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METHODS TO EVALUATE NORMAL RAINFALL FOR SHORT-TERM WETLAND HYDROLOGY ASSESSMENT

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Abstract: Identifying sites meeting wetland hydrology requirements is simple when long-term (>10 years) records are available. Because such data are rare, we hypothesized that a single-year of hydrology data could be used to reach the same conclusion as with long-term data, if the data were obtained during a period of normal or below normal rainfall. Long-term (40–45 years) water-table and rainfall data were obtained for two sites in North Carolina (with modeling), and one site in Minnesota (direct measurements). Single-year wetland hydrology assessments were made using two-rainfall assessment procedures recommended by the U.S. Army Corps of Engineers for their Wetland Hydrology Technical Standard, and two other rainfall assessment methods that were modifications of those procedures. Percentages of years meeting wetland-hydrology conditions during normal or drier than normal periods were identified for each plot with each rainfall assessment method. Although the wetland hydrology criterion was met in over 90% of the years across all plots using the long-term records, the four assessment techniques predicted the criterion was met in 41–81% of the years. Based on our results, we recommend that either the Direct Antecedent Rainfall Evaluation Method, or its modified version, be used for wetland hydrology assessment.

Key Words: technical standards, water table, wetland delineation, WETS data

INTRODUCTION

The U.S. Army Corps of Engineers (USACE) defines jurisdictional wetlands using three parameters: 1) wetland hydrology, 2) hydric soils, and 3) hydrophytic plants (Environmental Laboratory 1987). All three parameters must be present for an area to be considered a jurisdictional wetland (Mitsch and Gosselink 2000). For jurisdictional purposes, wetland hydrology occurs (by definition) when a site saturates to the surface or inundates for a period lasting at least 5% of the growing season in at least 50% of the years studied. Hydrology is the most difficult parameter to document because saturation frequency and duration cannot be assessed accurately in a single-site visit as can hydric soils or hydrophytic vegetation.

Wetland hydrology can be evaluated for a site by one of four ways (USACE 2005): 1) long-term water-table data, 2) hydrologic field indicators, 3) short-term hydrologic modeling, and 4) use of the USACE Hydrology Technical Standard. When available, long-term (10 years or more) water-table data provide reliable information for evaluating wetland hydrology. Unfortunately, such records are not available for most wetlands because they are expensive and time consuming to acquire.

Alternatively, Hunt et al. (2001) proposed a technique that compares single-season water-table levels for a site of interest (test site) to a site that is known to meet wetland hydrology in exactly 50% of the years. Water-table data are first simulated for both sites using a hydrologic model and measured rainfall data for the year of interest. If the modeled water-table data from the test site are above those levels from the site with known hydrology, under the same rainfall conditions, then the test site must also have wetland hydrology because it would presumably meet wetland hydrology conditions in over 50% of the years. This method appears to offer much potential for evaluating questionable sites.

Hydrologic field indicators are also acceptable for evaluating wetland hydrology. These are visible signs that saturation or inundation has occurred at a site, and include stained leaves, water marks on trees, or presence of a water table within 30 cm of the surface observed during a single site visit (Environmental Laboratory 1987). While such field indicators are easy to identify, they do not necessarily assure that a site meets the saturation duration or frequency requirements needed for wetland hydrology because few have actually been correlated with saturation duration and frequency (Vepraskas and Caldwell 2008).

Wetland hydrology can also be determined for jurisdictional purposes by using the U.S. Army Corps of Engineers' Hydrology Technical Standard, which is a short-term procedure that determines whether a site meets wetland hydrology by using water-table measurements made over 5 years or less (USACE 2005). The Standard is met if a water table occurs within 30 cm of the soil surface for 14 days or more during a period of acceptable rainfall. Rainfall is evaluated by one of three methods that consider antecedent precipitation. These methods have been described by Sprecher and Warne (2000) as: 1) direct antecedent, 2) moving total, and 3) Palmer Drought Severity Index.

The Hydrology Technical Standard has not been extensively tested, and it is not known how reliable the procedure is compared to long-term water-table monitoring. In addition, it is not known whether the methods for evaluating rainfall proposed in the Technical Standard produce equivalent results. Whether short-term measurements can be used to reach the same wetland hydrology conclusions as long-term data will depend on using reliable methods for evaluating rainfall data.

The objective of this study was to evaluate four methods for analyzing rainfall that could be used in the wetland hydrology technical standard. Our approach was to first assemble long-term (approximately 40 yr) water-table records for sites with wells in both plots with and without wetland hydrology, and then determine the percentage of years that wetland hydrology was met at each well location. These long-term records were considered the definitive method for assessing wetland hydrology. For each well location, we determined the percentage of years that met wetland hydrology conditions for the technical standard, by evaluating rainfall year by year using each of four different techniques for assessing rainfall. We then compared the percentage of years that met wetland hydrology based on water-table data to the percentage of years that met wetland hydrology for each rainfall assessment method. We assumed that the rainfall assessment method that identified wetland hydrology at the same periodicity as the long-term data would be appropriate to use with the wetland hydrology technical standard.

METHODS

Methods to Assess Rainfall

WETS Tables. All rainfall assessment procedures evaluated here used WETS data tables to define a normal rainfall range. WETS tables are a statistical summary of monthly precipitation and temperature that provide ranges of normal monthly precipitation that are available for over 8000 National Weather Service (NWS) stations that are published by the USDA National Weather Service and Climate Center (Sprecher and Warne 2000). The range of normal precipitation is reported using long-term precipitation data to determine the 30th and 70th percentiles of all the numbers in the precipitation record (Figure 1). Growing season dates are also found on WETS tables. The precipitation columns labeled "30% chance will have" show monthly ranges for normal rainfall. Above normal rainfall occurs when measured precipitation values exceed the 70th percentile on the WETS table labeled "30% chance will have more than". Below normal rainfall is that which is less than the "30% chance less than" values (Figure 1).

Methods to Assess Antecedent Precipitation and Maintenance Precipitation. WETS data are useful for assessing rainfall for specific time periods. Two time periods of interest for evaluating rainfall in the Wetland Hydrology Technical Standard are: 1) the period during which the water table is within 30 cm of the surface, and 2) the period before the water table rises to within 30 cm. Rainfall that occurs while the water table is within 30 cm of the soil surface is considered maintenance precipitation because that water is maintaining the water table above 30 cm. Rainfall that occurs when the water table is below 30 cm is considered antecedent rainfall because that water is contributing to the rise of the water table to meet the 30 cm criterion. Sprecher and Warne (2000) discussed two methods for evaluating antecedent and maintenance rainfall, 1) Direct Antecedent Rainfall Evaluation Methods, and 2) Moving Total Methods for Maintenance Rainfall.

Direct Antecedent Rainfall Evaluation Methods (DAREM). Antecedent rainfall is evaluated using a tabular approach that considers the 3-month period prior to a water-table rise. In this study, we termed this method the "The Direct Antecedent Rainfall Evaluation Method" or DAREM (Sprecher and Warne 2001). The DAREM method focuses on whole months during the 3-month period prior to when the water table rises to within 30 cm of the soil surface (Figure 2A). Although a water

WETS Station : GREENVILLE 2, NC3638 Creation Date: 10/23/2002
Latitude: 3537 Longitude: 07723 Elevation: 00030
State FIPS/County (FIPS) : 37147 County Name: Pitt
Start yr. - 1971 End yr. - 2000

Month	Temperature (Degrees F.) avg daily max	avg daily min	avg	Precipitation (Inches) avg	30% chance will have less than	30% chance will have more than	avg # of days w/ .1 or more	avg total snow fall
January	52.0	31.0	41.5	4.42	3.53	5.33	8	0.9
February	55.8	33.2	44.5	3.45	2.34	4.16	6	1.4
March	63.9	40.2	52.0	4.07	3.19	4.83	7	0.6
April	73.0	47.9	60.5	3.19	2.18	4.31	5	0.0
May	79.9	56.8	68.3	4.04	2.79	5.01	7	0.0
June	86.2	64.7	75.5	4.46	3.00	5.25	7	0.0
July	89.9	69.4	79.7	5.24	3.75	6.45	7	0.0
August	88.1	67.8	77.9	5.89	3.65	7.03	7	0.0
September	82.9	61.9	72.4	5.50	2.78	7.13	6	0.0
October	73.5	48.9	61.2	3.27	2.00	4.34	4	0.0
November	64.7	40.4	52.6	2.85	2.03	3.46	5	0.0
December	55.6	33.6	44.6	3.23	2.10	4.02	6	0.4
Annual					44.45	52.35		
Average	72.1	49.7	60.9					
Total				49.61			75	3.4

Figure 1. WETS data table. Area shaded in gray shows the 30th (i.e. 30% chance will have less than) and 70th (i.e. 30% chance will have more than) percentiles used for rainfall analysis.

table may rise on any day of the month, the DAREM method only considers the previous three whole months. The DAREM procedure computes a score for the precipitation that is used to assess whether the precipitation is "normal", "drier than normal", or "wetter than normal". The score is a sum of individual scores for each of the three months of data used (Table 1). Each monthly score (last column, Table 1) is based on two numbers, one for rainfall "condition" and the second for the "monthly weight". Rainfall condition has a value of 1, 2, or 3. A value of 1 shows that the measured rainfall was below the 30th percentile, and therefore the rainfall is drier than normal. A value of 3 indicates that the rainfall for the month was above the 70th percentile and is considered wetter than

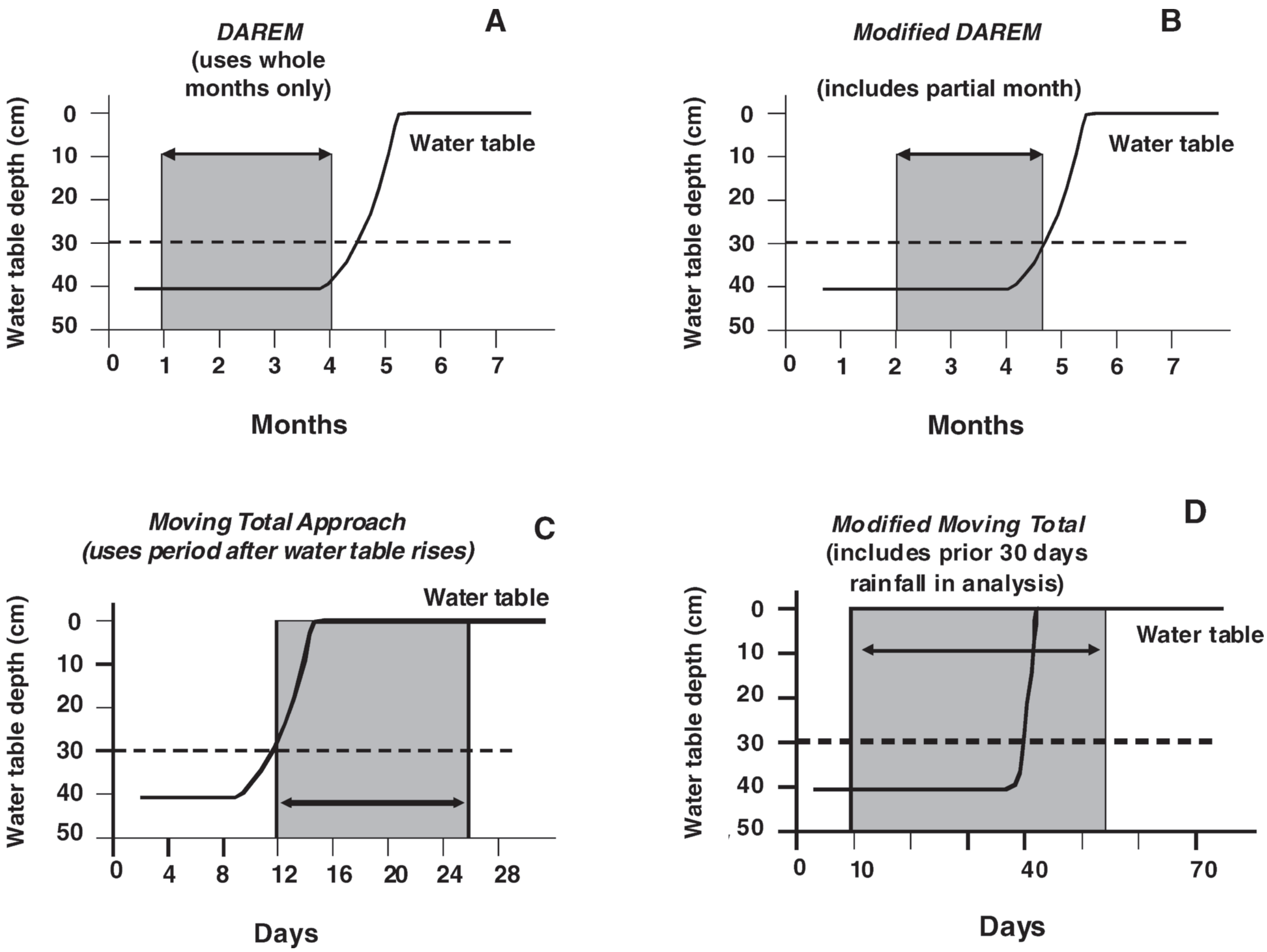


Figure 2. Schematic illustrating the differences among the: A) DAREM, B) Modified DAREM, C) Regular Moving Total, and D) Modified Moving Total methods of evaluating rainfall. DAREM uses only whole months of rainfall that occur before the water table rises to within 30 cm of surface, while the modified DAREM will include partial months. The regular moving total includes rainfall falling during the time the water- table is above a depth of 30 cm, whereas the modified moving total also includes a period prior to the time the water table rises to within 30 cm of the surface.

normal. The monthly weight is a value related to the proximity of the month to the initial time of water-table rise. The two ratings are multiplied together for each month, and then summed to give a cumulative score that is used to describe whether the prior three month period of precipitation was within the range of normal, drier than normal or above normal (Sprecher and Warne 2000).

Dr. Paul Rodrigue (USDA, personal communication) has recently proposed a modification to the DAREM approach. The modified DAREM technique includes a partial month of rainfall data in the antecedent rainfall (Figure 2B). For the first month, rainfall up to the day of saturation is prorated and included in the 3-prior-month calculation. The benefits of the modified DAREM approach are that all rainfall is counted within the calculation, and large rainfall events within the month of interest are not discounted.

Sprecher and Warne (2000) pointed out that the main weakness of using the DAREM technique is that it does not evaluate daily changes in rainfall, especially for the current month that is being analyzed. A similar weakness exists for the modified DAREM technique.

Moving Total Methods for Maintenance Rainfall. Maintenance rainfall is evaluated using a 30-day moving total, a time period that lends itself for use with the WETS tables which are computed on a monthly basis. The Moving Total method considers rainfall during the time the water table is within 30 cm of the surface (Figure 2C). A Modified Moving Total method also includes this rainfall, but adds in addition rainfall occurring during a 30

Table 1. DAREM calculation method to determine the condition of the rainfall period for June 1959 at plot 1R in Greenville. The month of June is being evaluated as the month of interest while the months May, April and March are taken into consideration. Once calculations have been completed, the 3-month period can be evaluated on whether it has acceptable rainfall amounts. In this case, this 3-month period is "normal" so the period for June is acceptable to use.

Prior Month		WETS Rainfall Percentile		Measured Rainfall	Condition: Dry, Wet, Normal	Condition Value (1=dry, 2=normal, or 3=wet)	Month weight	Multiply Previous two columns
	Name	30^{th}	70th					
		---------cm-----------						
1^{st} (most recent)	May	7.09	12.73	3.29	Dry	1	3	3
2nd	April	5.54	10.95	18.51	Wet	3	2	6
3rd	March	8.10	12.27	14.11	Wet	3	1	3
Sum								**12**
Rainfall of prior period was:								**Normal**
drier than normal (sum is 6–9), **normal** (sum is 10–14), **wetter than normal** (sum is 15–18)								

day period prior to the time the water table rose to within 30 cm of the surface (Figure 2D). Both methods use 30-day periods of rainfall. The 30-day moving total is generated by summing the past 30 days worth of precipitation and continually updating a tally of the prior 30-day rainfall totals (Sprecher and Warne 2000). These 30-day moving totals can be plotted against days of the year to get a continuous moving total graph for a particular site. To meet wetland hydrology criteria with the Modified Moving Total method, 30 days of normal or below normal rainfall are required prior to the time when the water table rises to within 30 cm of the surface for 14 consecutive days or longer during the growing season.

Sprecher and Warne (2000) suggest that the 30-day moving total approach is more desirable than DAREM approaches because it evaluates rainfall on a daily basis rather than using monthly totals that are reset to zero at the beginning of each month. However, a 30-day moving total also artificially sets rainfall to zero after 30 days and abruptly drops major rainfall events (from prior to the 30 days) out of the 30-day moving total (Sprecher and Warne 2000).

Site Descriptions

Rainfall and water-table data were obtained from two sites in North Carolina (sites 1 and 2) and one site in Minnesota (site 3). Sites in North Carolina were described previously by He et al. (2003) and Hayes and Vepraskas (2000) while the Minnesota site was previously described by Kolka et al. (1999). These sites were selected because previous work indicated they had soils that met wetland hydrology criteria on the basis of long-term water-table data (Verry and Kolka 2003, Vepraskas and Caldwell 2008).

Site 1 was located in Pitt County, NC, approximately 5.1 km southwest of the city of Greenville at N 35°34′10″, and W 77°26′26″. The average slope at the site was 2%. Vegetation consisted of loblolly pine (*Pinus taeda* L.), red maple (*Acer rubrum* L.), and white oak (*Quercus alba* L.). The site contained both upland and hydric soils that were used for this study. Upland soils (four plots) were members of the Lynchburg series (fine-loamy, siliceous, thermic Aeric Paleaquults). Hydric soils were members of the Rains series (fine-loamy, siliceous, thermic Typic Paleaquults). Soil boundaries between upland and hydric soils were determined by observations made on-site using the hydric soil field indicators. Four plots with hydric soils (labeled 1R through 4R) were also shown to have met wetland hydrology requirements, while the four upland plots (labeled 1L through 4L) did not meet wetland hydrology (Vepraskas and Caldwell 2008).

Site 2 was located in Bertie County, NC at N 76°48′00″, and W 36°5′30″. Vegetation at the site consisted of loblolly pine, red maple, sweet bay (*Magnolia virginiana* L.), white oak, red oak (*Quercus borealis* L.), and black cherry (*Padus serotina* L.). The hydric soils at this site were members of one of two soil series: Lenoir (clayey, mixed, thermic Aeric Paleaquults), and Leaf (clayey, mixed, thermic Typic Albaquults).

At both sites 1 and 2 water-table levels had been monitored daily to depths of 2-m using automatic monitoring wells (Remote Data Systems, Inc. P.O. Box 2522, Wilmington, NC 28402). Water-table data were collected from November 1996 until March 1999 at site 1, and from December 1996 to October 2000 at site 2. To ensure that recording wells were monitoring water levels accurately, a manual check well was installed at each plot to a depth of approximately 127 cm. Every 2 to 3 weeks the check wells were measured to compare with the water-table data from the recording wells. Rainfall was also measured daily at each site using recording gauges (Onset Computer Corp., 470 MacArthur Blvd., Bourne, MA 02532). The monitoring data were used to calibrate the DRAINMOD hydrologic model that was able to compute water-table depth for each plot when daily rainfall and temperature data were input into the model. A full description of the DRAINMOD model was presented previously (Skaggs 1999, Vepraskas and Caldwell 2008). The DRAINMOD models for sites 1 and 2 were calibrated for each plot using the measured well data and the approach outlined by He et al. (2002). Predicted and measured water-table depths were compared and then model parameters were adjusted individually to bring predicted values in line with measured water tables. The agreement between measured and predicted daily water-table depths was quantified by the average absolute deviation. Calibration was considered acceptable when the average absolute deviation between simulated and measured was less than 20 cm for both sites 1 and 2 (He et al. 2002).

Using the calibrated model, historic (40–45 years) daily water-table levels at sites 1 and 2 were estimated (He et al. 2003, Vepraskas et al. 2004). For the modeling, daily rainfall, maximum air temperature, and minimum air temperature data were available from January 1, 1959 through December 31, 1998. Data were obtained from weather stations 9.2 km (site 1) and 95 km (site 2) from the sites. It was assumed that over the 40–45 yr period the distribution of rainfall was similar between each research site and its respective weather station. This assumption was verified using rainfall probability maps compiled by Hershfield (1961) that showed the average volume of precipitation that fell at the research site was equal to that at the weather station. Water-table depths occurring during the growing season were of interest to assess wetland hydrology. Growing season dates were March 15 through November 16 for site 1, and March 22 through November 8 for site 2. Required inputs for the hydrologic analysis included the starting day and ending day of the simulation, continuous days of saturation, and maximum depth to saturation.

Rainfall and water-table data for site 3 were obtained for six forested wetlands at the Marcell Experimental Forest located in the Chippewa National Forest in north central MN (47°32′ N, 93°28′ W) (Verry and Elling 2005). Rain gauges were located within 0.5 km of the wells in each site. Each wetland was in a separate watershed that consisted of a mineral-soil upland and a bog (five sites) or fen (one site) organic-soil wetland. Only data from the wetlands were used in this study. Wetlands ranged in area from approximately 2 to 8 ha. Dominant trees in the bogs were black spruce (*Picea mariana* L.) and eastern tamarack (*Larix laricina* L.) while the fen was dominated by northern white cedar (*Thuja occidentalis* L.), black spruce, eastern tamarack, and occasionally black ash (*Fraxinus nigra* L.). Wetlands were labeled S1 through S6. The organic soils were members of Loxley peat (Dysic Typic Borosaprist, bogs S1, S2, S4, and S5), Mooselake peat (Euic Typic Borohemist, fen S3), and Greenwood peat (Dysic Typic Borosaprist, bog S6) series. Each wetland contained one well placed near its center that measured water-table levels with a chart recorder. Daily water-table levels were monitored for a 45-year period (1961–2005) and summarized from the continuous charts. Growing season dates were 4 May through 26 September for site 3.

EVALUATION OF RAINFALL ASSESSMENT METHODS

Long-Term Data Assessment

Our first step was to identify the years that wetland hydrology conditions were met at each plot from the long-term data. Daily water-table data from during the growing season were assessed for the number of years that the water table was within 30 cm of the soil surface for 14 or more continuous days. The 14-day limit is consistent with the Wetland Hydrology Technical Standard (USACOE 2005). Wetland hydrology was considered met when the water table was within 30 cm of the surface during the growing season in at least 50% of the years.

Short-Term Data Assessment

Using the spreadsheets of data developed for the long-term assessment, we evaluated each year of data separately for each plot to determine if wetland hydrology would be met if rainfall were evaluated by each of the four rainfall assessment methods: 1) Direct Antecedent Rainfall Method (DAREM), 2) Modified DAREM, 3) Moving Total Method and 4) Modified Moving Total Method. Basic procedures are summarized in Table 2 for each of the methods.

DAREM. To apply this method, data from WETS tables were obtained for weather stations, and were added into the 30th and 70th percentile columns

Table 2. Summary of the four rainfall analysis procedures that were compared in this study.

Method	Procedure	Method	Procedure
DAREM	1. Determine date that water table first rises to within 30 cm of surface and remains within 30 cm for at least 14 days during growing season. 2. Determine the prior 3-month period using whole months. For example, if water table rose on any day in August, then use rainfall for July, June, and May. 3. Complete Table 1 using monthly measured rainfall and WETS data to determine if the 3-month period is considered normal, drier than normal or wetter than normal. 4. If water table was within 30 cm of surface for 14 days or more, during the growing season, and during a period when the rainfall was normal or drier than normal, then the site meets wetland hydrology requirements.	Moving Total	1. Compute 30-day moving totals for rainfall beginning at least 30 days prior to the start of the growing season, and ending on the last day of the growing season. 2. Graph the moving totals versus days of the growing season along with the WETS values for the 70^{th} percentile. 3. Determine from the graph the periods during the growing season when the moving total was less than the 70^{th} percentile for periods at least 30 days long. 4. Using the periods identified above, determine whether the water table was within 30 cm of the surface for at least 14 days. 5. Wetland hydrology is considered met by this method if the water table was within 30 cm of the surface for 14 days during a 30-day period identified in step 3.
Modified DAREM	1. If water table rises during days 1–14, inclusive for a month, then follow the procedure for the regular DAREM method described above. 2. If the water table rises between days 15 and 27 of the month, then use the modified DAREM method to assess rainfall that is described in steps 3 and 4. 3. Determine the proportion of the month being used by dividing the number of the day that the water table rises to within 30 cm of the surface by the total number of days in the month. If the water table rose on August 16, then the proportion of the month to use would be 16/31 or 0.52. 4. Complete the DAREM table. The first month would be the pro-rated rainfall for August, followed by July and June. August rainfall would be that falling from day 1 through day 16 of the month in this example. For the WETS values for August, multiply the values for the 30^{th} percentile by 0.52 and enter the value in the DAREM table. Do the same for the 70^{th} percentile value. 5. If the water table rises on days 28 or later, then use the measured rainfall and the WETS data for the month without proration.	Modified Moving Total	1. Perform steps 1 to 4 as described for Moving Total. 2. For periods when the water table was within 30 cm of the surface for at least 14 days, examine the 30-day moving totals for the period coming 30 days prior to the time the water table rose. During this time, the 30-day moving totals must be less than the 70^{th} percentile for a cumulative period of 30 days. 3. Wetland hydrology is considered met by this method if the water table is within 30 cm of the surface for 14 days or more during the growing season while the 30-day moving total rainfall was less than the 70^{th} percentile for periods of at least: a) 14 days after the water table rose, AND also b) 30 days prior to the time the water table rose to within 30 cm of the surface.

shown in Table 1. Measured precipitation data were then added to the table under the column ''Measured Rainfall.'' The measured rainfall was assigned a condition value (1-dry, 2-normal, or 3-wet) based on the 30th and 70th percentile columns. For the example, rainfall for the month of May, was less than the 30th percentile measurement so it received a ''dry'' condition value of 1 (Table 1). However, the months of April and March were both greater than the 70th percentile measurement so they received a ''wet'' condition value of 3. The condition value was then multiplied by the monthly weight value and all products for the three months of interest were summed and compared to the wetness categories. In this example the overall rainfall evaluation was normal and therefore if saturation occurred for 14 days or longer in the upper 30 cm in the month of June this plot would meet wetland hydrology criteria.

The DAREM calculation method was applied to data from each plot at all sites for every year of the long-term records (40 years for sites 1 and 2, and 45 years for site 3). The analyses were performed for nine plots at site 1, eight plots at site 2, and six plots (wetlands) at site 3.

Modified DAREM. The Modified DAREM included rainfall from the month during which the water table rose to within 30 cm of the surface (Table 2). If the water table rose at some point during the first 14 days of the month, then the rainfall during this period of the month was ignored, and rainfall from the previous three full-months were used as in the DAREM technique. On the other hand, if the water table rose above a depth of 30 cm at anytime between days 15 to 27 of the month, then the month's rainfall coming prior to the time of water table rise were used in the calculation table as the first month's rainfall. The WETS data for this first month were then prorated to determine whether the precipitation values coincided with dry, normal, or wet conditions (see example in Table 2). As with the DAREM, the entire month was counted as the first month of interest when saturation began on day 28 or later. Wetland hydrology was met if the antecedent period was drier than normal or normal, and the water table was within 30 cm of the surface for 14 days or longer during the growing season. If the period of interest met the water-table requirements, but antecedent precipitation was within a wetter than normal period then the wetland hydrology criteria were not met.

The category breaks used to decide whether to include the rainfall (i.e., days 15 to 27) were made using professional judgment after considering the rainfall data. Rainfall occurring during the first 14 days of the month was generally small, and it was not necessary to consider it for the wetland hydrology assessment. Large storms were also rare and no special allowance was made for them. Rainfall occurring up to and including days 15 to 27 of the month contained sufficient amounts to include in the rainfall assessment, and prorating the WETS data was necessary for doing this. Prorating was found to have little impact after day 27.

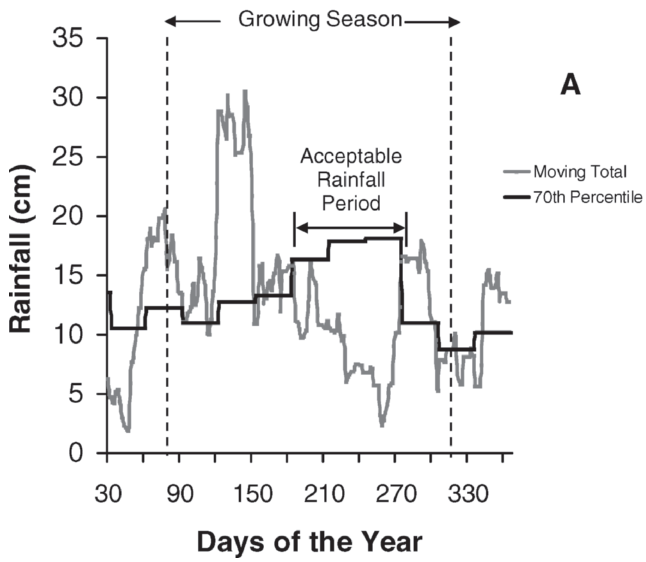
Moving Total Method. Daily precipitation values were obtained for each day of the long-term water-table record. The first 30 days of rainfall values were added together to generate the first moving total value. The first day from the 30 rainfall values was removed and the 31st day was added to generate the second moving total value. This was done for all the days of each year. Moving-total rainfall data were plotted on a chart using daily increments. The 70th percentile rainfall values were also plotted to determine the time periods for when the water table occurred within 30 cm of the surface for 14 or more days during the growing season (Figure 3A). Acceptable periods were those where the moving total values were less than the 70th percentile for at least a 30-day period. Plots could not meet wetland hydrology requirements, regardless of water-table levels, during periods when the moving total was above the 70th percentile threshold.

Modified Moving Total Method. The moving total procedure was modified to assess saturation periods when the moving total was less than the 70th percentile for a 30-day period prior to the date on which the water table rose to within 30 cm of the surface (Figure 3B). Plots that met wetland hydrology requirements for the regular Moving Total Method might be considered too wet by this procedure if the moving total rose above the 70th percentile within the 30 day period prior to water table rising within 30 cm of the surface.

RESULTS

Long-Term Records

A soil plot met the ''wetland hydrology criterion'' if it had a water table within 30 cm of the surface for 14 days or more in *over half the years of record*. The term ''wetland hydrology condition'' is used here to describe plots with water tables within 30 cm of the surface for 14 days or more during the growing season for a *single year*. There were 16 plots that met the wetland hydrology criterion across the three sites, whereas six plots did not (Table 3). Plots not



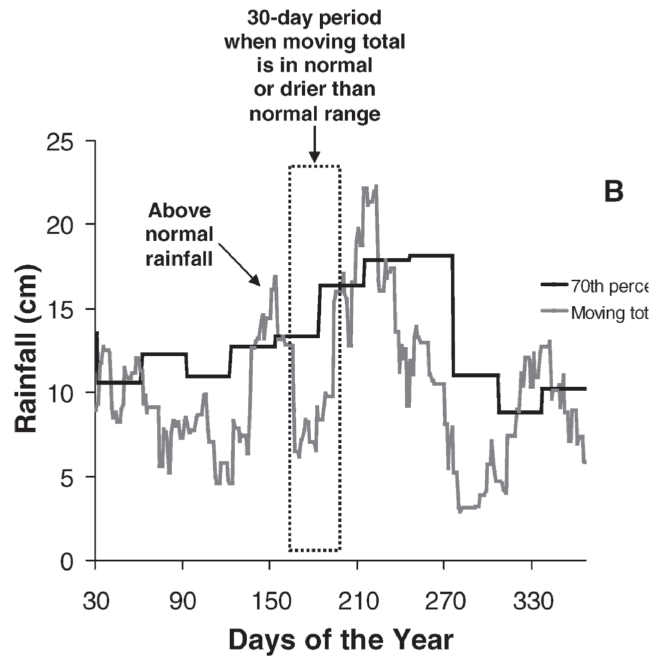


Figure 3. Illustrations showing applications of the two moving total methods used for rainfall analysis. A) The regular Moving Total method was applied to data from 1989 for Site 1. The computed moving total was above the 70th Percentile for most of the growing season through day 186. However, from day 186 through day 276 the moving total was below the 70$^{\text{th}}$ Percentile line and within the growing season. This is an acceptable period of rainfall to use for assessing wetland hydrology condition with this technique. B) Example of the Modified Moving Total method using results from 1972 for Site 1. The water table was within 30 cm of the surface during the period between days 160 and 200 (dashed box). Periods when the moving total was above the 70th percentile were considered too wet to be used for wetland hydrology assessment with the Modified method. This plot met the wetland hydrology conditions for the regular Moving Total Method because 14 days of saturation occurred within a period when the 30 days of normal or drier than normal precipitation were found. However, this plot did not meet wetland hydrology criteria with the Modified Moving Total method due to above-normal rainfall occurring prior to the time when wetland hydrology conditions occurred.

meeting the wetland hydrology criterion were the upland plots at sites 1 and 2. Plots meeting the wetland hydrology criterion at sites 1 and 2 did so in over 80% of the 40 years evaluated. The water table was within 30 cm of the surface in these plots for periods ranging from 20 to nearly 80 days.

At site 3, all six plots met the wetland hydrology criterion (Table 3). The portion of years when wetland hydrology conditions were met ranged broadly from 53 to 100%. The driest plot, fen plot S3, did not have a water table within 30 cm of the surface for 19 out of 21 years from 1961 through 1982, but did have a water table within 30 cm in most years after 1982. A similar water-table record was found in bog plot S6.

Assessing Rainfall Evaluation Methods

The overall mean for long-term measurements showed the wetland hydrology conditions were met in 90% of the years (Table 4). Single-season evaluations using the rainfall assessment techniques showed that the wetland hydrology criteria were met less often, in only 41 to 81% of the years. This is to be expected because while long-term data includes wet periods when water tables are high as meeting wetland hydrology conditions, short-term evaluations exclude wet periods of high water tables as qualifying for wetland hydrology. Hence, all short term methods will meet wetland hydrology conditions less often than with long-term data.

Both of the 30-day moving total techniques predicted that sites met wetland hydrology conditions in approximately 50% of the years or less (Table 4). Better predictions were obtained with the DAREM and modified DAREM techniques where wetland hydrology conditions were met in 78% and 81% of the years, respectively. Differences in results for the four rainfall-assessment methods are due largely to how the methods treat wet years (Table 5). Both of the 30-day moving total methods tended to classify periods during the early part of the growing season when water tables were high as wetter than normal. Although the water-table saturation criteri-

Table 3. Summary of results of long-term evaluation of water table data at all plots. Plots meeting the wetland hydrology criterion had a water table within 30 cm of the surface for 14 days or more during the growing season, in 50% or more of the years. All plots (wetlands) at site 3 met the wetland hydrology criterion.

	Plots meeting wetland hydrology criterion		Plots not meeting wetland hydrology criterion	
Site	Plot	Percentages of years wetland hydrology conditions met	Plot	Percentages of years wetland hydrology conditions met
Site 1	1R	88	1L	0
	2R	100	2L	3
	3R	98	3L	3
	4R	95	4L	0
	mean	95	mean	2
Site 2	3S	87	2N	0
	4S	91	2S	11
	5S	98		
	3N	83		
	4N	86		
	5N	98		
	mean	92	mean	6
Site 3	S1	78		–
	S2	100		–
	S3	53		–
	S4	100		–
	S5	98		–
	S6	69		–
	mean	83		

on was met, the 30-day moving total was usually above the 70th percentile and was considered ''wet'' during these periods. Suitable rainfall periods tended to be found later in the growing season, but this coincided with the times when water tables tended to fall below a 30 cm depth.

One reason the DAREM and modified DAREM methods performed more similar to the long-term data is because the methods considered 90 days of antecedent rainfall rather than 30 days as in the moving total methods. Longer periods lessen the impact of a single wet month on the assessment of antecedent conditions. With the DAREM, the most recent month could be classified as ''wet'' and the period may still have been acceptable if the 2nd or 3rd prior months had normal or drier than normal rainfall. When the same rainfall data are analyzed by a moving total method, the 30-day period prior to the time the water table is within 30 cm would be above the 70th percentile and would be classified as

Table 4. Percentage of years wetland hydrology conditions were met for long-term data, and single-year data evaluated by each of the four rainfall assessment methods. Means and ranges for plots at each site are shown. Only plots meeting wetland hydrology criterion as indicated by the long-term data (Table 3) are considered. Both DAREM methods have percentages closer to the long-term data than the moving total methods, indicating that using either of these methods to evaluate wetland hydrology will produce results most similar to those obtained with long-term data.

Site	Statistic	Long-term Record	DAREM	Modified DAREM	Moving Total	Modified Moving Total
		%				
Site 1	Mean	95	86	88	62	43
	Range	88–100	70–93	75–93	33–78	23–58
Site 2	Mean	92	69	75	23	18
	Range	83–98	53–78	62–84	11–29	7–29
Site 3	Mean	83	79	79	64	62
	Range	53–100	49–100	49–100	35–95	35–93
Overall Mean		90	78	81	50	41

Table 5. Partial record of results for plot 4R at Site 1 to compare all methods evaluated for determining wetland hydrology. Moving total methods failed to meet wetland hydrology conditions more than DAREM methods because the moving totals method had a greater chance of considering a period to be "wet" or have higher than normal rainfall.

	Years When Wetland Hydrology Condition Met or Not Met				
		DAREM		Moving Total	
Year	Long-Term Record	Regular	Modified	Regular	Modified
1959	met†	met	met	met	not met ‡
1960	"	not met ‡	not met ‡	not met ‡	"
1961	"	met	met	"	"
1962	"	"	"	"	"
1963	"	"	"	met	met
1964	"	not met ‡	not met ‡	not met ‡	not met ‡
1965	"	met	met	met	met
1966	"	"	"	not met ‡	not met ‡
1967	"	"	"	met	met†
1968	"	"	"	not met ‡	not met ‡
1969	"	"	"	"	"
1970	"	"	"	met	met
1971	"	"	"	not met ‡	not met ‡
1972	"	"	"	met	met
1973	"	"	"	"	not met ‡
1974	"	"	"	"	met†
1975	"	"	"	"	not met ‡
1976	not met*	not met*	not met*	not met*	not met*
1977	met	met	met	not met ‡	not met ‡
1978	"	"	"	"	met

† Year when wetland hydrology condition was met during a period of normal or drier than normal rainfall
‡ Year when wetland hydrology condition was not met during a period of above normal rainfall
*Years when wetland hydrology condition was not met because the year was dry

wetter than normal and unusable for hydrology condition assessment.

Data were reviewed to determine how long a site would need to be monitored to meet wetland hydrology criteria (Table 6). For example, plot 1R did not meet wetland hydrology conditions in 10 individual years when rainfall was evaluated by the modified DAREM technique. In 2 of those 10 years, wetland hydrology conditions were met in preceding and succeeding years, thus monitoring would have to be continued for at least 2 years to confirm wetland hydrology if data from a "wet" year had to be excluded. At sites 1 and 2, the mean values show that when wetland hydrology conditions were not met, this normally occurred in single years or a pair of years (Table 6). Site 3, however, did have extensive periods when multiple years (ranging from 5 to 15 years long) would need to be monitored to achieve appropriate rainfall conditions.

Using single-year data also increases the chances of concluding that a site does not meet wetland hydrology when long-term data shows that it does (Table 7). This is referred to as a false negative. A false negative occurs when monitoring is done during a wet period which must then be excluded from consideration. All of the single-season methods evaluated will produce false negatives (Table 7) because they have wet periods that must be excluded. Long-term measurements include wet periods in the hydrology assessment, and therefore they will always have a greater proportion of years meeting wetland hydrology requirements than do the single-year assessment techniques. Across all sites, mean values showed that the chance of a false negative prediction occurred more often with the moving total methods than with either DAREM. The moving total methods are more sensitive to wet periods than the DAREM techniques because they are based on a smaller range of days and this makes them more susceptible to the impacts of the large rainfall events. The DAREM methods consider longer time periods, and single large storms have less of an impact on the rainfall assessment unless such storms occur during the most recent prior month (Table 2). Alternatively, false positives may occur where an upland site does not meet wetland hydrology in most years according to long-term data, but does so in a single year of measurement with acceptable rainfall. As shown in Table 7, false positive predictions occurred in only 3% of the years.

Table 6. Number of years that wetland hydrology was not met for different lengths of consecutive years using the Modified DAREM. For example, plot S3 did not meet wetland hydrology for 23 out of 45 years. There was a single year, two consecutive years, one period of 5 consecutive years and one period of 15 consecutive years that did not meet wetland hydrology because plot S3 was considered too dry and did not meet the water-table criteria.

Site	Plot	Total Years of Record	No. Years Wetland hydrology Conditions "Not Met"	No. of Years Hydrology Not Met for Different Lengths of Consecutive Periods		
				Single Years	2 Consecutive Years	> 2 Consecutive Years
Site 1	1R	40	10	2	8	0
	2R	"	3	3	0	0
	3R	"	3	3	0	0
	4R	"	6	6	0	0
	5R	"	3	3	0	0
	mean	------	5	3	2	0
Site 2	3N	45	17	4	4	4 + 5†
	4N	"	9	5	4	0
	5N	"	7	5	2	0
	3S	"	17	6	6	5
	4S	"	10	4	6	0
	5S	"	7	5	2	0
	mean	-------	11	5	4	2
Site 3	S1	45	10	4	6	0
	S2	"	0	0	0	0
	S3	"	23	1	2	5 +15†
	S4	"	1	1	0	0
	S5	"	6	6	0	0
	S6	"	14	2	2	10
	mean	------	9	2	2	5

† Indicates there were two periods when hydrology was not met, with the number of consecutive years shown for each of the two periods.

DISCUSSION

Although long-term hydrologic records are the most reliable and best evidence to use to determine whether a site meets wetland hydrology in most years, such records are rare because they are time consuming and expensive to acquire. Four short-term rainfall evaluation methods developed by the USACE were investigated in this study. Two methods, DAREM and the Modified DAREM, had fewer wet periods that were unusable than the moving total methods, and were more consistent with the findings from long-term records. Both 30-day moving total methods led to more years that remained above the 70th percentile leading to the elimination of those years. Similar results were also found by Hunt et al. (2001) for the 30-day moving total method. Because the moving total only consists of 30 days of precipitation prior to water table evaluation, large precipitation events within the month drastically increase the chance of a 30-day period being considered too wet (Sprecher and Warne 2000).

Most of the years that were unusable due to above normal precipitation occurred as single years. However, some plots, especially at site 2, had above normal rainfall in multiple consecutive years that disallowed evaluation. At the S3 fen site in northern Minnesota, long consecutive periods occurred when the water table was not above 30 cm. Because fens are driven by regional ground water, ground-water elevation is relatively consistent year to year and slowly responds to rainfall events, unlike sites 1 and 2 and the bog sites at site 3. Cumulative annual changes in the water balance incrementally change fen water-table levels. Although the ground-water elevation was not above 30 cm, the elevation was consistently above 40 cm during these time periods. Bogs, however, are event driven and are more responsive to dry and wet years and behave similarly to the North Carolina sites (sites 1 and 2) (Mitsch and Gosselink 2000).

Although most plots studied had single years that did not accurately predict wetland hydrology, 2 to 3 years of monitoring appeared to be sufficient to accurately predict if a site has wetland hydrology. Periods of above normal rainfall can lead to false negatives at a site that does actually meet wetland hydrology. To avoid false negatives, more years would have to be monitored. False positives also occurred but only in a small percentage of cases.

Table 7. Percentage of false positives and false negatives for all plots at Sites 1, 2, and 3. False positives occur when a non-wetland plot meets wetland hydrology. A false negative occurs when a plot meets wetland hydrology according to long-term records, but fails to meet wetland hydrology by a short-term assessment because the rainfall assessment method for a given year encountered above normal rainfall.

Site	Plot	DAREM	Modified DAREM	Moving Total	Modified Moving Total
		Percent of Total Years			
		False Negatives			
Site 1	1R	18	13	55	65
	2R	10	8	30	53
	3R	8	5	30	53
	4R	10	10	33	55
Site 2	3S	27	24	76	80
	4S	18	13	67	73
	5S	20	13	71	76
	3N	29	20	58	69
	4N	24	16	76	78
	5N	22	13	69	69
Site 3	S1	9	9	31	36
	S2	0	0	11	18
	S3	4	4	16	13
	S4	7	5	9	9
	S5	14	14	18	20
	S6	8	8	35	38
Mean		14	11	41	50
		False Positives			
Site 1	1L	0	0	0	0
	2L	3	3	3	3
	3L	3	3	3	3
	4L	0	0	0	0
Site 2	2S	0	0	0	0
	2N	9	9	11	11
Mean		3	3	3	3

Results also indicated that adjacent upland soil plots without the hydric soil indicator should be monitored for 1–2 years to obtain an accurate assessment of wetland hydrology and to avoid the possibility of false positive assessments occurring.

Based on the results of this study, we recommend either of the two DAREM techniques be used to identify suitable rainfall periods for wetland hydrology determination. The modified DAREM performed slightly better than the DAREM technique, but the difference was small. The DAREM techniques are also appropriate to use for identifying hydric soils with the Hydric Soils Technical Standard (USDA 2008), which utilizes water-table and rainfall data collected over short time intervals such as one year.

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