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Chapter 19 Hydrology Tools for Wetland Identification and Analysis

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Acknowledgments

Chapter 19, Hydrology Tools for Wetland Identification, is one of the 19 chapters of the U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) National Engineering Handbook (NEH), Part 650. This chapter is designated Engineering Field Handbook (EFH), Part 650.19. Other chapters that are pertinent to and should be referenced in use with chapter 19 are:

Part 650.01 Engineering Surveys
Part 650.02 Estimating Runoff
Part 650.03 Hydraulics
Part 650.04 Elementary Soils Engineering
Part 650.05 Preparation of Engineering Plans
Part 650.06 Structures
Part 650.07 Grassed Waterways and Outlets
Part 650.08 Terraces
Part 650.09 Diversions
Part 650.10 Gully Treatment
Part 650.11 Ponds and Reservoirs
Part 650.12 Springs and Wells
Part 650.13 Wetland Restoration, Enhancement, or Creation
Part 650.14 Drainage
Part 650.15 Irrigation
Part 650.16 Streambank and Shoreline Protection
Part 650.17 Construction and Construction Materials
Part 650.18 Soil Bioengineering for Upland Slope Protection and Erosion Reduction

Part 650.19 was first issued in August 1997. This revision was done to incorporate significant advances in the science and practice of wetland hydrology. It maintains the significant work done by the original task group, whose efforts were maintained and built upon to produce this update.

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650.1900 Introduction

Wetland conditions are documented by the presence of hydric soils, hydrophytic vegetation, and wetland hydrology. Wetland hydrology can be documented by the observation of onsite hydrology indicators, or by the analysis of hydrologic data such as records of rainfall, streamflow, temperature, groundwater levels, and climate data. The scope of this document is the use of onsite and off-site data collected for the purpose of documenting wetland hydrology beyond the use of onsite hydrology indicators. This documentation may be needed for a variety of reasons. These include implementation of the wetland conservation provisions of the National Food Security Act of 1985 (FSA), the implementation of Wetland Protection Policy under Executive Order 11990, wetland determinations in accordance with the U.S. Army Corps of Engineers (USACE) Wetlands Delineation Manual, or the analysis needed to properly plan and design wetland restoration, creation, and enhancement projects under the Wetland Reserve Program and other programs involving wetlands.

Wetlands are not all defined uniformly in terms of the presence or absence of water. Generally, wetlands are areas where plants tolerant of anaerobic soil conditions can grow, and where evidence of anaerobic conditions are found in soil indicators. Anaerobic conditions are created by the presence of water which replaces air in the soil matrix. The duration of anaerobic conditions, the depth of inundation, or the depth to groundwater required for any given area to be a wetland is not a constant. Local conditions dictate the combinations of hydrologic parameters needed to support hydrophytic vegetation. For this reason, the hydrologist must work with the hydrophytic vegetation specialist and soil scientist to define hydrologic parameters. In some instances, the hydrologic parameters needed for a particular analysis are defined. This is the case when an analysis is needed to define FSA wetland labels, such as farmed wetland (FW) or prior converted cropland (PC). When these parameters are defined, they are referred to in this document with the term objective criteria. An example of objective criteria is 50 percent chance annual probability of inundation for 15 days.

This document does not contain objective criteria for wetlands or FSA wetland labels. The use of objective criteria in examples presented herein is for the purpose of demonstrating procedures. In wetland hydrology analysis, solutions are compared to objective criteria defined elsewhere. It is not possible for this document to include a step-by-step procedure for the documentation of wetland hydrology in every possible circumstance. Some procedures presented are specific to certain wetland types and conditions. However, wetlands with other circumstances can still be analyzed using the science of hydrology. Procedures and objective criteria specific to a certain wetland type, geographic region, and task may be incorporated by an individual state as a state supplement to this document, or in wetland policy documents.

To maintain an orderly presentation of wetland hydrology procedures, this document uses the Hydrogeomorphic (HGM) wetland classification system. This can help the user determine an appropriate procedure to use if the HGM wetland class being studied is known. Not all wetlands fall neatly within a certain HGM type, however, and examples presented do not supersede locally developed policies and procedures.

650.1901 Normal environmental conditions

(a) Definition of normal environmental conditions

Normal environmental conditions (NEC) occur when wetland inundation and shallow saturation are at threshold levels at the wetland boundary but not upslope in adjacent nonwetlands. During NEC, wetland hydrology exists within the wetland boundary for the duration of the hydroperiod. This section describes the evaluation of whether NEC exist at the time of an onsite wetland determination, or if NEC existed at the time when remotely sensed data was collected. The calculation of probabilities, durations, and frequencies in terms of objective criteria is described in later sections. In most cases, the same data used for NEC determination can be used for further detailed analysis.

When performing onsite wetland determinations or determinations using remotely sensed data, a delineator must know whether the evidence was collected during NEC. An analysis of NEC requires that external data be collected and analyzed for departures from statistical averages. Data must correlate with water budget parameters that actually affect conditions in the subject wetland. In general, wetlands respond to inputs from rainfall, streamflow, groundwater, surface runoff, or combinations of these.

(b) Current conditions and long-term conditions

Hydrology data is used for two separate NEC purposes:

- to determine whether normal environmental conditions exist at the time of a site investigation (or date of remote sensed data)
- to determine the actual parameters for long-term normal environmental conditions in terms of inputs such as rainfall, groundwater, or flooding.

Both analyses are needed to determine whether the hydrologic inputs at the time of investigation are within the long-term normal range. In the first analysis, an onsite investigation conducted in the current month must be compared against the rainfall, streamflow, groundwater level, etc. that occurred on the site within the current and previous few months, for instance. In the second analysis, hydrologic data is needed for a long period of record so that statistical analyses may be made for probabilities, durations, and frequency distributions to define long term normal conditions.

For data sets that are used to document local climatic conditions, such as daily rainfall and temperature records, climatologists recognize a 10 year period of record as a minimum for statistical accuracy. To account for the effects of long term changes in climate, the 30 year period of record is considered to be the maximum. By resetting the 30 year period of record every 10 years, the highest statistical accuracy is maintained that also accounts for climatic variation. The 30 year period is reset each decade. For example, a 30 year period is defined as the 1971 to 2000 period or the 1981 to 2010 period. For data sets that represent site specific data, such as groundwater levels or stream stages, a 10 year period of record including the date of evidence collection is generally recognized as the minimum to document long-term NEC. The time frame for the period of record, and the required length of that period will vary depending on the requirements of the analysis.

(c) Data sources

(1) WETS tables

For NEC that can be established by rainfall and temperature conditions, the NRCS National Water and Climate Center (NWCC) has prepared the WETS tables. The WETS tables can be found in the electronic Field Office Technical Guide (eFOTG) under Section II, Climate Data. The WETS tables display monthly rainfall data as the monthly average (50th percentile), and the values at which there is a 30 percent chance that the rainfall will be less or more than those values (30th and 70th percentiles). The range between the 30th and 70th percentiles defines normal monthly rainfall. Rainfall records from a defined period preceding the date of onsite or remotely sensed evidence can be compared with these values to determine if wetland conditions were within NEC. In addition, the WETS tables provide daily average, average daily minimum, and average daily maximum temperatures. These values can be compared to current temperature data to evaluate vegetation. Finally, the WETS tables suggest the starting and ending dates for the wetland growing season based on the 50 and 70 percent chance probability for temperatures greater than 24, 28, and 32 degrees Fahrenheit. Some areas of the country seldom experience temperatures of 28 degrees or less. These areas include coastal South Carolina, coastal Georgia, Florida, southern Alabama, southern Mississippi, southern Louisiana, coastal Texas, southern and coastal California, coastal Oregon, coastal Washington, and the Pacific and Caribbean Islands. Thresholds temperatures of 34, 32, 28 degrees should be selected for these areas.

Taken together, the temperature and rainfall data can be used to establish normal environmental conditions for those wetlands where hydrology is driven by precipitation. An example of a WETS table is shown in figure 19–1.

The WETS tables also provide the monthly rainfall totals for the entire period of record. The data is useful when determining whether NEC existed at the date that remotely sensed data such as aerial photography was taken. Figure 19–2 shows WETS monthly rainfall records.

The WETS system updates the tables automatically with time, so that the monthly rainfall record includes data up to the current month. This information is valuable for use in assessing NEC to support onsite wetland determinations.

When extracting data for hydrologic inputs such as stream gage records, only data from the growing season is to be used for analysis.

The use of WETS tables for establishing NEC is subject to the following limitations:

- In some areas of the United States climate stations with associated WETS tables are widely dispersed, and some climate stations have been shut down. The wetland site may not be near an active climate station.
- In arid and sub-humid regions, rainfall is more sporadic and episodic. The presence of water may result more from single, isolated storm events than previous monthly rainfall over a broad climate station area.

(2) Stream gage data

Although floodplain wetlands experience streamflows that coincide with high rainfall, these flows may not be connected with local precipitation and may be more influenced with weather events over a period of weeks or months. In the mountainous west many floodplain wetlands are maintained by stream hydrographs that are supplied by a snowpack source far from the wetland site. In these cases, streamflow data is often a better source of information than precipitation records

Figure 19–1 WETS table

USDA Field Office Climate Data

WETS Station : PERU, IL4922 — Creation Date: 02/17/2015
Latitude: 4121 — Longitude: 08906 — Elevation: 00620
State FIPS/County(FIPS): 17099 — County Name: La Salle
Start yr. - 1971 End yr. - 2000

Month	Temperature (Degrees F.) avg daily max	avg daily min	avg	Precipitation (Inches) avg	30% chance will have less than	30% chance will have more than	avg # of days w/.1 or more	avg total snow fall
January	29.0	11.6	20.3	1.46	0.75	1.78	4	7.3
February	34.7	16.8	25.8	1.42	0.72	1.73	4	4.4
March	47.4	27.7	37.6	2.67	1.65	3.24	6	2.8
April	61.1	37.8	49.5	3.60	2.54	4.26	7	0.3
May	72.8	48.7	60.8	4.55	2.86	5.49	7	0.0
June	82.3	58.7	70.5	4.10	2.49	4.96	7	0.0
July	85.3	63.1	74.2	4.04	2.17	4.93	6	0.0
August	83.1	61.0	72.1	4.11	2.36	5.00	6	0.0
September	76.5	51.9	64.2	3.63	2.19	4.46	5	0.0
October	64.8	40.6	52.7	3.00	1.95	3.61	5	0.1
November	48.0	29.8	38.9	2.83	1.45	3.46	6	1.2
December	34.6	18.0	26.3	2.29	1.42	2.77	5	6.6
Annual	-----	-----	-----	------	34.01	40.83	--	----
Average	60.0	38.8	49.4	------	------	------	--	----
Average	-----	-----	-----	37.70	------	------	67	24.6

GROWING SEASON DATES

Probability	Temperature: 24 F or higher	28 F or higher	32 F or higher
	Beginning and Ending Dates Growing Season Length		
50 percent *	4/ 2 to 11/ 2 213 days	4/10 to 10/21 193 days	4/27 to 10/ 6 162 days
70 percent *	3/28 to 11/ 7 223 days	4/ 4 to 10/27 206 days	4/23 to 10/10 170 days

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

for determining NEC. Daily flow data for a minimum 10 year period of record can provide reliable statistics for mean monthly flows and the 30th and 70th percentiles similar to the rainfall data in the WETS tables. The use of streamflow records is addressed in more detail later. High quality stream gage data is maintained by the U.S. Geological Survey (USGS), as well as the USACE, and other State and Federal agencies on various websites. The information on the sufficiency and reliability of stream gage data is presented here as it appears in NEH654.05:

Figure 19–2 WETS monthly rainfall records

Station : IL4922, PERU
------- Unit = inches

yr	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	annl
1				0.66	1.34	3.58	4.99	2.80	2.25	0.56	M1.34		17.52
2	0.35	1.75	3.57	2.30	4.36	8.90	10.70			1.67	3.05	M0.68	37.33
3	M0.28	1.27	2.94	M3.66				4.95	6.27	1.02	0.65	0.33	21.37
4	1.36	0.82	2.67	2.56	1.99						0.03	1.65	11.55
5	0.30	1.09	1.83	3.71	5.51	4.37	1.55	3.19	3.15	1.85	1.93	1.28	29.76
6	2.15	2.01	2.08	1.06	1.95	3.00	2.62	7.25	4.89	1.12	1.97	2.15	32.25
7	4.45	0.10	2.03	2.36	3.39	3.40	5.99	4.22	5.06	0.87	1.55	1.56	34.95
8	0.52	3.18	3.09	2.89	6.69	2.50	3.90	1.82	1.09	0.41	1.62	0.03	28.54
9	1.28	3.06	1.40	5.93	M3.01	2.37	2.52	4.00	3.15	1.46	3.89	3.64	35.71
10	1.93	1.17	0.19	3.30	6.50	0.89	0.79	3.74	5.09	1.03	0.77	1.11	26.51
11	1.78	2.16	1.31	2.97	2.37	3.32	2.63	6.98	7.37	2.45	2.26	2.04	37.64
12	0.12	0.74	1.47	2.98	3.73	2.77	2.40	4.35	2.54	3.88	2.28	0.98	28.24
13	1.29	2.45	3.08	1.53	4.45	3.32	1.42	3.71	1.92	M2.80	1.32	1.42	28.71
14	1.24	0.73	2.22	0.94	3.35	2.58	1.19	2.88	3.85	2.14	0.24	1.38	22.74
15	1.22	2.18	0.54	1.09	5.80	1.84	M7.53	2.86	7.84	0.98	2.07	0.86	34.81
16	5.00	0.79	3.09	1.34	4.58	5.03	0.20	2.30	2.82	4.61	1.55	M1.25	35.56
17				3.31	3.02	4.12	1.23	1.78	2.89	4.62	0.15		21.31
18		1.98	0.55	2.63	5.74	2.75	2.63	3.12	2.11	3.00	2.28	2.62	29.41
19	0.36	1.94	4.30	3.34	4.28	4.36	1.05	2.34	4.62	4.45	2.83	0.63	34.50
20	1.21	0.19	4.96	4.69	3.39	3.52	1.29	1.73	M2.54	1.80	1.16	2.39	28.87
21	1.35	0.33	4.85	4.88	2.96	3.54	0.81	5.96	6.73	2.67	2.56	3.37	40.01
22	1.06	0.57	3.49	3.04	5.14	0.59	1.20	2.95	3.51	1.24	2.07	0.94	25.80
23	0.84	1.32	3.61	1.24	3.37	2.78	1.06	2.81	5.16	3.78	1.59	1.81	29.37
24	1.42	1.53	M2.77	2.72	1.74	5.86	4.83	9.05	3.96	0.79	0.49	2.10	40.26
25	0.49	1.45	0.88	2.70	1.26	3.44	1.67	0.65	3.08	2.65	3.46	1.37	23.10
26	1.03	2.52	2.64	3.45	2.20	4.09	4.37	3.02	11.68	1.87	4.44	0.65	41.96
27	0.98	2.40	2.40	6.18	5.21	3.74	1.29	3.04	4.51	4.59	4.21	2.38	40.93
28	0.44	1.49	1.20	2.24	1.75	6.08	3.51	4.45	2.64	2.66	3.49	2.44	32.59
29	3.73	0.69	2.76	5.30	1.23	3.23	4.81	2.39	1.61	2.69	1.69	0.68	30.81
30	2.16	2.04	2.04	4.17	1.24	3.04	0.45	1.71	2.38	3.23	2.11	0.20	24.77
31	1.01	0.77	2.13	1.87	4.06	3.58	2.41	3.87	5.47	6.07	4.36	2.08	37.68
32	2.22	1.14	2.38	1.64	2.70	3.55	2.54	7.05	1.07	4.11	0.59	3.14	32.13
33	2.35	1.14	3.00	4.19	5.88	1.07	2.38	2.97	3.28	2.00	0.53	1.04	29.83
34	0.81	0.68	0.92	1.12	0.75	2.41	2.43	3.33	6.23	1.28	4.82	1.06	25.84
35	2.15	2.00	3.22	1.85	6.02	4.72	2.40	6.44	3.01	1.00	4.15	1.21	38.17
36	1.25	1.05	0.63	1.98	3.05	0.82	0.87	3.85	8.49	1.60	0.69	2.53	26.81
37	2.01	1.22	1.36	5.05	3.07	3.60	2.43	4.02	0.81	2.34	0.91	1.40	28.22
38	3.48	2.05	4.25	3.96	5.10	7.38	4.09	0.54	3.93	0.98	1.40	0.80	37.96
39	1.76	2.62	3.00	3.33	3.96	6.28	4.23	2.89	0.89	3.74	0.68	0.33	33.69
40	1.28	0.88	1.22	3.48	4.71	2.62	1.68	4.84	1.06	3.08	1.86	1.42	28.13
41	2.75	0.92	1.74	3.07	3.33	3.07	3.73	2.38	8.06	9.07	1.76	1.38	41.23
42	1.11	2.61	2.79	2.32	2.77	2.18	6.94	3.75	3.03	1.19	3.48	2.28	34.45
43	1.91	1.06	1.29	5.52	6.85	2.42	1.86	5.37	1.82	1.71	1.70	0.39	32.20
44	0.47	2.31	5.47	5.05	3.88	3.15	0.83	1.89	2.15	1.00	0.66	1.35	28.21
45	0.95	1.39	2.45	4.09	7.27	3.30	0.15	3.79	7.24	0.87	2.77	2.37	36.64
46	2.32	0.75	3.21	0.89	5.09	4.86	0.91	1.60	1.92	2.57	3.00	2.30	29.42
47	1.54	0.29	2.22	7.01	5.55	5.27	2.36	1.97	2.14	1.75	2.39	1.93	34.42
48	1.77	1.72	6.27	1.13	2.79	3.08	5.11	2.55	3.82	1.36	1.39	3.47	34.49
49	3.51	2.05	2.04	1.56	1.24	3.19	5.82	4.58	1.33	1.93	0.55	3.06	30.86
50	3.16	2.48	1.49	7.87	0.98	3.72	4.45	0.64	3.83	0.90	1.11	1.04	33.67
51	1.74	2.09	3.55	4.26	4.64	3.73	5.57	3.76	3.42	3.05	3.13	2.25	41.19
52	1.65	0.78	4.20	3.31	4.59	6.31	1.57	2.17	1.17	0.89	2.84	2.17	31.85
53	1.20	1.33	3.13	2.82	3.41	1.94	7.50	0.93	2.80	1.20	0.73	3.03	30.02
54	0.90	2.86	6.29	4.38	2.85	4.64	3.78	4.25	1.13	4.82	1.88	1.87	39.55
55	1.42	2.16	1.73	3.89	5.04	3.75	1.50	4.26	1.61	M5.26	1.37	0.47	32.76
56	0.27	2.18	0.47	3.37	1.70	2.00	3.17	2.76	0.28	0.32	1.21	1.18	18.91
57	3.32	1.37	1.44	6.95	3.57	M4.19	3.25	2.01	1.46	2.81	2.42	2.74	35.53
58	1.56	0.62	0.17	2.22	2.06	5.50	11.05	1.45	2.13	2.07	1.32	0.51	30.66
59	1.59	2.48	3.91	3.67	4.09	1.84	4.66	2.19	4.26	3.63	1.62	2.65	36.19
60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

(i) Data sufficiency

Gage records should contain at least 10 years of consecutive peak flow data and, to minimize bias, should span both wet and dry years. If a gage record is shorter, it may be advisable to consider relying more on other methods of hydrologic estimations. When the desired event has a frequency of occurrence of less than 2 to 5 years, a partial duration series is recommended. This is a subset of the complete record where the values are above a pre- selected base value. The base value is typically chosen so that there are no more than three events in a given year. In this manner, the magnitude of events that are equaled or exceeded three times a year can be estimated. Care must be taken to assure that multiple peaks are not associated with the same event so that independence is preserved. The return period for events estimated with the use of a partial duration series is typically 0.5 year less than what is estimated by an annual series (Linsley et al. 1975). While this difference is fairly small at large events (100 yr. for a partial vs. 100.5 yr. for an annual series), it can be significant at more frequent events (1 yr. for a partial vs. 1.5 yr. for an annual series). It should also be noted that there is more subjectivity at the ends of both the annual and partial duration series frequency curves.

Data should be used that fully captures the peak for peak flow analysis. If a stream is flashy (typical of small watershed) the peak may occur over hours or even minutes rather than days. If daily averages are used, then the flows may be artificially low and result in an underestimate of storm event values. Therefore, for small watershed, it may be necessary to look at hourly or even 15 minute peak data.

(ii) Reliability of flow estimates

Errors exist in streamflow records, as with all measured values. With respect to USGS records, data that are rated as excellent means that 95 percent of the daily discharges are within 5 percent of their true value, a good rating means that the data are within 10 percent of their true value, and a fair rating means that the data are within 15 percent of their true value. Records with greater than 15 percent error are considered poor (U.S. Geological Survey 2002).

These gage inaccuracies are often random, possibly minimizing the resultant error in the frequency analysis. Overestimates may be greatest for larger, infrequent events, especially the historic events. For example, research indicates that mobile-bed streams likely do not allow supercritical flow more than short distances and time periods, with a critical flow assumption being most appropriate in these situations. For more information on these methods, see Grant 1997; and Webb and Jarrett 2002. If consistent overestimation has occurred, the error is not random but is, instead, a systematic bias that may have resulting ramifications.

Before performing NEC analysis based on stream gage data, an assessment of stream-floodplain connectivity should be performed. Many floodplain wetlands are disconnected from their stream channel because channel capacity is high enough to contain flood pulses without floodplain access. If an alteration to the channel conveyance is suspected, channel cross-section ratings can be used to determine the lateral connectivity between the stream hydrograph and the adjacent floodplain wetlands. If the channel capacity is large enough to contain the 50 percent chance flow (2-yr annual peak discharge), the wetland can be determined to no longer experience normal environmental conditions due to flood inundation. In many cases, direct rainfall and surface runoff from adjacent uplands maintain a reduced floodplain wetland to some extent, but the use of stream gage records can be eliminated as an alternative.

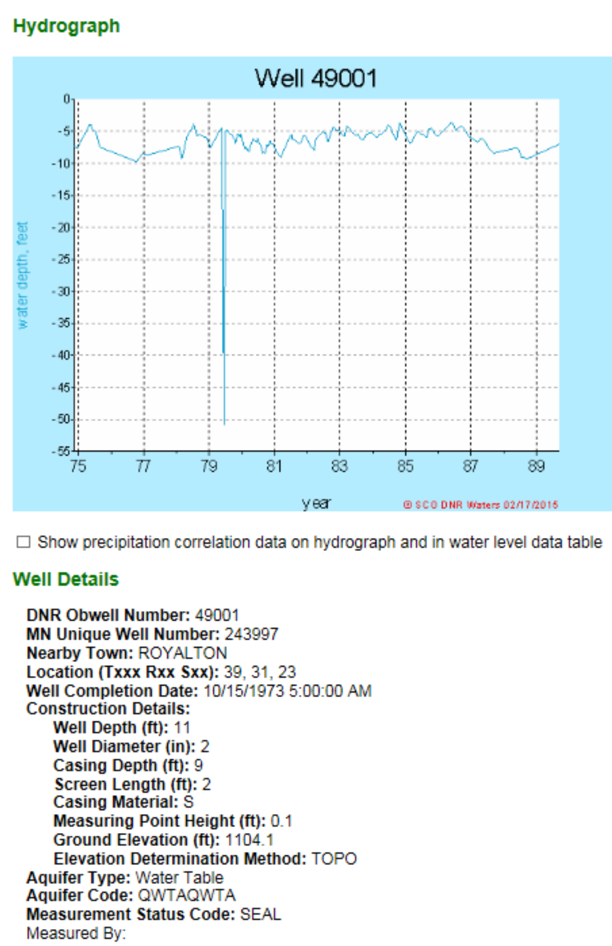
(iii) Groundwater and lake level data
Many wetlands are maintained by a high groundwater table or the level of water in an adjacent stream or lake with long-term fluctuations that do not correlate directly with local precipitation. In areas where groundwater levels are monitored by a local, State, or Federal agency, these records can be used to establish NEC. Unfortunately, most wetlands do not have long-term monitoring on site. However, evidence from one or more monitoring sites nearby with the same landscape position and soils can be used to determine if normal environmental (groundwater) conditions exist in the area.

Figure 19–3 shows a graph of water depth below the surface in blue, plotted with cumulative rainfall departures from normal over a 1 year time span. Periods of high water level at this well represent times when the local groundwater level is higher than normal. Note that there is poor correlation between normal rainfall and groundwater levels. If the local groundwater level at this location is known to respond to the groundwater level at the wetland site being analyzed, this record can be used to determine the periods when NEC existed.

Figure 19–4 shows a portion of a groundwater level record on 5-day intervals that covers a period of more than 30 years. This data can be analyzed using spreadsheet methods to extract monthly averages, and the 30th and 70th percentile values, similar to the precipitation data in the WETS tables.

The data must be from an observation well that is not significantly affected by groundwater withdrawals.

Figure 19–3 Graph of groundwater level vs. cumulative precipitation departure from normal over a 1-year time span



650.1902 Soil survey information

(a) Introduction

Wetland hydrologic analysis includes a wide range of methods. The applicability of each of these methods depends on the wetland type, landscape, climate, and dominant water source. The use of soils information readily available in the Web Soil Survey (WSS) is invaluable for making decisions about the correct analysis techniques. The user must verify that the soil map unit provided accurately reflects the actual soils on site. Soil survey information, by itself, cannot be used to complete a hydrology analysis. However, interpretation of soils data should be used to determine which hydrology methods to use.

(b) Flooding and ponding

The water features report from the WSS describes the presence of water on soils in terms of flooding and ponding, and may also provide the months of the year when these conditions occur. For these parameters, descriptive terms for duration and frequency are given. The descriptive terms and criteria for flooding and ponding are shown in tables 19–1 and 19–2.

Figure 19–4 Groundwater data taken at 5-day intervals

Water Level Data Used to Create the Hydrograph

Date/Time	Depth to Water (feet bgl)
11/12/1974 00:00,	7.35
12/17/1974 00:00,	7.58
05/08/1975 00:00,	3.94
05/21/1975 00:00,	3.94
06/12/1975 00:00,	4.79
07/16/1975 00:00,	5.04
08/27/1975 00:00,	7.44
09/16/1976 00:00,	9.58
09/24/1976 00:00,	9.75
10/21/1976 00:00,	9.56
11/18/1976 00:00,	9.00
12/16/1976 00:00,	8.46
02/02/1977 00:00,	8.68
03/08/1977 00:00,	8.58
01/25/1978 00:00,	7.32
03/02/1978 00:00,	9.23
04/27/1978 00:00,	5.84
07/14/1978 00:00,	3.82
08/15/1978 00:00,	5.70
09/18/1978 00:00,	5.46
10/26/1978 00:00,	5.79
12/05/1978 00:00,	5.96
01/10/1979 00:00,	7.46
01/17/1979 00:00,	7.50
04/17/1979 00:00,	5.04
04/19/1979 00:00,	4.99
05/10/1979 00:00,	4.55

Table 19–1 Flooding and/or ponding duration

Duration class	Criteria: estimated average
Extremely brief	0.1 to < 4 hours
Very brief	4 to < 48 hours
Brief	2 to < 7 days
Long	7 to < 30 days
Very long	> 30 days

Table 19–2 Flooding and/or ponding frequency

Frequency class	Criteria: estimated average number of flood events per time span
None	No reasonable chance (< once in 500 yr.)
Very rare	> 1 time in 500 yr., but < 1 time in 100 yr.
Rare	1 to 5 times in 100 yr.
Occasional	> 5 to 50 times in 100 yr.
Frequent	> 50 times in 100 yr.
Very frequent	> 50% chance in all months in year

It is important to recognize that flooding and ponding are separate parameters. Flooding is the inundation that occurs during the high stage of a stream hydrograph, and is associated with floodplains. Ponding is inundation from stagnant water. This may occur in floodplain depressions that are filled from short duration flooding, but maintain water long after the flood hydrograph passes. Floodplain depressions, like upland depressions, may also maintain wetland hydrology from water received from rainfall, or surface runoff from adjacent uplands.

Typically, those soils with longer than brief flooding duration, and more than occasional flooding frequency may be considered for a probability-duration analysis to check for wetland conditions due to the duration of flooding. Probability-duration analysis is described in NEH650.1904. Those soils with greater than occasional flooding frequency may also supply areas with water at the sufficient frequency to maintain ponded wetlands in floodplains, even though the duration of the flow is short.

(c) Depth to water table

The water features report also includes depth to water table, the average upper and lower limits of groundwater, and the months of the year where each condition occurs, on average.

(d) Limitations

Soil survey interpretations reflect the conditions for that soil series and phase under the conditions it was formed in, and do not reflect any changes in hydrologic conditions for the particular site. A stream channel may have been modified so that it floods with a different frequency and duration than those indicated by the soils interpretations. This may be due to upstream floodwater retarding structures, stream diversions, increase or decrease in channel conveyance, or other reasons. It may be reasonable to assume that such changes mean that the system is no longer under NEC. This is often the case. However, floodplain wetlands often maintain wetland hydrology from upland runoff, groundwater, or direct precipitation in the absence of floodwater.

Detailed information on the interpretation of soils data for wetlands is contained in the Hydrology Technical Note, Soil Hydrodynamic Interpretations for Wetlands.

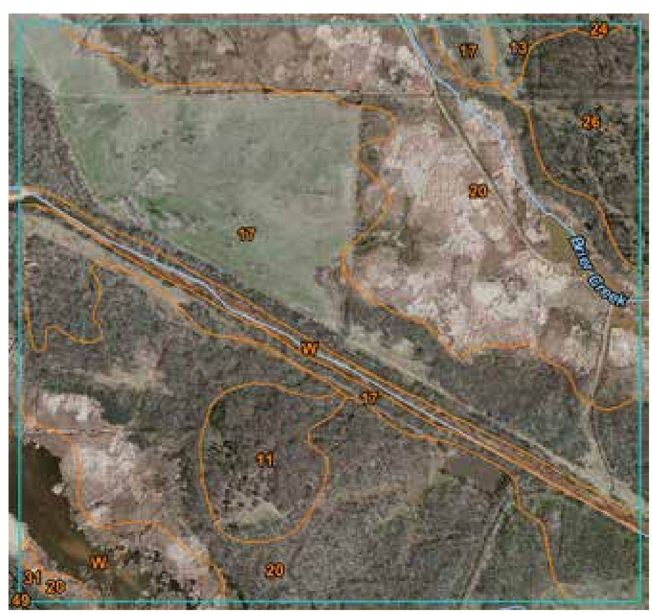
(e) Example

An example soil map produced from WSS is shown in figure 19–5.

The landscape is a floodplain, with a straight stream channel. The lack of channel sinuosity may indicate that the channel capacity is higher than normal conditions because of alteration. The two map units on the north side of the stream are map unit 17, Gracemont fine sandy loam, and map unit 20, Harjo clay. Both map units carry the phase name modifier frequently flooded. At this point, a determination should be made as to whether the current stream hydrograph has a duration long enough to maintain wetland hydrology. Figures 19–6 and 19–7 show the water features reports for Gracemont and Harjo soils.

The report for Gracemont indicates that its flooding rating is frequent, but the duration rating is brief, and the ponding rating is none. The Harjo soil has a long flooding duration rating and a long ponding duration. The use of stream gage records to determine wetland

Figure 19–5 WSS map



hydrology based on flood inundation might be appropriate for the Harjo soil area, but the rating of brief for the Gracemont indicates a duration of less than 7 days.

The apparently altered channel may not currently allow flood flows to access the Harjo soil areas of the floodplain. A quick analysis could be made using a nearby stream gage to determine the 2-year peak discharge. For ungaged sites, USGS maintains the StreamStats system, which is a Web-based Geographic Information System (GIS) application. It can provide streamflow statistics at a chosen channel location. Using a single channel cross section and the channel slope, a determination of 2-year discharge stage can be made using a normal depth calculation. If the 2-year peak discharge does not access the floodplain, an analysis using stream gage data to determine flood duration can be ruled out. If this discharge provides a stage that accesses the floodplain, further analysis using the procedures in this chapter is warranted. However, the Harjo soil has a ponding rating of long, indicating that it is capable of holding water on the surface for a long enough period to support wetland hydrology. A short duration peak discharge would be sufficient to fill a depression in the Harjo soil, so, the 2-year peak discharge analysis could be used. If a surface connection with the 2-year peak discharge stage is established, water budget methods can be used to

Figure 19–6 Water features report for Gracemont soil

Water Features---Pottawatomie County, Oklahoma

Report—Water Features

Absence of an entry indicates that the data were not estimated. The dash indicates no documented presence.

Water Features–Pottawatomie County, Oklahoma										
Map unit symbol and soil name	Hydrologic group	Surface runoff	Month	Water table		Ponding			Flooding	
				Upper limit	Lower limit	Surface depth	Duration	Frequency	Duration	Frequency
				Ft	*Ft*	*Ft*				
11—Dougherty loamy fine sand, 3 to 8 percent slopes										
Dougherty	A	Low	Jan-Dec	—	—	—	—	None	—	None
13—Eufaula fine sand, 3 to 8 percent slopes										
Eufaula	A	Very low	Jan-Dec	—	—	—	—	None	—	None
17—Gracemont fine sandy loam, 0 to 1 percent slopes, frequently flooded										
Gracemont	C	High	January	—	—	—	—	None	Brief	Frequent
			February	—	—	—	—	None	Brief	Frequent
			March	—	—	—	—	None	Brief	Frequent
			April	—	—	—	—	None	Brief	Frequent
			May	—	—	—	—	None	Brief	Frequent
			June	—	—	—	—	None	Brief	Frequent
			July	—	—	—	—	None	Brief	Frequent
			August	—	—	—	—	None	Brief	Frequent
			September	—	—	—	—	None	Brief	Frequent
			October	—	—	—	—	None	Brief	Frequent
			November	—	—	—	—	None	Brief	Frequent
			December	—	—	—	—	None	Brief	Frequent

USDA Natural Resources Conservation Service | Web Soil Survey National Cooperative Soil Survey | 4/21/2014 Page 3 of 5 determine the length of time needed for seepage and evapotranspiration to remove water from depressions on this soil type.

In addition to the information presented, soil taxonomy, drainage class, Official Series Descriptions, soil physical properties, and other information is available. A thorough search through this available data should be made as a first step before a hydrologic analysis is initiated. The services of a soil scientist should be obtained, as well.

650.1903 Hydrogeomorphic wetland classes

(a) Introduction to hydrogeomorphic wetland classification

The wetland classes in the hydrogeomorphic (HGM) system are based on the wetland's landscape position, dominant water source, and direction of water movement (hydrodynamics). In many cases, an appropriate hydrology analysis for wetland determination may be

Figure 19–7 Water features report for Harjo soil

Water Features---Pottawatomie County, Oklahoma

Water Features–Pottawatomie County, Oklahoma

Map unit symbol and soil name	Hydrologic group	Surface runoff	Month	Water table		Ponding			Flooding	
				Upper limit	Lower limit	Surface depth	Duration	Frequency	Duration	Frequency
				Ft	*Ft*	*Ft*				
20—Harjo clay, 0 to 1 percent slopes, frequently flooded										
Harjo	D	High	January	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			February	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			March	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			April	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			May	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			June	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			July	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			August	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			September	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			October	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			November	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
			December	—	—	0.0-1.0	Very long	Frequent	Very long	Frequent
24—Konawa fine sandy loam, 1 to 3 percent slopes										
Konawa	B	Low	Jan-Dec	—	—	—	—	None	—	None
26—Konawa fine sandy loam, 3 to 8 percent slopes, severely eroded										
Konawa, severely eroded	B	Medium	Jan-Dec	—	—	—	—	None	—	None
31—Norge loam, 1 to 3 percent slopes										
Norge	B	Medium	Jan-Dec	—	—	—	—	None	—	None
49—Grainola silty clay loam, 5 to 12 percent slopes										
Grainola	D	Very high	Jan-Dec	—	—	—	—	None	—	None

USDA Natural Resources Conservation Service | Web Soil Survey National Cooperative Soil Survey | 4/21/2014 Page 4 of 5 selected based on the HGM wetland type. For wetlands which do not fit into a broad HGM class, a hydrologic analysis method can still be selected with knowledge of the landscape position, water source, and hydrodynamics. Different wetlands exist on different landscape positions. For instance, Riverine wetlands exist on floodplains, and Depressional wetlands exist on uplands in topographic low areas with closed contours. Most wetlands have a dominant water source which defines the wetland's normal hydroperiod, and the associated frequencies and durations of wet conditions. This dominant source may be groundwater inflows, stream flooding, or surface runoff. Hydrodynamics are defined using the terms unidirectional, bidirectional, horizontal, and vertical. These directions are graphically illustrated in figure 19–8.

(b) The HGM wetland classes

The seven broad HGM wetland classes (fig. 19–9 through 19–15) as defined by Smith, et al., 1995 are:

- RIVERINE
- SLOPE
- MINERAL SOIL FLATS
- ORGANIC SOIL FLATS
- DEPRESSIONAL
- ESTUARINE FRINGE
- LACUSTRINE FRINGE

(c) Soil taxonomy, descriptive terms, and HGM

Soil taxonomic data and soil interpretations can provide information useful for wetland hydrology. Soil taxonomy does not use geomorphology and hydrodynamics as the primary criteria for assigning taxonomic names to soils. However, these parameters are often included in taxonomic names, and can often provide interpretations which are of great value in the analysis of wetland hydrology. Soil interpretations also provide useful information.

Figure 19–8 Wetland hydrodynamics

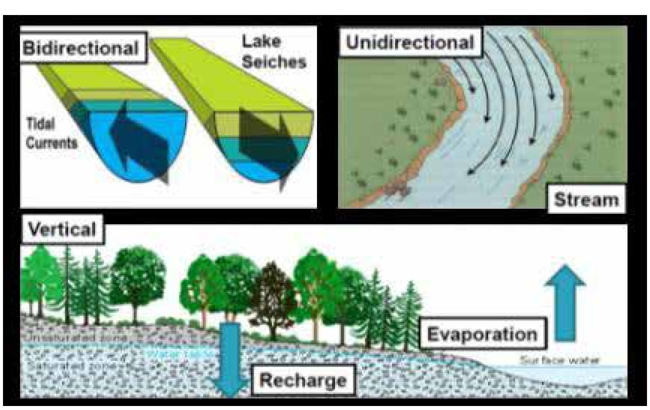


Figure 19–9 Riverine wetland

Figure 19–10 Slope wetland

Figure 19–11 Mineral flat wetland

Figure 19–12 Estuarine fringe wetland

Figure 19–13 Lacustrine fringe wetland

Included in soil taxonomy are the episaturated and endosaturated great groups. Episaturated soils maintain a perched water table that is above an unsaturated layer within the top 200 centimeters. Endosaturated soils are totally saturated down to 200 centimeters. Wetlands in endosaturated soils often have a supply of groundwater from an adjacent landscape as the dominant water source. The water supply for wetlands in episaturated soils can be assumed to be surface runoff from the adjacent watershed, stream flooding, or direct precipitation.

Other taxonomic and descriptive terms useful for wetland hydrology:

- **Histosol—**Organic soils. All organic soils except folists were formed in conditions of saturation. They usually, but not always, were formed in endosaturated conditions. These soils are common on Organic Flats and Slope HGM types.
- **Aquic—**Refers to saturated conditions.
- **Fluventic—**Formed by flowing water. These soils are common on, but not limited to, Riverine HGM types.
- **Ponding—**Inundation by stagnant water. Soil interpretations include the duration and months of the year that ponded water occurs. The Depression HGM type is defined by ponding, but the condition occurs on most other HGM types.
- **Flooding—**Inundation by flowing water. Soil interpretations include the frequency and duration class of flooding. This condition is only associated with Riverine HGM types.

Drainage class—Describes the relative wetness of the soil as it pertains to wetness due to a water table.

Free water occurrence—Includes the depth to, kind, and months of the year that a zone of free water (Soil Survey Manual, 1993) is present within the soil.

(d) Description of HGM wetland classes

The HGM wetland classification system uses a taxonomic naming system with upper case, lower case, and italic letters to denote classes and subclasses. At the

Figure 19–14 Organic flat wetland

Figure 19–15 Depressional wetland

class level, the names are always shown in upper case, and this convention is followed in this document.

(1) RIVERINE

RIVERINE wetlands exist in stream floodplains, and were formed by fluvial processes. They function with the active channel in a stream corridor. RIVERINE wetlands may receive surface water from stream flooding or runoff. They may also receive groundwater inflows from the stream through the banks or bed. Water from runoff and flooding creates episaturated conditions. Water supplied from groundwater creates endosaturated conditions. RIVERINE wetland features were formed by the dynamics of streamflow, mainly during flood events. These features include abandoned oxbows, scours, splays, natural levees, crevasses, and backwater swamps, among others. A wetland hydrologic analysis in a RIVERINE system typically consists of determining the magnitude, frequency, and duration of stream discharges, and determining the conveyance capacity of stream channels. For the purposes of HGM wetland classification, RIVERINE wetland types include only those in the active floodplain. Wetlands found on abandoned stream terrace landforms which no longer receive stream flooding, or lack groundwater influence from the stream water surface are not considered RIVERINE. Wetlands on this landform are usually classed as MINERAL FLAT (NEH650.1903(d)(vi)).

The primary source of data for RIVERINE wetland types is stream discharge records and stream geometry data. Groundwater data is also valuable when analyzing endosaturated wetlands on floodplains. The relationship between stream hydrographs and wetland hydroperiod is illustrated in figure 19–16. In the illustration, a flow of 200 cubic feet per second has been calculated to provide to inundation to a floodplain wetland. The duration of flows 200 cubic feet per second or above defines the hydroperiod for this wetland site.

Floodplain wetlands may have wetland hydrology due to dynamic flooding, surface ponding, or both. In figure 19–17, the floodplain has areas where dynamic floodwater exists, and other areas where ponded conditions exist. The hydroperiod of the areas under dynamic flooding are dictated by the stream hydrograph duration. Probability-duration analysis methods to determine frequency and duration are appropriate for these sites. These methods are covered in NEH650.1904 and NEH650.1908. On other sites, flood inundation periods are short, but peak discharges will fill depressions with water, which remains until evapotranspiration and percolation remove it. Return period peak discharge data can determine the frequency of floodwater access, and water budget methods must be used to determine the duration of ponding in the depression. This determination is also described later in the chapter.

Figure 19–16 Stream hydrograph defines RIVERINE wetland hydroperiod

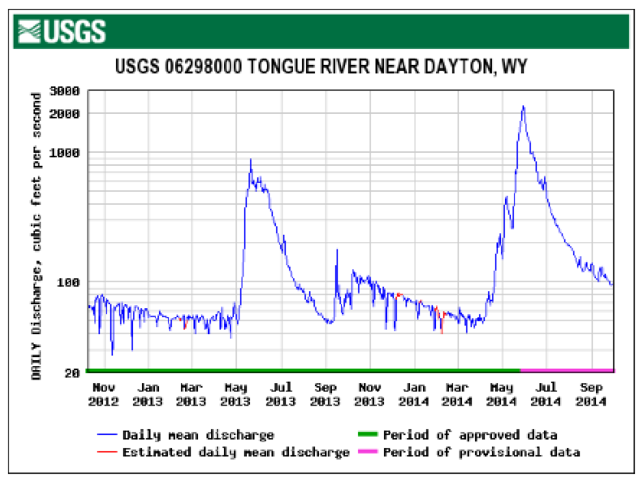


Figure 19–17 Riverine wetlands under dynamic flooding and ponding

Soils interpretations reflect the differences between flooding and ponding in the Water Features Report. In figure 19–18, the Osage soil series shows long-term, frequent ponding, but short–term, frequent flooding. The Verdigris soil has infrequent ponding, and short-term, frequent flooding.

Soils orders common in RIVERINE wetlands are entisols and inceptisols. Common suborders are aqu and fluv, and common great groups are the aqu, fluv, endo, and epi. The most valuable taxonomic information is included in the endo and epi formative elements. For example, an epiaquent will have surface runoff as the dominant water source, while an endoaquent will be supplied by groundwater. These have profound implications for duration, hydroperiod, and water budgeting. Common soil taxonomic names with interpretive value are: endoaquent, fluvaquoll, or fluvaquents.

The landscape position of the RIVERINE HGM class is floodplains.

The dominant water source is surface flooding or groundwater supplied from the stream channel. The hydrodynamics are bidirectional, horizontal.

Figure 19–18 Water regimes correspond to soil map units

(2) ESTUARINE FRINGE

ESTUARINE FRINGE wetlands exist in areas where the water inflows and outflows are dominated by the cyclic action of ocean tides. These wetlands are usually found in association with stream outlets, and may be saltwater, freshwater, or brackish. They usually exist as areas served by one or more discrete inlet channels, where salt or fresh water enters and exits under the influence of stream inflows and ocean tides.

ESTUARINE FRINGE wetlands can be manipulated in many ways. Dredging or filling will make the depth of inundation deeper or shallower. They can also be manipulated by blocking or altering the capacity of the discrete channels where fresh or salt water enter and exit the wetland. The volume of water entering the wetland is called the tidal prism. The prism volume is a function of the capacity of the inlet channel. The size of the channel naturally adjusts itself to be in equilibrium with the tide cycle, and the stability of the channel boundary. Blocking the inlet channels or changing their capacity affects the tidal prism, and results in changes in the wetlands' hydroperiod and hydrologic regime. Figure 19–19 shows a graphical example of tidal fluctuations.

The landscape position of the ESTUARINE FRINGE HGM class is tidal estuaries. The dominant water source is tidal flows or fresh water flows under tidal influence. The hydrodynamics are bidirectional, horizontal.

(3) LACUSTRINE FRINGE

A LACUSTRINE FRINGE wetland exists along the shore of a lake, which is the dominant water source. The hydrodynamics are associated with seasonal or longer cycles of lake level fluctuation, or with lake level rises associated with strong seasonal winds (lake seiches) and this is the focus of the hydrologic analysis. Various agencies maintain lake level records. An example of monthly lake level data from USGS is shown in figure 19–20.

The landscape positions of the LACUSTRINE FRINGE HGM class are areas near the shorelines of large lakes where the surface has been created and maintained by lake water energy. The dominant water source is flows associated with lake fluctuations. The hydrodynamics are bidirectional horizontal.

Figure 19–19 Tide graph

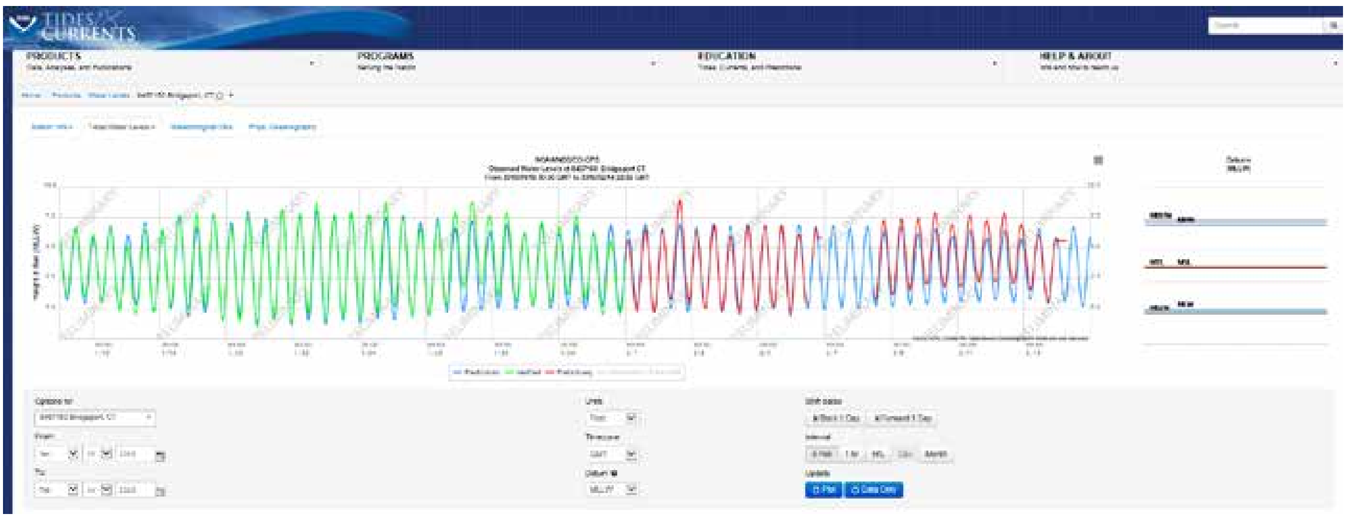
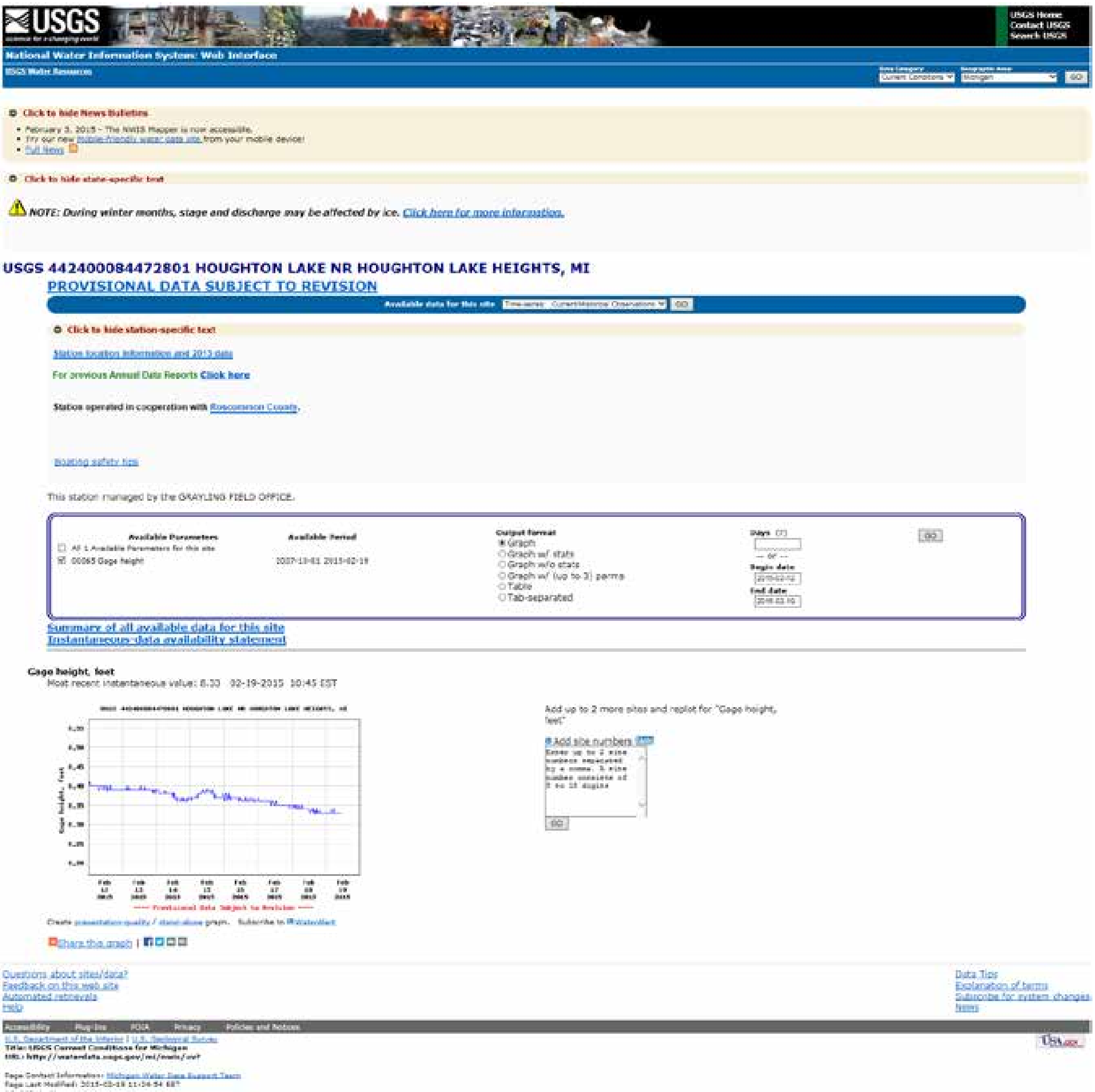


Figure 19–20 Monthly lake levels from USGS



(4) SLOPE

SLOPE wetlands are in locations where groundwater flow is forced to the surface by a low permeability layer, a concave topographic landscape, or a sharp slope break. In topographic SLOPE wetlands, water can be forced to a discharge area by the concave shape of the land surface (fig. 19–21). This is common in the headwater reaches of streams. SLOPE wetlands that form where a nearly horizontal layer of rock or low permeability soil, known as an aquiclude, directs water to discharge to the surface are called stratigraphic SLOPE wetlands (fig. 19–22). Topographic SLOPE wetlands also form where sharp breaks in the slope force groundwater to the surface (fig. 19–23). The dominant water source of slope wetlands is groundwater. Wetland hydrology studies focus mostly on the monitoring of data from wells and piezometers. Aerial photographs can be helpful to examine the pattern of wetness and vegetation. The soils exist in an endosaturated condition. Histosols are common. Entisols and inceptisols are not common. Soil taxonomic names often include an aquic designation. For instance, a mollisol in a slope wetland may have the taxonomic name endoaquoll.

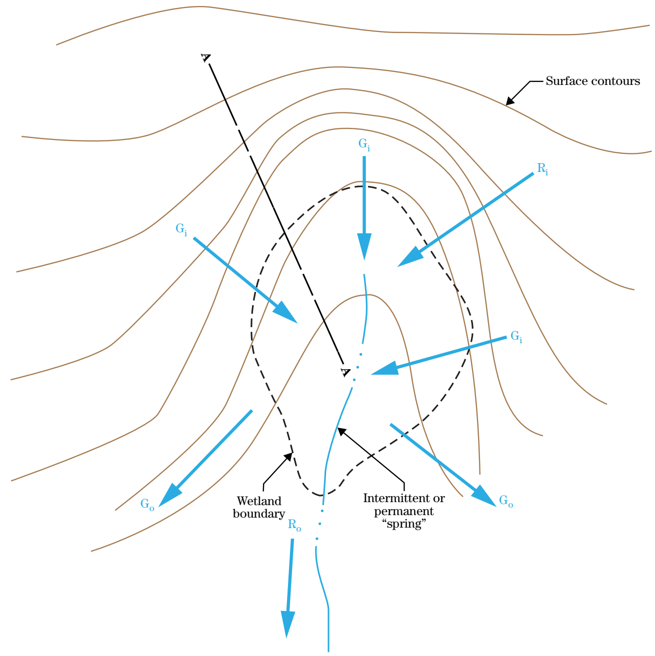
The interface between groundwater flow and the land surface creates a vertical component to the flow lines in a groundwater flow net. This vertical movement causes a condition where the groundwater head is higher at depth. This reverse head differential can be detected by water levels in wells and piezometers, and is a direct indication of groundwater inflow. The use of wells and piezometers is described in NEH650.1913.

The landscape position of SLOPE wetlands are concave landscape positions created by slope breaks or stream headwaters or where aquacludes outcrop. The dominant water source is groundwater. The hydrodynamics are horizontal, unidirectional, and vertical, unidirectional.

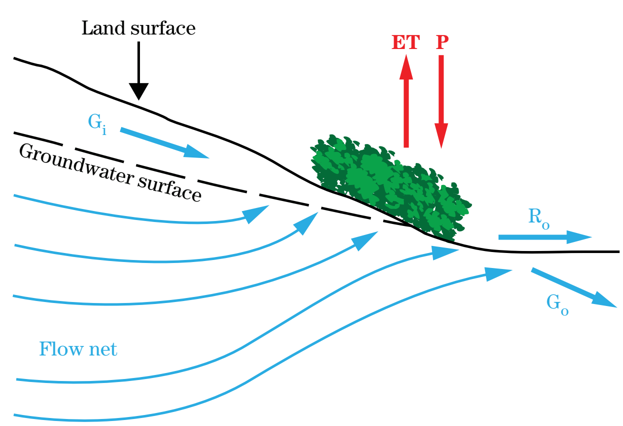
(5) ORGANIC FLATS

ORGANIC FLAT wetlands exist on interfluves, on the bottoms of large depressions, on coastal plains and in extensive bogs. The dominant water source for an ORGANIC FLAT wetland is precipitation, creating episaturated conditions. The soils are always histosols. Surface water may flow into the system, but with low energy, as histic soils are very easily eroded. ORGANIC FLAT wetlands are commonly drained by surface ditches or subsurface drainage tile. Hydrologic analy-

Figure 19–21 Plan view of topographic SLOPE wetland in concave landscape position at stream headwaters



Section A–A of plan view



sis is usually focused on determining the lateral effect of existing or proposed drainage. The hydrodynamics are vertical, (downward).

(6) MINERAL FLATS

MINERAL FLAT wetlands exist in interfluves and large stream terraces, and the dominant water source is precipitation. The direction of water movement is vertical, downward. MINERAL FLAT wetlands are never composed of histosols, and entisols and inceptisols are not common. MINERAL FLATS commonly have an aquic designation in their taxonomic name, but rarely a fluventic designation. They are commonly drained by surface ditching or subsurface tiles. Hydrologic analysis is usually focused on determining the lateral effect of existing or proposed drainage. The hydrodynamics are vertical (downward). Figure 19–24 illustrates the hydrodynamics of MINERAL FLAT wetlands. Lateral effects analysis for these wetland types are described in this chapter.

(7) DEPRESSIONAL

DEPRESSIONAL wetlands exist in topographic low areas with closed contours. Their primary water source can include direct precipitation, surface runoff, and/or groundwater inflows. The water may be perched on a low-permeability soil layer which is above the local groundwater table. Depressions, which have their bottom within the groundwater table, may have net flow into the groundwater table, or may be gaining water from the groundwater table. Depressions, which gain water from the groundwater, are discharge depressions. Those that collect surface runoff, and lose water to the local water table are recharge depressions. Those that have the groundwater inflows and outflows equivalent are flow-through depressions.

(i) Recharge DEPRESSIONAL wetlands

Recharge wetlands are arguably the simplest to analyze using hydrologic modeling. Water runoff is received from a known watershed which can be modeled using land use and cover and hydrologic soil group. Water is lost from evaporation from an open water surface, evapotranspiration from wetland vegetation, and seepage through the wetland substrate. Each of these water budget components can be estimated, and modeled using a time step analysis to determine the wetlands' hydroperiod. Playa wetlands found in the North American High Plains are recharge depressional wetlands. The soil orders histosol, entisol, and inceptisol rarely, if ever, exist. They rarely have a fluventic designation, but commonly have an

Figure 19–22 Stratigraphic SLOPE wetland created by an aquitard

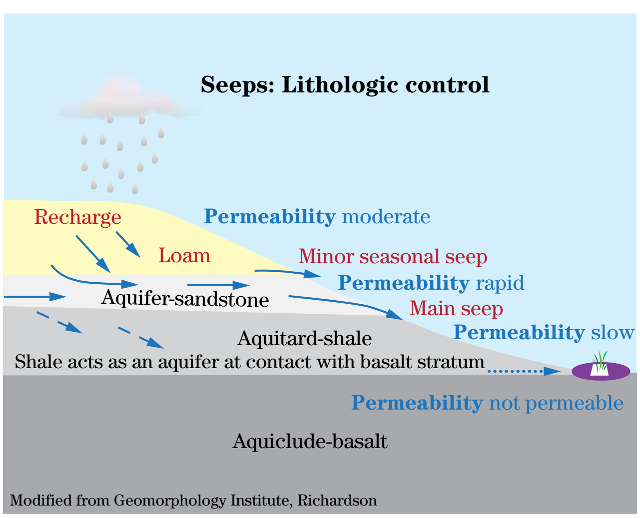
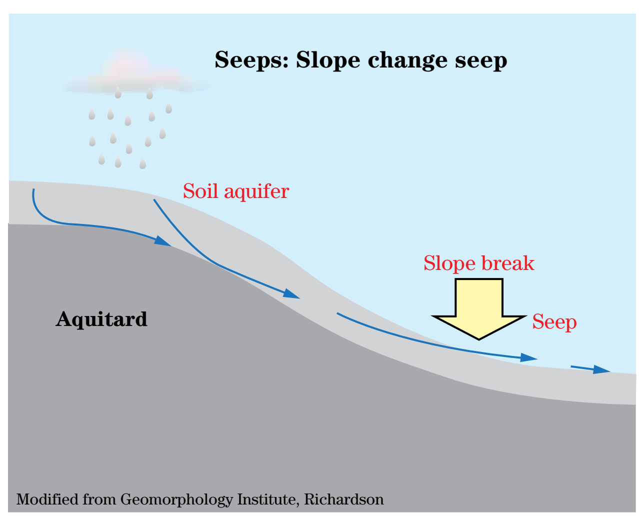


Figure 19–23 Topographic SLOPE wetland caused by a slope break



aquic designation. The soil profile commonly includes a Bt horizon formed from downward movement of clay particles. This horizon forms the low permeability layer which perches a water table. The wetland exists in an episatured state, and the soils commonly have that great group designation.

A common soil taxonomic name is epiaquoll. Figure 19–25 illustrates the hydrodynamics of recharge DEPRESSIONAL wetlands. Analysis using the Soil-Plant-Air-Water (SPAW) Model software is appropriate for these wetlands. A description of this method is included in 650.1912.

(ii) Discharge and flow through DEPRESSIONAL wetlands

These systems are difficult to model with water budgeting. Histosols are included in the possible soil orders. They exist in a state of endosaturation, and this designation is commonly included in the taxonomic name. Figure 19–26 illustrates the hydrodynamics of discharge and flow through DEPRESSION wetlands.

650.1904 Probability-duration analysis using daily data

(a) Introduction

Wetland hydrology analysis determines the probabilities, frequencies, and durations of inundation or saturation. One of the most common analyses made is probability-duration. Simply stated, it is the percent chance probability that a condition exists for a specified, uninterrupted duration. For example, on a floodplain site, the objective criterion may be 15 days of uninterrupted surface water during the growing season on an average annual basis, or the 50 percent chance, 15-day duration. While this water may be dynamic floodwater or ponded water, using stream gage data alone can be used to determine the duration of flooding, and if positive for a 15-day duration, a ponding analysis is not needed. As an example for a wetland determination on a site where a high groundwater table causes wetland conditions, the objective criterion may be defined as a groundwater level no more than 12 inches below the surface for 14 consecutive days during the growing season on an average annual basis. Hydrologists may use this criterion with ground-

Figure 19–24 Hydrodynamics of MINERAL FLAT wetlands

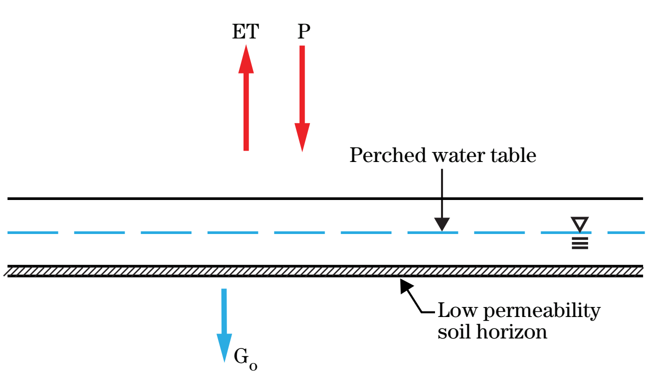
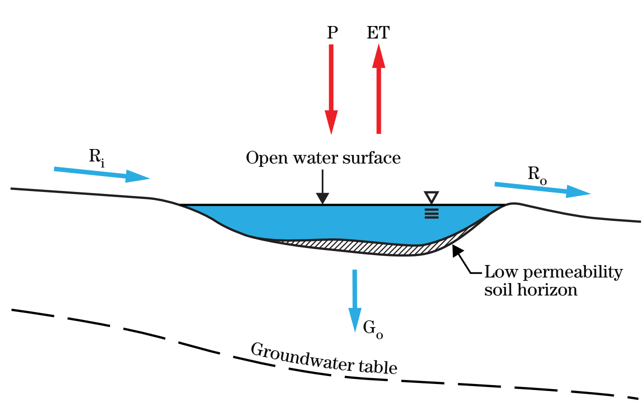


Figure 19–25 Hydrodynamics of recharge DEPRESSIONAL wetlands



water monitoring data to determine the 50 percent chance, 14-day duration water level.

Streamflow and groundwater level are the two most commonly used data types used in probability-duration analysis. However probability-duration analysis can be applied to any population of sequential data collected on a uniform basis, such as temperature.

(b) Example

A currently drained floodplain tract along the Grand River near Gallatin, Missouri, is proposed for construction of a new levee. A hydrology analysis has been requested to determine whether the area meets the criteria for farmed wetland (FW). The objective criteria used in this case is the 50 percent chance probability of inundation for 15 consecutive days during the wetland growing season.

Step 1: Extract growing season data

The available WETS tables for Daviess County, Missouri, do not include growing season data. The Amity weather station in DeKalb County has virtually the same latitude and elevation as Daviess County. The WETS table for this station shows that the wetland growing season extends from April 11 to November 18. Only streamflow from this 190-day growing season period can be considered when determining wetland inundation.

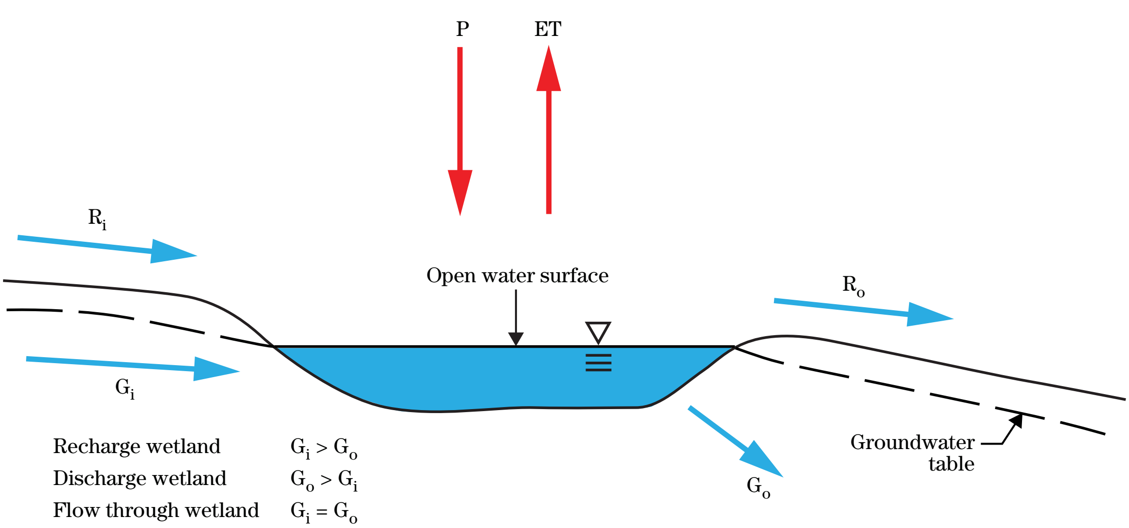
Step 2: Perform probability-duration analysis

The USGS operates a stream gage a short distance from the determination site. Available information includes mean daily flows. The mean daily flows for the previous 20 years of record are available, beginning with water year 1988, and ending with water year 2007. Note that water years begin on October 1, and ends on September 30. Analyzing data on a calendar year basis will usually not result in a significant difference in results. However, USGS published statistical data is based on the water year. To maintain consistency, following this format is good practice.

The analysis can be performed with spreadsheets as shown in table 19–3.

This analysis can also be performed by the Hydrologic Engineering Center – Ecosystem Functions Model (HEC-EFM) developed and maintained by the USACE. The user can perform the analysis using only the daily data within a specified date range, which in this case is the wetland growing season. The user can also specify any probability of occurrence, and any frequency.

Figure 19–26 Hydrodynamics of discharge and flow through wetlands.



On the spreadsheet shown in table 19–3, column A is the date column, followed by the mean daily flow value in column B. column C shows the lowest flow exceeded in the previous 15 days at each successive date, so the first figure appears at the 15th day of record. In column D, the highest 15-day low flow is extracted for each successive year. Only the 15-day flows occurring during the April 11 to November 18 growing season are considered. The figures in column D (which do not appear in table 19–3, as they are too far down in the spreadsheet) are transferred to column F. The 50th percentile of the data in column F appears at the top.

The result of the analysis is that there is a 50 percent probability that a flow of 1,270 cubic feet per second will occur for at least a 15-day duration during the growing season.

The USGS has software programs that can be used to extract duration flows, on request. However, at the time of this writing, they can only provide average flows for a requested duration, not the minimum flows. There can be a significant difference between the 15-day average and minimum flow. The criteria for assigning certain NFSAM wetland labels is specific, and requires the determination of continuous inundation flows for a certain duration, which must be determined from the minimums, not the average. However, other criteria may be appropriate for wetland restoration planning. For instance, the determination of the limit of bottomland hardwood plantings on a restoration may be better defined by average duration flows and different durations. The probability computation is the same.

Other data can also be evaluated using this method. Instead of using a data population of mean daily flows, stream stage data expressed as a mean sea level (MSL) elevation, or an elevation from an assumed datum may be used. Also, groundwater levels from a groundwater monitoring effort, lake elevation levels, or other data can be analyzed in terms of probability-duration. For instance, daily groundwater readings can be used to determine the groundwater depth for a 50 percent chance probability for a 14 day duration. If the objective depth criterion is 6 inches, for instance, the resulting 50 percent chance, 14 day groundwater depth can be compared to this criterion.

Table 19–3 Probability duration analysis using spreadsheet methods

Grand River near Gallatin, MO					
	50% chance 15-day flow exceedence				
	Discharge at wetland hydrology, CFS				
50th percentile		**1,270**			
A	**B**	**C**	**D**	**E**	**F**
Date	**Flow at gage**	**15 day duration flows**			
10/1/1987	156			1988	476
10/2/1987	145			1989	270
10/3/1987	137			1990	1040
10/4/1987	131			1991	1940
10/5/1987	128			1992	1270
10/6/1987	126			1993	17500
10/7/1987	121			1994	1410
10/8/1987	119			1995	3420
10/9/1987	115			1996	3560
10/10/1987	113			1997	2960
10/11/1987	113			1998	3170
10/12/1987	113			1999	2820
10/13/1987	113			2000	386
10/14/1987	113			2001	1220
10/15/1987	114	113		2002	923
10/16/1987	123	113		2003	138
10/17/1987	133	113		2004	1420
10/18/1987	139	113		2005	565
10/19/1987	139	113		2006	291
10/20/1987	128	113		2007	1100
10/21/1987	120	113		2008	1960
10/22/1987	117	113			
10/23/1987	123	113			
10/24/1987	125	113			
10/25/1987	123	113			
10/26/1987	117	113			
10/27/1987	113	113			
10/28/1987	115	113			

650.1905 The wetland water budget and data sources

(a) Introduction

Wetlands receive, store, and release water on a continual basis. In the HGM classification system, each wetland class has one dominant water source, although most wetlands receive water from at least two or more sources. Knowledge of wetland HGM class can be used to determine what information is needed for a hydrologic analysis, and save effort caused by seeking information on water sources that are minimal or non-existent. Also, each wetland class usually has only a few outflows, and knowledge of the HGM wetland class can help determine what information is needed for these as well. Guidance on the use of HGM classification for water budgeting is described in this chapter.

This section describes the basic procedures of performing water budget analyses, and the sources of needed data. The sources listed in this part also provide data for hydrologic models and procedures described in other parts of this document.

(b) Water budget parameters

Potential inflows to any wetland include:

- precipitation, P
- tidal inflow, T_i
- lake inflow, L_i
- groundwater inflow, G_i
- surface runoff inflow, P_i
- pumped inflow, P_i

Potential outflows from any wetland include:

- tidal outflow, T_o
- lake outflow, L_o
- evaporation, E
- groundwater outflow, G_o
- evapotranspiration, ET
- surface runoff outflow, R_o
- pumped outflow, P_o

(c) The water budget

Water entering a wetland is either stored or leaves the site. This is expressed as a formula where inflow minus outflow equals change in storage. Summing the inflows and outflows results in a change in wetland storage over a chosen time step:

$$I - O = \Delta S \qquad \text{(eq. 19–1)}$$

(d) Data sources

Data needed for hydrology analyses can be obtained from a wide variety of local, regional, or national sources. The following is a partial list of the data usually needed, and potential data sources.

(1) Precipitation, P

Precipitation occurs as rainfall or snowfall. It falls directly on the wetland surface, or on a contributing watershed area, where it may become surface runoff, or be stored for release as groundwater. Precipitation data is rarely available in more detail than daily total amounts. For storm events which span one or more days, the data will be published as separate daily totals. Two national sources of precipitation information are available for use in wetland determinations. State and local sources may be available also.

The NRCS National Water and Climate Center (NWCC) maintains the WETS tables, which have already been described. The WETS tables also include monthly and annual rainfall totals for the current 30 year period of record. An example WETS table is illustrated in figures 19–1 and 19–2.

Current daily and monthly rainfall data is also available from the Water and Climate Center for the active National Oceanographic and Atmospheric Administration (NOAA) weather stations, and temperature data is usually included. Daily data can be accessed through eFOTG, under Section II, Climate Data, AgACIS.

Rainfall for the current month is included, up to the day previous to the request. This is useful for documenting whether NEC exist at the time of onsite data collection for wetland determination. An example for daily data extracted on October 27, 2011, is shown in figure 19–27.

For sites at locations not near a weather station, the NWCC maintains the High Resolution Climate Extractor (HCE) system. For a given latitude and longitude, data is available for daily rainfall and temperature.

Figure 19–27 Daily data for current month, including previous day

USDA Field Office Climate Data

ABILENE (140010)
Observed Daily Data
Month: May 2014

Day	Max Temp	Min Temp	Avg Temp	GDD B50	GDD B40	Total Prcpn	New Snow	Snow Depth
1	62	39	50.5	1	11	0.00	M	M
2	75	36	55.5	6	16	0.00	M	M
3	84	48	66.0	16	26	0.00	M	M
4	97	54	75.5	26	36	0.00	M	M
5	89	51	70.0	20	30	0.00	M	M
6	100	54	77.0	27	37	0.00	0.0	0
7	97	70	83.5	34	44	0.10	M	M
8	81	66	73.5	24	34	0.00	M	M
9	75	47	61.0	11	21	0.00	M	M
10	89	57	73.0	23	33	0.00	M	M
11	91	66	78.5	29	39	0.10	M	M
12	84	50	67.0	17	27	1.30	M	M
13	64	46	55.0	5	15	0.00	M	M
14	70	40	55.0	5	15	0.00	M	M
15	68	40	54.0	4	14	0.00	M	M
16	63	35	49.0	0	9	T	M	M
17	66	39	52.5	3	13	0.00	M	M
18	77	44	60.5	11	21	0.00	M	M
19	91	62	76.5	27	37	0.00	M	M
20	95	63	79.0	29	39	0.00	M	M
21	94	63	78.5	29	39	0.00	M	M
22	83	63	73.0	23	33	0.05	0.0	0
23	78	60	69.0	19	29	0.69	M	M
24	80	62	71.0	21	31	0.25	M	M
25	84	64	74.0	24	34	0.06	M	M
26	84	64	74.0	24	34	0.00	M	M
27	85	61	73.0	23	33	0.00	M	M
28	93	63	78.0	28	38	0.00	M	M
29	91	66	78.5	29	39	0.00	M	M
30	90	65	77.5	28	38	0.00	M	M
31	88	65	76.5	27	37	0.00	M	M
Smry	82.8	54.9	68.9	593	902	2.55	0.0	0.0

Figure 19–28 shows monthly data extracted for the year 2011. This current monthly data is useful for documenting NEC for the months preceeding the collection date of remotely sensed data when the date is more recent than the WETS 30 year period of record.

Daily rainfall data can be used as input into water budget modeling software or input into spreadsheet tools. The extraction of this data is described in the climate data for the Soil-Plant-Air-Water (SPAW) Model. Models provide documentation of the probabilities and durations of wetland hydrology during the period of record of the data. Available models include the SPAW and DRAINMOD models. The SPAW model and DRAINMOD are described in this chapter. These parts also include more information on the data sources that are needed for the models

(2) Tidal flows, T_i, T_o

Information on the magnitude and frequency of ocean tides can be found at the Web sites maintained by NOAA. Tidal stage data can be used to determine the maximum and minimum daily sea level elevations which drive the hydrodynamics of the wetland system. It is also needed to calculate the volumes of flow which enter the wetland, based on the geometry of tidal inlet channels. This volume is referred to as the tidal prism. The maximum tide stage used is the

Figure 19–28 Monthly data for year 2011 extracted in October 2011

USDA Field Office Climate Data

ABILENE (140010)
Monthly Totals/Averages
Maximum Temperature (degrees F)
Year: 2014

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2014	42.2	[illegible]	57.8	71.8	82.8	87.4	92.7	[illegible]	84.1	74.2	51.7	42.0	[illegible]

mean higher high water (MHHW) and the minimum tide stage used is the mean lower low water (MLLW). These elevations are not constant for given latitudes and longitudes, but vary with the coastline due to changing shoreline and underwater structure. Tide stage information is only valid for a single location.

(3) Lake stage records, L_i and L_o

The water surface elevation of most large lakes is recorded by one or more Federal, State, or local agencies. For artificial reservoirs managed by the USACE, the U.S Bureau of Reclamation (BuRec), or the Tennessee Valley Authority (TVA), lake level records have often been kept throughout the life of the reservoir. Lake level records for large natural lakes are maintained by the USGS. State and local data may be available for a given location. Lake data sources and applications are described in NEH650.1907.

(4) Streamflow records

The primary source for streamflow records is the USGS. This website is the starting point for all of USGS' data nationwide: *http://waterdata.usgs.gov/nwis/sw*

Depending on the gage location, data can be obtained as real-time, daily, and/or peak discharge data. Stream stage statistics may also be available. In general, the information needed for wetland hydrologic analysis is daily mean flow data for at least a 10 year period of record.

(5) Evaporation data, E, and ET

The primary source for evaporation data (E) is the NOAA Technical Reports NWS 33 and 34 which provide average shallow lake evaporation values for the continental United States on a monthly basis. The data includes monthly precipitation and evaporation for virtually all counties in the United States.

Evapotranspiration (ET) is the combination of evaporation from moist soil surfaces in combination with the transpiration of water directly though the plant leaves and stems. Information on for the use of water by wetland vegetative plant communities is not commonly available. Many studies have been performed by universities, State, and Federal agencies on individual wetland locations around the United States. However, these studies are limited to the local area of the study, the specific plant community, and generally are not continued for more than one or two growing seasons. However, if local information is available to determine plant-water use, it can be extremely valuable.

The use of soil-plant-water relationships from irrigation studies can be useful for determining wetland plant water use. These analyses begin with the determination of the Potential Evapotranspiration (PET). This value can be computed for a wetland site, using the same data and procedures as used for an irrigated field. Guidance is available in NEH623.02. Once the PET has been determined, the user must determine a crop coefficient that is appropriate for the wetland plant community. Again, this information is limited. However, local plant specialists and agronomists can be consulted for the purpose of making reasonable estimates.

These items can be considered when making evapotranspiration estimates for wetland vegetative plant communities:

- Dense herbaceous plant communities greatly reduce the solar radiation, temperature, and wind velocities which drive surface evaporation. Early in the season, the standing dead biomass of annual plants will greatly reduce free water surface E and the wetland will have low ET rates until the plants have grown to maturity.
- Perennial herbaceous vegetation will increase ET rates earlier in the season than annual vegetation, because annual plants must produce new biomass each year, and biomass volumes are small at the start of plant growth.
- The peak ET rates of herbaceous plants may be relatively close to the daily PET rates in midsummer, computed by various methods.
- The ET rates of wetland plants may be closely tied to the soil moisture content or depth to groundwater.

(6) Groundwater and groundwater flow, G_i and G_o

(i) Groundwater monitoring data

State and local agencies may have repositories of groundwater data. Researchers at universities may have monitored specific sites. Groundwater data tends to be site specific and may be weather dependent. Potential lag time from rainfall should be considered. When using groundwater data to directly determine statistical probabilities of water table elevations and durations, at least 10 years of data should be available. Data sources and applications for groundwater data are described in NEH650.1913. The probability-duration methods described in NEH650.1904 may be applicable.

(ii) Groundwater flows

In many wetlands, a water budget analysis can be performed that includes groundwater flows. In most water budget situations, the volumes of water lost due to vertical, downward movement (G_o) through the soil substrate is a significant component. The movement of water through the soil in wetlands is defined by the saturated hydraulic conductivity, or K_{sat}. The most readily available source for K_{sat} is the WSS. The reports tab has an option for Physical Soil Properties. K_{sat} is provided in units of micrometers/second. This unit can be converted to inches per hour by multiplying by 0.1417. The data is provided in standard broad ranges. An example of a physical soil properties report is shown in figure 19–29.

K_{sat} data can also be obtained through the use of the Rosetta software. Hydraulic conductivity can also be measured in the field. Consult a qualified soil scientist or hydrologist for assistance in field measurements.

Figure 19–29 Physical Soil Properties Report

Physical Soil Properties---Brookings County, South Dakota

Physical Soil Properties–Brookings County, South Dakota

Map symbol and soil name	Depth	Sand	Silt	Clay	Moist bulk density	Saturated hydraulic conductivity	Available water capacity	Linear extensibility	Organic matter	Erosion factors			Wind erodibility group	Wind erodibility index
										Kw	Kf	T		
	In	Pct	Pct	Pct	g/cc	micro m/sec	In/In	Pct	Pct					
HeB—Hetland silty clay loam, 2 to 6 percent slopes														
Hetland	0-8	-18-	-43-	35-39- 45	1.20-1.30	0.42-1.40	0.13-0.19	6.0-8.9	4.0-7.0	.37	.37	5	4	86
	8-24	- 8-	-50-	35-43- 50	1.20-1.40	0.42-1.40	0.11-0.19	6.0-8.9	2.0-6.0	.37	.37			
	24-42	-18-	-43-	35-39- 50	1.30-1.40	0.42-1.40	0.11-0.20	6.0-8.9	1.0-4.0	.37	.37			
	42-60	-49-	-19-	25-33- 40	1.25-1.45	0.42-4.20	0.11-0.20	6.0-8.9	0.0-1.0	.37	.37			
Pa—Parnell silty clay loam, 0 to 1 percent slopes														
Parnell, undrained	0-17	-18-	-49-	27-34- 40	1.20-1.30	1.40-4.00	0.18-0.22	3.0-5.9	6.0-10.0	.37	.37	5	7	38
	17-45	- 6-	-47-	35-48- 60	1.20-1.30	0.42-1.40	0.13-0.19	6.0-8.9	1.0-5.0	.37	.37			
	45-60	-18-	-43-	35-39- 45	1.20-1.40	0.42-1.40	0.11-0.19	6.0-8.9	0.0-0.5	.43	.43			

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(7) Runoff, R_i, R_o

Surface runoff into a wetland from precipitation for water budgeting (R_i) is one of the most difficult parameters to obtain. Most methods estimate the daily or monthly runoff based on the runoff computed using the NRCS runoff curve number method. The precipitation used for these computations is the total precipitation for the time step (daily or monthly). Since the runoff curve number method is an event based model, the time step precipitation totals are assumed by the curve number method to be single rainfall events. This has been shown to work reasonably well if the analysis is performed on a daily time step. This is because most real discrete rainfall event totals are similar to daily precipitation totals from rain gage data. In addition, greater accuracy is obtained by making curve number adjustments based on antecedent runoff conditions (ARC). The SPAW computer program software performs the rainfall-runoff analysis on a daily time-step with these methods. The ARC adjustment in SPAW is made based on soil moisture accounting. The use of the SPAW Model is described in this chapter.

Wetland inflows and outflows (R_i and R_o) from discrete inlet streams can be measured directly, or estimated using channel hydraulics and visible evidence such as high water marks. In water budgeting situations, inflows are usually short-term events caused by rainfall on a watershed. Outflows can be continuous or nearly so, and match the rate of groundwater inflows. For this reason, measurement of R_o can often be used to estimate other water budget parameters. For instance, a discharge DEPRESSION wetland can have a current water budget composed of groundwater inflow, evapotranspiration loss, and runoff outflow. Between surface runoff events, the water budget equation reduces to:

$$G_i - ET = R_o \qquad \text{(eq.19–2)}$$

If ET can be reasonably estimated, a measurement of R_o can provide the current rate of G_i. The U.S. Bureau of Reclamation's Water Measurement Manual is a good source of water measurement information. Figure 19–30 shows the use of a simple sharp-crested weir for flow measurement.

(8) Pumped inflows and outflows

Pumped inflows and outflows are usually quite site specific and require examination and analysis of the equipment and conduits involved.

(9) Storage, ∆S

Water is stored in a wetland as surface water and as water stored in the soil matrix. Surface storage can be measured in depressions with accurate topographic mapping and calculation of depth-volume or depth-area relationships. Soil storage can be estimated based on soil properties. In theory, the determination of the total available storage in the soil matrix is relatively simple. The soil porosity can be estimated from soil bulk density. However, this is seldom adequate in an analysis because soil rarely experiences a condition where all water is removed from the matrix between wetland hydroperiods. For wetlands that have a significant transition to dry conditions at the end of the hydroperiod, but still maintain hydrophytic vegetation, the use of available water capacity can be considered. Assuming the vegetation typically survives the dry period, the driest condition will be at or above the permanent wilting point for the soil. During the hydroperiod, 100 percent of the voids will be full, which is in excess of field capacity. While this narrows the range for high and low moisture contents, the depth of the soil profile must be determined to find the total change in soil moisture storage. For wetland substrates that dry out from plant root extraction, the rooting depth can often be assumed to be the depth subject to

Figure 19–30 Flow measurement using a sharp-crested weir

moisture content change. In some cases, a significant restrictive soil layer exists, and this layer is at the effective rooting depth.

(i) Surface storage

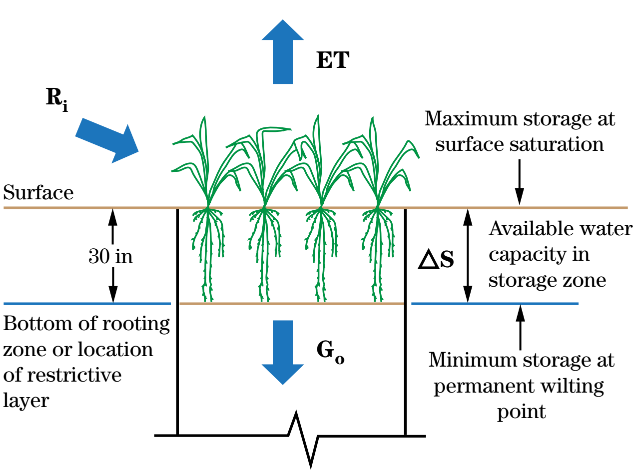
Surface storage is typically part of the hydrologic analysis of the DEPRESSIONAL HGM wetland type, or of depressions in the RIVERINE HGM wetland type. Topography is needed, and is obtained from onsite surveys or other high resolution sources. Many parts of the U.S. have Light Detection and Ranging (LIDAR) or other high resolution data which can be processed using GIS or Computer Aided Design (CAD) software.

(ii) Soil storage

The dynamics of water movement into and through soil, the storage of soil water, and the relationships between soil, water, and plants is complex, and requires an understanding of hydrology, soil physics, and plant physiology. The needed soil information varies depending on the HGM wetland type and hydrologic analysis.

For recharge DEPRESSIONAL wetlands that are not subject to groundwater inflows, a water budget can be performed using vertical saturated hydraulic conductivity and soil storage capacity. Figure 19–31 illustrates the water budget parameters for a wetland where soil storage is a component.

Figure 19–31 Soil storage in the water budget



Example—For the profile illustrated in figure 19–31, assume:

- A rooting depth of 30 inches
- Soil porosity ratio of 0.45
- Permanent wilting point at a volumetric water content of 2 inches per foot of depth

The maximum storage is:

$$0.45 \times 30 \text{ in} = 13.5 \text{ in}$$

Minimum storage is:

$$(2 \times 30)/12 \text{ in/ft} = 5 \text{ in}$$

Soil storage is:

$$13.5 - 5 = 8.5 \text{ in}$$

(e) Water budget applications

All wetland hydrologic analysis is based on water budgeting techniques to some extent. However, many applications do not solve the water budget directly. For instance, determination of the average amount of time a wetland is inundated by stream flooding uses stream gage data, but does not need the determination of the actual volume of water flowing through the floodplain. Another example is a SLOPE HGM wetland, where groundwater inflows maintain surface saturation. Since the actual volumes of groundwater entering and exiting the wetland are not easily measurable, the documentation of wetland hydrology is based on groundwater level monitoring applications, drainage lateral effects applications, or combinations of these and other methods.

(f) The time step

The term time step refers to the time increment with which the water budget is updated. Water budgeting is basically a checkbook method where inflows and outflows are tabulated, and the resulting balance of water in storage is recorded at each time increment. This balance update can be done in any time step increment, but the two most common are daily, and monthly. The time step can not be in smaller increments than available data. For instance, precipitation is readily available as daily data. Software programs, such as SPAW and DRAINMOD usually perform computations on a daily time step where daily data from a long-term period of record are processed.

Simplified techniques using spreadsheet methods or hand computations can, however, be applied to some wetland classes. These techniques generally use a monthly time step.

(g) Simplified water budget applications

Simplified water budget applications can be applied to wetlands with P and R_t as inflows, where outflows are limited to ET, G_o, and R_o, and where R_o is limited to water leaving the wetland after the wetland depression storage has been exceeded. The wetland water balance can be expressed as either a depth or a storage volume of water.

(i) Applicability to HGM classes

Simplified water budgeting applications are appropriate for DEPRESSIONAL HGM types that do not have significant groundwater inflows. These are recharge depressions. Many spreadsheet applications have been developed for simplified water budget applications.

Simplified water budgeting applications can also be applied on discharge depressions in the RIVERINE HGM type where there is no significant groundwater inflow. On RIVERINE depressions where surface flooding is not a significant water source, but water is supplied from an upland watershed, the analysis is the same as for DEPRESSIONAL HGM type wetlands. If stream flooding supplies water to a floodplain depression, but the duration of the flood hydrograph is short term, water budgeting can determine the duration of inundation after the depression is filled by short duration peak discharges. The determination of growing season peak discharges for streams is described in NEH650.1908, Floodplain applications.

(1) Limitations

The computation of surface runoff, R_t, is subject to the limitations described earlier.

The soil storage, S, is based on an assumed moisture content at the beginning of the hydroperiod. This requires the determination of a soil storage profile depth based on plant rooting depth, depth to a restrictive layer, or an assumed groundwater drawdown from ET and deep percolation. It also requires an assumption of the volumetric moisture content existing in this profile at the beginning of the analysis.

The groundwater outflow, G_o, is assumed to be a single value that represents the outflow throughout the hydroperiod. The analysis is not sensitive to this parameter where the soil has a relatively low permeability, especially where a distinct shallow perching layer exists.

(2) Examples

Example 1:

A recharge DEPRESSION wetland in Nebraska receives water from surface runoff and direct precipitation. Water is lost from vertical percolation through the soil, as well as evapotranspiration. The time step is monthly. In this case, the soil is assumed to be at permanent wilting point at the beginning of the analysis in September. The starting wetland volume, 6.93 inches, which is the available water capacity down to 33 inches, is obtained from the physical soil properties for Fillmore soil. The 33-inch depth is assumed to be the bottom of the root zone, and was chosen because it coincides with a soil horizon boundary. The monthly rainfall is from the WETS table for the nearest weather station. The volumes are expressed in inches. This assumes that the depression has an essentially flat bottom, and the change in depression surface area with depth is insignificant.

The surface runoff is calculated from a runoff curve number that is converted to a 30-day curve number. The 30-day curve number is used in the Agricultural Waste Management (AWM) computer program as a means to convert the total daily rainfall for an entire month into a single surface runoff value for the month. The AWM 30-day curve number is used only as an example. Use other appropriate curve number conversions, if available.

The loss of water due to movement through the soil is based on the K_{sat} values from WSS.

In the example, a monthly checkbook accounting is performed for a 12-month period. The depth of the depression is entered as 24 inches, and all water inputs that exceed this depth are assumed to flow out of the wetland. The ratio of drainage area to basin area is used as direct multiplier to convert depth of runoff to depth of basin storage. Starting with the beginning storage (either positive or negative), the monthly rainfall and runoff is added, and the monthly percolation and evapotranspiration is subtracted. In this example, the 12 month period ends with the storage at the maximum storage depth, and the basin can be assumed to maintain wetland hydrology. The results of the analysis are shown in figure 19–32.

Example 2:
The wetland is a floodplain depression, which is known to receive floodwater during the 50 percent chance annual peak discharge, or 2-year peak discharge. The depression has no significant drainage area of its own, so the ratio of drainage area to basin area is 0. Floodwater and monthly rainfall are the only hydrologic inputs. In this case, the flood discharge is assumed to occur in June. There is no need for the use of the runoff curve number (RCN) or any adjustment for 30-day runoff. In practice, the first step of this example would be the analysis of stream gage data to de-

Figure 19–32 Analysis of recharge DEPRESSION with drainage area

Wetland Water Budget Spreadsheet

County: Adams Cont. DA CN_1 = 85 CN_{III} = 67

Estimated Max. Deep Percolation= 0.5 Inches/Month Overflow Height = 24 Inches
Estimated Water Holding Capacity= 6.93 Inches
Ratio of Drainage Area: Basin Area= 10 (runoff multiplied by this ratio to obtain runoff, surface inches)

Month	Precip (Inches)	Runoff (Inches)	Runoff (Sur. In.)	Other Inflow (Sur. In.)	ET Potential (Inches)	Sum (Inches)	Deep Perc (Inches)	Sum (Inches)	Outflow (Inches)	Balance (Inches)
									Starting= →	-6.93
September	3.02	0.60	5.99		5.17	-3.09	0.00	-3.09	0.00	-3.09
October	1.67	0.08	0.85		3.76	-4.33	0.00	-4.33	0.00	-4.33
November	0.98	0.00	0.00		1.88	-5.23	0.00	-5.23	0.00	-5.23
December	0.85	0.00	0.00		0.94	-5.32	0.00	-5.32	0.00	-5.32
January	0.51	0.00	0.00		0.94	-5.75	0.00	-5.75	0.00	-5.75
February	0.70	0.00	0.00		1.41	-6.46	0.00	-6.46	0.00	-6.46
March	2.08	0.20	2.01		2.35	-4.72	0.00	-4.72	0.00	-4.72
April	2.54	0.38	3.76		4.70	-3.12	0.00	-3.12	0.00	-3.12
May	4.77	1.65	16.51		5.64	12.52	0.50	12.02	0.00	12.02
June	3.94	1.11	11.13		6.58	20.52	0.50	20.02	0.00	20.02
July	3.43	0.82	8.16		7.05	24.55	0.50	24.05	0.05	24.00
August	3.32	0.76	7.55		6.58	28.29	0.50	27.79	3.79	24.00
Total	27.8	5.8	55.96	0.00	47.00	47.8	2.00	45.8	3.84	

Soils Info:	Depth	AWC	Description
Fillmore, Clay County NE	0 - 19 in.	3.99	hydric
	19 - 33 in.	2.94	hydric
	33 - 45 in.	1.8	hydric

Design Info:
Precipitation and Runoff are monthly 50 percent chance events.
Et ~ 1.0 pan evaporation initial conditions, may be modified depending on location

termine the 50 percent chance annual peak discharge during the growing season. This flow would be converted to a stage using a channel rating to determine if the discharge accessed the floodplain. This step is described in case 4. Flood flows are assumed to fill depressions in the floodplain to their topographic storage capacity. Since floods can occur in any month during the growing season, it may be appropriate for the analysis to be performed for 2 or 3 separate months to determine the most critical month. Figure 19–33 shows the results of the analysis. The ponded depression, which is filled by floodwater in June, maintains surface ponding through August.

For depressions where the surface area changes significantly with depth, the stage-storage relationship must be determined from topography. The water budget must be calculated with the variable surface area taken into account, similar to reservoir routing. This can be done with manual calculations, or with the use of spreadsheet methods. The SPAW model software utilizes the depression's stage-storage in the water budgeting procedure.

Figure 19–33 Analysis for RIVERINE depression

Wetland Water Budget Spreadsheet

County: Adams   Cont. DA CN_1 = 85 CN_{II} = 67

Estimated Max. Deep Percolation= 0.5 Inches/Month   Overflow Height = 24 Inches

Estimated Water Holding Capacity= 6.93 Inches

Ratio of Drainage Area: Basin Area= 0 (runoff multiplied by this ratio to obtain runoff, surface inches)

Month	Precip (Inches)	Runoff (Inches)	Runoff (Sur. In.)	Other Inflow (Sur. In.)	ET Potential (Inches)	Sum (Inches)	Deep Perc (Inches)	Sum (Inches)	Outflow (Inches)	Balance (Inches)
									Starting= →	-6.93
September	3.02	0.60	0.00		5.17	-6.93	0.00	-6.93	0.00	-6.93
October	1.67	0.08	0.00		3.76	-6.93	0.00	-6.93	0.00	-6.93
November	0.98	0.00	0.00		1.88	-6.93	0.00	-6.93	0.00	-6.93
December	0.85	0.00	0.00		0.94	-6.93	0.00	-6.93	0.00	-6.93
January	0.51	0.00	0.00		0.94	-6.93	0.00	-6.93	0.00	-6.93
February	0.70	0.00	0.00		1.41	-6.93	0.00	-6.93	0.00	-6.93
March	2.08	0.20	0.00		2.35	-6.93	0.00	-6.93	0.00	-6.93
April	2.54	0.38	0.00		4.70	-6.93	0.00	-6.93	0.00	-6.93
May	4.77	1.65	0.00		5.64	-6.93	0.00	-6.93	0.00	-6.93
June	3.94	1.11	0.00	24.0	6.58	14.43	0.50	13.93	0.00	13.93
July	3.43	0.82	0.00		7.05	10.31	0.50	9.81	0.00	9.81
August	3.32	0.76	0.00		6.58	6.55	0.50	6.05	0.00	6.05
Total	27.8	5.6	0.00	24.00	47.00	-31.1	1.50	-32.8	0.00	

Soils Info:	Depth	AWC	Description
Fillmore, Clay County NE	0 - 19 in.	3.99	hydric
	19 - 33 in.	2.94	hydric
	33 - 45 in.	1.8	hydric

Design Info:
Precipitation and Runoff are monthly 50 percent chance events.
Et ~ 1.0 pan evaporation initial conditions, may be modified depending on location

650.1906 Tidal—estuarine applications

(a) Introduction

Wetlands under the influence of tidal fluctuations are in the ESTUARINE FRINGE HGM wetland class. The dominant water source is tidal, fresh, salt. or brackish water controlled by tidal action. Additional water sources can be precipitation, streamflow, and ground water recharge. In the estuaries of large rivers, the rise and fall of water becomes increasingly dominated by the stream hydrograph as the distance inland increases. For sites near the coasts where the tide cycle is the dominant influence, hydrologic modeling can concentrate on tide fluctuations alone.

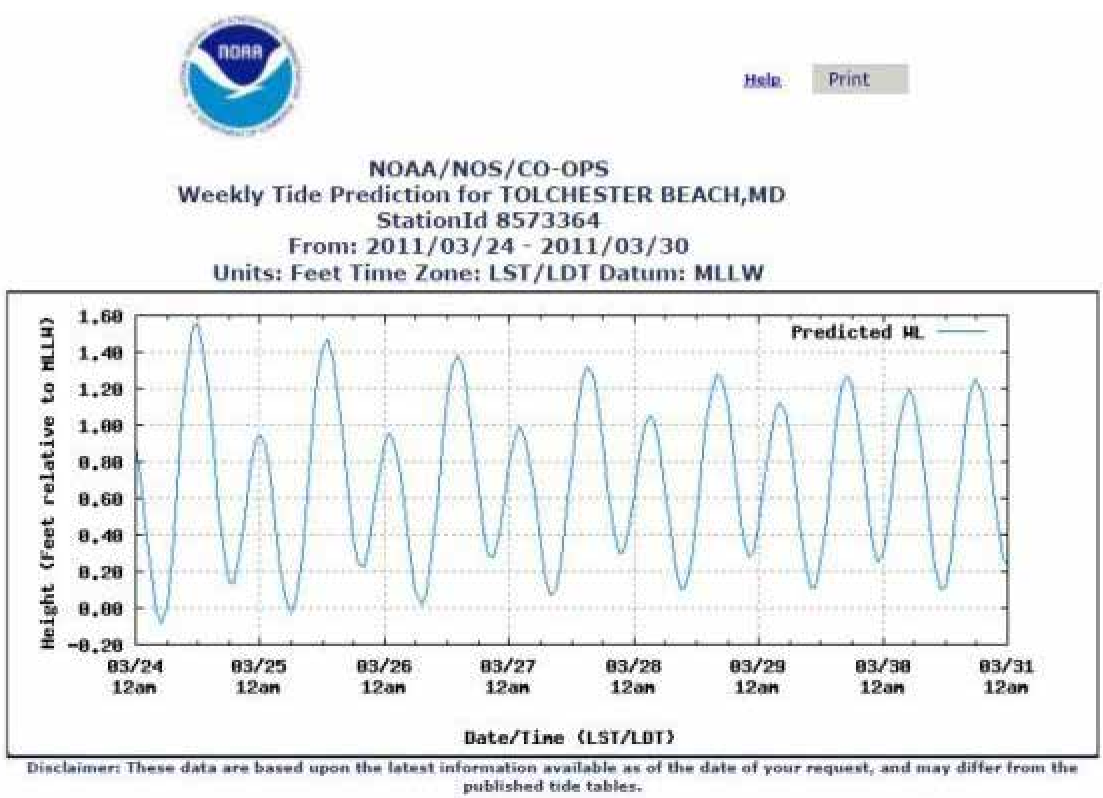
For these locations, water movement is essentially bidirectional and horizontal as tidal action moves water inland and seaward with tidal fluctuations.

(b) Tide data

Tide gage information is supplied by various agencies, but the main source of information is supplied by the NOAA, available at the current web location for tide and current data.

Tide information is available for historic maximums and minimums, daily data, and statistics, as well as predictions of future tide levels. Figure 19–34 shows a predicted tide hydrograph for a seven day period.

Figure 19–34 The hydrograph for 7-day period



(c) The tidal cycle

Tides are driven by the gravitational influence of the moon, and to a lesser extent, the sun. In addition, tides are affected by storm surges. Combinations of lunar, solar, and storm surge effects lead to extremes of tide elevation. When using tide data for design of infrastructure projects such as roads, bridges, or other elements where public safety and damage to property are of concern, these extremes should be considered. However, analysis of wetland hydrology for restoration design or wetland delineation is based upon long-term average conditions.

Tide data is only accurate for the location for which the data is presented. Large variations in tide elevation can occur across short distances. The transfer of tide gage data from a gage site to a project location should be done carefully, and with the assistance of a qualified hydrologist. Another option is the installation of water surface monitoring equipment at the wetland site. These installations are relatively inexpensive, and the data collection period need only cover a few lunar tide cycles which are not subject to lunar or storm extremes.

When basing analysis on tide elevations only, long term mean elevations are available from NOAA in terms of mean high water (MWH) and mean low water (MLW). These are the averages of all the high and low tide elevations over a 19–year period of record. It is apparent from the graph in Figure 19–34 that the daily tide cycle at this location has two high and two low tides, and they differ in magnitude. Not all locations have semidiurnal tides. The average of the highest daily tides is the mean higher high water (MHHW), and the average of the lowest daily tides is the mean lower low water (MLLW) and is calculated using data from the same period of record. In tidal fringe systems that are immediately adjacent to the tide gage station, the tide elevations can often be assumed to be the same as the elevations in the adjacent wetland.

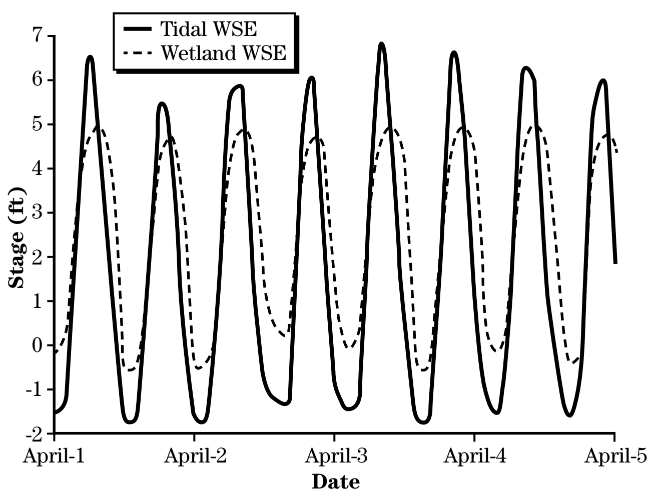
(d) Tidal inlet hydraulics

Tidal fringe wetlands typically receive water through discrete tidal inlet channels, which can be seen in the foreground of figure 19–35. These channels move water into and out of the wetland bidirectionally. They have a geometry that is in equilibrium with the volume of water and sediment moved in and out, and under the tractive stress induced by the flow. In many cases, the inlet channel has been modified by the construction of roads with bridges or culverts, or levees with control structures. The volume of water moved through an inlet during a tide cycle is referred to as the tidal prism. The volume of the tidal prism is controlled by the conveyance of the inlet channel or inlet structures. Both natural inlet channels and manmade structures attenuate the range of tidal fluctuation in the wetland. Therefore, the wetland high elevation is lower than the tidal high elevation and wetland low elevation is higher than the tidal low elevation. This is shown in figure 19–36, where the tide gage elevations are plotted with a solid line, and the wetland water levels are with a dashed line. The inlet illustrated in the figure is controlled by a culvert. In cases where freshwater surface inflows into the wetland from landward are negligible, the attenuated tidal elevation represents the inundation level for the wetland.

There are several methods for water surface profile modeling of the bidirectional flow in a tidal wetland system on a time step basis. It is recommended that the modeling period for such analyses cover at least one 28-day lunar cycle. This inflow hydrograph is analogous to the use of a stream inflow hydrograph used for design of hydraulic structures. When us-

Figure 19–35 Tidal inlet channels

Figure 19–36 Tide fluctuations attenuated by inlet geometry



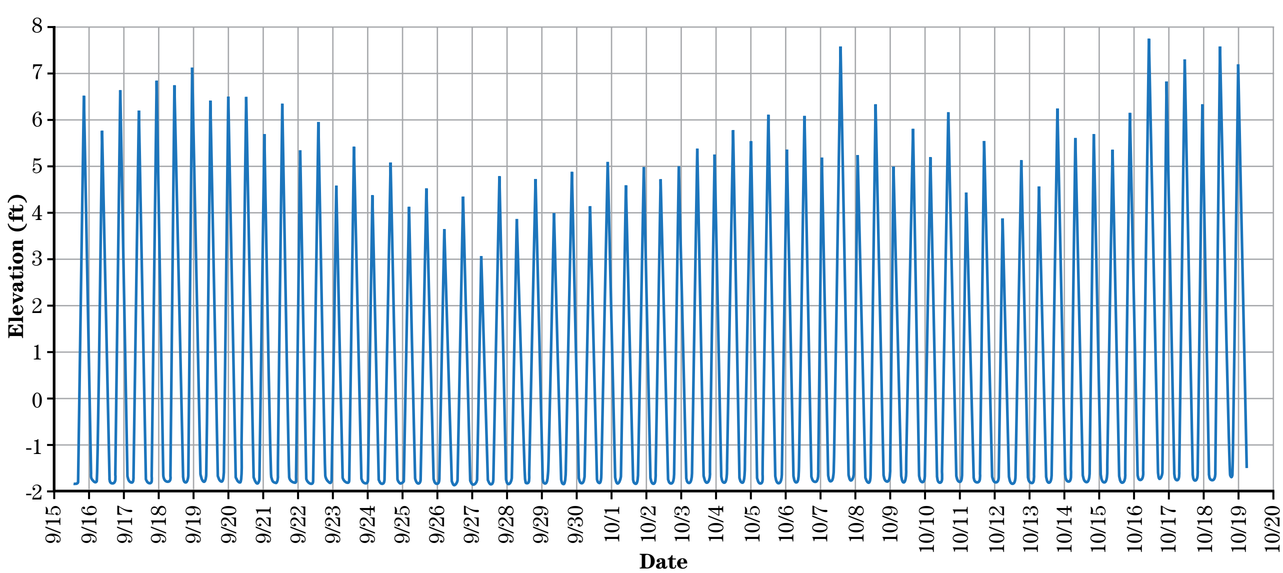
ing streamflow hydrographs for design, the methods require the development of a design hydrograph that is used to represent natural hydrographs for a certain probability and frequency of occurrence. However, there is no method for the development of a design hydrograph for tides. The data used for modeling should be historic data where there were no unusual storm surge events. Historic data is usually available in short time steps, such as 6 minutes, that are appropriate for use in the HEC-RAS water surface profile modeling software. Predictions of future tide cycles are usually only available as predicted daily highs and lows, with a time step too long for use by software. Figure 19–37 shows a plot of tide cycles covering a month long time period.

(e) Hydrologic Engineering Center River Analysis System (HEC-RAS) analysis

(1) Example

This example uses Hydrologic Engineering Center River Analysis System (HEC-RAS) to determine the maximum inundation level on a tidal fringe wetland. HEC-RAS is a powerful analysis tool but it has some inherent limitations that the user must be aware and account for in their analysis. These include:

Figure 19–37 Tide cycles for a one-month period

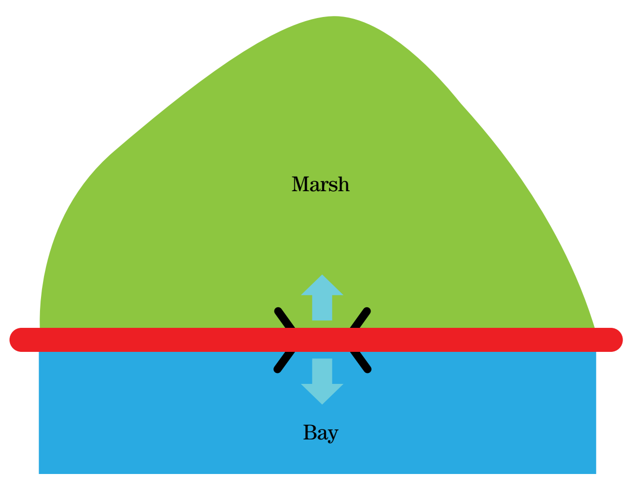


- *One-dimensional analysis*—Since HEC-RAS is a one-dimensional model, the calculations are based on the assumption of a level flow across a section. With a narrow wetland, this assumption is close to reality. If a wetland has a broader aspect ratio, the level of flow in the overbank may be different than the flow in the channels. As a result, a two-dimensional model may be more appropriate for larger wetlands depending upon the questions that are being asked of the model.
- *Static boundary*—Most applications of unsteady runs of the HEC-RAS model assume a static boundary. The cross sections stay the same over time. This assumption is valid in many circumstances for analysis durations of a few years. But over time, the interaction of soil, water and vegetation will cause the surface to rise or fall. The HEC-RAS model does not contain analysis tools to adjust the shape of sections. As a result, the predicted hydraulics may become progressively inaccurate.
- *Solid boundary:* Most application of HEC-RAS assumes flows as boundary conditions to the reaches. An exchange of water with the substrate that makes up the channel boundary is not part of the analysis tool. In many cases, water is stored in the soil profile on high tide and released during low tide. If the modeler expects this to be significant, other analysis may be necessary.
- There are some particular adjustments that a user should keep in mind in developing a HEC-RAS model of a wetland and analyzing the results. These include:
  - — *Roughness:* In most applications, a user of HEC-RAS assign a single roughness value for a portion of a section. This is appropriate in many high flow applications. However, for wetland analysis, the roughness may vary seasonally due to vegetative differences. In addition, since much analysis using HEC-RAS is directed towards low flows, the roughness may need to vary by height. HEC-RAS contains tools to allow for this analysis.
  - — *Cross section spacing*: One of the significant advantages of using HEC-RAS is the large number of existing models that have been developed for different reach conditions. It may seem to be a relatively easy application to take a model that was developed to analysis flood conditions and apply it to a wetland analysis. While this can save significant survey time, some caution needs to be applied by the modeler. The cross section spacing that is suitable for a high flow analysis often assumes that the flows fill the floodplain and proceed straight down the watershed. A wetland analysis is often focused on lower or more normal flows where the water proceeds in a more serpentine fashion down the channels. As a result, the cross section spacing may need to be longer.

(2) HEC-RAS example

There are two approaches for modeling. The first approach assumes that the water level in the marsh matches the water level at the end of the culvert across the entire marsh area in the same way as a small pond. This approach is more valid for wide areas that do not extend far inland (fig. 19–38). The second approach models the wetland area as a narrower channel where the water surface elevation is affected by flow resistance as water moves from the bay to the wetland fringe and back. In the first case, the wetland is modeled by using the stage-storage relationship. In the second case, the wetland is modeled with 1-D cross sections.

Figure 19–38 Schematic tidal inlet system



For both cases, the model uses the tide cycle as a downstream boundary condition. Figure 19–39 shows a screen shot of the Unsteady Flow Data dialog box.

The tidal fluctuations are attenuated due to the restriction of the culvert. In figure 19–40, the difference between the maximum tide level and the attenuated maximum water level in the wetland is nearly 3 feet. These water levels represent the maximum high tide and maximum water level reached in the wetland, respectively, over the month long period modeled. Note that the maximum water surface of the wetland side is level, even though the maximum water surfaces were attained at different times for different channel stations.

The maximum water surface should not be taken as the elevation at the wetland boundary. The water surface with the requisite duration and frequency for wetland hydrology will be lower. The daily maximum water surfaces can be extracted from the data available from the HEC-RAS model for statistical analysis. The minimum elevation for a specified duration criteria represents the elevation at the wetland boundary. This elevation is analogous to the water surface elevation representing the result of a probability-duration analysis in accordance with the methods in NEH650.1904. However, the period of record here is only one lunar tide cycle, not a 10 to 30 year period of record. If the required duration of inundation is 15 days, for instance, the modeling period represents only two 15-day periods. For this reason, the minimum elevation that satisfies this criterion can be assumed to be the minimum of the daily maximum water surface elevations during one lunar tide cycle.

Figure 19–39 HEC-RAS unsteady flow data dialog box

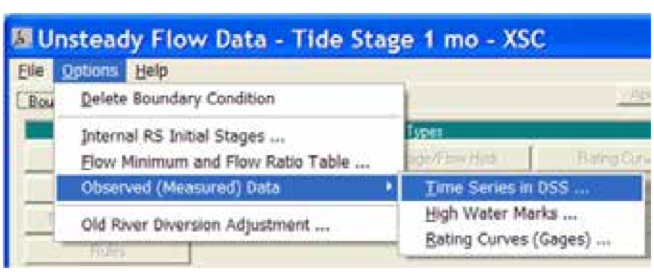
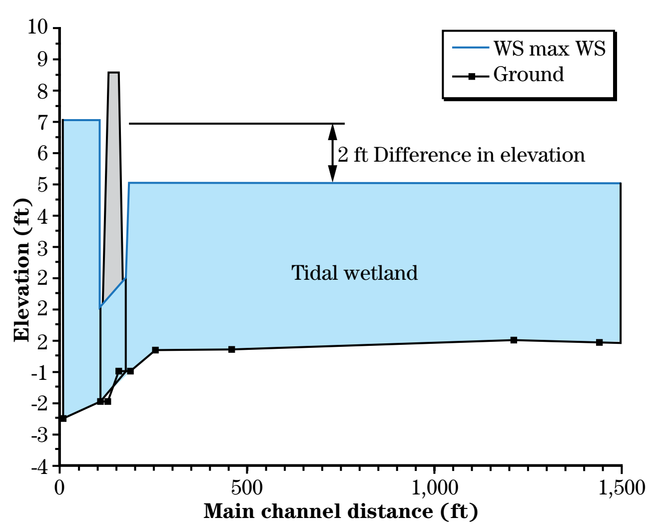


Figure 19–40 HEC-RAS graphic of tide stage and wetland stage



650.1907 Lake data applications

(a) Introduction

This section is applicable to those wetlands that have a hydrology dominated by lake water elevations. Many lakes have a nearly constant water level, while others have significant fluctuations. These fluctuations create wetland inflows and outflows, cause changes in groundwater levels, and can create hydrologic extremes from inundated to dry. These wetlands are generally of the LACUSTRINE FRINGE HGM wetland type. Before focusing on lake level data, it must be determined that the wetland does not receive significant water inputs from other sources. For instance, LACUSTRINE FRINGE wetlands often transition into SLOPE wetlands that have a strong source of groundwater inflow from adjacent uplands.

(b) Lake level data

The availability of lake level data varies significantly from state to state and even from location to location. The length of record will influence the usefulness of the data. A record that includes several periods of drought and abundance of water will have better statistics for numerical analysis for frequency of inundation.

(1) Normal environmental conditions

Aerial photography, or images over a period of time, tell the story of a lake's response to precipitation abundance and deficit, and changes in the watershed. Linking these images with a survey or topographic map allows conclusions to be drawn about the frequency at which a lake reaches high and low levels. The precipitation records can be examined for antecedent moisture conditions, but often the variability in the lag for water reaching a lake does not allow a strong correlation between recent weather and the lake level. The use of the remotely sensed images with precipitation data may provide misleading results. The water level in the wetland is related to the lake level, not recent precipitation.

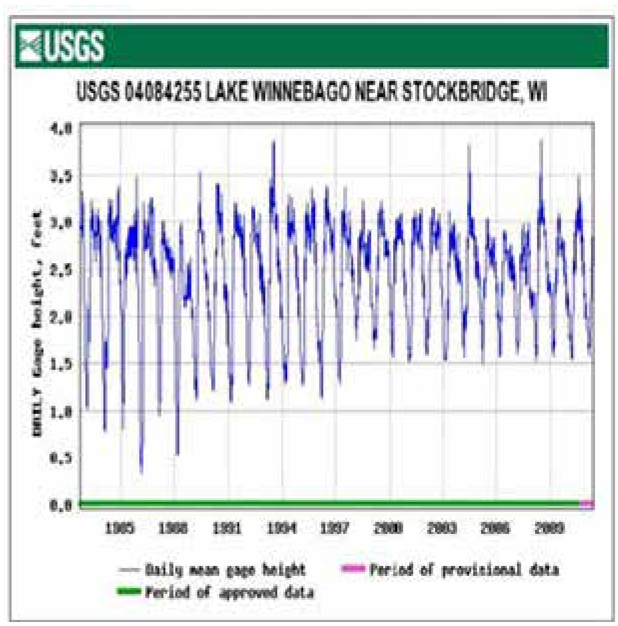
Using available lake level data on a daily, monthly, or annual basis can be used to document national environmental conditions (NEC). In this context, a lake level that is within the defined low and high percentile can be assumed to be within the NEC for an adjacent wetland. Generally, the 30th and 70th percentile is used for low and high levels. NEC is used when conducting an onsite determination of wetland hydrology.

(2) Probability duration analysis with lake gage data

Where daily lake level data statistics are available, often from a State or local agency, numerical analysis can be done to tie specific elevations to the probability of occurrence of a duration of inundation. This analysis requires that daily lake level data be available for a 10 year period of record. Figure 19–41 shows a graph of daily lake stage obtained from USGS.

The result of this analysis can be used to directly document wetland hydrology in terms of objective criteria for wetland hydrology, such as the 50 percent chance annual probability of inundation for a continuous 15 day period.

Figure 19–41 Graph of lake stage



(c) Other information

States may identify a level on each lake labeled something like ordinary high water. This is related to observations of natural fluctuations more than numerical statistics. For example, the ordinary high water level is an elevation delineating the highest water level that has been maintained for a sufficient period of time to leave evidence upon the landscape, commonly the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial. In the case of a simulated lake with a managed water level, the ordinary high water may be defined as the operating elevation of the normal summer pool. This elevation may be helpful for knowing the extent, duration and frequency of saturation or inundation and the probability that a site has sufficient wetness to meet the wetland hydrology criterion.

(d) Reservoirs

Wetlands adjacent to manmade or natural reservoirs modified to control outflow are maintained by lake level fluctuations in the same way as natural lakes. However, these wetlands are usually artificial wetlands, or are wetlands with altered hydrology. Their hydrology can be analyzed with the use of lake level reports maintained by the lake manager. If daily data is available for a long period of record, it can be used for probability-duration analysis as described. Use of this data is made under the assumption that reservoir operations over the period of record represent releases made using the same operation plan. Changes in the management of pool levels during the period of record must be taken into account.

650.1908 Floodplain applications

(a) Introduction

This application is appropriate for RIVERINE wetlands. The dominant water source of RIVERINE wetlands is the active stream channel, and the landscape positions where they exist are floodplains. The stream hydrograph supplies surface floodwater and/or supports a high groundwater table in a floodplain wetland system. There are many floodplain wetlands that do not rely upon stream supplied water to maintain wetland hydrology, even though they exist on a floodplain landscape. Altered channels may no longer be hydrologically connected with the floodplain. Water from sources such as direct precipitation, or surface runoff and groundwater inflows from uplands may be adequate to maintain floodplain wetlands without stream water. The applications presented only apply to the frequency and duration of water provided by the stream water source by dynamic flooding or groundwater. In systems where the stream frequently supplies water to its floodplain, the wetland hydroperiod usually persists past the duration of the stream hydrograph in floodplain depressions.

The situation where floodplain wetland hydrology is maintained by surface flooding, and the consequent ponding in depressional areas is referred to as episaturation. Floodplains with wetlands supported by a high groundwater table that is supported by the stream water surface profile are endosaturated. The documentation of wetland hydrology based on streamflow requires the collection of stream gage data and performing hydraulic analysis. The procedures differ depending on the proximity of the gage sites, whether the wetland is episaturated, or endosaturated, and whether inundation from dynamic flooding alone provides wetland hydrology.

(b) Limitations

The applications presented here require a reliable set of stream gage data that is near the wetland site. This data must cover at least a 10-year period of record, and the flow values must not have significantly changed because of changes in watershed condition, flow diversion or augmentation, the installation of upstream detention structures, or other reasons.

Gage data must be processed to provide probabilities of occurrence, flow durations, and return period intervals. The user must be familiar with statistical analysis techniques, spreadsheet methods, and computer tools. Knowledge of the hydraulics of open channel flow is also required.

Many wetlands in the RIVERINE HGM type receive a significant amount of water from other than streamflows, so these procedures alone may not adequately address all the water budget parameters that affect the wetland. They may need to be used in conjunction with other hydrologic analyses, such as the use of remotely sensed data to document saturation

(c) Cases

This section describes four separate cases.

- Wetland hydrology is maintained by depth and duration of surface flooding only. Site is near a stream gage.
- Wetland hydrology is maintained by depth and duration of surface flooding only, as in case 1, but site is not near a stream gage. This requires that adjustments be made in flows and/or stage.
- Wetland hydrology is maintained by high water table, which is supported by stream water surface. Surface flooding alone does not support hydrology.
- Wetland delineation site is a floodplain macrotopographic feature where surface ponding provides much of the hydroperiod. Neither flood duration nor high groundwater alone can maintain wetland hydrology.

Each of these cases are examined by separate procedures. The selection of the appropriate procedure can be assisted with the information provided.

(i) Case 1—Wetland hydrology maintained by depth and duration of surface flooding only. Site is near a stream gage.

Conditions where the duration of flooding alone maintains wetland hydrology are common in the southeastern United States region. However, this condition does exist in other areas where the climate, watershed characteristics, and stream/floodplain morphology commonly create conditions that provide flood durations from several days to several weeks during the growing season. This hydroperiod usually occurs from the late winter to early spring. In southern Florida, it occurs during the summer and fall. For these areas, the documentation of flood duration by itself may be adequate to prove wetland hydrology based on objective criteria for frequency and duration.

Assumptions

- The gage is adjacent to the wetland, so the gage elevations are the same as the resulting water surface levels at the wetland.
- The wetland is a floodplain flat, and the period of inundation is the same as the duration of the flood hydrograph.

Data requirements

- Mean daily flows for a continuous 10-year period of record. The primary source for mean daily flow data is the USGS, which provides access to stream gage data at their current web site. Other federal agencies, such as the USACE, the BuRec, or the Tennessee Valley Authority (TVA) may maintain flow data. In addition, many State agencies maintain stream gages and make data available.
- Known channel rating for the gage site. At USGS gage stations, the current channel rating curve is usually available. Gage ratings should be verified by contacting the responsible USGS office. There may be different rating tables for different flow stages or times of year.
- Topographic information for the floodplain.
- Climate data needed to determine the beginning and end of the growing season. This is available in the WETS tables.

Procedure

Step 1: Determine the duration criteria for the determination, and the growing season period where the duration criteria must be met. The criteria will vary depending on the purpose of the analysis. For instance, it may be 5 percent of the growing season, or 15 days. The growing season is determined from the WETS tables.

Step 2: Determine the flow corresponding to the applicable probability-duration criteria. The annual maximum duration flow must occur during the growing season.

Step 3: Obtain the gage rating to determine the stage-discharge relationship for the stream channel at the determination site.

Step 4: Add the gate datum to the stage corresponding to the flow determined in step 2.

Step 5: Using the elevation determined in step 4, and the topographic data collected for the determination site, determine the extent of inundation meeting the determination criteria.

Example 1

A floodplain tract along the Grand River near Gallatin, Missouri, has had recent drainage modifications. A hydrology analysis has been requested. The criterion in this case is 15 days of inundation during the growing season. The average elevation of the wetland tract is 740.0 feet above MSL.

The first steps of this example are the same as the example in NEH650.1904, and are repeated.

Step 1: The available WETS tables for Daviess County, Missouri, do not include growing season data. The Amity weather station in DeKalb County has virtually the same latitude and elevation as Daviess County. The WETS table for this station shows that there is a 50 percent probability that temperatures will not drop below 28 degrees between April 11 and November 18. Only streamflow from this 190-day growing season period can be considered when determining wetland inundation.

Step 2: The USGS operates a stream gage a short distance from the determination site. Available information includes mean daily flows. The mean daily flows for the previous 20 years of record were extracted, beginning with water year 1988, and ending with water year 2007. Note that water years begin on October 1, and ends on September 30. Analyzing data on a calendar year basis will usually not result in a significant difference in results. However, USGS published statistical data is based on water year. To maintain consistency, following this format is good hydrologic practice.

The result of the analysis is that there is a 50 percent chance that a flow of 1,245 cubic feet per second will occur for at least a 15-day duration during the growing season. Figure 19–42 shows a graphical presentation of the analysis. The spreadsheet used for the analysis is shown in table 19–4.

Step 3: Determine the stage-discharge relationship at the determination site. Since the determination location is relatively close to the gage location, the assumption is that it is appropriate to use the gage rating directly. The stream gage rating was obtained from USGS.

Since the determination site is relatively near the gage site, the difference in drainage area between the gage location and the determination location is small. No adjustment in the 50 percent probability flow or the stage is needed.

The gage rating is downloaded as a *.txt file, a portion of which is shown in table 19–5, and can be opened in Excel®.

The gage datum can be obtained from the same location as the mean daily flow data. Figure 19–43 shows the Web page.

Figure 19–42 Plot of annual duration flows

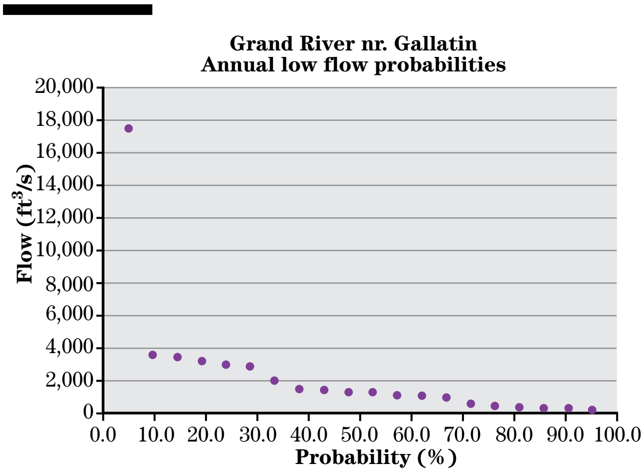


Table 19–4 Flow probability - duration spreadsheet

GRAND RIVER NEAR GALLATIN, MISSOURI

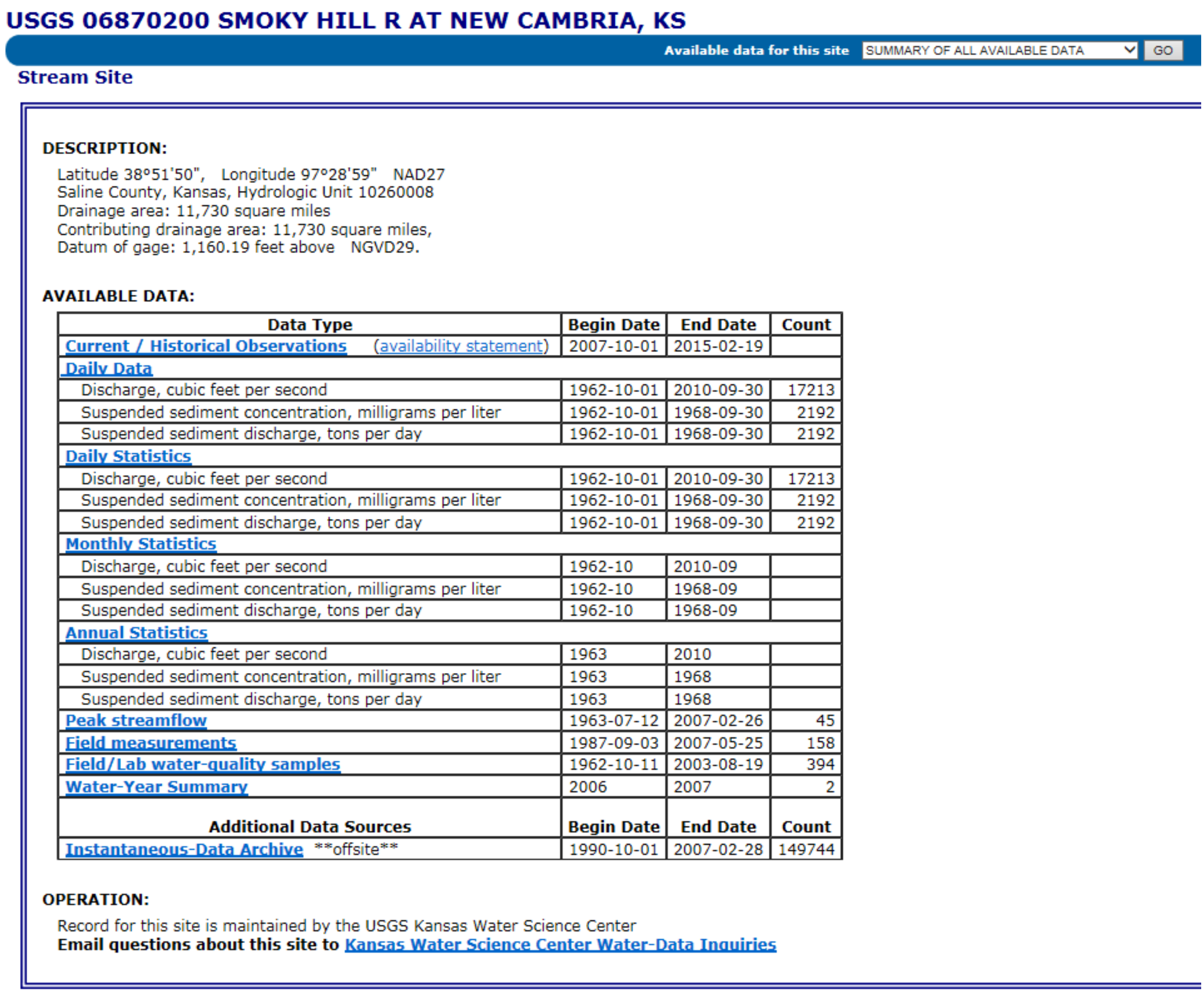
15 day flow exceedence probability—Annual series

Date	Flow at gage	15 day duration low flow	Water year	Max. 15 day flow	Rank	% Probability of exceedence (Weibull Plotting Position)
10/1/1987	156		1988	335	17	81.0
10/2/1987	145		1989	270	19	90.5
10/3/1987	137		1990	1,040	13	61.9
10/4/1987	131		1991	1,940	7	33.3
10/5/1987	128		1992	1,270	10	47.6
10/6/1987	126		1993	17,500	1	4.8
10/7/1987	121		1994	1,410	9	42.9
10/8/1987	119		1995	3,420	3	14.3
10/9/1987	115		1996	3,560	2	9.5
10/10/1987	113		1997	2,960	5	23.8
10/11/1987	113		1998	3,170	4	19.0
10/12/1987	113		1999	2,820	6	28.6
10/13/1987	113		2000	386	16	76.2
10/14/1987	113		2001	1,220	11	52.4
10/15/1987	114	113	2002	923	14	66.7
10/16/1987	123	113	2003	138	20	95.2
10/17/1987	133	113	2004	1,420	8	38.1
10/18/1987	139	113	2005	565	15	71.4
10/19/1987	139	113	2006	291	18	85.7
10/20/1987	128	113	2007	1,100	12	57.1
10/21/1987	120	113				
10/22/1987	117	113		Median		1,245
10/23/1987	123	113		50th percentile		1,245
10/24/1987	125	113		Average		2,287
10/25/1987	123	113				
10/26/1987	117	113				
10/27/1987	113	113				
10/28/1987	115	113				
10/29/1987	119	113				
10/30/1987	116	113				
10/31/1987	121	113				
11/1/1987	4270	113				
11/2/1987	9250	113				

Table 19–5 Stream gage rating table

```
                                GrandRiverRating.txt
# //UNITED STATES GEOLOGICAL SURVEY        http://water.usgs.gov/
# //NATIONAL WATER INFORMATION SYSTEM      http://water.usgs.gov/data.html
# //DATA ARE PROVISIONAL AND SUBJECT TO CHANGE UNTIL PUBLISHED BY USGS
# //RETRIEVED: 2008-05-08 20:45:39
# //WARNING
# //WARNING The stage-discharge rating provided in this file should be
# //WARNING considered provisional and subject to change. Stage-discharge
# //WARNING ratings change over time as the channel features that control
# //WARNING the relation between stage and discharge vary. Users are
# //WARNING cautioned to consider carefully the applicability of this
# //WARNING rating before using it for decisions that concern personal or
# //WARNING public safety or operational consequences.
# //WARNING
# //FILE TYPE="NWIS RATING"
# //DATABASE NUMBER=1  DESCRIPTION=" Standard data base for this site."
# //STATION AGENCY="USGS " NUMBER="06897500        " TIME_ZONE="CST" DST_FLAG=Y
# //STATION NAME="Grand River near Gallatin, MO"
# //DD NUMBER="   4" LABEL="Discharge (cfs)"
# //PARAMETER CODE="00060"
# //RATING SHIFTED="20080508200000 CDT"
# //RATING ID="36.0" TYPE="STGQ" NAME="stage-discharge" AGING=A
# //RATING REMARKS="Radical control change & new PZF"
# //RATING EXPANSION="logarithmic"
# //RATING OFFSET1=4.50
# //RATING_INDEP ROUNDING="2223456782" PARAMETER="Gage height (ft)"
# //RATING_DEP ROUNDING="2222233332" PARAMETER="Discharge (cfs)"
# //RATING_DATETIME BEGIN=20070508160000 BZONE=CDT END=20070930235959 EZONE=CDT
AGING=A
# //RATING_DATETIME COMMENT="Radical control change."
# //RATING_DATETIME BEGIN=20071001000000 BZONE=CDT END=20071030235959 EZONE=CDT
AGING=W
# //RATING_DATETIME COMMENT="Radical control change."
# //RATING_DATETIME BEGIN=20071031000000 BZONE=CDT END=20080228235959 EZONE=CST
AGING=R
# //RATING_DATETIME COMMENT="Radical control change."
# //RATING_DATETIME BEGIN=20080229000000 BZONE=CST END=23821230090000 EZONE=CST
AGING=W
# //RATING_DATETIME COMMENT="Radical control change."
# //SHIFT_PREV BEGIN="20080401152800" BZONE="CDT" END="--------------" EZONE="---"
# //SHIFT_PREV STAGE1="10.11" SHIFT1="2.20" STAGE2="16.00" SHIFT2="0.00"
# //SHIFT_PREV COMMENT="shift indicated by msmt 1188"
# //SHIFT_NEXT BEGIN="--------------" BZONE="---" END="--------------" EZONE="---"
# //SHIFT_NEXT STAGE1="---" SHIFT1="---" STAGE2="---" SHIFT2="---" STAGE3="---"
SHIFT3="---"
# //SHIFT_NEXT COMMENT=" "
INDEP   SHIFT   DEP     STOR
16N     16N     16N     1S
2.33    2.20    0.00    *
2.34    2.20    0.11
2.35    2.20    0.22
2.36    2.20    0.33
2.37    2.20    0.44
2.38    2.20    0.55
2.39    2.20    0.66
2.40    2.20    0.77    *
2.41    2.20    0.92
2.42    2.20    1.1
2.43    2.20    1.3
2.44    2.20    1.4
2.45    2.20    1.6
2.46    2.20    1.8
2.47    2.20    2.1
2.48    2.20    2.3     *
```

Figure 19–43 USGS Web site showing gage datum information



USGS 06870200 SMOKY HILL R AT NEW CAMBRIA, KS

Available data for this site SUMMARY OF ALL AVAILABLE DATA GO

Stream Site

DESCRIPTION:

Latitude 38°51'50", Longitude 97°28'59" NAD27
Saline County, Kansas, Hydrologic Unit 10260008
Drainage area: 11,730 square miles
Contributing drainage area: 11,730 square miles,
Datum of gage: 1,160.19 feet above NGVD29.

AVAILABLE DATA:

Data Type	Begin Date	End Date	Count
Current / Historical Observations (availability statement)	2007-10-01	2015-02-19	
Daily Data			
Discharge, cubic feet per second	1962-10-01	2010-09-30	17213
Suspended sediment concentration, milligrams per liter	1962-10-01	1968-09-30	2192
Suspended sediment discharge, tons per day	1962-10-01	1968-09-30	2192
Daily Statistics			
Discharge, cubic feet per second	1962-10-01	2010-09-30	17213
Suspended sediment concentration, milligrams per liter	1962-10-01	1968-09-30	2192
Suspended sediment discharge, tons per day	1962-10-01	1968-09-30	2192
Monthly Statistics			
Discharge, cubic feet per second	1962-10	2010-09	
Suspended sediment concentration, milligrams per liter	1962-10	1968-09	
Suspended sediment discharge, tons per day	1962-10	1968-09	
Annual Statistics			
Discharge, cubic feet per second	1963	2010	
Suspended sediment concentration, milligrams per liter	1963	1968	
Suspended sediment discharge, tons per day	1963	1968	
Peak streamflow	1963-07-12	2007-02-26	45
Field measurements	1987-09-03	2007-05-25	158
Field/Lab water-quality samples	1962-10-11	2003-08-19	394
Water-Year Summary	2006	2007	2
Additional Data Sources	**Begin Date**	**End Date**	**Count**
Instantaneous-Data Archive **offsite**	1990-10-01	2007-02-28	149744

OPERATION:

Record for this site is maintained by the USGS Kansas Water Science Center
Email questions about this site to Kansas Water Science Center Water-Data Inquiries

Step 4: The gage datum is 707.55 feet above the MSL. Adding this value to the gage height provides the MSL elevation for the individual flows. Table 19–6 shows the portion of the rating data covering the 1,245 cubic feet per second flow from the previous step after importing into Excel®, and making the gage datum adjustment.

The gage reading corresponding to 1,245 cubic feet per second can be seen to be approximately 6.84. Adding this figure to the gage datum of 707.55 results in a 15-day duration flow elevation of 714.39.

Step 5: Since the determination site's average ground elevation is 740, the duration criteria is not met by dynamic flooding.

This does not mean that surface inundation does not occur. But the analysis shows that flooding does not occur with a 50 percent chance probability of occurrence for 15 consecutive days during the growing season on an average year. Floodplain depressional areas capable of ponding water will still have inundated conditions after a short-term flood. This situation is described in example 3.

Example 2
An analysis is needed for a floodplain site on the James River near Huron, South Dakota. This example uses 14 days as objective criteria for inundation.

Step 1: The WETS table for the Huron Regional Airport shows a growing season starting on April 25, and ending on October 6.

Step 2: The USGS stream gage 06476000, James River at Huron is adjacent to the site. It has a continuous record of mean daily flows and annual peak discharges beginning in 1943. It also shows the National Weather Service (NWS) flood stage, which is 11.0 feet. Using the procedure described in NEH650.1904, the 50 percent annual probability 14-day duration flow was calculated, and found to be 1,460 cubic feet per second.

Step 3: The USGS gage rating for the site was downloaded, using the web address shown in the previous example. A portion of the rating table is shown in table 19–7.

The gage reading corresponding to 1,460 cubic feet per second is 10.39, which is within 0.6 feet of the NWS flood stage. Low lying areas adjacent to the James River can be expected to have a duration of inundation long enough to meet the criteria for wetland.

Step 4: The gage information includes the gage datum, which is 1,223.44 feet above the National Geodetic Vertical Datum of 1929. Adding this elevation to the gage reading of 10.39 provides a water surface elevation of 1,233.83 on the 1929 datum.

Table 19–6 Stream gage rating data

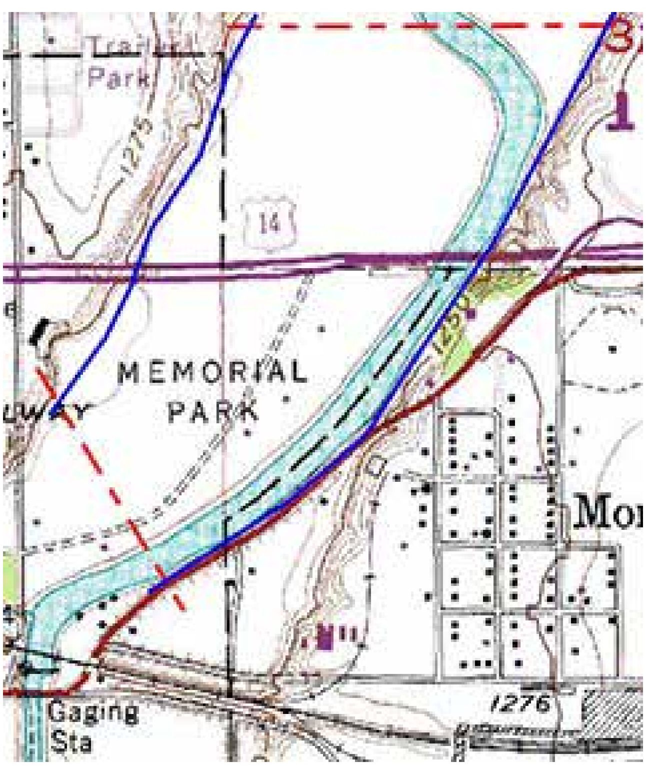
6.76	2.20	1,200	6.86	2.20	1,250
6.77	2.20	1,210	6.87	2.20	1,260
6.78	2.20	1,210	6.88	2.20	1,260
6.79	2.20	1,220	6.89	2.20	1,270
6.80	2.20	1,220	6.90	2.20	1,280
6.81	2.20	1,230	6.91	2.20	1,280
6.82	2.20	1,230	6.92	2.20	1,290
6.83	2.20	1,240	6.93	2.20	1,290
6.84	2.20	1,240	6.94	2.20	1,300
6.85	2.20	1,250	6.95	2.20	1,300

Table 19–7 Rating table for James River

10.30	0.00	1,330	10.40	0.00	1,480
10.31	0.00	1,350	10.41	0.00	1,490
10.32	0.00	1,360	10.42	0.00	1,510
10.33	0.00	1,380	10.43	0.00	1,520
10.34	0.00	1,390	10.44	0.00	1,530
10.35	0.00	1,400	10.45	0.00	1,550
10.36	0.00	1,420	10.46	0.00	1,560
10.37	0.00	1,430	10.47	0.00	1,580
10.38	0.00	1,450	10.48	0.00	1,590
10.39	0.00	1,460	10.49	0.00	1,610

Step 5: A map of the inundated area is shown in figure 19–44. The up and downstream boundaries are indicated with red dashed lines, and the water surface profile elevations are indicated by the solid blue lines. This map is based on a single elevation developed from the gage rating table adjusted to the gage datum. It is drawn on a USGS topographic map with contour resolution of 5 feet. It does not reflect water surface profile slope or the backwater effects on flow caused by bridges or other floodplain features. More accurate maps, if needed, can be made from topographic information available in digital elevation model (DEM) layers and processed using GIS software. Accuracy can be further improved by performing water surface profile analysis using HEC-RAS, and with more accurate topographic data using surveyed cross sections.

Figure 19–44 Inundation map



(ii) Case 2—Site is not near a gage, and dynamic flooding alone provides the duration of wetland hydroperiod.

Procedure:

Step 1: Determine growing season dates.

Step 2: Determine probability-duration flows from nearest available gage(s).

Step 3: Step 3 from case 1 is modified for wetland sites that are not adjacent to a USGS stream gage.

The available mean daily flow data may or may not be adequate without adjustment. If a judgment is made that the gage is far enough away from the site to warrant flow data adjustment, refer to the methods described in NEH654.05. This document describes methods for transferring peak discharge data from a gaged site to an ungaged site. EFH630.13, Stage Inundation Relations, can be used for developing a channel rating for a location not near a gage site.

For wetland hydrologic analyses, the flows are probability-duration flows instead of return period peak discharges. Considerable effort can be expended on gage data transfer calculations. The following should be considered before this effort is undertaken:

- If the wetland site is downstream of the gage, the calculated flow will usually be higher than the actual flow, making the result more conservative.
- If the wetland site is between two gage stations, their probability-duration flows can be used to determine the resulting stages at each gage, and the stage at the wetland site can be interpolated, as shown in case 2 example.

Steps 4 and 5*:* Same as in case 1 examples

Example 1

Steps 1 and 2*:* The procedures in NEH650.1904 were used to determine the 15-day, 50 percent chance low flows for a site between 2 gage sites with a long-term period of continuous data. The gage ratings were used to determine the flows corresponding to the 50 percent chance, 15-day discharges during the growing season at each site.

Steps 3 and 4*:* Stage interpolation alternative The rating tables for the upstream and downstream gage sites were used to determine the stages corresponding to the 15 day, 50 percent chance flows at each site, and these stages were converted to elevations by adding to the gage datums. Table 19–8 shows the flow elevations and the relative distance between the gages and the site.

Steps 5 and 6: Same as case 1.

Alternative step 3: Gage data transfer alternative. A channel rating may be developed for the cross-section at the wetland site. However, this requires the computation of an adjusted probability-duration flow, using the gage data transfer methods in NEH654.05. This flow may be converted to stage by the methods provided in NEH630.14, Stage-Discharge Relationships. An alternative method is the use of the WinXSPro computer program or the HEC-RAS computer program for cross section ratings at the delineation site. WinXSPro is a channel cross section analysis program, and accuracy depends on the proper input of the channel slope, and Mannings *n* value. Channel geometry must be obtained by conducting field surveys, or using High-Resolution Digital Elevation data (HRED).

An even higher degree of confidence can be obtained by using the HEC-RAS program to develop a water surface profile through the stream reach. This process is automated if using the HEC-GeoRAS software. The reach length of the HEC-RAS geometry model should extend for at least 10 channel widths up and downstream of the determination site to account for backwater effects along the channel reach.

Example 2:
Automated processes
This example illustrates the use of gage data with GIS tools to develop an inundation map.

Table 19–8 Gage locations and corresponding stages

Location	Distance, miles	15-day 50% chance elevation
Downstream gage	0	100.0
Site	15	130.0 (interpolated)
Upstream gage	20	140.0

With the advent of computers with advanced computational power, high resolution digital elevation data, and GIS tools, wetland boundary maps based on water surface profiles can be made quickly and accurately.

For this case, a map is needed to determine the boundary for planting bottomland hardwoods on potential wetland restoration sites in Indiana. Plant materials specialists have determined that for this region, survival can be expected on sites where the 50 percent chance probability of inundation is 7 days or less, based on the 7-day average flow. The USGS may be able to provide these average flows. Note that the average flow over a 7-day duration will be higher than the minimum flows that exist for the same duration.

This criterion is not dependant on wetland growing season.

Step 1: Not used

Step 2: Mean daily flow data is collected along multiple USGS stream gage sites on the same stream reach.

Step 3: Gage ratings are extracted for each gage site.

Step 4: Gage datums are added to the gage readings to determine the water surface profile elevation for the 50 percent chance, 7-day average flow at each gaged cross-section.

Step 5: The area flooded is mapped using GIS software on a USGS quad map. The area boundary is interpolated between the flood stages at individual gage sites. Figure 19–45 illustrates the resulting map.

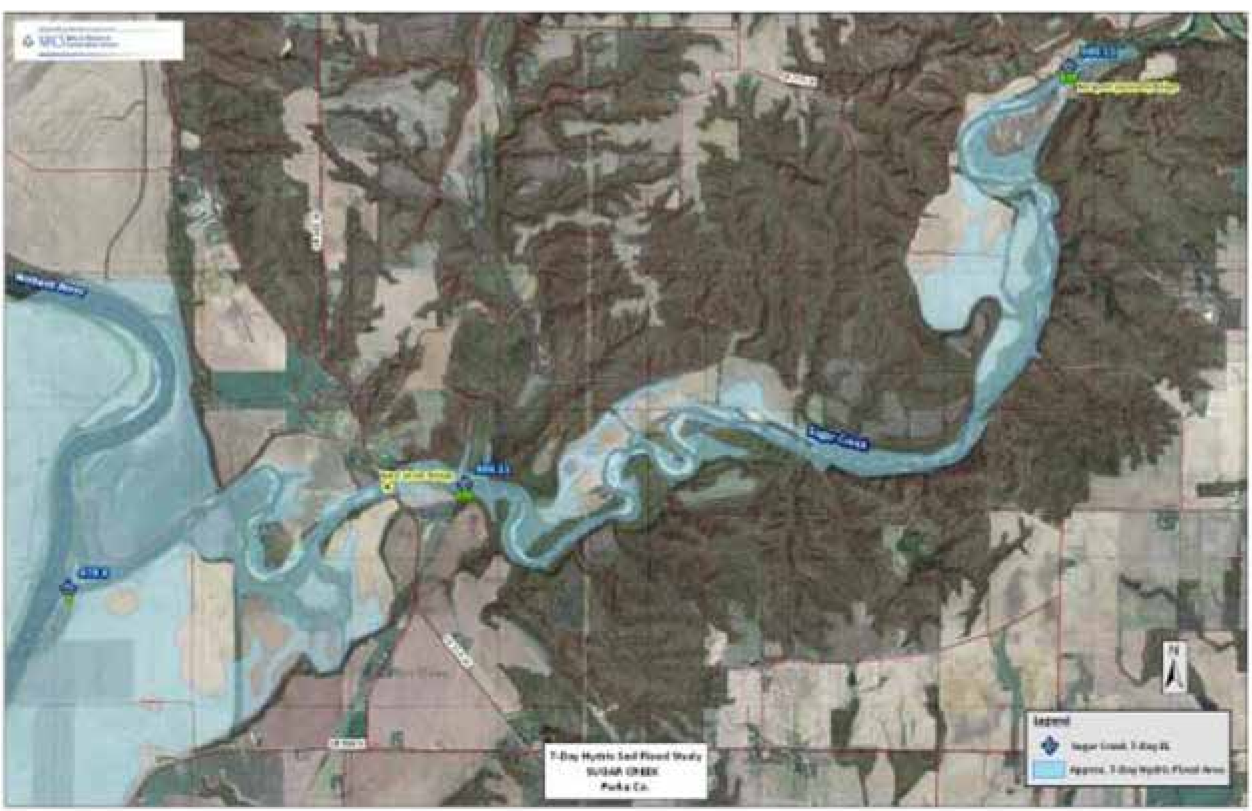
(iii) Case 3—Wetland hydrology maintained by high water table, which is supported by stream water surface. Nearby stream gage data is available.
In this case, adequate stream gage records are available to develop probability-duration flows, but the wetland is not maintained by surface flooding. Based on soils information, it is apparent that the floodplain is endosaturated, with a high water table that fluctuates in response to changes to stream stage. No groundwater records are available, but time allows for collection of groundwater data for 1 year. Collection of short-term groundwater records is not adequate to document wetland hydrology, but it can be used as corroborating evidence. In this procedure, evidence

is collected to document the connection between the stream water surface and the groundwater surface. The flow at the probability and duration meeting the objective criteria are then correlated with the short term groundwater data to determine the groundwater level corresponding with this flow. In topographic depressions, this water table can express itself as surface water. Otherwise, it may be close enough to the floodplain surface to maintain saturated conditions. The wetland hydroperiod then, is the period of time that the floodplain is subject to overbank flooding, plus the duration that the depth to groundwater is within the objective criteria limits. Typical limits are within 6 to 12 inches of the surface.

The procedures for this analysis will vary case by case. However, the steps listed here should apply to most cases where the stream flood frequency is low, but there is a strong connection between high in-bank flows and the groundwater surface on an adjacent floodplain.

Data requirements:
All of the data required for case 1 is needed for this case. In addition, this analysis requires the collection of groundwater monitoring data from at least one full wetland hydroperiod. The number of monitoring wells must be sufficient to develop a groundwater contour map which can delineate the presence of wetland conditions across significant surface topographic features on the delineation site. The main effort is in determining if a strong correlation exists between the groundwater table and the stream water surface profile. If this correlation cannot be proven, another method must be used to determine wetland conditions.

Figure 19–45 Map of 50% chance probability of inundation by 7-day average flow



Example 1:
In this case, the objective criteria are the presence of groundwater within 6 inches of the surface for a continuous duration of 15 days with a 50 percent chance probability of occurrence. Daily mean streamflow data exists for a 10-year period of record. Groundwater levels from monitoring are available for one wetland growing season. The groundwater data was collected during a period of NEC, based on rainfall and streamflow data.

Procedure:

Step 1: Develop a groundwater monitoring plan. The plan shows the locations for installation of monitoring wells. These wells may be installed in conjunction with piezometers, but only the data from monitoring wells are useful for this analysis. Piezometer information is useful for determining the direction of movement of water into and out of the site, and can provide valuable information on the wetland's hydrodynamics for use in wetland restoration planning and functional assessments. However, only the documentation of the actual free groundwater surface can be used for a wetland determination, and this data can only be provided by a monitoring well. The groundwater monitoring plan should specify the frequency of data collection from the monitoring wells. Data is also collected from a nearby stream gage, and at the same frequency. It is important that the readings include both the rising and falling limbs of the stream hydrograph.

The advent of inexpensive automated data recording devices makes the collection of continuous water level data possible in both stream channels and groundwater monitoring wells. This data can be collected in time increments of 20 minutes or less. For analysis, data collected and processed to provide daily mean values of groundwater level is adequate. The monitoring period should cover at least one season where the flow conditions are within a range considered to represent NEC.

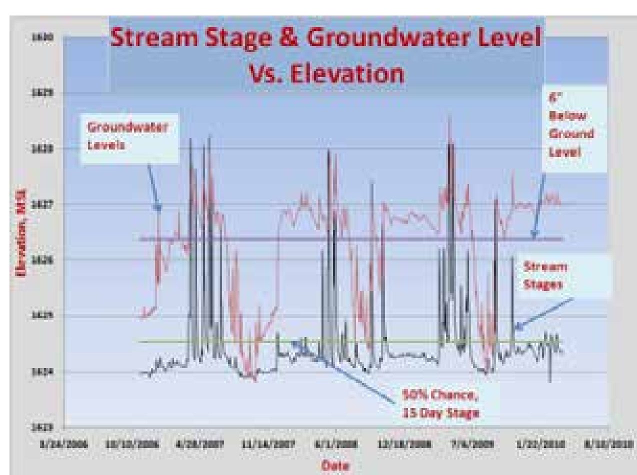
Step 2: Determine the probability-duration flow, and calculate the associated stream stage. The procedure is the same as the previous examples.

Step 3: Correlate stream stage data with groundwater level data. The correlation between stream stage and groundwater level is not direct on a daily basis. When the stream and groundwater hydrographs are plotted, they may appear to correlate well with each other, as shown in figure 19–46. Periods of high flow correspond well with periods of high groundwater. However, the daily correlation is usually quite poor. Among other factors, there is a lag between the two, as groundwater rise lags the increase in stream stage during the rising hydrograph limb, and the reverse is true during the falling limb.

However, it is still apparent that, for a period of record, the periods where stream stage is high will also be periods where the groundwater level is high. Making a plot of stage versus groundwater level for all days of record will show any days when a low groundwater table existed at the same day as a high stream stage or vice versa, as shown in figure 19–47.

In this plot, for all days when the flow rate was in excess of the 50 percent chance, 15-day duration flow, the groundwater level was 6 inches or less from the surface. It can be inferred, then that the durations of high groundwater were the same as the flow durations, and the wetland experiences groundwater within 6

Figure 19–46 Plot of streamflow and groundwater level vs. time

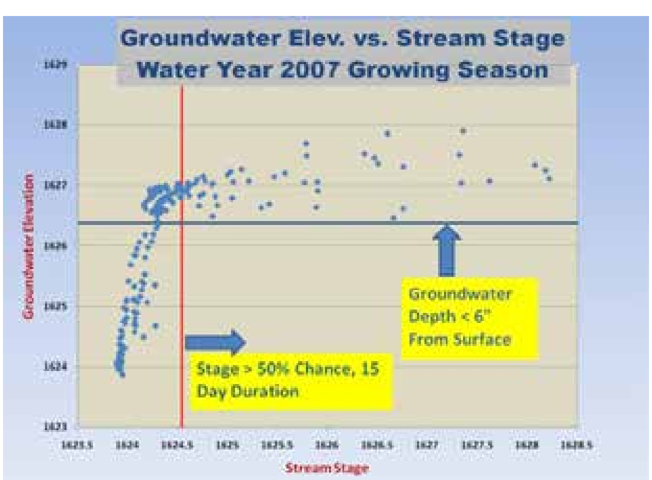


inches of the surface for 15 days with a 50 percent annual probability.

In this case, there were no days with the criteria flow with a low groundwater table. This may not always be the case. High flows following an extended dry period may exist for some time before the first groundwater rise, and should be considered to be outliers to the data set. Outliers must be included in data set, unless objective criteria has been established that allows less than 100 percent of the high groundwater levels to match high flow data.

Piezometers
Data from piezometers cannot be used directly to document the level of a free groundwater surface. However, evidence of strong groundwater movement in the vertical upward or vertical downward direction can provide strong corroborating evidence when used with short-term groundwater monitoring data. When used in an endosaturated floodplain, piezometers can determine the direction of flow during the rise and fall of a stream hydrograph. If these flows are shown to be only between the wetland and stream, the evidence for correlation between the hydrograph and the wetland groundwater level is strengthened. In a SLOPE wetland, piezometer data indicating a strong vertical upward component of groundwater flow is evidence that the wetland has a long duration water source.

Figure 19–47 Steam profile vs. groundwater level



Step 4: The previous steps document that the criterion for wetland hydrology are met at the floodplain elevation of the monitoring well. Elevations at or lower than this are mapped as wetland.

(iv) Case 4—Wetland delineation site is a floodplain macrotopographic feature where ponding provides much of the hydroperiod.
In these cases, the wetland receives water from stream flooding, but the duration of inundation is from ponding after a short-term hydrograph has passed. This is the common case on RIVERINE wetlands for much of the United States.

Floodplain macrotopographic features typically exist as abandoned oxbows, scour channels, or other features which form closed topographic depressions. They are supplied with water when the stream flood-stage is high enough for water to enter, and ponded water is left behind after the flood recedes. The first step is to determine whether the annual 50 percent chance peak growing season discharge stage is high enough for floodwater to access the depression. The next step is to determine the losses from seepage and evapotranspiration, during the duration required for the delineation. This situation exists on sites where the soil substrate is capable of supporting a perched water table in an episaturated condition. Published annual peak discharges from USGS or other agencies cannot be used without modification. These discharges may or may not have occurred during the wetland growing season. It is necessary to obtain the period of record daily discharges, and extract the highest discharges occurring during the growing season. This analysis is complicated by the fact that the USGS and other agencies usually publish only daily mean discharges, which are averages of all the incremental daily readings. For streams with small to moderately sized drainage areas, the difference between daily peak and daily mean discharges can be significant. Annual peak discharge data may need to be modified to construct a record of annual growing season peak discharges.

***Procedure*:**

Step 1: Determine the growing season using WETS tables.

Step 2: Obtain the annual peak discharges for a minimum 10-year period of record. Use discharge records from a nearby stream gage, if available.

The data transfer or stage interpolation methods described may be used if the delineation site is a significant distance from the nearest gage site.

Step 3: Identify peak discharges which fall outside of the growing season.

Step 4: Obtain mean daily flows corresponding to the annual season peaks for the same day.

Step 5: Use straight-line regression to determine ratio between the peak discharge and mean daily discharge. Use all peak discharge data in the period of record.

Step 6: Search mean daily flow data for highest discharges during growing season for years with annual peaks outside the growing season.

Step 7: Apply ratio from step 5 to the mean discharges to determine correlated growing season peak discharges.

Step 8: Use Log-Pearson Type III Distribution to determine 50 percent chance probability growing season peak discharge.

Step 9: Use nearby gage rating or develop channel rating to determine elevation of the discharge from step 8.

Step 10: Identify floodplain macrotopographic features accessed by this flow which will be filled during discharge event.

Step 11: Use water budget analysis to determine ponding level at end of duration.

Example

A large floodplain "oxbow" in the Smoky Hill River floodplain in Kansas is to be analyzed. The gage is adjacent to the site.

Step 1: The WETS table from the Abilene 2 W WETS station reports that the growing season extends from April 4 to October 29.

Step 2: Table 19–9 shows the annual peak discharges for the Smoky Hill River near New Cambria, Kansas, obtained from USGS.

Step 3: The annual peak discharges shown in bold in table 19–9 are those that fall outside the growing season. These must be replaced with growing season peak discharges for the same water year before determining the 50 percent chance peak discharge during the growing season.

Step 4: Table 19–10 shows a partial record of daily mean discharges for the year 1979, which is the first year in the period of record in which the peak discharge occurred outside the growing season (March 24). **Note** that the mean daily discharge on March 24 was 6,240 cubic feet per second. The peak discharge that occurred on that day from table 19–9 was 6,990. The ratio of daily mean to daily peak is 6,240/6,990, or 89.3 percent. Table 19–11 shows a table of all the annual peak discharges along with the daily mean discharge for the same day these peak discharges occurred. Again, those falling outside the growing season are in bold.

It is apparent that the differences between the peak and daily mean discharges are significant. However, the differences appear to have a uniform magnitude.

Step 5: Figure 19–48 shows a plot of the peak discharges versus the daily mean discharges. A linear regression is established. In this case, the R^2 value is 0.995.

Step 6: Now the highest daily mean discharges which occur within the growing season can be determined for those years where the peak discharges are outside the growing season. This involves searching all the daily mean discharge records for the maximum daily mean discharge from the beginning to the end of the growing season for those years where the peak occurs outside the growing season. This can be done by manual inspection. The use of spreadsheet tools can greatly assist in this effort. The highest growing season daily mean discharges are converted to peak discharges using the regression equation. These discharges are substituted for the annual peak discharges for years that they occur outside the growing season.

Step 7: The regression equation is used to compute the correlated growing season peak discharges. The completed analysis, with the annual peaks which occur during the growing season is shown in table 19–12.

Step 8: The annual growing season peak discharges are used to determine the 50 percent chance (2-yr. return period) flow using the Log-Pearson Type III distribution.

Table 19–9 Annual peak discharge data with nongrowing season peak discharges in bold

USGS	6870200	7/12/1963	3,430	6	18.59
USGS	6870200	6/16/1964	1,840	6	10.97
USGS	6870200	6/28/1965	9,340	6	25.87
USGS	6870200	8/22/1966	2,800	6	13.72
USGS	6870200	9/20/1967	11,200	6	27.32
USGS	6870200	10/8/1967	2,510	6	13.17
USGS	6870200	5/26/1969	7,300	6	23.52
USGS	6870200	6/19/1970	3,730	6	16.01
USGS	6870200	5/23/1971	15,000	6	29.89
USGS	6870200	9/3/1972	7,410	6	23.14
USGS	6870200	9/29/1973	22,000	6	30.26
USGS	6870200	10/12/1973	26,400	6	30.91
USGS	6870200	6/24/1975	7,440	6	24.93
USGS	6870200	4/29/1976	3,540	6	17.09
USGS	6870200	9/2/1977	8,040	6	26.39
USGS	6870200	9/21/1978	3,180	6	16.69
USGS	6870200	3/24/1979	**6,990**	6	25.27
USGS	6870200	3/31/1980	**12,100**	6	28.91
USGS	6870200	6/12/1981	6,600	6	23.99
USGS	6870200	7/2/1982	11,000	6	28.1
USGS	6870200	4/6/1983	2,080	6	13.57
USGS	6870200	5/1/1984	7,640	6	24.73
USGS	6870200	8/23/1985	4,470	6	19.02
USGS	6870200	9/15/1986	1,300	6	10.94
USGS	6870200	3/25/1987	**13,500**	6	30.29
USGS	6870200	8/24/1988	1,140	6	10.43
USGS	6870200	7/6/1989	1,870	6	12.94
USGS	6870200	7/27/1990	4,510	6	19.58
USGS	6870200	5/31/1991	3,330	6	16.96
USGS	6870200	8/13/1992	5,830	6	22.18
USGS	6870200	6/25/1993	18,600	6	31.72
USGS	6870200	10/2/1993	4,200	6	18.35
USGS	6870200	5/28/1995	15,500	6	30.78
USGS	6870200	6/2/1996	11,700	6	28.45
USGS	6870200	11/17/1996	**4,690**	6	19.49
USGS	6870200	3/31/1998	**7,950**	6	24.33
USGS	6870200	11/3/1998	**11,200**	6	29.59
USGS	6870200	3/25/2000	**10,300**	6	28.1
USGS	6870200	2/25/2001	**6,130**	6	21.1
USGS	6870200	4/22/2002	982	6	9.15
USGS	6870200	3/21/2003	**2,500**	6	12.98
USGS	6870200	3/6/2004	**3,990**	6	16.98
USGS	6870200	6/4/2005	3,710	6	16.74
USGS	6870200	6/23/2006	2,090	6	12.25
USGS	6870200	5/25/2007	31,700	8	31.42

Table 19–10 Partial record of daily mean flows with mean discharge on date of annual peak highlighted in red

USGS	6870200	3/17/1979	367
USGS	6870200	3/18/1979	1,140
USGS	6870200	3/19/1979	4,470
USGS	6870200	3/20/1979	2,570
USGS	6870200	3/21/1979	1,030
USGS	6870200	3/22/1979	1,390
USGS	6870200	3/23/1979	4,040
USGS	6870200	3/24/1979	**6,240**
USGS	6870200	3/25/1979	4,830
USGS	6870200	3/26/1979	2,880
USGS	6870200	3/27/1979	2,850
USGS	6870200	3/28/1979	2,730
USGS	6870200	3/29/1979	1,790
USGS	6870200	3/30/1979	1,460
USGS	6870200	3/31/1979	1,430
USGS	6870200	4/1/1979	1,410
USGS	6870200	4/2/1979	1,400
USGS	6870200	4/3/1979	1,280
USGS	6870200	4/4/1979	1,270
USGS	6870200	4/5/1979	1,380
USGS	6870200	4/6/1979	1,350
USGS	6870200	4/7/1979	1,270

Table 19–11 Daily peak and mean discharges on dates of annual peak discharges

Date	Water Year	Peak x	Mean y
7/12/1963	1963	3430	2600
6/16/1964	1964	1840	1710
6/28/1965	1965	9340	8600
8/22/1966	1966	2800	2510
9/20/1967	1967	11200	10300
10/8/1967	1968	2510	2360
5/26/1969	1969	7300	5390
6/19/1970	1970	3730	3470
5/23/1971	1971	15000	13400
9/3/1972	1972	7410	7040
9/29/1973	1973	22000	20300
10/12/1973	1974	26400	25000
6/24/1975	1975	7440	5960
4/29/1976	1976	3540	3410
9/2/1977	1977	8040	7590
9/21/1978	1978	3180	2810
3/24/1979	1979	**6990**	**6240**
3/31/1980	1980	**12100**	**11300**
6/12/1981	1981	6600	6300
7/2/1982	1982	11000	9080
4/6/1983	1983	2080	1930
5/1/1984	1984	7640	6510
8/23/1985	1985	4470	3690
9/15/1986	1986	1300	1280
3/25/1987	1987	**13500**	**12800**
8/24/1988	1988	1140	966
7/6/1989	1989	1870	1830
7/27/1990	1990	4510	4290
5/31/1991	1991	3330	2960
8/13/1992	1992	5830	5470
6/25/1993	1993	18600	17700
10/2/1993	1994	4200	4110
5/28/1995	1995	15500	13900
6/2/1996	1996	11700	11100
11/17/1996	1997	**4690**	**4190**
3/31/1998	1998	**7950**	**7200**
11/3/1998	1999	**11200**	**10700**
3/25/2000	2000	**10300**	**9570**
2/25/2001	2001	**6130**	**5300**
4/22/2002	2002	982	820
3/21/2003	2003	**2500**	**2230**
3/6/2004	2004	**3990**	**3310**
6/4/2005	2005	3710	3370
6/23/2006	2006	2090	1310

The Log-Pearson Type III distribution can be calculated by the use of a spreadsheet available at the National Design, Construction, and Soil Mechanics Center website.

The resulting 2-year return period peak growing season discharge is 4,840 cubic feet per second, shown in figure 19–49.

Step 9: The rating curve for the gage site is obtained using the procedures in case 4 example. The rating curve for the gage shows that the gage reading is 19.55, shown in table 19–13. The USGS website information includes the gage datum, which is 1,160.19 feet above MSL, shown in figure 19–50. Adding 19.55 to this elevation gives a stage elevation of 1,179.74 feet. If the site is not adjacent to a stream gage location, the alternatives in case 2 apply.

The stage for the 2-year growing season peak discharge can be interpolated, or gage data transfer methods may be used in combination with development of a stage-discharge curve.

The elevation of 1,179.74 can be used to determine if any low flow path exists that will allow water at this cross-section to enter the depression at this elevation.

Step 10: For floodplain depressions which are accessed at the stream stage determined in step 2, perform a water budget analysis to determine the water level at the end of the required duration. The beginning stage for the analysis can be taken as the overflow elevation of the depression. The elevation where inundation is maintained long enough to meet wetland hydrology can be determined using the procedures described in this chapter, Water budget applications.

Figure 19–48 Log-Pearson Type III return period analysis from spreadsheet

Recurrence interval (yr)	Percent chance	K-Value	Ln(Q)	Peak discharge (ft^3/s)	90% confidence interval	
					Upper (ft^3/s)	Lower (ft^3/s)
200	0.5	2.787	10.8616	52,100	90,200	35,000
100	1	2.491	10.6121	40,600	67,000	28,200
50	2	2.172	10.3444	31,100	48,700	22,300
25	4	1.826	10.0528	23,200	34,500	17,200
10	10	1.303	9.6127	15,000	20,700	11,600
5	20	0.828	9.2132	10,000	13,100	8,030
2	50	–0.037	8.4845	4,840	5,960	3,920
1.25	80	–0.851	7.8000	2,440	3,050	1,860

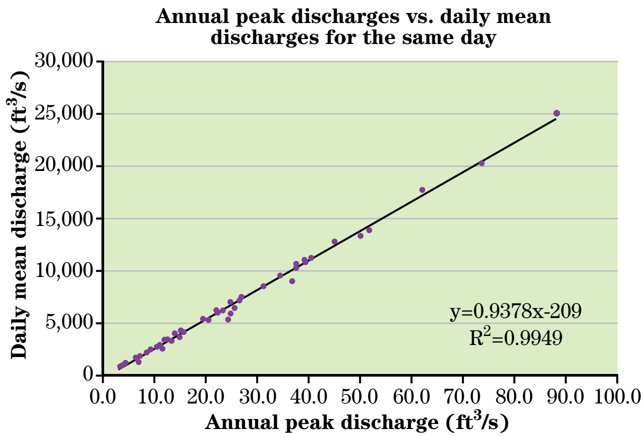
Table 19–12 Spreadsheet analysis, with annual growing season peak discharges

Date	Water year	Peak	Mean	Highest G.S. daily mean	Date	Correlated peak	Date	Water year	Peak	Mean	Highest G.S. daily mean	Date	Correlated peak
7/12/1963	1963	3430	2600				8/23/1985	1985	4470	3690			
6/16/1964	1964	1840	1710				9/15/1986	1986	1300	1280			
6/28/1965	1965	9340	8600				3/25/1987	1987	13500	12800	7860	4/20/1987	8604
8/22/1966	1966	2800	2510				8/24/1988	1988	1140	966			
9/20/1967	1967	11200	10300				7/6/1989	1989	1870	1830			
10/8/1967	1968	2510	2360				7/27/1990	1990	4510	4290			
5/26/1969	1969	7300	5390				5/31/1991	1991	3330	2960			
6/19/1970	1970	3730	3470				8/13/1992	1992	5830	5470			
5/23/1971	1971	15000	13400				6/25/1993	1993	18600	17700			
9/3/1972	1972	7410	7040				10/2/1993	1994	4200	4110			
9/29/1973	1973	22000	20300				5/28/1995	1995	15500	13900			
10/12/1973	1974	26400	25000				6/2/1996	1996	11700	11100			
6/24/1975	1975	7440	5960				11/17/1996	1997	4690	4190	2090	8/18/1997	2451
4/29/1976	1976	3540	3410				3/31/1998	1998	7950	7200	4730	7/31/1998	5267
9/2/1977	1977	8040	7590				11/3/1998	1999	11200	10700	8130	4/16/1999	8892
9/21/1978	1978	3180	2810				3/25/2000	2000	10300	9570	1700	4/4/2000	2036
3/24/1979	1979	6990	6240	3330	4/18/1979	3774	2/25/2001	2001	6130	5300	4130	6/21/2001	4627
3/31/1980	1980	12100	11300	5960	4/4/1980	6578	4/22/2002	2002	982	820			
6/12/1981	1981	6600	6300				3/21/2003	2003	2500	2230	1890	4/26/2003	2238
7/2/1982	1982	11000	9080				3/6/2004	2004	3990	3310	1870	7/12/2004	2217
4/6/1983	1983	2080	1930				6/4/2005	2005	3710	3370			
5/1/1984	1984	7640	6510				6/23/2006	2006	2090	1310			

Table 19–13 Rating table for USGS stream gage

```
# //UNITED STATES GEOLOGICAL SURVEY       http://water.usgs.gov/
# //NATIONAL WATER INFORMATION SYSTEM     http://water.usgs.gov/data.html
# //DATA ARE PROVISIONAL AND SUBJECT TO CHANGE UNTIL PUBLISHED BY USGS
# //RETRIEVED: 2009-02-23 13:54:43
# //WARNING
# //WARNING The stage-discharge rating provided in this file should be
# //WARNING considered provisional and subject to change. Stage-discharge
# //WARNING ratings change over time as the channel features that control
# //WARNING the relation between stage and discharge vary. Users are
# //WARNING cautioned to consider carefully the applicability of this
# //WARNING rating before using it for decisions that concern personal or
# //WARNING public safety or operational consequences.
# //WARNING
# //WARNING This rating does not include any shifts that may have been
# //WARNING used along with this base rating in converting stage to
# //WARNING discharge at this site. Stage data processed with the rating
# //WARNING thus may not match that displayed or published by the USGS.
# //WARNING
# //FILE TYPE="NWIS RATING"
# //DATABASE NUMBER=01 DESCRIPTION="Kansas District"
# //STATION AGENCY="USGS " NUMBER="06870200       " TIME_ZONE="CST" DST_FLAG=Y
# //STATION NAME="SMOKY HILL R AT NEW CAMBRIA, KS"
# //DD NUMBER="   1" LABEL="Discharge (cfs)"
# //PARAMETER CODE="00060"
# //RATING ID="0035" TYPE="STGQ" NAME="stage-discharge" AGING=A
# //RATING REMARKS="Just a low end extension of 34"
# //RATING EXPANSION="logarithmic"
# //RATING OFFSET1=3.80
# //RATING_INDEP ROUNDING="2223456782" PARAMETER="Gage height (ft)"
# //RATING_DEP ROUNDING="2222233332" PARAMETER="Discharge (cfs)"
# //RATING_DATETIME BEGIN=20060622140000 BZONE=CDT END=20080930235959
EZONE=CDT AGING=A
# //RATING_DATETIME BEGIN=20081001000000 BZONE=CDT END=20081013235959
EZONE=CDT AGING=R
# //RATING_DATETIME BEGIN=20081014000000 BZONE=CDT END=23821230090000
EZONE=CST AGING=W
INDEP            DEP              STOR
16N              16N              1S
3.88             0.93             *
3.89             1.1
---------        ---------
19.49            4810
19.50            4820
19.51            4820
19.52            4820
19.53            4830
19.54            4830
19.55            4840
19.56            4840
19.57            4850
19.58            4850
19.59            4850
19.60            4860
```

Figure 19–49 Regression analysis of annual peak vs. corresponding daily mean discharges



650.1909 Drainage equations for lateral effect determination

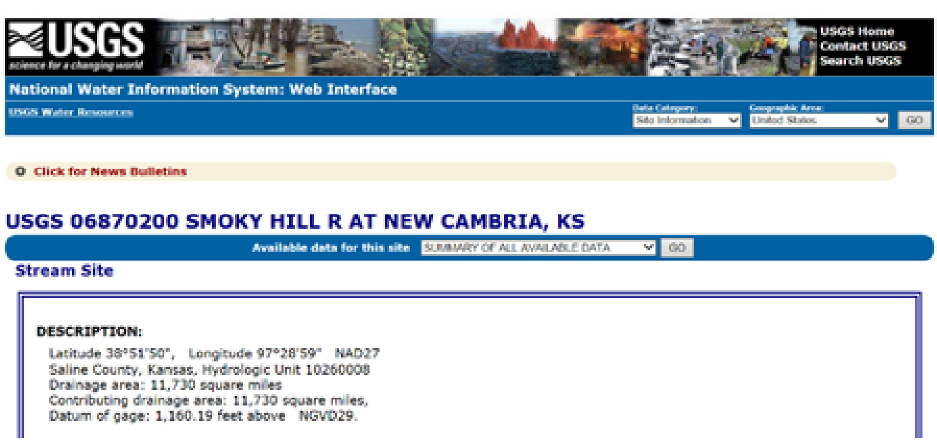
(a) Introduction

Lateral effect equations are used to determine the horizontal distance over which surface ditches or subsurface drainage tiles effect the water table depth. Methods for the design of drainage systems have long been used to determine the proper location, spacing, and depth of drains. These same methods can be used to determine if wetland hydrology has been removed, and to what degree. Some methods are more appropriate for determining the lateral effect of drains in a pattern drain system, and others are more appropriate for determining the lateral effect of a single drain on an adjacent wetland. This document refers to lateral effects equations in terms of these categories:

- design equations
- single drain lateral effect methods (single drain methods)

The DRAINMOD computer software program can model changes to groundwater level and moisture content of unsaturated soil due to the effects of local precipitation, crops, and drain spacing and depth.

Figure 19–50 USGS stream gage data showing gage datum



The North Dakota Drain (ND-Drain) computer software program includes both design equations for a pattern tile system and a single drain method. The use of this software is explained in this section.

(b) Applicability to HGM Classes

In general, drainage lateral effect equation methods assume that the dominant water source and hydrodynamics match the definition of MINERAL FLAT and ORGANIC FLAT HGM wetland classes. In these, the dominant water source is direct precipitation, and the original hydrodynamics is vertical. Water is lost vertically downward through the soil to an underlying water table, and vertically upward through evapotranspiration. The installation of drainage creates a horizontal movement of water into the drains that is then directed to a surface outlet. Minor discrete surface depressions exist in MINERAL FLAT wetlands. The Kirkham's equation and DRAINMOD software deals with the removal of water stored in surface depressions through tile drains. Kirkham is usually used in combination with other lateral effects equations to determine the total time for water level drawdown.

Single drain methods can be used to calculate the lateral effect on adjacent wetlands that are MINERAL FLAT, ORGANIC FLAT, and DEPRESSION. The level of the wetland's surface ponding or groundwater table is assumed to be a long-term constant, with local inflows and outflows in relative equilibrium. In this assumption, the effect of a single adjacent drainage feature is local, and does not affect the long-term water level of the wetland beyond the lateral effect distance.

(c) Drainage theory and methods

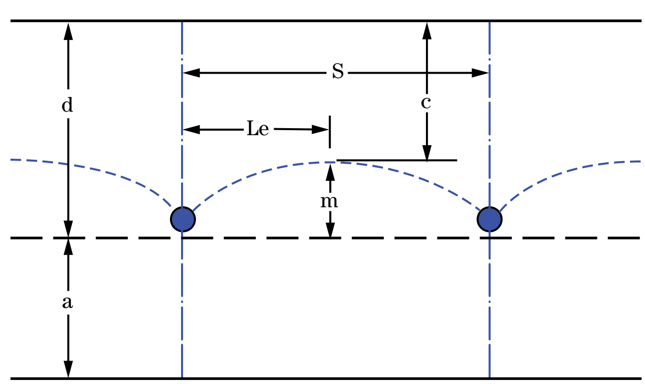
Drainage equations developed to design ditch and tile systems can be used in reverse to estimate the lateral effect of a ditch or tile within a system. However, these should not be relied upon without examining field conditions. The data entered into the equations must accurately reflect site conditions. Field evidence should be examined to see if it is consistent with the drainage equation or single drain method results.

The layout of a typical tile drainage system showing tile spacing, installation depth, the typical location of the impermeable layer and other parameters is depicted in figure 19–51. The terms shown in the figure are used in most drainage equations, and are defined as:

S = spacing of tile drains or surface drainage ditches
d = the depth from the ground surface to the flowline of the tile or ditch
Le = the distance from the tile or ditch to the point where the drawdown is at a specified minimum, (i.e. 1 ft).
c = the distance from the ground surface to the water table at the midpoint between the drains
m = the distance from the water table at the midpoint between drains to the flowline grade of the drains
a = the distance from the drain flowline to the impermeable layer

For evaluating the effect of a drainage system, the depth of the ditch is considered to be from the average land surface to the free water surface in the ditch and is defined as effective depth. The ditch may have been over-excavated, with deep spots where water ponds, but the ditch lacks the grade to remove the water from these over-excavated locations. Spoil piles are ignored when evaluating the effective depth of a ditch. The lateral effect is measured from the edge of the bottom at the free water surface to the point where the drawdown cone comes within the selected threshold depth below the surface at the selected time since saturation. The threshold depths and times used in the analysis must be defined by objective criteria.

Figure 19–51 Typical tile drainage system



Design of tile or ditch drainage systems for the humid region, where precipitation patterns are highly variable, may reasonably be based on a prescribed rate of water table drawdown following a sudden water table rise. These same equations can provide helpful information for understanding the impact of a ditch or tile on the wetland hydrology of a wetland site. Each equation must be carefully applied, respecting the limitations and understanding the situations where it is applicable. As mentioned, drainage design equations are best applied where the drainage system is placed through a wetland, not off to the side of the wetland. Where a drain is installed off to the side of a wetland, single-drain methods better describe water movement.

A tile or ditch is most effective in the first 5 to 10 years after installation. A large storm, or a series of smaller storms, may cause a layer of sediment to build up in the ditch or tile, reducing its effectiveness. If a section of tile becomes completely plugged, water pressure builds up, and a blowout may result. If the tile outlet is submerged, the system is not free-flowing and may cause water to back up into low-lying areas until the water level in the outlet drops to allow the water to leave the system. The deterioration of a system can be seen in a sequence of aerial photographs over a period of years. The site gradually appears wetter in normal years through increased size, apparent standing water which becomes deeper through the years, and more severely stressed crops.

Many of the equations were developed before the advent of calculators and computers. Assumptions were made in the application of Darcy's law and the Dupuit-Forcheimer theory which simplified the math, but may not have been valid for a given situation. Steady state equations generally are most suitable for irrigated soils and nonsteady state equations are applicable in humid areas. The various equations for analyzing drainage effects on wetlands require the determination of the drainable porosity and hydraulic conductivity of the soil. Understanding these terms requires knowledge of soil physics.

(1) Impermeable layer

An impermeable layer causes water movement to change from vertical to horizontal, allowing the water to reach the drainage feature. The impermeable layer is generally assumed to occur at 10 feet below the soil surface if it has not been encountered at a shallower depth, and the distance to this layer is shown as "a" in figure 19–51. A restrictive layer generally occurs at some depth in every soil profile. This layer inhibits the vertical transport of water through the soil, and a perched water table forms. The depth to this restrictive layer is a factor in the design process of a drainage system. In general, a layer well below the level of the drains can be considered relatively impermeable if its hydraulic conductivity is one-tenth or less of the permeability of the overlying layer(s) (van Schilfgaarde 1974).

This is considered a valid assumption because few roots extend below 10 feet, and earthworm channels are nearly nonexistent at this depth. Also, the weight of 10 feet of soil pressing on the lower layers compresses the soil so that permeability is reduced. A layer is considered to act as an impermeable layer if its permeability is less than the layer above it by a power of 10. For example, if layer A has permeability of 2.0 inches per hour, and layer B has a permeability of 0.2 inch per hour, layer B is considered to act as an impermeable layer.

(2) Hydraulic conductivity, K, inches/hour

The saturated hydraulic conductivity is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient (Soil Survey Technical Note 6). The one-dimensional flow of water through a saturated soil can be computed from the Darcy equation. Hydraulic conductivity is determined from field or laboratory measurements. The flow path may be downward (as during infiltration), horizontal, or upward. The equation is valid so long as the velocity of flow and the size of the soil particles are such that the Reynolds number is less than one. Hydraulic conductivity, K, is a function of the effective diameter of the soil pores and of the density and dynamic viscosity of the fluid. It is the average velocity of bulk flow in response to a unit gradient. Information on saturated hydraulic conductivity can be found for individual soil layers in the NRCS WSS.

Application of the Darcy equation is more difficult for two- and three-dimensional flow systems that have complex boundary conditions. Where water movement is through two soil layers, such as a topsoil layer and subsoil layer, the composite vertical hydraulic conductivity K can be computed from:

$$K = \frac{K_1L_1 + K_2L_2 + K_3L_3 + ..K_nL_n}{L_1 + L_2 + ..L_n} \qquad \text{(eq. 19–3)}$$

where:

L = total length of flow through all the layers (L) thru layer n. Subscripts 1, 2, and n represent the soil layers 1, 2, and n, respectively. In practice, the composite K used for drainage equations is computed using the weighted average of the K value above the drain depth and the weighted average K value from the drain depth to the impermeable layer. The weighted K above the drain depth is K_a, and K_b is the weighted K value below the drain. In some equations, the K_a and K_b values must then be used to compute a weighted composite K.

The relationship between soil layers, the impermeable layer, and the differentiation between K_a and K_b is shown in figure 19–52 for a typical ditch. Note that the flowline is at the ditch water surface, not the ditch bottom. In many cases, ditches have permanent surface water because of outlet control or local over excavation.

(3) Effective radius of a drain, r_e

The effective radius of a pipe is the small fraction of the pipe wall that is available for water entry in perforated plastic drainage tubing or concrete or clay drainage tile. This is a measurement that estimates the radius of a tile or pipe if the holes or slits were the entire radius of a tile or pipe. These values are usually expressed in feet or inches. If the water flows to a drainage ditch, the r_e value is assumed to be 12 inches. If a gravel envelope is used around a drain tile, the effective radius is increased because the envelope increases the effective size of the drain. Figure 19–53 shows the entry of water into both ditches and drain tiles.

Table 19–14 is taken from Skaggs' work, and provides r_e values for tiles, ditches, and tiles with gravel envelopes.

(d) Soil physics

Drainage equations require two specific soil input parameters: saturated hydraulic conductivity (K_s) and drainable porosity (f). The DRAINMOD program requires the determination of a third parameter, unsaturated hydraulic conductivity (K). Accurate values for these parameters are not readily available. These values are difficult and expensive to measure in the field or laboratory. Methods are available, however, for obtaining estimates of these parameters using known soil properties.

Figure 19–52 Soil layers in a drainage system

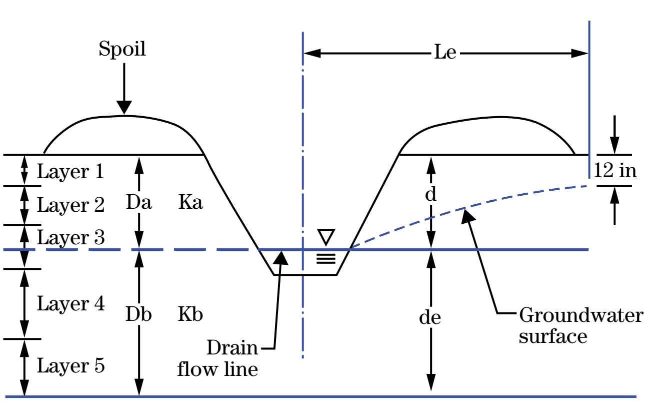
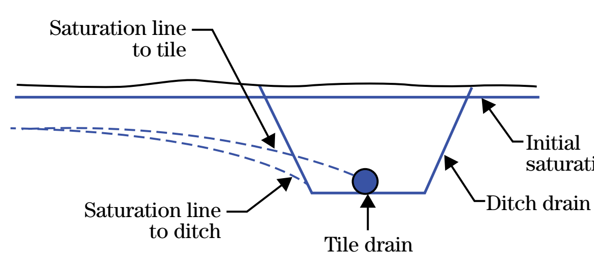


Figure 19–53 Water entry into ditch and tile



(i) Drainable porosity

Drainable porosity is a dimensionless number, and represents volume of water drained per unit area (drained water free pore space) divided by water table depth in the drained soil. In drainage analyses, this drainage is assumed to occur under a single drawdown event due to lowering of the water table. Lowering the water table does not remove all water in the soil profile above the water table. Water remains in the soil and is held there by matric suction. The matric suction head for an individual soil layer increment is the distance from the mid-point of that layer to the water level. The volume of water held in this increment is a function of the distance from the layer to the water level, and can be determined using the van Genuchten equations:

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{\left[1 + |\alpha h|^n\right]^m} \quad \text{(eq. 19–4)}$$

and

$$m = 1 - \frac{1}{n} \quad \text{(eq. 9–5)}$$

where:

θ = the volumetric water content of the incremental soil layer

θ_r = the residual volumetric water content of a well drained soil

θ_s = the saturation volumetric soil moisture

h = the matric suction head

α and n are independent curve shape parameters

For any homogeneous soil, the relationship between matric suction and retained water can be described by the van Genuchten equations and illustrated as a soil-moisture characteristic curve (fig. 19–54). The θ_r, θ_σ, α, and n values are determined using the Rosetta program described later in this section. It is important to note that the curve shown is specific to a particular water table depth. The retained water content for each layer obtained from the curve shown is only valid for a water table depth of 200 centimeters. In practical terms, retained water for each incremental layer of drained soil is dependent on the initial water table depth and the final drained depth. It is also important to note that the curve is representative of static conditions following a single drawdown event, with a final constant water table depth. These considerations require analysis based on an assumed final water

Table 19–14 Effective radius values for ditch and various pipe diameters

Tile diameter in	r_e in	r_e ft
4	0.20	0.0167
5	0.41	0.034
6	0.58	0.048
8	0.96	0.08 (extrapolated)
10	1.33	0.111 (extrapolated)
12 and larger	1.70	0.142 (extrapolated and limit set)
Ditch, any size	12	1.0 (chosen by practical experience)
Drain tube (surrounded by a square gravel envelope with dimensions of 2n on each side)	1.177n	1.177n

Figure 19–54 Soil moisture characteristic curve

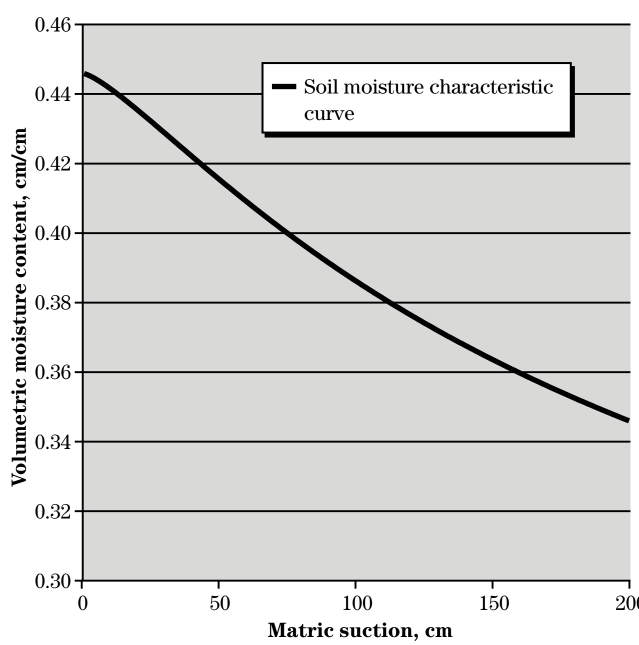


table depth, with assumption of a single drawdown from an initial wet condition to final drained condition. If the soil layers are divided into sufficiently small increments, the incremental differences can be added through the drawdown range to obtain the total drained volume. This volume divided by the total drained depth yields the drainable porosity, ϕ.

Figure 19–55 illustrates the determination of drainable porosity using the results of a Rosetta program analysis. The incremental depth (1 cm) is small to improve accuracy. Inputs on the top left side of the spreadsheet indicate that initial water table depth is 0 centimeters, final water table depth is 60 centimeters, and the analysis is performed for soil code 13 which is map unit 138B2, Clarion soil series. The selected theta r, selected theta s, selected alpha, and selected N are populated from the soil parameters for the selected soil, and will be explained later. The volume drained and drainable porosity, ϕ, are calculated from the values on the right-side of the sheet, and are a direct function of the initial and final water table depth. The drainable porosity is the volume drained divided by the drained depth of 60 centimeters (60–0 cm). The depth of 60 centimeters is appropriate in an analysis for a 2 foot drawdown. It is important to note that the values on the right side are not constants. They represent values obtained from the soil-moisture retention curve plotted using the van Genuchten equations, and will change with varying final water table depths. The initial water table depth is only used to calculate the volume drained and drainable porosity.

The data is used by the ND-Drain computer program, as well as the DRAINMOD program for computing drainable porosity. The drainable porosity value can be used as an entry in drainage equations using hand computations or computer applications.

(ii) Hydraulic conductivity

Saturated hydraulic conductivity, K_{sat}, is used by all lateral effect equations and DRAINMOD with the assumption that the soil profile beneath the water table boundary is saturated. A value for unsaturated hydraulic conductivity, $K(S_e)$, is needed by DRAINMOD for use in accounting for rainfall moving downward through unsaturated soil and for water moving upward through capillary tension induced by evapotranspiration. Like the van Genuchten drainable porosity parameters, the parameters needed for hydraulic conductivity are also generated by the Rosetta program.

Unsaturated hydraulic conductivity, K, is a function of the soil moisture content, and is calculated using the following expression (van Genuchten, 1980).

$$K(S_e) = K_o S_e^L \left\{ 1 - \left[1 - S_e^{\frac{1}{m}} \right]^m \right\}^2 \qquad \text{(eq. 19–6)}$$

where:

S_e = the effective saturation at a certain volumetric moisture content.

n = the van Genuchten curve shape parameter, same as used in equation 19–4.

L = an empirically derived tortuosity/connectivity parameter based on soil properties.

K_o = the hydraulic conductivity at saturation. This is an empirically derived parameter, and is not the same as saturated hydraulic conductivity, K_{sat}. (Schaap and Leij 2000, and Schaap and van Genuchten 2006).

For drainage analysis involving hydraulic conductivity and drainable porosity, values are needed for θ_r, θ_s, α, n, K_{sat}, K_o, and L. The Rosetta program provides these values using soils data from the Soil Data Access website.

(iii) Processing soil data using Rosetta software

The Rosetta model (Schaap 2000) creates output files of the hydraulic conductivity and van Genuchten parameters needed for drainage equations, single drain methods, the soils input file for ND-Drain, and the soils input file for DRAINMOD. It was developed by Dr. Marcel Schaap of the USDA Agricultural Research Service (ARS) in Riverside, California.

Five levels of input can be used for prediction of soil physical properties:

- texture
- percent sand, silt, and clay
- percent sand, silt, and clay, plus dry bulk density
- percent sand, silt, and clay; plus dry bulk density; plus one-third bar water content
- percent sand, silt and clay; plus dry bulk density; plus one-third and 15 bar water contents

Figure 19–55 Drainable porosity calculator

Water Table	Depth, cm.	60		Selected Theta r	0.08283	Selected N	1.32705
Start Drain	Depth	10		Selected Theta S	0.44598		
Soil Code		1		Selected Alpha	0.01058		
Drainable Porosity		0.01444	cm/cm				
Volume Drained		0.72224	cm				

Code	Description	Bottom Depth, cm	Theta_r, cm3/cm3	Theta_s, cm3/cm3	Alpha	N	Layer No.	Head at layer	Moisture content at Layer	Drained Volume by Layer, cm	Total Drained at Layer, cm
1	107Webster	41.00	0.08283	0.44598	0.01058	1.32705	0		0.40926	0.03672	0.03672
2	107Webster	102.00	0.08013	0.42784	0.00997	1.33088	1	59.5	0.40990	0.03608	0.07280
3	107Webster	152.00	0.06077	0.36945	0.01666	1.25947	2	58.5	0.41053	0.03545	0.10825
4	108BWadena	43.00	0.06626	0.41331	0.01281	1.32114	3	57.5	0.41117	0.03481	0.14306
5	108BWadena	81.00	0.06799	0.41087	0.01349	1.30997	4	56.5	0.41181	0.03417	0.17724
6	108BWadena	152.00	0.05123	0.35947	0.04219	2.19162	5	55.5	0.41245	0.03353	0.21077
7	1221Palms	36.00	0.07798	0.44714	0.00776	1.34171	6	54.5	0.41309	0.03289	0.24366
8	1221Palms	117.00	0.07798	0.44714	0.00776	1.34171	7	53.5	0.41374	0.03224	0.27590
9	1221Palms	152.00	0.06264	0.37099	0.00875	1.34563	8	52.5	0.41439	0.03159	0.30749
10	135Coland	99.00	0.07760	0.42394	0.01567	1.27400	9	51.5	0.41504	0.03094	0.33843
11	135Coland	130.00	0.07760	0.42394	0.01567	1.27400	10	50.5	0.41569	0.03029	0.36872
12	135Coland	152.00	0.05383	0.36367	0.01719	1.27385	11	49.5	0.41635	0.02963	0.39835
13	138B2Clarion	18.00	0.06259	0.40265	0.01357	1.31572	12	48.5	0.41701	0.02897	0.42733
14	138B2Clarion	41.00	0.06259	0.40265	0.01357	1.31572	13	47.5	0.41767	0.02831	0.45564
15	138B2Clarion	89.00	0.06259	0.40265	0.01357	1.31572	14	46.5	0.41833	0.02765	0.48329
16	138B2Clarion	152.00	0.04940	0.35370	0.01815	1.26910	15	45.5	0.41899	0.02699	0.51028
17	138BClarion	18.00	0.06259	0.40265	0.01357	1.31572	16	44.5	0.41966	0.02632	0.53661
18	138BClarion	46.00	0.06259	0.40265	0.01357	1.31572	17	43.5	0.42032	0.02566	0.56226
19	138BClarion	91.00	0.06461	0.37488	0.01654	1.25271	18	42.5	0.42099	0.02499	0.58725
20	138BClarion	152.00	0.04940	0.35370	0.01815	1.26910	19	41.5	0.42166	0.02432	0.61157
21	138C2Clarion	18.00	0.06259	0.40265	0.01357	1.31572	20	40.5	0.42233	0.02365	0.63521
22	138C2Clarion	41.00	0.06259	0.40265	0.01357	1.31572	21	39.5	0.42301	0.02297	0.65819
23	138C2Clarion	89.00	0.06259	0.40265	0.01357	1.31572	22	38.5	0.42368	0.02230	0.68049
24	138C2Clarion	152.00	0.04940	0.35370	0.01815	1.26910	23	37.5	0.42435	0.02163	0.70211
25	138CClarion	18.00	0.06259	0.40265	0.01357	1.31572	24	36.5	0.42503	0.02095	0.72306
26	138CClarion	46.00	0.06259	0.40265	0.01357	1.31572	25	35.5	0.42571	0.02027	0.74334
27	138CClarion	91.00	0.06461	0.37488	0.01654	1.25271	26	34.5	0.42638	0.01960	0.76294
28	138CClarion	152.00	0.04940	0.35370	0.01815	1.26910	27	33.5	0.42706	0.01892	0.78186
29	138D2Clarion	18.00	0.06259	0.40265	0.01357	1.31572	28	32.5	0.42773	0.01825	0.80010
30	138D2Clarion	41.00	0.06259	0.40265	0.01357	1.31572	29	31.5	0.42841	0.01757	0.81768
31	138D2Clarion	89.00	0.06259	0.40265	0.01357	1.31572	30	30.5	0.42908	0.01690	0.83457
32	138D2Clarion	152.00	0.04940	0.35370	0.01815	1.26910	31	29.5	0.42976	0.01622	0.85079
33	1507Brownton	56.00	0.09497	0.50828	0.01288	1.29155	32	28.5	0.43043	0.01555	0.86634
34	1507Brownton	96.00	0.10139	0.52530	0.01834	1.23448	33	27.5	0.43110	0.01488	0.88122
35	1507Brownton	152.00	0.07675	0.42134	0.01426	1.28747	34	26.5	0.43177	0.01421	0.89542
36	1536Hanlon	74.00	0.05114	0.39380	0.03496	1.27832	35	25.5	0.43244	0.01354	0.90896
37	1536Hanlon	96.00	0.05114	0.39380	0.03496	1.27832	36	24.5	0.43311	0.01287	0.92184
38	1536Hanlon	152.00	0.03595	0.34623	0.05706	1.27337	37	23.5	0.43377	0.01221	0.93405
39	1585Coland	99.00	0.08078	0.42828	0.01078	1.31925	38	22.5	0.43443	0.01155	0.94560
40	1585Coland	130.00	0.07760	0.42394	0.01567	1.27400	39	21.5	0.43508	0.01090	0.95649
41	1585Coland	152.00	0.05383	0.36367	0.01719	1.27385	40	20.5	0.43508	0.01090	0.96739
42	1585Spillville	91.00	0.06219	0.38973	0.01487	1.29564	40	20.5	0.43574	0.01024	0.97763
43	1585Spillville	152.00	0.05170	0.35222	0.01913	1.25180	41	19.5	0.43638	0.00960	0.98723
44	168BHayden	23.00	0.05387	0.37663	0.01479	1.30569	42	18.5	0.43702	0.00896	0.99619
45	168BHayden	36.00	0.05387	0.37663	0.01479	1.30569	43	17.5	0.43766	0.00832	1.00451
46	168BHayden	109.00	0.06612	0.38115	0.01656	1.25571	44	16.5	0.43829	0.00769	1.01221
47	168BHayden	152.00	0.05006	0.33258	0.02375	1.20000	45	15.5	0.43891	0.00707	1.01928
48	168C2Hayden	23.00	0.05387	0.37663	0.01479	1.30569	46	14.5	0.43952	0.00646	1.02574
49	168C2Hayden	36.00	0.05387	0.37663	0.01479	1.30569	47	13.5	0.44012	0.00586	1.03160
50	168C2Hayden	109.00	0.06612	0.38115	0.01656	1.25571	48	12.5	0.44071	0.00527	1.03687
51	168C2Hayden	152.00	0.05006	0.33258	0.02375	1.20000	49	11.5	0.44129	0.00469	1.04156
52	168CHayden	23.00	0.05387	0.37663	0.01479	1.30569	50	10.5	0.44186	0.00412	1.04568
53	168CHayden	36.00	0.05387	0.37663	0.01479	1.30569	51	9.5	0.44241	0.00357	1.04925
54	168CHayden	109.00	0.06612	0.38115	0.01656	1.25571	52	8.5	0.44294	0.00304	1.05229
55	168CHayden	152.00	0.05006	0.33258	0.02375	1.20000	53	7.5	0.44346	0.00252	1.05481
56	168EHayden	23.00	0.05387	0.37663	0.01479	1.30569	54	6.5	0.44395	0.00203	1.05683

The fifth, or highest, level of prediction can be achieved using data retrieved from NASIS or from the WSS. Algorithms used by Rosetta to predict hydraulic properties were developed based on a soil database of 2,085 soil samples from the USDA, NRCS, National Soil Survey Center in Lincoln, Nebraska. Using statistically based pedotransfer functions, Rosetta predicts water retention, saturated hydraulic conductivity, and hydraulic characteristics from basic soil physical data. In addition Rosetta predicts the unsaturated hydraulic conductivity Van Genuchten (VG) parameters required for the equation developed by Martinus van Genuchten (USDA ARS).

Procedure

The basic steps in the procedure are given and described in the remainder of this section.

Step 1: *Obtain the SSID code.* Soil survey identification codes can be found at the Soil Data Mart Web site *http://soildatamart.nrcs.usda.gov/State.aspx*. Note that some counties have multiple soil survey areas. SSID codes are a combination of a two-character alpha notation for the State, commonly used by the U.S. Postal Service. For example, Texas is TX. The three digit numeric portion is the county name in a State in alphabetic order and assigned sequential odd only numbers. For example, Lincoln County, Minnesota is MN081.

Step 2: *Obtain soils data using soil data access.* The Soil Data Access website is located at the URL: *http://sdmdataaccess.nrcs.usda.gov/*

Click on submit a custom request for soil tabular data for the resulting screen shown in figure 19–56. The user then inputs an SQL query into the dialog box, which can be inserted using copy and paste. The desired field and text delimiters can be selected (i.e. vertical bar, tab, single quotes, or double quotes). The requested data is provided by county and the response to the data request will be e-mailed to the address input at the bottom of the screen. The query shown will provide the necessary data for soil data processing, but the user must modify the soil survey area designation to correspond to their area of interest. The example shown shows the soil survey area designation NE109, indicating Lancaster County, Nebraska.

The query in the screen shown in figure 19–57 is reproduced.

Once the query is submitted, the Soil Data Access service will send an e-mail with a link to a *.zip file containing the text file of which a portion is shown in figure 19–58.

Step 3: Convert the soil data format for Rosetta. This data must be properly formatted for input into the Rosetta computer program. A properly formatted file is shown in figure 19–59.

The first column is a code used for selecting the desired soil record in Rosetta. The second column contains the soil map unit designation concatenated with the soil series name. The next two columns contain the beginning and ending depths, in centimeters, for all soil layers available for each map unit. Columns 5, 6, and 7 are the percentages of sand, silt, and clay. Column 8 is the bulk density in grams per cubic centimeter. Column 9 is the moisture content at one-third bar of matric suction, and column 10 is the moisture content at 15 bars. Insert –9.9 in the table where data is missing.

Step 4: Run the Rosetta Program. A screen view of the program after a simulation is shown in figure 19–60.

The program contains options providing output with limited input data. For instance, van Genuchten parameters and hydraulic conductivities can be computed with a simple input of texture class. If the soil texture percentages are known, Rosetta can be executed with only this data. Greater accuracy is obtained with data from Soil Data Access files, which include texture, bulk density, and volumetric moisture content at one-third and 15 bars. However, this data is based on representative properties for the soil map unit. If actual field conditions are known, the program should be run with known or estimated properties based on field data or observations. Figure 19–61 shows an example of Rosetta output.

(iv) Using Rosetta output

Various methods of drainage analysis use parameters provided in Rosetta output. The program output file can be used to prepare the *.SIN file needed for input into the DRAINMOD program, which uses the soil moisture retention parameters θ_r, θ_s, θ, and n as well as the hydraulic conductivity parameters K_{sat}, K_o, and L. The various lateral effect options in the ND-Drain program use these same parameters, with the exception of K_o and L.

Figure 19–56 Soil Data Access Web site

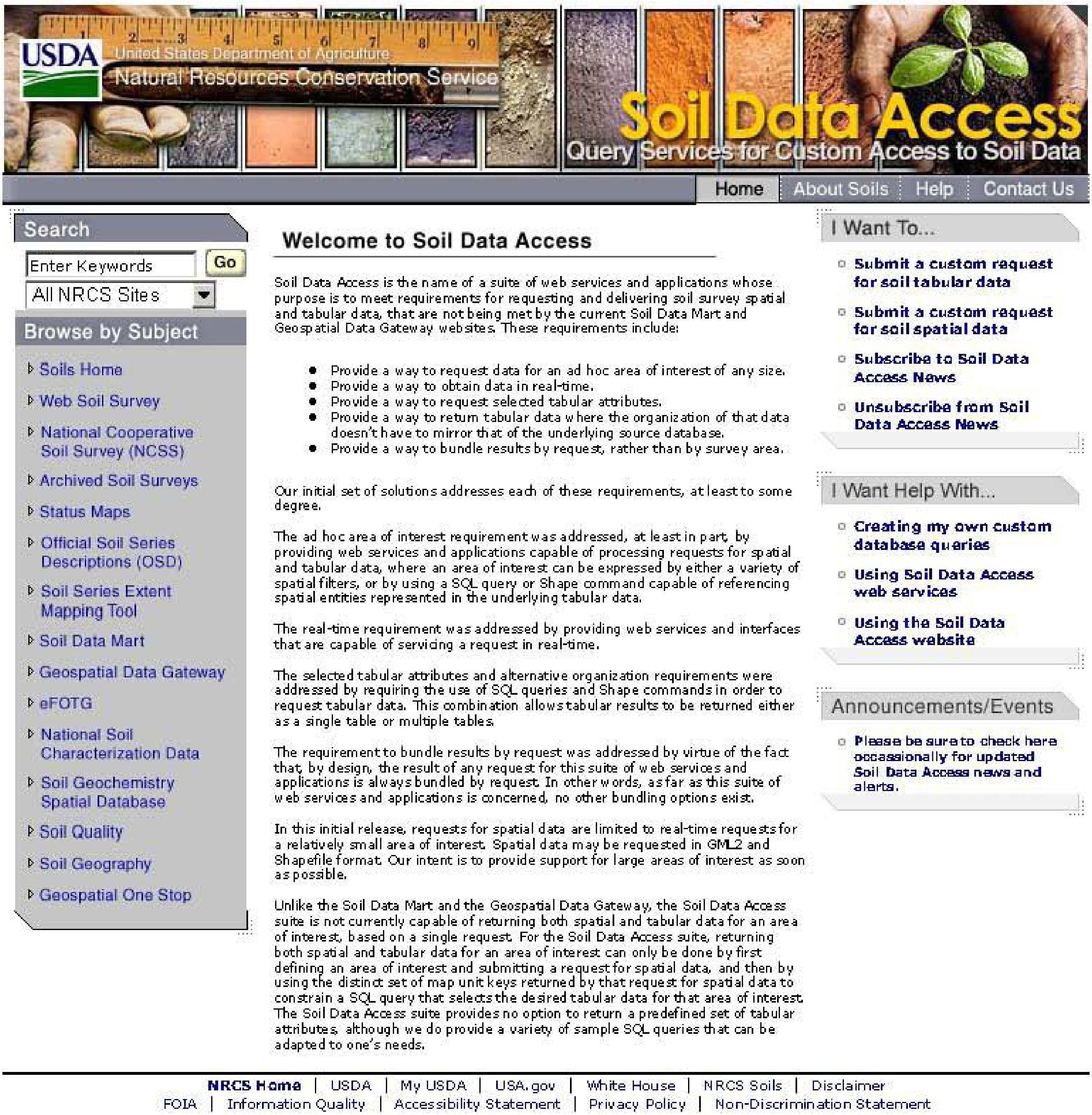


Figure 19–57 Soil Data Access query screen

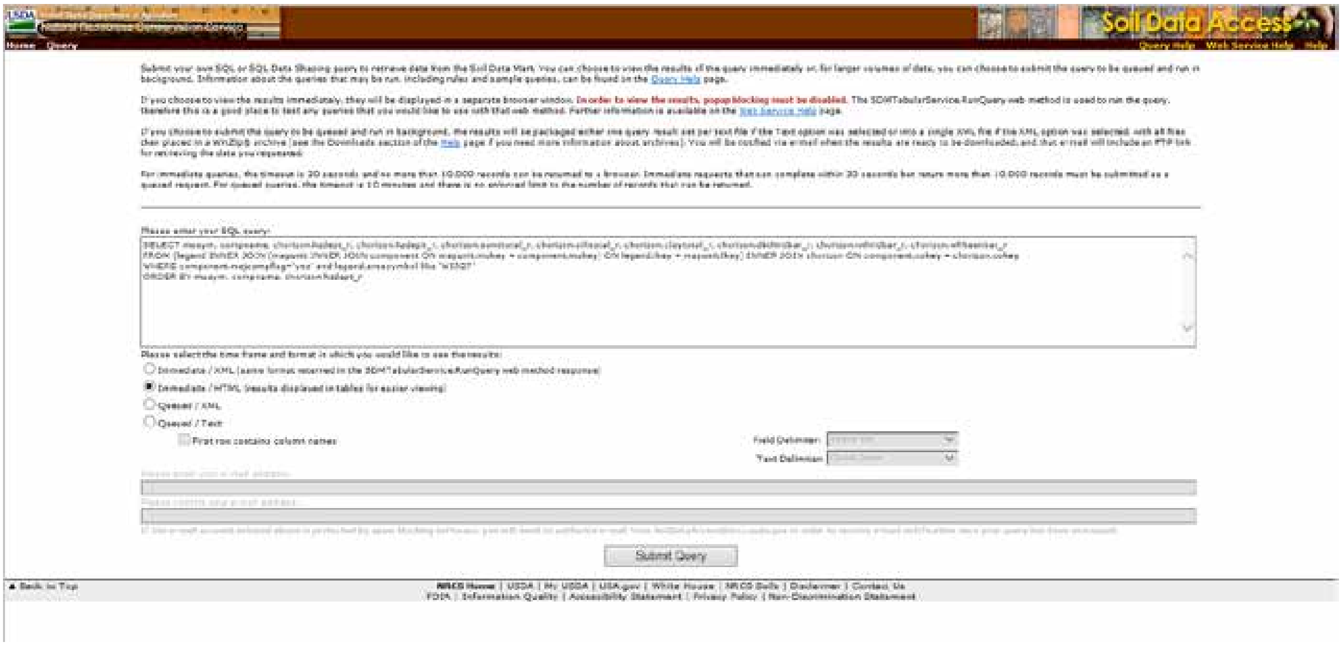


Figure 19–58 Soils data from Soil Data Access

```
Table.txt
"musym"|"compname"|"hzdept_r"|"hzdepb_r"|"sandtotal_r"|"silttotal_r"|"claytotal_r"|"
dbthirdbar_r"|"wthirdbar_r"|"wfifteenbar_r"
"3518"|"Lamo"|0|74|7.3|66.2|26.5|1.45|31.7|18
"3518"|"Lamo"|74|152|6.9|63.1|30|1.4|31.6|17.7
"3561"|"Hobbs"|0|18|11.3|67.7|21|1.3|29.4|14.5
"3561"|"Hobbs"|18|130|11.3|67.7|21|1.3|27.3|11.8
"3561"|"Hobbs"|130|152|7.8|69.7|22.5|1.3|28|12.6
"3640"|"Kezan"|0|23|9.4|67.1|23.5|1.3|30.3|15.8
"3640"|"Kezan"|23|152|7|67|26|1.3|29.3|14.4
"3641"|"Kezan"|0|15|3|73|24|1.3|30.4|16
"3641"|"Kezan"|15|33|7.3|66.7|26|1.3|30.3|15.8
"3641"|"Kezan"|33|81|6.8|67.2|26|1.3|29.3|14.4
"3641"|"Kezan"|81|152|7.3|66.7|26|1.3|30.3|15.8
```

Saturated hydraulic conductivity is rarely the same in both the horizontal and vertical directions, meaning soil is anisotrophic. This phenomenon is dealt with by calculating a weighted K_{sat} using equation 19–3. The saturated hydraulic conductivity provided by Rosetta does not directly account for the phenomenon of anisotropy. The use of Soil Data Access data compensates for this somewhat, as the data is based on individual soil horizon layers. However, the layer thickness may represent all of the drawdown range for the analysis, so the results are based on an isotropic K_{sat}. In practice, this condition is considered to be acceptable as long as the difference in conductivity rates from horizontal to vertical is less than a factor of 10. The ND-Drain and DRAINMOD programs utilize these values by layer to calculate a weighted K_{sat} if the depth to drain involves multiple soil horizons.

Drainable porosity is a common parameter needed by various lateral effect equations. It is commonly misinterpreted as a single number which is specific to the soil properties. It is a function of soil matrix properties as well as the initial and final water levels. The Rosetta program does not directly provide drainable porosity. This value can be obtained from hand computations, spreadsheet methods, DRAINMOD software, or ND-Drain software. Hand calculations can be performed using the Rosetta parameters by calculating the retained soil moisture using equations 19–4 and 19–5 for the initial and final water level, at a minimum. Accuracy is increased by making calculations for increments, and summing the volumes drained by increment. Spreadsheet methods, as shown in figure 19–55 can provide drained volumes by layer for more accurate results. The DRAINMOD program and lateral effect analysis tools in ND-Drain use the soil moisture retention parameters from Rosetta along with user input water levels to calculate soil moisture retention values internally for accurate drainable porosity values.

(e) Drainage equations

Examples of the use of each drainage equation are provided using data for the Glencoe soil series, obtained from Soil Data Access, and processed using the Rosetta Program. The results of Rosetta processing are shown in table 19–15:

Figure 19–59 Formatted Rosetta input file

```
                         RosettaInputLancaster.txt
Rosetta Input
"Lancaster County, Nebraska"

1     3518Lamo    0     74    7.3   66.2  26.5  1.45  31.7  18
2     3518Lamo    74    152   6.9   63.1  30    1.4   31.6  17.7
3     3561Hobbs   0     18    11.3  67.7  21    1.3   29.4  14.5
4     3561Hobbs   18    130   11.3  67.7  21    1.3   27.3  11.8
5     3561Hobbs   130   152   7.8   69.7  22.5  1.3   28    12.6
6     3640Kezan   0     23    9.4   67.1  23.5  1.3   30.3  15.8
7     3640Kezan   23    152   7     67    26    1.3   29.3  14.4
8     3641Kezan   0     15    3     73    24    1.3   30.4  16
9     3641Kezan   15    33    7.3   66.7  26    1.3   30.3  15.8
10    3641Kezan   33    81    6.8   67.2  26    1.3   29.3  14.4
11    3641Kezan   81    152   7.3   66.7  26    1.3   30.3  15.8
```

Figure 19–60 Rosetta screen

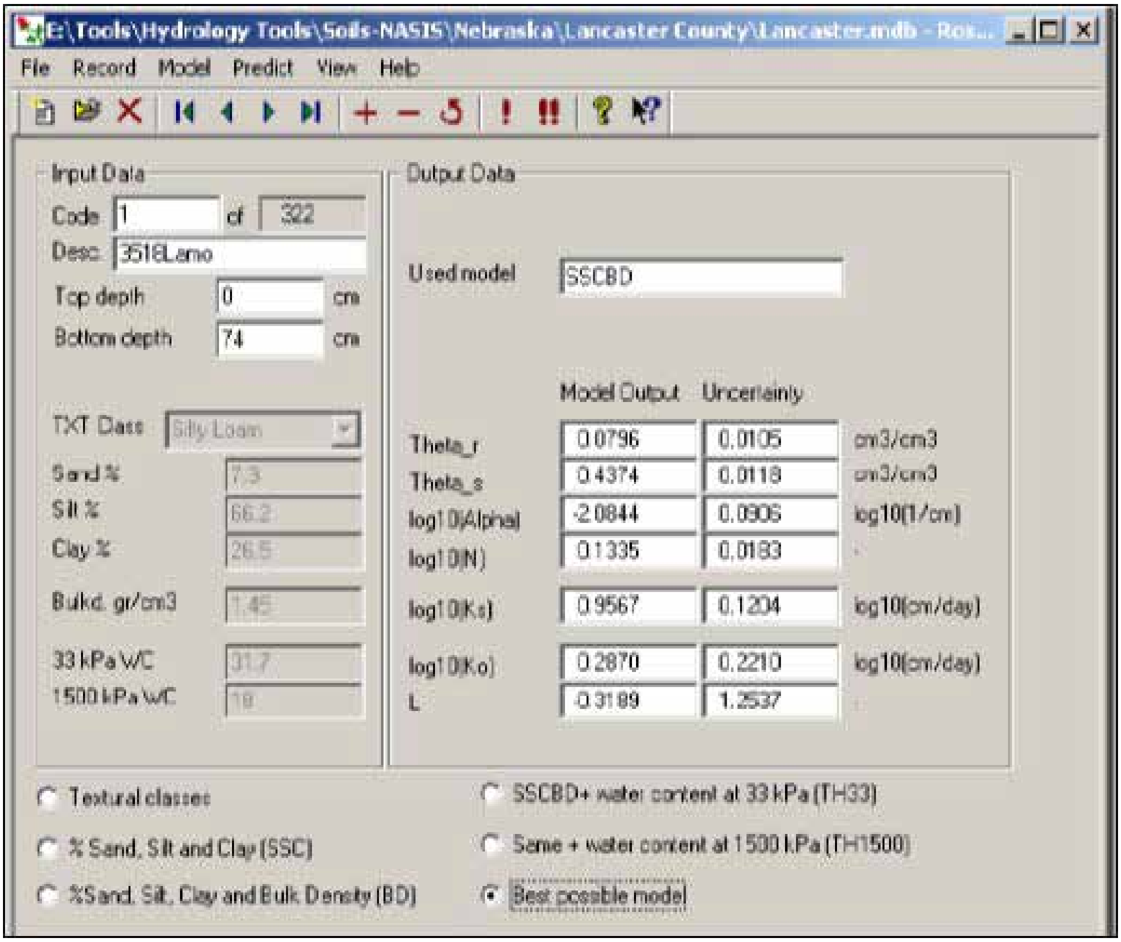


Figure 19–61 Rosetta output

Code	Description	Bottom Depth cm	Theta_r cm3/cm3	Theta_s cm3/cm3	Alpha log(1/cm)	N Log10	Ks Log(cm/day)	Ko Log(cm/day)	L No units
1	3518Lamo	74	0.07964	0.43738	0.00823	1.36	9.05057	1.93654	-0.31888
2	3518Lamo	152	0.08448	0.45542	0.00912	1.3418	9.96797	2.1073	-0.43701
3	3561Hobbs	18	0.07555	0.45708	0.00662	1.404	26.24413	1.74872	0.07
4	3561Hobbs	130	0.07555	0.45708	0.00662	1.404	26.24413	1.74872	0.07
5	3561Hobbs	152	0.0789	0.46796	0.00708	1.3908	23.13123	1.83549	0.00229
6	3640Kezan	23	0.07928	0.46538	0.00718	1.3878	22.60359	1.83713	-0.03042
7	3640Kezan	152	0.08288	0.47461	0.0079	1.3697	19.40461	1.9703	-0.14946
8	3641Kezan	15	0.08262	0.48244	0.00779	1.3733	18.57215	2.00346	-0.09489
9	3641Kezan	33	0.08277	0.47392	0.00788	1.3701	19.52444	1.96555	-0.14824
10	3641Kezan	81	0.08296	0.47507	0.00791	1.3694	19.32109	1.97366	-0.15034

For each analysis, the example depth of drain is 48 inches, the objective criterion for drawdown is 12 inches, and the depth to impermeable layer is 10 feet. The objective criterion for time to drawdown is 14 days. The computation of saturated hydraulic conductivity and drainable porosity is needed for all four methods:

(i) Saturated hydraulic conductivity

Each of the various drainage equations require computation of saturated hydraulic conductivity, K_{sat}. This computation will be shown here to avoid repetition. The separation between Ka and Kb is at the drain depth of 4 feet (48 inches).

K for the multi-layered soil is:

$$\text{Ka} = \frac{\left[(0.164 \text{ in/hr})(39)+(0.141 \text{ in/hr})(9)\right]}{48}$$
$$= 0.160 \text{ in/h}$$

for hydraulic conductivity above the drain.

$$\text{Kb} = \frac{\left[(0.141)(2)+(0.148)(70)\right]}{72}$$
$$= 0.148 \text{ in/h}$$

for hydraulic conductivity below the drain.

Table 19–15 Soil data processed using Rosetta

Glencoe soil							
Layer cm	Theta_r cm^3/cm^3	Theta_s (1/cm)	Alpha	N	K_{sat} (cm/d)	K_{sat} (in/h)	K_{sat} (ft/d)
0–99 (39 in)	0.079	0.437	0.015	1.28	10.0	0.164	0.32
99–127 (50 in)	0.077	0.426	0.014	1.29	8.58	0.141	0.28
127–152 (60 in)	0.073	0.418	0.013	1.39	9.04	0.148	0.30

Overall conductivity:

$$(0.160 \text{ in/h})(0.48)+\frac{\left[(0.148 \text{ in/h})(72 \text{ in})\right]}{120} = 0.153 \text{ in/h}$$

Using the factor of 2 to convert from inches per hour to feet per day, gives a composite hydraulic conductivity, K, of 0.31 foot per day.

(ii) Drainable porosity

The drainable porosity, θ, used in the equations is based on these beginning and ending water levels. Since the 12 inch drawdown occurs within the 0 to 99 centimeter layer, it can be calculated using the Theta r, Theta s, Alpha, and N parameters from this layer using the van Genuchten equations 19–4 and 19–5.

The matric suction head is 30 centimeters (12 in) at the bottom. Since the head and resulting moisture content varies with depth, the mid-point of the drained layer is used for the value of h. This is 30/2, or 15 centimeters. Using equations 19–4 and 19–5, the resulting value for m is 1 – 1/1.28 equals 0.22, and the average moisture content of this 30 centimeter drained layer, θ(h), is 0.426 centimeter per centimeter.

The volume drained, then is the difference between the moisture content at saturation, θ_s, and θ(h).

θ_s = 0.437 (from table 19–15), so the volume drained is 0.437 – 0.426 = 0.011 centimeter per centimeter.

For a 30 centimeter drained depth the total volume drained is:

$$30 \times 0.011 = 0.33 \text{ cm}$$

The drainable porosity, ϕ, is the total volume drained divided by the drained depth of 30 centimeters.

$$\phi = \frac{33}{30} = 0.011 \text{ cm}$$

Note that the ϕ for the 30 inch drawdown is 0.011 centimeter per centimeter, which is the same value as the 0.011 centimeter volume drained at the 15 centimeters midpoint layer. This is not uncommon, but it must be recognized that these are not the same parameters.

Greater accuracy can be achieved by performing the calculations on smaller layers, and summing the volume drained by layer. The results of a spreadsheet computation where this was performed in 1 centimeter increments is shown in table 19–16. The total volume drained is 0.33553 centimeter, which rounds up to 0.336 centimeter.

Dividing a total volume drained of 0.336 centimeter by a drained depth of 30 centimeters results in the drainable porosity for the drained depth:

$$\phi = \frac{0.336}{30} = 0.011 \text{ cm/cm}$$

which is the same value as from the hand computations, using the entire 30 centimeters as one layer, with a mid-point at 15 centimeters.

For the next examples, then, the K_{sat} values used will be from table 19–15, and ϕ will be 0.011.

(iii) Nonsteady state drainage equations
van Schilfgaarde equation
This is a nonsteady state equation, meaning that water is not continuously added to the system. The assumptions of this equation are appropriate for many parts of the United States where the rainfall is more sporadic than constant. The equation does not yield a reasonable solution when the drain rests on the impermeable layer, that is when a=0. The equation must use equivalent depth instead of actual depth to give the best results. Surface water must be removed from a site in order to apply this equation correctly. The surface water may be removed by a ditch, natural ground slope, or the surface intake for a tile.

The van Schilfgaarde equation includes a parameter for time, so it can be used to compare how much water is removed in 7 days versus 14 days, for instance The time period selected does significantly affect the results. The drainable porosity, ϕ, affects the results of the equation but ϕ values that are similar in magnitude such as 0.02 and 0.026 result in minor differences in the spacing calculated. Values computed should be rounded up to the nearest 5 feet.

The van Schlifgaarde equation has been modified by NRCS hydrologists to a form that uses these parameters:

Table 19–16 Drainable porosity calculation using spreadsheet methods

Layer	Head	Water content	Volume drained by layer	Total drained
0				
1	29.5	0.41324	0.02346	0.02346
2	28.5	0.41409	0.02261	0.04607
3	27.5	0.41495	0.02175	0.06782
4	26.5	0.41580	0.02090	0.08872
5	25.5	0.41666	0.02004	0.10876
6	24.5	0.41753	0.01917	0.12793
7	23.5	0.41839	0.01831	0.14624
8	22.5	0.41926	0.01744	0.16368
9	21.5	0.42013	0.01657	0.18026
10	20.5	0.42100	0.01570	0.19596
11	19.5	0.42187	0.01483	0.21079
12	18.5	0.42273	0.01397	0.22476
13	17.5	0.42360	0.01310	0.23786
14	16.5	0.42447	0.01223	0.25009
15	15.5	0.42533	0.01137	0.26146
16	14.5	0.42619	0.01051	0.27197
17	13.5	0.42704	0.00966	0.28162
18	12.5	0.42789	0.00881	0.29043
19	11.5	0.42873	0.00797	0.29840
20	10.5	0.42956	0.00714	0.30553
21	9.5	0.43038	0.00632	0.31185
22	8.5	0.43119	0.00551	0.31736
23	7.5	0.43198	0.00472	0.32209
24	6.5	0.43274	0.00396	0.32604
25	5.5	0.43349	0.00321	0.32925
26	4.5	0.43420	0.00250	0.33175
27	3.5	0.43488	0.00182	0.33357
28	2.5	0.43551	0.00119	0.33475
29	1.5	0.43608	0.00062	0.33537
30	0.5	0.43655	0.00015	0.33553

S = drain spacing, ft
K = hydraulic conductivity, in/h
d_e = equivalent depth, ft, from drainage feature to impermeable layer
m = height of water table above the center of the drain at midplane after time, ft
m_o = height of water table above the center of the drain at midplane at time zero, ft
t = time in days for water table to drop from m_o to m
ϕ = drainable porosity of the soil
a = depth from free water surface in drainage feature to impermeable layer, ft
s = water trapped on the surface by soil roughness, in
S´ = estimated drain spacing, ft
L_e = lateral effect distance, ft = ½ S
f´ = drainable porosity adjusted for surface roughness, dimensionless, calculated with the equation:

$$f' = f + \left(\frac{s}{(m_o - m)}\right) \quad \text{(eq. 19–7)}$$

The adjustment to f´ using soil roughness, s allows for an increase in the drainable porosity, f, to provide an adjusted drainable porosity, f´. van Schilfgaarde did not use this soil storage adjustment in his original equation. Use of the values for s must be carefully considered and be based on local experience.

Application of the original or modified van Schilfgaarde equation is a two-step process. The initial equation is used to determine the estimated spacing, S´.

$$S' = \sqrt{\frac{9(K)(t)(a)}{f'\left[\ln\left(m_o(2a+m)\right) - \ln\left(m(2a+m_o)\right)\right]}} \quad \text{(eq. 19–8)}$$

The parameters for this equation are illustrated in figure 19–51.

Using the estimated spacing S´, an equivalent depth, d_e, is calculated from one of these equations:

$$d_e = \frac{a}{1+\left(\frac{a}{S'}\right)\left[\left(\frac{8}{\pi}\right)\ln\left(\frac{a}{r_e}\right) - 3.4\right]}; \text{ for } a/S' \le 0.3 \quad \text{(eq. 19–9)}$$

$$d_e = \frac{S'\pi}{8\left[\ln\left(\frac{S'}{r_e}\right) - 1.15\right]}; \text{ for } a/S' > 0.3 \quad \text{(eq. 19–10)}$$

With the equivalent depth d_e, equation 19–11 is used to determine the final spacing. The difference between the initial spacing, S´ and the final spacing S must be less than 10 percent.

$$S = \sqrt{\frac{9Ktd_e}{f'\left[\ln\left(m_o(2d_e+m)\right) - \ln\left(m(2d_e+m_o)\right)\right]}} \quad \text{(eq. 19–11)}$$

The lateral effect distance is half the calculated spacing, or d_e = 1/2 S

Example
A 5-inch corrugated plastic drainage tubing will be installed at a 4-foot depth in Glencoe soil. The impermeable layer depth used will be 10 feet. The surface storage is estimated to be 0.1 inches. The saturation is to be removed to a depth of 12 inches in 14 days.

Drawdown time, t – 14 d

Drawdown depth – 12 in

Drainable porosity, f = 0.011

K_{sat} = 0.153 in/h

Depth to impermeable layer – 10 ft

Tile size = 5 in

Solution
A 5-inch drain has an effective radius of 0.034 feet (table 19–14). At time is 0, the soil is saturated to the surface so m_o is 4 feet (depth of the drain). After 14 days, the saturation is desired to be 12 inches or 1 foot below the soil surface, so m is 4 feet minus 1 foot equals 3 feet. The impermeable layer is at 10 feet.

The adjusted drainable porosity is:

$$\begin{aligned} f' &= f + \frac{s}{12\text{ in}} \\ &= 0.011 + \frac{0.1}{12} \\ &= 0.0193\text{ ft/ft} \end{aligned}$$

The value for a needed to compute the effective depth, d_e, is the difference between the depth to the impermeable layer, 10 feet, and the depth to the drain, 4 feet:

$$\begin{aligned} a &= 10 - 4 \\ &= 6 \end{aligned}$$

An initial estimate of the spacing, S´ must be made. Using equation 19–9, S´ is calculated to be 231 feet. Use the estimated spacing S´ to calculate d_e from equations 19–9 or 19–10. The ratio a/S´ = 6/232 = 0.02 foot. This is less than 0.3 so equation 19–3 will be used.

$$d_e = 4.78\text{ ft}$$

Use this in equation 19–11 to calculate the spacing, S.

$$S = 212\text{ ft}$$

Check that the estimated and actual spacing is within 10 percent of each other.

$$\left(\frac{(231-212)}{212}\right)\times 100 = 8.2\%$$

The 212 foot spacing may be used. The lateral effect distance is half of the spacing:

$$\begin{aligned} L_e &= \frac{212}{2} \\ &= 106\text{ ft} \end{aligned}$$

This is rounded to the nearest 5 feet, so:

$$L_e = 105\text{ ft}$$

(iv) Steady state drainage equations
Ellipse equation

This steady state equation was widely used in the early days of drainage to estimate the economical drainage spacings and depths for agricultural drainage tile or tubing and ditches. It was commonly applied with the requirement that the water table should be lowered below the root zone within 24 to 48 hours after saturation. It is the simplest of the drainage equations.

This equation assumes that the soil is homogeneous and has a hydraulic conductivity of K. Further assumptions are that:

- the drains are evenly spaced at a distance S
- an impermeable layer underlies the drain at a depth, a, but the equation is not valid for large values of a, greater than 2 times the drain depth
- rain is falling or irrigation water is applied at a continuous rate, v

The equation should not be used where the vertical hydraulic conductivity exceeds the horizontal hydraulic conductivity. The equation does not have a factor of time, and therefore the user must adjust the parameters to account for a time difference if the time desired is other than the 24 to 48 hours routinely assumed. The ellipse equation assumes that surface water has been removed and does not have to go through the subsurface drainage system. Further, this equation assumes the tile is in a good state of repair and has an adequate outlet. As with all drainage equations, it assumes the soil is uniform, when in reality, the soil survey cautions that inclusions of up to 40 percent can occur in a soil mapping unit.

The ellipse equation uses the concept of drainage coefficient, given the symbol, q. This is the rate of removal, expressed in inches per hour that the system must provide to remove excess water. This number is based on rainfall patterns, and other climatic conditions which exist in a local area. The designer made a selection of drainage coefficient in accordance with local practice and experience. This parameter can be used in lateral effects analysis to account for a time factor.

The value assumed for the drainage coefficient, q, has a significant effect on the results of the equation. Minor variability in the hydraulic conductivity, K, does not change the resultant spacing much. The depth to the impermeable layer affects the resultant spacing most significantly when the hydraulic conductivity is high, such as with sandy soils. The ellipse equation is

$$S = \sqrt{(4K)\left(m^2 + \frac{2am}{q}\right)} \qquad \text{(eq. 19–12)}$$

where:
S = parallel drain spacing, ft
K = weighted horizontal hydraulic conductivity above the restrictive layer, inches per hour
m = vertical distance after drawdown of the water table above the drain and at the midpoint between drains, ft (m = d–c)
a = depth to the impermeable layer or barrier below drains, ft
q = drainage rate, in/h
d = depth to drain from ground surface(or reference elevation), ft
c = depth to water table (drawdown) after the evaluation period, measured from the ground surface (or reference elevation), ft
v = depth of water drained, in

Example

Drawdown time, t – 14 days
Drawdown depth – 12 in
Drainable porosity, f = 0.011
K_{sat} = 0.153 in/h = 3.672 in/d
Depth to impermeable layer – 10 ft
r_e = 0.034 for 5 in tile

Solution:

m = d–c = 4 – 1 = 3 ft
a = 10 – 4 = 6 ft
v = drainable porosity × depth of drawdown at the midpoint; v = 0.011 in/in × 12 in = 0.132 in
q = v/t = 0.132 in/14 d = 0.0094 in/d
S = $\{(4K)(m^2 + 2am)/q\}^{1/2}$
S = $\{(4 \times 3.672)((3)^2 + (2 \times 6 \times 3))/0.0094\}^{1/2}$ = 265 ft
L_e = 265/2 = 133 ft

Rounding to the nearest 5 feet:

$$L_e = 135 \text{ ft}$$

Hooghoudt equation

This equation has long been used to design drainage and water supply systems across the United States. It is a steady state equation which assumes that the system steadily removes the rain that falls at a constant rate. This equation is used to determine approximate economical spacings and depths of agricultural drainage tubing and ditches for agricultural crops using the requirement that the water table should be lowered below the root zone within 24 to 48 hours after saturation. The Hooghoudt equation is quite similar to the ellipse equation except that the hydraulic conductivity is calculated separately for the layers above and below the drainage feature.

When this equation was developed, a number of assumptions were made which need to be recognized by the user.

- The soil is homogeneous and has a hydraulic conductivity K.
- The drains are evenly spaced a distance of S apart.
- An impermeable layer underlies the drain at depth a, but the equation is not valid for large values of a.
- Rain is falling or irrigation water is applied at a constant rate.

The Hooghoudt equation does not apply in situations where the vertical hydraulic conductivity exceeds the horizontal hydraulic conductivity. The actual depth to the impermeable layer cannot be more than twice the depth of the drain, and is not to exceed ten feet. This equation assumes the tile is in a good state of repair and has an adequate outlet. The equation itself does not have a factor for time, and as such, one must then adjust the parameters to account for a time difference if a time is desired other than the 24 to 48 hours normally assumed.

The value assumed for the drainage coefficient, q, has a significant effect on the results of the equation. Minor variability in the hydraulic conductivity, K, does not change the resultant spacing much. The depth to the impermeable layer affects the resultant spacing most significantly when the hydraulic conductivity is high, such as with sandy soils.

The Hooghoudt equation is:

$$S' = \sqrt{\left(8K_2 am + \frac{4K_1 m^2}{q}\right)} \quad \text{(eq. 19–13)}$$

After an initial spacing S´ is determined, the effective depth, d_e is calculated using either equation 19–10 or 19–11, repeated here.

$$d_e = \frac{S'\pi}{8\left[\ln\left(\frac{S'}{r_e}\right) - 1.15\right]}; \text{ for } a/S' > 0.3 \quad \text{(eq. 19–10)}$$

$$S = \sqrt{\frac{9Ktd_e}{f'\left[\ln\left(m_o\left(2d_e + m\right)\right) - \ln\left(m\left(2d_e + m_o\right)\right)\right]}} \quad \text{(eq. 19–11)}$$

Equation parameters:

- S´ = estimated parallel drain spacing, ft
- K_1 = weighted horizontal hydraulic conductivity above the drainage feature, in/h
- K_2 = weighted horizontal hydraulic conductivity below the drainage feature, in/h
- m = vertical distance after drawdown of the water table above the drain and at the midpoint between drains, ft (m = d – c)
- a = depth to the impermeable layer or barrier below the drains, feet
- q = drainage rate, inches per hour
- d = depth to drain from ground surface, feet
- c = depth to water table drawdown after the evaluation period, ft
- π = 3.1416
- r_e = effective radius of the drain, ft (table 19–14)
- v = depth of water drained, in (drainable porosity × depth of drawdown at the midpoint)

Using the equivalent depth, d_e, the final spacing can be calculated with equation 19–14. The lateral effect distance d_e is half the spacing distance, S.

$$S = \sqrt{\left(8K_2 d_e m + \frac{4K_1 m^2}{q}\right)} \quad \text{(eq. 19–14)}$$

Equation 19-14 is the same as equation 19-13, except that d_e is substituted for a.

Example:

Drawdown time, t – 14 days
Drawdown depth – 12 in
Drainable porosity, f = 0.011
d = 4 ft
K_1 = 0.160 in/h (3.98 in/d)
K_2 = 0.148 in/h (3.55 in/d)
Depth to impermeable layer – assumed at 8 feet (twice drain depth)
r_e = 0.034 for 5 in tile

Solution:

m = d – c = 4 – 1 = 3 ft
v = 0.011 ft/ft × 12 in = 0.132 in
t = time to remove saturation in days = 14 d
q = v/t = 0.132 in/14 d = 0.0094 in/d
a = 8 – 4 = 4 ft
S´ = $\{(8K_2\ am + 4K_1m^2)/q\}^{1/2}$
S´ = $\{(8 \times 3.55$ in/d $\times 4 \times 3) + (4 \times 3.98$ in/d $\times (3\text{ ft})^2)/0.0094$ in/d$\}^{1/2}$
S´ = 198 ft
a/S = 4/198 ft = 0.02 which is less than 0.3 so the first equation for converting a to d_e will be used
d_e = a/{1+ [(a/S´)[(8/π)ln (a/r_e) – 3.4]]}
d_e = 4 /{1+ [(4/198)[(8/3.1416)ln(4/ 0.034) – 3.4]]} = 4.63 ft
S = $\{(8K_2\ d_e\ m + 4K_1m^2)/q^{1/2}$
S = $\{(8 \times 3.55$ in/d $\times 4.63 \times 3) + (4 \times 3.98$ in/d $\times (3\text{ ft})^2)/0.094$ in/d$\}^{1/2}$
S = 180 feet

Check: 180 feet is within 10 percent of 198 feet so d_e does not need to be adjusted for a different spacing, the result will essentially be the same.

$$Le = \frac{1}{2}S = \frac{1}{2} \times 180 = 90 \text{ ft}$$

Kirkham's equation

Kirkham's equation evaluates the flow through the soil where water is ponded above a tile line or system. It is often combined with other drainage equations to describe the total removal of the water (ponded and water table). Kirkham's equation calculates the time to remove the ponded water, and the van Schilfgaarde equation determines the time to remove the saturation to the specified depth. Kirkham's equation is meant to be applied where the tile line(s) lies directly under the ponded water areas, but the site has no surface inlets to the drain.

Kirkham's equation for parallel drains:

$$Q = \frac{4\pi k\left(t + e - r_e\right)}{g} \qquad \text{(eq. 19–15)}$$

where:

$$g = 2\ln\left\{\frac{\sinh^2\left(\frac{2\pi nh}{s}\right)}{\sinh\frac{\pi r_e}{S}}\right\} \qquad \text{(eq. 19–16)}$$

$$-2\sum_{n-1}^{\infty}(-1)^n \ln\left\{\frac{\sinh^2\left(\frac{2\pi nh}{S}\right) - \sinh^2\left(\frac{\pi r_e}{S}\right)}{\sinh^2\left(\frac{2\pi nh}{S}\right) - \sinh^2\left(\pi\frac{(2d - r_e)}{S}\right)}\right\} \qquad \text{(eq. 19–17)}$$

For a single drain:

$$Q = \frac{2\pi k\left(t + d - r_e\right)}{\ln\left(2d - r_e\right)} \qquad \text{(eq. 19–18)}$$

For both equations the variables are:

- Q = drain flow rate per unit length of drain, $ft^3/h/ft$
- k = hydraulic conductivity, ft/h
- r_e = effective radius of drain, ft
- S = spacing between parallel drains, ft
- d = depth from soil surface to centerline of drain, ft
- t = depth of ponded water, ft
- π = 3.1416
- h = depth to impermeable layer, ft
- n = summation value (i.e. 1,2,3,....)

***Example*:**

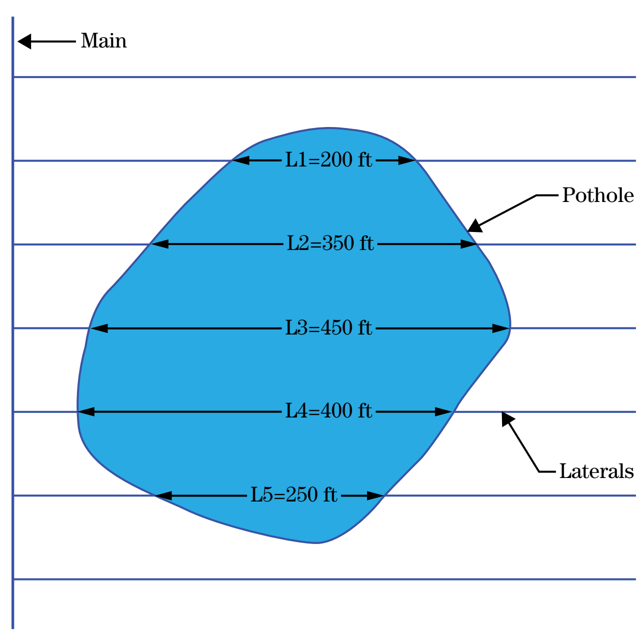
The pothole shown in figure 19–62 has an effective surface area of 1.6 acres. The soil is identified as Greenwood with a permeability of 0.6 to 3.4 inches per hour. An average hydraulic conductivity is estimated at (0.6+3.4)/2 equals 2.0 inches per hour. The drainable porosity is 0.04 foot per foot. Assume an evapotranspiration rate of 0.10 inch per day.

The tile installed under the basin has the following lengths within the basin boundary.

- S = 50 ft (spacing)
- L_1 = 200 ft
- L_2 = 350 ft
- L_3 = 450 ft
- L_4 = 400 ft
- L_5 = 250 ft

The corrugated plastic drain tubing is 4 inches with an effective radius of 0.20 inch. It is installed at a 3 foot depth with an impermeable layer 8 foot below the soil surface. The surface drainage area is 15 acres. After a 2-year rainfall event, water is ponded in the pothole at a depth of 7.5 inches. How long is required for the surface ponding to be removed?

Figure 19–62 Drain layout for Kirkham's equation example



Solution:

The total length of tile under the basin is:

$$200+350+450+400+250=1{,}650 \text{ ft}$$

Use equation 19–16 first to determine the value of g.

Using S is 50 feet, r_e is 0.0167 foot, d is 3 feet, h is 8 feet, and using n is 2 because the values decrease below 0.1 after 2 repetitions, in equation 19–16, g is 12.01

Use equation 19–15 since this system has parallel tile at even spacing.

$$Q=\frac{4\pi(2)(1\text{ft}/12 \text{ inches})(0.625+3-0.0167)}{12.01}$$
$$=0.629 \text{ ft}^3/\text{h}$$

Q equals 0.629 cubic foot per hour per foot length of drainage tubing.

The total length of drains under the pothole was summed above as 1,650 feet.

$$1{,}650\times 0.629 \text{ ft}^2/\text{h}=1{,}038 \text{ ft}^3/\text{h}$$

This represents the flow rate that would pass through the soil to the drain assuming the drain flows full with no back pressure. Whether the system would actually take this flow rate depends on the length, grade, and size of the main, condition of the main, and outlet. The area of the pothole is 1.6 acres, or 69,696 square feet. This area, at a depth of 7.5 inches, converts to a volume of 43,560 cubic feet.

$$\begin{aligned} Q &= 1{,}038 \text{ ft}^3/\text{h}\times 24 \text{ h/d}\\ &= 24{,}912 \text{ ft}^3/\text{d}\\ q &= \frac{24{,}912}{69{,}696}\times 12\\ &= 4.28 \text{ in/d}\end{aligned}$$

That is the drainage coefficient would be 4.28 inches per day.

7.5 inches to be drained divided by 4.28 inches per day drainage rate equals 1.7 days

In most cases the main would not be designed for 4.8 inches per day. This pothole may be only a small part of the total field or of a larger drainage system.

Now, assume that the hydraulic system only has the capacity to remove 2.0 inches per day, this equates to 11,616 cubic feet per day.

Add the hydraulic capacity to remove the water, Q, to the evapotranspiration rate, ET, for the day to get the total water removal rate.

$$Q=11{,}616 \text{ ft}^3/\text{d}+\left(1.6\times 43{,}560\times 0.1\times\frac{1}{12}\right)$$
$$= 12{,}197 \text{ ft}^3/\text{d}$$

The total volume of water to be removed, the ponded water is:

$$v=7.5\times 1.6\times 1\times 43{,}560$$
$$=43{,}560 \text{ ft}^3$$

The time to remove this ponded water is the ratio:

$$\begin{aligned} t &= \frac{V}{Q}\\ &= \frac{43{,}560}{12{,}197}\\ &= 3.57 \text{ days}\end{aligned}$$

This does not include the time to remove the saturation in the top 6 to 12 inches of the soil profile.

The equations for Kirkham's are complicated and mistakes can occur in computations. Use of a spreadsheet or small computer program is recommended to avoid errors.

(f) Seepage analysis and single drain lateral effect methods

Drainage equations are applicable for analyzing hydrology where a drainage system exists onsite. In many cases, the effect of a drainage system on an otherwise unaltered adjacent wetland is needed. All drains have some effect on adjacent wetlands. The results of lateral effects analysis on an adjacent wetland are expressed in terms of the magnitude of the effect. Hydrologic analysis cannot define what level of effect is considered to be acceptable. It can only quantify the effect.

The effects of drains adjacent to wetlands are dependent on season and weather conditions. Any method used to evaluate water movement will have to simplify the situation to be practical.

(1) Seepage analysis

The effect of a single drain on an adjacent wetland which is separated from the drain by a distance can be assessed by seepage analysis. This analysis looks at the seepage flux at the wetland boundary. The analysis compares the before and after drainage water table drop between the wetland and the drain, regardless of whether the wetland has ponded water, or maintains a sub-surface water table. Seepage analysis does not result in a lateral effect distance. It determines the increase in seepage loss for comparison with an acceptable loss.

The effect of a drain on an adjacent wetland is not a steady state problem. The water table fluctuates whether or not a drain is present due to rainfall and evapotranspiration. Since the drainable porosity of the soil is often less than 5 percent of the soil volume, the water table may fall at least 20 times faster in the soil than in an adjacent ponded wetland. This sets up a gradient which results in seepage from the wetland, even when no drain is present, as shown in figure 19–63. Thus the question becomes how much greater is the seepage after the drain is installed?

Assume the evapotranspiration demand can be satisfied by upward flux from the water table as long as the water table remains within a reasonable distance of the surface, perhaps 2.5 feet. The distance over which evapotranspiration is satisfied by seepage from the wetland is given by equation 19–18 (Skaggs 1980, DRAINMOD manual, eq. 9–14).

$$S_{et} = \left\{ \frac{\left(h_1^2 - h_2^2\right)K}{E} \right\}^{\frac{1}{2}} \qquad \text{(eq. 19–18)}$$

where:

S_{et} = distance over which evapotranspiration is satisfied by seepage from the wetland, ft

E = rate of evapotranspiration, ft/d

K = hydraulic conductivity, ft/d

h_1 = height of water table above reference elevation in wetland, ft

h_2 = height of water table above reference elevation in adjacent field area, ft

h_1–h_2 = depth to which evapotranspiration can be met by upward flux from the water table, ft

Using the sample shown in figure 19–63, and inputting the values shown into equation 19–18, S_{et} equals 94 feet. If S_{et} is multiplied by the evaporation rate E, the rate of water movement, q, is known.

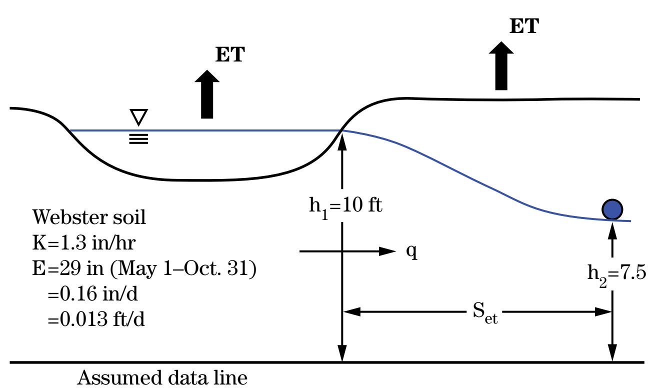
$$q = S_{et} \times E$$
$$= 1.22 \text{ ft}^2\text{/d/ft}$$

Reminder: This is only as valid as the parameters used. The height difference of 2.5 feet was assumed for the depth that E is satisfied through upward flux through the soil and may vary among soils and circumstances. For example, if only a 1 foot depth is deemed more appropriate for the sample shown in figure 19–63,

$$S_{et} = 62 \text{ ft}$$
$$q = 0.81 \text{ ft}^2\text{/d}$$

Looking at a second case, assume a drain 3 feet deep is located 100 feet away from a wetland. This condition

Figure 19–63 Distance over which water table drop due to ET is replaced by seepage from the adjacent wetland



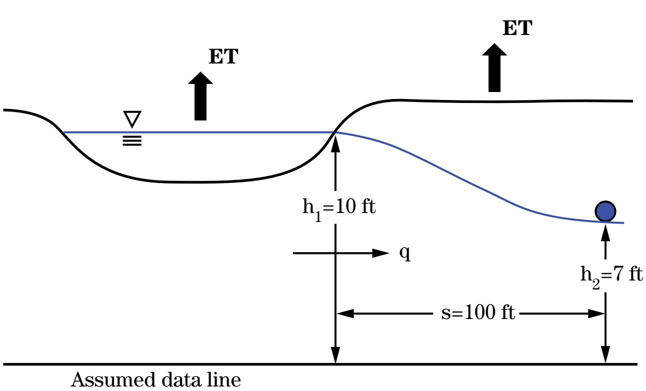
is illustrated in figure 19–64. Equation 19–19 can be used to solve for the seepage rate:

$$q = \frac{K\left(h_1^{\,2} - h_2^{\,2}\right) + E\left(S\right)^2}{E} \qquad \text{(eq. 19–19)}$$

where:
S = horizontal distance from the edge of the wetland to the drain, feet
K = hydraulic conductivity, ft/d
E = rate of evapotranspiration, ft/d
Q = rate of water movement in the soil horizontally, ft^2/day/ft length of wetland
h_1 = height of water table above reference elevation in wetland, ft
h_2 = height of water table above reference elevation in adjacent field area, ft

Using the values shown in figure 19–63, q = 1.31 square foot per day per foot. This value is only 0.09 square foot per day more than the situation where no drain existed. Hence, the change in seepage due to the presence of the drain is only about 7 percent of the seepage rate caused by evapotranspiration alone for the set of parameters used. However, if a depth of 1 foot were used for the difference between h_1 and h_2 with equation 19–19, the percentage increase is 11 percent due to the influence of the drain. The value selected for the depth to which the water table replenishes soil moisture has an impact on the results.

Figure 19–64 Seepage from wetland with adjacent tile drain



If the drain tile were only 50 feet from the wetland edge in figure 19–64, q is 1.46 square foot per day, which is a 20 percent increase over the 1.22 square foot per day rate for the system with no drainage system.

The use of these seepage equations must be used with well defined objective criteria. The criteria must define minimal effect in terms of percentage increase in seepage. It should also define the water table depth at which seepage can supply losses due to ET. With these criteria, a combination of depth of drain and distance, S can be determined that meets the defined minimal effect.

(2) Skaggs semi-infinite medium method

This procedure described is referred to as the Skaggs method because it applies the research work of Dr. R. Wayne Skaggs (Skaggs 1976). This method assumes a nonsteady state condition, which is a more realistic condition, especially in humid regions. For the case of a single drawdown, numerical solutions are graphically presented for the relationships between the water level in the adjacent wetland, drawdown depth, lateral effect distance, drainable porosity, saturated hydraulic conductivity, and time. In the graphical solutions presented in figure 19–65, the results are presented as plots of H versus $1/\eta$. The initial water table is represented by the dashed line at $\tau = 0$. The variables used in the method are:

d = distance from impermeable layer to water level at drain
h = distance from impermeable layer to water level at lateral effect distance x
x = lateral effect distance
t = time
f = drainable porosity
K = weighted saturated hydraulic conductivity
h_o = initial distance from impermeable layer to water table level
H = h/h_o
$1/\eta$ = $(((K/f)h_o t)^{0.5})/x$
D = d/h_0

Using the appropriate curve for D, and a desired drawdown depth to determine H, a result for $1/\eta$ can be obtained. The lateral effect distance x can then be determined be rearranging the equation for $1/\eta$ and using the inverse of η:

$$X = \eta\left(\left(\frac{K}{f}\right)h_o t\right)^{.05} \qquad \text{(eq. 19–20)}$$

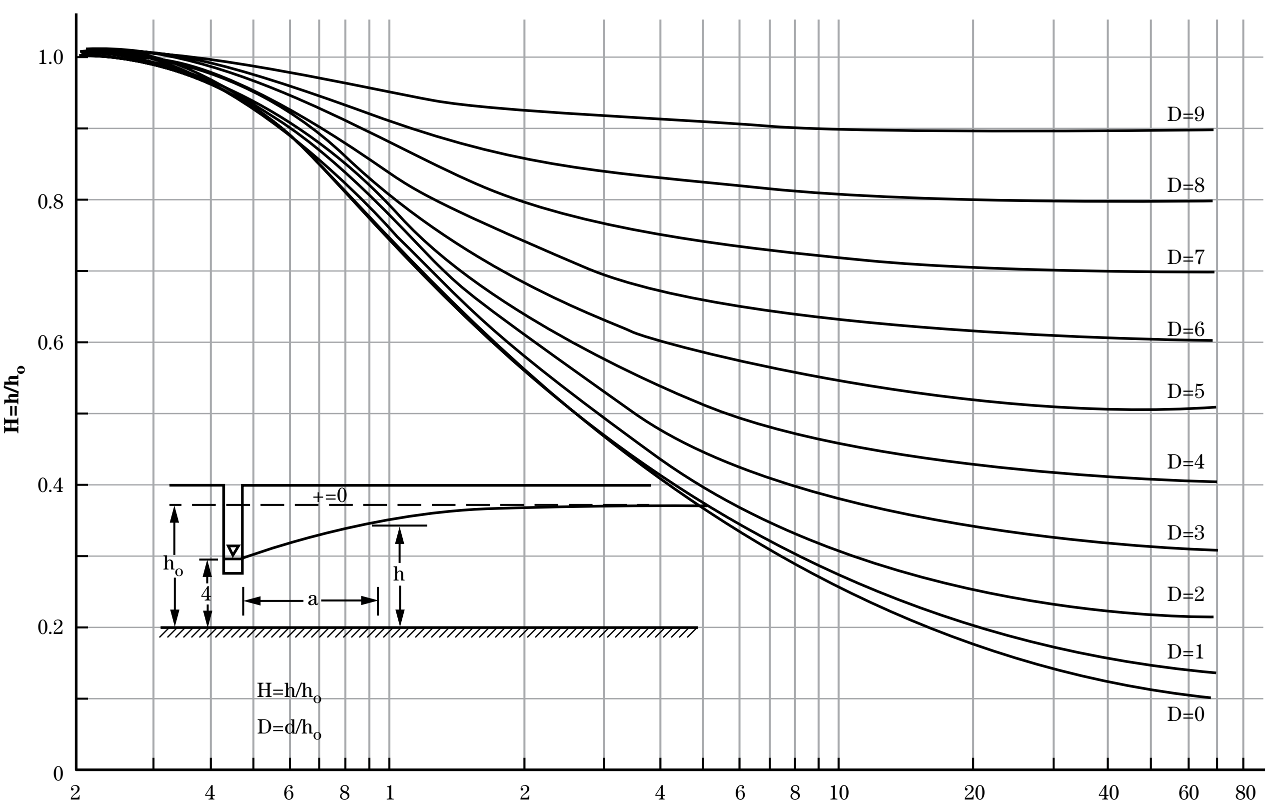
The Skaggs method is one of the options included in the ND-Drain computer program.

Computation of time (t) for non-steady state methods (Skaggs)—The use of the Skaggs method requires the user to determine a value for the time, t. The value for t must not be confused with the duration of time for saturation as defined by objective criteria for wetlands. In this analysis, the lateral effect distance beyond which wetland conditions no longer exist is determined, not the duration of wetland conditions within the wetland. The time, t, as defined for this analysis is the time required for a single drawdown to lower the water table below the wetland hydrology threshold. The result of the analysis is a lateral effect distance only. The method assumes that the drawdown criterion is 25 centimeters.

A second method was developed by Skaggs to determine this t value based on these assumptions:

For each climate region, drainage will lower the water table past the wetland hydrology threshold in approximately the same amount of time. This common time value, called T25, is defined as the time required for the water table, in a site that marginally satisfies the wetland hydrologic criterion, to be drawn down, by drainage alone, from the surface to a depth of 25 centimeters (approx. 9.84 in). T25 varies by location because of weather differences, and the amount of surface depressional storage, but not soil type. Skaggs (2005) describes this method in detail. A users guide is provided for this method separate from this document. This time is used for the parameter t in the Skaggs semi-infinite medium method, and can also be used for the time input for the Skaggs method in the ND-Drain computer program.

Figure 19–65 Graphical solutions for lateral effect of drain on an adjacent wetland using the Skaggs method



The use of the DRAINMOD computer software program is recommended for determination of t for a given region.

Other considerations for determining t for Skaggs semi-infinite medium method—The time, t, for use in the Skaggs semi-infinite medium method can be based on local knowledge of climate, crop patterns, and experience. This determination, once documented, can be made a part of the objective criteria for use with the Skaggs method. Figure 19–66 illustrates an example of such a determination used in Minnesota, Iowa, North Dakota, and South Dakota.

NRCS National Water and Climate Center (NWCC) in Portland, performed an analysis of rainfall data in Minnesota, Iowa, North Dakota, and South Dakota to determine the average number of days until one inch of rain had accumulated (total) at each NWS station. This data was used to put a boundary on time, t, for when the ground was re-saturated and the system must again actively remove water immediately above it and not continue to influence water tables at longer distances. The t parameter in the Skaggs equation is assumed to be the time to remove saturation due to this 1 inch of rainfall.

Figure 19–66 Average days to accumulate 1 inch precipitation during May for North Dakota, South Dakota, Minnesota, and Iowa (USDA-NRCS, NWCC, Portland, OR)

(g) The North Dakota drain computer software program

(1) Background

The ND-Drain software is programmed in Visual Basic and was written by Terry Carlson, project engineer, assistant state conservation engineer, NRCS, Bismarck, North Dakota in 2001 to 2002. Assistance was provided by Sonia Maassel Jacobsen, project engineer, NRCS hydraulic engineer, St. Paul, Minnesota. ND-Drain was developed to address the many requests for lateral effect evaluations from field and area offices in North Dakota, South Dakota, and Minnesota. The program provides the option of using these methods:

- Ellipse equation
- Hoodghoudt equation
- van Schilfgaarde equation
- Skaggs semi-infinite medium method

Descriptions of the first three are in numerous drainage textbooks and NRCS handbooks (Fangmeier et al. 2006; USDA-SCS, 1971; van Schilfgaarde 1974; Schwab et al. 1966; Jacobsen et al. 1997). The Ellipse and Houghoudt equations both assume a steady state condition which may not be valid in humid regions where rainfall is sporadic or intermittent, such as the upper Midwest. The van Schilfgaarde equation, which is a nonsteady state equation, was developed for fields with a pattern tile system, but has an adaptation for a single line. The Skaggs method (Skaggs 1976) was developed for the situation involving a single drain installed a distance away from a wetland. The purpose is to analyze the effects on a wetland's hydrology. Within ND-Drain, the routine is set up for a falling water table rather than a rising one, as the two are different due to hysteresis effects.

ND-Drain was originally programmed to use soils data from the Soil Survey Geographic (SSURGO) database in Ames, Iowa. When the NRCS National Soil Information System (NASIS) became available in 2005, the input routines were modified to accept data from that source. The input soil data is processed by the USDA-ARS model, Rosetta (Schaap 2000). The ND-Drain main screen is shown in figure 19–67.

(2) Soils data

Soils data is normally sorted in ND-Drain by county and then by soil name. Exceptions occur where multiple soil surveys exist within a single county and unique identifiers are necessary to distinguish soil hydraulic properties of soils found in multiple survey areas. NRCS limits user access to the NASIS database, but the same basic soil data is publicly available from the NRCS WSS.

ND-Drain uses these parameters to calculate the likely movement of water in the soil column for prediction of drainage lateral effects. The ND-Drain screen for selection of soils data is shown in figure 19–68.

The first step is to select the county in which the site lies. A similar drop down menu chooses the specific soil after the selected county database is retrieved.

County level soils files can be input using output from the Rosetta software, described in NEH650.1909(d)(3).

(3) Data input to ND-Drain

The description of the water elevation parameters is illustrated in figure 19–69.

The selection of the soils data generates the conductivity and drainable porosity parameters shown in figure 19–70. The top three parameters are computed when the lateral effects calculation method is selected from the Compute dropdown menu.

The initial water height over the barrier must be determined based on the requirements of the analysis. The final water height over barrier is the water table elevation at the lateral effect distance from the drain after time, t. The effective radius is determined from the Help menu. Time for drawdown depends on the requirements of the analysis.

Figure 19–67 ND-Drain main screen

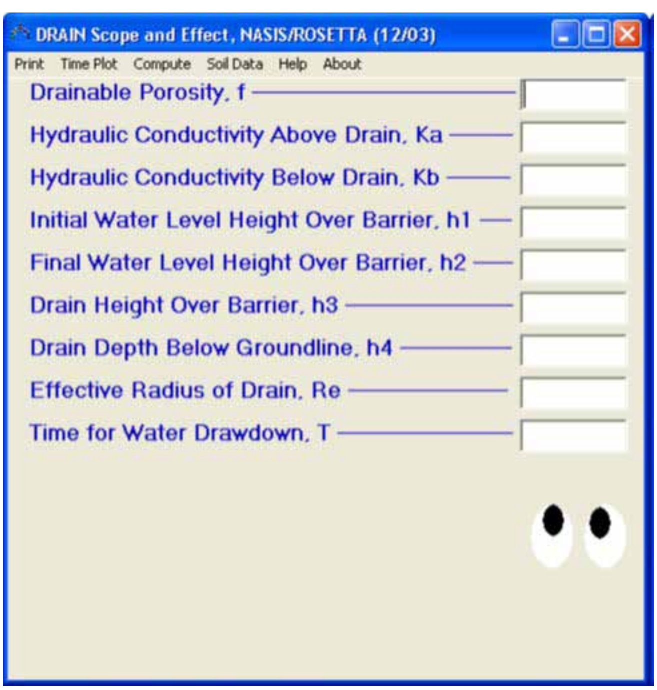
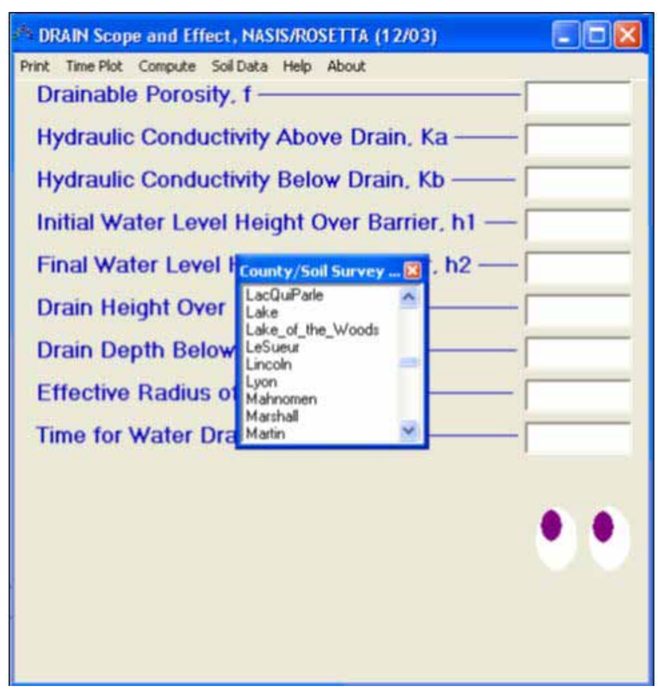


Figure 19–68 ND-Drain soils data selection screen



The screen for selection of a lateral effect method is shown in figure 19–71.

Soils information for the site should be examined to see whether an impermeable layer has been identified in the soil profile that will act as a barrier layer. If not, in most cases, a value of 10 feet can be used as the default depth to the impermeable layer. Most tile in agricultural drainage systems is 5 feet or shallower in depth, and drainage equations are more reliable if the depth to the impermeable layer is at least twice the depth to the flowline of the tile.

The effective radius of the drain (Re) is a critical parameter and is not the same as the drain radius (*e.g.* a 4-inch-diameter drain does not have a 2 inch effective radius). Effective radius accounts for the increased resistance to inflow as flow paths converge near the drain. Improving the inflow characteristics of the drain increases Re (e.g. increasing the size and number of openings per unit length of drain, increasing the drain diameter). Drain envelopes increase Re by allowing water to move to the drain openings more freely. Fabric wraps on corrugated drains can improve flow to drain openings by excluding soil from corrugation valleys. Within the ND-Drain program, the Help menu shown in figure 19–72 provides an option to extract a chart of the effective radii of several drain sizes, shown in figure 19–73.

Figure 19–69 Illustration of input parameters

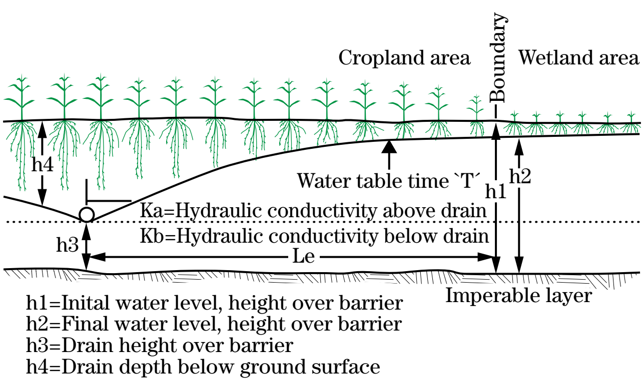


Figure 19–70 Input screen for entry of required parameters

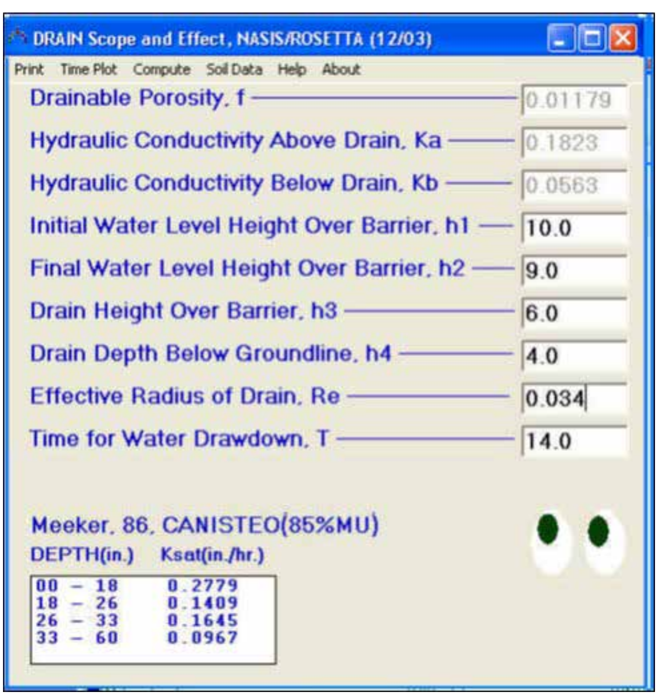
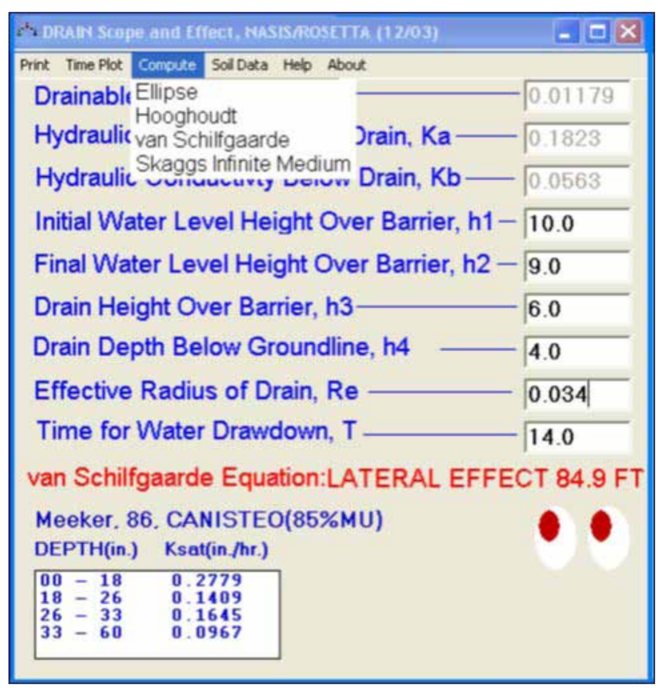


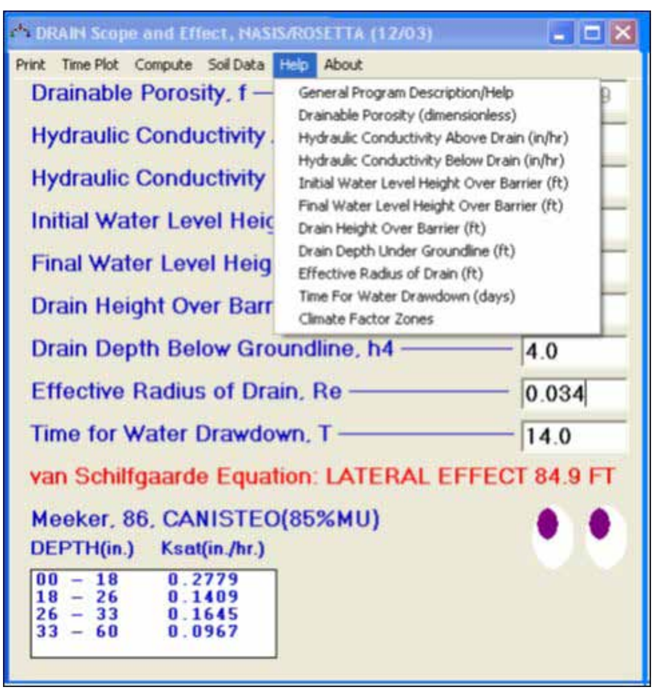
Figure 19–71 Selection of lateral effect method screen



In the Skaggs equation, the abbreviation used for the hydraulic conductivity of the layer above the drain is K1. This is the same as Ka used in the Ellipse and Hooghoudt equations. The permeability of the soil layers above the drain are weighted by depth and respective permeability to develop a weighted average. All the layers are used from the surface to the flow line of the drain. This value is expressed in inches per hour.

Drainable porosity, f, is the volume of water that will be released per unit volume of soil by lowering the water table. It is treated as a constant in drain-spacing equations for the falling water table condition. In reality, however, the rate of pore space drainage varies with time, and also depends on rate of water table fall. Since the water table midway between drains does not fall at the same rate as that in the vicinity of the drains, the rate of pore space drainage is also a function of distance from the drain(s). This value has a typical range between 0.02 and 0.07 (dimensionless), but it can be smaller in clay soils and larger in organic soils. This parameter is computed internally if the user selects an input soils file.

Figure 19–72 Help menu



(4) Output from ND-Drain

From the menu at the top of the screen, Compute is selected to access a dropdown menu that offers choices of the Ellipse, Hooghoudt, van Schilfgaarde, or Skaggs methods. After selecting a method, the resultant computations appear at the bottom of the screen. The user can choose the print option for a paper copy of the computations which includes some of the internal calculations as well as the final lateral effect value. One can change h3 and h4 and compute again without re-entering the other data. This allows a quick check, in case the exact depth of the drain is uncertain.

Figure 19–74 shows the output screen when the Skaggs equation is used. Figure 19–75 shows the output when the Van Schilfgaarde equation is used.

Figure 19–73 Help screen, drain effective radius, feet

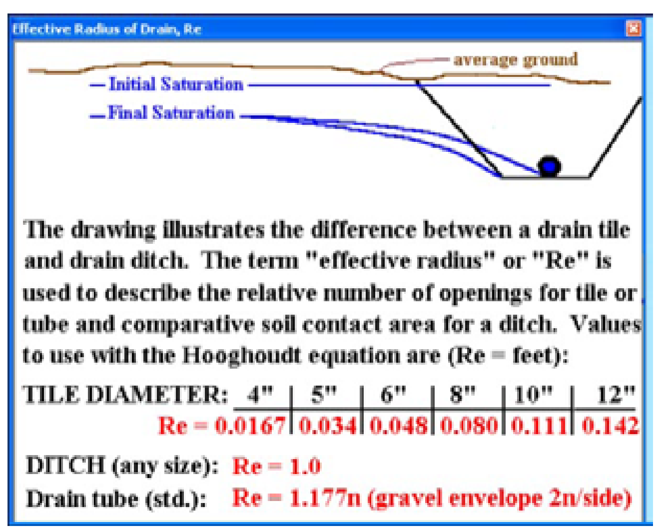


Figure 19–74 Output from the Skaggs method

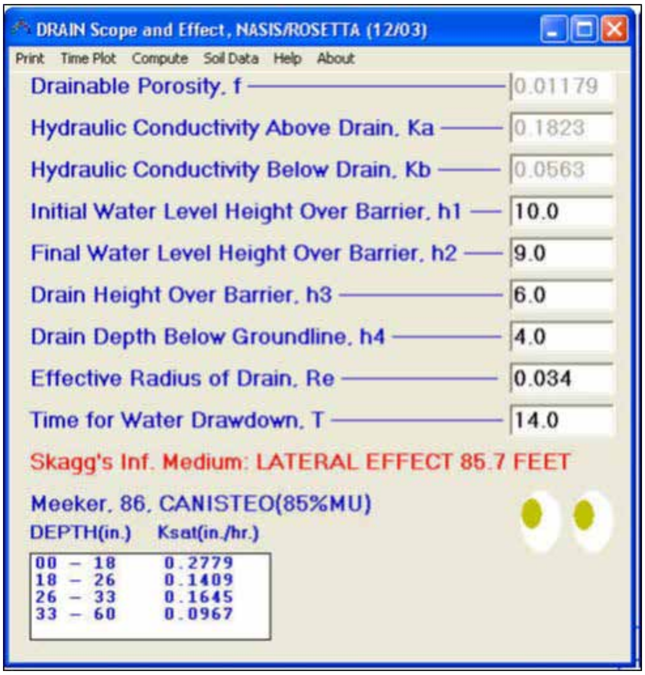
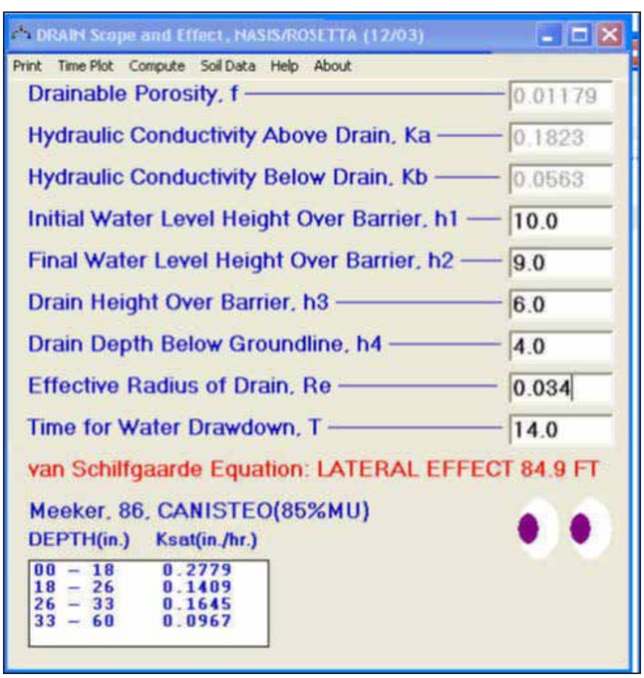


Figure 19–75 Output from the Van Schilfgaarde equation



650.1910 DRAINMOD software

(a) Introduction

DRAINMOD is a computer simulation model developed by Dr. Wayne Skaggs at the Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, North Carolina, in 1980. The model simulates the hydrology of poorly drained, high water table soils on an hour-by-hour, day-by-day basis for long periods of climatological record (e.g. 50 years). The model predicts the effects of drainage and associated water management practices on water table depths, the soil water regime, and crop yields. It has been used to analyze the hydrology of certain types of wetlands and to determine whether the wetland hydrologic criterion is satisfied for drained or partially drained sites. The model is also used to determine the hydraulic capacity of systems for land treatment of wastewater. The model has been successfully tested and applied in wide variety of geographical and soils conditions. In the last 20 years, the model's capability has been extended to predict the effects of drainage and water management practices on the hydrology and water quality of agricultural and forested lands both on field and watershed scale.

The latest version, DRAINMOD 6.0 , combines the original DRAINMOD hydrology model with DRAINMOD-N (nitrogen sub-model) and DRAINMOD-S (salinity sub-model) into a Windows-based program. The new version includes a graphical user interface that allows easy preparation of input data sets, running simulations, as well as displaying model outputs. In addition to organizing the hydrology, nitrogen, and salinity components of DRAINMOD, the interface facilitates analyses of the effect of drainage system design on subsurface drainage, surface runoff, SEW30, crop yield, and nitrogen loss in surface and subsurface drainage by automatically editing drainage design parameters (e.g. drain spacing and drain depth) over a specified range, simulating the different designs and graphically displaying the results. The interface also calculates the runoff volume from surrounding areas that drain to a site and adds that runoff volume to a DRAINMOD water balance of the site. Version 6.0 also includes routines for soil temperature modeling and considers freezing and thawing effects on drainage processes.

(b) Applicability to HGM classes

The DRAINMOD model is applicable to wetlands in the MINERAL FLATS wetland class. It will accurately model the removal of water from shallow depressions which commonly exist within MINERAL FLAT wetlands, but it is not appropriate for modeling deep depressions which are within the DEPRESSION HGM class. In MINERAL FLATS wetlands, the dominant water source is direct precipitation, P, and the dominant losses are through vertical downward movement of water, G_o, and evapotranspiration, ET. The latest version will calculate the addition of surface runoff inputs, R_i to the water budget.

(c) The use of DRAINMOD for wetland identification or restoration design

DRAINMOD will report the probability and duration of wetland conditions due to saturation for comparison with objective criteria. The site may be analyzed even if it does not have drainage features installed. Figure 19–76 shows an example report for a site where the number of periods with saturation within 30 centimeters (12 in) of the surface for 14 days or longer are shown. This analysis had a drain spacing of 15,000 centimeters (492 ft), and a drain depth of 120 centimeters (3.94 ft).

The objective criteria for the report shown in figure 19–76 are:

- 14 consecutive days of saturation
- saturation within 12 inches of the surface
- surface saturation occurrences must be within the wetland growing season
- 50 percent chance probability of occurrence annually

This duration and saturation depth criteria was met in 34 years of the 40 year period of record. The site met the objective criteria with an 84 percent chance probability of occurrence.

(d) Data requirements

(1) Climate data

Climate data are available from the NWCC.

The DRAINMOD program uses rainfall data in hourly time steps. Daily rainfall data for a period of record can be processed in a DRAINMOD utility that distributes the daily total in hourly increments. The user must input the beginning and ending hour for the event, and this distribution is applied to all days for which a daily rainfall is recorded. For wetland determination analysis, there is no standard for this distribution. Individual States should use a distribution that is appropriate for their climatic region. The resulting hourly rainfall data must be formatted as a *filename*. RAI file.

Figure 19–76 DRAINMOD report for wetland analysis

```
        -------------------------------------------------------
        *               DRAINMOD version 5.1                  *
        * Copyright 1980-04 North Carolina State University   *
        -------------------------------------------------------

ANALYSIS OF WETLAND HYDROLOGIC CRITERIA FOR Portse soil at Wilmington, N.C.
for corn:100m D/SPACING, STMAX=1.0cm, thwtd=30cm/14days, Ksat=15,2,8
****************************************************************************
 ----------RUN STATISTICS ----------          time: 11/18/2011  @ 10:22
input file:   C:\Program Files\DrainMod\inputs\WCW.prj
parameters:    free drainage             and yields not calculated
              drain spacing =   15000. cm   drain depth =  120.0 cm
|------------------------------------------------------------------------
                   D R A I N M O D --- HYDROLOGY EVALUATION
                   ****** INTERIM EXPERIMENTAL RELEASE ******

        Number of periods with water table closer than  30.00 cm
              for at least   14 days.  Counting starts on day
               58 and ends on day  332 of each year

        YEAR             Number of Periods        Longest Consecutive
                         of   14 days or            Period in Days
                           more with WTD
                             < 30.00 cm
                         -----------------        -------------------
        1951                    2.                       26.
        1952                    3.                       24.
        1953                    1.                       19.
        1954                    1.                       17.
        1955                    2.                       25.
        1956                    1.                       19.
        1957                    2.                       17.
        1958                    2.                       52.
        1959                    2.                       35.
        1960                    2.                       30.
        1961                    2.                       23.
        1962                    3.                       26.
        1963                    2.                       24.
        1964                    0.                       13.
        1965                    2.                       31.
        1966                    2.                       15.
        1967                    0.                        8.
        1968                    1.                       24.
        1969                    3.                       30.
        1970                    3.                       38.
        1971                    2.                       21.
        1972                    1.                       14.
        1973                    2.                       18.
        1974                    1.                       28.
        1975                    0.                       13.
        1976                    1.                       16.
        1977                    1.                       16.
        1978                    2.                       18.
        1979                    2.                       35.
        1980                    1.                       35.
        1981                    0.                       13.
        1982                    1.                       16.
        1983                    2.                       21.
        1984                    2.                       50.
        1985                    0.                       12.
        1986                    3.                       19.
        1987                    1.                       15.
        1988                    3.                       16.
        1989                    3.                       21.
        1990                    0.                       12.

       Number of Years with at least one period =    34. out of   40 years.
```

The DRAINMOD program also requires potential evapotranspiration (PET) data. There are various options for developing this data. Daily temperature data available from NWCC in climate data can be used by DRAINMOD to calculate PET using the Thornwaite method. If PET data are available, they can also be used. Temperature data are supplied as a *filename*.TEM file.

Figure 19–77 shows the DRAINMOD screen where weather data are selected. The user supplies rainfall and temperature data. In this example, monthly PET data is provided, and the program uses the Thornwaite method to calculate the daily ET.

(2) Soil data

Soil data from Soil Data Access, processed using the Rosetta computer program are used for data input into DRAINMOD. Processing using Rosetta is described in NEH650.1909.

The Rosetta output, in the same format as is used in the NDDrainNASIS program, must be further processed using DMRosette software to produce an input file in *filename*.SIN format. Assistance should be requested from resource soil scientists, water management engineers, or wetland hydrologists with access to this software. These data include the following parameters:

- saturated hydraulic conductivity by layer
- soil moisture characteristic data of water content versus matric suction by layer
- green and ampt parameters for water entry into the soil surface

(3) Wetland objective criteria Information

The DRAINMOD Hydrology Evaluation Report will provide the frequency of saturation for a specified duration based on objective criteria inputs:

- threshold low water table depth
- duration of saturation (at the threshold depth)
- growing season start and end dates

The input screen for wetland hydrologic analysis is shown in figure 19–78.

After the Hydrologic Analysis of Wetlands box is checked, the inputs for objective criteria are input as shown in figure 19–79. The threshold water table depth is 30 centimeters (12 in) and the wetland season starting and ending dates are on Julian day 58 and 322, respectively. The analysis will determine the incidence of periods with a water table less than 30 centimeter deep during the growing season for durations of 14 days or more.

(4) Drainage system parameters

These are basically the same parameters as are used in drainage equations, and include:

- depth of drain from the soil surface
- drain spacing

Figure 19–77 DRAINMOD input screen showing weather data inputs

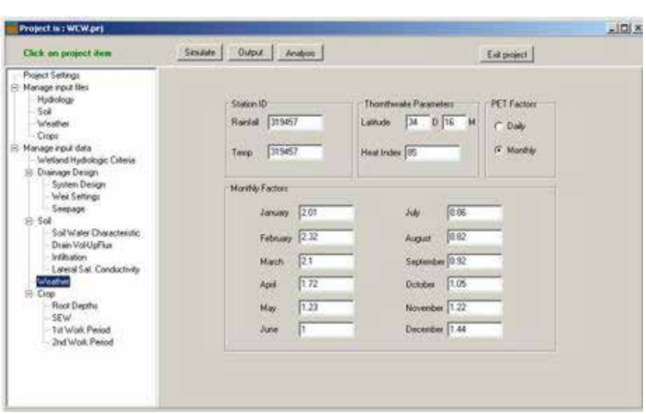
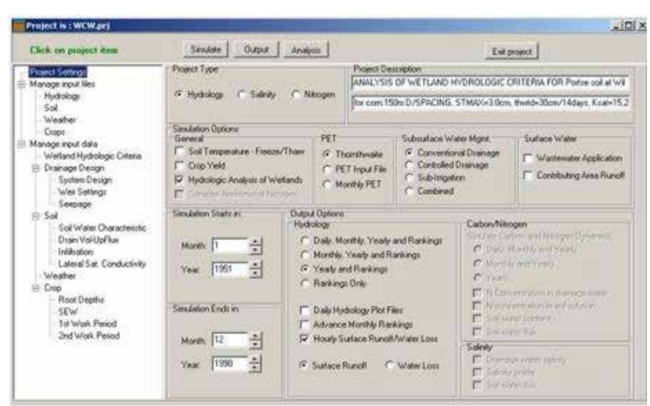


Figure 19–78 DRAINMOD screen showing inputs for wetland analysis



- effective radius of tile drains or ditch
- distance from the drain to the restrictive layer
- depth of storage in shallow local depressions
- maximum depth of storage due to topography

(5) Suitability and limitations for use

Knowledge and experience required

Knowledge of the extraction and processing of rainfall, temperature, and evapotranspiration data is required.

Knowledge of the extraction and processing of soils data is required.

Climatic regions of applicability.

DRAINMOD is applicable to humid and sub-humid regions.

General conditions of applicability

DRAINMOD is applicable in pattern drainage systems to evaluate wetland hydrology on site. It is not applicable for lateral effects of a drain on an adjacent wetland. It is applicable in general to MINERAL FLAT HGM wetland types, where the dominant water source is direct precipitation, the site does not experience the deep ponding conditions of a DEPRESSION wetland, and the water losses are mainly due to deep percolation and evapotranspiration. DRAINMOD will also account for the input of surface runoff from an adjacent watershed.

(e) DRAINMOD system technology

The program uses equations developed by Hooghoudt, Cuthin, Kirkham, and Ernst to calculate drainage rates. Infiltration rates are predicted by the Green and Ampt equation. Surface drainage is characterized by the average depth of depressional storage. Kirkham's equation is used for computing the effects of ponded water. Figure 19–80 shows a generalized view of DRAINMOD parameters.

Figure 19–79 DRAINMOD screen showing objective criteria and wetland growing season inputs

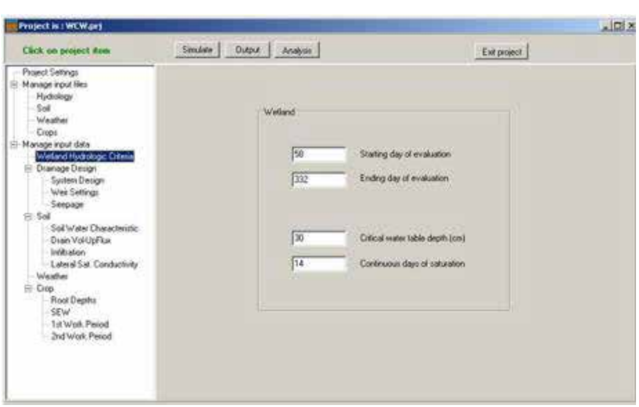
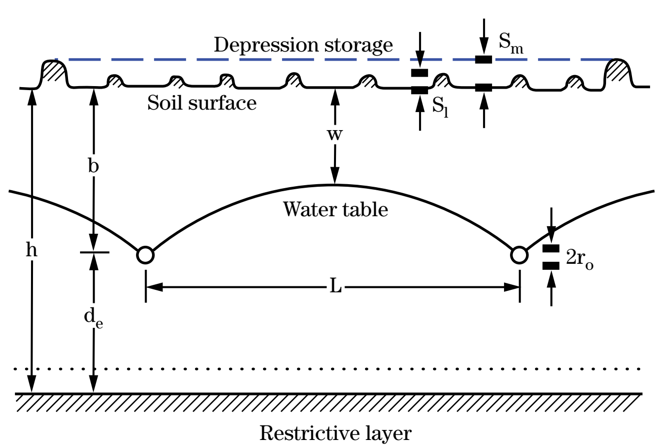


Figure 19–80 Schematic view of DRAINMOD parameters



650.1911 Remote sensing applications

(a) Introduction

Remotely sensed data includes aerial photography, multi-spectral imagery (including infrared), or other image sources. These images are evaluated for signatures that indicate the presence of wetland conditions on the ground. Wetness signatures in an image are evidence that wet conditions existed on the date that the image was collected. A series of images can be used to determine the frequency of wetland hydrology. Other hydrology methods provide information about the annual probability and duration of wetland hydrology based on climate or streamflow data. Remotely sensed images, on the other hand, can be taken as direct evidence of wetland hydrology. Image datasets should include all available images taken during the wetland growing season. In general, wetness signatures corresponding to normal or drier than normal environmental conditions are considered to be positive signatures, and a lack of wetness signatures during normal or wetter than normal environmental conditions are considered to be negative signatures..

This section describes the use of remotely sensed data with a determination of NEC, and documenting the results. The interpretation of these results for making a wetland determination for FSA purposes are based on criteria in individual State Offsite Methods (SOSM). These methods include such rules as minimum number of years needed for data, and the correlation of positive evidence with normal, wetter than normal, and drier than normal environmental conditions. Regardless of the rules in the SOSM, this method requires the development of a body of evidence to support a determination.

(b) Normal environmental conditions

As applied to use with remotely sensed data, these cases apply:

- For sites where direct precipitation is the dominant water source, and where other inputs are directly related to current rainfall, the use of rainfall records and rainfall statistics are most appropriate. These wetland types include DEPRESSION, ORGANIC FLAT, and MINERAL FLAT wetlands. They also include wetlands of the RIVERINE wetland type where there is little or no lateral connectivity with stream floodwater or stream profile supported groundwater. For these wetland types, increases in the presence of wetland hydrology are directly related to the amount and distribution of precipitation within the previous few weeks or months. This is the most common application of remote sensing with climate data, and the examples in this section illustrate these situations.
- For sites where the dominant water source is relatively constant, such as LACUSTRINE FRINGE, ESTUARINE FRINGE, or SLOPE wetlands with a constant lake level, tidal cycle, or groundwater input, remotely sensed images may be used alone, as normal environmental conditions are essentially always present.
- For sites where the dominant water source is not precipitation, and inputs of groundwater or lake water fluctuate independently of precipitation, the determination of normal environmental conditions can be conducted with stream gage, lake stage, or groundwater monitoring data. These wetlands include SLOPE wetlands and many RIVERINE wetlands. While precipitation may dictate the fluctuations of groundwater, streamflow, and lake stage over the long term on these wetland types, the correlation between antecedent precipitation and wetland hydrology is less direct.

Remotely sensed data can be used as corroborating evidence with any of the other tools described in this document.

(c) Methods using precipitation data

(1) Images

Many States have developed SOSM that allow sequential remotely sensed imagery to be used to determine whether the criteria for wetland hydrology are met on a site. The procedures state the detailed methods to be used, but all look for a correlation between precipitation and possible wet signatures on an aerial photograph or image. The procedures described require the availability of remotely sensed images of the land surface taken during the wetland growing season. Until approximately the year 2000, the Farm Service Agency contracted for color photography on a sufficient frequency to be useful for wetland determinations. Currently, the images provided are in the form of digital orthophotography (DOQ), and, in general, the frequency of the collection of photographic imagery is decreasing. However, many other forms of digitally sensed data are being made available from State, Federal, private, and even International sources. The wavelengths recorded include the visual spectrum (RGB), near infrared (NIR), and many other combinations. They are being recorded from satellite platforms as well as from aircraft. The procedures described in this document are applicable for use with any and all forms of remotely sensed images. The users of these images must be trained in their interpretation.

All available images should be collected for which corresponding precipitation (or other appropriate hydrologic inputs) data exists.

(2) Precipitation data

The data is usually available from the same weather station represented by the WETS table. If other reliable data closer to the site is available, it should be evaluated for use. In some cases, a WETS table for a discontinued weather station may be available, but current rainfall data is not. In these cases, the best possible data from the nearest site should be sought for recent data. Reliable data is maintained by many other local, State, and Federal agencies if NWS climate station data is unavailable.

(3) General procedures

The use of images with precipitation data involves 4 steps:

Step 1: The images, regardless of the type of data provided, are evaluated by a trained interpreter to determine if the delineation site shows a wetland signature. The date that the image was captured or processed must be part of the image's record. The delineator records a positive or negative signature, and the date of the image.

Step 2: A determination is made of how much antecedent precipitation occurs normally. Normal precipitation is defined as a range. Antecedent rainfall less than the lower bound of the range is drier than normal, and rainfall higher than the upper bound of the range is wetter than normal. These ranges are defined by the WETS tables. This determination is usually made once for a weather station's range, or for a county, and used for all succeeding determinations in the same area.

Step 3: The actual precipitation that occurred in the time period that preceded the image capture or processing date is determined. This amount is compared to the WETS table amounts, and is assigned a normal, wetter than normal, or drier than normal designation.

Step 4: The preceding designation is assigned to the same image, so that it now has the following attributes assigned:

— Signature (yes or no)

— Actual environmental conditions at time of data collection (wet, dry, normal)

(4) Detailed procedures

The procedure described provides a uniform way to evaluate the precipitation, and is described in 11 steps. Step 6 has 3 options, depending upon whether one uses weighting factors, weights the precipitation, or uses equal weighting of precipitation.

Step 1: Determine the climate station nearest to the site that has sufficient records to have statistical information calculated for it. Ideally, a WETS table with associated precipitation data near the site can be downloaded from eFOTG using the AgACIS link under Section II, the Climate Data tab If a reliable nonNWS site is closer to the field site than the nearest NWS station, the statistics from the nearest NWS station can be used with the data from the nonNWS site. In some cases it may be necessary to use a regional average. Some States have a State climatology office that provides precipitation data. If a site is located between two or more climate stations, the data can be averaged or pro-rated to estimate the likely precipitation on the field site. An example WETS table is shown in figure 19–1.

Step 2: Determine what aerial photographs/images are available. It is helpful to know the approximate date of the photograph, especially in years where a significant rainfall event occurred that may be reflected in the image or may have impacted the vegetation in the image.

Step 3: Review of all aerial imagery is highly recommended, regardless of whether the months preceding the slide are dry, normal, or wet for precipitation. In a dry year, a wetland may have the darkest green color as it has moisture available when surrounding areas do not. In wet years, the potential sites may drown out or have standing water. These help the user locate all potential sites so that each can be examined for possible wet signatures. It may also help determine the maximum extent of the wetland such that its size under normal circumstances can be estimated. Generally, only images taken during the wetland growing season are used. Using professional judgement, and following applicable SOSM, a dataset of available slides is compiled.

Step 4: Based on the known or estimated date of the images, determine the precipitation for the 3 months prior to the slide. The period immediately before the photograph was taken is the most likely to influence the image, unless it is a groundwater-supplied site that has a significant lag for runoff to reach the site.

Step 5: From the WETS table, record the values for dry, normal, and wet antecedent rainfall for the preceding 3 months. The actual rainfall records extracted in step 4 will be compared to these two values, and the month when the image was collected will be labeled dry, normal, or wet accordingly.

It may be useful to determine extreme wet and dry monthly precipitation values. Extreme wet and dry conditions can have a greater effect on conditions at the time of image collection than accounted for by precipitation averaging or weighting. The WETS tables do not include the 10 percent chance wetter than and 10 percent chance dryer than values which denote extremely dry and extremely wet prior moisture conditions. However, these values can be easily calculated by finding the 10th and 90th percentile values from the population of monthly rainfall in WETS data. Using these values, the user can note months that fall into one of these extreme categories and adjust the results according to potential effect on the vegetation at the site.

Step 6: There are three possible options:

- — use of weighted time and wetness condition
- — use of weighted time and antecedent precipitation
- — use of unweighted time, wetness condition, or antecedent precipitation

The user is advised to select the procedure which is most appropriate for their geographic area and climatic conditions, or is called for in their SOSM. Only one of the three choices for step 6 procedures needs to be used for a site.

Option 1: Weighting by time and wetness condition—This procedure takes the monthly rainfall total and compares it to the values for the lower and upper 30 percent boundaries for the month. Each month is assigned a description of wet, normal, or dry, and a corresponding numerical weight value. Wet is assigned a value of 3, normal a value of 2, and dry a value of 1. The most recent preceding month is also assigned a weight of 3, with the next preceding months assigned a weight of 2 and 1.

See figure 19–81 for a calculation form that can be used for a single growing season and figure 19–82 for a completed form with sample data.

If the results of the weighting procedure result in a value within the range of 6 to 9, the condition is drier than normal. Results in the range of 10 to 14 are normal, and those in the range of 15 to 18 are wetter than normal.

Use the precipitation information and WETS table to calculate the potential moisture conditions before the aerial photograph was taken. This process is repeated for each year for which an aerial photograph is available. This can be built into a spreadsheet for a quick summary for a single climate station (fig. 19–83).

A single spreadsheet can be developed for each climate station and used for any field sites that lie near the climate station. This saves recalculating this information each time it is needed. Also, future years' precipitation can be added to the spreadsheet, lengthening its record and usefulness.

The user may wish to circle or highlight any precipitation values which fall outside the 10- and 90-percent values for each month. Carefully evalu-

Figure 19–81 Rainfall documentation form

Rainfall Documentation
(Use with photographs)

Date ____________

Weather station ___________________ Landowner ___________________________ Tract no. __________

County ___________________ State ___________________

Soil name ___________________ Growing season ____________________

Photo date _______________

	Month	Long-term rainfall records: 3 yrs in 10 less then	Long-term rainfall records: Normal	Long-term rainfall records: 3 yrs in 10 more then	Rain fall	Condition dry, wet normal	Condition value	Month weight value	Product of previous to columns
1st Prior month									
2nd Prior month									
3rd Prior month									
								Sum	

Compared to photo date

Note: If sum is

6-9	Then prior period had been drier than normal
10-15	Then prior period has been normal
15-18	Then prior period has been wetter than normal

Condition value

Dry	=1
Normal	=2
Wet	=3

Figure 19–82 Completed rainfall documentation form

Rainfall Documentation
(Use with photographs)

Date 5-31-93

Weather station Hillsboro

Landowner D. Wood

Tract no. ______

County Washington

State OR

Soil name ______

Growing season 3/7—11/15

Photo date 6/86

	Month	Long-term rainfall records: 3 yrs in 10 less then	Long-term rainfall records: Normal	Long-term rainfall records: 3 yrs in 10 more then	Rain fall	Condition dry, wet normal	Condition value	Month weight value	Product of previous to columns
1st Prior month	May	1.06	1.62	1.94	2.04	W	3	2	9
2nd Prior month	Apr	1.50	2.15	2.56	1.47	D	1	2	2
3rd Prior month	Mar	2.67	4.02	4.81	3.47	N	2	1	2
								Sum	13

Compared to photo date

Note: If sum is

- 6-9 Then prior period had been drier than normal
- 10-15 Then prior period has been normal
- 15-18 Then prior period has been wetter than normal

Condition value

- Dry =1
- Normal =2
- Wet =3

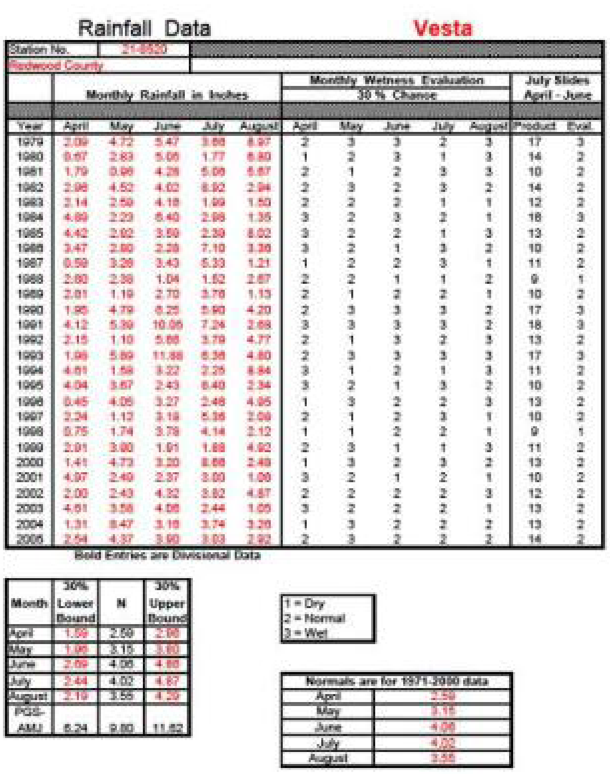
ate whether the extreme values may affect the vegetation and other items in the aerial image.

Option 2: Weighting by time and precipitation values—Follow the example in table 19–17 to determine the weighted growing season precipitation condition for a given site.

Determine 30 percent lower and upper boundaries for antecedent precipitation for the 3 prior months from the WETS table, and assign antecedent monthly weighting factors. In this example, the upper and lower 10 percent chance values are also recorded.

For use with a July slide, precipitation values for the 3 prior months that are less than the sum in column (g) are dry and those greater than the sum in column (h) are wet. Those in-between the values in columns (g) and (h) are normal by the precipitation weighting method.

Figure 19–83 Precipitation data spreadsheet



Rainfall Data | Vesta

Station No. 21-8520
Redwood County

	Monthly Rainfall in Inches					Monthly Wetness Evaluation 30 % Chance					July Slides April - June	
Year	April	May	June	July	August	April	May	June	July	August	Product	Eval.
1979	2.09	4.72	5.47	3.68	8.97	2	3	3	2	3	17	3
1980	0.67	2.83	5.06	1.77	6.80	1	2	3	1	3	14	2
1981	1.79	0.96	4.28	5.09	5.67	2	1	2	3	3	10	2
1982	2.98	4.52	4.02	6.92	2.94	2	3	2	3	2	14	2
1983	2.14	2.59	4.18	1.99	1.50	2	2	2	1	1	12	2
1984	4.69	2.23	6.40	2.98	1.35	3	2	3	2	1	18	3
1985	4.42	2.02	3.59	2.39	8.02	3	2	2	1	3	13	2
1986	3.47	2.80	2.28	7.10	3.38	3	2	1	3	2	10	2
1987	0.59	3.28	3.43	6.33	1.21	1	2	2	3	1	11	2
1988	2.80	2.38	1.04	1.62	2.67	2	2	1	1	2	9	1
1989	2.01	1.19	2.70	3.78	1.13	2	1	2	2	1	10	2
1990	1.95	4.79	6.25	5.90	4.20	2	3	3	3	2	17	3
1991	4.12	5.39	10.06	7.24	2.68	3	3	3	3	2	18	3
1992	2.15	1.10	5.66	3.79	4.77	2	1	3	2	3	13	2
1993	1.96	5.69	11.88	6.38	4.80	2	3	3	3	3	17	3
1994	4.61	1.58	3.22	2.25	8.84	3	1	2	1	3	11	2
1995	4.04	3.67	2.43	6.40	2.34	3	2	1	3	2	10	2
1996	0.45	4.05	3.27	2.48	4.95	1	3	2	2	3	13	2
1997	2.24	1.13	3.18	5.36	2.09	2	1	2	3	1	10	2
1998	0.75	1.74	3.78	4.14	2.12	1	1	2	2	1	9	1
1999	2.01	3.80	1.01	1.88	4.92	2	3	1	1	3	11	2
2000	1.41	4.73	3.20	8.68	2.48	1	3	2	3	2	13	2
2001	4.97	2.49	2.37	3.00	1.00	3	2	1	2	1	10	2
2002	2.00	2.43	4.32	3.82	4.87	2	2	2	2	3	12	2
2003	4.61	3.58	4.08	2.44	1.05	3	2	2	2	1	13	2
2004	1.31	8.47	3.18	3.74	3.28	1	3	2	2	2	13	2
2005	2.54	4.37	3.90	3.03	2.92	2	3	2	2	2	14	2

Bold Entries are Divisional Data

Month	30% Lower Bound	N	30% Upper Bound
April	1.59	2.59	2.98
May	1.96	3.15	3.80
June	2.09	4.06	4.88
July	2.44	4.02	4.87
August	2.19	3.55	4.29
PGS-AMJ	6.24	9.80	11.62

1 = Dry
2 = Normal
3 = Wet

Normals are for 1971-2000 data	
April	2.59
May	3.15
June	4.06
July	4.02
August	3.55

The values from table 19–17 are to be used with the row labeled July for the month of the image in table 19–18. In this table, the actual precipitation amounts are used for the preceding 3 months, and weighted by month.

In column (b) the abbreviations are for the first letter of the month: April-A, May-M, June-J.

The values in column (i) in this table are compared with the sums in Columns (g) and (h) in table 19–17. The value of 37.20 in column (i) is greater than 24.62 therefore the evaluation is wet. If the value in column (i) is less than 13.37, the result is dry. If the value in column (i) is between 13.37 and 24.62, the result is normal.

This procedure is followed for each year for which a photograph or image is available.

Option 3: Equal weighing of time and precipitation—Follow the example in table 19–19 to determine the growing season antecedent moisture condition for a given site and image. Columns (c) through (g) are taken from the WETS table.

The 30 percent chance boundary values in column (c) for the 3 prior months are added for a cumulative lower boundary. The 30 percent chance boundary values in column (e) for the 3 prior months are added for a cumulative upper boundary. The sum of the 3 prior months actual rainfall is compared to these boundaries in table 19–20, below. As in option 2, the 10 percent upper and lower boundaries are recorded.

For each year for which an image is available, the actual antecedent moisture condition prior to the date of the image for the 3 prior months is recorded, as shown in table 19–20 for a July image.

In column (b) the abbreviations are for the first letter of the month: April-A, May-M, June-J.

The values for column (f) in this table are compared with the sums in columns (c) and (e) in table 19–19. If the column (f) amount is greater than column (e), the evaluation is wet. If the column (f) amount is less than column (c), the evaluation is dry. If the column (f) amount is between the values in columns (c) and (e), the evaluation is normal.

Table 19–17 Weighting wet, dry, and normal rainfall values by month

(a)	(b) Month	(c) Lower 30% chance	(d) Normal	(e) Upper 30% chance	(f) Weight	(g) Column (c) x Column (f)	(h) Column (e) x column (f)	(i) Lower 10% chance	(j) Upper 10% chance
3rd prior month	April	1.78	2.68	3.13	1	1.78	3.13	1.0	4.2
2nd prior month	May	2.36	3.78	4.67	2	4.72	9.34	1.5	5.4
1st prior month	June	2.29	3.34	4.05	3	6.87	12.15	1.45	5.07
					Sum	**13.37**	**24.62**		

Table 19–18 Weighting actual antecedent rainfall values by month

(a) Month of Image	(b) Months for weighted precipitation	(c) 1st prior month actual rainfall	(d) 2nd prior month actual rainfall	(e) 3rd prior month actual rainfall	(f) Column (c) × 3	(g) Column (d) × 2	(h) Column (e) × 1	(i) Sum of columns f, g, & h	(j) Condition
July	J-M-A	8.79	4.16	2.51	26.37	8.32	2.51	37.20	wet

Table 19–19 Unweighted wet, dry, and normal values by month

(a)	(b) Month	(c) Lower 30% chance	(d) Normal	(e) Upper 30% chance	(f) 10% chance	(g) 90% chance
3rd prior month	April	1.78	2.68	3.13	1.0	4.2
2nd prior month	May	2.36	3.78	4.67	1.5	5.4
1st prior month	June	2.29	3.34	4.05	1.45	5.07
	Sum	**6.43**	**9.80**	**11.85**	**3.95**	**14.67**

Table 19–20 Actual antecedent 3 month rainfall for a July image

(a) Month of Image	(b) Months for weighted precipitation	(c) 1st prior month actual rainfall	(d) 2nd prior month actual rainfall	(e) 3rd prior month actual rainfall	(f) Sum of columns c, d, and e	(g) Condition
July	J-M-A	8.79	4.16	2.51	15.46	wet

Note that the precipitation for June exceeds the 90 percent chance value, making it an extreme. If this month could be critical in the life of the crop planted, the user needs to adjust the results. This could mean the image is omitted from consideration or the results of the precipitation analysis for that year are automatically labeled wet regardless of what the overall analysis may show.

Step 7: Determine from the data and from local information which growing season was extremely wet, such that any site that has even the slightest potential to be a wetland would appear wet. Use a reference drawing or aerial photograph and mark the locations of any sites which appear wet in the extremely wet growing season image.

Step 8: Move through the sequence of photography available, noting whether the site seems to have a wet signature or not on each one, regardless of the antecedent precipitation condition calculated. Count the number of times the site has a wet signature, recording each with a tick mark on the reference drawing or photograph. Sites that appear infrequently can be discarded as potential wetlands, and those that appear frequently have high potential to be wetlands. Those that appear somewhat often may or may not be wetlands. Number the sites that will receive a careful review. The right-hand column in table 19–21 can be divided into multiple columns so that one form can record the observations on multiple sites.

Step 9: Prepare a slide review form, including the precipitation data. Fill in the date of the slide as best known or estimated. See a completed sample form in table 19–22. Indicate the antecedent moisture condition in the column labeled climatic condition. As the images are reviewed, record observations in the right hand column. Avoid making interpretations at first, and just record color tone differences, shape changes, etc.

Each State may have a nomenclature that they prefer to use for slide review, such as drowned out (DO), standing water (SW), crop stress (CS). For each image note whether or not a wet signature is evident.

Step 10: In the center column of the form, highlight or otherwise note which years had normal growing season precipitation, not dry or wet. The procedure works best with at least 5 normal years, and preferably at least 10. Count the number of normal growing seasons (years) where the imagery showed a wet signature and note it as a ratio with the total number of normal years.

Step 11: The slides can be reviewed again to determine the delineation boundary.

Example

Refer to figures 19–84 and 19–85 which show potential wetland sites on section 16 of Henry Township near Vesta, Minnesota.

Step 1: The nearest WETS table including precipitation data was obtained.

Step 2: **A**erial photographic images were available for the years 1991 thru 2008 which were collected during the wetland growing season, all in the month of July.

Step 3: The images were examined for inclusion in the review dataset. Figure 19–85 shows the results of the preliminary slide analysis, which does not differentiate between dry, normal, and wet years. The presence of wet signatures was recorded for each available image.

Section 16 showed 3 wet areas on a image taken during an extremely wet year. The site is near the community of Vesta, MN. The precipitation analysis was used with the sequence of imagery to determine how many times each site appears in a sequence of 18 photographs.

Site 1 only appears in 5 of 18 growing seasons, or 28 percent of the time. This is unlikely be a wetland when the climate station is known to have 12 normal growing seasons. Site 2 shows signatures in 15 of 18 images, which indicates it may have sufficient wetness to meet the wetland hydrology criteria. Site 3 has 10 wet signatures in the 18; it should be looked at closely to determine whether it has sufficient wetness to meet wetland hydrology criteria.

Complete the careful review of the sequential aerial imagery to determine how many times a site appears to have a wet signature in all the years. Count the number of normal growing seasons/ years in the precipitation data. Site 1 may not have to be reviewed per SOSM, but all 3 sites are given to demonstrate the method.

Table 19–21 Sequential aerial images review form

USDA – NRCS **CPA–32** **WETLAND DOCUMENTATION RECORD** **REMOTELY SENSED DATA SUMMARY** **Station:**	**1. Owner/landowner** **2. County/State** **3. Field investigator** **Title** **4. Site identification No.** **Date** **5. (Tract no. farm no. site no.)**

FSA Color Slide Data

Data

Date Month/Year	**Climatic Condition Wet/Normal/Dry**	**Interpretation – List of signatures observed e.g., drowned crop, standing water, crop stress**

NWI Data:

Number of years observed that have wet signatures:

Table 19–22 Sample sites in section 16 of Henry Township, Vesta, MN

USDA – NRCS **CPA–32** **WETLAND DOCUMENTATION RECORD** **REMOTELY SENSED DATA SUMMARY** **Station:**	**1. Owner/landowner** Ole Svenson **2. County/State** Redwood, MN **3. Field investigator** **Title** **4. Site identification No.** **Date** 9/21/08 **5. (Tract no. farm no. site no.)**

FSA Color Slide Data

Date Month/Year	Climatic Condition Wet/Normal/Dry	Interpretation – List of signatures observed e.g., drowned crop, standing water, crop stress		
		Site 1	Site 2	Site 3
7/1991	W	C	DO*	DO*
7/1992	D	D, C	D, C	D, C
7/1993	N	D, C	CS*	D, C
7/1994	N	D, C	CS*	CS*
7/1995	W	CS*		
7/1996	D	D, C		
7/1997	N	D, C		
7/1998	N	D, C		
7/1999	N	D, C		
7/2000	W	CS*		
7/2001	N	D, C		
7/2002	N	D, C		
7/2003	N	CS*		
7/2004	N	D, C		
7/2005	N	D, C		
7/2006	D	D, C		
7/2007	N	CS*		
7/2008	N	CS*		

Legend: DO = drowned out SW = standing water CS = crop stress C = cropped
NC = not cropped * = wet signature observed D = dry

Number of normal years observed that have wet signatures:
Site 1: 3/12 = 25% Site 2: 11/12 = 92% Site 3: 7/12 = 58%

Steps 4–6: Antecedent rainfall and WETS data were used to complete the climatic condition column in table 19–23.

Steps 7–9: The remainder of table 19–23 was completed for the 3 sites, and note made of years which were either extremely wet or dry.

Step 10: The years with normal conditions are shown in bold in column 2. The documentation of evidence of wetness signatures, wet, dry, or normal conditions is examined and a decision is made upon the SOSM used. In this case, there were 12 years with conditions defined as normal. The tabulation shown at the bottom of the form is based on these years alone. Site 2 had one year noted as dry which had crop stress (CS) indicated. All 3 sites indicated wetness signatures in the 2 years which were wet. All of these results are potential evidence.

Step 11: For sites which are determined to be wetland, a delineation boundary is drawn based on the extent of signatures.

(d) Use of imagery for evidence of drainage and drainage system function

Use of remote sensing is valuable when evaluating an artificial drainage system. The deterioration of a system can be seen in a sequence of aerial photographs over a period of years. The site gradually appears wetter in normal years through increased size, apparent standing water which becomes deeper through the years, and more severely stressed crops. Also, if the drainage system is improved or maintained, the aerial images show the wetland “disappears” or is reduced in size and extent.

The location of ditches or tiles can often be readily seen on imagery when they cannot be detected on the ground. In the case of buried tile, a gradient of wetness can be detected, with dry conditions showing as linear features following the laterals, and changing to wet signatures away from them.

The figure 19–22 is a full page copy of NRCS–CPA–32 Wetland Documentation Record, Remotely Sensed Data Summary.

Figure 19–84 Map of potential wetland sites

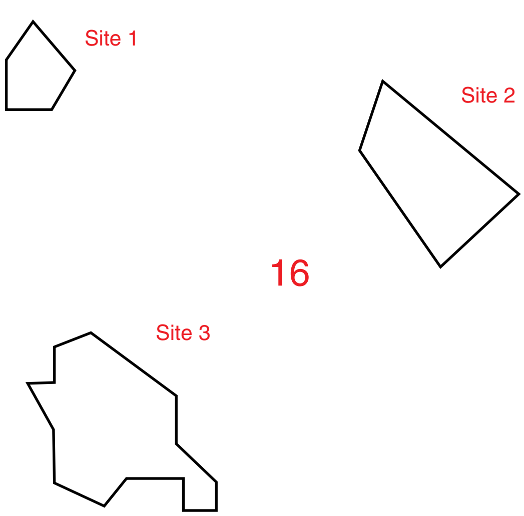
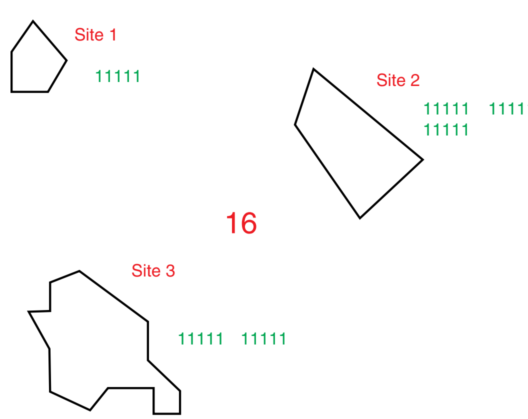


Figure 19–85 Results of preliminary slide review



650.1912 Surface runoff using Soil-Plant-Air-Water (SPAW) model

(a) Introduction

The soil-plant-air-water (SPAW) computer model simulates the daily hydrologic water budgets of agricultural landscapes by two connected routines, one for farm fields and a second for impoundments such as wetland ponds, lagoons or reservoirs. Climate, soil and vegetation data files for field and pond projects are selected from those prepared and stored with a system of interactive screens. Various combinations of the data files readily represent multiple landscape and pond variations.

Field hydrology is represented by:

- daily climatic descriptions of rainfall, temperature and evaporation
- a soil profile of interacting layers each with unique water holding characteristics
- annual crop growth with management options for rotations, irrigation and fertilization

The simulation estimates a daily vertical, one-dimensional water budget depth of all major hydrologic processes such as runoff, infiltration, evapotranspiration, soil water profiles and percolation. Water volumes are estimated by budget depths times the associated field area.

Pond hydrology simulations provide water budgets by multiple input and depletion processes for impoundments which have agricultural fields or operations as their water source. Data input and selection of previously defined data files are by graphical screens with both tabular and graphical results. Typical applications include analyses of wetland inundation duration and frequency, wastewater storage designs, and reliability of water supply reservoirs.

The objective of the SPAW model was to understand and predict agricultural hydrology and its interactions with soils and crop production without undue burden of computation time or input details. This required continual vigilance of the many choices required for the representation of each physical, chemical and biological process to achieve a reasonable and balanced approximation of the real world with numerical solutions.

Over the development period, both the model and the method of data input with system descriptors have evolved for improved accuracy, extended applications, and ease of use. The program documentation includes theory, data requirements, example applications, and operational details. The model results have been corroborated through research data, workshops and application evaluations.

The SPAW field model is a daily vertical water budget of an agricultural field, provided the field can be considered, for practical purposes, spatially uniform in soil, crop and climate. These considerations will limit the definition of a field depending on the local conditions and the intended simulation accuracy. For many typical cases, the simulation will represent a typical farm field of tens to a few hundred acres growing a single crop with insignificant variations of soil water characteristics or field management. In other cases, a single farm field may need to be divided into separate simulation regions because of distinct and significant differences of soil or crop characteristics. These definitions and divisions will depend on the accuracy required, however users soon gain enough experience through alternative solutions to guide these choices.

Since the field model has no infiltration time distribution less than daily and no flow routing, it is generally not applicable for large watershed hydrologic analyses. However, it can be utilized for water budgets of agricultural watersheds composed of multiple farm fields, each simulated separately and the results combined. The combined field concept to represent a watershed is used as an input source for the pond simulations. With no streamflow routing there are no channel descriptors included. Daily runoff is estimated as an equivalent depth over the simulation field by the runoff curve number method (RCN).

The SPAW-Pond model simulates the water budget of an inundated depression or constructed impoundment. The water supply to the inundated area is estimated runoff from one or more previously simulated fields, plus, if applicable, that from external sources, such as an off-site pump or flush water from an animal housing facility. Pond climatic data are provided from that input to the field simulation. Additional features are included such as outlet pipe discharge, drawdown pumps, irrigation supply demands and water tables to allow for a wide variety of pond situations described as wetlands, small ponds, water supply reservoirs, lagoons, or seasonal waterfowl ponds.

Basic interactions of soil chemicals such as nitrogen and salinity with soil water and crop production are included. The chemistry is represented in daily budget form, therefore does not include interactions and minor processes which occur within soil and crop environments. These budgets are useful as a screening tool to define potential effects and hazards related to the chemical inputs and dispositions for situations often encountered in agricultural hydrologic analyses.

(b) The applicability of SPAW for the DEPRESSIONAL HGM wetland class

The SPAW model is applicable to depressional HGM wetland types where surface runoff is the dominant water source. If groundwater inflows and outflows are a significant part of the water budget, surface runoff tools are not applicable. Depressions in Riverine HGM wetland types can be analyzed using the SPAW model in combination with streamflow data, and Riverine wetland analysis tools.

(c) SPAW water budgeting

The comprehensive water budget equation for depressional wetlands is:

$$\left(P + R_i + G_i\right) - \left(ET + R_o + G_o\right) = \Delta S \qquad \text{(eq. 19–21)}$$

The SPAW model solves this water budget equation in a depression on a daily time step to track the depth of inundation. It will not determine the depth and/or duration of a shallow water table in the depression substrate (saturation).

(1) Precipitation (P)

The SPAW model requires daily precipitation and temperature data. For purposes of wetland delineation, at least 10 years of daily data are required. Usually, at least 30 years of data are available. Daily climate data for current weather stations is available through eFOTG, using the AgACIS link under section II, the Climate Data tab.

The SPAW model interprets precipitation which falls when the temperature is above freezing as rain. Precipitation recorded as rain when the temperature is below freezing, or precipitation recorded as snow is assumed to be held on the ground surface until the temperature allows the snow and ice to thaw. Precipitation is added directly to the depth of water in the pond. Precipitation falling on the portion of the pond not currently inundated is modeled as bank runoff, and assigned to pond storage. Precipitation falling on the pond's watershed is infiltrated or assigned to surface runoff using the NRCS RCN methodology.

All rainfall occurring during the period of record is treated as individual precipitation events. A multi-day storm, then is assumed to be a series of daily rainfall events.

(2) Surface runoff from the field model

The dominant source for water when using the SPAW model is surface runoff from the contributing watershed. The watershed is modeled as one or more fields. Each field is a separate land unit or group of land units with land cover, soils, and management that are similar enough to deliver the same surface runoff. Precipitation that either falls on the field(s) or melts during a thaw period is assigned to infiltration or runoff. Using the RCN method, the water runs off or is stored based on the curve number that exists at the time of the precipitation or melt event. Water that does not run off enters the soil, and moves within the profile based on soil-plant-water relationships. The option exists to assign some or all of the water that percolates below the plant root zone back into the pond as groundwater discharge, G_i.

One important function of the modeling of the vegetative cover is done to maintain an accurate daily RCN. The RCN is a function of canopy cover, and soil moisture. Soil moisture is a function of the rooting depth of the plants, which determine how much moisture is extracted from soil storage and from what depth. When the top layers of the soil have been depleted of moisture to 60 percent of the field capacity (FC), an adjustment in RCN is made based on a change in antecedent runoff condition (ARC) from ARC II to ARC I.

Likewise, when precipitation fills up the top layers of the soil profile to 100 percent of FC, the ARC changes to III, with a corresponding increase in the RCN. The other parameter which affects the RCN is the Hydrologic Soil Group (HSG) of the soil, which is entered once for the analysis, and does not change. The HSG for each soil is either A,B,C, or D.

(3) Groundwater inflow and outflow, G_i and G_o

The groundwater inflows into and out of the depressional wetland pond are simplifications. For this reason, systems for which groundwater flows are a significant part of the water budget should be further analyzed beyond the use of SPAW model. The SPAW model uses a single seepage rate input to calculate the rate of inflow and outflow. When the elevation of the local groundwater table is input above the pond bottom grade, this differential head is used with the seepage rate to add groundwater inflow. When the groundwater table is lower than the pond bottom, seepage loss is based on the input seepage rate. The seepage rate is not the hydraulic conductivity, and does not vary with the head of water above or below the pond bottom.

(4) Surface runoff out

The surface runoff, (R_o) out of the depression begins when the pond fills up to a known spillway elevation. This elevation is an input to the pond model. Daily inputs of water to the pond after the depth reaches the spillway elevation are assumed to leave the site as runoff outflow. In some cases, the depression is significantly deeper than the maximum storage depth(s) during the period of climate record, and an accurate spillway elevation is not needed. In instances where the inundation depth reaches the spillway frequently, this elevation must be determined with a good degree of accuracy.

(5) Evapotranspiration, ET

The SPAW model removes water from the soil surface and from storage in the soil profile. The losses are from interception evaporation, soil water evaporation, and plant transpiration. Calculation of each of these losses is based on the potential evapotranspiration (PET).

Potential evapotranspiration—The potential for the combination of temperature, wind velocity, solar radiation and air temperature to extract water from the land surface and return it to the atmosphere is referred to as PET. The value for PET is then used with factors to determine the actual evaportanspiration (AET) on a daily time step. The accuracy is increased with increased availability of data. The SPAW model will allow the user to input values for measured pan evaporation, measured Penman evaporation, or estimated Penman evaporation values. Since actual measured values for evaporation are seldom available, the daily temperature values associated with the basic climate data are used by SPAW to compute PET using the Penman equation. The monthly evaporation defaults provided by the user are used to compute an average daily PET for days when temperature data is missing.

Interception evaporation—When precipitation events or irrigation applications place free water on the soil surface, it readily evaporates. The user must enter values for both canopy and soil surface interception. These values are a constant, and the input volume is subtracted from the PET on a daily time-step basis before water is removed through soil evaporation or plant transpiration. These values are typically in the range of 0.1 in. While small, it is important to understand that this value will be subtracted first from all precipitation events, large and small. With a 0.2 inch rainfall, an interception value of 0.1 inch will remove 50 percent of this volume.

Soil water evaporation—The water lost in this process moves vertically upward through a shallow surface layer as water vapor. The amount of water lost is a function of the moisture content of the subsurface layer(s), the soil physical parameters controlling upward movement of water from wetter layers, and the temperature of the ambient air. The percentage of crop canopy is also used to assign some solar radiation energy to the process.

Plant transpiration—The SPAW model removes water through plants leaves and stems based on 3 parameters. These parameters are input into the model in a time vs. value function to reflect changes through the plant's annual growth cycle. The parameters are percentage canopy cover, rooting depth, and greenness, and were previously mentioned in the section on RCN. The model assumes that any growing plant with similar values of canopy, greenness, and rooting depth will transpire water at the same rate, regardless of biomass volume, growth height, etc. The percent canopy determines how much biomass is available. The greenness is simply the ratio of living biomass available for transpiration versus inert biomass (such as crop residue). The rooting depth is used to determine the layers from which moisture is extracted.

Storage—Storage is evaluated as the storage available in the soil profile in the watershed fields, the surface storage in the depressional wetland, and the storage available in the wetland substrate.

Wetland field soil profile—This is the most complex of the three storage evaluations made by SPAW. Water is stored in the various layers of the soil profile based on input parameters. Water also moves vertically upward and downward based on the amount of precipitation falling on the surface and the removal of water by plant transpiration and surface evaporation. Water in excess of the available soil storage can move through the bottom of the soil profile and be lost to deep percolation. The SPAW model allows the user to devote all or part of this lost water to groundwater inflow to the depressional pond.

Storage in the wetland substrate—The user can input a single value as Infiltration into Dry Pond Bottom in the Pond Depths tab in the pond data entry screen. This storage must be satisfied each time the pond fills, and is extracted based on the soil evaporation calculations after the inundated depth goes to zero. In situations where the pond fills frequently to shallow depths, the analysis is particularly sensitive to this input value.

Surface storage in the pond—This data is typically developed from detailed topography, and consists of a table of stage versus storage. The water budget parameters are computed on a volume basis. As the volumes are added and subtracted from the pond storage on a daily basis, the resulting depth is computed from the stage-storage table. This is necessary because the amount of surface evaporation from the pond, and the amount of precipitation on the non-inundated, bare banks of the pond are a function of the surface area. This area, in turn, is a function of the stage-storage relationship.

The user should be aware that the actual pond size does not change with changes in stage. Likewise, the watershed area does not increase or decrease as the inundated area changes. As the pond dries up, exposed pond bottom is assigned to bank, and precipitation falling on this surface is infiltrated up to the limit of the infiltration into dry pond bottom limit, and evaporated based on the PET for surface evaporation. Excess precipitation is assigned to runoff into the pond.

It is recommended that the highest input depth of the stage-storage table not be significantly above the potential maximum ponded depth during the analysis period. Doing so will cause more potential watershed area than necessary to be treated as bank than watershed. This problem is eliminated for those ponds where a natural spillway experiences flow on a frequent basis. The spillway elevation is the upper limit of the stage-storage table.

(d) Program input and output

The SPAW model allows the user to input and examine simulation results through a graphical user interface. The program actually executes by accessing various ASCII text files that may be built outside of the user interface, as long as they are stored in the proper program files directories.

The program also provides output in the form of ASCII text or as plotted graphics. The SPAW users manual is available through the help menu, which provided detailed information about data input and program functions. Table 19–24 shows the SPAW output information contained in the *.ind file.

The program provides the probability of a selectedinundation period for depths in 10 percent depth increments. The 50 percent chance probability depth can be inter-polated using the values highlighted. Int his case the 50 percent chance probability depth for 14 days of inundation is 1.27 feet. The program allows the user to select the duration based on the objective criteria for the analysis.

650.1913 Groundwater monitoring applications

(a) Introduction

The presence of saturated soil conditions is one of the distinguishing characteristics of wetlands. Saturation creates the anaerobic conditions necessary to form the morphology of hydric soils, and also create the conditions necessary to support hydrophytic vegetation. While many wetlands have conditions of long-term inundation, others are only saturated because of shallow groundwater tables for all or part of their hydroperiod. Groundwater monitoring methods are used to document the frequency, duration, and probability of saturation for a desired range of depth from the surface.

(b) Applicability to HGM classes

Groundwater monitoring is applicable to wetlands in all HGM wetland types. However, not all wetlands are capable of maintaining wetland hydrology because of saturated soil conditions. Furthermore, certain wetland types do not have groundwater as a dominant water source, even though they exhibit high groundwater as a result of water supplied from precipitation, flooding, or surface runoff.

The general HGM classes and subclasses that have groundwater as a dominant water source are:

- SLOPE, both topographic and stratigraphic: These wetlands depend on a steady, long-term groundwater source. This groundwater flow usually has a vertical, upward component.
- RIVERINE, endosaturated: Many floodplain wetlands are associated with a stream that maintains high flows for the duration of the wetland hydroperiod due to snowmelt or conditions that maintain a large amount of stored water in the watershed and floodplain. If the floodplain soils are coarse grained sands and gravels with a high hydraulic conductivity, the stream water surface is directly connected to the floodplain groundwater level. In other words, the groundwater level rises and falls with the stream stage.
- DEPRESSION, discharge and flowthrough: These wetland types are especially difficult to analyze using water budgeting techniques. Their hydrology is not directly dependent on precipitation or surface runoff, but these factors interact with watershed conditions to create changes in groundwater inflow. Like the SLOPE wetland type, the groundwater flow usually has a vertical upward component.

Wetland classes that exhibit high groundwater tables from other dominant water sources are:

- MINERAL FLATS: This HGM wetland type receives water from precipitation, and limited surface runoff. It often has a water table that is perched above the local groundwater table. The perching layer may be a thin, discrete layer of soil, or a deep layer of relatively low permeability soil. Monitoring of groundwater can document wetland hydrologic conditions due to saturation, but this saturation is a result of water supplied from other sources. Because of this, other methods can often be used as corroborating evidence.
- ORGANIC FLATS: This wetland type is unique in that the formation of the organic soils depends on conditions of near continuous surface satura-

Table 19–23 SPAW Output

Percentage of years pond depth greater than given depths (10% intervals) For 14 consecutive days during the wetland growing season: Feb. 1 to Dec. 25											
Depth (ft)	Dry	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00
Area (ac)	0.00	2.44	2.69	2.92	3.18	3.45	3.76	4.08	4.43	4.82	5.23
Years (%)	100	97	90	72	54	36	18	15	10	0	0

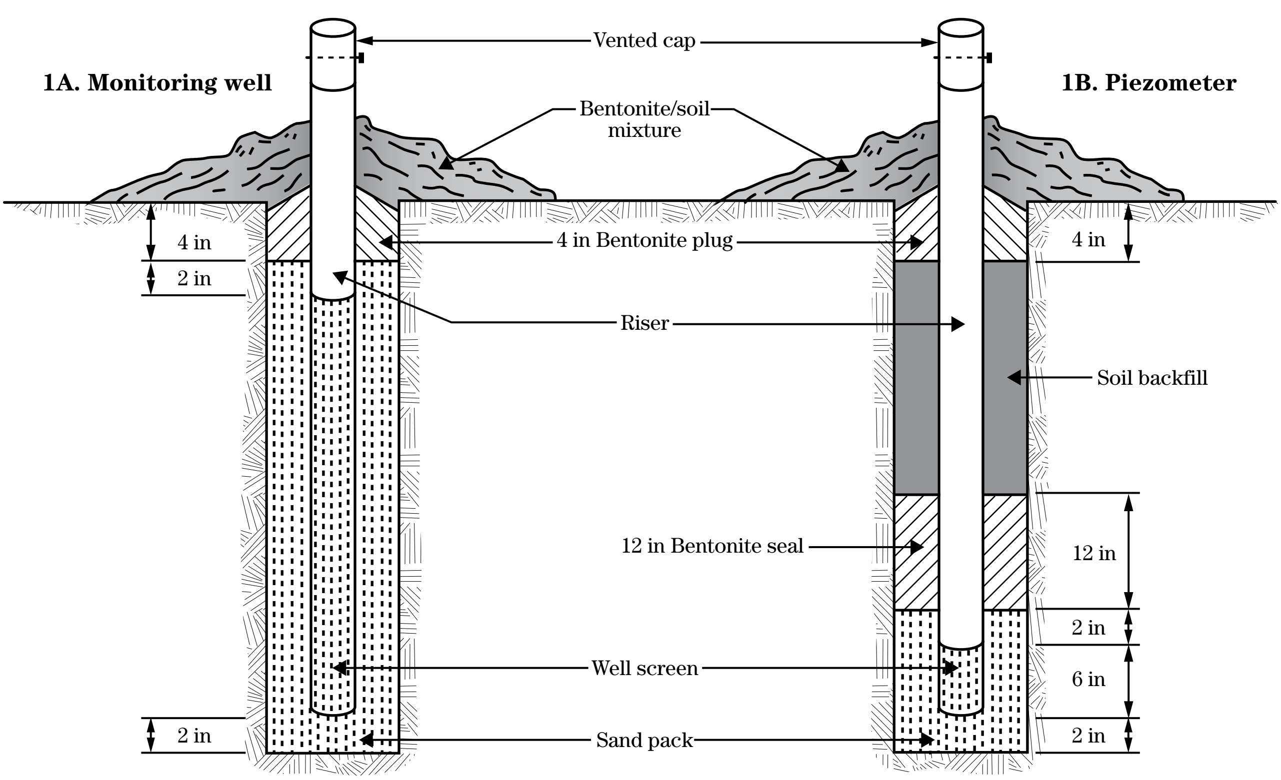
tion. The water table can be perched, or it can be the true local water table. The dominant water source is precipitation, with surface runoff. in some cases. If an ORGANIC FLAT wetland is drained, the organic soil surface is exposed to oxygen, and aerobic bacteria convert the organic matter to gaseous compounds in a process called mineralization. The resultant lowering of the land surface is called subsidence. Documentation of subsidence can be used as corroborating evidence with groundwater monitoring data.

- LACUSTRINE FRINGE: The dominant water source for this wetland type is lake water, and the groundwater level in the associated wetland can respond directly with lake levels. Lake level information can be used as corroborating evidence with groundwater monitoring data.
- ESTUARINE FRINGE: Similarly to LACUSTRINE FRINGE wetlands, the groundwater levels in ESTUARINE FRINGE wetlands can respond directly with tide levels, and tidal fluctuations can be used as corroborating evidence.
- RIVERINE, episaturated: This wetland type is quite similar to MINERAL FLATS. If the floodplain does not receive flood flows in a semi-annual basis, the use of groundwater monitoring data is the same as in MINERAL FLATS. If the stream does flood frequently, the floodplain inundation applications in NEH650.1908 can be used in addition to groundwater monitoring data.

(c) Monitoring wells and piezometers

Monitoring wells and piezometers are collectively referred to as observation wells, and are used to collect information on groundwater conditions. Figure 19–86 shows the recommended installation of both. The monitoring well is installed to measure the actual level

Figure 19–86 Monitoring well and piezometer installation



of the free groundwater surface which would appear if a shallow bore hole was excavated in the surface. This level is the same as that obtained with an open bore hole during an onsite wetland determination using the procedure in the USACE Wetlands Delineation Manual, (USACE 1987).

If there is no movement of groundwater in the soil profile, the resulting free water surface in the groundwater monitoring well is independent of the location or length of the screened interval. If groundwater is moving, however, the free water surface will be altered by the magnitude and direction of the groundwater movement, referred to as hydrodynamics. More information about the hydrodynamics can be obtained by one or more piezometers. If one or more piezometers are installed at the same location, and placed adjacent to a monitoring well, the hydrodynamics can be fully defined. These installations are referred to as nested wells and piezometers.

Only monitoring well data is allowed for direct documentation of the duration, frequency, and probability of groundwater levels for wetland determinations. However, piezometer data can be used for corroborating evidence in cases where groundwater data is from periods outside normal environmental conditions, where the groundwater monitoring period of record is limited, or where the wetland site has been altered by drainage.

Monitoring wells and piezometers placed specifically for a wetland determination should be installed according to the recommendations in TN–WRAP–00–02, Installing Monitoring Wells/Piezometers in Wetlands, USACE.

(d) The use of monitoring wells

A monitoring well in a potential wetland area indicates groundwater depths over time. Thus, durations of saturation (groundwater levels) above or below a specific elevation can be determined. Water level records provide an index of the duration and frequency of saturation of the area. These records are obtained on either a continuous or a fixed time interval basis.

(1) Data required

The following data are required:

- location of the observation well
- ground level and the reference elevation of the measurements
- depth from the reference elevation to the water surface in the observation on a continuous or regular basis during the growing season

(2) Limitations

Monitoring wells are only appropriate for wetlands where hydrology is maintained by the presence of a water table. Staff gages should be used to measure the depth of surface inundation, and can be installed in conjunction with monitoring wells.

(3) Knowledge and experience required

General knowledge of statistical procedures and specific knowledge of soil, hydrology, and observation well installation are required.

(4) Climatic regions of applicability

This hydrology tool is applicable to all climate regions.

(5) Factors affecting the accuracy of results

Wells that have been properly installed and maintained provide the best data. Artesian or flowing wells provide information about a confined aquifer and may not represent the shallow water table under a wetland. Water levels in nonartesian or nonflowing wells may not represent the local shallow water table, depending on intake screen location and seal. Piezometers are not to be used to measure water table levels. Water levels that have been obtained on a continuous basis are the best data. Continuous records indicate both the duration and frequency of saturation. The information on a fixed time interval provides an index of the frequency and duration if the sampling interval is equal to or shorter than the minimum duration of wetland saturation. If there are 10 or more years of continuous daily data, then a statistical analysis can be made using the procedures in NEH650.1903 to determine the probability of occurrence for a specific duration. The statistical analysis determines how often the wetland has been saturated in the past. It can be assumed that the same frequency of saturation will happen in the future if no alterations occur.

If the record length is between 5 and 10 years, the number of years of saturation of the wetland is used. It is then necessary to determine if the periods of saturation occurred during normal environmental conditions. This case is similar to the use of remotely sensed data to determine wetness signatures, with monitoring well data used as a substitute for the observance of wet signatures. Records collected on longer than daily intervals may be used if the collection interval is less than the reference duration. For instance, if the analysis must determine the occurrence of saturation for a 14 day duration, a weekly measurement interval can provide useful data. Low level readings taken before and after a 14 day duration can be interpolated with time to obtain a duration.

If the record length is less than 5 years, corroborating evidence must be obtained to support a conclusion.

(6) Sources of information

Observation well data may be available from local and state agencies responsible for regulating well drilling. State agencies include geologic survey, water right, or water resource agencies. Local agencies may also have copies of the water levels. The state geologist can provide assistance in obtaining the record of water levels. The data should be used with great care because most water level data were established for another purpose.

(7) Methodology

The steps involved in the analysis of the observation well data are:

Step 1: Determine the growing season.

Step 2: Obtain the observation well data or water levels for the growing season.

Step 3: Determine the maximum water level for the critical duration for each year

Step 4: Determine if the critical duration was met 50 percent of the time for the period of record.

If the record length is 10 years or more, statistical inferences about the mean conditions can be made using the procedures in NEH650.1904

If the record length is between 5 and 10 years, determine the number of years the criteria were met during normal environmental conditions, for example, 4 out of the 10 years. Use the methods used for interpreting normal environmental conditions in NEH650.1901.

If the record length is less than 5 years, determine if the record can be correlated with other corroborating data.

If no other well data are available, correlate the well observations with precipitation to determine if the precipitation for the recharge period was wet, normal, or dry. If the recharge period precipitation is less than the lower 3 out of 10 year value, the period is dry. If it is greater than the higher 7 out of 10 year value, the period is wet. If the water level elevation met the criteria during a dry period, the area is most likely a wetland. If the water level elevation met the criteria during a wet period, additional analysis is needed.

(e) Establishing an observation well

An observation well can be established in a wetland to verify the wetland mapping or initial identification. The well needs to be observed for 10 years to establish the average conditions. The observations should be on a continuous basis during the growing season. The State geologist, soil scientist or hydraulic engineer should be consulted before an observation well is established in a wetland. The state geologist has specifications and information on how to install, case, and seal the well and how to take and record the measurements. Sprecher (2008) provides guidelines on installation of wetland observation wells.

(f) Examples

(1) 14 years of records

This analysis is of the well records from a State agency data base. The records indicate 14 years of records and that the water levels were obtained on a continuous basis. The values are feet below the ground level. Thus a value of zero indicates the water in the well is at ground level. This well is in the wetland. It was installed for observation purposes, and no pumping has occurred. The criteria for this analysis states that if the water level is within 1 foot of the surface for a duration of 15 days during the growing season with an annual probability of 50 percent, the area meets the wetland hydrology criteria for saturation. The record has been analyzed, and the water level of 1 foot or less for a continuous 15-day period during the growing season (March 1 through October 15) has been determined. The tabulated values (table 19–25) represent the shallowest water level or the smallest reading in that 15 day period. For example, in 1975 the 15-day consecutive values were 0.9, 1.0, 0.9, 0.95, 0.9, 1.0, 1.0, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, and 0.9, thus the value used in the analysis for the year 1975 is 0.9. It should be remembered that the highest water level in the well would be the smallest depth to water from the ground surface. The 50th percentile value for the annual 15 day duration value is 1.0, which falls between the values represented by the figures shown in bold in table 19–25. This water table level was exceeded in 11 out of the 14 years. The wetland hydrology indicator is met for this situation.

(2) 5-year records where water level is taken every 5 days

This analysis is of the observation well records from state data base. A search of the data base indicates that there are 5 years of records (tables 19–25 to 19–29) and that the water levels were obtained every 5 days on a regular basis. The values are in feet below ground level. This means that a value of zero indicates the water in the well is at ground level. This well is located at the edge of a potential wetland. The record is for water years 1980 through 1984. For this example the wetland criteria are water level at the surface and for a duration of 15 consecutive days. The growing season is from March 15 to September 15.

Analysis of the data indicates:

- *Water year 1980*—The water level in the well is at ground level during one period of 16 to 24 consecutive days, three periods of 6 to 14 consecutive days in, and one period of 1 to 9 consecutive days.
- *Water year 1981*—The water level in the well is at ground level for one period of 6 to 14 consecutive days in length and two periods of 1 to 9 days.
- *Water year 1982*—The water is at the soil surface for one period of 6 to 14 consecutive days in length, and two periods of 1 to 9 consecutive days in length.
- *Water year 1983*—The water does not reach the soil surface.
- *Water year 1984*—The water does not reach the soil surface.

This analysis indicates that water level has been at the ground surface for 3 out of the 5 years of record. In water year 1980, the water was at ground level for longer than the minimum of 15 days. This analysis also illustrates the problem of making conclusions if the observations are not taken every day; therefore, no conclusions can be made regarding the duration of the water table during the noted periods.

For example, in 1982 the record shows:

May 20	0.10
May 25	0.00
May 31	0.00
June 5	0.20

From May 21 to June 4, a period of 15 days, the inundation criteria is met. However, it may have been met only during the 7 day period between May 25 and 31

Table 19–24 Observation well records for 1970 to 1983

Year	Highest level during 15 days	Array from largest to smallest
1970	1.0	1.3
1971	1.1	1.2
1972	0.9	1.1
1973	1.0	1.0
1974	1.0	1.0
1975	0.9	1.0
1976	1.3	**1.0**
1977	0.9	**1.0**
1978	1.0	0.9
1979	0.9	0.9
1980	1.0	0.9
1981	0.9	0.9
1982	1.0	0.9
1983	1.2	0.9

Table 19–25 Water level, in feet below land-surface datum, for October 1979 to September 1980

Pittsburg County

350422095341901. local Number, 07W-16E-24 B&B 1

Location—Lat 35 4’22" Long 95 34’19", Hydrologic unit 11090204

Owner:

Aquifer—Local aquifer

Well characteristics—Observation well

Datum—Altitude of land-surface is unavailable

Water level, in feet below land-surface datum, for October 1979 to September 1980

Date	Water level	Date	Water level	Date	Water level	Date	Water level
Oct 5	2.00	Jan 5	0.55	Apr 5	0.10	Jul 5	0.05
Oct 10	1.90	Jan 10	0.40	Apr 10	0.05	Jul 10	0.00
Oct 15	1.80	Jan 15	0.30	Apr 15	0.00	Jul 15	0.10
Oct 20	1.75	Jan 20	0.20	Apr 20	0.00	Jul 20	0.20
Oct 25	1.70	Jan 25	0.10	Apr 25	0.05	Jul 25	0.30
Oct 31	1.65	Jan 31	0.00	Apr 30	0.10	Jul 31	0.50
Nov 5	1.60	Feb 5	0.00	May 5	0.05	Aug 5	0.80
Nov 10	1.55	Feb 10	0.05	May 10	0.00	Aug 10	1.00
Nov 15	1.54	Feb 15	0.00	May 15	0.00	Aug 15	1.20
Nov 20	1.50	Feb 20	0.05	May 20	0.00	Aug 20	1.40
Nov 25	1.45	Mar 5	0.00	May 25	0.00	Aug 25	1.60
Nov 30	1.40	Mar 10	0.00	May 31	0.10	Aug 30	1.80
Dec 5	1.35	Mar 15	0.05	Jun 5	0.20	Sep 5	1.85
Dec 10	1.30	Mar 20	0.00	Jun 10	0.15	Sep 10	1.90
Dec 15	1.25	Mar 25	0.00	Jun 15	0.10	Sep 15	2.00
Dec 20	1.00	Mar 30	0.05	Jun 20	0.05	Sep 20	2.05
Dec 25	0.90			Jun 25	0.00	Sep 25	2.00
Dec 31	0.80			Jun 30	0.00	Sep 30	2.10

Table 19–26 Water level, in feet below land-surface datum, for October 1980 to September 1981

Pittsburg County

350422095341901. local Number, 07W-16E-24 B&B 1

Location—Lat 35 4'22" Long 95 34'19", Hydrologic unit 11090204

Owner:

Aquifer—Local aquifer

Well characteristics—Observation well

Datum—Altitude of land-surface is unavailable

Water level, in feet below land-surface datum, for October 1980 to September 1981

Date	Water level	Date	Water level	Date	Water level	Date	Water level
Oct 5	2.00	Jan 5	0.80	Apr 5	0.10	Jul 5	0.05
Oct 10	2.00	Jan 10	0.70	Apr 10	0.05	Jul 10	0.20
Oct 15	1.90	Jan 15	0.60	Apr 15	0.05	Jul 15	0.10
Oct 20	1.75	Jan 20	0.50	Apr 20	0.05	Jul 20	0.20
Oct 25	1.70	Jan 25	0.40	Apr 25	0.05	Jul 25	0.30
Oct 31	1.60	Jan 31	0.30	Apr 30	0.10	Jul 31	0.50
Nov 5	1.60	Feb 5	0.20	May 5	0.05	Aug 5	0.90
Nov 10	1.50	Feb 10	0.10	May 10	0.00	Aug 10	1.10
Nov 15	1.50	Feb 15	0.20	May 15	0.05	Aug 15	1.20
Nov 20	1.50	Feb 20	0.15	May 20	0.05	Aug 20	1.40
Nov 25	1.40	Mar 5	0.10	May 25	0.00	Aug 25	1.60
Nov 30	1.40	Mar 10	0.00	May 31	0.15	Aug 30	1.80
Dec 5	1.30	Mar 15	0.05	Jun 5	0.25	Sep 5	1.85
Dec 10	1.30	Mar 20	0.00	Jun 10	0.20	Sep 10	1.90
Dec 15	1.25	Mar 25	0.00	Jun 15	0.2	Sep 15	2.10
Dec 20	1.00	Mar 30	0.05	Jun 20	0.15	Sep 20	2.25
Dec 25	0.95			Jun 25	0.10	Sep 25	2.20
Dec 31	0.80			Jun 30	0.10	Sep 30	2.20

Table 19–27 Water level, in feet below land-surface datum, for October 1981 to September 1982

Pittsburg County
350422095341901. local Number, 07W-16E-24 B&B 1
Location—Lat 35 4’22" Long 95 34’19", Hydrologic unit 11090204
Owner:
Aquifer—Local aquifer
Well characteristics—Observation well
Datum—Altitude of land-surface is unavailable
Water level, in feet below land-surface datum, for October 1981 to September 1982

Date	Water level	Date	Water level	Date	Water level	Date	Water level
Oct 5	2.20	Jan 5	1.85	Apr 5	0.20	Jul 5	0.05
Oct 10	2.30	Jan 10	1.70	Apr 10	0.15	Jul 10	0.00
Oct 15	2.25	Jan 15	1.60	Apr 15	0.10	Jul 15	0.10
Oct 20	2.15	Jan 20	1.50	Apr 20	0.05	Jul 20	0.20
Oct 25	2.00	Jan 25	1.30	Apr 25	0.05	Jul 25	0.30
Oct 31	2.15	Jan 31	1.10	Apr 30	0.10	Jul 31	0.50
Nov 5	2.20	Feb 5	1.00	May 5	0.05	Aug 5	0.60
Nov 10	2.35	Feb 10	0.85	May 10	0.05	Aug 10	0.70
Nov 15	2.30	Feb 15	0.80	May 15	0.05	Aug 15	0.80
Nov 20	2.20	Feb 20	0.75	May 20	0.10	Aug 20	0.90
Nov 25	2.15	Mar 5	0.60	May 25	0.00	Aug 25	1.00
Nov 30	2.10	Mar 10	0.50	May 31	0.00	Aug 30	1.10
Dec 5	2.05	Mar 15	0.45	Jun 5	0.20	Sep 5	1.25
Dec 10	2.30	Mar 20	0.40	Jun 10	0.15	Sep 10	1.40
Dec 15	2.20	Mar 25	0.30	Jun 15	0.10	Sep 15	1.60
Dec 20	2.00	Mar 30	0.25	Jun 20	0.05	Sep 20	1.75
Dec 25	1.90			Jun 25	0.00	Sep 25	1.80
Dec 31	0.80			Jun 30	0.10	Sep 30	1.90

Table 19–28 Water level, in feet below land-surface datum, for October 1982 to September 1983

Pittsburg County

350422095341901. local Number, 07W-16E-24 B&B 1

Location—Lat 35 4’22" Long 95 34’19", Hydrologic unit 11090204

Owner:

Aquifer—Local aquifer

Well characteristics—Observation well

Datum—Altitude of land-surface is unavailable

Water level, in feet below land-surface datum, for October 1982 to September 1983

Date	Water level	Date	Water level	Date	Water level	Date	Water level
Oct 5	2.00	Jan 5	2.30	Apr 5	0.80	Jul 5	0.45
Oct 10	2.00	Jan 10	2.40	Apr 10	0.65	Jul 10	0.40
Oct 15	2.10	Jan 15	2.30	Apr 15	0.50	Jul 15	0.30
Oct 20	2.25	Jan 20	2.20	Apr 20	0.40	Jul 20	0.20
Oct 25	2.30	Jan 25	2.10	Apr 25	0.45	Jul 25	0.30
Oct 31	2.45	Jan 31	2.00	Apr 30	0.40	Jul 31	0.40
Nov 5	2.60	Feb 5	1.90	May 5	0.45	Aug 5	0.60
Nov 10	2.55	Feb 10	1.80	May 10	0.50	Aug 10	0.80
Nov 15	2.45	Feb 15	1.70	May 15	0.60	Aug 15	0.90
Nov 20	2.30	Feb 20	1.60	May 20	0.70	Aug 20	1.00
Nov 25	2.20	Mar 5	1.50	May 25	0.60	Aug 25	1.00
Nov 30	2.10	Mar 10	1.40	May 31	0.50	Aug 30	1.00
Dec 5	2.00	Mar 15	1.30	Jun 5	0.30	Sep 5	1.00
Dec 10	2.10	Mar 20	1.10	Jun 10	0.45	Sep 10	1.10
Dec 15	2.20	Mar 25	1.00	Jun 15	0.40	Sep 15	1.00
Dec 20	2.30	Mar 30	0.90	Jun 20	0.45	Sep 20	1.00
Dec 25	2.40			Jun 25	0.40	Sep 25	1.50
Dec 31	2.30			Jun 30	0.40	Sep 30	1.80

Table 19–29 Water level, in feet below land-surface datum, for October 1983 to September 1984

Pittsburg County

350422095341901. local Number, 07W-16E-24 B&B 1

Location—Lat 35 4’22" Long 95 34’19", Hydrologic unit 11090204

Owner:

Aquifer—Local aquifer

Well characteristics—Observation well

Datum—Altitude of land-surface is unavailable

Water level, in feet below land-surface datum, for October 1983 to September 1984

Date	Water level	Date	Water level	Date	Water level	Date	Water level
Oct 5	1.90	Jan 5	2.30	Apr 5	0.80	Jul 5	0.45
Oct 10	2.00	Jan 10	2.40	Apr 10	0.65	Jul 10	0.40
Oct 15	2.10	Jan 15	2.30	Apr 15	0.50	Jul 15	0.30
Oct 20	2.25	Jan 20	2.20	Apr 20	0.40	Jul 20	0.20
Oct 25	2.30	Jan 25	2.10	Apr 25	0.45	Jul 25	0.30
Oct 31	2.45	Jan 31	2.00	Apr 30	0.40	Jul 31	0.40
Nov 5	2.60	Feb 5	1.90	May 5	0.45	Aug 5	0.60
Nov 10	2.55	Feb 10	1.80	May 10	0.50	Aug 10	0.80
Nov 15	2.45	Feb 15	1.70	May 15	0.60	Aug 15	0.90
Nov 20	2.30	Feb 20	1.60	May 20	0.70	Aug 20	1.00
Nov 25	2.20	Mar 5	1.50	May 25	0.60	Aug 25	1.00
Nov 30	2.10	Mar 10	1.40	May 31	0.50	Aug 30	1.00
Dec 5	2.00	Mar 15	1.30	Jun 5	0.30	Sep 5	1.00
Dec 10	2.10	Mar 20	1.10	Jun 10	0.45	Sep 10	1.10
Dec 15	2.20	Mar 25	1.00	Jun 15	0.40	Sep 15	1.00
Dec 20	2.30	Mar 30	0.90	Jun 20	0.45	Sep 20	1.00
Dec 25	2.40			Jun 25	0.40	Sep 25	1.50
Dec 31	2.30			Jun 30	0.40	Sep 30	1.80

only. Based on the readings, and the intervals between readings, the hydrology criterion is not met.

(3) 5-year records where water level taken daily

This analysis is of the well records from a state data base. A search of the data base indicates that there are 5 years of records (tables 19–31 to 19–35) and that the water levels were obtained every day. Only the data for March through October are shown in the example. For this example, it is assumed that the growing season is March 15 through September 15. The values are feet below ground level. This means that a value of zero indicates the water in the well is at ground level. This well is located at the edge of a potential wetland. The record is for water years 1980 through 1984. Two assumptions for this example are that the wetland criterion is 10-day duration for saturation and water must be at the surface for the entire duration.

Analysis of the data indicates the following:

- *Water year 1980*—The water level in the well is at ground level during two periods 10 days in length.
- *Water year 1981*—The water level in the well is at ground level during three periods, two periods of 5 days and one of 20 days.
- *Water year 1982*—The water is at the soil surface during two periods. One period is 10 days, and the other is 5 days.
- *Water year 1983*—The water reaches the soil surface for one period of 10 days.
- *Water year 1984*—The water does not reach the soil surface.

This analysis indicates that for this potential wetland, the water surface has been at the ground level 4 out of the 5 years of record. Water is at the ground surface for a period of at least 10 days in 1980, 1981, 1982, and 1983, but not in 1984. The saturation periods are highlighted in figures 19–31, 19–32, 19–33, and 19–34. The evidence of saturation for the required duration should be correlated with the determination of normal environmental conditions.

Figure 19–87 NRCS-CPA–32 Wetland documentation record, remotely sensed data summary

USDA – NRCS **CPA–32** **WETLAND DOCUMENTATION RECORD** **REMOTELY SENSED DATA SUMMARY** **Station:**	**1. Owner/landowner** **2. County/State** **3. Field investigator** **Title** **4. Site identification No.** **Date** **5. (Tract no. farm no. site no.)**

FSA Color Slide Data

Data

Date Month/Year	**Climatic Condition Wet/Normal/Dry**	**Interpretation – List of signatures observed e.g., drowned crop, standing water, crop stress**			
		Site #	**Site #**	**Site #**	**Site #**
1979					
1980					
1981					
1982					
1983					
1984					
1985					
1986					
1987					
1988					
1989					
1990					
1991					
1992					
1993					
1994					
1995					
1996					
1997					
1998					
1999					
2000					
2001					
2002					
2003					
2004					
2005					
2006					

National Wetland Inventory (NWI)
Classification

Number of normal years observed that have wet signatures.
{Partial Growing Season (PGS)}

650.1914 References

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