UNCERTAINTY IN MEASURING RUNOFF FROM SMALL WATERSHEDS USING INSTRUMENTED OUTLET PONDS

M. H. Nichols, E. Anson, T. Keefer

ABSTRACT. *This study quantified the uncertainty associated with event runoff quantity monitored at watershed outlet ponds. Inflow and outflow depth data were collected from 2004 to 2011 at seven instrumented monitoring stations at the outlet of watersheds ranging in size from 35.2 to 159.5 ha on the USDA-ARS Walnut Gulch Experimental Watershed in southeastern Arizona. The effects of instrumentation, field methods, and data processing procedures were considered. Uncertainty was assessed separately for runoff that did not exceed pond capacity and for runoff that exceeded pond capacity and was discharged through overflow spillways. The largest relative measurement uncertainty was associated with runoff volumes that were less than 50 m^3 in magnitude and with events exceeding pond capacity and discharging over the spillway. The largest source of measurement uncertainty was associated with error in establishing the position of the depth sensor relative to the pond spillway hydraulic control elevation. This analysis is of practical importance for improving field methods for measurement of pond inflow and outflow and was conducted to encourage similar analyses of flow data collected from all monitored watersheds.*

Keywords. *Data collection, Data processing, Discharge monitoring, Ephemeral runoff, Semi-arid.*

Accurate discharge measurements are fundamental for most hydrologic analyses to quantify basic processes and to develop and evaluate prediction models. Although runoff is monitored and measured, assessments of the uncertainty associated with measurements are generally not conducted (Harmel et al., 2006, 2009). Uncertainty analyses increasingly are receiving emphasis because of the role that simulation model results, which rely on measurements, play in management and policy. Efforts such as the USDA Conservation Effects Assessment Project (CEAP) (Weltz et al., 2008) and the USDA Long-Term Agricultural Research (LTAR) Network (Walbridge and Shafer, 2011) point to the need for measured data in support of process interpretations and modeling at watershed scales. Increasingly, simulation models are being used to support policy and decision making, and their scientific defensibility requires estimates of the uncertainty in measurements in addition to assessments of the uncertainty in model calibration, validation, and prediction capability (Beven, 2006; Muñoz-Carpena et al., 2006; Shirmohammadi et al., 2006; Harmel and Smith, 2007).

Although measurement uncertainty is generally acknowledged, and formally called for in the engineering community (Wahlin et al., 2005; Harmel et al., 2006), uncertainty associated with long-term data from instrumented watersheds is rarely reported. In an in-depth analysis of the uncertainty associated with measured streamflow compiled from the literature, Harmel et al. (2006) indicated that the probable error in measured streamflow ranged from 6% to 19% for a typical range of measurement techniques and channel conditions, and it was estimated to be as high as 42% for the worst-case scenario, which involved estimating streamflow with Manning's equation with a stage-discharge relationship for an unstable, mobile bed and shifting channel. These results are informative toward providing uncertainty limits within which simulation model output should be expected to range for the assessed data; however, measurement uncertainties are unique to individual data sets because they are influenced by variations in hydrologic regime as well as measurement methods and equipment (Pelletier, 1988).

Runoff data have been collected on the USDA-ARS Walnut Gulch Experimental Watershed (WGEW) in southeastern Arizona since the 1950s (Stone et al., 2008). Within the WGEW, runoff is monitored at the outlets of instrumented small watersheds ranging in size from 35.2 to 159.5 ha. Stock ponds located at the outlets of these watersheds were instrumented in the 1950s through the 1970s. In the early 2000s, analog instruments were upgraded and converted to digital electronic instruments (Moran, 2008), which offered the opportunity to review field data collection and QA/QC procedures, including uncertainty analyses. The objectives of this study were to: (1) briefly describe the WGEW small watershed runoff measurement and data reduction procedures, (2) identify and quantify the dominant sources of uncertainty related to field methods, measurement, and data processing, and (3) provide recom-

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mendations for improving small watershed runoff measurement.

METHODS

SITE DESCRIPTION

The study site is located in southeastern Arizona at the USDA-ARS Walnut Gulch Experimental Watershed (WGEW) surrounding the town of Tombstone (fig. 1). The primary land use on the WGEW is cattle grazing, although recreation and urbanization have been increasing recently. Rainfall during the summer monsoon season from July through September is characterized by high-intensity, short-duration convective storms. During the winter, low-intensity, long-duration frontal storms are common. Mean annual precipitation is approximately 312 mm, with approximately 60% occurring during the monsoon months (Goodrich et al., 2008).

Runoff data are collected at the outlets of seven small watersheds within the WGEW, ranging in size from 35.2 to 159.5 ha. Stock ponds at the watershed outlets consist of an excavated reservoir contained by an earthen dam with an outlet spillway (fig. 2). Mean annual runoff measured at the stock ponds ranges from 7.6 to 24.8 mm (Nichols, 2006). Almost all of the runoff into stock ponds on the WGEW is generated during the summer monsoon season. Figure 3 illustrates the following general characteristics of small watershed runoff within the WGEW: (1) the ponds are dry for much of the year, (2) runoff is seasonal, (3) with few exceptions runoff occurs in discrete events with an identifiable beginning and end, and (4) the annual number of runoff events is small. In addition, most runoff events have short durations: 93% of the events recorded during this study lasted than 2 h, and 72% lasted than 1 h. Therefore, losses from evaporation and seepage are negligible during inflow durations. Mean annual sediment yields from the stock pond watersheds range from 0.6 to 3.7 t ha^{-1} year^{-1} (Nichols, 2006). The stock ponds were not cleaned to remove sediment during the period of study.

Measuring runoff at the stock ponds is conceptually simple. Depth of water in the pond is measured and converted to volume based on a stage-volume relationship determined from a topographic model of the dry pond surface. The total inflow volume is computed for each discrete runoff event, which is defined by the onset and cessation of runoff. If the runoff volume exceeds the capacity of the pond, outflow discharge (termed a "spill" herein) is computed based on a stage-discharge relationship associated with flow over a rectangular sharp-crested weir or, if the pond is not instrumented, through a largely level although uneven earthen spillway modeled as a broad-crested weir. In each of these measurement processes, uncertainty arises from factors related to the field methods and instrumentation associated with data acquisition and from the processing procedures associated with data reduction. This analysis addresses runoff volumes for individual inflow events and outflow volumes at ponds instrumented with rectangular sharp-crested weirs. The analysis does not include outflow through earthen spillways because data describing the spillway cross-sectional geometry during past annual instrumentation setup and calibration efforts are not available.

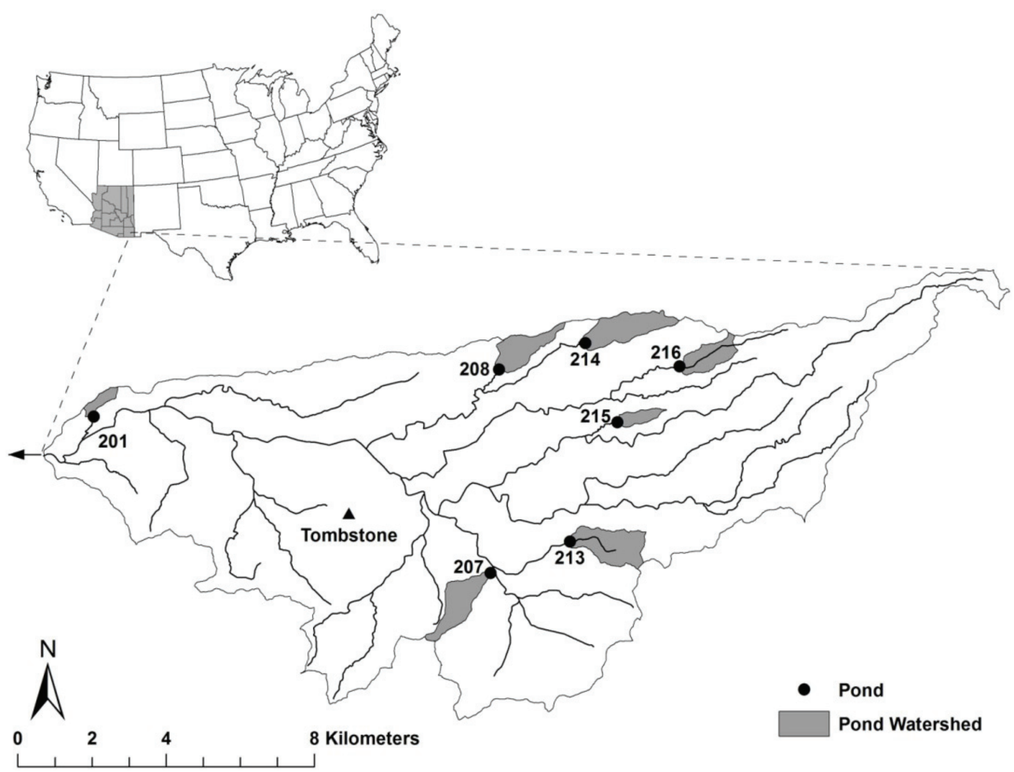

Figure 1. USDA-ARS Walnut Gulch Experimental Watershed location map showing the general drainage pattern and the instrumented stock pond watersheds.

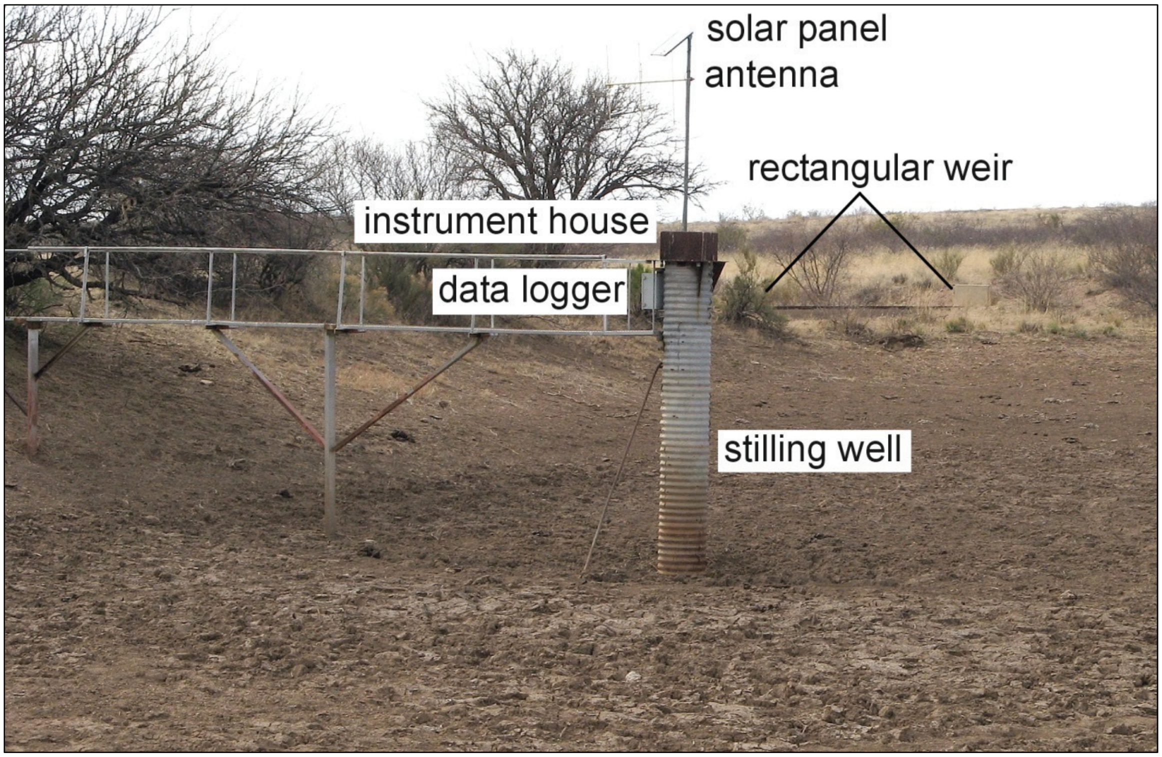

Figure 2. Photograph of pond 208 on the USDA-ARS Walnut Gulch Experimental Watershed showing a typical stilling well and rectangular sharp-crested weir.

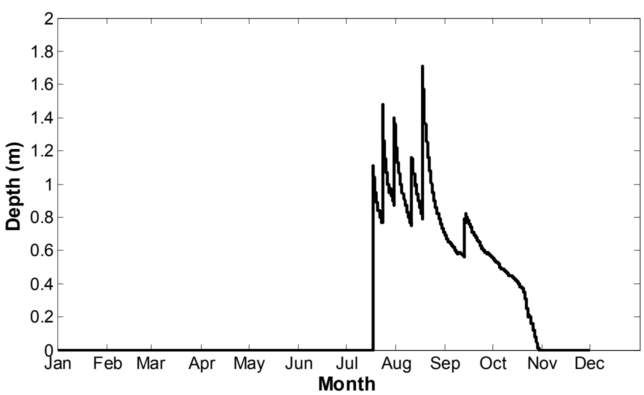

Figure 3. Typical annual trace of water depth in a stock pond on the USDA-ARS Walnut Gulch Experimental Watershed.

DATA ACQUISITION

Depth Measurement

Water depth in each pond was measured with a float attached to a potentiometer in a stilling well (fig. 2). Each stilling well is located such that water in the shallowest part of the pond can be measured. The manufacturer's stated precision of the potentiometer is 0.02% full scale or 0.001 m (0.003 ft). Depths were recorded in the voltage equivalent of the nearest 0.003 m (0.01 ft) and were output to a datalogger when an increase in depth exceeded 0.01524 m (0.05 ft). In the absence of an increase, depth data were output once per hour. If flow occurred in the pond outlet spillway, sensor output was recorded every minute until the flow receded to the height of the rectangular weir or to the low point in an earthen spillway. Recorded voltage values were converted to feet based on a sensor calibration coefficient, approximately 170 mV ft^{-1}.

For each pond, a calibration coefficient (mV ft^{-1}) was determined by locating the float relative to the weir outlet (or spillway) and the instrument platform. The vertical distance (ft) between the weir outlet (or spillway) and the platform was measured using a level and rod. The float was then raised within the stilling well to the weir level (a measuring tape was placed into the stilling well and lowered from the platform), and the potentiometer output was read as the weir level in mV. The float was then lowered such that the float sat as close as possible to the dry pond surface in the stilling well to establish the zero level. The potentiometer output in mV at the zero level was recorded. The float was then raised from zero to weir level, and both depth (ft, measured with the tape) and potentiometer output (mV) were recorded in incremental steps. The calibration coefficient was determined by dividing the potentiometer output by depth (mV ft^{-1}).

The floats are 15.24 cm (6 in.) in diameter and between 10.16 and 15.24 cm (4 and 6 in.) thick and thus exhibit variability in the way they sit in water. Each float was evaluated, and the location where the float sat in water was marked on the float to minimize error during field setup. To establish the location of the float at spillway level, each float was physically raised in the stilling well such that the marked location on the float was positioned at the spillway elevation as measured down the stilling well with a measuring tape. Slots in the stilling well allowed for visual inspection of the float. The physical location of the float may have been off by approximately 0.03048 m (0.1 ft) in elevation relative to the elevation of the spillway measured during topographic surveys.

It is important to note that the physical setup and field calibration of the float and potentiometer were accomplished independently of the topographic survey of the pond surface described in the next section. In addition, the float setup and recorded data are reported in English units (i.e., feet and inches) to maintain consistency with historic procedures. The topographic surveys described in the next section were conducted in real-world coordinates (UTM) in units of meters.

Pond Bottom Surface Shape

Topographic surveys were conducted to model the pond surface shape (fig. 4). Surveys were conducted using a Sokkia Set 3C total station (measurement accuracy ±3 mm) when the ponds were dry. At each pond, three aluminum-capped rebar benchmarks set in concrete provide horizontal and vertical control. In addition, the depth sensor platform and spillway were surveyed. In 2004, a post-processed real-time kinematic survey was conducted with a survey-grade Trimble GPS system to establish UTM coordinates for all stock pond benchmarks.

Spillway Discharge

Three of the ponds are instrumented with rectangular sharp-crested weirs in the spillways (fig. 2). The elevation of each sharp-crested weir was re-measured during the topographic surveys. Outflow from the remaining four ponds was estimated based on measured spillway cross-section geometry and the broad-crested weir formula. Because the earthen spillway channel dimensions were subject to change through scour and/or deposition, spillway geometry was re-measured during the topographic surveys if outflow had occurred since the prior survey.

Data Reduction

Modeled Pond Bottom Surface and Stage-Volume Curves

The topographic survey data were interpolated to create models of the pond surface shape. Surveys were conducted by measuring points on the ground up to the elevation of the maximum water depth achieved since the time of the prior survey. In the absence of outflow through the spillway, the topographic surveys were supplemented with values from the most recent survey completed following a year when the pond filled to capacity in order generate a surface model inclusive of the spillway elevation.

The relationship between water depth and volume was established by plotting the volume at contour intervals of 0.25 m from the bottom of the pond to spillway level to create a stage-volume curve for each pond (fig. 5). Volume change between contours was assumed to be linear, and thus error in volume is proportional to the slope of the segment.

Computed depth-volume relationships varied depending on the method of interpolation and the number of points

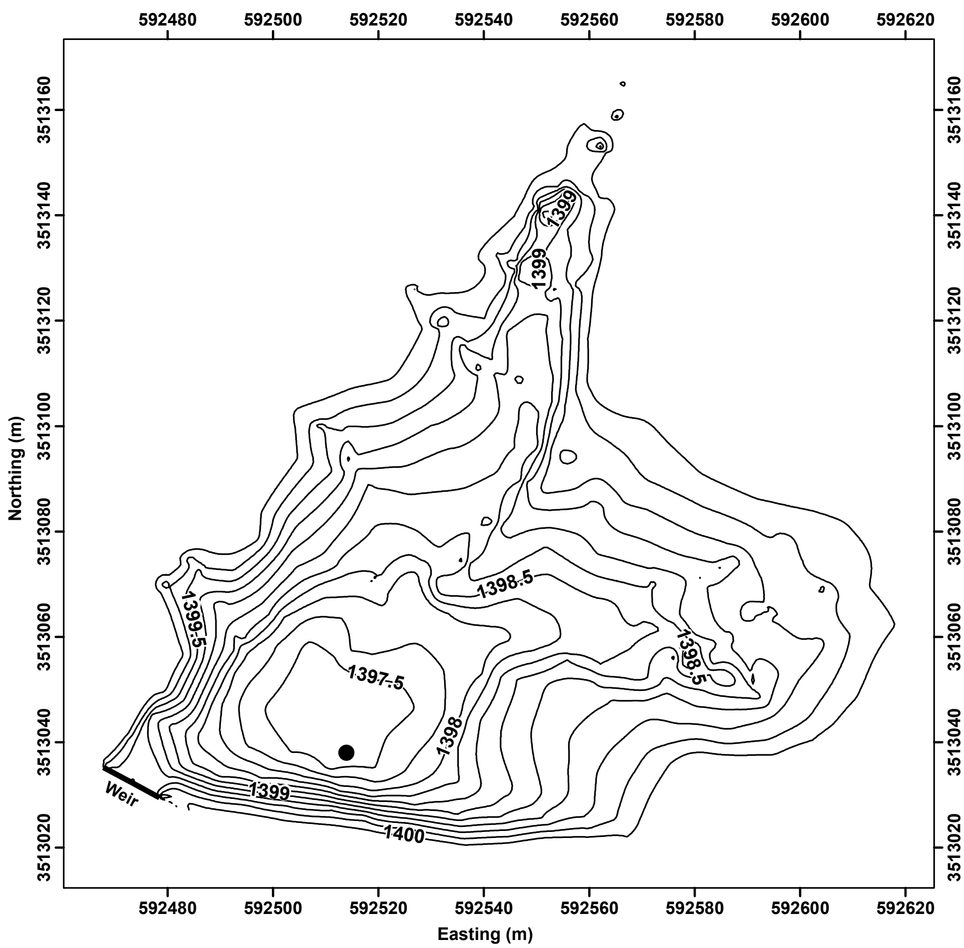

Figure 4. Example pond bottom surface model. The black circle indicates the location of the stilling well.

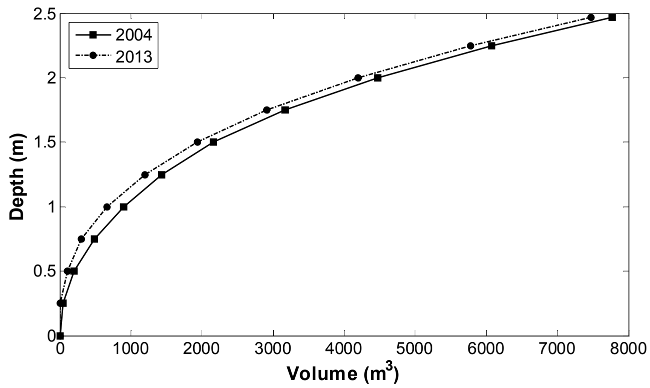

Figure 5. Example relationship between water depth and stock pond volume for two years at pond 208.

collected during a survey. These effects were examined using Surfer for Windows (Surfer, 1994) to create surface models based on three interpolation methods (linear triangulation, kriging, and inverse distance weighting). Volumes were found to vary within approximately 2% depending on interpolation method.

Inflow Volume

Runoff was quantified by interpolating logged gauge heights between successive stage-volume curves to convert water depths to volumes. For each runoff event (defined by the start and cessation of flow), the stage-volume curves from the survey conducted prior to the runoff season and after the runoff season were interpolated to calculate event volume. Inflow volumes were not reduced in response to rainfall on the pond surface. The weight given to each curve was directly proportional to the amount of the season's total runoff that occurred before the event in question. The proportioning was done to accommodate the fact that sediment is deposited through the runoff season, and the stage-volume curve changes during the runoff season. Deposited sediment responsible for a change in the stage-volume curves was assumed to be proportional to runoff amount. Error introduced through this interpolation is minor and was not greater than the difference in volume between successive stage-volume curves.

Spillway Discharge

Discharge through the spillways was calculated using the formula presented by Howe (1949) for rectangular sharp-crested weirs:

$$Q = CLh^{1.5} \tag{1}$$

where Q is discharge (cfs), L is the length of the weir (ft), h is the upstream head (ft), and C is an empirical constant. In the absence of a weir, the broad-crested weir formula, in English units, was applied based on the surveyed cross-sectional geometry of the earthen spillway:

$$Q = \frac{1}{1.1} A\sqrt{Dg} \tag{2}$$

where A is cross-sectional area, D is mean water depth, g is gravitational constant, and the constant incorporates the discharge coefficient and the coefficient of velocity.

Uncertainty Analysis

Uncertainty (U) was calculated using the first-order variance method (Coleman and Steele, 1999) as follows:

$$U_r^2 = \left(\frac{\partial r}{\partial X_1}\right)^2 U_{x_1}^2 + \left(\frac{\partial r}{\partial X_2}\right)^2 U_{x2_1}^2 + \ldots + \left(\frac{\partial r}{\partial X_J}\right)^2 U_{x_J}^2 \tag{3}$$

where r is an experimental result, and X_i is a measured variable.

In this study, uncertainty was calculated for two conditions: (1) for measurement of runoff into the pond up to spillway level and (2) for measurement of runoff above spillway level. For each part, the contributions of uncertainty sources indicated in the following sections were combined to determine the root sum square uncertainty as presented by Coleman and Steele (1999).

Inflow Measurement below Spillway Level

The sources of uncertainty in measured runoff event volume (E) are uncertainty in:

Vol = the surveyed volume of the pond.

S = the function that uses the stage-volume curve to determine the volume in the pond at real-world height h.

d = the measured height of water above the float zero level.

z = the measured height of the zero level in real-world (UTM) coordinates.

Incremental event runoff volume can be expressed as:

$$E = Vol(h_1, h_2) \tag{4}$$

or

$$E = S(h_2) - S(h_1) \tag{5}$$

where h_1 and h_2 are the water depths at the start and end of the inflow time period, respectively, and $h_i = d_i + z$.

Uncertainty is then expressed as:

$$U_E^2 = \left(\frac{\partial E}{\partial Vol} U_{Vol}\right)^2 + \left(\frac{\partial E}{\partial d_1} U_{d_1}\right)^2 + \left(\frac{\partial E}{\partial d_2} U_{d_2}\right)^2 + \left(\frac{\partial E}{\partial z} U_z\right)^2 \tag{6}$$

The uncertainty in the measured values of Vol, d_1, d_2, and z were assumed independent and:

$$\frac{\partial E}{\partial Vol} = 1 \tag{7}$$

$$\frac{\partial E}{\partial d_1} = -\frac{\partial S}{\partial h_1} \tag{8}$$

$$\frac{\partial E}{\partial d_2} = \frac{\partial S}{\partial h_2} \tag{9}$$

$$\frac{\partial E}{\partial z} = \frac{\partial S}{\partial h_2} - \frac{\partial S}{\partial h_1} \tag{10}$$

Inflow measurement uncertainties were assigned as follows:

U_{Vol} = (0.02)Vol (2% error associated with topographic surveys).

$U_{d1} = U_{d2} = 0.003$ ft (instrument precision).

$U_z = 0.1$ ft (error in mapping float height to UTM coordinates).

Thus, the root mean squared uncertainty in event runoff for inflow into the pond up to spillway level was computed as:

$$U_E = \sqrt{\left(0.02 Vol(h_1,h_2)\right)^2 + \left(0.003\frac{\partial S}{\partial h_1}\right)^2 + \left(0.003\frac{\partial S}{\partial h_2}\right)^2 + \left(0.1\left(\frac{\partial S}{\partial h_2} - \frac{\partial S}{\partial h_1}\right)\right)^2} \quad (11)$$

Outflow Measurement

Measurement uncertainty in pond outflow was quantified by assessing the uncertainties associated with the components of the standard equation for rectangular sharp-crested weirs (eq. 1). Following the procedures presented by Wahlin et al. (2005), the relative uncertainty is expressed as:

$$\left(\frac{U_Q}{Q}\right)^2 = \left(\frac{U_C}{C}\right)^2 + \left(\frac{U_L}{L}\right)^2 + (1.5)^2\left(\frac{U_{h_1}}{h_1}\right)^2 \quad (12)$$

Uncertainty associated with measurement of the weir length is negligible and not carried forward in this analysis. We assumed a value of 3 for the discharge coefficient, a value of 5% for uncertainty in the discharge coefficient (Howe, 1949), and a value of 0.1 ft as the uncertainty in measurement of upstream head.

The upstream head changes through the course of a runoff event. To simplify the uncertainty calculations, the upstream head used to compute uncertainty for each spill, defined as h_0, was computed as:

$$h_0 = \frac{1}{2}h_{max} \quad (13)$$

Examination of the characteristics of the spilled outflow revealed that more than 84% of the total event discharge occurred when $h_0 < h < h_{max}$, and computed uncertainty was likely overestimated. Thus, from equation 12, the root mean squared uncertainty in spillway discharge computed for sites instrumented with sharp-crested weirs was computed as:

$$\frac{U_Q}{Q} = \sqrt{\left(\frac{0.05}{3}\right)^2 + (1.5)^2\left(\frac{U_h}{h_0}\right)^2} \quad (14)$$

Results and Discussion

Uncertainty in Inflow Measurement below Spillway Level

The relative uncertainty (%) for inflow volume computed for 360 individual runoff events recorded from 2004 to 2011 among all ponds ranged from 1% to 144% (table 1). The computed event runoff volume for more than 1/4 of the events (101 events) was less than 50 m^3. In general, as runoff event size increased, relative measurement uncertainty decreased (fig. 6). Inspection of figure 6 reveals that relative uncertainties (%) in inflow volume of less than 10% are not realized until the event runoff volume reaches approximately 500 m^3. In contrast to relative uncertainty, the absolute uncertainty in event runoff volume increased as runoff event size increased (fig. 7).

Clearly, small flows are subject to the largest relative uncertainty. Evaluation of the sources of measurement uncertainty assessed in this analysis (measurement of water depth, measurement of pond capacity, and application of the stage-volume relationship) indicates that the primary source of uncertainty in computed event runoff volume is uncertainty in the positioning of the depth measurement float relative to vertical control benchmarks used to develop the stage-volume curves. Instrument precision and variability in the modeled surface shape have a minor contribution to total uncertainty. Although water depth can be measured with high precision, conversion of depth to volume with inadequate vertical positioning control introduces high uncertainty.

Further, relative uncertainty varies over the depth measurement range as a function of the amount of water in the pond at the time of inflow. As a result, small flow volumes that can be detected when the pond is dry or contains little water are not detectable when the pond is full of water. For example, when pond 208 contains 5800 m^3 of water (0.20 m below spillway level), a change of water depth of 0.01524 m (0.05 ft., depth sensor output resolution) translates to a change in volume of approximately 100 m^3; thus, runoff events smaller than 100 m^3 may not be detected.

The relative importance of small events can be considered in the context of runoff event magnitude, frequency, and temporal distribution. In very dry years, the entire annual runoff volume may be made up of a few very small events. In very wet years, annual runoff may be dominated by a few very large events or may be the accumulation of runoff over a range of runoff magnitudes. When the volume of water in a pond is low, small events are more likely to be detected as a change in water depth. A sequence of relatively small events that occurs when the pond is empty will be detected and quantified; conversely, a sequence of small events that occurs when the pond is full will not be detected.

Uncertainty in Spillway Discharge

During the study period, eight runoff events exceeded pond capacity at ponds instrumented with weirs, resulting in outflow through a spillway. Although events that resulted in spillway outflow made up less than 5% of the recorded runoff events during the period of study, the volume of outflow associated with a single event can make up a substantial portion of annual watershed runoff. For example, in 2008, spillway outflow during a single runoff event into pond 208 contributed 57% (±12%) of the computed annual runoff.

The best measurements of outflow are associated with ponds instrumented with weirs. Among the runoff events recorded at ponds with weirs, the highest relative uncertainties (±49% to 63%) are associated with smaller events; as event size increases, relative uncertainty decreases although absolute volume uncertainty increases (table 2).

Discharge computed with the weir formula requires

Table 1. Summary of measured runoff and relative uncertainty at seven instrumented stock ponds.

	Year							
Measurement	2004	2005	2006	2007	2008	2009	2010	2011
Pond 201								
Non-spill runoff volume (m^3)	400	9262	16849	6864	6839	10	1777	5721
Number of runoff events	4	8	18	6	5	1	8	7
Mean event volume (m^3)	100	1158	936	1144	1368	10	222	817
(min-max)	(4-351)	(73-4639)	(10-3613)	(16-4851)	(13-5349)		(13-767)	(27-2303)
Rel. uncertainty min-max	±11%-69%	±4%-18%	±0.1%-35%	±5%-14%	±5%-16%	±20	±4%-30%	±5%-15%
Pond 207								
Non-spill runoff volume (m^3)	0	1397	10168	612	25819	0	4594	17843
Number of runoff events	-	4	12	4	10	-	6	8
Mean event volume (m^3)	-	349	847	153	2582	-	766	2230
(min-max)		(8-736)	(28-2987)	(17-258)	(22-8934)		(16-3402)	(152-7521)
Rel. uncertainty min-max	-	±7%-13%	±3%-57%	±6%-27%	±2%-69%		±4%-144%	±3%-17%
Pond 208								
Non-spill runoff volume (m^3)	155	14467	3161	14956	12551	8336	8915	1487
Number of runoff events	3	7	9	8	5	5	9	5
Mean event volume (m^3)	52	2067	351	1870	2510	1667	991	297
(min-max)	(13-114)	(11-5866)	(10-818)	(4-7462)	(105-7104)	(97-4865)	(8-6698)	(14-822)
Rel. uncertainty min-max	±18%-38%	±4%-45%	±3%-40%	±4%-83%	±3%-11%	±4%-7%	±4%-71%	±5%-10%
Pond 213								
Non-spill runoff volume (m^3)	0	1293	4900	670	5491	0	2550	169
Number of runoff events	-	7	10	10	12	-	3	5
Mean event volume (m^3)	-	185	490	67	458	-	850	34
(min-max)		(3-669)	(13-3525)	(4-163)	(7-3658)		(88-1844)	(15-62)
Rel. uncertainty min-max	-	±4%-92%	±3%-74%	±0.1%-88%	±3%-74%	-	±3%-11%	±8%-98%
Pond 214								
Non-spill runoff volume (m^3)	306	17973	19213	23233	18760	2175	11268	3719
Number of runoff events	2	8	11	6	9	7	7	7
Mean event volume (m^3)	153	2247	1747	3872	2084	311	1610	531
(min-max)	(31-275)	(29-13721)	(21-6302)	(8-12991)	(20-15518)	(17-1351)	(6-5885)	(29-3312)
Rel. uncertainty min-max	±8%-13%	±3%-58%	±3%-77%	±4%-72%	±3%-72%	±5%-36%	±2%-39%	±4%-72%
Pond 215								
Non-spill runoff volume (m^3)	0	2179	2152	9477	3612	855	5170	1616
Number of runoff events		2	12	9	10	3	5	4
Mean event volume (m^3)		1090	179	1053	361	285	1034	404
(min-max)		(52-2127)	(13-620)	(10-5327)	(6-1352)	(103-578)	(21-2856)	(92-1093)
Rel. uncertainty min-max		±5%-15%	±4%-60%	±3%-61%	±4%-21%	±8%-19%	±5%-34%	±7%-29%
Pond 216								
Non-spill runoff volume (m^3)	101	6917	12000	12626	6725	5820	5629	6471
Number of runoff events	5	12	11	7	11	7	2	4
Mean event volume (m^3)	20	576	1091	1804	611	831	2815	1618
(min-max)	(8-29)	(1-5743)	(14-4340)	(5-6102)	(2-5598)	(3-3418)	(504-5125)	(13-4405)
Rel. uncertainty min-max	±0.1%-70%	±0.1%-60%	±4%-70%	±4%-72%	±4%-62%	±4%-39%	±4%-4%	±2%-79%

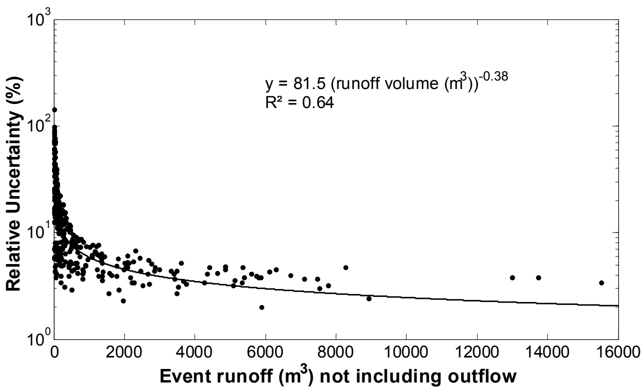

Figure 6. Relative uncertainty in measured inflow volume that did not result in outflow through a spillway.

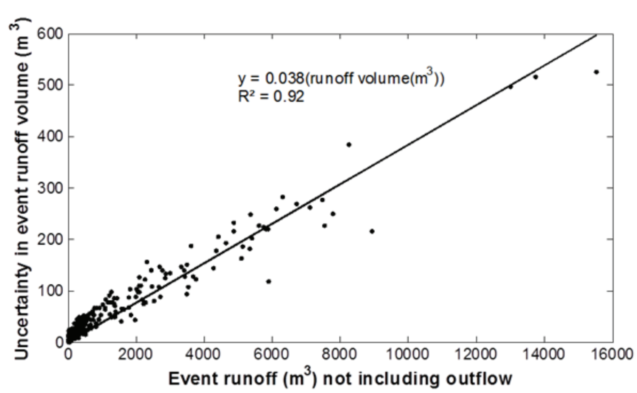

Figure 7. Absolute uncertainty in measured inflow volume for events that did not result in outflow through a spillway.

Table 2. Characteristics of eight events that resulted in outflow through spillways instrumented with rectangular sharp-crested weirs.

	Event Volume		Outflow Volume		Volume Below Spillway	
Date	Volume (m^3)	Relative Uncertainty (%)	Volume (m^3)	Relative Uncertainty (%)	Volume (m^3)	Relative Uncertainty (%)
31 July 2007	11134	16	3672	41	7462	4
4 August 2007	13148	18	7751	58	5397	4
22 July 2008	23682	15	16578	20	7104	4
22 August 2005	10775	17	5032	31	5743	4
10 August 2006	6271	20	1931	56	4340	4
20 July 2007	7976	16	1874	56	6102	4
28 August 2008	7784	21	2186	63	5598	4
29 July 2011	7768	24	3363	49	4405	5

coupled measurements of depth of water over the weir (head) and time. Error in each of these component measurements is associated with error in establishing the location of the float relative to the elevation of the weir. The effect of error in float location on relative uncertainty in computed discharge rate is shown in figure 8.

Error in float location relative to the spillway level introduces uncertainty in measuring the depth of water over the weir and in determining discharge duration. During large spills, when the height of flow over the weir is greatest, uncertainty due to error in float location can result in large uncertainty in runoff volume computed from the discharge rate. Although flow is not sustained for long periods at the peak rate, error in float location contributes substantially to absolute uncertainty in volume calculations.

The second component of uncertainty associated with error in float location is in determining discharge duration. A typical pond runoff hydrograph is characterized by a rapid rise with flow tapering off through a longer recession. The end of a flow through a spillway can be difficult to determine from the recorded data if errors in the spatial coordinates and the physical location of the float cause very long recession periods to be indicated by the recorded water depth. For example, if the float is physically higher than the weir, even by a small amount, the recorded data will indicate outflow (water above the weir height) when in fact there is no outflow. This can cause a very long recession period to be indicated in the recorded data, and integration over time to compute total discharge volume can lead to

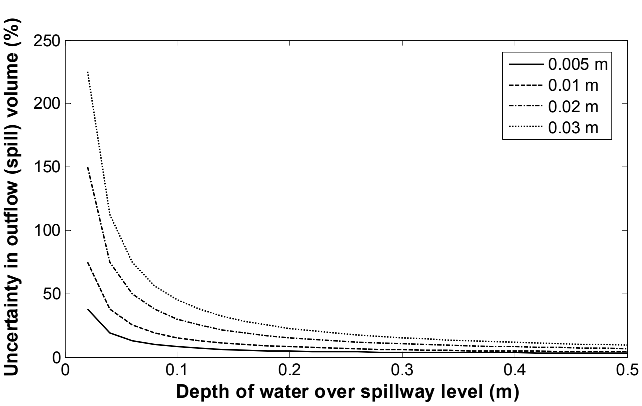

Figure 8. Effect of error in establishing the position of the depth measurement float relative to the level of the spillway hydraulic control elevation on uncertainty in calculated outflow. Errors of 0.005, 0.01, 0.02, and 0.03 m result in the four plotted relationships. For example, a difference of 0.01 m in establishing the position of the float will result in uncertainties in measured spill volumes ranging from 4% to 75% depending on flow depth over the spillway level.

overestimation. Thus, manual inspection of the data is needed when events with longer-than-expected hydrograph tails are recorded.

The results presented thus far in this section are based on evaluation of runoff measured through spillways instrumented with rectangular sharp-crested weirs. Uninstrumented spillways are subject to higher uncertainty. Measurement uncertainty associated with discharge through earthen spillways will generally be affected by the same measurement factors as that based on a weir, but there is additional uncertainty associated with estimating discharge through an irregular channel section. The stage-discharge relation in an open channel is governed by the characteristics of the channel, including size, shape, energy head slope, and roughness. The measurement cross-section is subject to deposition and scour, and spillway channel bed characteristics are subject to change over time. These changes are generally incorporated by resurveying the spillways during topographic surveys. The uncertainty associated with uninstrumented spillways is thus assumed greater that that associated with weirs, although it was not specifically quantified as part of this analysis. As pointed out by Kline (1985a), no measurements will be perfectly accurate; thus, uncertainty analysis plays a role in examining procedures and improving measurement methods. Generally, outflow is associated with large runoff events, and these events are important because they are expected to do most of the geomorphic work and transfer the largest amounts of sediment. Given the importance of high-quality discharge measurements, the best practical recommendation for improving measurement is to install a flume or weir in the spillway.

Conclusions

This study was conducted to identify and quantify the dominant sources of uncertainty related to field methods, measurement, and data processing associated with the small watershed monitoring program on the USDA-ARS Walnut Gulch Experimental Watershed. Although data have been collected on the WGEW since the mid-1950s, uncertainty estimates have not been made. Procedures are in place to ensure that rainfall and runoff instrumentation is calibrated and operating as expected and that data logging and transfers are successful. In addition, quality assurance checks ensure that recorded values fall within expected ranges and are spatially consistent with our understanding of runoff-generating rainfall in the watershed.

This study quantified the relationship between uncertainty and estimated runoff event magnitude. The highest relative uncertainties in computed runoff volume were associated with small runoff events that were generally less than 50 m^3 and with large runoff events that resulted in spillway outflow. The dominant factor contributing to uncertainty in inflow estimated with a stage-volume relationship is the position of the float sensor. Development of field procedures to improve the location of the float relative to vertical control benchmarks will reduce measurement uncertainty. In addition, maintenance to remove accumulated sediment and thus re-establish accurate pond capacity relationships will improve the relationship between pond shape and volume. Experienced field crews are needed to conduct the topographic surveys with attention to detail such that topographic relief is modeled adequately. Measurement uncertainty associated with discharge through the outflow spillways can be reduced by improving the location of the float zero level and by installing hydraulic structures in uninstrumented spillways.

Because rainfall and runoff data are fundamental to the development and validation of hydrologic simulation models, uncertainty analyses of data generated from instrumented watersheds are needed to provide critical information for assessing the quality of model predictions (Harmel and Smith, 2007). Although the presented uncertainty analysis can be further refined, conducting an uncertainty analysis is more important than the selection of a particular methodology (Kline, 1985b). We hope that this uncertainty analysis will encourage similar analyses of data collected at WGEW and other monitored watersheds.

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