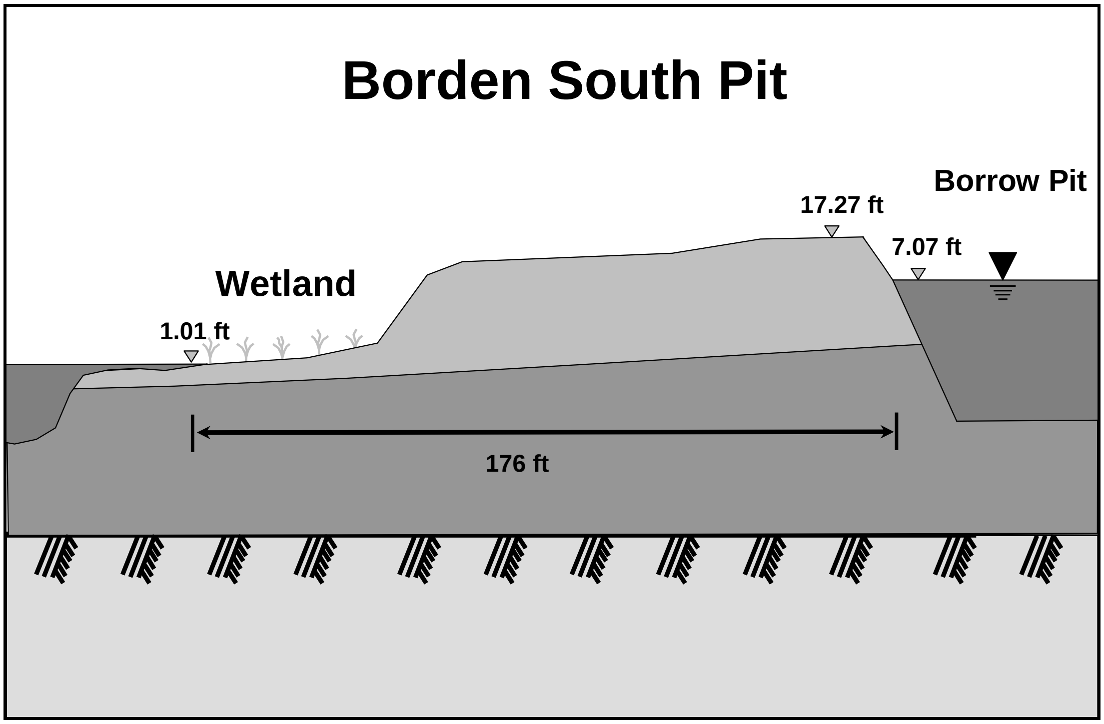


**Figure 20. Type 2 - Wetland down slope of pit. Borden South Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the stream.**

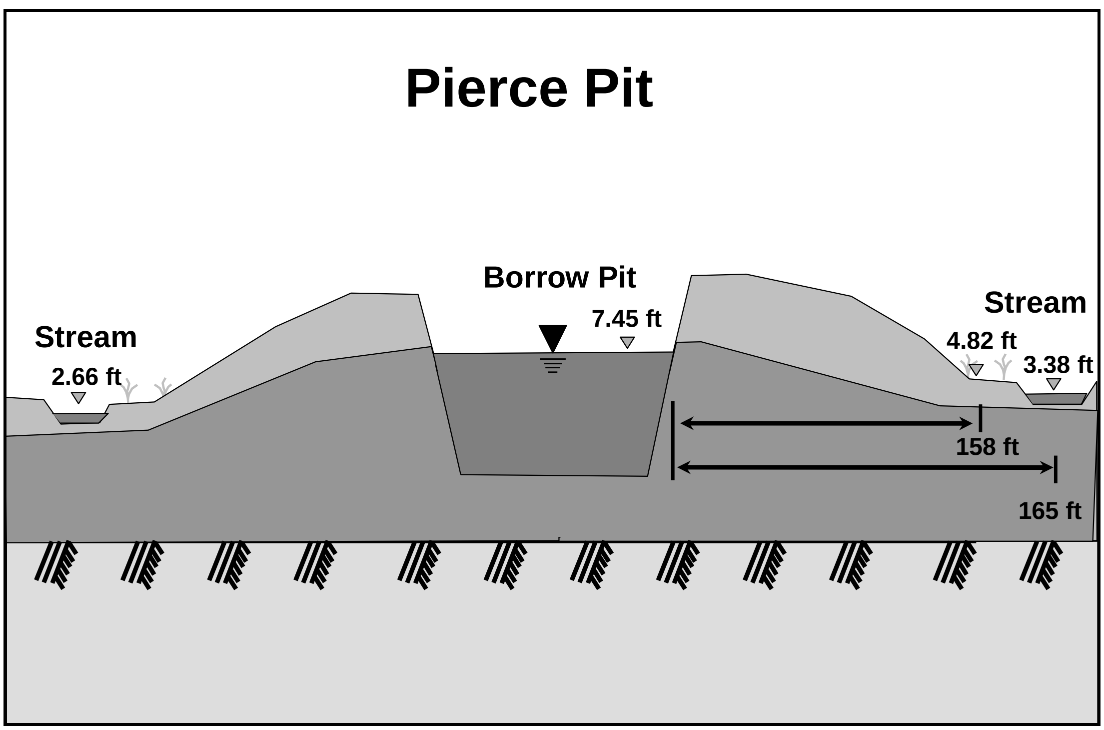


**Figure 21. Type 2 - Wetland down slope of pit. Pierce Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the streams. Pit is located on a ridge between streams.**

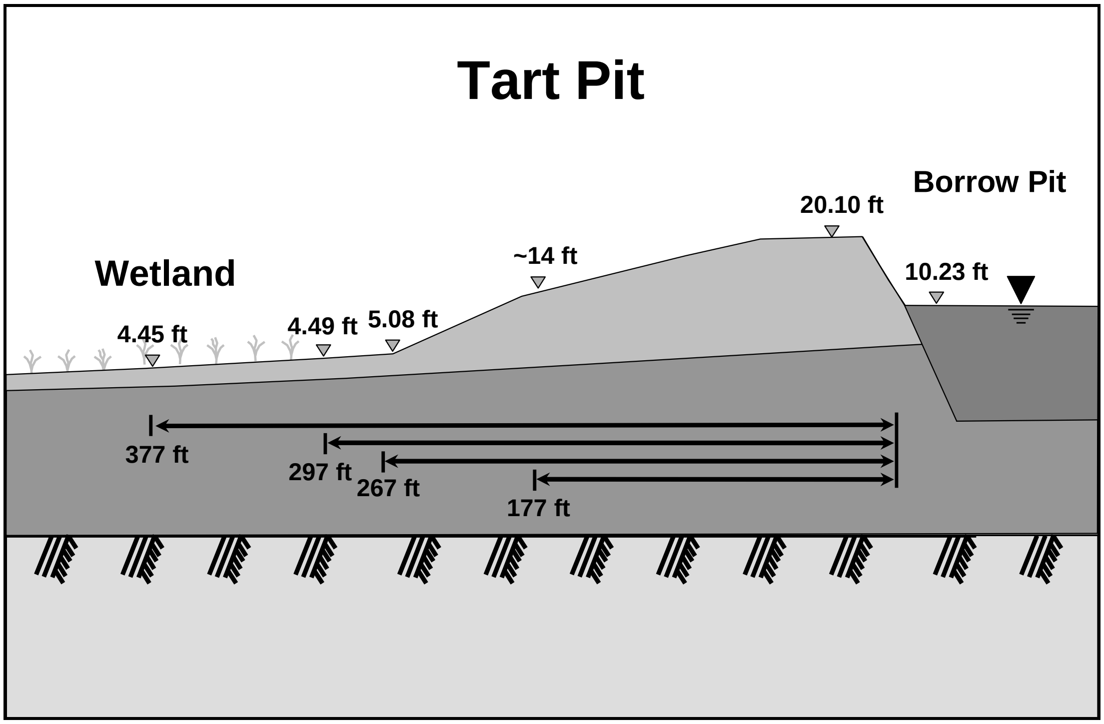


**Figure 22. Type 2 - Wetland down slope of pit. Tart Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on a slope away from the pit.**

**Type 3: Wetlands Upslope And Down Slope of the Pit**. The **Type 3** borrow pit is a combination of **Types 1 and 2**. That is, the pit is adjacent to two wetlands with one wetland upslope of the pit and the other wetland is downslope of the pit. The Vann pit and the Prime Ridge pit (Figures 23 and 24) are examples of Type 3 pits. The potential impact of the borrow pits on the upslope wetland would be a much greater concern than the impact on the down slope wetland in most cases. The method developed in this study can be used to determine the setback distance necessary to avoid detrimental effects to the wetlands upslope from the pit. Our observations indicate that the equilibrium water level in the pit will be approximated as the seasonal high water table at the location of the pit prior to its construction.

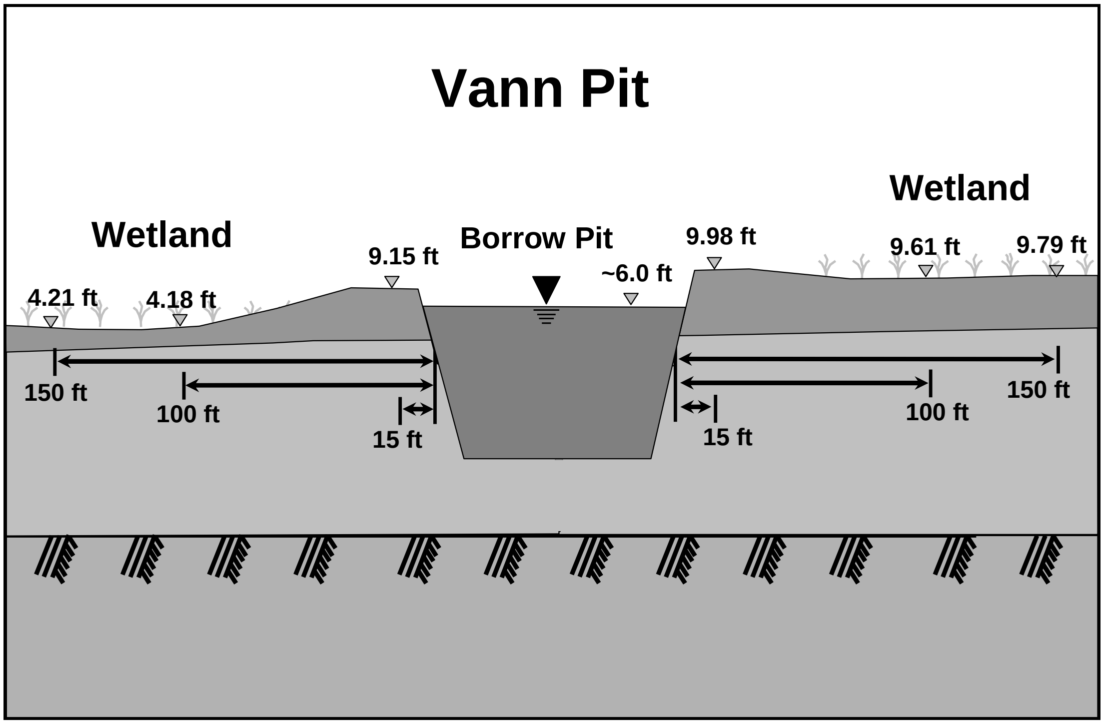


**Figure 23. Type 3 – Wetlands both upslope and down slope of pit. Vann Pit. Ground surface elevation of one wetland is lower than pit water level, and ground surface elevation of other wetland is higher than pit water level.**

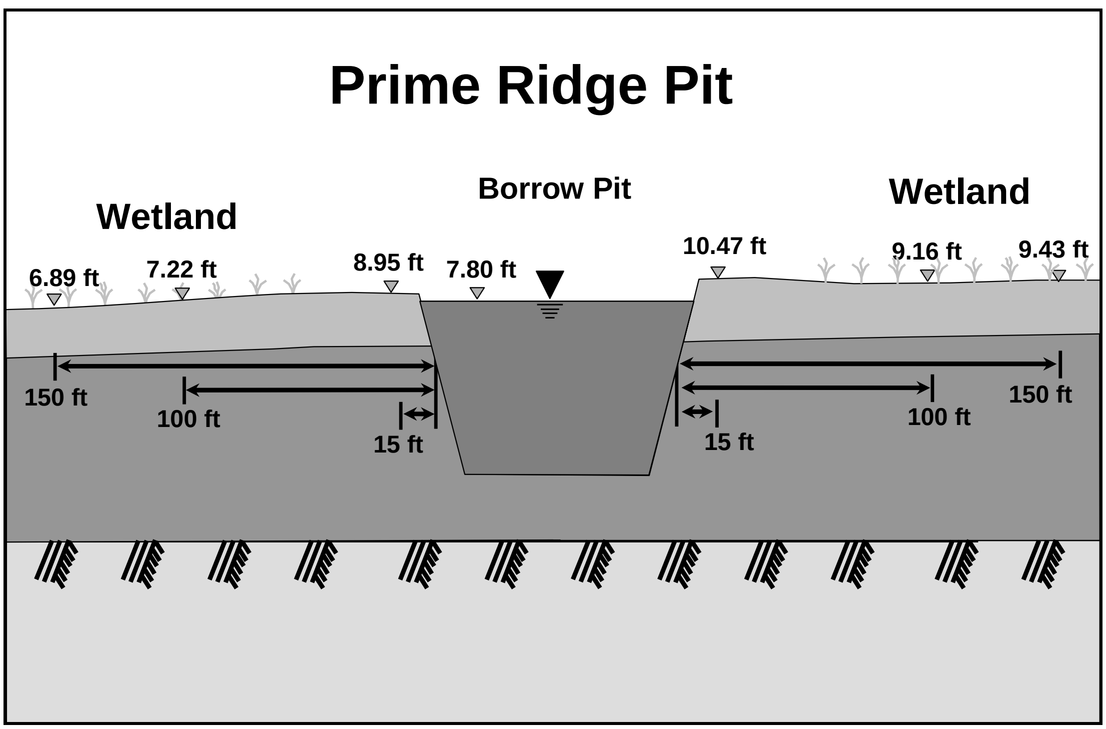


**Figure 24. Type 3 – Wetlands both upslope and down slope of pit. Vann Pit. Prime Ridge Pit. Ground surface elevation of one wetland is lower than pit water level, and ground surface elevation of other wetland is higher than pit water level.**

Table 5 lists a summary of initial observations of the elevations of pit water level and wetland ground surface at all visited pits. Pit water level elevations higher than those observed in the wetland indicated a general seepage direction from the pit to the wetland. Of the 26 visited sites, the direction of seepage was from the pit to the wetland at 8 sites (31%) and from the wetland to the pit at 11 sites (42%). At the remaining 7 sites (27%), it was either unclear whether the direction of seepage would be from the pit to the wetland or from the wetland to the pit, or seepage was sometimes in one direction and sometimes in the other.

**Table 5. Summary of survey data. Negative elevation difference denotes a flow direction from pit to wetland. * Open/closed designation indicates status when monitoring started. All pits were full at end of study**

| Instrument Status | Pit Name | Open/ Closed* | Flow direction | Relative elevation of water surface in pit (ft) | Relative elevation of wetland soil surface (ft) | Elevation difference (ft) | Distance from pit (ft) | Pit status |
|---|---|---|---|---|---|---|---|---|
| Instrumented | Spruill | Open | Wet to Pit | | | | | Full |
| | Davis | Open | Wet to Pit | | | | | Full |
| | Vann | Open | Maybe both | 3.69 | 4.18 | 0.49 | 100 | Full |
| | South | | | 3.69 | 4.21 | 0.52 | 200 | |
| | North | | | 3.69 | 9.61 | 5.93 | 100 | |
| | | | | 3.69 | 9.79 | 6.10 | 200 | |
| | Prime Ridge | Open | Wet to Pit | 4.75 | 7.22 | 2.47 | 100 | Full |
| | East | | | 4.75 | 6.89 | 2.14 | 200 | |
| | West | | | 4.75 | 9.16 | 4.41 | 100 | |
| | West | | | 4.75 | 9.43 | 4.68 | 200 | |
| | Mildred Woods | Closed | Wet to Pit | 4.04 | 4.97 | 0.93 | 100 | Full |
| | | | | 4.04 | 5.91 | 1.87 | 200 | |
| | | | | 4.04 | 6.30 | 2.26 | 300 | |
| | Stallings | Closed | Pit to Wet | 3.42 | 6.10 | 2.68 | 59 | Full |
| | | | | 3.42 | 1.67 | ***-1.75*** | 117 | |
| | | | | 3.42 | 1.17 | ***-2.25*** | 150 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Twiddy | Closed | Unclear | 2.52 | 2.50 | -0.02 | 127 | Full |
| | Hardy | Closed | Wet to Pit | | | | | Full |
| Survey Only | Vail | Closed | Pit to Wet | 13.27 | 1.15 | ***-12.12*** | 201 | Full |
| | | | | 13.27 | 6.24 | ***-7.03*** | 100 | |
| | Hobbs | Open | Unclear | | | | | |
| | Bullard 6 | Closed | Wet to Pit | 5.74 | 8.13 | 2.39 | 315 | Full |
| | Bethel | Closed | Wet to Pit | | | | | Full |
| | Park Lake | Open | Pit to Wet | | | | | Filling |
| | Bordan-S | Closed | Pit to Wet | 7.07 | 1.01 | ***-6.06*** | 176 | Full |
| | Bordan-E | Closed | Unclear | 4.43 | 5.64 | 1.21 | 98 | Full |
| | Bordan-N | Open | Pit to Wet | | | | | Filling |
| | Pierce | Open | Pit to Wet | 7.45 | 4.82 | ***-2.63*** | 156 | Full |
| | | | | 7.45 | 3.38 | ***-3.07*** | 165 | |
| | | | | 7.65 | 2.66 | *-4.99* | 150 | |
| | Nance | Closed | Pit to Wet | 5.33 | 1.77 | *-3.44* | 90 | Full |
| | Tart | Closed | Pit to Wet | 10.23 | 5.08 | *-5.17* | 267 | Full |
| | Bullard 4 | Closed | Wet to Pit | 1.26 | 5.05 | 3.79 | 70 | Full |
| | Bullard 3 | Open | Unclear | 1.62 | 6.77 | 5.15 | 60 | Full |
| | *Ditch* | | | 1.62 | 1.97 | 0.35 | 83 | |
| | | | | 1.62 | 5.00 | 3.38 | 160 | |
| | Aycock | Closed | Wet to Pit | | | | | Full |
| | Thomason | Closed | Unclear | | | | | Full |
| | Alexander | Closed | Unclear | 3.24 | 7.06 | 3.82 | 110 | Full |
| | *Ditch* | | | 3.24 | 2.66 | *-0.58* | 122 | |
| | | | | 3.24 | 4.24 | 1.00 | 233 | |
| | Callie Rd | Closed | Wet to Pit | 4.13 | 8.43 | 4.20 | 125 | Full |
| | Williams | Closed | Wet to Pit | 2.89 | 5.60 | 2.71 | 112 | Full |

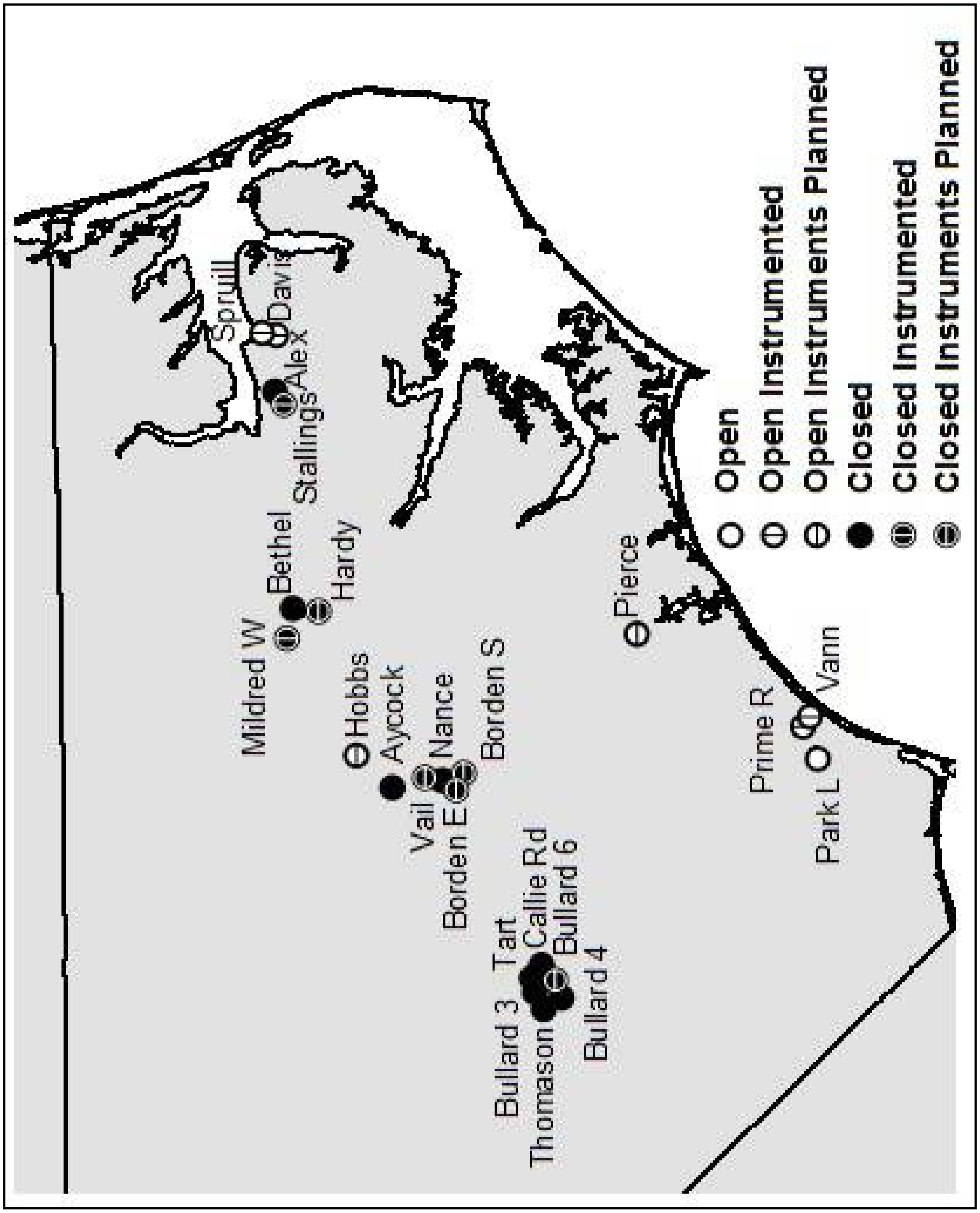


**Figure 25. Location of visited pits and status at time of initial visit.**

## EQUILIBRIUM WATER LEVELS

### RECENTLY CLOSED PITS

Data were collected on four borrow pits that were "recently" closed and in the process of filling; Davis, Spruill, Vann, and Prime Ridge. Hourly water levels were recorded in both the pit and in a transect of two or three wells leading away from the pits. These water levels were related to one another at each site by defining an arbitrary datum selected at the time of equipment installation.

The time required for the pits to fill varied from 10 months for the Vann pit to 23 months for the Spruill pit. Table 6 summarizes the closure dates of the instrumented pits and time required for the water level to reach equilibrium in each case. Time required to reach equilibrium would obviously depend on rainfall conditions during the period. It varied from 10 to 23 months with an average of 17 months for the four pits studied.

**Table 6. Time required for "recently" closed pits to attain equilibrium water level.**

| Borrow Pit | County | Date Closed | Date Equilibrium Water Level Attained | Time to Reach Equilibrium Water Level |
|---|---|---|---|---|
| Davis | Tyrrell | July 2005 | January 2007 | 18 months |
| Spruill | Tyrrell | April 2005 | March 2007 | 23 months |
| Vann | New Hanover | October 2004 | August 2005 | 10 months |
| Prime Ridge | New Hanover | October 2004 | January 2006 | 15 months |

After attaining equilibrium, the depth to pit water surface from the ground surface of the wetlands varied from -1.3 to 4.3 ft, where a negative value indicates that the water level in the pit was at a higher elevation than the ground surface of the wetland. Results of the depth to the pit water surface from the ground surface of the transect wells are summarized in Table 7.

**Table 7. Depth (ft) of equilibrium water level below ground surface in "recently" closed pits. Negative values indicates water level in pit higher that wetland ground surface.**

| **Borrow Pit** | Davis | Spruill | Vann North | Vann South | Prime Ridge East | Prime Ridge West |
|---|---|---|---|---|---|---|
| Pit Type | Type 1b | Type 1b | Type 3 | Type 3 | Type 3 | Type 3 |
| 100 ft well | | | | | | |
| Average | 3.8 ft | 2.1 | 4.1 | -1.3 | 1.0 | -0.9 |
| Std Dev | 0.24 | 0.22 | 0.58 | 0.58 | 0.35 | 0.35 |
| Max | 4.3 | 2.4 | 5.7 | 0.2 | 2.0 | -0.06 |
| Min | 3.3 | 1.6 | 2.7 | -2.8 | 0.5 | -1.5 |
| 200 ft well | | | | | | |
| Average | 4.0 ft | 1.6 | 4.3 | -1.3 | 1.3 | -1.2 |
| Std Dev | 0.24 | 0.22 | 0.58 | 0.58 | 0.35 | 0.35 |
| Max | 4.5 | 1.9 | 5.9 | 0.2 | 2.3 | -0.3 |
| Min | 3.5 | 1.1 | 2.9 | -2.8 | 0.8 | -1.8 |

The Davis and the Vann pits exhibited the greatest depth to the pit water surface, 4.0 and 4.3 ft, respectively. Water level in the Davis pit (type 1b) was controlled by seepage to drainage ditches in the vicinity, and in the Vann pit by natural seepage from north to south in the landscape. There is a 0.5 ft elevation difference in the ground surface of the 100 and 200 ft wells at the Spruill pit. These differences in elevation are reflected in the depths to the pit water surface in Table 7. The Prime Ridge East site showed the smallest difference between depth to the water level in the pit and the ground surface in the wetland; 1.0 ft at the 100 ft well and 1.3 ft at the 200 ft well. Two sites showed conditions such that the water level in the pit was at a higher elevation than the ground surface of the wetland. No lateral effects were observed at these sites, Vann South and Prime Ridge West.

### *Davis Borrow Pit*

The Davis pit was closed in July 2005 and attained an equilibrium water level in January of 2007. This is a Type 1b pit (Figure 11) with a shallow (1.5 – 2 ft) ditch located between the pit and the adjacent wetland on the eastern side and a deeper ditch (3 – 4 ft) between the borrow pit and an agricultural field to the south. Monitoring of the water table at wells in the wetland and located 100 and 200 ft from the pit began in November 2004. Pit water levels were recorded starting in early August 2005. Daily water table and pit water level elevations are shown in Figure 26.

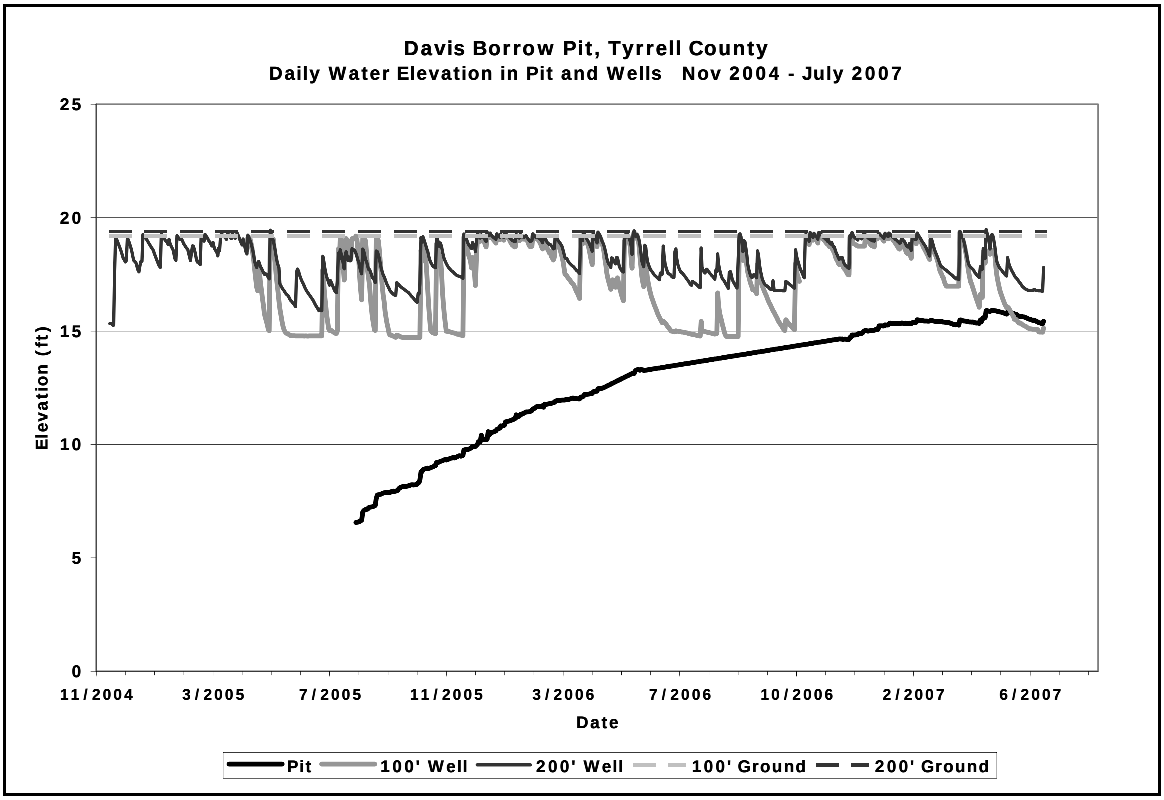


**Figure 26. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) Nov. 2004 to July 2007 at Davis borrow pit. This pit closed in late July, 2005. Well at 100' and Well at 200' refer to wells located 100 ft. and 200 ft. from the edge of pit.**

The elevations shown in Figure 26, as well as all subsequent water elevation plots, are relative in nature. A common datum was defined at some depth and all well and pit elevations are referenced to that common datum.

Shortly after closure, the pit water level was at elevation 6.7 ft and reached an elevation of 15 ft at the time of equilibrium. The pit attained it highest daily elevation (15.9 ft) during May 2007. This followed a rain event (4.91 inches during May 6 – 12) sufficient to raise the water table in both wells to the surface from depths of up to three feet. The equilibrium water level of 15 feet is 4.2 ft below the ground surface of the 100 ft well and 4.4 ft below the ground surface of the 200 ft well. LIDAR[1] data for the area indicate that the topography of the Davis site and surrounding agricultural fields slopes in a north to south direction towards the Scuppernong River. Maximum elevations in the pit will be controlled by the southern ditch and probably will maintain a long term equilibrium water level of about 15 ft, which is approximately the elevation of the bottom of the drainage ditch.

[1] NC Floodplain Mapping Program: http://www.ncfloodmaps.com/default_swf.asp

The ditch located between the pit and the adjacent wetland on the eastern side will behave as a drainage sink and will intercept seepage from the wetland towards the pit in some cases. This will be discussed further in the next section.

***Spruill Borrow Pit***

The Spruill borrow pit, located in Tyrrell County, was closed in April 2005. The pit required the longest time to equilibrate (23 months) and increased about 14 ft in elevation from the onset of water level measurements. The Spruill pit is a Type 1b pit (Figure 12) with the ground surface of the wetland gently sloping away from the pit. Ground surface at wells located in the wetland at distances of 100 and 200 ft away from the ditch are 22.5 and 22.0 ft, respectively. At equilibrium, the pit water level was approximately 2.3 ft below the ground surface at the 100 ft well and 1.8 ft below the ground surface at the 200 ft. well. The Spruill pit and the Davis pit are in close proximity to one another (2 miles). As with the Davis pit, the Spruill pit showed a small spike in the elevation of the pit water level due to a large rain event in mid-May 2007. Following the rain event, the pit water level began to recede and most likely will maintain a long term equilibrium level of about 20.3 ft. Observed water elevations in the pit and in the wetland wells are shown in Figure 27.

Bull Bay is located 1.2 miles north of the Spruill pit. As expected, LIDAR data indicate a topography sloping away from the pit and towards Bull Bay. During the study period, the Spruill site showed no signs of tidal influence. That is no diurnal fluctuations were observed in the pit water level or in the water table of the wetland.

***Vann Borrow Pit***

Located in New Hanover county, the Vann borrow pit is a type 3 pit (Figure 23). Wetlands are located on the northeast (designated north) and the southwest (designated south) sides of the pit. The Vann pit was closed in October 2004 and reached an equilibrium water level in about 10 months. Daily water elevations in the wetland and in the pit are shown in Figures 28 and 29.

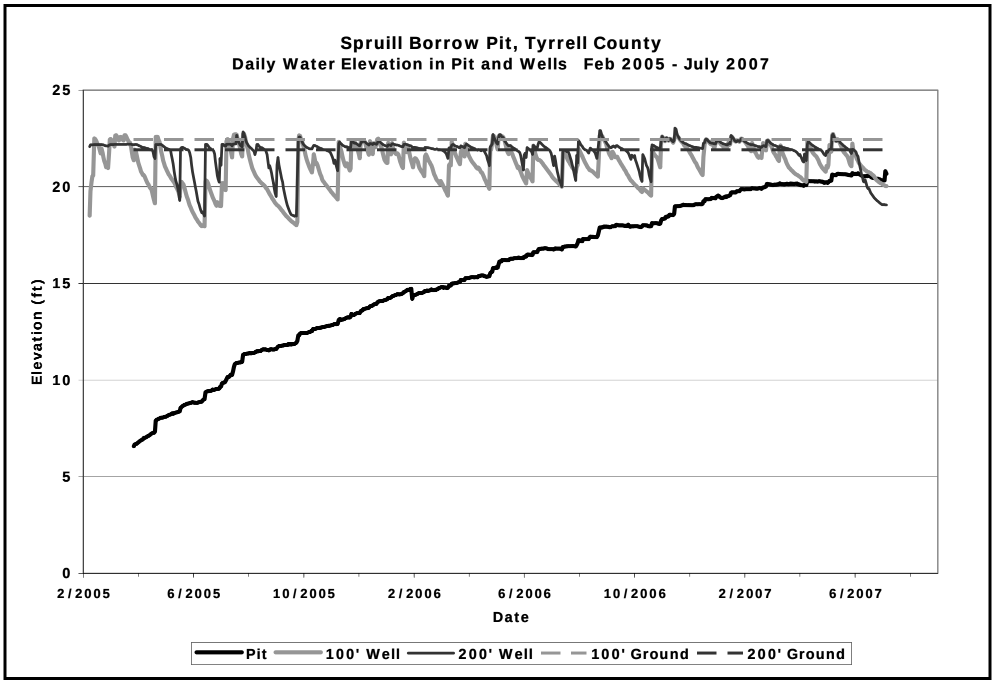


**Figure 27. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for Feb 2005 to July 2007 at the Spruill borrow pit. This pit closed in April, 2005. Well at 100' and Well at 200' refer to wells located 100 ft. and 200 ft. from the edge of pit**

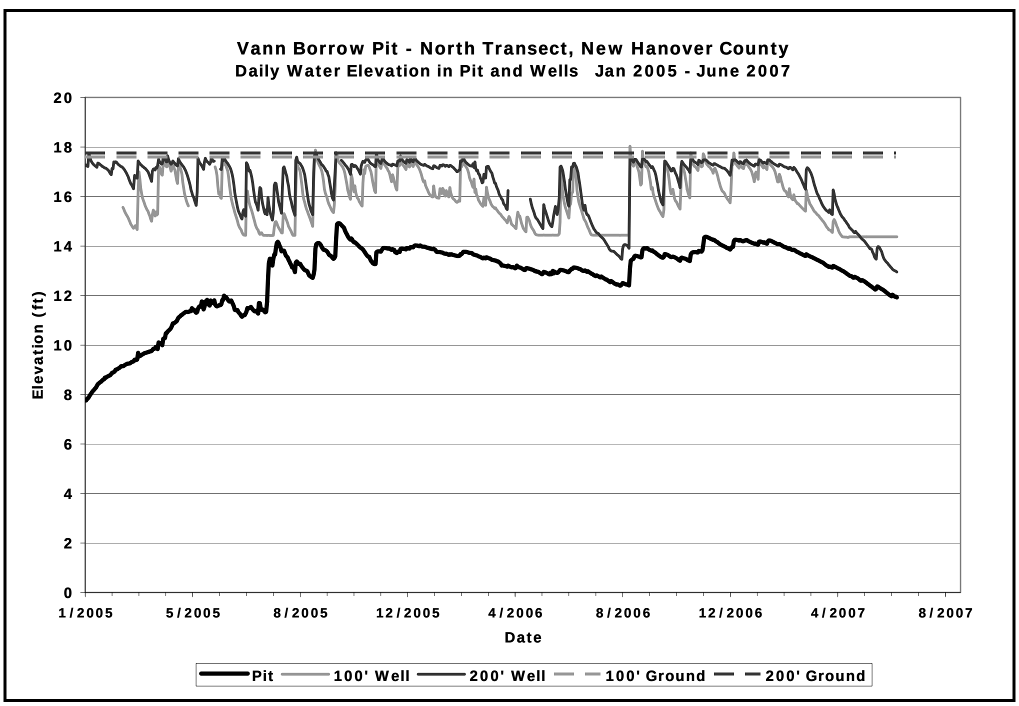


**Figure 28. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for Jan 2005 to June 2007 at the Vann borrow pit north transect. The water table data were measured along a line north of the pit where land is upslope from the pit. This pit closed in October, 2004. The increase in stage at the end of July 2005 was caused by water (approx 1,728,000 gallons) being pumped into the pit.**

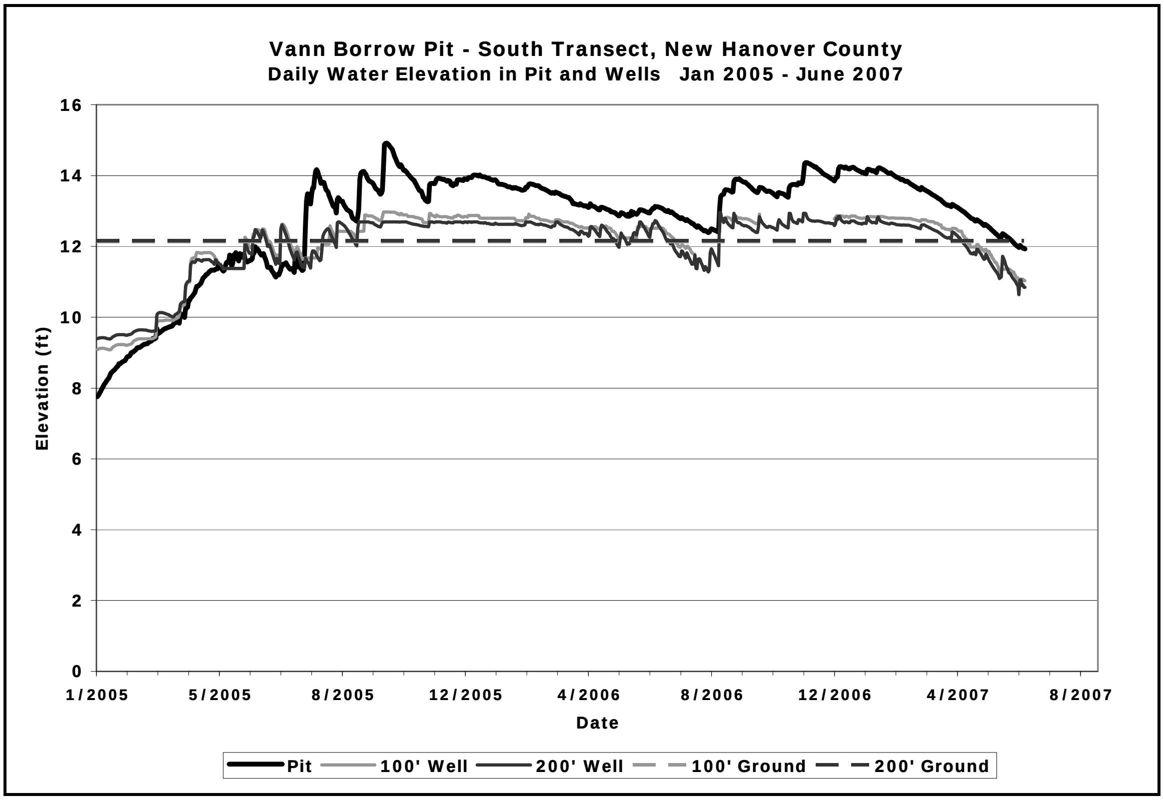


**Figure 29. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for Jan 2005 to June 2007 at the Vann borrow pit south transect. The water table data were measured along a line south of the pit where land is downslope from the pit. This pit closed in October, 2004. The increase in stage at the end of July was caused by water (approx 1,728,000 gallons) being pumped into the pit.**

Both sides of the pit had monitoring wells in the wetlands at distances of 100 and 200 ft. Ground elevations on the north side were 17.6 and 17.8 ft at the 100 and 200 ft well, respectively. When the pit equilibrated, the water level averaged 4.1 and 4.3 ft below the ground surface of the north side. Ground elevations on the south side were nearly identical at 12.1 ft. This was 1.3 ft below the average equilibrated pit water level.

The pit exhibited a natural hydraulic gradient from northern wells to the southern wells. In this case the pit served as a flow through entity; behaving as both a sink and a source. The general slope of the ground surface, as measured during the equipment installation survey and from New Hanover 2 ft contours, is from northeast to southwest. These data indicate that, in the absence of the pit, the general direction of groundwater movement would have been the same as it is now and that the pit water surface depth is close to the seasonal high water table elevation prior to pit construction.

### *Prime Ridge Borrow Pit*

The Prime Ridge borrow pit, also located in New Hanover county, is a type 3 pit (Figure 24). Wetlands are located on both the northern and southern sides. The pit attained equilibrium in January 2006, about 15 months after closure. Ground elevations were higher on the eastern side compared to the western side with an overall difference of 2.5 ft. Figures 30 and 31 show daily water level elevation plots for the pit and the water table recording wells in the wetlands on both sides of the pit.

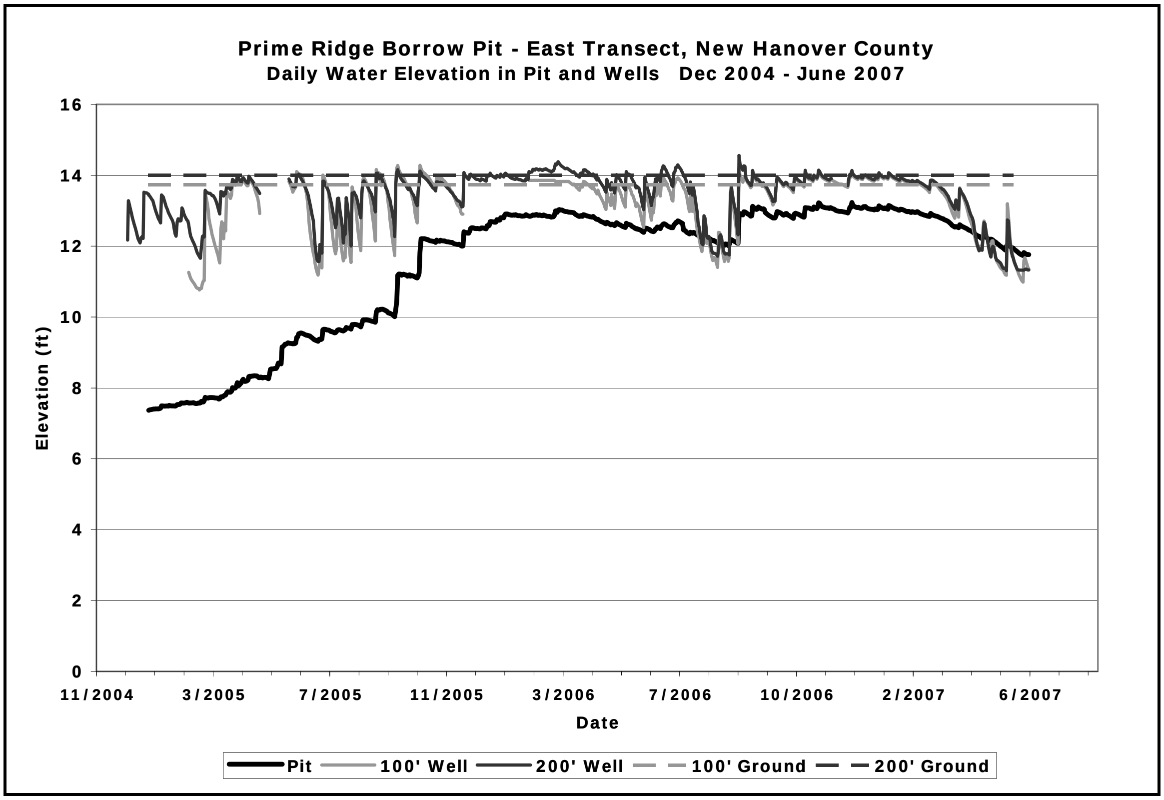


**Figure 30. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for Dec 2005 to June 2007 at the Prime Ridge borrow pit east transect. The water table data were measured along a line west of the pit where land is vegetated with grasses.**

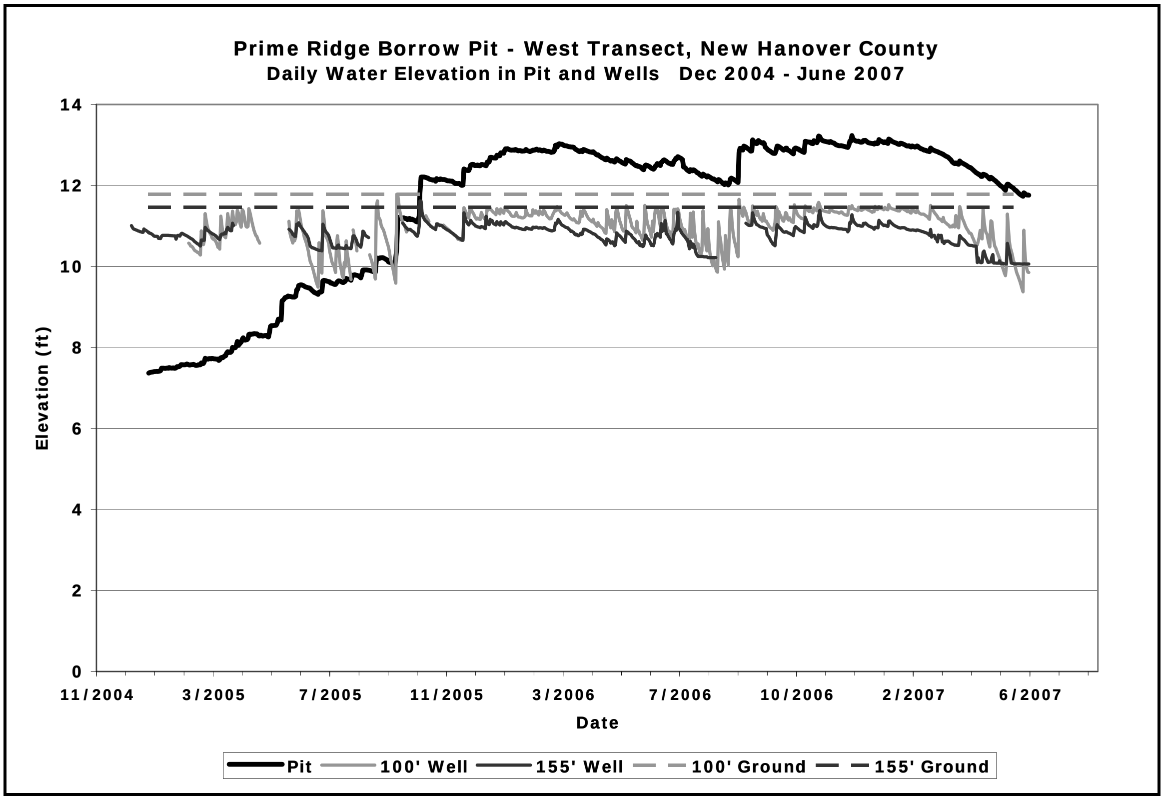


**Figure 31. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for Dec 2005 to June 2007 at the Prime Ridge borrow pit west transect. The water table data were measured along a line west of the pit where land is vegetated with mature trees.**

The average depth of the pit water surface below the ground surface of the wetlands was 1 ft and 1.3 ft at the locations of the 100 and 200 ft wells, respectively. The reverse is noted on the northern side of the pit where ground elevations are lower. Pit water levels were about 1 foot higher than the ground surface of the northern 100 ft well and about 1.3 ft higher at the 200 ft well. Water table data indicate a hydraulic gradient sloping from south to north and the absence of a lateral impact due to the pit on the northern wetland. These data are in agreement with New Hanover 2 ft contours which also indicate a decrease in topographic elevations in the north direction.

## OLD PITS

Monitoring was performed at four old closed pits: Mildred Woods, Hardy, Stallings, and Twiddy. These pits had been closed for at least 4 years at the time of instrumentation and water levels in the pit were assumed to have equilibrated. Hourly water levels in the pit and in wells located in adjacent wetlands as well as precipitation were recorded at each site and will be presented in plot form in this section.

While the pit water levels had attained an “equilibrium” status, they were not constant, but varied with rainfall, evaporation and other factors. Maximum changes in the pit water levels varied from site to site and ranged from 4.2 ft at the Hardy pit to 1.2 ft at the Twiddy pit. The observed maximum water level range at the Mildred woods site was 3.7 ft and 2.0 ft at the Stallings site. It must be noted that on August 31 and September 1, 2006, Tropical Storm Ernesto produced rainfall amounts between 7 and 10 inches at the sites. Except for the Mildred Woods site, water levels in the pits increased 1 to 3 feet. The water in the Mildred Woods pit had previously overtopped the bank on portions of the east side (area near transect). Therefore, a pronounced spike in the water level in the pit was not observed at the Mildred Woods site compared to the other sites. High rainfall events due to hurricanes and tropical storms are normal occurrences in North Carolina and, as mentioned, cause water levels in the pits to temporarily increase in elevation. This would skew short term calculations of the maximum and range of observed pit water levels. Table 8 lists a summary of pit water level elevation data for each of the instrumented closed pits for cases when the effect of Tropical Storm Ernesto is included and when the effect is removed from the dataset (i.e. exclusion of September 2006 data). As expected, the maximum and range of pit water levels observed during the study period were lower when the effect of Tropical Storm Ernesto was removed. There was no difference between calculated values at the Mildred Woods site for reasons mentioned above.

Calculations were made to determine daily differences between the ground surface at the location of the wells in the wetlands and the pit water level. Daily averages, standard deviations, and max and min values for the old pits are listed in Table 9. The daily average ranged from -2.3 ft at the Stallings pit (signifying that the pit water level was on average 2.3 ft higher than the ground surface of the wetland) to 3.8 ft at the Hardy pit. Daily differences will vary from pit to pit and will be affected by conditions such as pit outlet structures, adjacent drainage ditches, and topography.

Table 8. Pit water level elevations for instrumented old closed pits.

| | Mildred Woods | Hardy | Stallings | Twiddy |
|---|---|---|---|---|
| **Monitoring Period** | April 2005 – July 2007 | May 2005 – July 2007 | Feb 2005 – July 2007 | Dec 2005 – July 2007 |
| **Pit Water Level Relative Elevation (ft)** | Including Tropical Storm Ernesto Data | | | |
| Average | 8.7 | 8.0 | 8.2 | 7.4 |
| Std Dev | 1.1 | 0.5 | 0.4 | 0.2 |
| Max | 10.6 | 11.1 | 9.3 | 8.3 |
| Min | 6.9 | 6.9 | 7.3 | 7.1 |
| Range | 3.7 | 4.2 | 2.0 | 1.2 |
| | Tropical Storm Ernesto Data Removed | | | |
| Average | 8.7 | 7.9 | 8.1 | 7.4 |
| Std Dev | 1.1 | 0.3 | 0.4 | 0.2 |
| Max | 10.6 | 8.9 | 9.0 | 8.0 |
| Min | 6.9 | 6.9 | 7.3 | 7.1 |
| Range | 3.7 | 1.9 | 1.7 | 0.9 |

Table 9. Depth (ft) of equilibrium water level below ground surface in old closed pits. Negative values indicates water level in pit higher that wetland ground surface. Notes: 1. Wells at 115 and 230 ft, 2. Wells at 75 and 150 ft. 3. Single well only at 129 ft.

| Borrow Pit | Mildred Woods | Hardy[1] | Stallings[2] | Twiddy[3] |
|---|---|---|---|---|
| 100 ft well[See Notes] | | | | |
| Average | 0.4 | 3.8 | 0.6 | -0.4 |
| Std Dev | 1.1 | 0.5 | 0.4 | 0.2 |
| Max | 2.2 | 4.8 | 1.5 | -0.1 |
| Min | -1.4 | 0.6 | -0.5 | -1.4 |
| 300 ft well[See Notes] | | | | |
| Average | 1.8 | 3.3 | -2.3 | |
| Std Dev | 1.1 | 0.5 | 0.4 | |
| Max | 3.6 | 4.4 | -1.5 | |
| Min | -0.1 | 0.2 | -3.5 | |

***Mildred Woods Borrow Pit***

Mildred Woods is a type 1a borrow pit (Figure 9) located in Edgecombe county. Water level and rainfall monitoring began in April, 2005, and continued until July, 2007. A transect of two recording wells (100 and 300 ft from the edge of the pit) and one monitoring well (150 ft from pit edge) were installed in an adjacent wetland along the eastern side of the pit. Observed daily water level elevations in the pit and at the location of the recording wells are plotted in Figure 31.

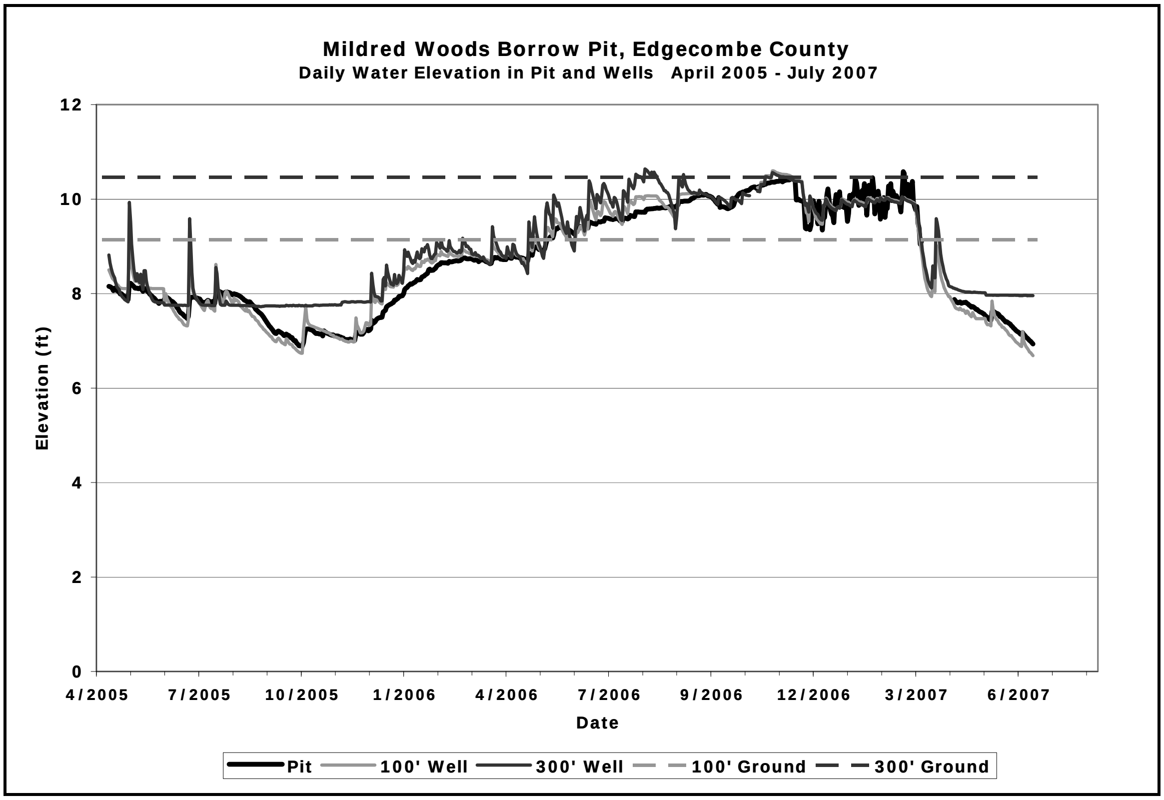


**Figure 31. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for April 2005 to July 2007 at the Mildred Woods borrow pit. 100' Well and 300' Well refer to wells located 100 ft. and 300 ft. from the edge of pit.**

The elevation of the water level in the pit began to increase in November 2005, and continued to increase until December 2006. The outlet structure of the pit was apparently blocked by some means causing an abnormal increase in the pit water level during this time period. Ponding conditions at the 100 ft well began in May 2006 and continued to April 2007. Had the outlet structure of the pit been open, pit water levels would have been lower and most likely been similar to the start and end of the plot shown in Figure 31.

Observed daily water table elevations at the 100 and 300 ft well locations were very similar to the pit water levels. Average daily differences between the pit water level and the water level in the 100 and 300 ft wells were 0.05 and 0.2 ft, respectively. This would indicate that the water level in the pit and in the adjacent wetland at the Mildred Woods site have a negligible hydraulic gradient. Therefore, there will be no lateral effect due to drainage to the pit at this site.

***Hardy Borrow Pit***

Located in Pitt county, the Hardy borrow pit is a type 1a pit. An outlet located at the southeast corner of the pit limits the maximum elevation in the pit under normal conditions. Daily water levels in the pit and at the location of monitoring wells in the adjacent wetland on the western side are plotted in Figure 32. As mention above, heavy rainfall produced by Tropical Storm Ernesto in late August 2006 caused submergence of the outlet control culvert and a spike in the water level in the pit. Over one month was required for complete discharge of the backwater held in the pit.

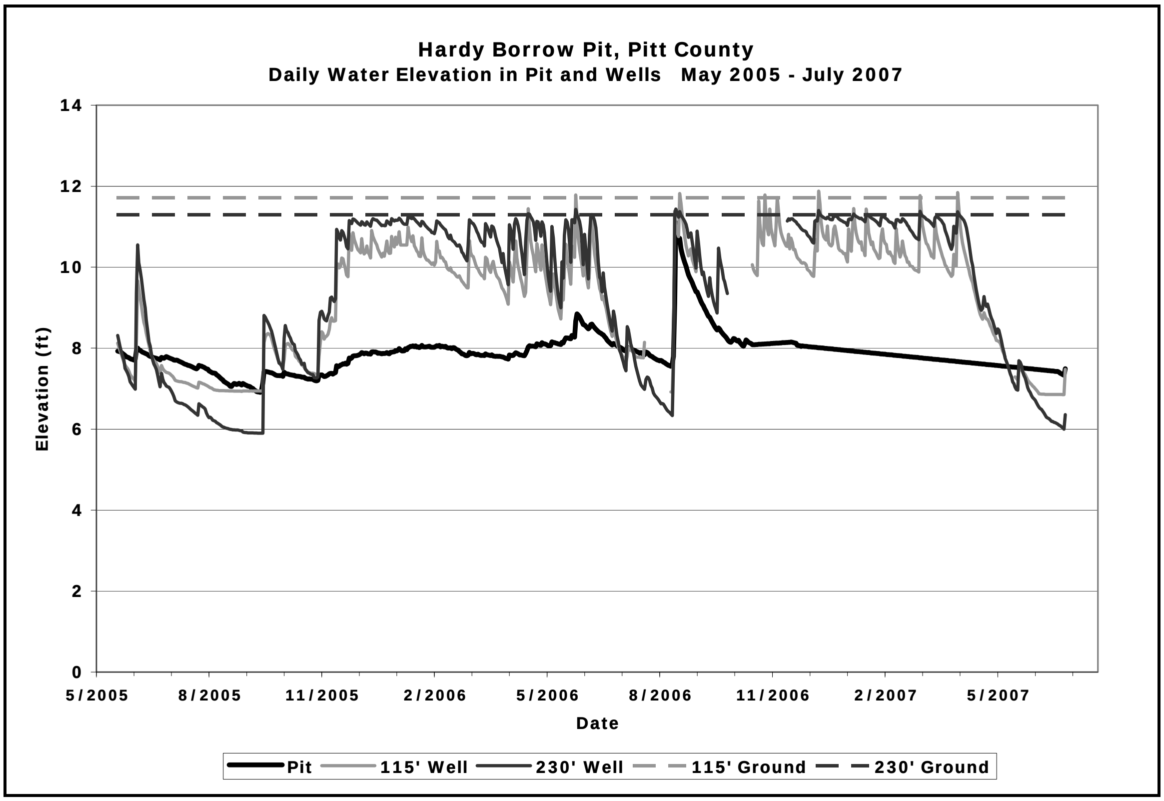


**Figure 32. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for May 2005 to July 2007 at the Hardy borrow pit. Well at 115' and Well at 230' refer to wells located 115 ft. and 230 ft. from the edge of pit.**

The Hardy pit was closed some years prior to instrumentation in May 2005, and it was assumed that the pit water level had attained equilibrium. Discounting the effect of Ernesto, the pit water level had an average elevation of 7.9 ft and a standard deviation of

0.3 ft. As noted above, the elevation of the pit water level was controlled by an outlet culvert.

The elevation of water levels observed at the wells in the wetland, were typically higher in the winter months as compared to summer. For various time periods during the three summer months of record (2005 – 2007), water levels in the pit were higher than those in the wetland. During these times, the pit served as a source and the direction of seepage was from the pit to the wetland. For all other times of the years, the gradient was such that the direction of seepage was from the wetland to the pit. A potential lateral effect could occur at this site due to drainage of the wetland caused by the pit.

***Stallings Borrow Pit***

The Stallings pit, located in Washington County, is a type 2 pit (Figure 17). The wetland is located downslope of the pit on the west side. This wetland is also on a small floodplain of a Kendrick Creek tributary. Daily observations of water levels in the pit and at the locations of monitoring wells installed in the wetland are plotted in Figure 33. For the entire monitoring period of February 2005 to July 2007, the water elevation in the pit was higher than observed at the 75 and 150 ft recording wells, 1.8 and 2.3 ft respectively. The direction of seepage was from the pit to the wetland for all months. No lateral effect would be observed at this site. Furthermore, the Stallings borrow pit serves as a continuous source of water for the wetland and for Kendrick Creek.

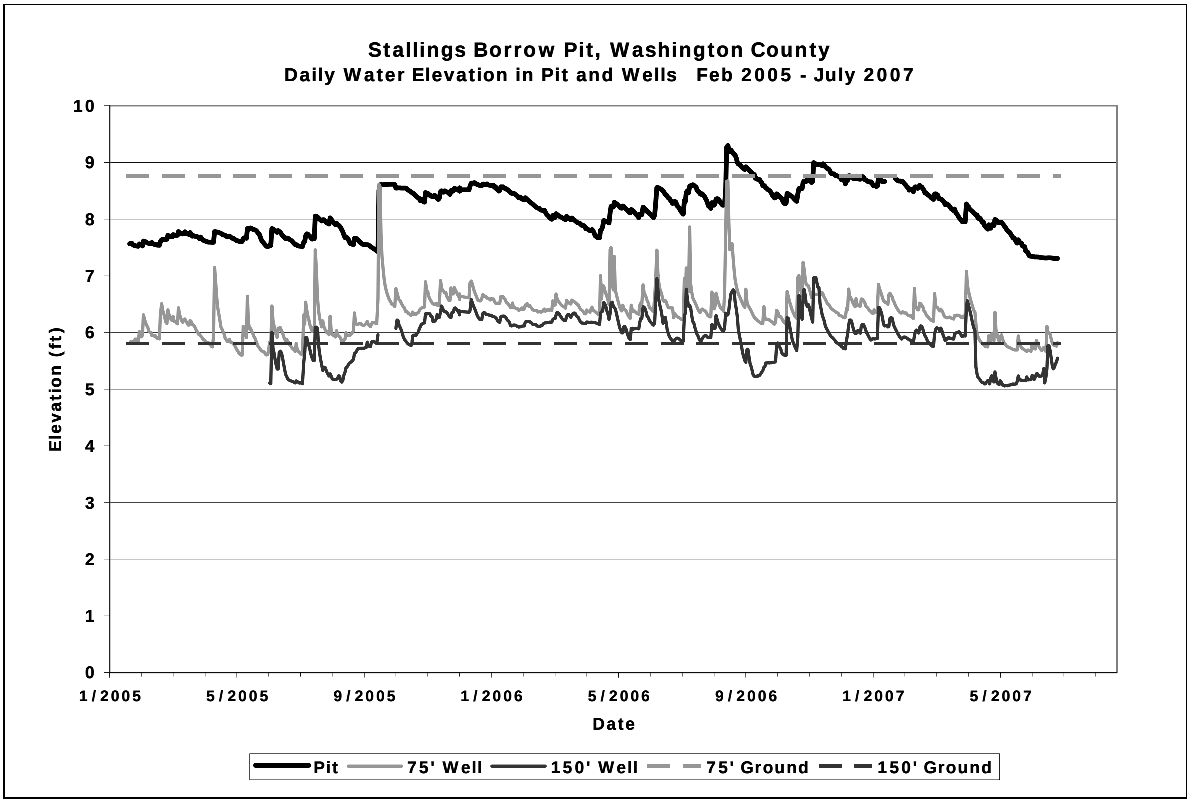


**Figure 33. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for February 2005 to July 2007 at the Stallings borrow pit. This pit has been closed since 2003. Well at 75' and Well at 150' refer to wells located 75 ft. and 150 ft. from the edge of pit.**

***Twiddy Borrow Pit***

The Twiddy pit is located in Washington County. It is a type 2 pit. A single monitoring well was installed 129 ft downslope of the pit in a wetland on the southern side of the pit. The wetland is located in what is termed a swamp that serves as floodplain for Deep Creek. During the monitoring period, December 2005 to July 2007, water was ponded on average 0.5 ft above the ground surface in the wetland. Daily water level elevations in the pit and at the wetland well are plotted in Figure 34. The pit and wetland water levels are very similar on a day to day basis and varied on average 0.2 ft during the study period. This trend was also observed at the Mildred Woods site. A lack of any significant hydraulic gradient between the water level in the pit and the wetland signifies that no lateral effect, as defined in this study, will be observed.

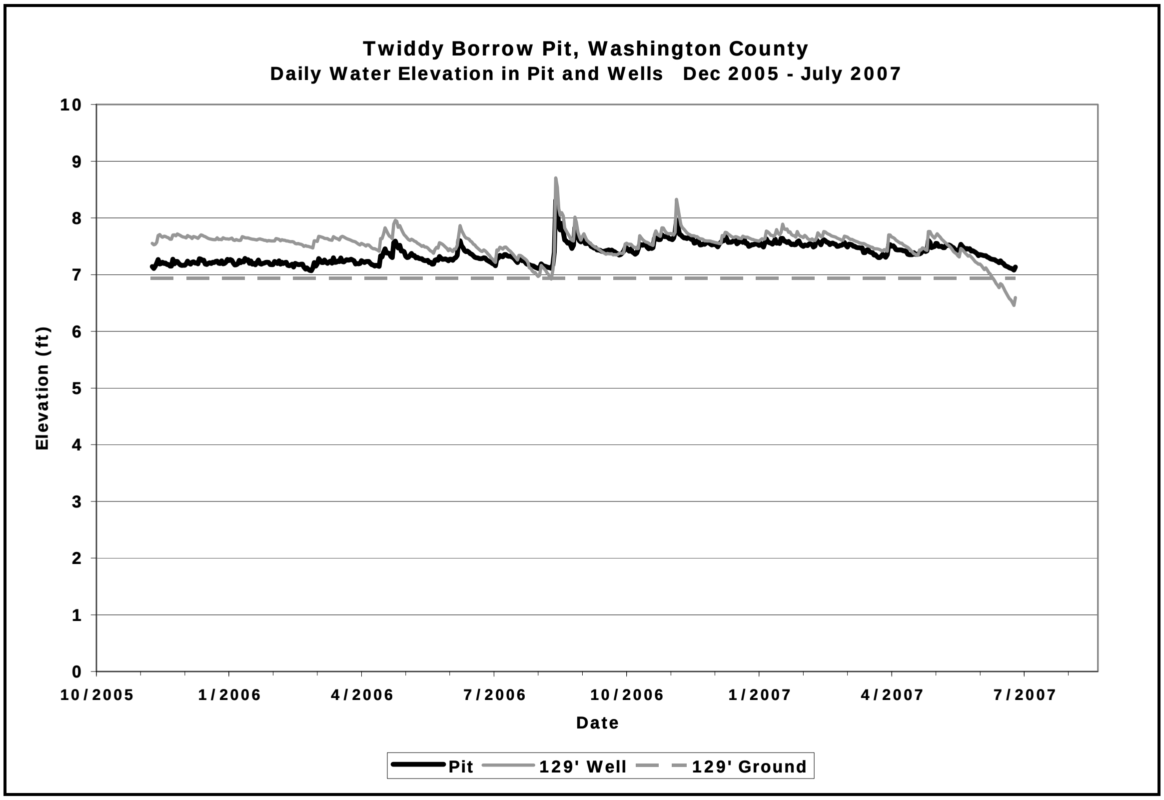


**Figure 34. Water table and pond elevations (referenced to 6.5 ft below the base of the pond staff) for December 2005 to July 2007 at the Twiddy borrow pit. Well at 129' refer to wells located 129 ft. from the edge of pit.**

## LATERAL EFFECT OF PITS

A potential lateral effect of borrow pits on wetland hydrology can be estimated from observed data and calculated with the method developed in this study on the following five study locations: Hardy, Davis, Spruill, Van North, and Prime Ridge South. At these sites, the water levels in the wetlands were higher that those observed in the pit causing the direction of seepage to be from the wetland to the pit. Observed well data for the sites were analyzed to estimate the maximum lateral effect of the pits directly from our on-site measurements. Results for the Hardy pit for 2006 will be used to demonstrate the method. First, the duration that the water table stayed above the 1 ft depth during the growing season was determined for each of the observation wells. Durations are plotted in Figure 35 for wells located 115 and 230 feet from the edge of the borrow pit.

The Hardy pit is located in Pitt county which has a 246 day growing season (NRCS[2]) and a critical duration, the threshold duration to satisfy the wetland hydrologic criterion, of 12

[2] NRCS Web Soil Survey: http://websoilsurvey.nrcs.usda.gov/app/

days.  The lateral effect due to the pit may be estimated as the distance from the pit where the water table will be within 1 ft of the soil surface for a continuous period of 12 days during the growing season in 50% of the years.  This location will be denoted X.  At that location X, the water table will be within 1 ft of the soil surface for 12 or more consecutive days in half of the years.  For the other half, the water table will be deeper than 1 ft.  Weather conditions will be the dominate influence on water table conditions; and for any particular year the water table at X will be within 1 ft of the soil surface for greater than or less than 12 consecutive days.  Therefore, it is not possible to simply determine the location of X by comparing the number of observed consecutive days plotted in Figure 35 to the threshold duration of 12 days.

To determine the lateral effect of the pit, X, the observed saturation durations shown in Figure 35 should be compared to a reference duration.  The reference duration would be the duration of saturation one would expect to observe at the location on the landscape where the wetland hydrologic criterion is met in exactly half of the years for a similar site.  In order to define the reference duration for each year of observation, DRAINMOD was used to determine a threshold drain spacing for conditions of this site following procedures described earlier in this report.  Threshold drain spacings were determined for each site, that is the spacing such that the land midway between the drains satisfied the wetland hydrologic criterion in exactly half of the years (25/50).  Simulations were then conducted at the threshold spacing for the study years using rainfall measured from onsite gauges to predict the consecutive duration that the water table of a threshold wetland would be within 1 ft of the soil surface during the growing season for each study year for each site.  That duration, 11 days, is plotted for 2006 for the Hardy site as “Threshold” in the bar plot of Figure 35.

The lateral effect can then be estimated from the data in Figure 5 by linear interpolation. This is shown in Figure 36 where the duration of saturation observed at the 115 and 230 ft wells, 9 and 24 days, respectively, is plotted as a function of the distance from the edge of the wetland.  The threshold condition based on the reference simulations was 11 days. This means that a site that would barely satisfy the wetland hydrologic criterion in 50% of the years over a 50 year period would have the water table within 1ft of the surface for 11 consecutive days during the growing season in 2006.  Based on the data for this year, the lateral effect would be some distance between 115 and 230 ft.  Thus, the lateral effect can be estimated from Figure 36 as the intercept of 11 days with the observed relationship for the two recording wells.  For 2006, the intersection point of the threshold duration and observed duration occurs at about 130 ft. Based on the threshold analysis method presented above, the observed lateral effect for the Hardy pit in 2006 is 130 ft.  A similar analysis was performed for the other pits, and other years where a lateral effect was observed.  A summary of the results is given in Table 10.

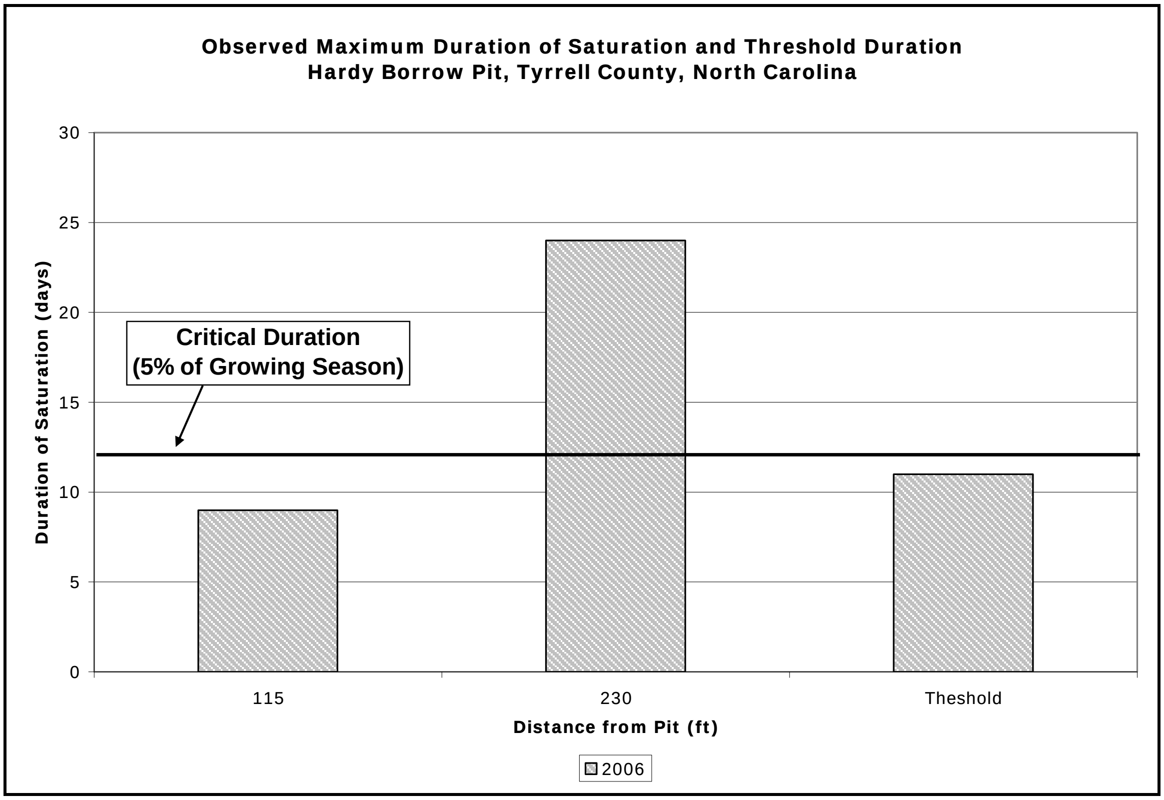


**Figure 35. Observed and predicted number of consecutive days when water table was within 1 ft of the surface during the growing season plotted for 2006 for the Hardy site. Threshold conditions represent the number of days in each year for a site that barely satisfies the wetland hydrologic criterion.**

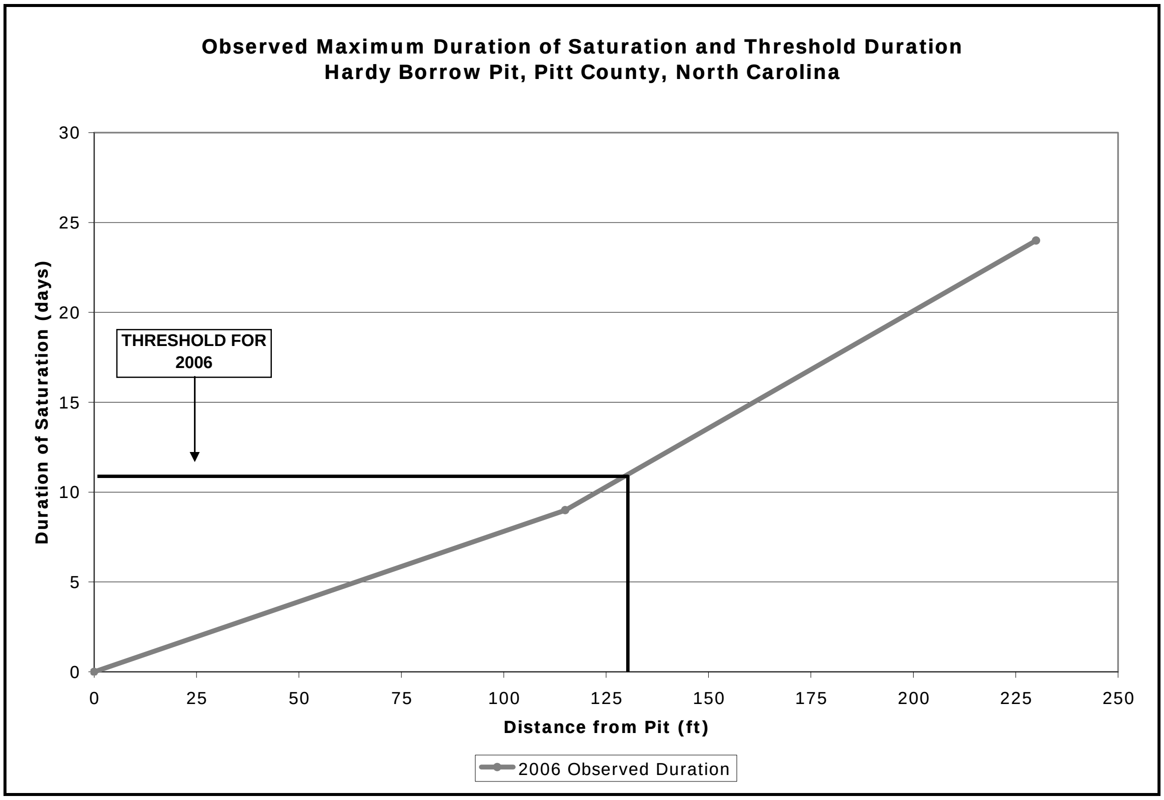


Figure 36. Observed consecutive number of days with water table within 1 ft of surface as a function of distance from ditch. Threshold values are the number of consecutive days that a site that barely satisfies the criterion would have in each year.

**Table 10. Lateral effects of borrow pits estimated from observed data for five pits. Note that effects could not be determined for 2007 because of dry conditions in the spring of the year and because a complete year of data could not be collected.**

| | 2005 | | 2006 | | 2007 | |
|---|---|---|---|---|---|---|
| | Threshold Condition (days) | Lateral Effect (ft) | Threshold Condition (days) | Lateral Effect (ft) | Threshold Condition (days) | Lateral Effect (ft) |
| **Hardy** | 6 | NA | 11 | 128 | 0 | 0 |
| **Davis** | 17 | 205 | 8 | 75 | 0 | 0 |
| **Spruill** | 17 | 62 | 10 | 36 | 0 | 0 |
| **Vann North** | 12 | 53 | 24 | 166 | 0 | 0 |
| **Prime Ridge East** | 12 | 28 | 24 | 30 | 0 | 0 |

A summary of the inputs to the approximate method for each site is given in Table 11. These inputs were used to predict the lateral effect of each of the five borrow pits; results are given in Table 12. Lateral results were predicted for three different pit water levels for each case. We did this because the pit water level is among the most difficult to estimate, so we wanted to see how different estimates would affect the results. One of the water levels was that measured as the equilibrium condition in the field. These results should provide the best test of the method since we know the pit water levels based on site measurements. Results in Table 12 show that predicted lateral effects based on measured pit water surface elevations were greater than observed for all cases except Prime Ridge South where the water level in the pit was very close to the elevation of the wetland surface. That the method overestimated the effect of the pit was not a surprise, as it is based on conservative assumptions. The other calculations were made for pit water elevations of 1.0 and 2.0 ft below the wetland surface. The 2 ft. value has been used in practice on an interim basis as this research was being completed. Results in Table 5 indicate that predictions by the method using a depth of the pit water level of 2 ft. below the surface of the wetland gave very reasonable estimates of the lateral effect. Results were still conservative as the lateral effects predicted were greater or equal to those calculated from observed data for all five pits, but the agreement was close considering the uncertainties of the inputs. Results based on a water level depth in the pit of 1 ft. below the surface of the wetland were less than estimated from observed data for all cases.

**Table 11. Input data for the method developed in this study to predict potential lateral effects of borrow pits on wetland hydrology.**

| | County | Surface storage (in) | Depth to restrictive layer (ft) | Drainable porosity, f | $K_{eff,}$(in/hr) |
|---|---|---|---|---|---|
| **Hardy** | Pitt | 2 | 18 | .0375 | 3.0 |
| **Davis** | Tyrrell | 2 | 19 | .023 | 4.5 |
| **Spruill** | Tyrrell | 2 | 19 | .023 | 2.9 |
| **Vann North** | New Hanover | 2 | 19.7 | .035 | 3.7 |
| **Prime Ridge South** | New Hanover | 2 | 19.7 | .038 | 4.1 |

**Table 12. Predicted and observed lateral effects for five borrow pits. The predicted lateral effect is shown for three different pit water levels for each of the pits.**

| | | Lateral Effect | | | |
|---|---|---|---|---|---|
| | | | Predicted by the approximate method | | |
| | Equilibrium Water Depth (ft) | Observed (ft) | At Equilibrium Depth (ft) | 1 ft Water Depth (ft) | 2 ft Water Depth (ft) |
| **Hardy** | 3.3 | 128 | 181 | 36 | 121 |
| **Davis** | 3.8 | 140 | 227 | 40 | 143 |
| **Spruill** | 1.6 | 50 | 118 | 43 | 155 |
| **Vann North** | 4.1 | 110 | 212 | 34 | 130 |
| **Prime Ridge South** | 1.0 | 30 | 35 | 35 | 130 |

Another input to the approximate method that is somewhat difficult to determine is drainable porosity. We have suggested that a value of 3.5% (0.035) could be used as a reasonable estimate of this input if soil property measurements or other means of determining the value are not available. The method was used for each pit and for all three assumptions regarding the pit water levels, to estimate the lateral effects and compare them to the values obtained from measured data. Results are given in Table 13. Results were similar to those given in Table 12 in that the method with either observed water levels in the pit, or with a 2 ft. depth of the pit water level below the wetland surface, and a drainable porosity of 0.035 gave conservative but reasonable estimates of the lateral impacts.

**Table 13. Using drainable porosity of 0.035 for all sites.**

| | | Lateral Effect | | | |
|---|---|---|---|---|---|
| | | | Predicted | | |
| | Equilibrium Water Depth (ft) | Observed (ft) | At Equilibrium Depth (ft) | 1 ft Water Depth (ft) | 2 ft Water Depth (ft) |
| **Hardy** | 3.3 | 128 | 187 | 38 | 125 |
| **Davis** | 3.8 | 140 | 191 | 34 | 120 |
| **Spruill** | 1.6 | 50 | 95 | 35 | 126 |
| **Vann North** | 4.1 | 110 | 212 | 34 | 130 |
| **Prime Ridge South** | 1.0 | 30 | 41 | 36 | 136 |

## COMPUTER PROGRAM FOR APPLYING METHOD

A PC computer program has been developed for calculation of the lateral effect based on the method described in the first part of this report. A screenshot of the program is shown in Figure 37. Required inputs are county, depth to water surface, surface storage conditions, depth to the impermeable layer, drainable porosity, and lateral conductivity. The lateral conductivity can be entered as a composite value for the entire profile, or values may be entered based on individual layers for up to five layers. The program automatically retrieves the appropriate $T_{25}$ value and performs a sub-routine to calculate the lateral effect. Other features include the ability to save project information to a file for later use or reference. The program eliminates the need to determine the Boussinesq parameter from the chart shown in Figure 4. Results from the program can be interpreted as the setback distance for a borrow pit or the lateral effect of a drainage ditch when adjacent to wetlands. A unit conversion program is included to convert units of length, area, volume, and rate. Updates to the program will be published late 2007 / early 2008. These updates will allow the user to 1. Enter a range of depth to water surface values (currently only 1, 2, 3, 4, 5 or 6 can be chosen), 2. Chose a metric or English unit interface, and 3. Provide a table of possible conductivity values based on texture classification. Brian Phillips (brian_phillips@ncsu.edu ) will be available to address questions and comments regarding the use and further development of the software. The program for calculating the lateral effect can be found at the following website: http://www4.ncsu.edu/~bdphilli/downloads.html .


**Figure 37. Screenshot of computer program for calculating the lateral effect based on the approximate**

## TRAINING

Preliminary findings of our research were presented in a review session held on November 22, 2005 with members of the Steering and Implementation committee and several DOT Engineers attending. Comparison of predicted lateral effects with monitored water table depths at various distances from the pit indicated that the method developed in our research over predicted the lateral effect. That is, the data did not support the need for additional buffer length farther than values calculated using the "Skaggs Method". The methods are based on conservative assumptions and the over-prediction was expected. As a result it was agreed to remove the 2x factor of safety that has been previously required for calculating the lateral effect of the borrow pit.

An overview of this research project was presented at the NCDOT Researchers Review Meeting held on May 23, 2006 at the URS office in Morrisville, NC. On August 2, 2006, we met with several NCDOT personnel at the Pierce Pit in Onslow County. At issue was the failure of the water level in the pit to rise to an expected elevation after closure. Attached as Appendix 2 is a copy of the email from Dr. Skaggs to the NCDOT detailing our observations and recommendations regarding the Pierce pit. We plan to conduct workshops to instruct users on the application of the method once we have completed development and testing of the procedures. The workshops, in addition to providing training, would provide opportunity for feedback, and address questions that come up in the application of the methods.

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## APPENDIX 1. SOIL INFORMATION FOR STUDY SITES

Hydraulic conductivities as determined by auger hole method for sites exhibiting lateral effect.

| | County | Layer Depth (in) | K (in/hr) | Layer Depth (in) | K (in/hr) | Layer Depth (in) | K (in/hr) | $K_{eff}$ (in/hr) |
|---|---|---|---|---|---|---|---|---|
| **Hardy** | Pitt | 12 | 6 | 47 | 2 | 217 | 3 | 3.0 |
| **Davis** | Tyrrell | 6 | 6 | 79 | 1 | 228 | 3 | 4.5 |
| **Spruill** | Tyrrell | 6 | 6 | 51 | 2 | 228 | 3 | 2.9 |
| **Vann North** | New Hanover | 47 | 6 | 236 | 3 | | | 3.7 |
| **Prime Ridge South** | New Hanover | 15 | 6 | 236 | 4 | | | 4.1 |

Average drainable porosities for top 12 inches of soil profile as determined from soil water retention data from soil cores obtained at sites exhibiting lateral effect.

| | Drainable porosity, f |
|---|---|
| **Hardy** | .0375 |
| **Davis** | .023 |
| **Spruill** | .023 |
| **Vann North** | .035 |
| **Prime Ridge South** | .038 |

DRAINMOD formatted soil files for sites where multi-layer soil cores were collected and exhibited lateral effect

```
Hardy
1111
    .591     0.
    .562    -4.
    .522   -14.
    .487   -34.
    .452   -64.
    .429  -104.
    .397  -204.
    .383  -304.
    .368  -404.
    .130 -15000.
      .0    .000   .5000
     3.0    .034   .5000
```

| | | |
|---|---|---|
| 6.0 | .126 | .5000 |
| 9.0 | .255 | .5000 |
| 12.0 | .420 | .3977 |
| 15.0 | .620 | .2796 |
| 20.0 | .996 | .1661 |
| 25.0 | 1.415 | .1220 |
| 30.0 | 1.878 | .0904 |
| 35.0 | 2.313 | .0708 |
| 40.0 | 2.693 | .0573 |
| 45.0 | 3.038 | .0474 |
| 60.0 | 4.059 | .0292 |
| 75.0 | 5.116 | .0198 |
| 90.0 | 6.205 | .0139 |
| 120.0 | 8.627 | .0072 |
| 150.0 | 11.447 | .0039 |
| 200.0 | 16.967 | .0016 |
| 500.0 | 60.108 | .0000 |
| 1000.0 | 100.000 | .0000 |

10

| | | |
|---|---|---|
| .0 | .00 | 12.80 |
| 10.0 | 1.10 | 12.80 |
| 20.0 | 1.63 | 12.80 |
| 40.0 | 1.80 | 10.10 |
| 60.0 | 2.17 | 10.10 |
| 80.0 | 2.39 | 10.10 |
| 100.0 | 2.58 | 10.10 |
| 150.0 | 7.43 | 10.10 |
| 200.0 | 7.43 | 10.10 |
| 1000.0 | 7.43 | 10.10 |

PrimeRidge
1111

| | |
|---|---|
| .547 | 0. |
| .535 | -4. |
| .532 | -8. |
| .527 | -14. |
| .467 | -34. |
| .398 | -64. |
| .364 | -104. |
| .338 | -204. |
| .318 | -304. |
| .306 | -404. |
| .100 | -15000. |

| | | |
|---|---|---|
| .0 | .000 | .5000 |
| 3.0 | .014 | .5000 |
| 6.0 | .050 | .5000 |
| 9.0 | .094 | .5000 |
| 12.0 | .146 | .5000 |
| 15.0 | .205 | .5000 |
| 20.0 | .358 | .5000 |
| 25.0 | .585 | .5000 |
| 30.0 | .888 | .5000 |
| 35.0 | 1.265 | .3099 |
| 40.0 | 1.702 | .1199 |

```
     45.0     2.169     .0498
     60.0     3.994     .0057
     75.0     7.305     .0011
     90.0    11.174     .0003
    120.0    19.192     .0000
    150.0    27.079     .0000
    200.0    40.255     .0000
    500.0   100.000     .0000
   1000.0   100.000     .0000
10
       .0       .00     13.70
     10.0      1.58     13.70
     20.0      3.71     13.70
     40.0      8.83     13.31
     60.0     13.12     13.31
     80.0     15.24     13.31
    100.0     16.83     13.31
    150.0     41.19     13.31
    200.0     41.19     13.31
   1000.0     41.19     13.31

Vann
1111
     .434       0.
     .425      -4.
     .425      -8.
     .422     -14.
     .344     -34.
     .294     -64.
     .276    -104.
     .261    -204.
     .258    -304.
     .258    -404.
     .100  -15000.
       .0      .000     .5000
      3.0      .011     .5000
      6.0      .037     .5000
      9.0      .064     .5000
     12.0      .095     .5000
     15.0      .132     .5000
     20.0      .260     .5000
     25.0      .486     .5000
     30.0      .809     .5000
     35.0     1.229     .4483
     40.0     1.708     .2753
     45.0     2.229     .1655
     60.0     4.041     .0505
     75.0     6.155     .0208
     90.0     8.380     .0109
    120.0    13.095     .0044
    150.0    17.932     .0022
    200.0    24.840     .0009
    500.0    64.709     .0000
   1000.0   100.000     .0000
10
       .0       .00      8.60
```

| | | |
|---|---|---|
| 10.0 | 1.35 | 8.60 |
| 20.0 | 4.72 | 8.60 |
| 40.0 | 13.09 | 8.60 |
| 60.0 | 17.44 | 8.60 |
| 80.0 | 19.21 | 8.60 |
| 100.0 | 20.15 | 8.60 |
| 150.0 | 43.05 | 8.60 |
| 200.0 | 43.05 | 8.60 |
| 1000.0 | 43.05 | 8.60 |

## APPENDIX 2. EMAIL REGARDING OBSERVATIONS AND RECOMMENDATIONS FOR PIERCE BORROW PIT

All:
This a brief email report of our observations and recommendations based on our August 2 visit to the Pierce Pit in Onslow County. The problem we were investigating is the failure of water to rise to expected elevations in the pit after closure several months ago. Dr. Chip Chescheir, Dr. John Hornbuckle (visitor from Australia), Brian Phillips, Wilson Huntley and I met DOT personnel Jerry Yarborough, Jimmy Zepeda and Frank Dixon at the pit. We visually examined the pit and the surrounding area and made the following observations.

The pit is divided into three sections. The sections on the south end and on the North end appear to have 4 feet or more of water at the time of our visit. The middle section has a lesser depth of water although the surface elevation appears to be about the same as in the north end (the section on the north end appears to be deeper). None of the three pit sections are close to full. Why isn't the pit filling up faster (all sections)? There appear to be three main reasons.

1. There is seepage out of the pit to the streams on both the east and the west. The stream elevations are within a few feet of the bottom of the pit, so as water builds up in the pit, seepage increases. The amount of seepage depends on the hydraulic conductivity (K) of the soil between the pit and the streams, the distance from the pit to the stream on each side and the square of the elevation of water in the pit above the water level in the stream or adjacent wetland. The K value may be small and the seepage small, but there is no doubt some seepage. The seepage could be reduced by compacting clay fill on the inside of the pit or installing a plastic liner. Both would be expensive but could be used to address the seepage problem. This problem is not typical of the normal borrow pit in that the streams on both sides are very deep with respect to the top of the pit and the desired water surface elevation in the pit. You are trying to hold water in a reservoir that is elevated above streams on either side, one of which (the west side) is close to the pit. In most cases we have observed the water surface elevation in the pit is within a few feet (maybe 2 to 6 ft.) of the normal water table depth in the surrounding lands. In those cases water seeps in to help fill the pit and there is not a large gradient for it to seep out, even during dry periods. In this case, if the pit was full, you could have 15 to 20 feet of difference in water surface elevation between the pit and the stream over a relatively short distance to the stream on the west side. Seepage will continue to occur and will ultimately limit the elevation water will rise in the pit.

2. The pit has very little watershed. As it now stands most of the water that enters the pit is rainfall directly within the pit walls. Berms on top of the pit walls prevent runoff into the pit from the adjacent area. This was designed this way to prevent runoff from eroding the pit walls, but in this case it robs the pit of runoff water needed to fill the pit. Incidentally, one of the reasons the middle section has less water than the north section is that runoff water from the area east of the pit is running north inside the berm(outside the

pit) along the top of the pit wall until it reaches the fill separating the middle and north sections where it runs along that berm and finally into the north section. There is a large gully indicating this route. Since the watershed to the pit is limited (again in contrast to other pits located at lower elevations where water both seeps in and runs in by surface runoff during wet periods), one alternative is to shape the surface (especially along the east side where there appears to be over 100 feet of area that would drain into the pit) so that the runoff goes into, not away from the pit. You would need to route the runoff to a spillway or other facility so that the pit wall is not eroded, but it would greatly help the cause of raising the water level in the pit. Seepage is going to continue at some rate. The idea is to increase the amount of water going into the pit by runoff so that the amount in is greater than the amount seeping out.

3. If the watershed is not enlarged as discussed above, the water level in the pit may still rise, but slowly. Average rainfall at the pit location is between 50 and 55 inches per year. Evaporation from the pit will be 38 to 40 inches per year. The difference is the amount of water available each year to raise the water level in the pit. So if seepage were zero the water level would rise about 10 to 17 inches per year on average. It would actually be somewhat greater than this because the walls aren't vertical so the water falling in the pit is caught by a surface larger than the water surface. In any case the rate of rise will be slow based on these calculations IF seepage is zero. (Seepage isn't zero--I don't know what it is, but it is certainly greater than zero--that is the reason you have wet areas at the base of the slope near the streams). All of this points to the need to increase the watershed contributing to the pit as much as possible. There is a small ditch along the outside of the pit wall on the west side. That ditch needs to be blocked and a pipe installed to direct the water back into the pit in a way that won't erode the walls.

I hope these observations and recommendations will help. It certainly possible to increase the amount of water entering the pit and that will increase the water level elevation. It will also increase the seepage. However it may very well allow the water to reach a satisfactory "equilibrium" elevation. If the property is developed there will be lots of impervious surfaces that will shed water, some of which can be directed to the pits to maintain the desired level.
Let me know if there are questions.

Wayne Skaggs
August 4, 2006

## Appendix 3. Guidance Document for Determining Input Parameters to Skaggs Method for Calculating Lateral Effect of Borrow Pits

## Step 1. Pit type and the need to calculate a lateral effect

**Description:**

There are three main types of borrow pits (see Borrow Pit Types below). The type is dependent on the location of the wetland ground surface in relation to expected water level in the pit. Type 1 pits will have wetlands upslope of the pit water level. Type 2 pits will be downslope. Type 3 pits have adjacent wetlands on more than one side of the pit and will be some combination of Type 1 and Type 2 pits.

**Determining:**

1) Determine area designated as jurisdictional wetland
2) Determine the wetland ground surface elevation (WGE) relative to the elevation of the adjacent borrow pit edge.
    - Onsite survey
    - LiDAR
3) Determine if control structures (culvert, spillway, riser, etc…) will be installed to control water level in pit and note the proposed invert elevation
4) Determine if drainage ditches will be adjacent to the pit and note the bottom elevation of the ditch
5) If
    A. No control structure to be installed or adjacent drainage ditch present, then equilibrium water level in borrow pit (PWE) may be best estimated as elevation of the seasonal high water table in soil at the pit location. This can be estimated in terms of the soil survey (see county soil survey), or by on-site evaluation by a soil scientist or engineer.

    B. If control structure installed, at elevation less than A above, then
       invert elevation = PWE
    C. If adjacent drainage ditch present, then
       ditch bottom elevation = PWE

6) If

   A. WGE > PWE , then

      a. Type 1. Wetland upslope of pit.

      b. Need to calculate lateral effect : YES and continue to Step 2

   B. WGE < PWE, then

      a. Type 2. Wetland downslope of pit

      b. Need to calculate lateral effect : NO and stop here

*NOTE: For proposed pits with wetlands on more than one side, follows steps 1 – 7 above for each adjacent wetland.*

## Step 2. Depth from the wetland ground surface to the expected depth of water in the equilibrated pit

**DESCRIPTION:**

The depth to the water surface represents the depth from the soil surface of the wetland area to the expected water level in the borrow pit.

**DETERMINING:**

If

A. No control structure to be installed or adjacent drainage ditch present, then approximate depth as,

   depth = 2ft

B. Control structure installed, then

   depth = wetland surface elevation - invert elevation

C. Adjacent drainage ditch present, then

   depth = wetland surface elevation - ditch bottom elevation

*NOTE: If the depth calculated using B. or C. above is less then 2ft, then set the depth = 2ft.*

**<u>Note on Steps 3 – 6.</u>**
Several methods of obtaining results are listed for each step. The methods are listed in order of highest accuracy to lowest. That is Method 1 will provide results that most closely represent field values.

## Step 3. Surface storage

**DESCRIPTION:**

Surface storage of water will be caused by variations in the micro topographical relief of a site. These depressions can be due to land management practices (e.g. disking and harrowing), old planting beds, uprooted vegetation, consolidation or shrinkage of soils, naturally forming small sinkholes, rooting animals, etc… In general, as the pocket-like and pothole-like depressions increase in average depths across the site, surface runoff will decrease and precipitation infiltration will increase. Thus there is a direct correlation between the wetness of a site and the depth of surface storage. Two options are currently available for use in the Skaggs Method, 1 and 2 inches of surface depressional storage. All other inputs being equal, the lateral effect will decrease as surface storage increases (Skaggs et al. 2005).

**DETERMINING:**

<u>Method 1.</u> Visually measure onsite
Measurements of depressional storage depths below and the average ground surface can be determined conducting an intensive grid survey of surface elevations. An average value can be calculated from the measured values and judgment used to choose the most appropriate value in the model. Alternatively, the depth of water ponded on the surface after heavy rainfall can be measured at many locations and averaged to determine a representative value.
<u>Method 2.</u> Assume a value.
In lieu of any minimal onsite observations or knowledge, a surface depressional storage value of 1 inch should be applied. This will be the more conservative of the two options. That is, the lateral effect calculated using a 1 inch surface storage will be larger than a 2 inch surface storage.

## Step 4. Depth to restrictive layer

**DESCRIPTION:**

The restrictive layer is **often referred to as an aquitard**. Conductivities of this layer may be on the order of 0.01 to 0.1 of the overlying layer and thus prevents vertical seepage from the overlying layers. In eastern North Carolina, the restrictive layer is most often very tight marine clay.

**DETERMINING:**

Method 1. Use a hand or power auger to drill down through the soil profile. This method will also allow for a description of the soil profile and measurement of relative layer thicknesses.
Method 2. Use the geotechnical boring log to determine depth of unsuitable very clayey or silty material. This will often coincide with the proposed depth of the borrow pit.

## Step 5. Drainable porosity

**DESCRIPTION:**

Drainable porosity is the volume of water per unit area that drains when the water table falls by a unit distance. For example a drainable porosity of 1% (0.01) means that for a given unit area, 1cm of water will drain from the profile for a 100 cm drop in the water table. Conversely, 1 cm of rainfall added to the profile would cause a 100 cm rise in the water table. In an unconfined aquifer system, the drainable porosity can be equated to the specific yield.
For purposes of the Skaggs Method, the drainable porosity can be considered a property of the soil. The drainable porosity for the top 1 ft of the soil property is required as an input in the method.

**DETERMINING:**

Method 1. Based on research in the development of the Skaggs Method as it applies to borrow pits, use a value of 0.035 in lieu of using measured data
Method 2. Soil water characteristic data.
This method requires a soil lab perform water retention tests (Klute, 1986) to determine the water content ($cm^3/cm^3$) at saturation and at 30 cm of pressure head for multiple soil core samples (collected within the top 1 ft of the soil profile). The drainable porosity for each core can be calculated by multiplying the difference in equilibrium water contents at saturation (pressure head =0) and a pressure head of 30 cm by 0.5 . Example: Assume the volumetric water content is 0.45 $cm^3/cm^3$ (45%) when the water table is at the surface and the soil is saturated (pressure head = 0). Further assume that the equilibrium volumetric water content for a pressure head of 30 cm is 0.39 $cm^3/cm^3$. Then the drainable porosity may be estimated as (0.45 – 0.39)*0.5 = .03 or 3%.

## Step 6. Lateral Hydraulic conductivity

**DESCRIPTION:**

Hydraulic conductivity is a measure of the soils ability to transmit water. In this case, we are concerned with the ability of the soil to transmit water horizontally (laterally) under saturated conditions. The lateral hydraulic conductivity is a mainly a property of the soil

texture (relative percentages of sand, silt, clay, and organic matter), structure (how those soil particles are arranged), and void ratio (volume of voids compared to volume of solids). Void ratios will be a function of land management practices, root structure, and macropores (e.g. worm holes). Because void ratios will be unique to a given locale, the best method to determine the lateral hydraulic conductivity is to perform field tests using one of the method listed below under Method 1A .
The methods to measure Ksat listed under Method 1B can be employed when relatively deep water tables are encountered or when a soil layer to be tested is above the water table. The Ksat tests do not measure conductivities in a solely horizontal direction but instead measure a more three dimensional conductivity. All methods may be subject to errors due to hole smearing, water supply temperature and viscosity, and water supply solute content (Amoozegar and Wilson, 1999). Due to Ksat values typically underestimating the lateral conductivity and the potential for other errors, multiply measured Ksat values by 2 or 3 to approximate the lateral conductivity for use in the Skaggs Method (Bouwer and Jackson, 1974). Care must be taken to perform Ksat test properly. Otherwise, extremely low values can be measured resulting in an inappropriate lateral effect calculation. Measured Ksat values significantly less than 1/3rd of a comparable texture's value listed in Table 1 below should be viewed as suspect and re-measured.

**DETERMINING:**

Method 1. Field testing

A. Test to measure **Lateral Hydraulic Conductivity** under shallow water table conditions.

1. Auger hole test (van Beers, 1970)
2. Slug test (Bouwer and Rice, 1976; Bouwer, 1989)
3. Pump test

B. Test to measure **Ksat** above the water table.

1. Constant head test (Amoozegar and Warrick, 1986)
    a. Constant head permeameter
    b. Amoozemeter

Method 2. Based on the soil texture.
If information is available for the texture (USDA classification), the following lateral conductivities can be applied.

Table 1. Suggested lateral conductivity values based on soil texture.

| **Soil Texture (USDA classification)** | **K lateral (in/hr)** |
|---|---|
| Sand | 11 |
| Loamy sand | 4.8 |
| Sandy loam | 3.1 |
| Loam | 1.6 |
| Silt loam | 0.8 |
| Sandy clay loam | 0.5 |
| Clay loam | 0.3 |
| Silty clay loam | 0.2 |
| Sandy clay | 0.2 |
| Silty clay | 0.1 |
| Clay | 0.1 |

*Note: The value listed in table 1 are adopted from Ksat values published by Rawls et al. 1988. A factor of 2 was applied to the sand and loamy sand and a factor of 3 applied to all other textures. The factor compensates for discrepancies between Ksat values and lateral conductivity values.*

Method 3. Soil Survey permeability values.
For preliminary calculations, permeability values are listed in published Soil Surveys or available online through the Soil Data Mart (http://soildatamart.nrcs.usda.gov/) or the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/). These resources are managed by the U.S. Natural Resources Conservation Service.
Permeability values will be given as a range for each soil layer down to a depth that will be typically less than the depth of the restrictive layer. For each soil layer, it is recommended to use the average permeability value as input in to the Skaggs Method. It is also recommended to assume the deepest layer listed for a particular soil series extends to a depth equal to the restrictive layer depth.
More recent sources of permeability values may employ units of micrometers/second (µm/s). To convert these values to inches/hr, multiply by 0.1417 .

## Borrow Pits Types

**Type 1: Wetland Upslope of the Pit**. The ground surface of the wetland adjacent to a pit of this type is higher than the equilibrium water level in the pit. Concern about detrimental effects of borrow pits on wetland hydrology is greatest for this type as water could seep from the wetland to the borrow pit potentially decreasing water levels in the wetland. It should be noted that the natural direction of seepage prior to construction may well have been from the wetland to the site that is now the borrow pit. In that case it is not the seepage direction that is the question or potential problem, but whether or not the presence of the pit increases seepage rates such that detrimental effects result. The equilibrium water level in the pit is an important factor in these types of pits, since it determines the gradient from the wetland to the pit. We observed two conditions that would limit the water level in the pit and further classified those pits as **Type 1a** and **Type 1b**. The water level in **Type 1a** pits is controlled by the elevation of a weir or spillway at the outlet of the pit. Examples are the Mildred Woods pit and the Hardy pit shown schematically in Figures 1 and 2. **Type 1b** pits did not have surface outlets but the water levels were controlled by seepage to nearby drainage ditches or other sinks. Examples of **Type 1b** pits are the Davis pit and the Spruill pit (Figures 3 and 4). These pits are located in a drained agricultural field where field ditches are sinks receiving lateral seepage from the pit.

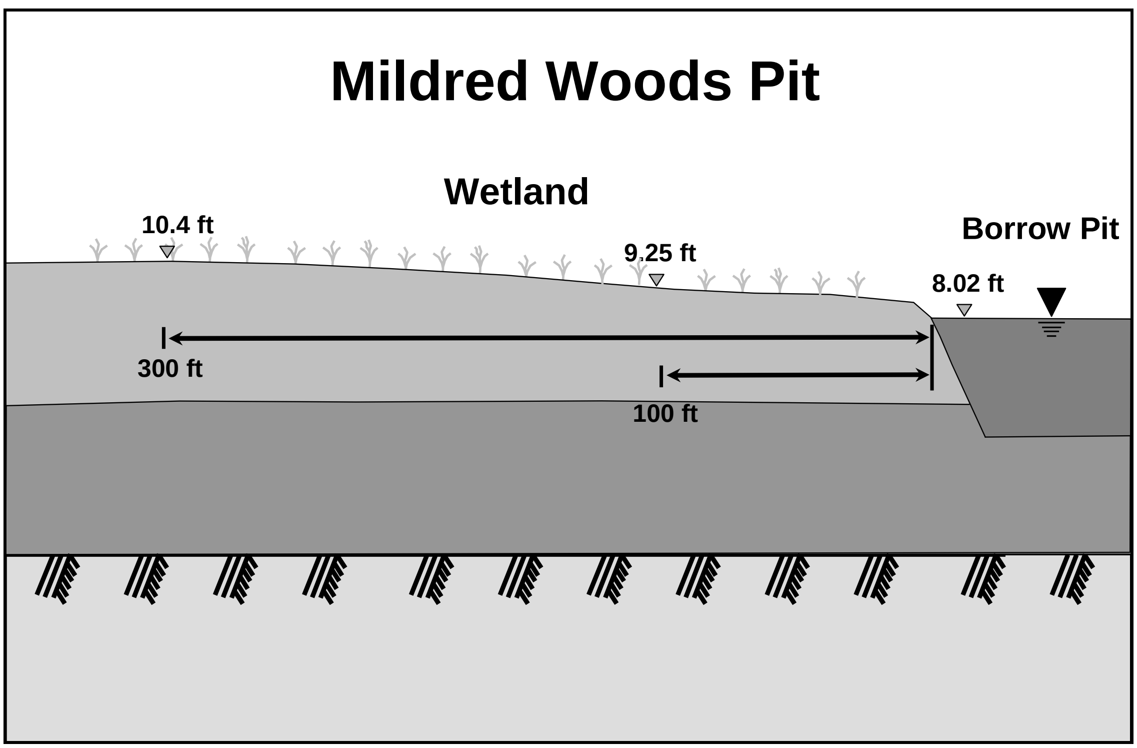


**Figure 1. Type 1a – Wetland upslope of pit. Mildred Woods Pit. Ground surface of wetland at higher elevation than pit water level. Water level of pit controlled by elevation of outlet.**

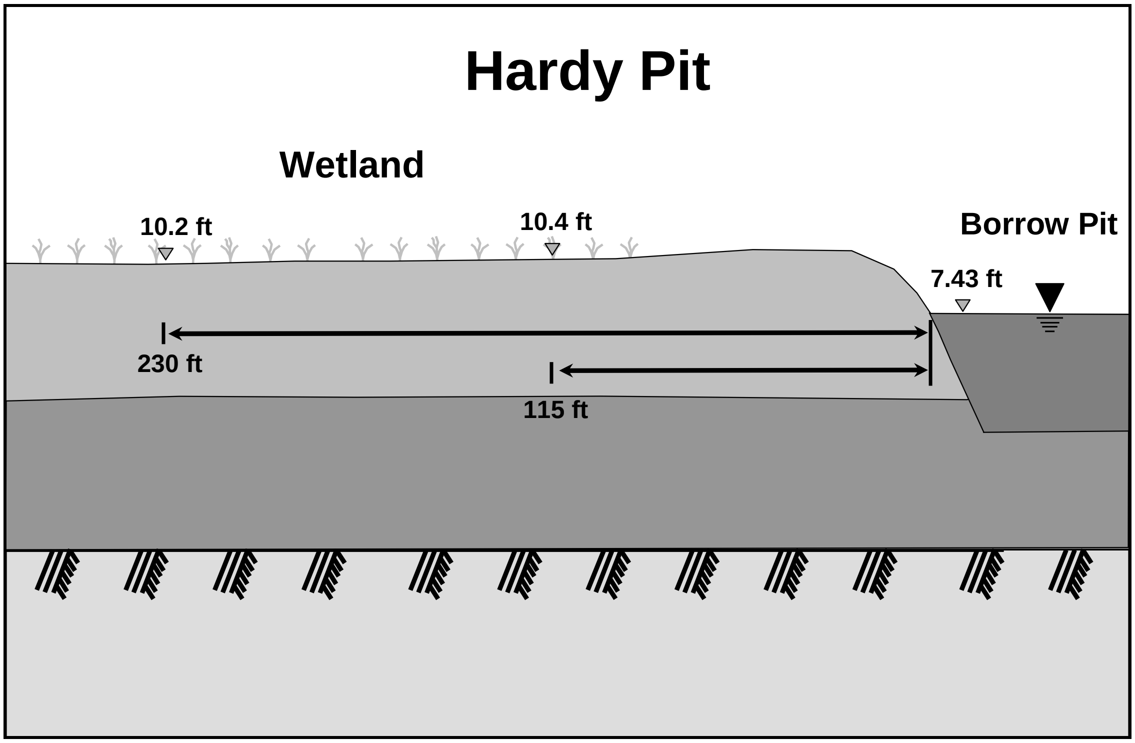


**Figure 2. Type 1a – Hardy Pit. Ground surface of wetland at higher elevation than pit water level, which is controlled by weir elevation in outlet control structure.**

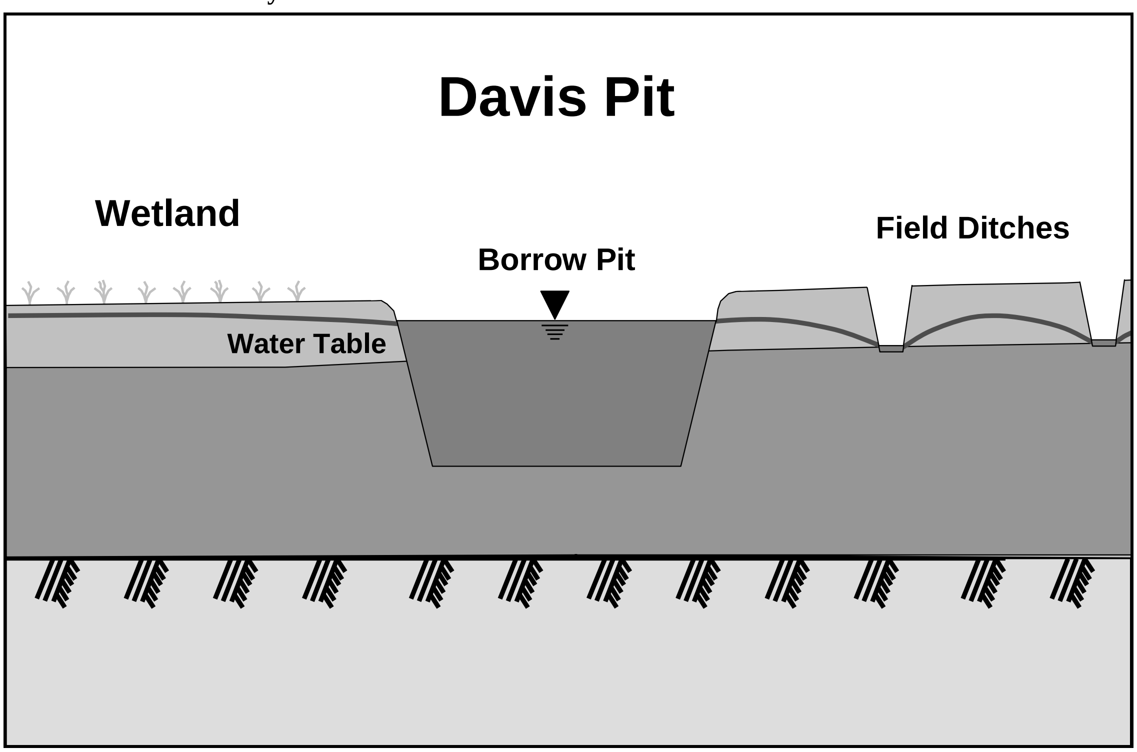


**Figure 3. Type 1b. Davis Pit. Wetland upslope of pit. Ground surface of wetland at higher elevation than pit water level. Water level of pit controlled by seepage to field ditches.**

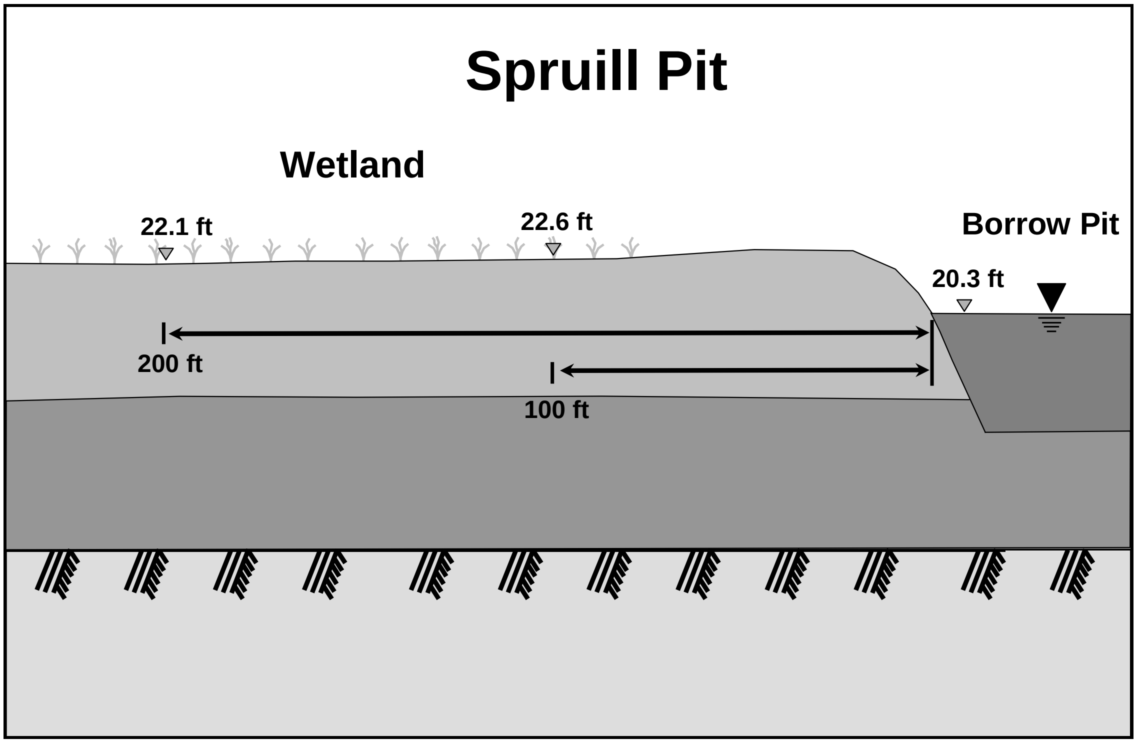


**Figure 4. Type 1b. Spruill Pit. Water level of pit limited by seepage to sink. Ground surface of wetland at higher elevation than pit water level. Water level of pit limited by seepage to field ditches (not shown).**

Two different scenarios of Type 1b borrow pits are demonstrated by the Alexander pit (Figure 5) and the Borden East pit (Figure 6). The water level in the Alexander pit was most likely controlled by the ditch located between the pit and the wetland. In this case there was minimal, if any, impact of the pit on the wetland, because the wetland was affected by the pre-existing ditch before construction of the borrow pit. The ground elevation of the wetland near the Borden East pit was higher than the water level in the pit. Elevation measurements were made at this site during a wet period when the stage of stream next to the wetland was higher than normal and higher than the elevation of the water in the pit. Under drier conditions the stage of the stream would be lower than the water level in the both the wetland and the pit, with seepage from the wetland and the borrow pit to the steam. The water level in the pit could also be affected by seepage to undocumented sinks. Other examples of Type 1b pits are the Callie Road pit and the Bullard 6 pit (Figures 7 and 8). The water levels in these pits were apparently controlled by seepage to undocumented sinks. The standing water near the wetland in the Bullard 6 pit was not part of a stream.

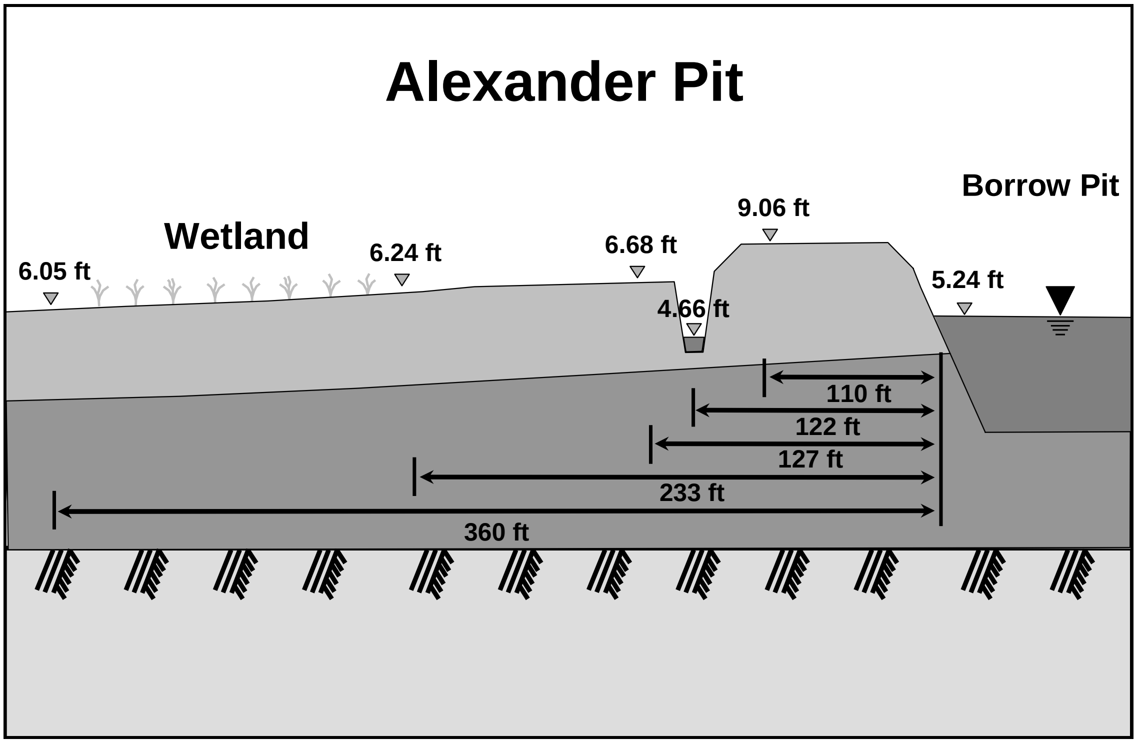


**Figure 5. Type 1b - Wetland upslope of pit. Alexander Pit. Ground surface of wetland at higher elevation than pit water level. Water level of pit limited by seepage to ditch. Note that the ditch between the wetland and the pit.**

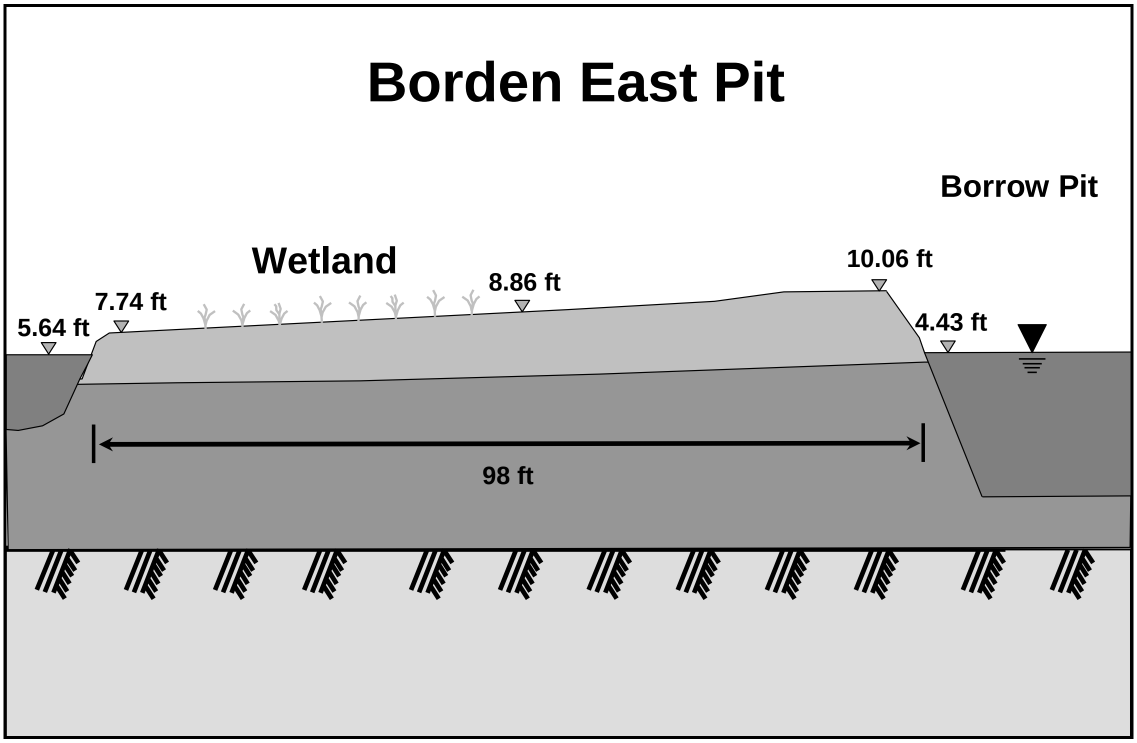


**Figure 6. Type 1b - Water level of pit limited by seepage to sink. Borden East Pit. Ground surface of wetland at higher elevation than pit water level. Water level of pit limited by seepage to stream. The stream level was high during this measurement.**

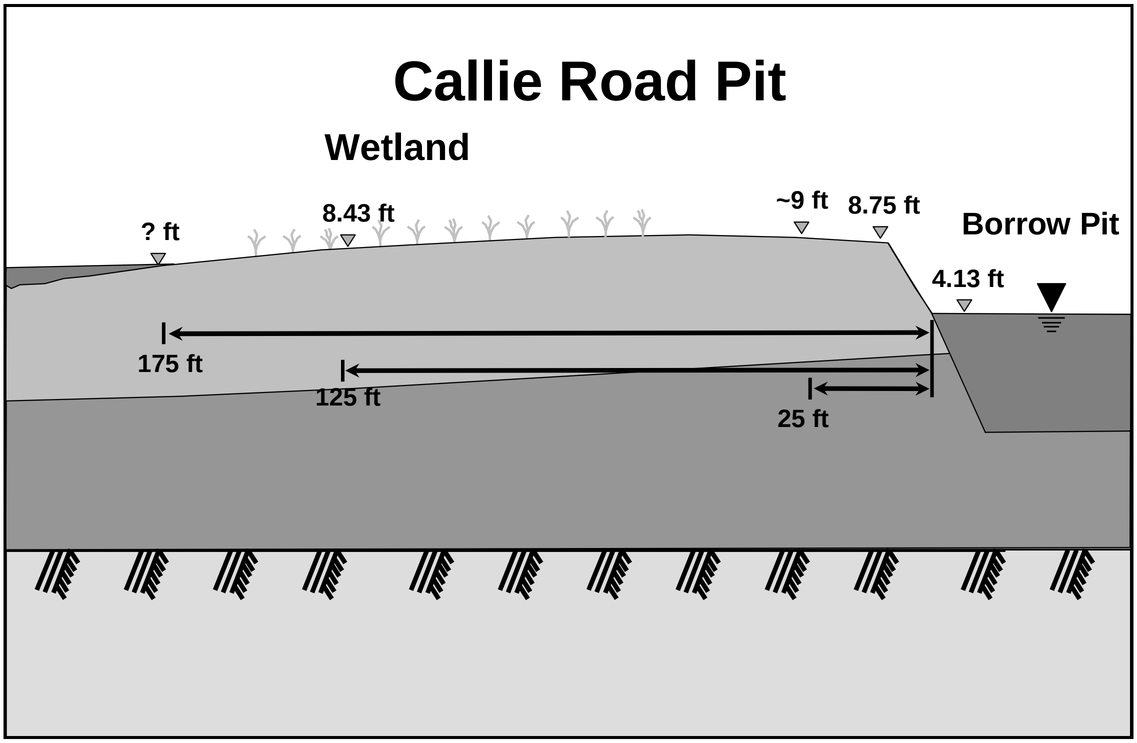


**Figure 7. Type 1 - Wetland upslope of pit. Callie Road Pit. Ground surface of wetland at higher elevation than pit water level. Limit of pit water level not determined.**

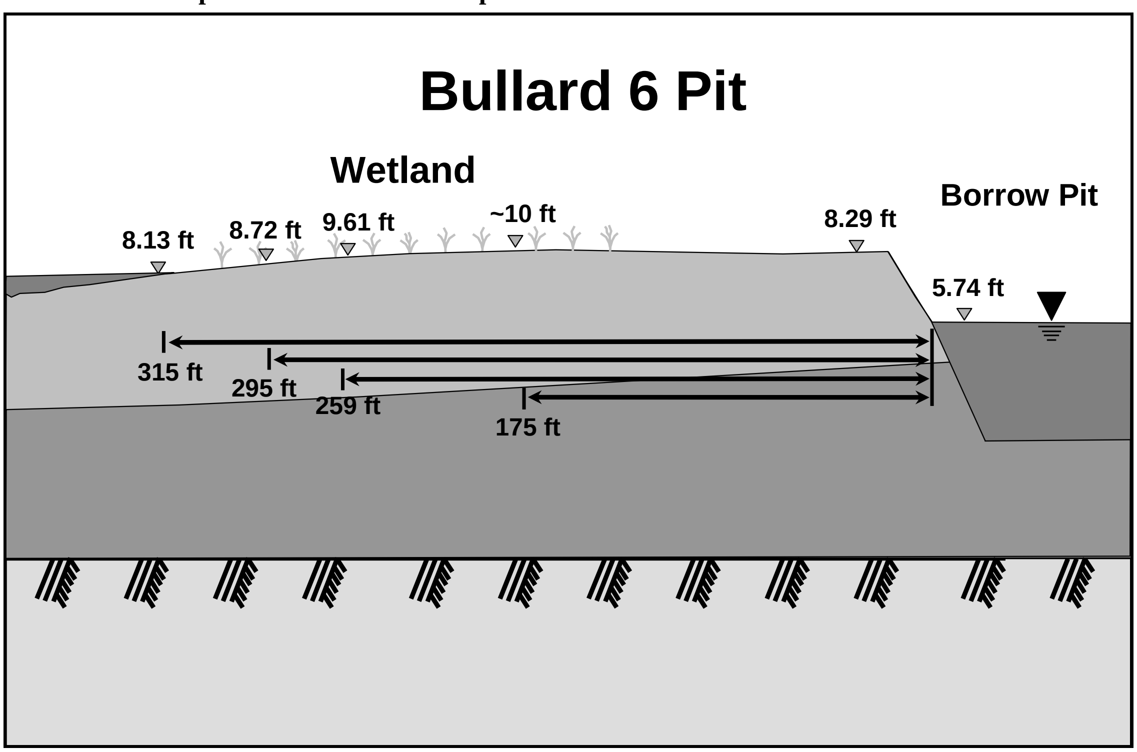


**Figure 8. Type 1 - Water level limit unknown. Bullard 6 Pit. Ground surface of wetland at higher elevation than pit water level. Limit of pit water level not determined.**

**Type 2: Wetland Down Slope From The Pit.** The **Type 2** borrow pit represents the condition where the wetland is down slope from the pit. The ground surface of the wetland is at an elevation lower than the average water level of the borrow pit. This situation usually occurs when the pit is constructed near a stream and the wetland is located on the floodplain between the pit and the stream. Examples of these pits are the Stallings pit, the Vail pit, the Nance pit, and the Borden South pit (Figures 9 to 12). The Pierce pit (Figure 13) was located on a ridge between two streams with wetlands on the floodplain. Type 2 pits also occur if the wetland is located on a slope away from the pit. The Tart pit (Figure 14) is an example where the wetland is on a slope. Our observation is that the equilibrium water levels in Type 2 borrow pits are close to seasonal high water table elevations prior to construction. The volume of water stored in the pit provides a continuous source of seepage so the pit may cause the wetland to be somewhat wetter during the summer months rather than drier. However these effects are not expected to be large and would be difficult to detect in most years.

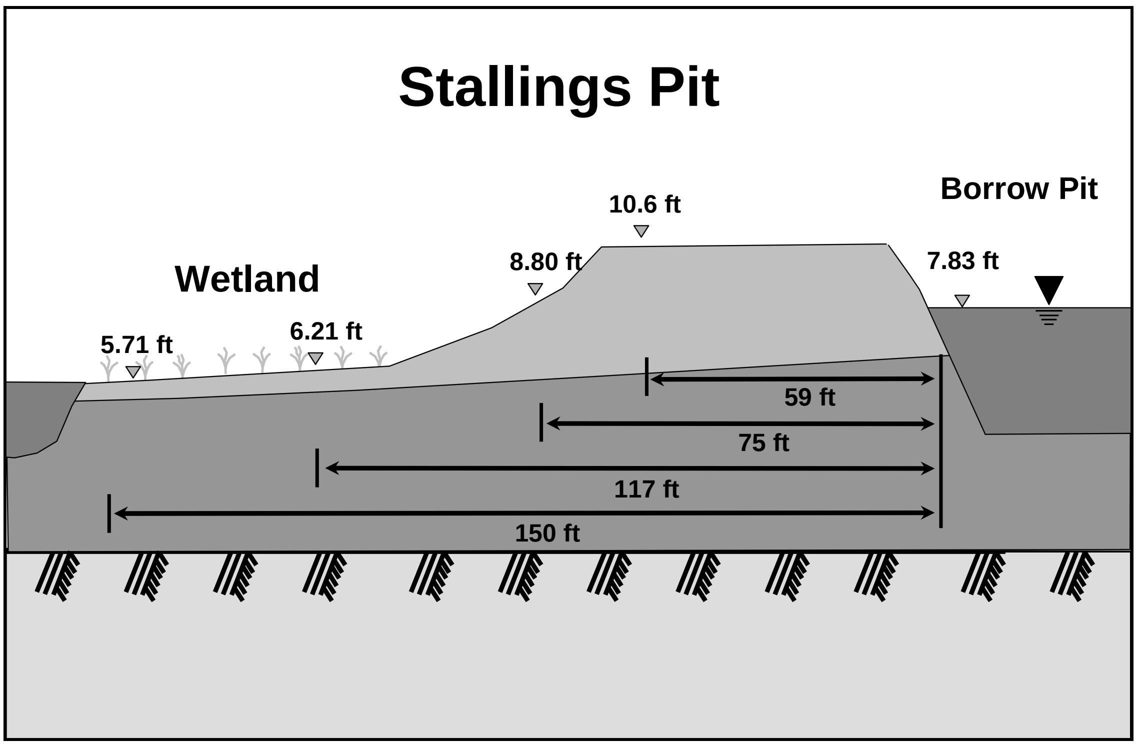


**Figure 9. Type 2 Stallings Pit. Wetland down slope of pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the stream.**

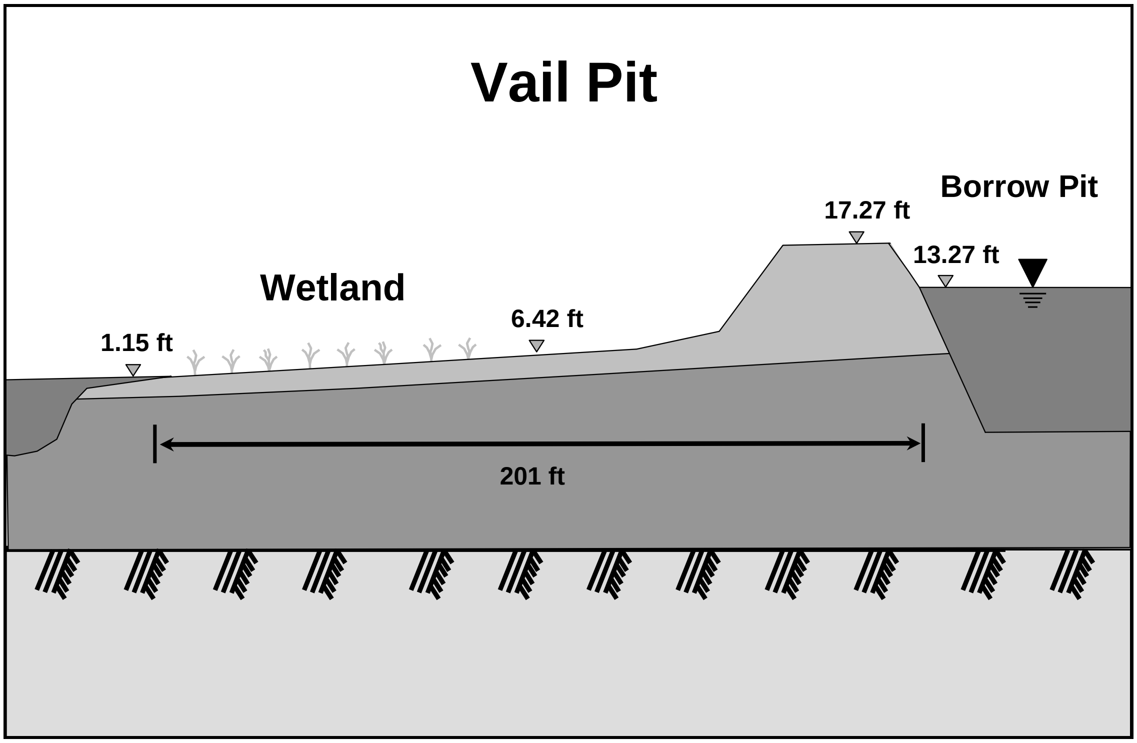


**Figure 10. Type 2 - Wetland down slope of pit. Vail Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the stream.**

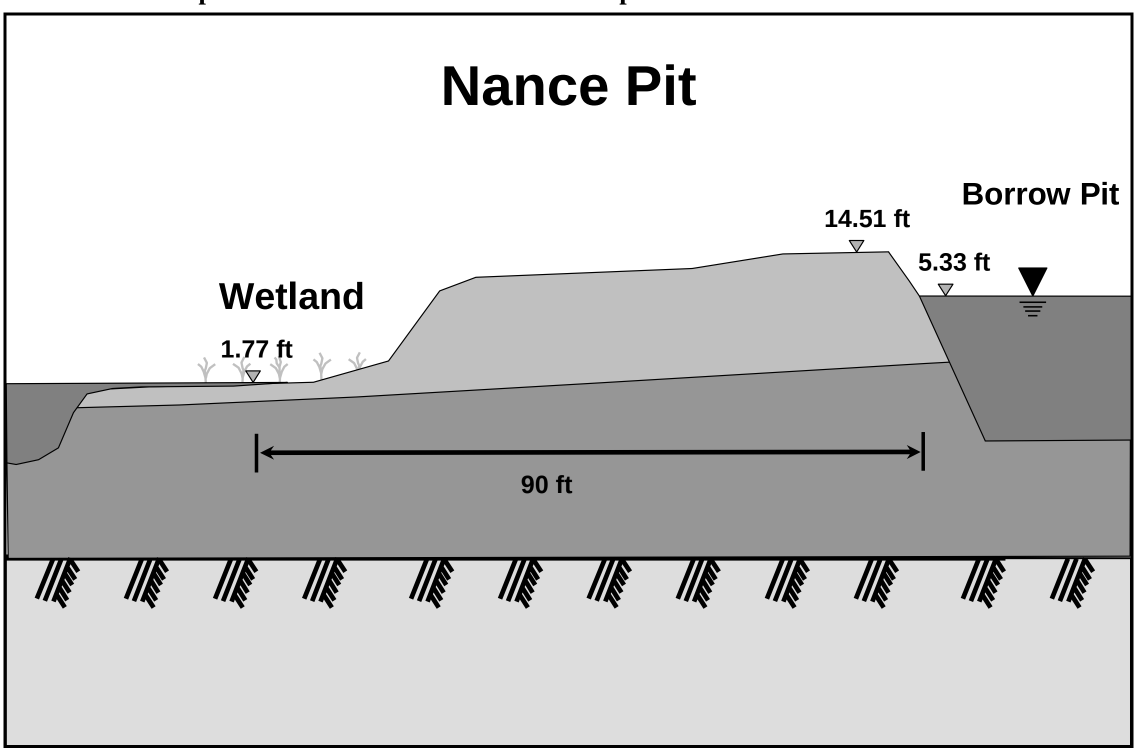


**Figure 11. Type 2 - Wetland down slope of pit. Nance Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the stream.**

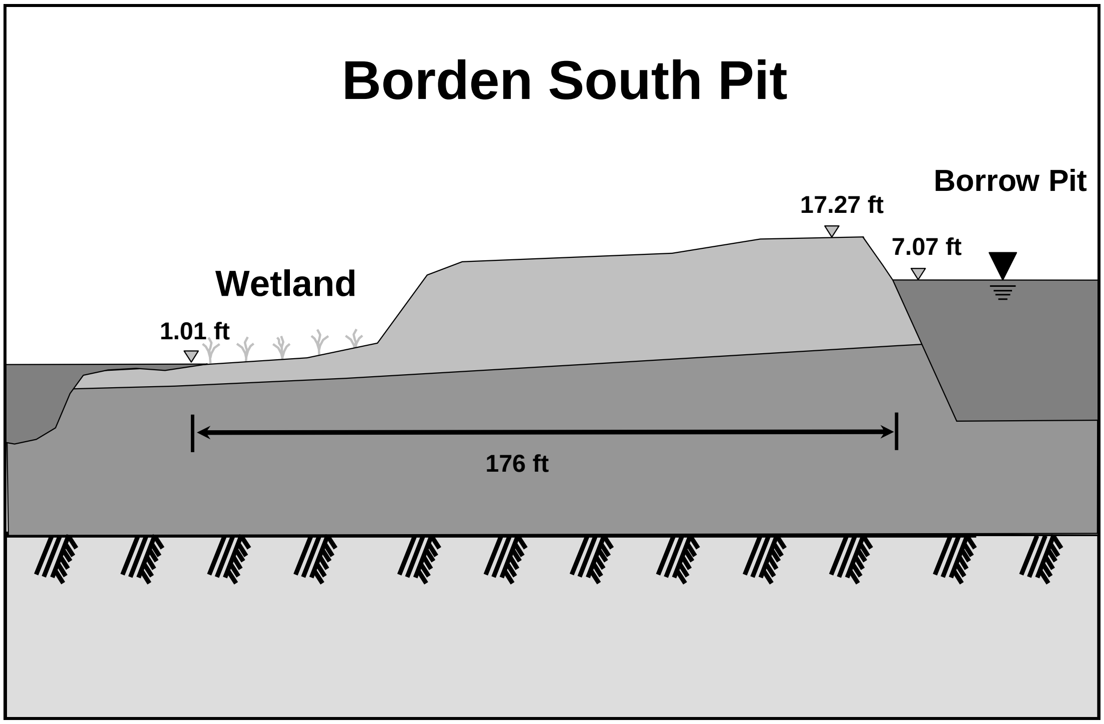


**Figure 12. Type 2 - Wetland down slope of pit. Borden South Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the stream.**

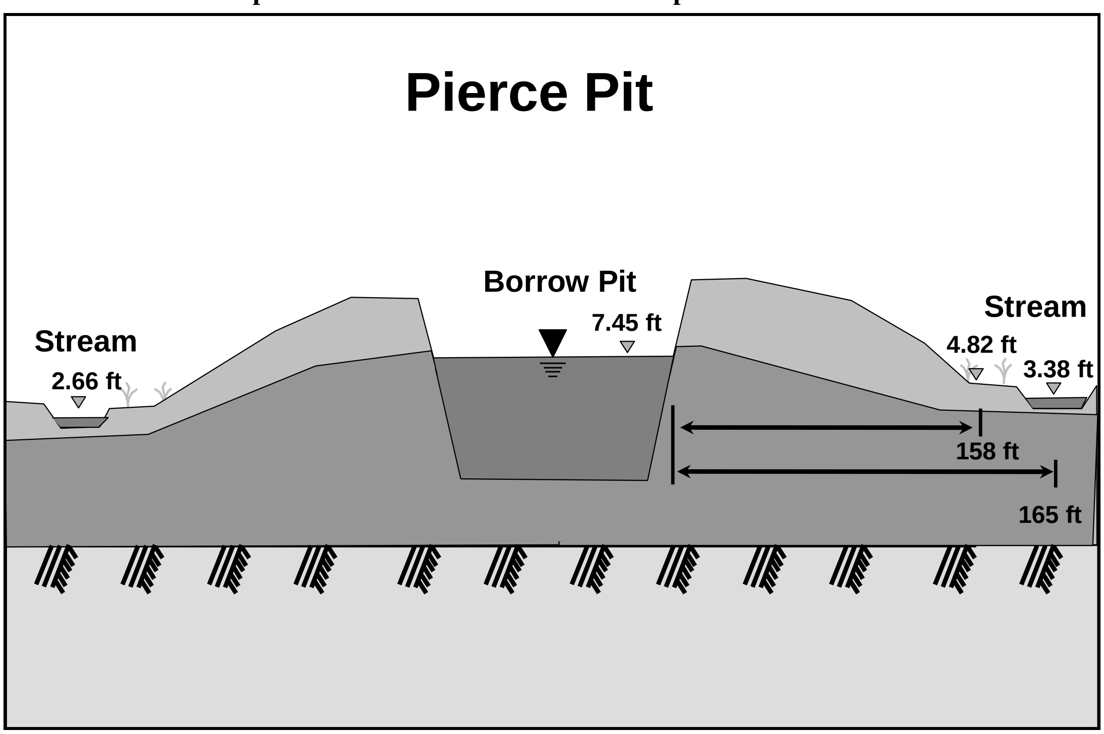


**Figure 13. Type 2 - Wetland down slope of pit. Pierce Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on the floodplain of the streams. Pit is located on a ridge between streams.**

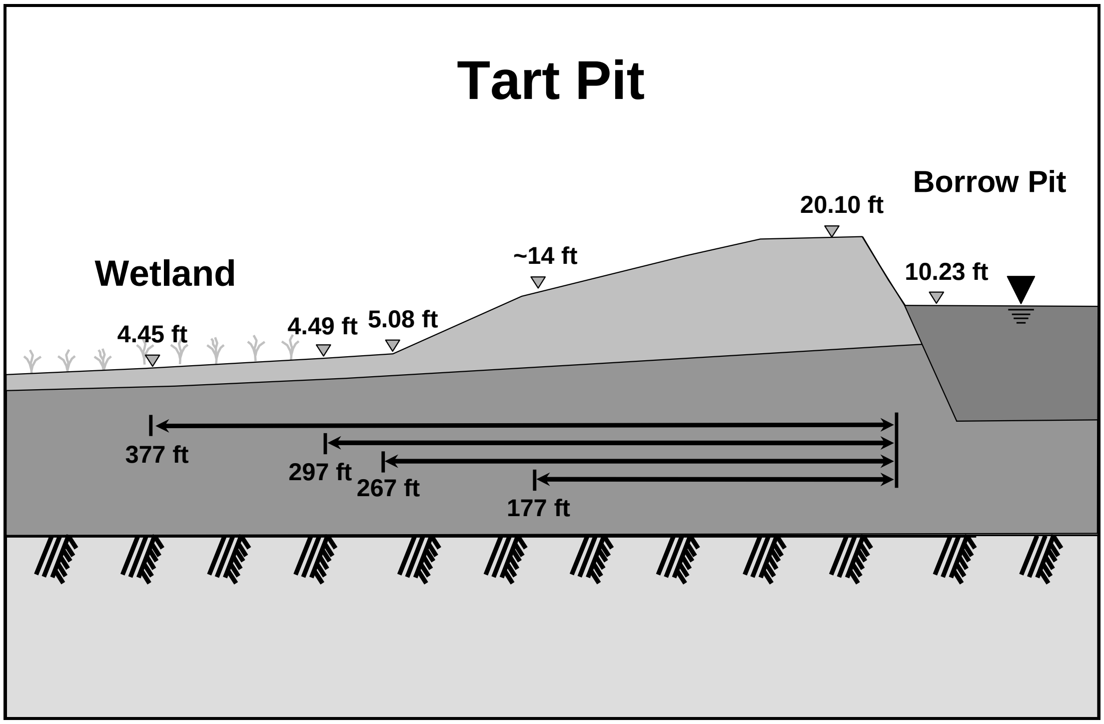


**Figure 14. Type 2 - Wetland down slope of pit. Tart Pit. Ground surface of wetland at lower elevation than pit water level. Wetland on a slope away from the pit.**

**Type 3: Wetlands Upslope And Down Slope of the Pit**. The **Type 3** borrow pit is a combination of **Types 1 and 2**. That is, the pit is adjacent to two wetlands with one wetland upslope of the pit and the other wetland is downslope of the pit. The Vann pit and the Prime Ridge pit (Figures 15 and 16) are examples of Type 3 pits. The potential impact of the borrow pits on the upslope wetland would be a much greater concern than the impact on the down slope wetland in most cases. The method developed in this study can be used to determine the setback distance necessary to avoid detrimental effects to the wetlands upslope from the pit. Our observations indicate that the equilibrium water level in the pit will be approximated as the seasonal high water table at the location of the pit prior to its construction.

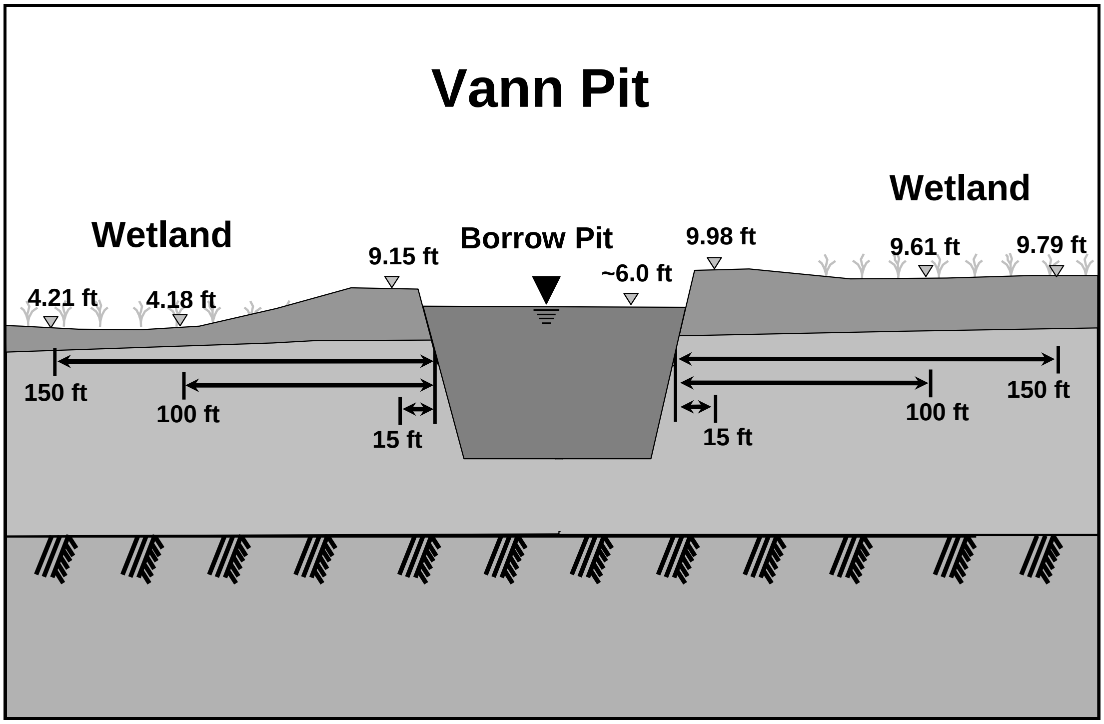


**Figure 15. Type 3 – Wetlands both upslope and down slope of pit. Vann Pit. Ground surface elevation of one wetland is lower than pit water level, and ground surface elevation of other wetland is higher than pit water level.**

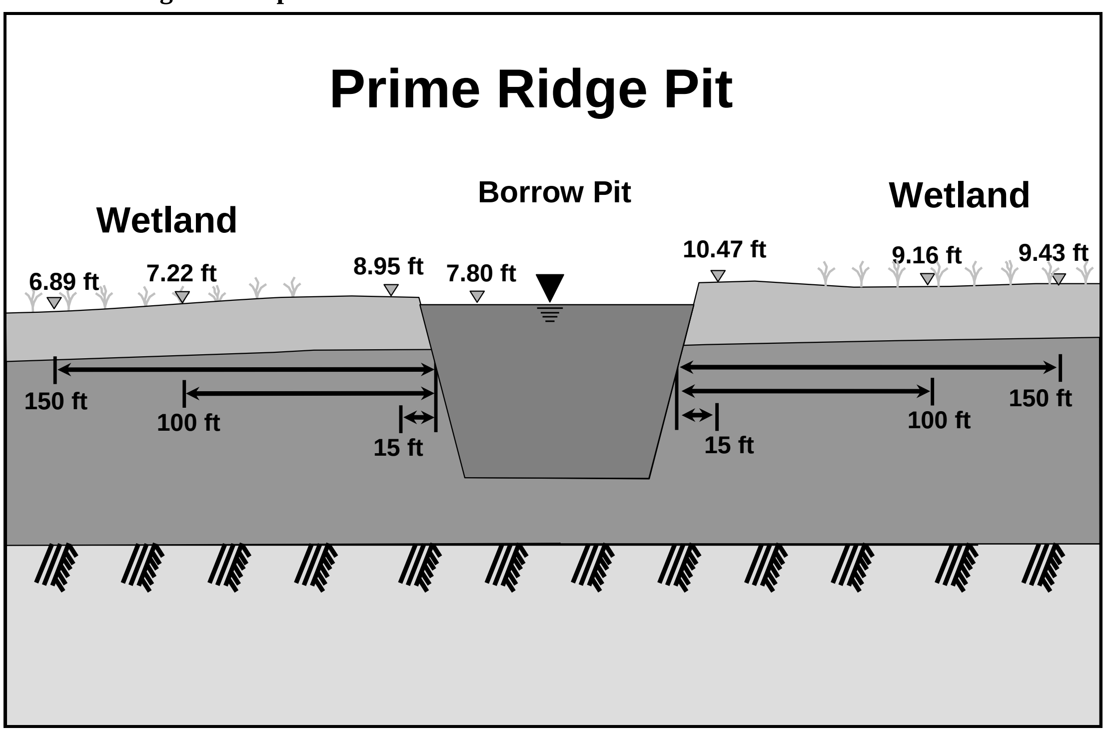


**Figure 16. Type 3 – Wetlands both upslope and down slope of pit. Vann Pit. Prime Ridge Pit. Ground surface elevation of one wetland is lower than pit water level, and ground surface elevation of other wetland is higher than pit water level.**

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