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

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[1] A long-term streamflow discharge 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 streamflow discharge data were collected at the outflow of WE-38 from 1968 to 2007, producing a 40 year record of streamflow. Data are available on USDA ARS's Sustaining the Earth's Watersheds—Agricultural Research Data System (STEWARDS) Web site.

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1. Introduction

[2] Streamflow discharge integrates all hydrological processes occurring within a watershed, and its measurement contributes to our understanding of water and nutrient cycles at the watershed scale. The U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) Pasture Systems and Watershed Management Research Unit (PSWMRU) collects streamflow data from the 7.3 km^2 WE-38 Experimental Watershed, which is located in the northern portion of the Mahantango Creek Watershed in central Pennsylvania [*Bryant et al.*, 2011, Figure 1]. Streamflow discharge has been recorded on the WE-38 Watershed since 1968 [*Gburek*, 1977; *Gburek and Weaver*, 1982], and the data have supported research on precipitation-runoff relationships, runoff generation processes, evapotranspiration at the watershed scale, crop and land management impacts on water resources, nutrient transport and loss from agricultural lands, simulation model development and validation, seasonal and extreme event effects, and geologic influences on streamflow. This article describes the infrastructure used to measure streamflow discharge from WE-38, and summarizes the resulting streamflow discharge 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].

2. Streamflow Data Collection and Processing

[3] USDA ARS scientists designed and oversaw construction of the streamflow gauging infrastructure for the WE-38 Watershed beginning in 1966 with completion in late 1967. The stream gauging station features a concrete, 1.22 m high, 5:1 broad-crested V notch weir in tandem with a metal, 0.46 m, 90° sharp-crested V notch weir (Figure 1 and Table 1). The 90° V notch weir provides low-flow control and measures streamflow discharge rates <0.155 m^3 s^{-1} (approximately 82% of the flows in an average year). In contrast, the broad-crested weir is designed to measure streamflow discharge rates ranging from 0.155 m^3 s^{-1} to 15 m^3 s^{-1} (approximately 18% of the flows in an average year). An in-line rectangular pond (18 m wide, 80 m long) is maintained upstream of the concrete weir to promote consistent approach velocities, particularly during storm events. The downstream water surface is located well below the crest elevation of the weir, thereby supporting free overfall conditions for the full range of discharge rates. Weir crest and wing wall elevations (Table 1) were determined by detailed topographic survey that used benchmark elevations established by USGS personnel (benchmarks located within 1 km of the weir) and USDA ARS personnel (benchmarks located on the extension of the wing wall behind the gauge house).

[4] Streamflow from WE-38 is determined using rating curve equations that relate gauge height (water surface elevation minus weir crest elevation) to stream discharge. For each of the weirs, gauge height is measured in separate stilling wells contained in a gauge house that is built over

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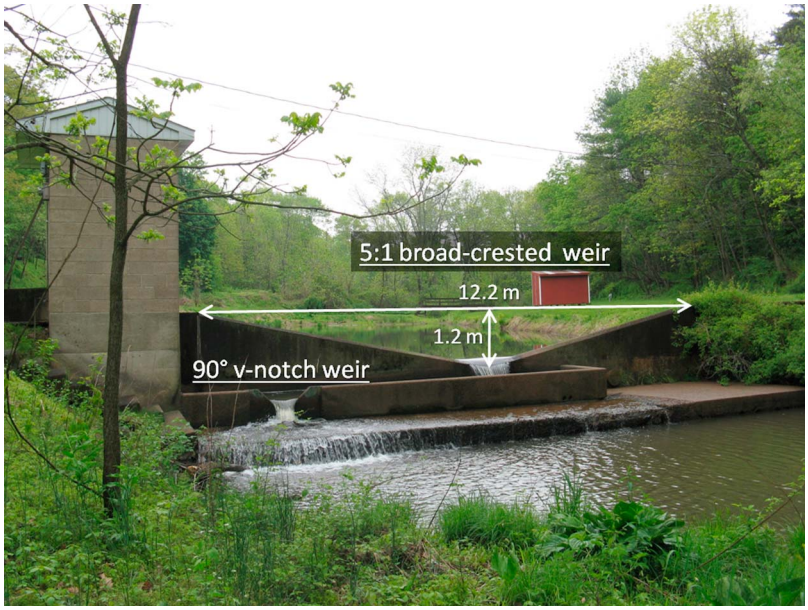

Figure 1. Photograph of the stream gauging station at the WE-38 watershed outlet.

the edge of the weir pond (Figure 1). Originally, the stream gauges were fitted with Fischer-Porter float-and-pulley water level recorders that punched paper tape at precise 5 min intervals in a binary decimal code format [*Gburek and Weaver*, 1982]. In 1997, these Fischer-Porter devices were replaced with float-and-shaft encoder systems connected to a Campbell Scientific data logger. Both systems yield gauge height measurements to the nearest 3 mm (see Table 2 for instrumentation details).

[5] The paper punch tapes from the original Fischer-Porter stage recording systems were retrieved at regular intervals (30–45 days) by ARS technicians and checked for errors. Timing errors (time gain or loss) caused by clock stoppage, battery failures, and other moving part malfunctions represented the most common type of error with the Fischer-Porter system. All timing errors were recorded on field notes and flagged in the raw data using detailed error codes [*Carr*, 1973]. These errors typically could not be corrected and resulted in a loss of stream discharge data.

[6] Once the tapes were checked for errors, they were translated into digital format and stored on magnetic tapes [*Carr*, 1973]. The data were maintained in breakpoint format, that is, consecutive, redundant numbers were eliminated. The raw data record consisted of a gauge value, time stamp, and error code. The original data were converted to a continuous record with the use of spreadsheet computer software.

[7] Since 1997, gauge height data have been recorded by Campbell Scientific data loggers. All data are directly downloaded from the data loggers on a biweekly basis and imported into a spreadsheet program for postprocessing, which includes final error checks and data corrections. For example, on occasions when the 90° V notch weir was inoperable (because of equipment malfunctions), stream discharge was estimated using the broad-crested weir, which resulted in estimation errors of up to 30%. These time periods are flagged in the final discharge records. In addition, debris and ice buildup at the weir resulted in noticeable step increases in stream discharge that were easily identified and corrected during postprocessing. Instances of debris and ice buildup at the weir are flagged in the raw data.

[8] All 5 min stream discharge data are archived as comma-separated value (CSV) files with 6 months of data per file. Daily stream discharge data sets were generated by calculating the daily average of the 5 min stream discharge data. These data sets are available in STEWARDS; data that could not be corrected are labeled as "no data" in the processed data records.

3. Rating and Maintenance of the Weirs

[9] Rating curves for the weirs were initially developed using handbook formulae [e.g., *Gwinn et al.*, 1979] and verified using field measurement techniques. The current meter technique was used to measure streamflow over a range of flow rates, and these values along with corresponding gauge height measurements were used to verify the rating curve for the broad-crested weir. The rating curve

Table 1. Geographic Location, Basic Description, and Record Length for the WE-38 Stream Gauging Station

Station	Area (km^2)	Location		Weir Crest Elevation[a]	Wing Wall Elevation[a]	Period of Record	
		Latitude	Longitude			Start Date	End Date
WE-38	7.3	40°42′16″N	76°35′16″W	215.6	216.8	1 Jan 1968	31 Dec 2007

[a]Elevation is determined using a detailed topographic survey. Units are meters above mean sea level.

Table 2. Instrumentation History for the Primary (Broad-Crested) and Low-Flow (Sharp-Crested) Weirs Used at the WE-38 Stream Gauging Station

Period of Record	Data Recording Device	Water Surface Elevation Measurement Device	Accuracy (mm)	Data Collection Interval (min)
1968–1996	Fischer-Porter digital paper punch recorder	Float-pulley mechanism connected to Fischer-Porter recorder	3	5
1997–2007	Campbell Scientific CR10 data logger	Float-pulley mechanism connected to shaft encoder	3	5

for the 90° V notch weir was verified using simple bucket-and-stopwatch techniques [*Gburek and Weaver*, 1982]. Over the course of the 40 year monitoring period, channel geometry in the 50 m section of channel upstream of the concrete, broad-crested weir has not changed and the integrity of the weir has remained intact. Therefore, the rating curves for both weirs are assumed stable for the period of record.

[10] The weirs and associated gauge height measuring equipment are regularly maintained by ARS technicians. Technicians visit the site on a biweekly basis to perform routine instrument checks, record any changes to the weir (e.g., debris buildup following storms and ice buildup in the winter) and to download data. Technicians also verify the accuracy of gauge height measurements by comparing water level measurements in the weir notches to those indicated by visual inspection of the shaft encoder float tape and data logger readouts. Long-term weir maintenance mainly involves removing sediment that accumulates primarily in the upper 30 m of the weir pond. This is done approximately once every 5 years (depending on resource availability) to maintain consistent approach conditions [*Gburek and Weaver*, 1982] and to assure the stability of the weir rating curves.

4. Length and Quality of Streamflow Record

[11] Forty years of stream discharge data are available from the WE-38 stream gauging station, although brief periods of missing data (Figure 2) occurred as a result of equipment failures and routine maintenance. In two instances, extreme flooding events produced discharge rates that exceeded the measurement capacity of the broad-crested weir, resulting in the temporary loss of stream discharge data. One of the events occurred in response to substantial rainfall from the remnants of Tropical Storm Agnes (22 June 1972; weir overtopped for ~20 h), while the other event resulted from heavy rain falling on a rapidly melting snowpack (19 January 1996; weir overtopped for ~3 h). Peak flow estimation was performed for the Agnes flood using weir flow and slope area methods. (See discharge data for W-6 in *Engman et al.* [1974].) Unfortunately, no such estimates of peak flow are available for the storm on 19 January 1996. Gauge height readings for both storms are available in the raw data files and can be used to estimate discharge rates for the period of time when the weir capacity was exceeded.

5. General Streamflow Patterns

[12] Annual streamflow totals are shown in Figure 3. Mean annual streamflow for the period 1968–2007 was 500 mm, which was approximately 46% of mean annual precipitation (1080 mm) over the same period. The two years with the highest streamflow discharge were 1972 (940 mm) and 1996 (845 mm), while the two years with the lowest streamflow discharge were 1980 (266 mm) and 2001 (207 mm).

[13] Mean monthly stream discharge totals are shown in Figure 4. A strong seasonal pattern in monthly flow is evident, with the highest flows in March (74 mm) and the lowest flows in August (12 mm). In general, high flows typically occur during the late winter and early spring months, when evapotranspiration by vegetation is minimal. Low flows dominate during the growing season, which includes the midsummer and early fall months.

6. Examples of Data Use

[14] Stream discharge data from WE-38 have been used to conduct a variety of different hydrological and water quality investigations. Early work focused on improving our understanding of runoff generation through development of water balance equations [*Rawitz et al.*, 1970] and testing of important runoff generation concepts [*Engman*, 1974]. Streamflow data from WE-38 were instrumental in characterizing nutrient export trends from agricultural watersheds typical of those found in the northeastern United States [*Pionke et al.*, 1996, 1999]. Streamflow discharge data from WE-38 have supported a number of basic hydrologic [*Loague*

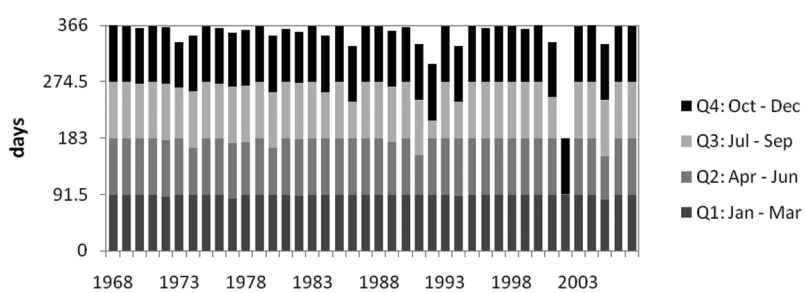

Figure 2. Number of days with valid streamflow data at the WE-38 weir.

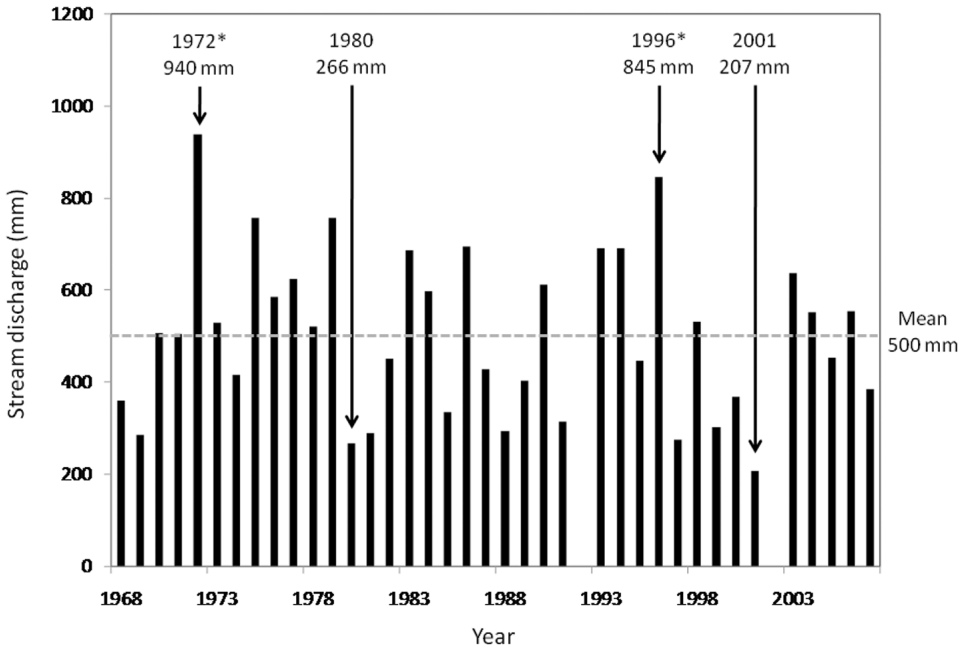

Figure 3. Annual stream discharge totals at the WE-38 stream gauging station for the period of record (1968–2007). Arrows point to notable wet and dry years during the period. The gray dashed line indicates the long-term mean annual discharge (500 mm). Annual discharges for 1992 and 2002 were not plotted because the gauge site was shut down for parts of those years in order to perform routine maintenance. The asterisks indicate discharge estimated for Tropical Storm Agnes (22 June 1972) and a rain-on-snow event (19 January 1996).

and Freeze, 1985; *Wigmosta and Lettenmaier*, 1999; *Kenward et al.*, 2000; *Yu et al.*, 2000; *Morrison and Bonta*, 2008], climatic [*Tucker and Slingerland*, 1997], and geomorphic [*Huang and Niemann*, 2006] modeling studies as well as applied research on the effectiveness of agricultural conservation practices on water quality [*Van Liew et al.*, 2007]. The data have also been used to understand the hydrology of extreme flooding events [*Engman et al.*, 1974; *Troch et al.*, 1994]. Recently, discharge data from WE-38 were utilized to gain insight into groundwater recharge processes using base flow recession and hydrograph separation techniques [*Risser et al.*, 2009]. Continued collection of streamflow

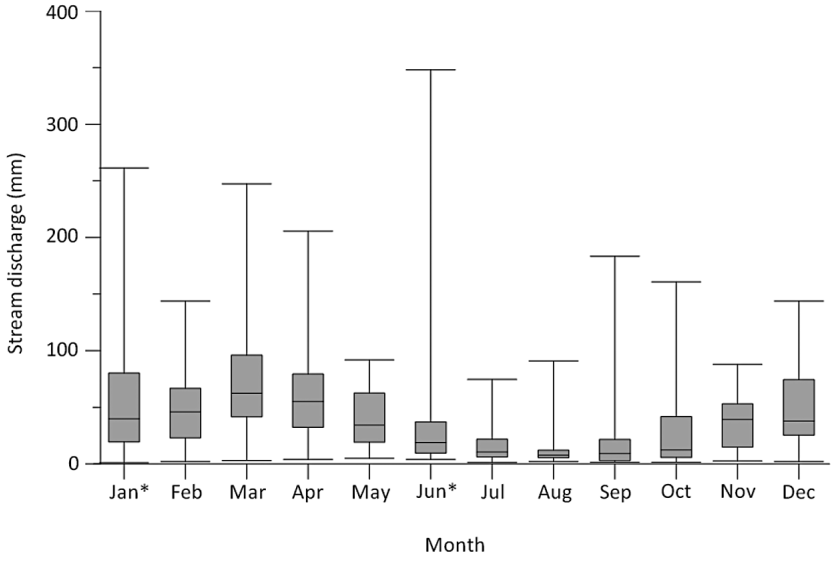

Figure 4. Mean monthly stream discharge patterns at WE-38 stream gauging station for the period of record (1968–2007). The asterisks indicate discharge estimated for Tropical Storm Agnes (22 June 1972) and a rain-on-snow event (19 January 1996).

discharge data from WE-38 will be critical to understanding how ongoing changes in climate and land management influence watershed hydrology and water quality.

7. Data Availability

[15] Daily stream discharge data are available on the USDA ARS STEWARDS Web site (http://www.ars.usda.gov/Research/docs.htm?docid=18622). The Web site includes information about WE-38 Watershed characteristics, research objectives, and metadata associated with the discharge data. The 5 min stream discharge data, raw data files, station records, and field notes are maintained in-house. Information on accessing these data and relevant links are available at http://www.ars.usda.gov/Services/docs.htm?docid=21452.

[16] **Acknowledgment.** The existence, accuracy, and consistency of the Mahantango Creek Watershed data are a testament to the dedication of numerous past and present USDA ARS employees. This study is a contribution from the USDA ARS Pasture Systems and Watershed Management Research Unit with collaboration and financial support from the USDA NRCS. All programs and services of the U.S. Department of Agriculture are offered on a nondiscriminatory basis, without regard to race, color, national origin, religion, sex, age, marital status, or disability. Mention of trade names in this publication does not imply endorsement by the USDA.

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