U.S. Department of Agriculture Agricultural Research Service Mahantango Creek Watershed, Pennsylvania, United States: Long-term precipitation database

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[1] A long-term precipitation database has been developed by the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) Pasture Systems and Watershed Management Research Unit to support intensive hydrologic and water quality research within WE-38, a 7.3 km^2 experimental subwatershed of Mahantango Creek Watershed located in east central Pennsylvania and draining to the Susquehanna River. Daily precipitation data were collected at three sites, with record lengths of 40 years (1968–2007) at two sites and of 29 years (1979–2007) at a third site. Data are available on the USDA ARS's Sustaining the Earth's Watersheds—Agricultural Research Data System (STEWARDS) Web site.

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1. Introduction

[2] Measuring precipitation and characterizing its spatio-temporal trends is critical to the study of watershed hydrology. The U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) Pasture Systems and Watershed Management Research Unit (PSWMRU) operates a precipitation gauge network on the WE-38 Experimental Watershed to support long-term intensive research on the impacts of agriculture on water quality in the northeast United States [*Bryant et al.*, 2011, Figure 1]. The WE-38 Watershed is situated within the Northern Appalachian Ridges and Valleys Province and drains 7.3 km^2 of mostly rolling farmland within the northern portion of the Mahantango Creek Watershed, a 420 km^2 tributary to the Susquehanna River about 48 km north of Harrisburg in Northumberland County, Pennsylvania [*Bryant et al.*, 2011, Figure 1]. The climate of the region is temperate and humid. This paper provides a brief history of precipitation data collection in WE-38 and describes the data set that is a component of the Sustaining the Earth's Watersheds—Agricultural Research Data System (STEWARDS), a digital repository for long-term watershed monitoring data [*Sadler et al.*, 2008].

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2. Rainfall Monitoring Network and Instrumentation

[3] In 1966, scientists from the Northeast Watershed Research Center (NWRC) established an intensive rainfall monitoring network throughout Mahantango Creek Watershed to study spatial and temporal variation of precipitation and its effects on watershed hydrology [*Gburek*, 1977]. During the peak of this effort in 1968, the network consisted of 43 rain gauges [*Carr*, 1971]. These gauges were located to provide uniform aerial coverage and characterize the full range of elevations in Mahantango Creek Watershed. Between 1968 and 1976, the network size was reduced to 15 rain gauges because of changes in funding and research priorities. In 1976, hydrologic studies involving the entire Mahantango Creek Watershed were discontinued, and the research focus shifted to more intensive efforts within the 7.3 km^2 WE-38 subwatershed [*Gburek*, 1977]. Two long-term rain gauges (RB-37 and RE-37) that were part of the original network as well as a third gauge (MD-38) that began monitoring in 1979 provide precipitation data for the WE-38 watershed database (Table 1). Figure 1 of *Bryant et al.* [2011] shows the location of the 3 rain gauges within the WE-38 watershed.

[4] The initial rainfall monitoring network was instrumented with Fischer and Porter digital punch paper tape weighing rain gauges (hereafter referred to as Fischer-Porter rain gauges) [*Hamon et al.*, 1979]. At the time, the network of Fischer-Porter rain gauges installed across the Mahantango Creek Watershed was one of the most extensive of its kind in the United States [*Gburek*, 1977]. Fischer-Porter rain gauges had an unshielded 203 mm diameter opening and could store up to 495 mm of accumulated precipitation. During installation, recommended procedures were followed

Table 1. Information on Geographic Location, Elevation, and Length of Record for the Three Long-Term Rain Gauges in the WE-38 Watershed

	Location			Period of Record	
Station	Latitude	Longitude	Elevation[a]	Start Date	End Date
RB-37	40°43′33″N	76°35′32″W	279.1	1 Jan 1968	31 Dec 2007
RE-37	40°42′34″N	76°35′30″W	222.2	1 Jan 1968	31 Dec 2007
MD-38	40°42′51″N	76°34′56″W	254.4	1 Jan 1979	31 Dec 2007

[a]Elevation is determined from a lidar-derived digital elevation model, vertical resolution ±15 cm. Units are meters above mean sea level.

for minimum gauge height (~78 cm above the ground surface) and limited influence of obstructions on gauge rainfall catch (≤45° between the top of the gauge and surrounding vegetation and structures) [e.g., *Hamon et al.*, 1979]. All gauges were programmed to record accumulated precipitation at 5 min intervals to the nearest 2.5 mm. A rain trace indicator was incorporated into each gauge during the growing season. The rain trace indicator was sensitive to precipitation amounts less than 2.5 mm (e.g., fog, dew, very light rainfall) and therefore provided more accurate information on the occurrence and timing of precipitation events [*Carr*, 1971].

[5] In 1996, the advent of data-logging and measurement technology made it possible to upgrade the existing network of Fischer-Porter rain gauges. The digital punch paper tape system (drive shaft and gears) and weighing mechanism on each Fischer-Porter gauge were replaced with an Interface (Model SSB-AJ-100) load cell and connected to a Campbell CR10X data logger. The load cell data-logging system, which is still in use today, records accumulated precipitation every 5 min to the nearest 0.254 mm, representing a tenfold increase in precision over the original Fischer-Porter paper tape design. In addition, the load cell data-logging system does not have the intricate moving parts of the Fischer-Porter rain gauges, which were subject to frequent failure. At sites RB-37 and RE-37, where Fischer-Porter rain gauge failures were most common (Figure 1), switching to the load cell system increased the average number of days per year with valid data by 17 and 22, respectively.

3. Rain Gauge Maintenance and Calibration

[6] The original Fischer-Porter rain gauge network was maintained on a routine schedule. Technicians visited the gauges approximately every 30–45 days to change tapes, perform routine checks on batteries, and empty the gauges if needed [*Carr*, 1971; *Gburek and Weaver*, 1982]. Technicians also checked the chart time against a wristwatch that

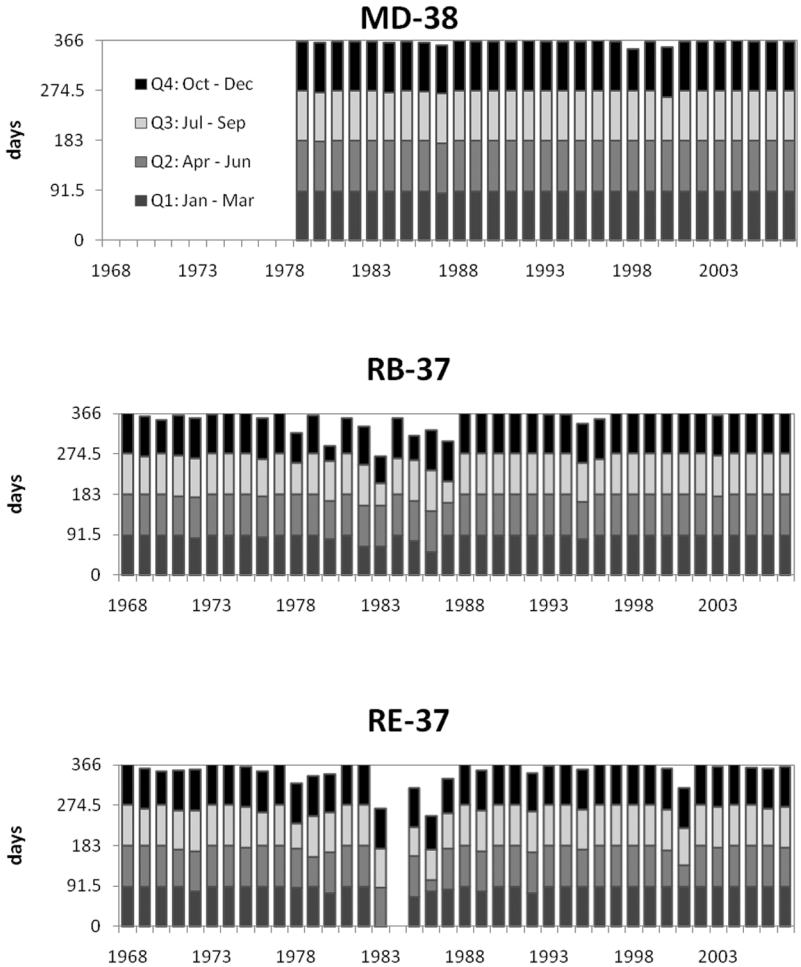

Figure 1. Number of days with valid precipitation data for the three rain gauges in the WE-38 watershed.

was set to National Institutes of Standards and Technology standard time. If the chart time was incorrect, technicians would make the necessary corrections at the gauge site and note the occurrence of a time gain or loss in the data records. All Fischer-Porter rain gauges were calibrated twice per year using a series of weights specifically designed for the Fischer-Porter system [*Gburek and Weaver*, 1982]. During spring, gauge mechanisms were overhauled and a small amount of oil was added to the catch bucket to impede evaporation. Antifreeze was used during winter to prevent accumulated precipitation from freezing.

[7] Maintenance of the current load cell data-logging system differs slightly from previous maintenance of the Fischer-Porter rain gauges. A technician visits the gauge sites on a biweekly schedule to download data and check a desiccant cartridge that is used to prevent moisture from adversely affecting data-logger electronics. The load cells are calibrated each time the gauge is emptied (about 4–5 times per year) using 4.1 and 8.2 kg weights that represent 127 and 254 mm of rainfall, respectively. Winter and summer maintenance remain unchanged.

4. Data Processing

[8] Fischer-Porter rain gauges yielded measurements of accumulated precipitation that were recorded on binary-coded paper tape. Technicians retrieved paper tapes during routine site visits (every 30–45 days) and checked the tapes for errors at the field station. Timing errors (time gain/loss) caused by clock stoppage, battery failures, and other moving part malfunctions represented the most common error type. All timing errors were recorded on field notes and flagged in the raw data using a detailed error-code system summarized by *Carr* [1973]. While every attempt was made to correct timing errors using valid timing information from the nearest rain gauge, these errors often resulted in the loss of precipitation data. Another common error that technicians noted during routine paper tape checks was the malfunction of the punch die mechanism. These errors were easily corrected, providing that the failed punch die did not rip or tear the paper tape.

[9] Once the tape records were error-checked, they were then transferred to a magnetic storage tape using a paper tape translator [*Carr*, 1973; *Gburek and Weaver*, 1982]. To reduce the data storage requirement, Fischer-Porter rain gauge records were stored in "breakpoint" format. This yielded a data set that consisted only of measured rainfall and a corresponding time stamp. Breakpoint data were then converted to a continuous record of precipitation using a simple computer program. These data are stored as text files that include the date, time, rain trace indicator, precipitation amount, and error codes.

[10] Precipitation data from the load cell data-logging system are much easier to process than those recorded by the Fischer-Porter system. All data are directly downloaded from Campbell data-loggers and imported into a spreadsheet program for postprocessing. A computer program is used to remove daily fluctuations in raw load cell precipitation measurements (±0.254 mm) that occurred as a result of wind oscillation and or changes in temperature and pressure. These corrections are not flagged in the final precipitation data set. Missing data related to the load cell system are primarily the result of equipment malfunctions, and these instances are flagged in the raw and processed data records.

[11] The combined precipitation data set (Fischer-Porter and load cell systems) was assembled in a spreadsheet program. All 5 min precipitation data are archived as comma-separated value (CSV) files with 6 months of data per file. Daily precipitation data sets were generated by calculating the daily average of the 5 min precipitation data. These data sets are available in STEWARDS; data that could not be corrected are labeled as "no data" in the processed data records.

5. Length and Quality of Precipitation Record

[12] Forty years of precipitation data are available from two of the long-term rain gauges in WE-38 (1968–2007; sites RB-37 and RE-37), while 29 years (1979–2007) are available at the third site (MD-38). Each record contains occasional periods with missing data (Figure 1), a result of suspending gauge site operation because of equipment failure or scheduled maintenance. Despite this fact, missing data periods rarely occurred at more than one site at a time. As a result, users of the data may consider a number of approaches to replace missing data at one site using good data from a nearby site. Some examples include station-averaging methods [e.g., *McCuen*, 1998; *Dingman*, 2002], normal-ratio methods [e.g., *Paulhus and Kohler*, 1952; *Dingman*, 2002], inverse-distance weighting methods [*Wei and McGuiness*, 1973; *Dingman*, 2002], and regression approaches [e.g., *Salas*, 1993]. The original raw data files can also be made available to users interested in performing their own data reduction techniques to potentially recover lost data.

6. General Precipitation Patterns

[13] Annual precipitation totals are shown in Figure 2. Mean annual precipitation for the 40 year period of record in WE-38 is 1080 mm. The 2 years with the largest total annual precipitation amounts were 1972 (1448 mm) and 1996 (1386 mm). In contrast, persistent droughts in 1980 and 2001 resulted in only 718 and 721 mm of precipitation, respectively.

[14] Mean monthly precipitation totals are fairly uniform throughout the year (Figure 3), with the largest mean monthly precipitation in June (125 mm) and the smallest in February (60 mm). The seasonal precipitation pattern depicted in Figure 3 largely reflects the synoptic climatology of east central Pennsylvania. Precipitation during fall, winter, and early spring months primarily results from large-scale anticyclones and frontal overrunning, whereas in late spring and summer, precipitation can result from these same conditions as well as from convective activity, including short-duration, high-intensity thunderstorms [e.g., *Gburek et al.*, 1977].

[15] The most notable event during the 40 year period occurred when the remnants of Tropical Storm Agnes passed over central Pennsylvania on 21–23 June 1972. The highest 24 h rainfall totals in Pennsylvania during the event were recorded in the heart of Mahantango Creek Watershed, with amounts ranging from 274 to 320 mm [*Engman et al.*, 1974]. At the time, these 24 h rainfall totals were considered to be more than double those anticipated from a storm with

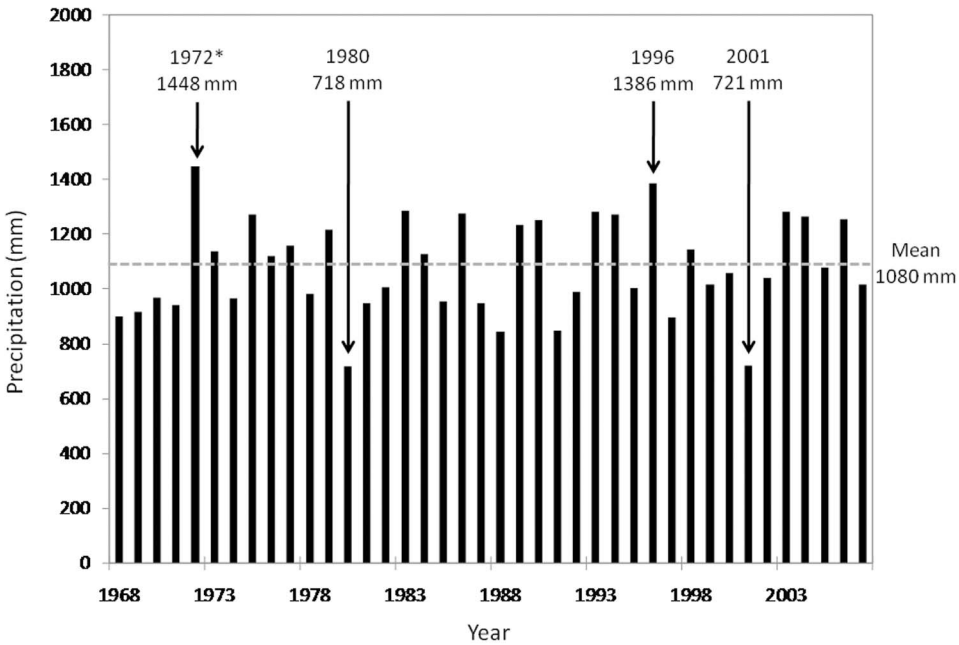

Figure 2. Annual precipitation totals (mean of gauges RB-37 and RE-37) for the period of record (1968–2007). Arrows point to notable wet and dry years during the period of record. The gray dashed line indicates the long-term mean annual precipitation (1080 mm). The asterisk indicates precipitation estimated for Tropical Storm Agnes (22 June 1972).

an annual exceedance probability of 0.01 [*Engman et al.*, 1974]. Using more recent data, 24 h rainfall totals from Tropical Storm Agnes would have an annual exceedance probability of 0.001 [*Bonnin et al.*, 2004]. Although none of the gauges in WE-38 captured the rainfall from Tropical Storm Agnes, a complete record of the 3 day rainfall event was available from a rain gauge (RE-40, discontinued operation in 1976) located approximately 3.2 km east of WE-38. (See map by *Engman et al.* [1974] for location of rain gauge RE-40.) Data from this rain gauge could potentially be used to estimate rainfall totals from Tropical Storm Agnes for the two long-term rain gauges in WE-38 (RB-37 and RE-37) that were operating in 1972.

7. Examples of Data Use

[16] Precipitation data from WE-38 have been used in a number of different hydrologic and water quality studies. Early research included basic studies on the efficiency of the rain gauge network to measure rainfall [*Parmele*, 1970] and predict base flow and stormflow runoff [*Parmele et al.*, 1972]. In addition, researchers have used precipitation data

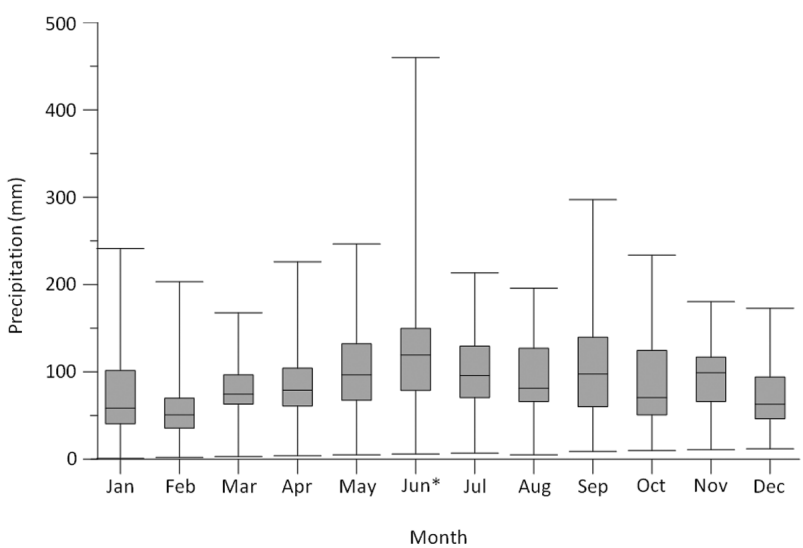

Figure 3. Mean monthly precipitation (mean of gauges RB-37 and RE-37) for the period of record (1968–2007). The asterisk indicates precipitation estimated for Tropical Storm Agnes (22 June 1972).

from WE-38 to characterize the hydrology of convective thunderstorms [*Gburek et al.*, 1977] and extreme events [e.g., *Troch et al.*, 1994], specifically those resulting from tropical storm remnants [*Engman et al.*, 1974]. More recently, WE-38 precipitation data have been used to model groundwater flow [*Gburek et al.*, 1999] and study patterns of groundwater recharge [*Risser et al.*, 2009]. The data have also been used to parameterize and validate watershed models as part of the USDA Conservation Effects Assessment Project [e.g., *Van Liew et al.*, 2007; *Veith et al.*, 2011]. Long-term precipitation data allow researchers to investigate and explain the significance of temporal hydrologic patterns [e.g., *Kang and Lin*, 2007] and may be useful in future efforts to understand the potential effects of changing climate on agricultural productivity, hydrology, and water quality in agricultural watersheds typical of northeastern United States.

8. Data Availability

[17] Daily precipitation data for the three long-term rain gauges in WE-38 are available for download on the USDA ARS Sustaining the Earth's Watersheds—Agricultural Research Data System (STEWARDS) Web site (http://www.ars.usda.gov/Research/docs.htm?docid=18622). The 5 min precipitation data, raw data files, station records, and field notes are maintained in-house. Information on accessing these data these data and relevant links are available at http://www.ars.usda.gov/Services/docs.htm?docid=21452.

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