Accessing and Using Meteorological Data to Evaluate Wetland Hydrology

Steven W. Sprecher and Andrew G. Warne

April 2000
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Accessing and Using Meteorological Data to Evaluate Wetland Hydrology

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# Contents

Preface ................................................................................................................. vii

Overview ............................................................................................................. viii

1. Background Concepts ....................................................................................... 1

   1.1 Why be concerned with antecedent precipitation ....................................... 1
   1.2 What is “normal precipitation” .............................................................. 1
      1.2.1 “Normal precipitation” as a single value ........................................ 1
      1.2.2 “Ranges of normal precipitation” ............................................... 1
      1.2.3 The three-decade base period ..................................................... 2

2. Range of Normal from the “WETS Tables” ..................................................... 3

   2.1 Accessing the WETS Tables ................................................................... 3
   2.2 Important information in the WETS Tables ........................................... 3
   2.3 Interpreting “zero” precipitation levels in the WETS Tables .................... 5
   2.4 Graphical presentation of the information on WETS Tables...................... 5

3. Finding Recent Precipitation Data ................................................................. 7

   3.1 Existing sources ..................................................................................... 7
   3.2 Unified Climate Access Network (UCAN) ........................................... 7
   3.3 Using onsite rain gauges ......................................................................... 8
      3.3.1 Rain gauge quality and location ................................................... 8
      3.3.2 Interpreting onsite precipitation data .......................................... 9
      3.3.3 Summary of use of onsite rain gauges ....................................... 14

4. Evaluating Antecedent Precipitation Conditions at a Site ............................. 15

   4.1 NRCS Engineering Field Handbook ..................................................... 15
      4.1.1 Background .................................................................................. 15
      4.1.2 NRCS procedure for estimating antecedent moisture
            conditions at a site ......................................................................... 15
      4.1.3 Comments on the NRCS method ............................................... 16
   4.2 Method of rolling totals ......................................................................... 16
      4.2.1 Background ................................................................................ 16
      4.2.2 Procedure of 30-day rolling totals ............................................. 18
      4.2.3 Determining whether tallied precipitation was within
            range of normal ............................................................................. 20
4.2.4. Comments on the method of 30-day rolling totals ..................... 20
4.3 Combined method of 30-day rolling totals and NRCS Engineering
   Field Handbook weighting factors ................................................. 21
   4.3.1 Procedure for combining the methods of 30-day rolling totals
   and Engineering Field Handbook weighting factors ................... 21
   4.3.2 Comments on the combined method ........................................ 21
4.4 General Observations on Assessments of Antecedent Precipitation.... 23

5. Growing Season .............................................................................. 24

6. Drought Analyses on the Internet .................................................... 25
   6.1 Preliminary nature of near-real time analyses .............................. 25
   6.2 Palmer Drought Indices ................................................................ 25
   6.3 Standardized Precipitation Index ............................................... 29
   6.4 USGS Stream Gauge Data ............................................................. 32

7. Geographic Variation in Precipitation ............................................. 36

8. Comparing Data from Monitoring Wells and Rain Gauges ............. 38

9. Statistical Background and Common Problems ............................... 43
   9.1 Gamma distribution: Introduction to the statistics of normal
      precipitation .................................................................................. 43
   9.2 Arid lands ..................................................................................... 45
   9.3 Bimodal precipitation ................................................................. 46

10. Summary and Recommendations .................................................. 49
    10.1 Summary ..................................................................................... 49
    10.2 Recommendations ...................................................................... 49

11. References ...................................................................................... 51

Appendix A Addresses for Collection and Analysis of Meteorological
    Data ..................................................................................................... A1
Appendix B NWS guide on rain gauges .............................................. B1
Appendix C Forms .............................................................................. C1
Appendix D Comparison of probability distributions, for temperature
         and precipitation data ................................................................. D1
Appendix E Notation ........................................................................... E1

SF 298
List of Figures

Figure 1. WETS Table for Grand Island, NE.............................................................. 5

Figure 2. Graphic presentation of WETS Table information plus
monthly precipitation totals for a particular year................................. 6

Figure 3. Example of comparison of data from an unofficial weather station.. 10

Figure 4. A. Ranges of normal for monthly precipitation at three NWS
stations in Indiana. B. Actual monthly precipitation totals at
three NWS stations and a research station in Indiana,
superimposed on a graph of average range of normal monthly
precipitation at the NWS stations ...................................................... 13

Figure 5. Worksheet to determine whether precipitation was within the
range of normal prior to a site visit.................................................... 17

Figure 6. 30-day rolling totals of precipitation at Grand Island, NE,
overlaid on graph of daily precipitation and monthly
precipitation ....................................................................................... 18

Figure 7. Three 30-day periods prior to May 15, superimposed on Figure 6... 22

Figure 8. Growing season information as presented in WETS Tables,
for Wooster, OH ................................................................................ 24

Figure 9. Palmer drought indices for Climate Division 5, NE (includes
Grand Island) for 1991........................................................................ 26

Figure 10. Example of Palmer Drought Severity Index by climate division
for the Nation from provisional data at the Climate Prediction
Center................................................................................................. 28

Figure 11. Period of record for Palmer Drought Severity Index for
Climate Division 5, NE (includes Grand Island) ............................... 30

Figure 12. Example of precipitation percentiles for Division 1 of Nevada,
for periods of 1 to 72 months............................................................. 33

Figure 13. Example of USGS streamflow graph at USGS website,
including table of exceedence thresholds .......................................... 34

Figure 14. Precipitation patterns across the Sierra Nevada divide
expressed as percentiles of monthly precipitation ............................. 37

Figure 15. Daily precipitation and water well data near Columbus, OH, 1997 .. 39

Figure 16. Daily precipitation and water well data near McHenry, IL,
1995-1996 .......................................................................................... 40
Figure 17. Histogram and gamma distribution for same set of precipitation data, Aprils 1961-1990, Grand Island, NE ........................................... 44

Figure 18. Histogram of July precipitation at Mojave, CA, for 1961 to 1990 .... 46

Figure 19. Frequency distributions of June precipitation at Raleigh, NC ........ 48

List of Tables

Table 1. Upper and Lower Percentile Thresholds for Middle Ranges of Precipitation Models.......................................................... 2

Table 2. Daily Precipitation and 30-day Rolling Totals for Jan-May 1991 at Grand Island, NE ................................................................. 19

Table 3. Comparison of Engineering Field Handbook Method and Combined Method, Grand Island, Hall County, NE, 1991 .................. 22

Table 4. Palmer Classes for Wet and Dry Periods........................................ 29

Table 5. Exceedence Thresholds and Percentiles for SPI Values............... 32

Table 6. Characteristics for Contrasting Weather Stations in the Tahoe/Reno Region ................................................................. 37
Preface

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The report was prepared by Dr. Steven W. Sprecher, U.S. Army Engineer District, Detroit, South Bend, IN, and by Dr. Andrew G. Warne, Texas Bureau of Economic Geology.

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At the time of publication of this report, Dr. Lewis E. Link was Acting Director of ERDC, and COL Robin R. Cababa, EN, was Commander.

This report should be cited as follows:

OVERVIEW

Investigators of wetland hydrology need to know whether they are making their observations during normal weather conditions or during abnormal conditions of drought or excess precipitation. Such decisions require knowledge both of current precipitation inputs and of the frequency distribution of precipitation over the long-term record at or near the site. Information pertinent to accessing and using these meteorological data to evaluate wetland hydrology is presented in various sections of this report. Also, much of this information is now easily available on the Internet at the Websites shown below.

SITE-SPECIFIC FREQUENCY DISTRIBUTIONS OF PRECIPITATION

The USDA National Water and Climate Center publishes the ranges of normal monthly precipitation for over 8000 National Weather Service (NWS) weather stations. These analyses are called WETS Tables and are available for one to several weather stations in most counties in the Nation. The range of normal is reported as a “30 percent chance will have less than” (30th percentile) and a “30 percent chance will have more than” (70th percentile). The WETS Tables provide the user with the ability to determine whether precipitation inputs were within the range of normal at a particular NWS weather station and, by inference, in the immediately surrounding area. These tables are discussed and available at:

WETS Tables Section 2 http://www.wcc.nrcs.usda.gov/water/wetlands.html

SITE-SPECIFIC REAL-TIME DATA

The WETS Tables do not supply real-time precipitation data. The National Water and Climate Center (NWCC) is working on an Internet Web site (UCAN) that will publish real-time data for the 8000+ weather stations used in the WETS Tables, but until that site is established, rainfall records for the current and immediately preceding months are most readily obtained from State Climatologists and the Regional Climate Centers. They can be contacted at:

State Climatologists Section 3.1 http://www.ncdc.noaa.gov/ol/climate/aasc.html#STAT

Regional Climate Centers Section 3.1 http://met-www.cit.cornell.edu/other_rcc.html

Weekly and monthly precipitation data for approximately 225 cities in the Nation can be obtained at the following Web site. Click on “Weekly Precipitation Table” or “Monthly Precipitation Table.”

Climate Prediction Center Section 3.1 http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/prcp_temp_tables/

UCAN (site in progress) Section 3.2 http://www.wcc.nrcs.usda.gov/bbook(bb20.html
ONSITE RAIN GAUGES

Onsite rain gauges are occasionally used at projects in order to document precipitation patterns that may not be the same as those recorded at the nearest NWS stations included in the WETS Tables. To assure reliability, data collected onsite must be compared to the long-term precipitation record collected at NWS stations. A method for comparing onsite data with NWS data is presented in

Using Onsite Rain Gauges Section 3.3
Portions of NWS Observing Handbook No. 2 Appendix B

EVALUATING ANTECEDENT PRECIPITATION

The Natural Resources Conservation Service (NRCS) Engineering Field Handbook uses monthly precipitation data in conjunction with the WETS Tables to evaluate the preceding two or three months’ precipitation input; the major weakness of the NRCS method is that it does not evaluate daily changes in precipitation patterns, especially for the current month of analysis. A method of computing 30-day rolling totals has also been devised to incorporate daily data into the analysis, but this method considers antecedent precipitation for only 30 days. Therefore, a third method is presented that combines the methods of the NRCS and 30-day rolling totals. These methods are discussed as follows:

Hydrology Tools Method Section 4

30-day Rolling Totals Method Section 4.2
Combined Method Section 4.3

THE REGULATORY GROWING SEASON

The growing season is defined for wetland hydrology on the basis of soil temperatures, which in turn are estimated based on NRCS reports of 50 percent likelihood of last and first 28°F frost. These dates are available in NRCS soil survey reports, but more current dates are available in the WETS Tables.

Growing Season Dates Section 5 http://www.wcc.nrcs.usda.gov/water/wetlands.html

DROUGHT ANALYSES ON THE INTERNET

Several Web sites present real-time data on drought and precipitation excess. These data are presented for Climate Divisions, which are regions of states that are meteorologically similar. The advantages of these drought indices are that they are statistically based information available for the current or preceding month. The disadvantages are that they are not site-specific and that the real-time data have not undergone official quality control procedures. The most widely used drought index is the Palmer drought index, which evaluates evapotranspiration and soil water content as well as precipitation. The Standardized Precipitation Index avoids some of the assumptions of the Palmer Index and provides frequency analyses for twenty different time periods leading up to a month of observation, ranging from one month prior to five years prior. The US Geological Survey reports percentile frequency analyses of
stream gauge levels around the Nation, which often serve as independent measures of climatic patterns. The appropriateness of individual tools to a specific site depends on the hydrologic controls of that site. Wetlands with a strong groundwater control need to be assessed with some of these longer term drought indices as well as with the WETS Tables. The drought indices are discussed and available at:

**Palmer Drought Indices**  
Section 6.2  
Previous month and prior  

Current week (provisional)  

**Standardized Precipitation Index**  
Section 6.3  
Percentiles for climate divisions  
[http://www.wrcc.sage.dri.edu/spi/spi.html](http://www.wrcc.sage.dri.edu/spi/spi.html)

National and archival  
[http://enso.unl.edu/ndmc/watch/watch.htm](http://enso.unl.edu/ndmc/watch/watch.htm)

**Stream Gauge Analyses**  
Section 6.4  

**SPATIAL VARIATION IN PRECIPITATION**

Spatial variability of precipitation is greater for individual storms than for precipitation averaged over a month or season. The National Climatic Data Center (NCDC) estimates missing values in weather data by interpolating between reporting stations within 30 miles. If a project does not have an onsite rain gauge, one should estimate monthly precipitation by averaging or interpolating between nearby NWS weather stations.

**Geographic Variation in Precipitation**  
Section 7

**COMBINING DATA FROM MONITORING WELLS AND RAIN GAUGES**

Data from shallow monitoring wells can be overlain on time series plots of daily precipitation data. Thirty-day rolling totals can also be plotted on these graphs. These graphs serve to clarify the relationship between local precipitation and site hydrology and provide a basis for determining the long-term hydrology of a site.

**Monitoring Wells and Rainfall Data**  
Section 8

**STATISTICAL BACKGROUND TO PRECIPITATION FREQUENCY ANALYSIS**

Precipitation data do not fit a bell curve but instead fit a gamma distribution. The reason for this is that a site cannot experience less than zero precipitation in any day or week or month, but in theory it can always experience a larger rainfall amount than the last record high. Consequently, the frequency distribution is skewed to the right. Precipitation frequency distributions are skewed more strongly in arid regions and for short-term analyses (for example, a month vs a year). These and related problems are discussed at:

**Statistical Background**  
Section 9
1. BACKGROUND CONCEPTS

1.1 WHY BE CONCERNED WITH ANTECEDENT PRECIPITATION?

Water levels in wetlands are influenced by the various components of the hydrologic budget, including precipitation. Because precipitation exerts such a strong control of the input side of the hydrologic budget, a variety of wetland assessments need information about the prior precipitation inputs influencing water levels observed on a site. The *Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory 1987) advises that

“because seasonal conditions and recent weather conditions can contribute to surface water being present on a nonwetland site, both should be considered when applying this indicator” [visual observation of inundation] (para. 49.b(1)), and

“[w]hen applying this indicator [visual observation of soil saturation], both the season of the year and preceding weather conditions must be considered” (para. 49.b(2)).

1.2 WHAT IS "NORMAL" PRECIPITATION?

“Normal” has two different meanings when used to describe precipitation. One is a single-value estimate of the mean and the other is a range of precipitation amounts.

1.2.1 “Normal Precipitation” as a Single Value  The National Climatic Data Center (NCDC 1995) defines “normal” as the “arithmetic mean of a climatological element computed over three consecutive decades.” Therefore, normal precipitation is the average of the precipitation amounts for the period of interest, for instance, for a particular month. For example, using this definition, normal April precipitation in Grand Island, NE, is 2.50 inches, because that is the average amount of rain that fell in all Aprils evaluated at that recording station during the previous three decades. Any April precipitation amounts greater than or less than 2.50 inches in Grand Island would be reported as deviations from normal for that month. Although this definition is useful for maintaining climatological records, it has little utility for classifying meteoric inputs into broad classes such as “normal,” “below normal,” or “above normal.” For that purpose, the concept of a “range of normal” precipitation amounts is more appropriate.

1.2.2 “Ranges of Normal Precipitation”  The concept of a “range of normal precipitation” is useful for grouping precipitation inputs into broad classes. The boundaries of these classes depend on the number of classes desired, the purpose of the classification, and tradition in the discipline. The NCDC\(^1\) computes several different probability ranges for different purposes, including quintiles (0-20\(^{th}\) percentile, 20\(^{th}\)-40\(^{th}\) percentile, etc.), deciles (0-10\(^{th}\) percentile, 10\(^{th}\)-20\(^{th}\) percentile, etc.), and others oriented toward extreme events. Some meteorologists prefer to assign the label of “normal” to the middle two quartiles (25\(^{th}\) to 75\(^{th}\) percentiles of probability). Various frequency analyses use slightly different cutoff thresholds for their middle range of precipitation frequencies (Table 1).

The Standardized Precipitation Index (SPI) has the widest range of normal, but intermediate percentiles are also available at their Web site. The 30\(^{th}\) to 70\(^{th}\) percentile thresholds are used in this report as the range of normal because those are the ones used in the only analysis that was specifically designed for wetland regulation (Food Security Act). The user of this report, however, should recognize that local climatologists may prefer slightly different ranges of normal. The technical definition of the WETS Tables range of normal can be found in Appendix D.

\(^1\) For convenience, abbreviations are listed in the Notation (Appendix E).
Table 1. Upper and Lower Percentile Thresholds for Middle Ranges of Precipitation Models.

<table>
<thead>
<tr>
<th>Model</th>
<th>Lower Threshold</th>
<th>Upper Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>USDA National Water and Climate Center WETS Tables</td>
<td>30\textsuperscript{th} percentile</td>
<td>70\textsuperscript{th} percentile</td>
</tr>
<tr>
<td>National Climate Data Center Palmer drought indices</td>
<td>28\textsuperscript{th} percentile</td>
<td>72\textsuperscript{nd} percentile</td>
</tr>
<tr>
<td>National Drought Mitigation Center Standardized Precipitation Index</td>
<td>16\textsuperscript{th} percentile\textsuperscript{1}</td>
<td>84\textsuperscript{th} percentile\textsuperscript{1}</td>
</tr>
<tr>
<td>US Geological Survey Stream Gauge analyses</td>
<td>25\textsuperscript{th} percentile</td>
<td>74\textsuperscript{th} percentile</td>
</tr>
</tbody>
</table>

\textsuperscript{1} The values of 26 and 74 found at the National Drought Center Web site are wrong (M. Svoboda, NDMC, personal communication, July 1999).

1.2.3 The Three-Decade Base Period  Many climatological probabilities, including the USDA WETS Tables discussed below, are calculated on the basis of the most recent three decades of data. The current base period is 1961-1990. On January 1, 2001, the new base period for calculations will become 1971-2000. The reasons for choosing the most recent three decades are both statistical and historical (Kunkel and Court 1990). For example, comparisons between different recording stations need to be made for the same time period; climatic change may alter probabilities of occurrence over the decades; recording technologies have been upgraded around the Nation at roughly comparable times; etc. Longer records are available at many weather stations, and these longer records are useful for calculating extreme events, such as 100-year floods, but the range of most likely precipitation is currently calculated on the basis of the most recent three decades of record.
2. RANGE OF NORMAL FROM THE “WETS Tables”

A WETS Table (Figure 1) is a statistical summary of monthly precipitation and temperature for any of the 8000+ reporting stations of the National Weather Service (NWS) Cooperative Network. The Tables are available for free on the Internet and from District Offices of the Natural Resources Conservation Service (NRCS). They present the ranges of normal precipitation, growing season dates as recommended for wetlands regulation, and monthly and annual precipitation totals for the period of record of each NWS reporting station.

2.1. ACCESSING THE WETS TABLES

The Internet address for the WETS Tables is:


The sequence of menu selections from this Web site is:

1. “Select desired region”; “Go to county selection”
2. “Select desired county”; “Go to FTP download”
3. “Select this line to receive the information for _____ county from our FTP site”

The WETS Table for a particular county may include tables for several weather stations in that county, so one may have to scroll through a series of tables to find the desired locations. These can be saved to a computer word-processing file by cut-and-paste techniques. For word processing they format best as Courier 10-point text with 0.5-inch margins.

2.2 IMPORTANT INFORMATION ON THE WETS TABLES (FIGURE 1)

Key elements of a WETS Table are

- Station location (name, latitude, longitude, and elevation)
  e.g., Grand Island WSO AP, NE; 4058 lat, 09819 long, 1840 ft elev.

- “Starting year” and “ending year” tell the time period used to calculate ranges of normal and means
  e.g., 1961 to 1990

- Temperature averages are arithmetic means of the monthly records
  e.g., mean April temperature is 50.8° F

- Precipitation data
  i) monthly average (arithmetic mean)
     e.g., mean April precipitation is 2.50 inches
  ii) range of normal (30% chance will have “less than” and “more than”)
     e.g., normal April rainfall is between 1.37 inches and 3.05 inches

- Growing season dates
  e.g., April 15 to October 16, for 50% likelihood of last and first 28° F frost

- Page (Sheet) 2 of the output shows monthly precipitation totals for the long-term record for the station.
<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature (Degrees F.)</th>
<th>Precipitation (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>avg daily</td>
<td>avg daily</td>
</tr>
<tr>
<td></td>
<td>max</td>
<td>min</td>
</tr>
<tr>
<td>January</td>
<td>32.7</td>
<td>11.1</td>
</tr>
<tr>
<td>February</td>
<td>38.1</td>
<td>16.4</td>
</tr>
<tr>
<td>March</td>
<td>49.2</td>
<td>26.3</td>
</tr>
<tr>
<td>April</td>
<td>54.4</td>
<td>38.2</td>
</tr>
<tr>
<td>May</td>
<td>73.3</td>
<td>49.4</td>
</tr>
<tr>
<td>June</td>
<td>84.0</td>
<td>59.1</td>
</tr>
<tr>
<td>July</td>
<td>88.8</td>
<td>64.7</td>
</tr>
<tr>
<td>August</td>
<td>86.4</td>
<td>62.0</td>
</tr>
<tr>
<td>September</td>
<td>76.6</td>
<td>51.6</td>
</tr>
<tr>
<td>October</td>
<td>65.8</td>
<td>39.2</td>
</tr>
<tr>
<td>November</td>
<td>49.2</td>
<td>26.2</td>
</tr>
<tr>
<td>December</td>
<td>35.8</td>
<td>14.9</td>
</tr>
<tr>
<td>Annual</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Average</td>
<td>61.9</td>
<td>38.3</td>
</tr>
<tr>
<td>Total</td>
<td>---------</td>
<td>---------</td>
</tr>
</tbody>
</table>

GROWING SEASON DATES

<table>
<thead>
<tr>
<th>Probability</th>
<th>Temperature</th>
<th>24 F or higher</th>
<th>28 F or higher</th>
<th>32 F or higher</th>
<th>36 F or higher</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Beginning and Ending Dates</td>
<td>Growing Season Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 percent *</td>
<td>4/ 7 to 10/25</td>
<td>4/15 to 10/16</td>
<td>4/26 to 10/6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>202 days</td>
<td>184 days</td>
<td>164 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70 percent *</td>
<td>4/ 3 to 10/29</td>
<td>4/11 to 10/20</td>
<td>4/21 to 10/11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>209 days</td>
<td>192 days</td>
<td>172 days</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Percent chance of the growing season occurring between the Beginning and Ending dates.

Figure 1. WETS table for Grand Island, NE (NWC 1996) (Continued)
2.3 INTERPRETING “ZERO” PRECIPITATION LEVELS IN THE WETS TABLES

The WETS Tables report missing precipitation data in two ways, either with an "M" beside the monthly value (for example, "M1.25"), or with a blank for the month. An "M" is used if one or more days of data have been recorded as “missing.” A blank monthly total is shown if no data are available for that month. “0.00” is entered for a month that has a full record of data but in which no precipitation fell.

2.4 GRAPHICAL PRESENTATION OF THE INFORMATION ON WETS TABLES

Changes in monthly precipitation data and their deviation with respect to range of normal are often more understandable when presented in a graphic format, such as Figure 2. This graph shows monthly precipitation totals for a particular year, the range of normal precipitation for each calendar year.
month based on the preceding three decades, and the duration of the growing season. It is easy to plot the range of normal precipitation (shaded area in Figure 2) for the weather stations that are within the area of responsibility of the field office. These can then serve as templates, be photocopied, and be used to plot monthly totals on a case-by-case basis. Plotting of WETS Table and monthly total precipitation data in a standard format reduces ambiguities when evaluating precipitation conditions during the period of concern.
3 FINDING RECENT PRECIPITATION DATA

3.1 EXISTING SOURCES

As of this writing, finding recent precipitation data is the most cumbersome part of determining whether precipitation was normal during the two or three months prior to a site visit. There currently is a several month delay between the date of collection and final release of data to the public by the National Oceanic and Atmospheric Administration (NOAA). The delay results from quality-control protocols used by the NCDC. Raw data are usually very similar to those finally published, but data should undergo NCDC quality control steps before being used for legal purposes. All data published in the Climatologic Data Summaries and in the WETS Tables have undergone this process.

Excellent sources of recent data are the Regional Climate Centers (RCC) and the state climatologists.

- Regional Climate Centers:  http://met-www.cit.cornell.edu/other_rcc.html

These offices may be able to provide data from stations that are not part of the WETS network as well as raw data from official recording stations. Recent precipitation information may also be available from unofficial sources outside of the NWS network, such as newspapers, research sites, etc. Caution should be used with data from non-NWS sources, as turbulence at improperly located instruments, equipment used, and data transcription are all potential sources of error that may not be monitored as closely as done by the NCDC. To determine their reliability, unofficial data should be correlated with long-term data from surrounding official weather stations using procedures described in Section 3.3.

A great number of Internet Web sites claim to provide recent weather data. Users of climatic data are encouraged to explore city, state, and university Web sites for locally useful information that may be accessed on a continuing basis. On a national basis, the Climate Prediction Center publishes weekly and monthly precipitation data for approximately 225 cities around the Nation at

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/prcp_temp_tables/

The US Geological Survey (USGS) publishes precipitation data from various rain gauges around the Nation. This information is published on a state-by-state basis. The national index for the Web site is found at:

http://water.usgs.gov/realtime.html

3.2 UNIFIED CLIMATE ACCESS NETWORK (UCAN) ²

The NRCS, six RCC's (NOAA), and NCDC (NOAA) are currently designing and constructing the Unified Climate Access Network (UCAN). UCAN is a consortium of Federal and state agencies whose focus is to unify access and availability of climate data and information for natural resource management. UCAN will allow user access to quality-controlled climate information more quickly, easily, and efficiently than previously possible.

² Contributed by P. Pasteris, National Water and Climate Center, Portland, OR.
This Internet-based climate system will provide access to climate information as current as a month old for 8000+ climate stations and historical data from over 25,000 stations collected by Federal, state, and county networks located throughout the U.S. As of October 1998 a prototype UCAN demonstration Web site has been established at the following Uniform Resource Location (URL):

http://www.srcc.lsu.edu/ucan.net/UCAN.html

A major goal of this project is to enable climate information users to obtain information from a UCAN Web page. The UCAN system will automatically send requests for specific data sets and climate products to a network of regional and national climate center computer systems that maintain the data archive for the requested product.

In addition to access to multiple data sets and output formats, users will be able to run a variety of climatic data analysis programs. These include statistical averages, frequency analyses, spatial mapping, risk analyses, and modeling applications that require specialized climatic information.

3.3 USING ONSITE RAIN GAUGES

It is a common practice on research projects to collect precipitation data on or near an investigation site in order to record differences between rainfall onsite and that recorded at the nearest NWS station. This is done because rainfall can vary considerably over short distances, particularly in locations and seasons where meteorology is dominated by convective thunderstorms. When using onsite rain gauges, however, caution is required for several reasons:

- The previous three-decade precipitation record is usually not available at project sites, so one must compare onsite data with official NWS data from nearby stations to determine whether onsite precipitation was outside the range of normal.

- Onsite precipitation data seldom undergo the same quality-control procedures as those applied to the NWS database.

- Onsite rain gauges may be unreliable due to poor quality, improper installation, or infrequent readings.

3.3.1. Rain Gauge Quality and Location

Of the above-mentioned problems, the easiest to address is quality of the rain gauge. Automatic, recording rain gauges are available from numerous scientific and environmental supply houses. Most of these meet the minimum standards specified for Cooperative Weather Station observations (NWS 1989; section on rain gauges reproduced herein in Appendix B). Whatever rain gauge is chosen, it should be read daily because it is necessary to compare onsite and nearby NWS data for daily differences in order to interpret the source of discrepancies. Gauge quality and installation should be reported in studies using unofficial data; a sample form for such reporting is included in Appendix C.

Because wind turbulence varies with shelter and topographic setting (Smith 1993), a rain gauge should be located with care. The NWS recommends that

Gages should not be located close to isolated obstructions such as trees and buildings, which may deflect precipitation due to erratic turbulence. Gages should not be located in wide-open spaces or on elevated sites, such as tops of buildings, because of wind and the resulting turbulence problems. The best location is where the gage is uniformly protected in all directions, such as in an opening
in a grove of trees. The height of the protection should not exceed twice its distance from the gage. As a general rule, the windier the gage location is, the greater the precipitation error will be. (NWS 1989, p. 6)

This advice is essentially the same as the more recent recommendations by the World Meteorological Organization (1996) and the US Environmental Protection Agency (Finkelstein et al. 1983). Advice regarding installation in forests has not been located, but a knowledge of rainfall interception by forest canopies suggests that rain gauges should not be located under trees, because precipitation interception will vary with canopy closure and age and with storm intensity and duration (Smith 1993).

3.3.2 Interpreting Onsite Precipitation Data

In order to check the accuracy of records from unofficial rain gauges it is necessary to plot daily precipitation data from both the unofficial and nearby official weather stations on the same graph (Figure 3). If practicable, several official weather stations should be used, even if they are located fairly far apart. This way it can be determined how much rainfall varies in the geographic region and whether the unofficial rain gauge varies by comparable amounts. Topographic variability between stations should be taken into account when comparing one station with another. Generally, rain gauges closer to one another report more similar records than those further apart. Using this method, anomalies in the unofficial record should be obvious.

Figure 3 shows such a plot for an unofficial rain gauge in southeast Indiana (Wetland Research Site, black bars) and for three official sites within 20 miles of the research site. A year’s worth of data is presented. Note the variability among official weather stations, for example, in the first week in January. All stations had over an inch of precipitation on the 4th and 5th of January, but the precipitation fell over two days at North Vernon and Seymour and fell in one day at Scottsburg.

On February 16 and 17 the research station reported two precipitation events, one as snow and one as rainfall; temperatures on both days remained below freezing. Only one event was reported at the official stations. A subsequent telephone call to the operator showed that the second record was a conversion to wet precipitation amounts; the erroneous entry was left in Figure 3 to illustrate such problems with raw data. Two lessons can be learned here: (1) Raw field data are bound to have inconsistencies and need to be scrutinized before final publication. This is why the NWS submits all data to quality-control procedures. (2) Temporarily installed rain gauges bought from environmental supply houses are often unheated and therefore do not record snowfall accurately, as was the case with this unofficial rain gauge, too.

There seem to be no inconsistencies in the March records. The lone precipitation record at North Vernon on the 31st was probably part of the same system that delivered precipitation at all four stations on April 1st. One wonders whether precipitation on April 10-12 was accurately reported; temporal distributions would have been more consistent had the April 12 rainfall at the research site occurred on the same day as the three official stations. Rainfall on May 13, July 2, and November 15 was higher at the research site than at the official stations, but not so high as to seriously question the accuracy of the readings without statistical analyses of variance for the entire period of record.

Such informal comparisons of readings at the unofficial and official sites indicate that precipitation fell at all four stations in the same patterns. Therefore, antecedent precipitation at the research site could be evaluated using analyses from the surrounding official weather stations, as in Figure 4.
Figure 3. Example of comparison of data from unofficial weather station (black bars; Jenkinson and Franzmeier 1996) and from surrounding official NWS weather stations (gray bars; NOAA 1994). The data from the unofficial station are plotted from uncorrected field sheets (Jenkinson, personal communication, 1998). Note variability between NWS sites. Precipitation amounts recorded at the unofficial site were similar to those reported at the NWS stations and could therefore be accepted as reasonably accurate (Sheet 1 of 3)
Figure 3. (Sheet 2 of 3)
Figure 3. (Sheet 3 of 3)
Figure 4. A. Ranges of normal for monthly precipitation at three NWS stations in Indiana (NWCC 1996). B. Actual monthly precipitation totals at three NWS stations and a research station in Indiana, superimposed on a graph of average range of normal monthly precipitation at the NWS stations (gray)
Figure 4A shows the monthly ranges of normal for the three NWS stations. Because differences between ranges of normal were so small, it is acceptable to use any of these ranges of normal to evaluate precipitation data at the research site. As a general policy, ranges of normal at nearby stations should be compared to assure that elevation and physiography are not producing systematic differences between weather stations.

Comparison of onsite and offsite data (Figure 4B) indicates that precipitation was within the range of normal in February, March, May, June, July, October, and December. In this case these same conclusions would have been reached without the onsite data, but with less confidence. One can envision situations where several nearby NWS stations have similar precipitation amounts that straddle the boundary between normal and above normal; for example, if April precipitation had been slightly less at all stations in Figure 4B. Onsite data are helpful in such cases where data from official stations fall on either side of a boundary of normal.

3.3.3. Summary of Use of Onsite Rain Gauges

1. Onsite rain gauges can identify onsite precipitation events that differ significantly from those recorded at nearby NWS stations.

2. Onsite rain gauges should meet minimum quality standards described in NWS Observing Handbook No. 2 (NWS 1989) (pertinent section reproduced in Appendix B).

3. Onsite rain gauges should be installed in somewhat sheltered areas, but the distance from sheltering trees or buildings should be at least twice the height of the trees or buildings.

4. Onsite rain gauges should be read daily, and for a long enough monitoring period to develop a record that can be confidently compared with records from nearby NWS stations.

5. Data from onsite rain gauges need to be compared with data from several nearby NWS stations to check for deviations from regional patterns. Such comparisons can be easily performed by plotting daily data (onsite and NWS) on the same chronological graph.

6. Discrepancies between temporal patterns of onsite and NWS data need to be explained. If unofficial data track the official data for most storm events, then the data can probably be trusted, and an anomalous rainfall record at one site probably reflects genuine geographic variability. However, if the data at the official stations track together and the data from the unofficial site do not, then the unofficial data set should be evaluated for errors. Numerous differences would call into question the data from the onsite rain gauge.
4. EVALUATING ANTECEDENT PRECIPITATION CONDITIONS AT A SITE

This section presents three alternate procedures to evaluate whether precipitation prior to a particular date was within the range of normal for a particular reporting station. The first and simplest method utilizes monthly precipitation data and the WETS Tables, and is taken from the NRCS Engineering Field Handbook (NRCS 1997). The second method evaluates daily precipitation data on the basis of 30-day rolling sums. The third method combines the two procedures.

4.1 NRCS ENGINEERING FIELD HANDBOOK

4.1.1 Background

The NRCS Engineering Field Handbook (NRCS 1997; hereafter “the NRCS method”) presents a procedure to systematically evaluate rainfall conditions for the three-month period prior to the site investigation. The method is summarized below; the complete procedure can be found on pages 24-26 of “Hydrology Tools for Wetland Determination,” which can be downloaded as a .pdf file at http://www.wcc.nrcs.usda.gov/water/quality/text/hydrolog.html.

The methodology calculates a numerical rating of prior precipitation by weighting the data for both (1) amount of precipitation, and (2) relative age of a rainfall event (Warne and Woodward 1998; Woodward et al. 1996). These two weighting factors (“departure from normal” and “recentness”) are multiplied to give a numerical rating that is used to decide whether the prior precipitation for the entire 3-month period was within the range of normal or not. The procedure is as follows:

4.1.2 NRCS Method for Estimating Antecedent Moisture Conditions at a Site.

Using the NRCS rainfall documentation sheet (Figure 5; values entered for an example from Grand Island, NE).

a. Fill out the background information (Weather Station and Growing Season from WETS Table, Figure 1). “Photo date” is the date of a hydrologic observation.

b. Fill in the “Month” column. Usually the “1st prior month” is the month of the hydrologic observation. When hydrologic observations were made early in a calendar month, the “1st prior month” might be evaluated better as the preceding calendar month. The entire month’s worth of rainfall is entered in this column because this method assumes that only monthly totals of precipitation are available.

c. Fill in the columns “3 yrs. in 10 less than” and “3 yrs. in 10 more than.” using information from the station’s WETS table (Figure 1).

d. In column “rainfall” enter the actual rainfall that fell in months listed in the “Month” column.

e. Compare the actual rainfall amounts for each month with the ranges of normal you entered in the columns of long-term rainfall records. In the column “Condition dry, wet, normal” enter “dry,” “wet,” or “normal,” depending on the comparison between actual rainfall and long-term ranges of normal.
f. In the column “Condition value,” enter the appropriate “condition value” from the small table immediately below. For example, if the actual rainfall was wetter than normal, then enter condition value “3.”

g. Multiply the “condition value” by the “Month weight factor” to obtain the value to enter into the column “Product of previous two columns.”

h. Add the three products in the last column to obtain the “sum” at the bottom of that column. The sum should be a whole number between 6 and 18.

i. Conclude whether the prior period was drier than normal, normal, or wetter than normal by comparing the calculated sum to the small look-up table in the Note below the first three columns of Figure 5.

4.1.3. Comments on the NRCS Method.

The NRCS method has the advantages of considering data from the previous three months rather than just one, of weighting those data for length of time since the precipitation contributed to the water budget, of using easily accessible information, and of being simple to apply. It has obvious weaknesses, the most important being the assumption that rainfall was evenly distributed during the month of observation. Nevertheless, the method is a significant improvement on the situation of ignoring antecedent precipitation inputs into site hydrology. Some of the assumptions one must be aware of when using the method are:

- that rain was evenly distributed for the month of observation. The importance of this assumption is magnified by the fact that the “recency” weighting factor is largest for the month of observation.

- that three months is the proper length of time to evaluate antecedent precipitation. Evapotranspiration becomes more intense during the middle of the growing season and therefore surface and near surface residence times may be much less than three months. Furthermore, antecedent precipitation typically influences flooded, open system wetlands differently than closed depressions or in seeps.

- that snowmelt contributes to wetland hydrology the same as rainfall.

4.2 METHOD OF ROLLING TOTALS

4.2.1 Background

The NRCS Engineering Field Handbook compares actual precipitation with monthly ranges of normal by accessing published monthly rainfall summaries from NOAA and National Water and Climate Center (NWCC). Precipitation patterns within a particular month are not reflected in monthly totals. Because the period of continuous inundation required for wetland hydrology is less than a month, it is commonly desirable and necessary to utilize and evaluate higher frequency (daily) precipitation data. The 30-day rolling total is technically more sound than monthly totals in that monthly totals are reset to zero at the beginning of each month and therefore may not accurately reflect antecedent rainfall in the middle of the month.

The 30-day rolling total is generated by summing the past 30 days’ precipitation. By continually updating a tally of the prior 30-day rainfall totals, one can plot a record of rainfall for the immediately preceding 30 days of rain on a daily basis (for example, Figure 6). Overlaying a plot of range of normal
### Rainfall Documentation (use with photographs)

**Date:** May 15, 1991  
**Weather station:** Good Island  
**Landowner:** J. Doe  
**County:** No. 11  
**State:** NE  
**Soil name:** alpha beta  
**Growing season:** 4/15 - 10/16  
**Photo date:** May 15, 1991

#### Long-term rainfall records

<table>
<thead>
<tr>
<th>Month</th>
<th>3 yrs. in 10 less than</th>
<th>Normal</th>
<th>3 yrs. in 10 more than</th>
<th>Rainfall</th>
<th>Condition dry, wet, normal</th>
<th>Condition value</th>
<th>Month weight value</th>
<th>Product of previous two columns</th>
</tr>
</thead>
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<td>2.51</td>
<td>4.59</td>
<td>6.27</td>
<td>Wet</td>
<td>3</td>
<td></td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Apr.</td>
<td>1.87</td>
<td>3.05</td>
<td>2.73</td>
<td>Normal</td>
<td>2</td>
<td></td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Mar.</td>
<td>0.49</td>
<td>2.28</td>
<td>1.79</td>
<td>Normal</td>
<td>2</td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

* Compared to photo date

**Note:** If sum is
- 6 - 9 then prior period has been drier than normal
- 10 - 14 then prior period has been normal
- 15 - 18 then prior period has been wetter than normal

**Condition value:**
- Dry = 1
- Normal = 2
- Wet = 3

**Conclusions:**

Antecedent precipitation was wetter than range of normal

---

**Figure 5.** Worksheet to determine whether precipitation was within the range of normal prior to a site visit, taken from the NRCS Engineering Field Handbook, Chapter 19 (NRCS 1997)
precipitation on such a daily plot allows the delineator to evaluate whether antecedent precipitation was greater or less than normal throughout a month rather than just at the beginning or end.

4.2.2. Procedure of 30-day Rolling Totals

The procedure of 30-day rolling totals consists of three parts:

1. Calculating and plotting 30-day rolling totals for the time period of interest (Figure 6 and Table 2).

2. Overlaying a plot of monthly ranges of normal on the plot of 30-day rolling totals (Figure 6).

3. Comparing the rolling 30-day sums to the monthly ranges of normal to determine whether antecedent precipitation was within the range of normal.

Preparing a plot of 30-day rolling totals and monthly ranges of normal (Figure 6)

The graphics needed for the method of 30-day running totals are prepared as follows. Continuing with the Grand Island example, Table 2 shows the 30-day rolling total calculated for February through May 1991.

<table>
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<th>Date</th>
<th>Daily Precip</th>
<th>30-day Rolling Total</th>
<th>Date</th>
<th>Daily Precip</th>
<th>30-day Rolling Total</th>
<th>Date</th>
<th>Daily Precip</th>
<th>30-day Rolling Total</th>
</tr>
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<td>15-Feb</td>
<td>0.27</td>
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<td>1-Apr</td>
<td>0.06</td>
<td>1.53</td>
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<td></td>
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<td></td>
<td>2-Apr</td>
<td>1.53</td>
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<td>0.05</td>
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<td></td>
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<tr>
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<td>18-Feb</td>
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<td>4-Apr</td>
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<td>4-May</td>
<td>0.24</td>
<td>3.49</td>
</tr>
<tr>
<td>4-Feb</td>
<td>0.32</td>
<td></td>
<td>21-Mar</td>
<td>0.09</td>
<td>1.08</td>
<td>5-May</td>
<td>3.49</td>
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<tr>
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<td>0.32</td>
<td></td>
<td>22-Mar</td>
<td>0.17</td>
<td>1.25</td>
<td>6-May</td>
<td>3.49</td>
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</tr>
<tr>
<td>6-Feb</td>
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<td></td>
<td>23-Mar</td>
<td>1.25</td>
<td></td>
<td>7-May</td>
<td>0.09</td>
<td>3.58</td>
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<tr>
<td>7-Feb</td>
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<td></td>
<td>24-Mar</td>
<td>1.25</td>
<td></td>
<td>8-May</td>
<td>3.58</td>
<td></td>
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<tr>
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<td></td>
<td>25-Mar</td>
<td>1.25</td>
<td></td>
<td>9-May</td>
<td>3.58</td>
<td></td>
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<tr>
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<td></td>
<td>26-Mar</td>
<td>0.03</td>
<td>1.28</td>
<td>10-May</td>
<td>3.58</td>
<td></td>
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<tr>
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<td></td>
<td>27-Mar</td>
<td>0.51</td>
<td>1.79</td>
<td>11-May</td>
<td>3.15</td>
<td></td>
</tr>
<tr>
<td>11-Feb</td>
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<td></td>
<td>28-Mar</td>
<td>1.79</td>
<td></td>
<td>12-May</td>
<td>2.98</td>
<td></td>
</tr>
<tr>
<td>12-Feb</td>
<td>0.27</td>
<td></td>
<td>29-Mar</td>
<td>1.79</td>
<td></td>
<td>13-May</td>
<td>2.81</td>
<td></td>
</tr>
<tr>
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<td>0.27</td>
<td></td>
<td>30-Mar</td>
<td>1.79</td>
<td></td>
<td>14-May</td>
<td>2.81</td>
<td></td>
</tr>
<tr>
<td>14-Feb</td>
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<td></td>
<td>31-Mar</td>
<td>1.47</td>
<td></td>
<td>15-May</td>
<td>2.81</td>
<td></td>
</tr>
</tbody>
</table>
1. In a 3-column table, tally date and daily precipitation for the 120 days preceding a site observation (the three columns in Table 2 are wrapped to fit on the page).

2. Starting with the 30th day, total the precipitation amounts for that day and the preceding 29 days; enter the sum in the third column, “30-day Rolling Total.” This tedious calculation can be automated in most personal computer spread sheet software programs by copying and pasting the first instance of the command into subsequent rows of the third column. In Microsoft Excel (Microsoft Corporation 1985-1997) the command is “=sum(b1:b30).”

3. Plot Column 3 against Column 1 (30-day rolling total against time, as in Figure 6).

4. Superimpose the monthly ranges of normal from the appropriate WETS Table. Plot the ranges of normal for each month at the end of that particular month, rather than the beginning or middle, because the range of normal from the WETS Table is for the preceding days of the month (preceding 28/29, 30, or 31 days).

5. Superimpose the daily rainfall data (“spike graph”) to provide details of the distribution of rainfall within the months of interest.

4.2.3. Determining Whether Tallied Precipitation Was Within Range of Normal

Deviation from the range of normal precipitation is determined by use of the superimposed plots of 30-day rolling totals and ranges of normal precipitation for the period of interest (for example, Figure 6). Daily precipitation data should also be superimposed on such graphs in order to understand how the 30-day rolling totals evolved.

Using this methodology it is seen that in 1991 at Grand Island, January, March, and April precipitation levels were largely within the range of normal, and February precipitation was slightly below normal. The first half of May was within the range of normal until May 16 when a 1.35-inch rain caused the 30-day total to rise above the range of normal. Between May 23 and May 25, 2.33 inches of rain fell at the weather station, which caused the 30-day rolling sum to rise significantly above normal, where it stayed for the rest of the summer, except for a short period in early July. Scanty rains in the last half of July initiated a drought that lasted well into the fall. November and December precipitation levels were above normal.

4.2.4. Comments on the Method of 30-day Rolling Totals

The strength of the method of 30-day rolling totals can be seen by comparing it to the method of monthly totals used by the WETS Tables (Figures 1 and 6). The two methods agree that precipitation levels in January, March, and April were within the range of normal and that February was slightly drier than normal. Note, however, that the monthly tallies of the WETS Tables indicate that May was significantly wetter than normal whereas the more detailed method of 30-day rolling totals detected that the heavy rains of the wet summer did not occur until the middle and, especially, the end of May. Detailed knowledge of rainfall distributions in early May could have been particularly important to wetland scientists because that is shortly after the beginning of the regulatory growing season when field decisions were likely to have been made. The method of 30-day rolling totals provides a more accurate assessment of antecedent moisture conditions at a site than do monthly averages, which artificially zero rainfall totals at the beginning of each month.
However, the method of rolling sums also artificially zeroes rainfall after 30 days. Note in Figure 6 that 30-day rolling precipitation totals were much above normal for most of July and early August, despite the fact that daily rainfall records show most of July was dry (spike graph at bottom of Figure 6). Furthermore, antecedent precipitation levels fell from much above normal to well below normal within a space of three days in early August. This is a direct consequence of the method of calculating a 30-day rolling sum. A large input remains within the rolling sum for exactly 30 days, and then abruptly drops out of the rolling total. In loamy and finer textured soils, changes in water tables are unlikely to be so abrupt.

The method of rolling totals is often used to track the influence of antecedent precipitation on water levels in monitoring wells. It is well suited for this purpose because each well reading can be compared to an updated tally of antecedent precipitation.

4.3 COMBINED METHOD OF 30-DAY ROLLING TOTALS AND NRCS ENGINEERING FIELD HANDBOOK WEIGHTING FACTORS.

Combining the method of 30-day rolling totals with the NRCS Engineering Field Handbook method of weighting antecedent precipitation is appropriate where precipitation influences site hydrology for two or three months.

4.3.1 Procedure for Combining the Methods of 30-day Rolling Totals and NRCS Engineering Field Handbook Weighting Factors.

1. On the plot of 30-day rolling totals (Figure 7) mark off 30-day blocks starting backward from the date of interest. Continuing with the Grand Island example, if a wetland is delineated on May 15, the plot of 30-day rolling totals would be blocked off into 30-day blocks: April 16-May 15; March 17-April 15; and February 15 - March 16.

2. Decide whether the 30-day blocks reflect normal, drier than normal, or wetter than normal precipitation by comparing the 30-day rolling totals with the ranges of monthly normal. Some of these decisions will require professional judgment.

3. Record your decisions for the 30-day blocks in the Rainfall Documentation Form in the column labeled “Condition dry, wet, normal” (Table 3).

4. Fill out the subsequent columns of the form as instructed for the Engineering Field Handbook method (Section 4.1.2).

4.3.2 Comments on the Combined Method

The combined method rated the three-months’ precipitation prior to May 15 as being normal whereas the NRCS Engineering Field Handbook method rated it as wetter than normal (Table 3). The difference is the ability to calculate 30-day increments starting on any date rather than only at the beginning of the calendar month. Frequent use of the combined method will show how difficult it is to decide whether a particular 30-day period of rolling totals falls on one side of a threshold of normal or on the other side. For example, it would be a close call to decide whether the period of April 24 to May 23, 1991, was within or above the range of normal.
Figure 7. Three 30-day periods prior to May 15, superimposed on Figure 6

Table 3. Comparison of Engineering Field Handbook Method and Combined Method

<table>
<thead>
<tr>
<th></th>
<th>Engineering Field Handbook Method</th>
<th>Combined Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Month</td>
<td>30&lt;sup&gt;th&lt;/sup&gt; %ile</td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; mo</td>
<td>May</td>
<td>2.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.27</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; mo</td>
<td>April</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.73</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; mo</td>
<td>March</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.79</td>
</tr>
</tbody>
</table>

sum = 15 wetter than normal

|                             | 4/16-5/15 | See Fig 7 | See Fig 7 | See Fig 7 | Normal | 2 | 3 | 6 |
| 1<sup>st</sup> mo          | 3/17-4/15 | See Fig 7 | See Fig 7 | See Fig 7 | Normal | 2 | 2 | 4 |
| 2<sup>nd</sup> mo          | 2/15-3/16 | See Fig 7 | See Fig 7 | See Fig 7 | Dry    | 1 | 1 | 1 |

sum = 11 normal
4.4 GENERAL OBSERVATIONS ON ASSESSMENTS OF ANTECEDENT PRECIPITATION

- The WETS Tables alone are quickest and probably sufficient to use when simple generalizations about long-term trends are all that is needed.

- The method of the Engineering Field Handbook will perforce be used when daily precipitation data are not readily available.

- The simple method of 30-day rolling totals is readily used with long sets of monitoring well data because of ease of plotting information. These plots, when superimposed on a daily precipitation spike graph, provide a powerful tool for explaining water well fluctuations.

- The combined method is useful for making decisions regarding individual dates of observation at a site. Whenever feasible, the monthly analyses should be interpreted using the daily data from which the monthly summaries were aggregated.

- The methods of the WETS Tables and rolling totals should be used in conjunction with indices of longer term hydrologic input, such as the Palmer drought indices, the Standardized Precipitation Index, and/or USGS stream gauge analyses (Section 6 below). The longer term record (many months to a year) may show the presence of a prolonged drought; a couple of months of normal rain-fall in the middle of the drought may not raise water tables to levels typical outside of the drought.

- The WETS Tables evaluate the range of normal precipitation in monthly increments. Antecedent precipitation probably does not affect wetland hydrology in monthly or 30-day increments. The Standard Precipitation Index and Palmer drought indices (Section 6) have more flexible periods of evaluation of antecedent conditions.

- Antecedent precipitation is only one part of the water budget. The other parts of the water budget need to be considered when interpreting observed levels of ground or surface water.

- The duration of impact of antecedent precipitation typically varies with the seasons. In the early spring, when evapotranspiration (ET) is low, there is probably a longer duration impact of prior precipitation than later in the summer when ET is high.

- The duration of influence of antecedent precipitation on wetland hydrology does not seem to have been studied. The NRCS hydrologists chose three months as a reasonable length of time to evaluate antecedent precipitation for Food Security Act programs. The National Drought Mitigation Center (NDMC) reports a three-month calculation of their Standardized Precipitation Index at their Web page of drought estimates for the Nation (http://enso.unl.edu/monitor/current.html). In default of site-specific information to the contrary, three months preceding a date of site monitoring seems to be a reasonable length of time to evaluate whether precipitation was within the range of normal.

- There is no way to remove professional judgment in borderline situations. Remember that the limits of the range of normal (30th and 70th percentiles) are themselves professional judgments. Moreover, when antecedent precipitation levels are close to thresholds of normal, uncertainties about other parts of the water budget become a major consideration.
5. GROWING SEASON

Guidance of 6 March 1992 (Office of the Chief of Engineers, 6 March 1992, para. 3.b.) allows determination of the regulatory growing season with reference to NRCS soil survey information. In 1992, the most current soil survey information was contained in soil survey reports, which may be more than a decade old. More current growing season information may be obtained from the NRCS WETS Tables at the bottom of the first page of the entry for each reporting station. For most of the Nation the wetland delineation growing season is approximated by the last and first dates with a 50 percent likelihood of 28°F frost. In Wooster, OH, for example, the growing season is April 23 to October 21 (Figure 8). The soil survey report (Soil Conservation Service 1984) gives the growing season as April 23 to October 18. The dates differ by three days at the end of the growing season (October 18 vs October 21) because the 1984 information was based on different baseline data (1951-1978 vs 1961-1990).

![WETS Station: WOOSTER EXP STATION, OH9312](image)

**WETS Station:** WOOSTER EXP STATION, OH9312  **CREATION DATE:**
6/24/96

**Latitude:** 4047  **Longitude:** 08155  **Elevation:** 1020

**State FIPS/County(FIPS):** 39169  **County Name:** Wayne

**Start yr.** - 1961  **End yr.** - 1990

**GROWING SEASON DATES**

<table>
<thead>
<tr>
<th>Probability</th>
<th>24°F or higher</th>
<th>28°F or higher</th>
<th>32°F or higher</th>
</tr>
</thead>
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<tr>
<td>50 percent *</td>
<td>4/11 to 11/2</td>
<td>4/23 to 10/21</td>
<td>5/5 to 10/7</td>
</tr>
<tr>
<td></td>
<td>205 days</td>
<td>181 days</td>
<td>155 days</td>
</tr>
<tr>
<td>70 percent *</td>
<td>4/7 to 11/6</td>
<td>4/19 to 10/25</td>
<td>5/1 to 10/11</td>
</tr>
<tr>
<td></td>
<td>213 days</td>
<td>189 days</td>
<td>163 days</td>
</tr>
</tbody>
</table>

* Percent chance of the growing season occurring between the Beginning and Ending dates.

Figure 8. Growing season information as presented in WETS Tables, for Wooster, OH (NWCC 1996)
6. DROUGHT ANALYSES ON THE INTERNET

There are several Internet Web sites that complement the NWCC WETS Tables by (1) providing near-real time precipitation information and (2) providing long-term frequency analyses of regional patterns of drought and moisture excess. These Web sites are not substitutes for analyses of site-specific data using the WETS Tables because of trade-offs made to develop real-time, regional assessments. However, one should utilize Web sites in order to get a sense of long-term climatic trends in the region. Three analyses are discussed here: (1) Palmer drought indices, (2) Standard Precipitation Index (SPI), and (3) USGS stream gauge data. The Palmer index is reported for the previous week and for previous months. The SPI is available for the previous month. USGS data are reported for the previous day, week, and month. All are reported as or can be converted to frequency probabilities.

The Palmer analyses incorporate precipitation, evapotranspiration, and regional soil properties and the SPI analyzes precipitation alone. The USGS analyses complement the Palmer and SPI analyses because they come from independent sources of information (stream flows vs weather). The authors recommend that wetland scientists consult both the USGS Web site and one of the climate Web sites to assess near-real time drought conditions. Final decisions involving quantitative evaluations of hydrology should be postponed until site-specific precipitation data can be collected and compared with the WETS data.

The NDMC provides maps of eight different indices or climatic conditions related to drought or moisture excess at http://enso.unl.edu/monitor/current.html. Indices and sites commonly do not map drought or moisture excess the same in the different climate divisions of the country. Users of these indices should compare them with each other to determine which ones seem most appropriate for their part of the Nation.

6.1 PRELIMINARY NATURE OF NEAR-REAL TIME ANALYSES

Near-real time drought indices are calculated from preliminary data that have not undergone quality-control protocols. Therefore, the Palmer drought indices and the Standardized Precipitation Index should probably not be used in reports until the indices have been recalculated with official data; this is especially true of the weekly updates of the Palmer indices published by the Climate Prediction Center (Section 6.2, below). Quality control is usually completed after three months time for the drought indices. The updated calculations are inserted into published files automatically, so indices for the preceding three months should be considered preliminary and those four months or older can be assumed official (R. Heim, NCDC, personal communication, July 1999). Changes in SPI data after quality control are usually so small that SPI indices are not updated on the NDMC Web pages (M. Svoboda, NDMC, July 1999, personal communication), the disclaimer at their Web site notwithstanding: http://enso.unl.edu/ndmc/watch/datadis.htm.

Real-time stream gauge data, too, are preliminary and need to undergo quality-control protocols before being cited. The USGS disclaimer says that “data users are cautioned to consider carefully the provisional nature of the information before using it for decisions that concern personal or public safety or the conduct of business that involves substantial monetary or operational consequences” (USGS 1999a: http://water.usgs.gov/provisional.html).

6.2 PALMER DROUGHT INDICES

Every month the NCDC publishes four Palmer Drought Indices: Palmer Drought Severity Index (PDSI), Modified Palmer Drought Severity Index (MPDSI), Palmer Hydrological Drought Index (PHDI), and Palmer Z Index at the URL: http://www.ncdc.noaa.gov/onlineprod/drought/main.html (Figure 9). The
Figure 9. Palmer drought indices for Climate Division 5, NE, (includes Grand Island) for 1991 (http://www.ncdc.noaa.gov/onlineprod/drought/xmgrg2.html; NCDC, nd).
Climate Prediction Center also publishes the PDSI on a weekly basis at: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif. (Figure 10). Each Palmer index models both deficit and excess of precipitation, and each is calculated as a function of precipitation and temperature over a period of weeks to months. Evapotranspiration and soil moisture content are inferred from the measured precipitation and temperature data. These indices are widely used by state and Federal agencies to classify drought in the Nation. The Palmer indices complement the WETS Tables in that they integrate several components of the hydrologic budget. The Palmer indices also are sensitive to climatic patterns that are longer than just a month or two.

The PDSI, MPDSI, and PHDI differ from each other in rapidity of response to change in precipitation and temperature patterns: the PDSI responds most rapidly, the PHDI most slowly, and the MPDSI at an intermediate rate (Karl and Knight 1985). The PDSI should probably be used to approximate meteoric drought in precipitation-driven wetlands. The PHDI would be more appropriate to approximate drought in groundwater-driven wetlands. Usually the three drought indices can be interchanged with each other for wetlands purposes because most of the time the differences between them are smaller than the error of extrapolating from the regional scale of the indices to the site-specific scale of a wetlands permit. Remember, for site-specific evaluations the drought indices provide a long-term, regional context in which to interpret the more locally specific information of the WETS Tables. The Palmer Z-index is probably the least useful for wetlands purposes because it provides a short-term adjustment to the PDSI that reflects short-term precipitation deviations from the longer term PDSI. Differences between the Palmer indices are discussed in more detail at:

http://www.ncdc.noaa.gov/onlineprod/drought/readme.html
and
http://enso.unl.edu/ndmc/enigma/indices.htm#pdsi

Except for the Z index, positive numbers in these indices reflect wetter than median conditions, and negative numbers reflect drier than median conditions (Table 4). Note that in analogy to the WETS Tables, the range of normal in this scheme is from the 28th to 72nd percentiles rather than the 30th to 70th percentiles. These differences are probably insignificant because the confidence intervals about these climatic statistics are likely greater than the differences between these two ranges of normal (P. Pasteris, NWCC, personal communication, 1999). The Palmer indices are calculated from data from 1931 to the present, whereas the WETS Tables are calculated for the most recent three decades.

More important than the fine differences between the Palmer indices, however, is the fact that these indices are regional in nature and are not site-specific. Hydrology at a particular site may differ from the regional pattern because of localized rainfall events and because of site-specific soil conditions. For example, the PDSI (Figure 9) indicates that drought conditions in June and July 1991 were slightly below median and within the range of normal in Division 5 of Nebraska, which includes Grand Island, NE, and that the Division averaged approximately 2.5 and 2 inches of rain in those months, respectively. The precipitation record at Grand Island itself, though, reports that 5.25 and 5.74 inches of rain fell there in June and July 1991, respectively (Figure 1).

Advantages of the Palmer Drought Indices are:

• Data are current.

• The drought indices integrate precipitation, soil moisture, and evapotranspiration into one value.

• The information is easily accessible.
Figure 10. Example of Palmer Drought Severity Index by climate division for the Nation from provisional data at the Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif; NCDC, nd)
Table 4. Palmer Classes for Wet and Dry Periods (NCDC 1994).

<table>
<thead>
<tr>
<th>Approximate Cumulative Frequency % (percentile)</th>
<th>Palmer Drought Severity Index</th>
<th>Modified Palmer Drought Severity Index</th>
<th>Palmer Hydrologic Index</th>
<th>Palmer Z Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 96</td>
<td>≥ 4.00</td>
<td>≥ 3.5</td>
<td>≥ 4.00</td>
<td>≥ 2.75</td>
</tr>
<tr>
<td>90 to 95</td>
<td>3.00 to 3.99</td>
<td>2.5 to 3.49</td>
<td>2.75 to 3.25</td>
<td></td>
</tr>
<tr>
<td>73 to 89</td>
<td>1.5 to 2.99</td>
<td>1.0 to 2.49</td>
<td>2.00 to 2.75</td>
<td></td>
</tr>
<tr>
<td>28 to 72</td>
<td>-1.49 to 1.49</td>
<td>-1.24 to 0.99</td>
<td>2.00 to 2.74</td>
<td></td>
</tr>
<tr>
<td>11 to 27</td>
<td>-1.50 to -2.99</td>
<td>-1.25 to -1.99</td>
<td>2.00 to 2.74</td>
<td></td>
</tr>
<tr>
<td>5 to 10</td>
<td>-3.00 to -3.99</td>
<td>-2.00 to -2.74</td>
<td>2.00 to 2.74</td>
<td></td>
</tr>
<tr>
<td>≤ 4</td>
<td>≥ 4.00</td>
<td>≥ 3.5</td>
<td>≥ 4.00</td>
<td>≥ 2.75</td>
</tr>
</tbody>
</table>

- Data can be converted to percentile frequencies from Table 4.
- The NCDC Web site publishes data for both national and historic coverage (Figures 10 and 11).

Disadvantages of the Palmer Drought Indices are:
- The Palmer indices do not distinguish between snowfall and rainfall.
- The conversion to percentiles is only approximate given the resolution of the graphs at the URL.
- Indices are not site-specific.
- The most recent indices are provisional and subject to change, so should not be reported in legal documents.
- Some of the assumptions in calculating soil moisture content may not be valid for the specific site being evaluated.

Utility:

Palmer drought indices complement WETS Table analyses by (1) evaluating evapotranspiration and soil moisture content as well as precipitation inputs and (2) providing longer term analyses than do the USDA Engineering Field Handbook and associated methods (Section 4 above). The most appropriate Palmer or SPI index should be used to determine occurrence of long-term drought or excess in a region once the indices have been recalculated with official data. Real-time Palmer indices should be consulted to get a sense of regional drought patterns.

6.3 STANDARDIZED PRECIPITATION INDEX (SPI)

The Standardized Precipitation Index (SPI) is a relatively new index that reports precipitation totals as exceedence frequencies for the Nation’s 350 climate divisions. It differs from the WETS Tables...
Period of record for Palmer Drought Severity Index for Climate Division 5, NE (includes Grand Island) [http://www.ncdc.noaa.gov/onlineprod/drought/xmgrg3.html](http://www.ncdc.noaa.gov/onlineprod/drought/xmgrg3.html) NCDC, nd)
in that it calculates exceedence frequencies for several different time periods (1-, 3-, 6-, 9-, and 12-month periods of accumulated precipitation). SPI information is available at:

http://enso.unl.edu/ndmc/watch/watch.htm#sectiona (scroll to hyper text link “Current Standardized Precipitation Index Maps”) 

or


The SPI itself is a numerical index varying between -2 or less and +2 or more. Values between -0.99 and +0.99 represent precipitation amounts with exceedence frequencies between 16 and 84 percentile (Table 5). This is a wider middle range of exceedence frequencies than used by either the WETS Tables or the Palmer indices. Thus, it is difficult to compare the SPI with them. The Western Regional Climate Center (http://www.wrcc.sage.dri.edu/spi/spi.html) uses the SPI raw data set to create curves of percentile exceedence frequency vs time (months prior to query date). These curves are much more useful than the SPI itself because they show all percentile levels between 0 and 100, including the threshold levels used by the WETS Tables and the Palmer indices. Exceedence frequency percentiles are available in graphical format (Figure 12) for twenty time periods preceding the current calendar month, going back five years. Interpretations of SPI’s calculated at different time scales are discussed at http://enso.unl.edu/ndmc/watch/interp.htm.

Both the plot of precipitation percentiles for various preceding time periods (Figure 12) and the NRCS Engineering Field Handbook method provide calculated estimates of cumulative precipitation inputs for more than one preceding month. The NRCS method weights earlier months progressively less whereas the SPI calculates exceedence frequencies without any weighting factors. It is up to the user to decide which time period is of greatest significance to his or her needs when using the SPI. In some situations two months’ preceding precipitation may explain water levels whereas in other situations it may be several months.

Advantages of the SPI Web site are:

• This is the only easily accessible analysis that the authors know of that presents precipitation exceedence frequency data for time periods longer than one month for all the climatic divisions of the Nation.

• Regional patterns of drought or excess are quickly observed from the Web site; the WETS Tables present only one station at a time.

• Exceedence frequency percentiles are not limited to discrete class thresholds, such as 30th and 70th percentiles for the WETS Tables.

Disadvantages are:

• Indices are not site-specific.

• Calculated exceedence frequencies are not weighted for length of time prior to a month of interest, in contrast to the method of the NRCS Engineering Field Handbook (Section 4.1).

• Indices published at this Web site are usually a couple of months old.

• As of this writing, historic SPI’s are archived only back to 1996 (http://enso.unl.edu/ndmc/watch/watch.htm).
### Table 5. Exceedence Thresholds and Percentiles for SPI Values

<table>
<thead>
<tr>
<th>SPI</th>
<th>Exceedence Threshold</th>
<th>Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.00 or more</td>
<td>2.3 percent</td>
<td>97.7</td>
</tr>
<tr>
<td>1.50 to 1.99</td>
<td>4.4 percent</td>
<td>95.6</td>
</tr>
<tr>
<td>1.00 to 1.49</td>
<td>9.2 percent</td>
<td>90.8</td>
</tr>
<tr>
<td>0 to 0.99</td>
<td>15.9 percent(^2)</td>
<td>84.1</td>
</tr>
<tr>
<td>0 to -0.99</td>
<td>84.1 percent(^2)</td>
<td>15.9</td>
</tr>
<tr>
<td>-1.00 to -1.49</td>
<td>90.8 percent</td>
<td>9.2</td>
</tr>
<tr>
<td>-1.50 to -1.99</td>
<td>95.6 percent</td>
<td>4.4</td>
</tr>
<tr>
<td>-2.00 or less</td>
<td>97.7 percent</td>
<td>2.3</td>
</tr>
</tbody>
</table>

\(^1\) National Drought Mitigation Center (1996).  
\(^2\) Exceedence thresholds for 0 to 0.99 and -0.99 to 0 ranges as reported by National Drought Mitigation Center (1996) should be replaced with values in this table (Mark Svoboda, NDMC, July 1999, personal communication).

Utility:

- The SPI Web site reports cumulative precipitation in terms of percentiles for many different time scales. It can provide a longer term perspective on drought than do the analyses recommended for the WETS Tables. The SPI analyzes only precipitation and, therefore, complements the Palmer indices, which reflect many assumptions about soil moisture characteristics and evapotranspiration. The SPI has been most widely used in the West, which is the region where the Palmer indices might be weakest due to questionable assumptions about snowmelt, runoff, and spatial homogeneity of drought.

#### 6.4. USGS STREAM GAUGE DATA

The USGS provides near-real-time streamflow data and summary graphs from around the Nation at [http://water.usgs.gov/realtime.html](http://water.usgs.gov/realtime.html). Real-time gauge station data for individual streams and lakes can be accessed by clicking on the U.S. map and following the menus. The national and state maps of streams are color coded by percentile classes, including one class that is comparable to the range of normal defined on the WETS Tables. Real-time data for individual streams are accessed through the state map Web pages. Many state pages provide 20-, 50-, and 80-percentile thresholds for gauge data for individual streams; these percentiles are presented at the bottom of the page with recent gauge data in graphical format (Figure 13).

Precipitation Percentile (non-exceedance)

- Each point on the graph represents the likelihood that a precipitation value as high as that observed over the number of months indicated at the bottom would not be exceeded. This is very similar to the percentile, or to the rank. (0 is lowest, 50 is the median, 100 is the highest.) For example, if 90% is shown for the 12-month period, then the likelihood of a lesser value occurring over any similar 12-month period is 90% (or 9 out of 10 similar periods will have lesser amounts.)

(http://www.wrcc.sage.dri.edu/spi/spi.html; Western Regional Climate Center, nd)
Figure 13. Example of USGS streamflow graph at USGS website, including table of exceedence thresholds (http://water.usgs.gov/realtime.html; USGS 1999b)
Advantages of this information are:

- Current information is available.
- Streamflow rates integrate several elements of the hydrologic budget, including precipitation, groundwater flows, runoff, and evapotranspiration.
- Regional patterns of drought or excess are quickly observed from the Web site; the WETS Tables present only one station at a time.
- The data are reported in exceedence frequency ranges rather than just absolute elevations or rates.

Disadvantages are:

- Hydrologic regimes at some sites may not correlate with streamflows.
- Exceedence frequency information on historical data is cumbersome to obtain.
- There are fewer stream gauges reported at the USGS Web site than there are NWS stations reporting in the NWCC WETS Tables (2100 vs 8000+; Harry Lins, USGS Office of Surface Water, personal communication, July 1999).
- Exceedence frequencies are calculated for the period of record rather than for a set time period, so calculated percentiles are not strictly comparable between gauges.

Utility:

- The stream gauge data at this URL reflect hydrologic conditions upstream of the gauging stations. They therefore complement the indices of precipitation inputs in evaluating hydrologic conditions at nearby investigation sites. Because of the provisional nature of the data, the information at the site should not be used in formal reports before consulting the state USGS Water Resources division office to verify the accuracy of the preliminary data presented on the Web site.
7. GEOGRAPHIC VARIATION IN PRECIPITATION

Common experience tells us that daily precipitation varies even within a radius of a few miles. Consequently, there is always the concern that precipitation affecting a site may vary significantly from that recorded at the nearest weather station. Therefore, rain gauges are often installed onsite in research situations.

If onsite rain gauge data are not available, determine whether or not precipitation was within the range of normal at NWS stations of comparable elevation within a radius of 30 miles (30 miles being the radius that the National Climatic Data Center [1995] uses to select neighboring stations for estimating missing data). If temporal variation was comparable among the stations evaluated, assume that precipitation at the site in question varied in the same way as the majority of the stations evaluated.

An example from the Reno/Tahoe area of California and Nevada provides insight to geographic variation in precipitation. Figure 14 shows the precipitation levels as percentiles of monthly precipitation in 1979 at four different weather stations in California and Nevada: Colfax, CA; Tahoe, CA; Virginia City, NV, and Reno, NV. These stations are located up to 85 miles apart in four orographically distinct regions: the western foothills of the Sierra Nevada, the crest of the Sierra Nevada, the eastern foothills of the Sierra Nevada, and the eastern rain shadow desert in Nevada. Absolute differences in average annual precipitation range from 7.5 inches at Reno to 46.5 inches at Colfax. The year 1979 was chosen because total precipitation was approximately average and there were no missing values at those stations that year. Station characteristics are summarized in Table 6.

Several lessons can be drawn from Figure 14 and Table 6:

- Despite geographic differences, overall patterns of rainfall are similar across the orographic rainfall divide.

- The further precipitation deviates from the mean, the more similar records tend to be (note fluctuations from June to July, and September through December).

- The greater the distance from a site, the greater the deviation in precipitation pattern. Here, the most distant station, Colfax, showed the greatest deviation from the common pattern (wetter than normal January and February, drier than normal August).

- Precipitation should be compared within geographically similar regions. Note that precipitation in May at the two desert sites was on the dry side of normal and in the mountains was wetter than normal.
Figure 14. Precipitation patterns across the Sierra Nevada divide expressed as percentiles of monthly precipitation (NWCC 1996). Normal precipitation is between the 30\textsuperscript{th} and 70\textsuperscript{th} percentiles (shaded light gray). See text for further discussion.

| Table 6. Characteristics of Contrasting Weather Stations in the Tahoe/Reno Region. |
|-----------------------------------------------|-----------------|-----------------|-----------------|-----------------|
|                                              | Colfax, CA      | Tahoe, CA       | Virginia City, NV | Reno, NV        |
| Distance from Reno, miles                   | 85              | 33              | 18              | 0               |
| Elevation, feet                             | 2410            | 6230            | 6340            | 4400            |
| Ave. annual precip., inches                | 46.5            | 32.3            | 14.85           | 7.53            |
| Geography                                   | Western foothills of Sierra Nevada range | Sierra Nevada mountains | Virginia Range of Basin & Range Province | Truckee Basin of Basin and Range Province |
| Climate (Trewartha 1968)                    | Temperate Oceanic | Temperate Continental | Semi-arid, temperate boreal | Arid, temperate boreal |
8. COMPARING DATA FROM MONITORING WELLS AND RAIN GAUGES

Antecedent precipitation is often compared monitoring well data. Therefore, two examples of such comparisons are provided, one from a site where water levels in wells track precipitation inputs closely, and a second where the response is less well defined. The methodology requires overlaying time series analyses of wells and precipitation adjacent to each other. A template for these figures is in Appendix C.

Figure 15 shows the second of three years of data from a site with rapid water well response to precipitation inputs. The well is located in the Columbus, OH, area at a slope break at a floodplain-upland transition. Water levels were read twice daily by an automatic recording device. The soils are likely to conduct shallow interflow in the silt loam surface above a relatively impermeable argillic horizon (Soil Conservation Service 1980). Therefore, precipitation enters the soil and 40-inch-deep water well by direct infiltration and by interflow from upslope. The argillic horizon allows relatively little discharge from or recharge to deeper groundwater. Note the short duration peaks in water level response to precipitation inputs during the spring of 1997. These are what one would expect from interflow inputs rather than from groundwater discharge. These flashy spikes tend to start at the boundary of the silt-loam topsoil and clay-loam argillic horizon in April, May, November, and December.

There were two water level spikes in September 1997 at the study site and only one large precipitation event. The second spike probably resulted from a locally heavier thunderstorm input at the study site than at the rain gauge seven miles away. Other wells onsite also recorded the second spike in late September, so the discrepancy between water levels and rainfall records cannot be attributed to monitoring well malfunction.

The rapidity of water level response at this site is striking. In late August it took less than a week for water levels to drop to the top of the argillic horizon, despite the heavy rains in the first half of the month. It seems appropriate to evaluate antecedent precipitation for 30 days rather than several months in this setting. The sluggish water table drop to 2 ½ feet or more in the late summer or early fall probably reflects one of two possibilities: (1) There really was a water table in the argillic horizon and water tables dropped out of it as slowly as the well records indicate; or (2) water from the A and B1 horizons ran into the well and seeped out into the nearly saturated argillic horizon only slowly. Considering the sluggish drop in water tables in midsummer when evapotranspiration was high, the second explanation is worth checking out with a drawdown test in the field (Warne and Smith 1995).

Figure 15 also shows the difference between monthly, daily, and 30-day rolling sums of precipitation data. Monthly sums would indicate that May was a wet month, but the 30-day rolling totals show most of May to have been normal in precipitation. The daily data provide the explanation for the difference, in that almost half of the month’s rain fell in the last three days. Here the 30-day rolling totals depict precipitation inputs more accurately than does the monthly sum.

Figure 16 is an example of a system where water levels fluctuate more slowly in response to precipitation inputs. The soils here (Boone Creek, IL) are shallow mucks (16-23 inches thick) over alluvium. The wetland hydrology has strong groundwater discharge components as well as overbank flooding (Richardson et al., 1997). Furthermore, the muck soils hold water much longer than do the shallow topsoils of the Columbus, OH, area shown in Figure 15. Both years of data in Figure 16 show a significant drop in water levels during the summer, due to evapotranspiration. However, precipitation inputs were much higher in May 1996 than in May 1995, delaying the spring evapotranspirative drawdown by about a month. After the heavy rains in May and June 1996 abated, groundwater levels dropped to their 1995 depths, but four heavy rain storms in July and August induced water levels that
Figure 15. Daily precipitation and water well data near Columbus, OH, 1997, displayed in a format that includes monthly ranges of normal, 30-day rolling totals, monthly precipitation amounts, and soil profile (NOAA 1998)
Figure 16. Daily precipitation (NOAA 1996, 1997) and water well data (Richardson et al. 1997) near McHenry, IL, 1995-1996 (Sheet 1 of 2)
Monitoring Well Record

Project name: Water Level Example 1

General location: 
Boone Creek, McHenry County, IL

Well name/number: 2

Year: 1996

Number of years of record: 2 years

Frequency of water level readings: Generally biweekly

Organization responsible for water level readings: EPA

Description of well: 2 inch ID PVC pipe, 18 in. deep

Pipe slotted throughout, with sand pack in annulus and bentonite seal at surface

Soil Description:

Edina Series - Planosol

A Horizon Muck

E Horizon Silt with 17% clay

Bt Horizon Silt with 52% clay

C Horizon Loess (silt)

Paleosol Silt with 75% clay

Range of Normal Precipitation:
Marango, McHenry Co. IL WETS Table

Monthly Precipitation Totals McHenry NWS Station, McHenry Co. IL, 1996

Daily Precipitation
30-Day Rolling Total

Precipitation (inches)

Depth (feet)

Ground/Surface Water Level Readings

Growing Season

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
were much higher than in 1995. Note that after the August 23, 1996, rain storms the water levels stayed high for a few days to a week, but two weeks later had dropped to their 1995 levels.

These two examples – shallow, mineral, interflow system versus muck soil on the floodplain of gaining stream – indicate the advantages of daily precipitation data from NWS sources as opposed to monthly data from the WETS Tables in interpreting the overall hydrology of a site. In the Ohio example the responses to rain and evapotranspiration were rapid and would have been inexplicable or missed altogether without daily data; in the mucks of Illinois water tables dropped more slowly after the rains stopped. In both cases daily data were important in interpreting water table fluctuations and understanding key processes driving the hydrology of the sites.
9. STATISTICAL BACKGROUND AND COMMON PROBLEMS

9.1 GAMMA DISTRIBUTION: INTRODUCTION TO THE STATISTICS OF NORMAL PRECIPITATION

Fundamental to precipitation data analysis is the fact that precipitation data for most of the Nation do not fit a bell curve ("normal distribution"). The reason for this is that the probability distribution for precipitation is not symmetrical. The left-hand tail of the distribution is bounded by zero, because there cannot be less than zero precipitation in any given time period. The right-hand tail, on the other hand, has no theoretical upper limit. The statistical evaluation method that best describes precipitation data is called a gamma distribution, which is a theoretical curve similar to the Gaussian distribution but skewed to the right.

To explain the gamma curve and probability distributions more fully, let's pursue the comparison between normal and gamma curves. For example, if you wanted to know something about the heights of 30 students in a class, you would find the mean and standard deviation of the sample and develop a normal curve. In a similar fashion, meteorologists take the 30-year-long sample of a particular month's precipitation data (30 Aprils, for example) and fit that sample to a gamma curve. Neither sample of 30 individuals (heights or rainfall months) fits its theoretical curve exactly, but experience has shown that the populations of student heights or rainfall months are best described by their respective theoretical curves. (See Appendix D for a more technical discussion of frequency distributions of precipitation and temperature data.)

Figure 17 shows the frequency distribution of a sample set of monthly precipitation totals in two formats: a simple histogram and the smoothed curve of the gamma distribution for the population inferred from that sample. X-axes are the same for both graphs: inches of April precipitation at Grand Island, NE. In concept, the Y-axes are the same, too: frequency of the X-axis amounts. In the histogram, the Y-axis frequency is simply the number of April precipitation months with a given amount of rain divided by the total number of Aprils sampled, for example, 9/30 = 0.3 for the second bar (1.00-1.99 inches). The mathematics are not quite so straightforward for the Y-axis for the idealized curve in Figure 17 but the concept is the same: increasing probability of occurrence with increasing height on the Y-axis. A principal advantage of the calculated gamma curve is that it allows interpolation and extrapolation based on the existing data.

The histogram and gamma curve in Figure 17 have similar shapes, and both of them depict the same qualitative concept: the likely rainfall amounts in April at Grand Island, NE. The histogram of the 30-year sample (Figure 17) is limited to Aprils between 1961 and 1990. Most Aprils during those three decades had between 1 and 3 inches of rain at Grand Island. A few Aprils were wetter; two were very

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3 Probability distributions are patterns of occurrence for populations of data. The best known probability distribution is the "normal distribution;" this is also known as a "bell curve" or a "Gaussian distribution." Many, but not all, natural phenomena fit a normal distribution. For example, plant heights within a species fit a normal distribution; radioactive decay is best described by a Poisson distribution; and precipitation fits a gamma distribution.

4 "If a set of data consists of all conceivably possible (or hypothetically possible) observations of a given phenomenon, we call it a population; if a set of data consists of only a part of these observations, we call it a sample" (Freund 1988; emphasis added). For example, the amounts of precipitation at Grand Island, NE, for the thirty Aprils between 1961 and 1990 comprise a sample; the population from which the sample was taken consists of all possible amounts of April precipitation at Grand Island since the last significant climatic change. The discipline of statistics analyzes data from samples to infer general patterns about populations.
Figure 17. Histogram and gamma distribution for same set of precipitation data (Aprils 1961-1990, Grand Island, NE; (NWCC 1966)). X-axis is inches of April precipitation in both figures. Y-axis is a measure of relative frequency, for example, second bar in Figure 17A is $n_i/n_{total} = 9$ months / 30 months = 0.3. Y-axis in gamma distribution is also relative frequency, but idealized to total number of possible occurrences.
much wetter, with between 6 and 8 inches of rain. If you think of the histogram as having tails, the right-hand tail is longer than the left-hand tail; the data are skewed to the right.

The gamma curve for the population of April precipitation at Grand Island (Figure 17) is estimated by fitting an idealized curve to the 30-year sample. Comparing the gamma curve and the histogram, it is obvious that some Aprils in Grand Island will have between 5 and 6 inches of precipitation. There is no rational explanation for that gap in the 30-year sample other than random chance. The gamma distribution smooths the 30-year sample data to fill in such gaps and describes the gamma curve that fits the 30-year sample most closely.

The three vertical lines marked “30, 50, and 70 % likelihood” on the gamma curve indicate the precipitation amounts at the 30th, 50th, and 70th percentile levels, from left to right. The 30th and 70th percentile levels represent the lower and upper thresholds of normal April precipitation at Grand Island (although other boundaries of normal such as 25th and 75th percentiles could be calculated). Half of the Aprils are predicted to have less than the 50th percentile level, 2.09 inches. These values can be calculated from the frequency distribution of 30 monthly rainfall values, too, by rank ordering the 30 values and lopping off the nine highest and nine lowest values. When this is done, ranges of normal are 1.39 and 2.79 inches.

Two points need to be made about the comparison of the histogram and gamma curve.

- Average April precipitation is not in the middle of the frequency distribution. Average April precipitation is the arithmetic mean of the 30 Aprils in the histogram. This is 2.50 inches (Figure 1). The middle of the frequency distribution of April precipitation amounts is the 50th percentile. This is 2.09 inches. The average is greater than the median value because the probability distribution is skewed to the right.

- The ranges of normal April precipitation are slightly different using the histogram and the gamma curves: 1.39 to 2.79 inches versus 1.37 to 3.05 inches, respectively. This difference underscores the difference between samples and populations of data. The gamma curve gives the preferred estimate, which is the one found in the WETS Tables, because it is determined from the statistically smoothed 30-year sample.

9.2 ARID LANDS

In contrast to the humid east and south, monthly precipitation levels in arid lands vary greatly from year to year and may include zero precipitation for months on end. For example, Figure 18 reports July precipitation for 1961-1990 in Mojave, CA. Note that 19 of the 30 Julys within the three-decade reporting period had zero precipitation. It is obvious that the most likely precipitation level in July at Mojave, CA, is no rainfall at all. Normal precipitation is 0.00 to 0.08 inch; that is, the wettest 30 percent of the Julys between 1961 and 1990 had more than 0.08 inch of rain, and the driest 30 percent of the Julys between 1961 and 1990 had 0.00 inch of rain. In fact, the concept of “less than normal” has no meaning in this extreme climate. “Average” precipitation, too, has little meaning in deserts, because of how extremely skewed the distribution is; the arithmetic mean (0.16 inch) is twice as high as the highest “normal” rainfall (0.00-0.08 inch).
many people assert that the majority of years have either very high or very low precipitation amounts. They feel that Junes, for example, are either wet or dry, with relatively few Junes having intermediate amounts of rainfall. This would imply that the June rainfall distribution is bimodal, and, hence, the unimodal gamma distribution does not describe the probability distribution of precipitation in their part of the country. Meteorologists, however, have analyzed precipitation records around the world and found that precipitation in the vast majority of places is best described by a unimodal model, although rain falls in some places in the tropics with truly bimodal frequency distributions (Granger 1987).

Two regions of the country where this misconception is most common are the arid West and the hurricane zone of the Southeast. Analyses of longer term precipitation records in the arid West (70 years at Ogden, UT, and 60 years at Bakersfield, CA; NWCC 1996) show that the right-hand tail of the frequency distributions tends to be flat, so these precipitation distributions are still unimodal. Along the
Southeast and Gulf Coasts and in the Caribbean, late summer and autumn tropical storms may seem to cause truly bimodal rainfall distributions. Even these distributions, however, are usually unimodal over a long period of record. Compare, for example, the 30-year vs 96-year records at Raleigh, NC (Figure 19); although June is not in the height of the hurricane season, the 30-year record shows a strong possibility of bimodality. Histograms of major cities along the south Atlantic and Gulf coasts from Wilmington, NC, to Galveston, TX, throughout the summer and autumn indicate that tropical storms do not create bimodal precipitation distributions in the region, possible exceptions being southern Florida and Puerto Rico.
Figure 19. Frequency distributions of June precipitation at Raleigh, NC. The 30-year record (1961-1990, top graph) shows the possibility of bimodal precipitation with a second small peak at the end of the right-hand tail. The total record (1900-1990, bottom graph), however, shows the distribution to be unimodal. The X-axis is inches of June precipitation; Y-axis is the frequency of Junes with X-axis amounts of precipitation (NWCC 1996)
10. SUMMARY AND RECOMMENDATIONS

10.1 SUMMARY

1. Characterization of the long-term hydrology of a site requires evaluation of meteorologic conditions prior to and during the assessment period.

2. Evaluation of meteorologic conditions typically involves determining whether current precipitation is normal, wetter than normal, or drier than normal during the assessment period. This requires knowledge of both historic rainfall frequencies and rainfall amounts at the time of assessment.

3. WETS Tables, which were generated by the NWCC for more than 8000 NWS stations across the U.S., provide information for determining the range of normal rainfall conditions for a site. WETS Tables also provide accurate assessments of the growing season for a site.

4. Precipitation amounts at the time of the assessment can be obtained from the Regional Climate Centers and State Climatologists. The UCAN network should provide real-time precipitation records in late 1999.

5. Onsite rain gauges may be used to identify daily differences between precipitation onsite and at NWS stations, and are particularly valuable in areas where geographic distribution of rainfall is patchy.

6. Relatively quick and easy-to-follow methods are presented to evaluate antecedent precipitation at a site. These include:
   a. Method of NRCS Engineering Field Handbook
   b. Method of 30-day rolling totals
   c. Method combining (a) and (b) above

7. Regional measures of drought and precipitation excess are available on a near real-time basis at Internet Web sites run by the NCDC and the NDMC.

10.2 RECOMMENDATIONS

1. Precipitation antecedent to a date of hydrologic monitoring should always be evaluated to determine whether it was within the range of normal for the site.

2. The NRCS WETS Tables should be used to determine monthly ranges of normal precipitation unless other frequency distributions are available that are more site-specific.

3. When practicable, records of daily precipitation should be used to interpret monthly totals for deviation from range of normal.

4. When practicable, a default duration of three months, weighted for recency, should be used to decide whether antecedent precipitation was within the range of normal prior to a date of monitoring. If local information is available about the duration of influence of precipitation on hydrology, that local knowledge should be used to select the proper length of precipitation record to evaluate prior to a date of monitoring.
5. Wetland scientists with field responsibilities should keep up with regional patterns of drought or excess by referring to the various drought maps published by the NDMC and other sources of information on variation of climate (for example, state climatological experts). Local experience should guide selection of indices (Palmer, SPI, USGS streamflow, etc.) that seem to work best in the scientist's particular region.

6. Regional data published by the NDMC should be used to complement the more locally specific WETS Tables, not to replace the WETS Tables.

7. Growing season dates reported in the WETS Tables are often preferable to those published in county soil survey reports because climate data are more recent.

8. If precipitation data are gathered from non-NWS stations, those data should be compared to daily records from surrounding NWS stations.

9. Wetland evaluations that use monitoring wells should provide comparisons of rainfall to groundwater levels.
11. REFERENCES


