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Development of Methods to Determine Lateral Effect of Highway Drainage Systems on Wetland Hydrology – Phase 2

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16. Abstract

A method was developed in the first phase of this project to predict the lateral effect of a drainage ditch on adjacent wetland hydrology. The method predicts the distance of influence of a single ditch constructed through a wetland, i.e. the width of a strip adjacent to the ditch that is drained such that it would no longer satisfy wetland hydrologic criteria, in terms of T_{25} values which are dependent on climatological conditions. Main objectives of the second phase were to complete determination of the T_{25} values and to test the validity of the method.

T_{25} represents the time required for the water table to draw down from the surface to a depth of 25 cm at the location on the landscape that will just barely satisfy the wetland hydrologic criterion. Values were determined for all 100 North Carolina counties for ditch depths of 0.3 to 1.8 m (1 – 6 ft) and for surface depressional storage values of 2.5 and 5.0 cm (1 and 2 inches).

Data to test the method were collected at two wetland mitigation sites in eastern North Carolina: Mildred Woods in Edgecombe County and ABC near the town of Pinetown in Beaufort County. The method predicted lateral effects of 42.6, 7.2, and 14.1 m for Mildred Woods, ABC shallow ditch, and the ABC deep ditch, respectively. Compared to direct interpolation of 3-year average field results for Mildred Woods (41 m) and the deep ditch (12 m), the method performed well. The lateral effect predicted by the method for the shallow ditch at the ABC site was at least two times that measured in the field (<3.75 m). In this case, the ditch was located in a tight clay layer which substantially reduced the effective transmissivity of the profile and the lateral effect of the ditch on the hydrology adjacent wetlands.

Long-term simulations, (1951 – 2004), were performed with DRAINMOD and WATRCOM for all transect wells to provide alternative assessment of the lateral effects. Results were in general agreement with the predictions of the new method, and, except for the ABC shallow ditch site, with lateral effects determined from field data.

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DISCLAIMER

EXECUTIVE SUMMARY

Methods were developed in the first phase of this project to predict the lateral effect of a drainage ditch on adjacent wetland hydrology. The methods can be used to calculate the distance of influence of a single ditch constructed through a wetland, where the distance of influence is defined as the width of a strip adjacent to the ditch that is drained such that it would no longer satisfy wetland hydrologic criteria. The objectives of the second phase of this project were to complete determination of the T_{25} values required in the method, test the validity of the method, develop a computer program to easily apply the method, publish the research results in an M.S. thesis as well as journals, and to conduct training to the NCDOT on application of the method.

The T_{25} value represents the threshold time required for the water table to draw down, due to the drainage influence of the ditch, from the surface to a depth of 25 cm at the location on the landscape that will just barely satisfy the wetland hydrologic criterion. The T_{25} value is dependent on the depth of the water in the ditch, surface depressional storage, and location. T_{25} values were determined for all 100 North Carolina counties for ditch depths of 0.3 to 1.8 m (1 – 6 ft) and for surface depressional storage values of 2.5 and 5.0 cm (1 and 2 inches).

A field study was conducted to test the approximate method developed to predict lateral effects of highway drainage ditches. Three and one-half years (early 2002 – mid 2005) of hydrologic data were collected at field sites located at the Mildred Woods mitigation site in Edgecombe County, North Carolina and the ABC mitigation site located in Beaufort County, North Carolina. Hourly water table depths were recorded at several locations on transects perpendicular to one drainage ditch (1.2 m depth) at Mildred Woods and a shallow ditch (0.9 m depth) and deep ditch (1.3 m depth) at the ABC site. Rainfall was recorded at each site and temperature data were collected from nearby weather stations.

DRAINMOD simulations were performed for a 54-year period for each ditch to determine the threshold drain spacing, i.e. a spacing associated with water table fluctuations that would just barley satisfy the wetland hydrologic criterion in one half of

the years. DRAINMOD was used with the threshold ditch spacing and depth along with recorded rainfall data for 2002-2004 to predict the maximum consecutive duration that the water table would be above the 30 cm depth for those specific years. Based on the measured durations for each year the estimated lateral effect was 41 m for Mildred Woods, <3.75 m for the ABC shallow ditch, and 12 m for the ABC deep ditch.

DRAINMOD and WATRCOM were calibrated for each study transect by comparing model predicted water table depths and observed water table depths. The calibrated models were then used to simulate water table depths at each observation well for a 54-year period, and the results were analyzed to determine the distance from the ditch where the criterion was satisfied in exactly one-half of the years. Based on the DRAINMOD simulation results the lateral effect was estimated to be 38.6 m for Mildred Woods, <3.75 m for the ABC shallow ditch, and 18.0 m for the ABC deep ditch. Simulation results with WATRCOM estimated a lateral effect of 41.5 m for Mildred Woods, and 8.9 m and 20.3 m ABC shallow and deep ditches, respectively.

Results of the approximate method estimated the lateral effect to be 42.6 m for the ditch at the Mildred Woods site. This was close to the values obtained from the observed data and the two simulation models. A lateral effect of 14.1 m was estimated for the ABC deep ditch using the approximate method. This value is slightly larger than obtained from the field data, 12 m, and less than the values predicted by DRAINMOD and WATRCOM. The approximate method estimated a lateral effect of the ABC site shallow ditch of 7.2 m, compared to < 4 m determined from field measurements. The ABC site shallow ditch resides in a tight clay layer that apparently cut off most of the drainage from the lower, higher conductivity layer. Additional research is needed to determine how the method should be modified for shallow ditches confined in a low conductivity layer.

A computer program has been developed to apply the approximate method. Inputs include county, ditch depth, surface storage conditions, depth to the impermeable layer, drainable porosity, and lateral conductivity. The program eliminates the need for the user to read values from charts and tables, thereby reducing error.

INTRODUCTION

Drainage systems can impact adjacent lands. When drainage ditches are located adjacent to wetlands, the hydrology of the wetland will likely be modified to some extent. The North Carolina Department of Transportation, as well as other governmental and private entities involved in highway construction, is currently required to determine the extent to which construction and maintenance of highways changes the hydrology of adjacent wetlands such that they no longer function as wetlands.

Methods were developed in the first phase of this project to predict the lateral effect of drainage ditches on wetland hydrology. The lateral effect of a drainage ditch, as shown in Figure 1, will be defined as follows:

> "The width of a strip of land which is drained such that it no longer satisfies the wetland hydrologic criterion."

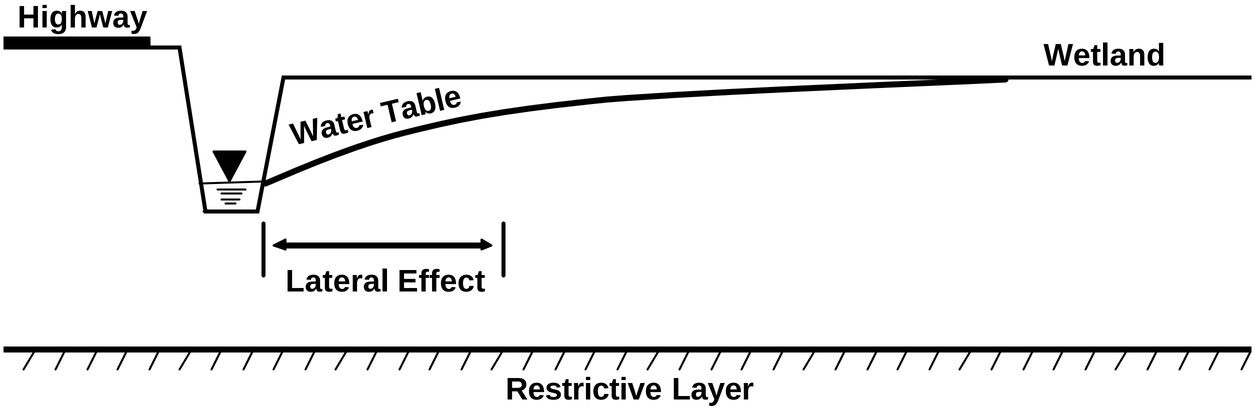

Figure 1. Schematic of highway ditch showing the lateral effect of the ditch on wetland hydrology

It is important to note that this definition defines the lateral effect purely based on the hydrologic impact of the drainage ditch as it relates to the jurisdictional wetland hydrologic criterion. Non-hydrological methods of determining the lateral effect have been explored. Hayes and Vepraskas (2000) proposed a method to determine the lateral effect of a drainage ditch based on Fe mass concentrations. Their research showed that subsurface drainage due to the ditch caused a migration of Fe masses in a direction towards the ditch. By examining cores for oxidized masses along a perpendicular transect leading away from the ditch, one can predict the lateral effect of the ditch. It must be noted that the definition of lateral effect, as it applies to this study, is solely based on the influence on the hydrology of the adjacent wetland hydrology. Analysis of the influence of a drainage ditch on modifications to the functional values of the wetland is neither analyzed nor researched in the scope of this project.

WETLAND HYDROLOGIC CRITERION

Before proceeding it is necessary to define the hydrologic criterion for wetlands. The criterion may be expressed as follows: a site has wetland hydrology if, during the growing season, the water table is normally within 30 cm of the surface for a continuous critical duration. The critical duration was specified as 5% to 12.5 % of the length of the growing season in the 1987 U.S. Army Corps of Engineers Wetland Delineation Manual (USACE, 1987). Recognizing the uncertainty in the data supporting a critical duration, the National Research Council Committee (NRC, 1995) recommended a duration of 14 days be used until more definitive limits could be determined. The lower limit of 5% of the growing season is used in most cases in North Carolina, and is assumed in this paper to define the critical duration. The growing season is defined for this purpose as the period between the average last date having 28° F in the spring to the average first date of 28°F in the fall, as given in the published county Soil Survey. Finally, the word normally in the criterion is defined as meaning that conditions satisfying the criterion occur at least once in two years on average (e.g., 25 out of 50 years).

CURRENT METHODS OF CALCULATING LATERAL EFFECT

One method that has been used to determine the lateral effect of a roadside drainage ditch on adjacent wetland hydrology is based on the "Scope and Effect Guide" for North Carolina hydric soils (NRCS, 1998). The guide groups together soils of similar soil properties and estimates the lateral effect of a particular drainage ditch depth / soil group combination. The method is based on the ellipse equation for flow to parallel drains with several simplifying assumptions. Calculations by the method relate only approximately to the criteria for wetland hydrology. Further, the method does not consider the fact that the lateral effect of a single ditch is less than that of parallel drains. Effects of surface depressional storage are neglected in the guide.

APPROXIMATE METHOD MODEL DESCRIPTION

An approximate method was developed in the first phase of this project to estimate the lateral effect of a drainage ditch on adjacent wetland hydrology. The method has been referred to as the "Skaggs Method" by the NCDOT[1]. The method is based on the time required for water table drawdown in an initially saturated profile with the water table coincident with the surface. DRAINMOD simulation analyses showed that sites barely satisfying the wetland hydrologic criterion will have drainage intensities that provide water table drawdown from the surface to a depth of 25 cm (10 in) in a specific time. This threshold draw down time, T_{25}, was found to depend moderately on ditch depth but was nearly constant among soils having a wide range of profile transmissivities and drainable porosities. T_{25} was found to depend strongly on surface depressional storage, decreasing as surface storage increased. T_{25} also depended strongly on location, which affects both the growing season and weather variables. Once the T_{25} values are determined, published solutions for water table drawdown due to a single drain (Skaggs, 1976) can be used to estimate the lateral effect of a drainage ditch or subsurface drain on wetland hydrology. Two main objectives of this project were to complete development of the T_{25} values for all counties of North Carolina and to test the validity of the approximate method.

OBJECTIVES OF PHASE 2

1. Develop T25 values for drainage ditches for all 100 NC counties
2. Complete testing of the method with field data
3. Develop computer program to easily apply the "Skaggs Method"
4. Conduct training workshop for DOT personal on application of the method and interpretation of the results
5. Publish research results in an M.S. thesis and refereed journal articles to enhance the validity of the method

T25 VALUES FOR NORTH CAROLINA

The first objective of this project was to complete the determination of T_{25} values for surface storage conditions of 1 and 2 inches for all 100 North Carolina counties.

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[1] http://www.ncdot.org/doh/operations/dp%5Fchief%5Feng/roadside/fieldops/downloads

Those values are listed in Tables 1 and 2. The T_{25} value (days) represents the time required for the water table to recede from the surface to a depth of 25 cm (10 in), due solely to the drainage influence of the ditch, at a site that marginally satisfies the wetland hydrologic criterion. The T_{25} value is dependent on location and the surface storage conditions and depth of water in the ditch. The reader is referred to the final report of Phase 1 of this project for a complete discussion on the relevance and development of the T_{25} values.

It should be noted that the current T_{25} values were developed using a continuous saturation time equal to 5% of the growing season for the county of interest. If the Army Corps of Engineers (COE) modifies the hydrologic criterion portion of the wetland definition, T_{25} values would need to be recalculated to reflect the change in the continuous saturation time.

Table 1. 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 2. 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.

TESTING THE METHOD

Field testing of the method was conducted at two wetland mitigation sites in eastern North Carolina. These sites are managed by the North Carolina Department of Transportation's Office of Natural Environment. The first study site is located in Edgecombe County at Mildred Woods Mitigation Site (NCDOT Natural System Unit Monitoring Report 2001 Mildred Woods, 2001; 35.87 N, 77.48 W), approximately five kilometers east of Tarboro. The second study site is located in the town of Pinetown, Beaufort County at the ABC Mitigation Site (NCDOT Natural System Unit Monitoring Report 2002 ABC, 2002; 35.62 N, 76.86 W).

Transects of seven water table wells were installed perpendicular to drainage ditches at the sites. One transect was installed at the Mildred Woods. At the ABC site, transects were installed on a shallow ditch and a deep ditch. Five of the seven water table wells were equipped with automatic recording mechanisms and the water levels in the remaining two wells were measured manually. One manual rain gage and one recording rain gage were located at each study site. The reader is referred to the final report for Phase 1 of this project for a complete description of the study sites, weather data, and observed water table measurements.

Four methods were studied to predict the lateral effect – a field method based on threshold drainage conditions, long-term simulations in both DRAINMOD and WATRCOM, and the approximate method. The computer model DRAINMOD (Skaggs, 1978) is a water balance simulation model originally developed to evaluate the long term hydrologic response of a drainage system design in agricultural settings with a relative shallow depth to the impermeable layer and overall shallow water tables (Evans and Fausey, 1999). The computer simulation model WATRCOM (Parsons, 1987; Parson et al., 1991b) is a finite element water management simulation model developed to quantify drainage and water table fluctuations on a watershed scale. Whereas the model DRAINMOD was designed to predict the water table response to a parallel drainage system design, the two dimensional model WATRCOM was designed to predict water table fluctuations for multiple intersecting drains of varying depths and slopes. Results from the field method and long-term simulations were used to test the validity of the approximate method results.

PREDICTING THE LATERAL EFFECT BASED ON FIELD DATA

The data for all sites were analyzed to determine the maximum duration that the water table at each well stayed above the 30 cm depth during the growing season. Results varied from year-to-year (as expected) because of weather variability.

Mildred Woods

Maximum durations for each observation well at Mildred Woods are plotted in Figure 2. The critical duration at this site (5% of the growing season) is 12 days; so the lateral effect of the drainage ditch (call it x for convenience) is the distance from the ditch where the water table is within 30 cm of the surface for 12 consecutive days in 50% of the years. At distance x the water table will be within 30 cm of the surface for 12 or more consecutive days in 50% of the years, but not in every year. For any given year, the water table at x may remain in the top 30 cm for more or less than 12 days, depending on weather conditions. So it not possible to simply compare the measured number of consecutive days plotted in Figure 2 with 12 to determine the lateral effect, x. In order to define a reference duration for each year of observation, DRAINMOD was used to determine a threshold drain spacing for conditions of this site following procedures described by Skaggs et al. (2005). Simulations were conducted for a 54-year period (1951-2004) of local weather data and using site-specific soil data for multiple drain spacings. The threshold spacing for the Mildred Woods site was determined to be 96 m. This means that the land midway between ditches 96 m apart would satisfy the criterion in 50% of the years. Next DRAINMOD was used with the threshold ditch spacing and depth along with recorded rainfall data for 2002-2004 to predict the maximum duration that the water table would remain above the 30 cm depth for those specific years. These threshold durations were 20 days for 2002, 13 days for 2003, and 10 days for 2004, and are plotted as “threshold condition” in the bar plot of Figure 2.

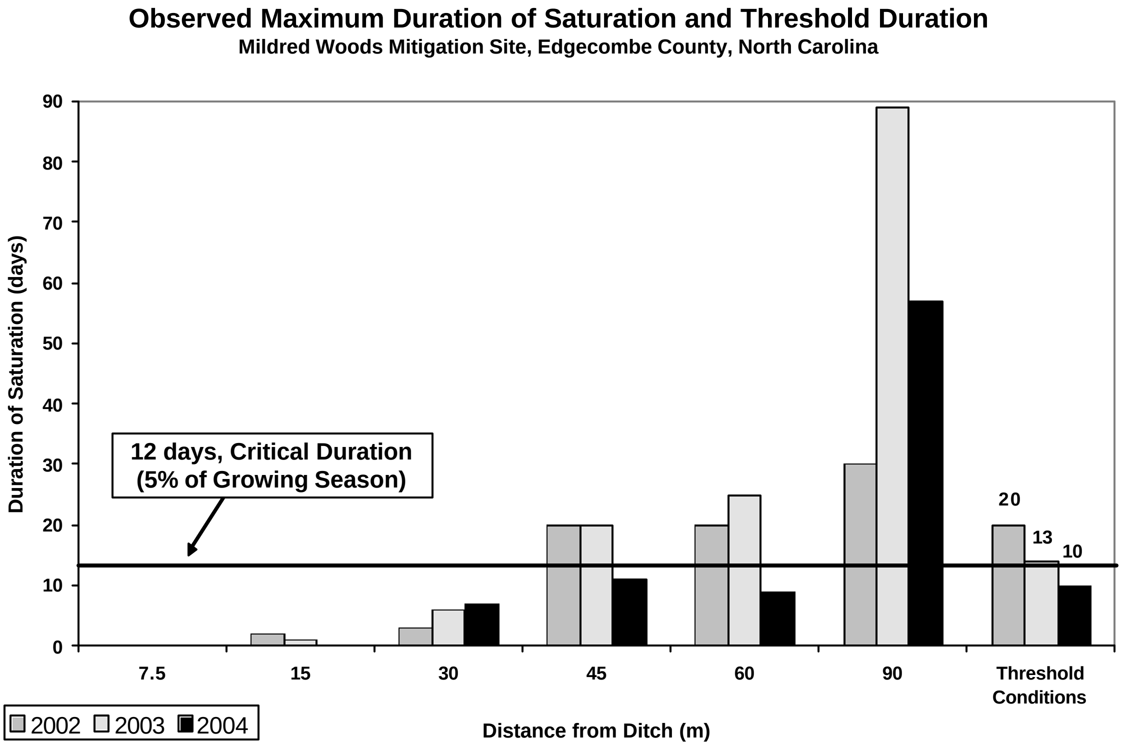

Figure 2. Observed and predicted number of consecutive days when water table was within 30 cm of the surface during the growing season plotted by year for the Mildred Woods site. Threshold conditions represent the number of days in each year for a site that barely satisfies the wetland hydrologic criterion.

Using these values as a reference, the durations plotted in Figure 2 can be analyzed to estimate the lateral effect. For example, the duration predicted for threshold conditions for 2002 was 20 days. This means that a site that would barely satisfy the wetland hydrologic criterion in 50% of the years over a 54-year period would have had the water table within 30 cm of the surface for 20 consecutive days during the growing season in 2002. This is very close to the measured duration at a distance of 45 m from the ditch in 2002 (Figure 2). So based on data from 2002, the estimate of the lateral effect is 45 m.

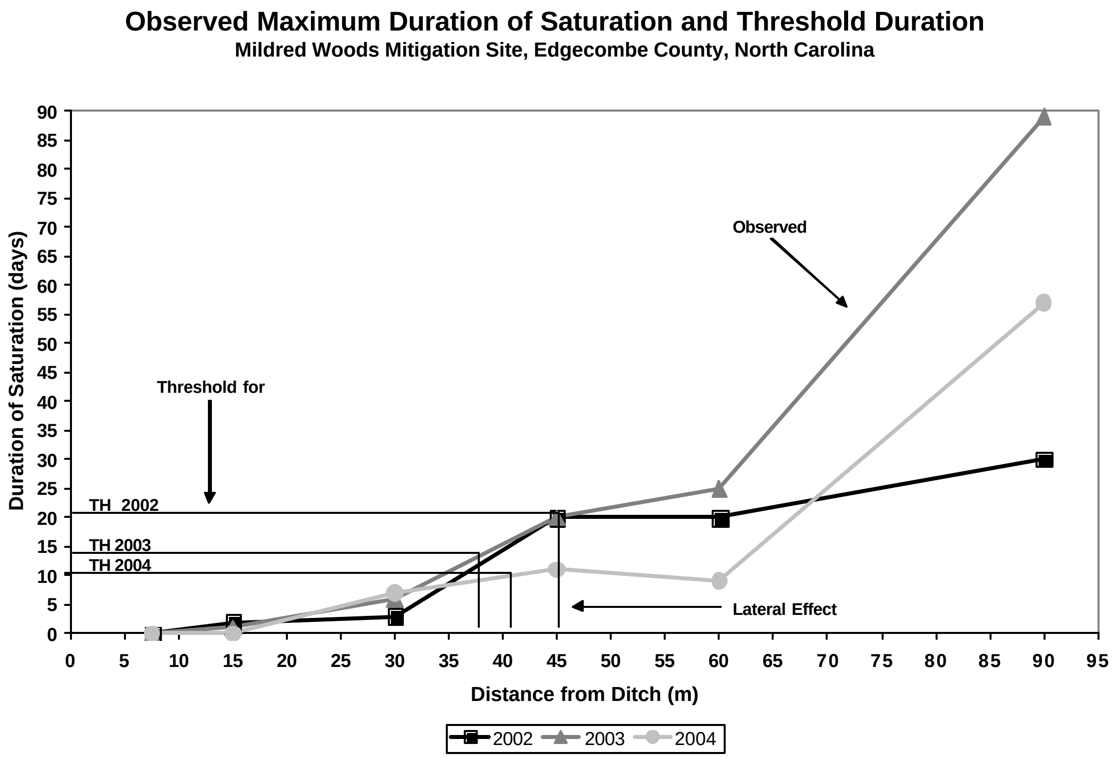

Figure 3. Observed consecutive number of days with water table within 30 cm of surface as a function of distance from ditch at the Mildred Woods site. Threshold (TH) values are the number of consecutive days that a site barely satisfies the criterion would have in each year.

Results in Figure 2 may be plotted by year as shown in Figure 3, for easy determination of the lateral effect. Once the measured duration is plotted versus distance from the ditch for a given year, the lateral effect can be estimated as the intercept of that curve and the duration predicted for the threshold ditch spacing for that year (Figure 3). Application of this method resulted in estimated lateral effects of 45 m for 2002, 37 m for 2003, and 41 m for 2004 (Figure 3).

ABC Site Shallow Ditch

Maximum durations for each observation well at shallow ditch at the ABC site are plotted in Figure 4. The critical duration at this site (5% of the growing season) is 13 days. Simulations, using the method prescribed earlier, were conducted for the 54-year period (1951-2004) of local weather data for multiple drain spacings. The threshold ditch spacing and depth along with recorded rainfall data for 2002-2004 were used to predict the maximum consecutive duration that the water table would be above the 30 cm depth for those specific years. Those durations are plotted as “threshold condition” in the bar plot of Figure 4. They were 13 days for 2002, 16 days for 2003, and 5 days for 2004.

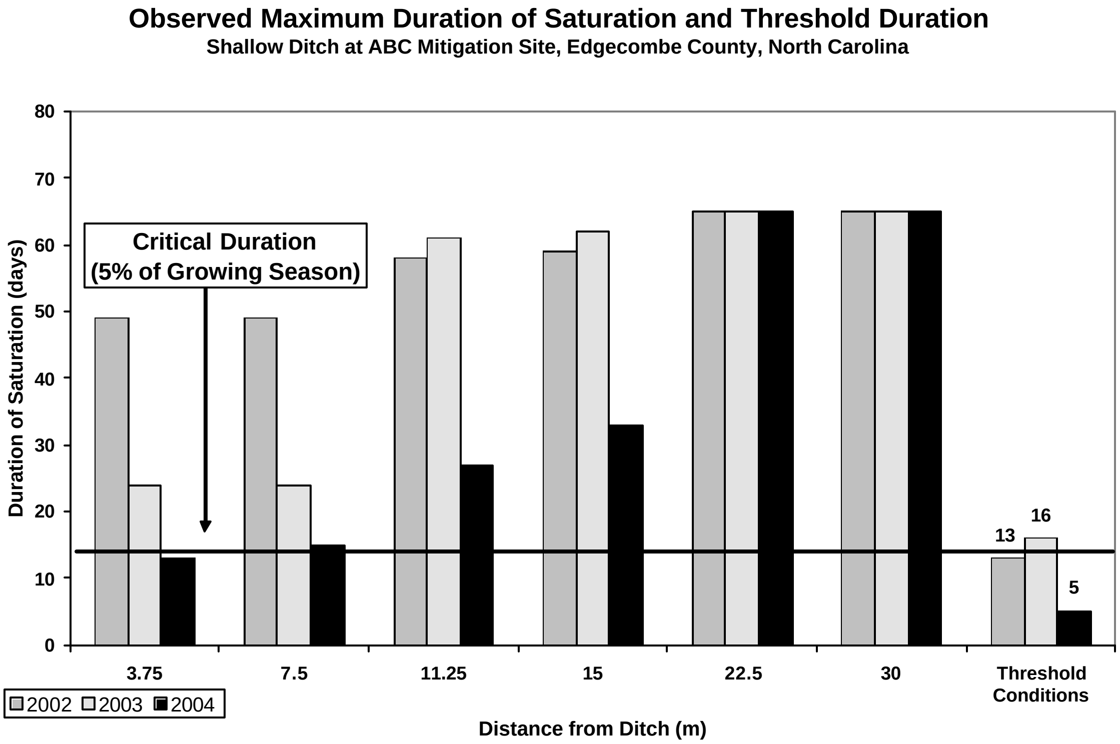

Figure 4. Observed and predicted number of consecutive days when water table was within 30 cm of the surface during the growing season plotted by year for the Shallow Ditch at the ABC site. Threshold conditions represent the number of days in each year for a site that barely satisfies the wetland hydrologic criterion.

In contrast to the Mildred Woods site, threshold conditions shown in Figure 4 are all below the maximum consecutive days for any given year / distance from the ditch combination. Based on the threshold conditions, it may be concluded that the lateral effect is less than 3.75 m for this ditch.

ABC Site Deep Ditch

Maximum durations for each observation well at deep ditch at the ABC site are plotted in Figure 32. Threshold conditions for this ditch were simulated using the methods described previously. Those durations were 13 days for 2002, 18 days for 2003, and 6 days for 2004, and are plotted as “threshold condition” in the bar plot of Figure 5.

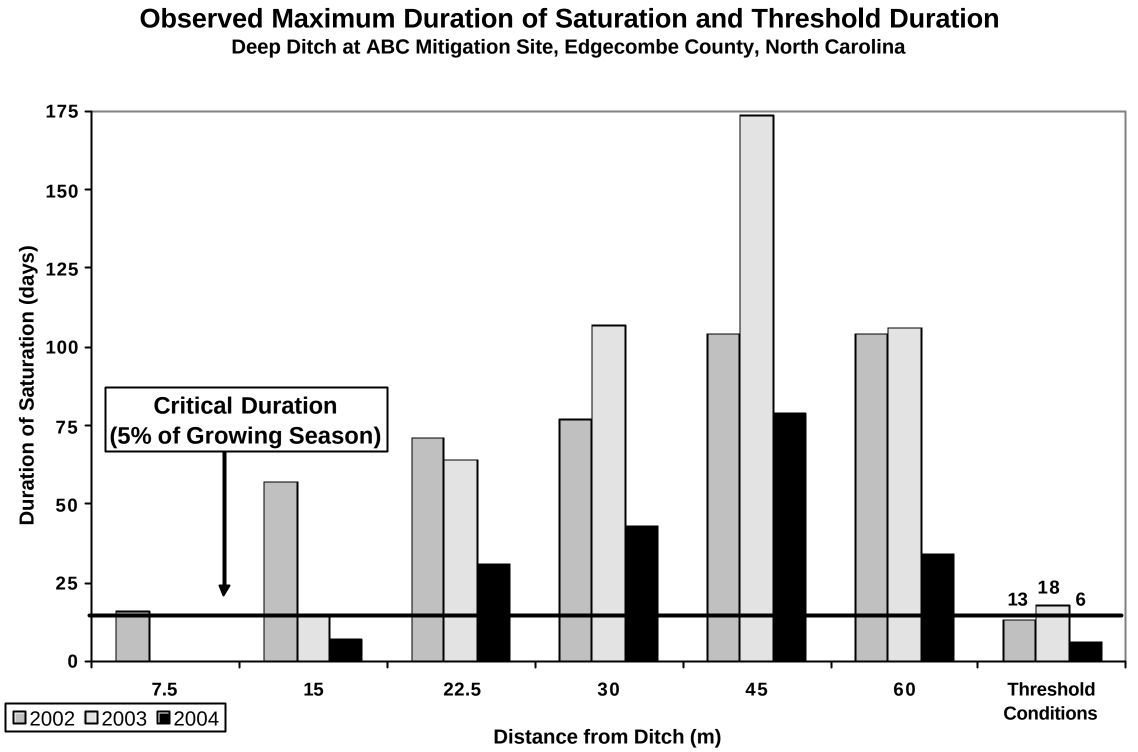

Figure 5. Observed and predicted number of consecutive days when water table was within 30 cm of the surface during the growing season plotted by year for the Deep Ditch at the ABC site. Threshold conditions represent the number of days in each year for a site that barely satisfies the wetland hydrologic criterion.

Using these threshold condition values as a reference, the duration plotted in Figure 5 can be analyzed to estimate the lateral effect. The duration predicted for threshold conditions for 2002 was 13 days, which is very close to the measured duration at a distance of 7.5 m from the ditch in 2002 (Figure 6). So based on data from 2002, the estimate of the lateral effect x = 7.5 m.

Results in Figure 5 were plotted by year as shown in Figure 6, for easy determination of the lateral effect, as was done above for Mildred Woods. The lateral effect was estimated as the intercept of that curve and the duration predicted for the threshold ditch spacing for that year (Figure 6). As shown, the predicted lateral effect was 15 m based on the data for 2003 and about 14 m for 2004, compared to 7.5 m based on data for 2002.

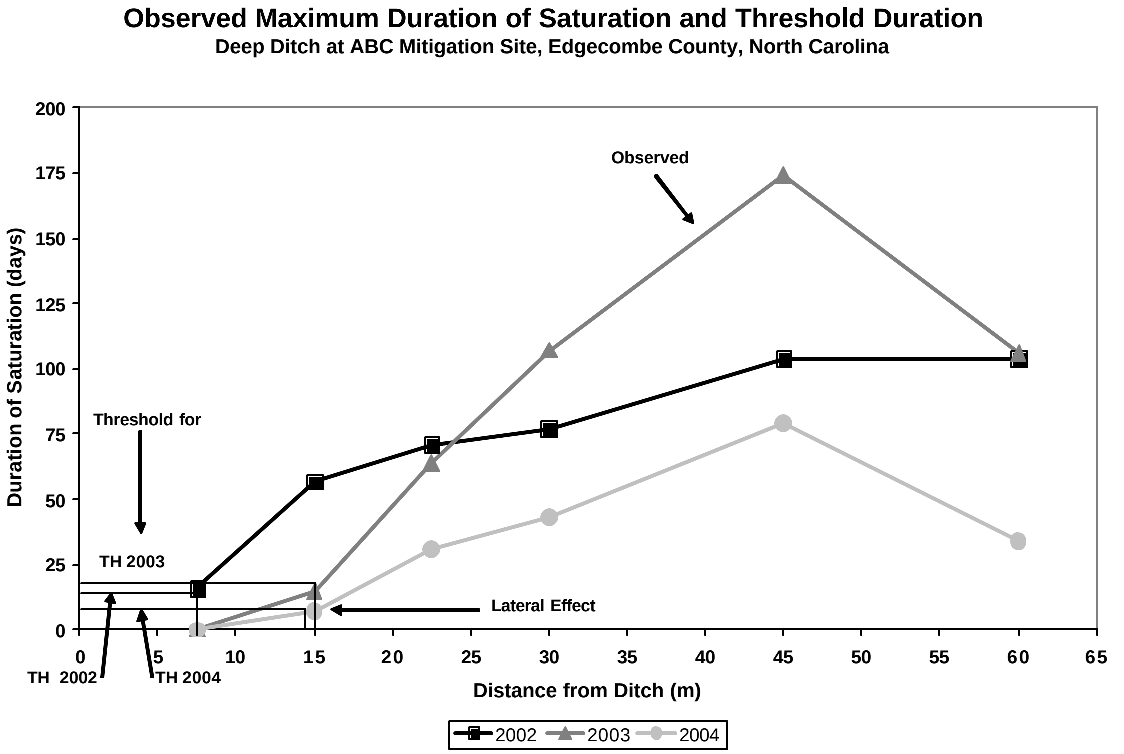

Figure 6. Observed consecutive number of days with water table within 30 cm of surface as a function of distance from ditch at the Deep Ditch at the ABC site. Threshold (TH) values are the number of consecutive days that a site barely satisfies the criterion would have in each year.

Summary of results based on field data

Results of estimations of the lateral effect for all sites are summarized in Table 3.

Table 3. Summary of results for lateral effect at drainage ditches based on 3 years of observations.

	Mildred Woods		ABC Shallow Ditch		ABC Deep Ditch	
	Threshold Condition (days)	Lateral Effect (m)	Threshold Condition (days)	Lateral Effect (m)	Threshold Condition (days)	Lateral Effect (m)
2002	20	45	13	< 3.75	13	7.5
2003	13	37	16	< 3.75	18	15
2004	10	41	5	< 3.75	6	14
Avg		41		< 3.75		12

PREDICTING LATERAL EFFECT USING LONG TERM COMPUTER SIMULATIONS

DRAINMOD and WATRCOM Calibrations

DRAINMOD and WATRCOM were calibrated for Mildred Woods using observed water table data from January 2002 through August 2003 for the first three transect wells nearest the ditch. The three farthest wells were calibrated from January 2002 through December 2004. The discrepancy in the calibration period was due to unnatural water table fluctuations near the ditch due to the influence of a downstream beaver dam beginning in September 2003. The models were calibrated for the ABC shallow ditch and deep ditch using data from January 2002 through December 2004 and from November 2002 through May 2005, respectively. The models were calibrated using known parameters and best estimates. Parameters were then adjusted, within reason, so that predicted water table values best matched observed water table values for the calibration periods.

DRAINMOD and WATRCOM Long term Simulation Results

Long-term DRAINMOD and WATRCOM simulations were conducted using calibrated inputs for each well on each transect for a 54-year period from 1951 to 2004. It was possible to determine from measured data whether water table conditions at each well satisfied wetland hydrologic criterion. The purpose of the simulations was to determine whether the wetland criterion would be satisfied in one-half or more of the years on a long-term basis. The hydrologic criterion assumed a threshold duration of 5% of the growing season. This means that a site that would barely satisfy the wetland hydrologic criterion in 50% of the years over a 54 -year period would have the water table within 30 cm of the surface for a continuous period of time equal or greater than 5% of the growing season (12 days at Mildred Woods, 13 days at the ABC site). Results of the DRAINMOD long-term simulations for each well are listed in Table 4.

Table 4. DRAINMOD long term simulation results.

Summary of long term simulations

Mildred Woods		**ABC Shallow Ditch**		**ABC Deep Ditch**	
Distance of well from ditch	Number of years out of 54 meeting criterion	Distance of well from ditch	Number of years out of 54 meeting criterion	Distance of well from ditch	Number of years out of 54 meeting criterion
7.5 m	0	3.75 m	50	7.5 m	0
15 m	0	7.5 m	50	15 m	16
30 m	0	11.25 m	54	22.5 m	43
45 m	47	15 m	54	30 m	53
60 m	42	22.5 m	54	45 m	54
90 m	54	30 m	54	60 m	54

Based on these results, the lateral effect of the drainage ditches is between 30 and 45 m for Mildred Woods. Linear interpolation results in a lateral effect of 38.6 meters. Results of both field results and the DRAINMOD model indicate the lateral effect is less than

3.75 m for the ABC shallow ditch. The lateral effect for the ABC deep ditch is between 15 and 22.5 meters. Linear interpolation would indicate an effect of 18 meters.

Table 5 lists the results of the WATRCOM long-term simulations for the Mildred Woods and the ABC sites.

Table 5. WATRCOM long term simulation results**.**

Summary of long term simulations

Mildred Woods		**ABC Shallow Ditch**		**ABC Deep Ditch**	
Distance of well from ditch	Number of years out of 54 meeting criterion	Distance of well from ditch	Number of years out of 54 meeting criterion	Distance of well from ditch	Number of years out of 54 meeting criterion
7.5 m	0	3.75 m	9	7.5 m	0
15 m	0	7.5 m	23	15 m	15
30 m	0	11.25 m	34	22.5 m	32
37.5 m[1]	11	15 m	34	30 m	34
45 m	41	22.5 m	39	45 m	39
60 m	45	30 m	40	60 m	40
90 m	53				

1. No physical well located at this distance from ditch.37.5 m represented by WATRCOM simulated node.

WATRCOM predicted the lateral effect of the drainage ditches to be between 37.5 and 45 meters for Mildred Woods, between 7.5 and 11.25 meters for the ABC shallow ditch, and between 15 and 22.5 meters for the ABC deep ditch. A linear interpolation of the WATRCOM results indicates a lateral effect of 41.5, 8.9, and 20.3 m for the Mildred Woods and ABC shallow and deep ditch, respectively.

PREDICTING THE LATERAL EFFECT USING THE APPROXIMATE METHOD

Theory

The approximate method developed by Skaggs et al. (2005) (and referred to as the Skaggs Method by the NC DOT) may be used to predict the lateral effect of a drainage ditch on adjacent wetland hydrology. As previously defined, the lateral effect of a ditch or subsurface drain may be defined as the width of a strip of land adjacent to the ditch in which the hydrology has been changed such that it will no longer meet the wetland hydrologic criterion as defined in the 87 Manual (USACOE , 1987). Skaggs et al. (2005) determined that, for poorly drained soils in North Carolina, sites that barely satisfied the wetland hydrologic criterion had characteristic water table draw down rates that depended on local weather conditions and surface depressional storage, but were relatively independent of soil type. The characteristic draw down rates can be quantified as the threshold time, T_{25}, required for the water table to be lowered by drainage from the surface to a depth of 25 cm. Example results are shown in Figure 7 for five soils in New Hanover County, NC. Long-term (50 year) simulations were conducted for a wide rang of ditch spacings for each soil. The threshold spacing, that spacing that resulted in conditions midway between the drains barely satisfying the wetland hydrologic criterion, was determined for each of the five soils. Results in Figure 7 were calculated for the threshold drain spacing for each soil. They indicate that sites barely satisfying the wetland hydrologic criterion in New Hanover County have characteristic draw down rates of 25 cm in 6.4 days. That is, the T_{25} value for a ditch depth of 120 cm and surface depressional storage of 2.5 cm is 6.4 days for New Hanover County.

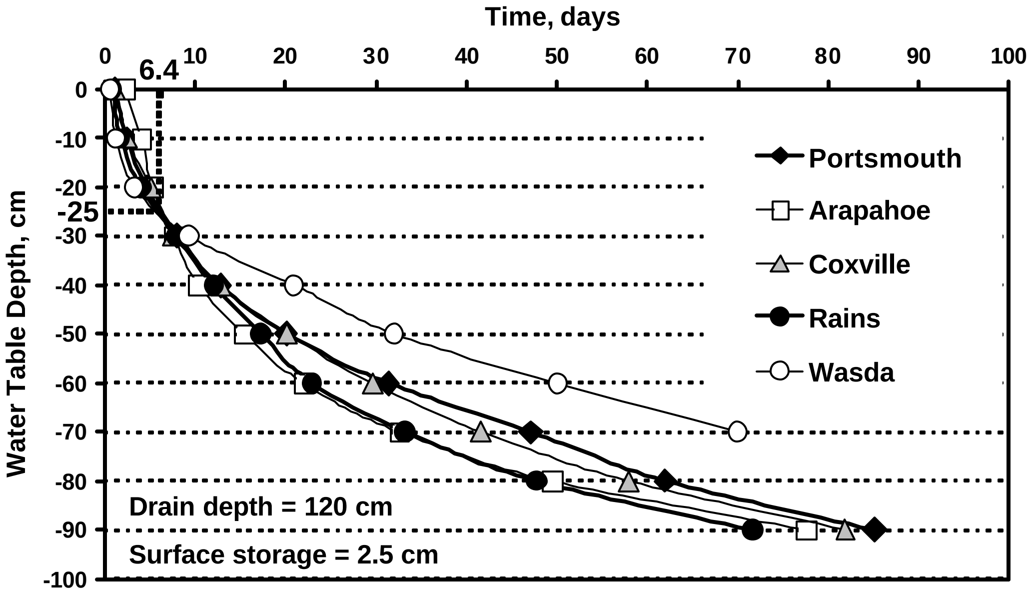

Figure 7. Predicted midpoint water table drawdown for threshold ditch spacings of 5 North Carolina soils. Results are for a ditch depth of 120 cm and surface storage of S = 2.5 cm. Time for water table drawdown of 25 cm (T_{25}) is approximately 6.4 days for all soils (after Skaggs et al., 2005).

The approximate method estimates the lateral effect of a ditch as the distance from the ditch where the water table drawdown, from an initially saturated profile (water table coincident with the surface) is 25 cm in a time of T_{25}. This distance may be calculated with numerical solutions to the Boussinesq equation presented by Skaggs (1976). These solutions are plotted in nondimensional form in Figure 8.

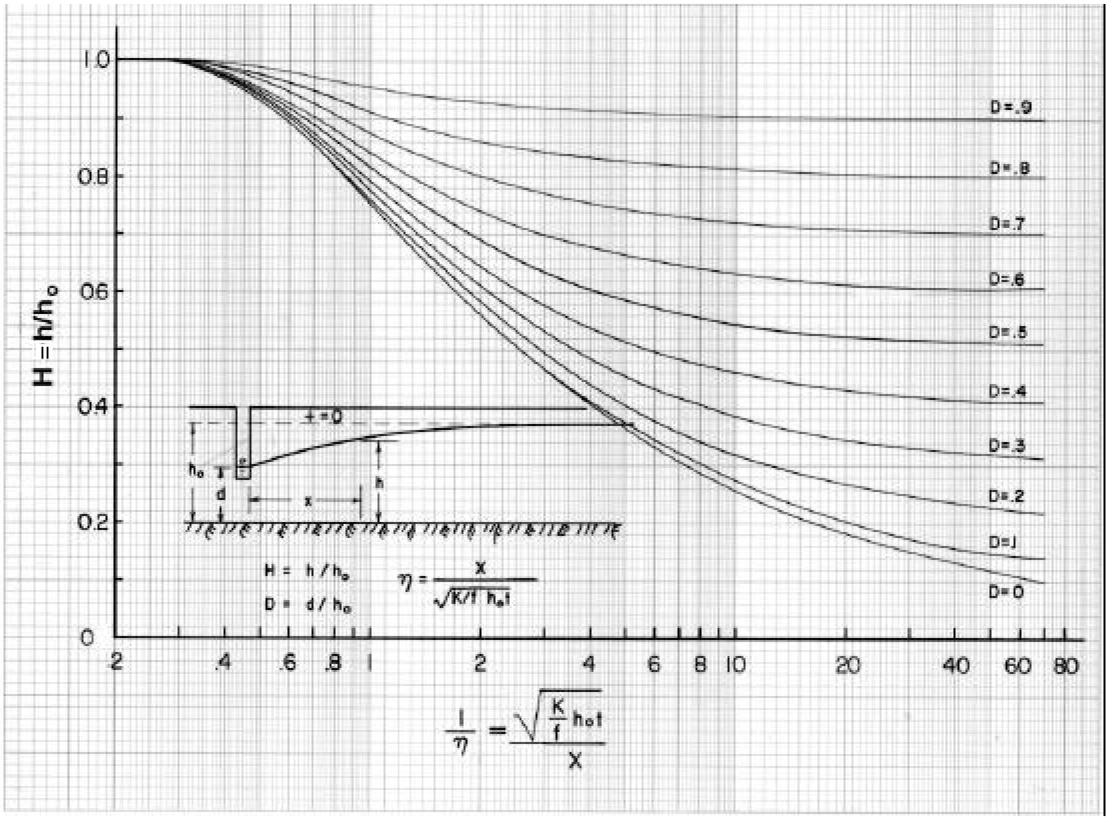

Figure 8. Nondimensional solutions to the Boussinesq equation for water table drawdown due to drainage to a single ditch (after Skaggs, 1976).

An explanation of the variables involved in using the numerical solution follows:

x = distance from the ditch,
t = time, days
$H = h/h_o$, where h is the water table elevation above the impermeable layer at time t and h_o, is that elevation at t=0,
$D = d/h_o$, where d is the elevation of the water level in the ditch above the impermeable layer,
K = effective hydraulic conductivity of the profile extending from the ground to the impermeable layer,
f = drainable porosity,
? = nondimensional parameter.

For a given application we need to find x where $h = h_o - 25$ (25 cm of drawdown) at $t=T_{25}$. The terms h_o and d are known, so it is a simple matter to determine H and D and find the corresponding value of 1/ ? from Figure 8. Then the lateral effect, x, can be solved as,

$$x = \frac{\sqrt{[\frac{K}{f}] * h_o * t}}{\frac{1}{h}} \qquad [1]$$

By substituting $t=T_{25}$ the lateral effect can be determined in terms of known values of K, f and h_o. In other words, if one knows the soil and site parameters and the characteristic T_{25} value, the lateral effect can be calculated from the solutions plotted in Figure 8. A complete list of T_{25} values determined for all 100 North Carolina counties is given in Tables 1 and 2.

Input Parameters

Required input parameters for the approximate method of calculating the lateral effect include the following:

Location – county of roadside ditch
Ditch depth
Surface storage conditions
Effective hydraulic conductivity – for profile extending from soil surface to impermeable layer
Drainable porosity – for top 30 cm
Depth to impermeable layer
T_{25} value – from table based on location, ditch depth, surface storage
Boussinesq solution – from nondimensional solution plot.

Example

An example of using the approximate method to calculate the lateral effect is presented here. The lateral effect at the Mildred Woods site will be calculated for this example. The Mildred Woods input parameters are listed in Table 6.

Table 6. Approximate method inputs for Mildred Woods site.

Parameter	
Location	Edgecombe Co.
Ditch depth	1.20 m
Surface storage	5.0 cm
K_{eff}	0.94 m/hr
Drainable porosity, f	0.035
Depth to impermeable layer	4.8 m

As shown in Table 2, a 1.2 m deep ditch and 5.0 cm surface storage located in Edgecombe Co. has a T_{25} value of **5.6 days**.

Two values are required to determine the lateral effect from plotted solutions to the Boussinesq solution, H and D. H can be viewed as the nondimensional water table depth and D the nondimensional ditch water elevation. For this example H and D are,

$$H = \frac{4.8 - 0.25}{4.8} = 0.95 \qquad [2]$$

$$D = \frac{4.8 - 1.2}{4.8} = 0.75 \qquad [3]$$

From Figure 8 with these values of H and D, the value for 1/ ?   is approximately **0.63**. Applying equation [1] the predicted lateral effect of the drainage ditch considered is,

$$x = \frac{\sqrt{[(0.94m/hr)*(24hr/day)/0.035]*4.8m*5.6days}}{0.63} = \mathbf{43}\boldsymbol{m} \qquad [4]$$

The user may note that ET is not directly considered in these calculations. However its effect is accounted for in that ET is addressed in the long term DRAINMOD simulations used to determine the T_{25} values.

Calculations of Lateral Effect Method for Field Sites

The approximate method for calculating the lateral effect was applied to each of the three field transects. A summary of the input parameters is listed in Table 7. These parameters were based on calibrated inputs to the WATRCOM model.

Table 7. Inputs and results for calculating lateral effect of drainage ditch on field sites by approximate method.

	Mildred Woods	**ABC Shallow Ditch**	**ABC Deep Ditch**
Location	Edgecombe Co	Beaufort Co.	Beaufort Co
Ditch depth, m	1.2	0.9	1.3
Surface storage, cm	5.0	10.0	2.5
$K_{eff,}$, m/day	0.94	0.10	0.10
Drainable porosity	0.035	0.06	0.06
Depth to impermeable layer, m	4.8	6.0	6.0
T_{25}, days	5.6	2.63	7.6
H	0.95	0.96	0.96
D	0.75	0.85	0.80
1/? (from Figure 2)	0.63	0.72	0.62
Lateral Effect (m)	**43**	**7**	**14**

A summary of the predicted lateral effects for the methods listed in this report is given in Table 8. The lateral effects for the DRAINMOD and WATRCOM models in Table 8 represent linear interpolations based on the long-term simulations results.

Table 8. Summary of lateral effect predicted or calculated for all methods presented.

	Mildred Woods	ABC Shallow Ditch	ABC Deep Ditch
Method		Lateral Effect (m)	
Field Results	41	<3.75	12
DRAINMOD	38.6	<3.75	18.0
WATRCOM	41.5	8.9	20.3
Approximate Method	42.6	7.2	14.1

Discussion

The approximate method was evaluated by comparing predicted lateral effects for three sites to “measured” values. Because the definition of the lateral effect involves conditions that are satisfied on a frequency basis (i.e. in more than 50% of years), it is impossible to measure it directly. In this study, the “measured” lateral effect was determined by three methods of analyzing the field data: (1) a direct interpolation for each year of observation (field results in Table 8); (2) by calibrating DRAINMOD for each water table observation well, conducting long-term simulations for each point, and calculating the lateral effect by interpolation; and (3) by calibrating WATRCOM for each point and using a similar procedure as used for DRAINMOD in (2) above. Results predicted by both DRAINMOD and WATRCOM were subject to calibration errors as discussed previously.

The approximate method closely predicted the lateral effect for the Mildred Woods and ABC deep ditch sites as compared to field results. The method over predicted the effect for the ABC site shallow ditch compared to the field results. The lateral effect calculated by the approximate method was about 43 m for the Mildred Woods site. Results from direct interpolation of field data indicated that the lateral effect of the ditch had an average value of 41 m. Due to the variability in annual climatic conditions, the interpolated lateral effect values differed from year to year: 45 m, 37 m, and 41 m for 2002, 2003, and 2004, respectively.

The average lateral effect for the 3-year period for the ABC deep ditch was 12 m based on interpolation of the measured data. This is about 14% less than the 14.1 m predicted by the approximate method. However, measured results for 2003 and 2004, 15 and 14 m, respectively, were even closer to the predicted. Discrepancies in the water table data early in 2002 may have affected the low value (< 7.5 m) obtained from the field data for that year.

The lateral effect for the ABC site shallow ditch was less than3.75 m, based on the field data. This is about half of the value (7.2 m) predicted by the approximate method. The bottom of this ditch resides in a tight clay layer. Observed water table fluctuations close to the ditch indicate very slow drainage and high head loss in the vicinity of the ditch. The tight soil around the ditch could reduce water movement in the higher conductivity layer under the clay layer. In essence, the effective transmissivity, defined as the thickness of the profile multiplied by the effective conductivity, is likely lower than used in the equation to calculate the lateral effect in Table 7. Lowering the transmissivity will lower the lateral effect predicted by the approximate method. In Equation [1], the transmissivity is represented by the product of K and h_o. Any reduction in the transmissivity will reduce the value of x calculated. For example, setting the depth of the impermeable layer to be equivalent to the depth of the ditch and adjusting the effective conductivity results in a calculated lateral effect of 5 m for the shallow ditch. Although still an over prediction, it is closer to the field result of <3.75 m. Additional research is needed to determine how the method should be modified for shallow ditches confined in a low conductivity layer.

Long-term simulations, (1951 – 2004), in the water management models DRAINMOD and WATRCOM were performed using calibrated inputs for all transect wells. The objective was to determine the number of years the wetland hydrologic criterion was satisfied for each well, and, in the case of WATRCOM, for nodes between the wells. As shown in Table 8, the lateral effect obtained from field results, DRAINMOD, WATRCOM, and the approximate methods were within 4 m of each other for the Mildred Woods ditch. The ratio between the largest and the smallest predicted distance was 1.10. The largest ratio for the ABC deep ditch was 1.70. It was not possible to calculate a ratio for the ABC shallow ditch, but as listed in Table 8 the difference is at least 2.40 and probably greater.

Lateral Effect Method Limitations

The approximate method was developed for relatively flat sites with soils having slow drainage rates. The dominant source of water is precipitation and the method should not be applied to sites where flooding due to upstream conditions is a primary cause of wetland hydrologic status. More research is needed to determine how the method can be adjusted for cases where there are high head losses near the drain, such as the ABC shallow ditch case.

COMPUTER SOFTWARE

A PC computer program has been developed for calculation of the lateral effect based on the method developed in the first phase of this project. Required inputs are county, ditch depth, 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 8. It can also be used to calculate the set back distance of a borrow pit adjacent to wetlands. A unit conversion program is included to convert units of length, area, volume, and rate. Brian Phillips (brian_phillips@ncsu.edu) will be available to address questions and comments regarding the use and further development of the software. The beta version of the program for calculating the lateral effect can be found at the following website: http://www.bae.ncsu.edu/soil_water/lateral_effect/software/release/software_lateral_effect.htm. Improvements to include specified help files and better documentation will be included in an early 2007 release of the program.

TRAINING

A workshop on the method was conducted on October 6, 2004 with about 20 DOT engineers attending. A meeting on the method as it applies to borrow pits (HWY-2005-24) was conducted on November 22, 2005 with several DOT engineers and an

Army Corps representative 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.

M.S. THESIS & JOURNAL ARTICLES

Brian Phillips successfully defended his work based on this project and his thesis entitled "Methods to predict the lateral effect of a drainage ditch on adjacent wetland hydrology" in March of this year. The section of this report entitled "Testing the Method" highlights the main findings of the thesis. An electronic copy of the thesis is available at the following: http://www.lib.ncsu.edu/theses/available/etd-04282006-131958/unrestricted/etd.pdf .

A paper describing field testing of the method was presented at the ASABE International Conference on Hydrology and Management of Forested Wetlands to be held in New Bern, North Carolina in April of 2006. The paper is available at: http://www.bae.ncsu.edu/soil_water/projects_lateral_effect.htm . A manuscript describing the field testing, modeling, and verification of the method will be submitted for ASABE journal publication during the summer of this year. A peer review of submitted manuscript(s) is required and final publication will likely occur during 2007.

SUMMARY

T_{25} values for North Carolina were calculated using the procedures described in the first phase of this project. The method developed in Phase 1 of this study for predicting the lateral effect of a drainage ditch on adjacent wetland hydrology can now be applied for surface storage conditions of 2.5 or 5.0 cm (1 or 2 inches) and ditch depths of 0.3 to 1.8 m (1 to 6 ft) for any North Carolina county.

Data to test the method developed Phase 1 to predict the lateral effect were collected at two wetland mitigation sites in eastern North Carolina. One site was at Mildred Woods in Edgecombe County and the other near the town of Pinetown in Beaufort County. Water tables were measured at several locations on transects perpendicular to drainage ditches on both sites. Data were collected for the three-year period 2002-2004 on one transect at the Mildred Woods site and for the three and one half year period 2002-June 2005 on two transects at the ABC site. An analysis of the field data indicated that the lateral effect of drainage ditches was between 37 and 45 m at the Mildred Woods site, less than 3.5 m for the shallow ditch (0.9 m deep) at the ABC site and about 14 to 15 m at the deep ditch (1.3 m deep) site at the ABC site.

The Mildred Woods, ABC shallow ditch, and ABC deep ditch were modeled using the two-dimensional water management models DRAINMOD and WATRCOM. The models were calibrated for the period of January 2002 to December 2004 (August 2003 for the three wells nearest the ditch) for the Mildred Woods site, January 2002 to December 2004 for the ABC shallow ditch, November 2002 to May 2005 for the ABC site deep ditch. It should be noted that the scope of both models limited quantifying all physical parameters of each site; thus introducing a source of error in the calibrations.

Long-term simulations, (1951 – 2004), were performed with each model for all transect wells. The objective was to determine the number of years the wetland hydrologic criterion was satisfied for each well, and, in the case of WATRCOM, for nodes between the wells. Linear interpolation of the DRAINMOD results indicates a lateral effect of 39, <3.75, and 18 m for Mildred Woods, ABC shallow, and ABC deep, respectively. WATRCOM results predicted lateral effects of 42, 9, and 20 m for Mildred Woods, ABC shallow, and ABC deep, respectively.

The approximate method provides a theoretically sound approach to calculating the lateral effect of a drainage ditch on adjacent wetland hydrology. The method uses inputs of ditch depth, depth to impermeable layer, effective hydraulic conductivity, drainable porosity, T_{25}, and the nondimensional solution to the Boussinesq equation to calculate the lateral effect. T_{25} times, based on the drawdown time of several soils at threshold drain spacings, were determined for all 100 counties in the state of North Carolina. Once soil properties and site parameters are known, published numerical solutions to the Boussinesq equation (plotted in non-dimensional form) may be used to calculate the lateral effect.

The lateral effect was calculated by applying the approximate method for the three study transects. The method predicted a lateral effect of 42.6, 7.2, and 14.1 m for Mildred Woods, ABC shallow ditch, and the ABC deep ditch, respectively. Compared to 3-year average field results for Mildred Woods (41 m) and the deep ditch (12 m), the method performed well. It over predicted the lateral effect but by only 4% for Mildred Woods and 17% for the ABC deep ditch. Predicted results were nearly exactly the same as measured at the ABC deep ditch site for two out of three years of the study. The lateral effect predicted by the method for the shallow ditch at the ABC site was at least two times that measured in the field. In this case, the ditch was located in a tight clay layer which substantially reduced the effective transmissivity of the profile and the lateral effect of the ditch on the hydrology adjacent wetlands. Additional research is needed to determine how the method should be modified for such situations.

A computer program has been developed to facilitate easy use of the approximate method. Based on user inputs, the program automatically retrieves T_{25} values and performs a subroutine to predict the lateral effect of a drainage ditch or the set back distance of a borrow pit. A version of the program is available online and will be updated to include additional help files and improved documentation in early 2007.

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