doi:10.2489/jswc.69.5.414

Effect of check dams on runoff, sediment yield, and retention on small semiarid watersheds

V.O. Polyakov, M.H. Nichols, M.P. McClaran, and M.A. Nearing

Abstract: Erosion dynamics in semiarid environments is defined by high magnitude, low frequency rainfalls that produce runoff with high sediment concentration. Check dams are widely used in this environment as a sedimentation mitigation technique, however their impact on overall watershed sediment balance is not well known. In 2008 a total of 37 loose rock semipermeable check dams were installed on two small (4 and 3.1 ha [9.8 and 7.6 ac]) watersheds located on the alluvial fan of the Santa Rita Mountains in southern Arizona. Each watershed was equipped with a rain gauge, supercritical flow flume, and sediment sampler. The runoff and sediment yield characteristics following the check dam installation were compared with 35 years of historical records. Impacts of the check dams on runoff from major rainstorms were not detectable; however the number of runoff events generated by small (less than one year recurrence interval) rainstorms decreased by 60%. During four years check dams retained 75 t (82.6 tn) of sediment (50% of sediment yield) and were filled to more than 80% of their capacity. Depositional areas upstream of the dams have potential to support watershed restoration.

Key words: check dam—erosion—runoff—sediment yield—semiarid—watershed

Arid ecosystems of the southwestern United States have been experiencing rapidly increasing anthropogenic pressure over the last century (Brown et al. 2005; Renard et al. 1993). Exacerbated by vegetation change (Parsons et al. 1996) such as proliferation of trees and shrubs (Browning et al. 2008) and spread of invasive species (McClaran et al. 2010), this significantly affects channel and watershed hydrology in the region. Erosion dynamics in semiarid environments are defined by high magnitude, low frequency rainfalls that produce runoff with sediment concentrations generally greater than those in humid environments (Cohen and Laronne 2005). On small (<4 ha [9.8 ac]) watersheds of the Santa Rita Experimental Range where the current experiment was conducted, storms generating 5 t ha^{-1} (2 tn ac^{-1}) of sediment have a return period of six years, while yields as high as 37 t ha^{-1} y^{-1} (15 tn ac^{-1} yr^{-1}) have been observed (Polyakov et al. 2010).

Installation of check dams is one of the approaches for erosion mitigation on small watersheds. These are small barriers constructed of rocks, or other materials placed across the flow and anchored into the bottom and sides of the channel. Check dams produce upstream and downstream effects. Upstream they modify water and sediment transport by impounding storm flow, reducing its velocity and peak rate, decreasing channel slope, and allowing more time for infiltration and sediment settling (Mishra et al. 2007). In addition, depositional areas upstream alter soil moisture distribution (Nichols et al. 2012) and may become the starting point for channel revegetation. Downstream of the dam decreased sediment load may result in accelerated channel erosion due to greater transport capacity (Castillo et al. 2007). Check dam effect on scour dynamics varies greatly depending on initial slope, soil texture, spacing, drop height, flow depth, etc. (Lenzi and Comiti 2003). On watersheds with coarse soil texture check dams may be particularly effective due to greater sediment retention and formation of a permeable bed.

Check dams are used frequently in arid or mountainous environments with ephemeral hydrology (Castillo et al. 2007; Lenzi and Comiti 2003; Sougnez et al. 2011). They are often employed across large areas. For example, sediment trapped by check dams built since the 1960s created a substantial amount of land area (68,000 ha [168,031 ac]) in the Yellow River basin (Xu 2005).

Check dams have been shown to be an effective sedimentation mitigation technique. A 4.5-fold reduction of sediment yield from a 826 km^2 (513 mi^2) watershed in southeast Spain was reported after installation of 400 check dams in an effort to reduce reservoir sedimentation (Romero-Diaz et al. 2007). A 3-fold to 5-fold decrease in mean diameter of sediment particles on channel floor was observed after check dam installation on a mountain river in northern Italy where 10 year floods reach a discharge rate of 40 m^3 s^{-1} (1,413 ft^3 sec^{-1}) (Lenzi and Comiti 2003). The effect of check dams has been simulated for a subhumid environment, predicting 50% reduction in sediment yield during 5 years after installation on a 1,100 ha (2,718 ac) watershed (Mishra et al. 2007). Increase in vegetation diversity, canopy cover or creation of new habitats were also recognized as indirect benefits of the check dams (Bombino et al. 2006).

Observation of channel cross section and bed material in several studies (Castillo et al. 2007; Porto and Gessler 1999), indicate that check dams may increase erosion downstream; however the amount of material held by the downstream dams accounted for that sediment. This might limit the effectiveness of the treatment in the environments where dams fill to their full capacity quickly (Castillo et al. 2007; Nyssen et al. 2004). Strong vertical erosion downstream of the check dams was observed in coastal areas of central Italy in the lower tracts of the channels (Coltorti 1997). High failure rates (39% of the structures within two years) have been reported (Nyssen et al. 2004) in areas with smectite-rich or other soils prone to swelling. The failure occurred primarily through piping and bypass and showed correlation with drainage area and the slope.

Viktor Polyakov is an assistant research scientist and **Mary Nichols** and **Mark Nearing** are research scientists at Southwest Watershed Research Center with the USDA Agricultural Research Service in Tucson, Arizona. **Mitch McClaran** is a professor of rangeland plant ecology and management in the School of Natural Resources and the Environment at the University of Arizona in Tucson, Arizona.

Copyright © 2014 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 69(5):414-421 www.swcs.org

While the effect of check dams on channel stability has been studied extensively (Conesa-Garcia et al. 2007; Porto and Gessler 1999), their impact on overall watershed sediment balance is not well known (Castillo et al. 2007). In most cases sediment yield history of the study site is lacking and dam efficiency is estimated from deposited sediment volume, using assumed retention coefficient (Molina et al. 2008; Romero-Diaz et al. 2007). The goals of this study were to (1) measure the change in watershed outlet sediment yield and runoff as a response to check dam construction on two small, monitored watersheds, and (2) quantify internal watershed sediment retention and channel morphologic change.

Materials and Methods

Description of the Experimental Site. The experimental site was located in Santa Rita Experimental Range (SRER) 45 km (28 mi) south of Tucson in southern Arizona (31°48′55.2″ N; 110°51′4.4″ W; 1,160 m [3,806 mi] above sea level) on the alluvial fans of the Santa Rita Mountains, which are in the eastern part of the Sonoran Desert (McClaran et al. 2003). The area has semiarid climate dominated by North American Monsoon (Sheppard et al. 2002). Precipitation is highly spatially and temporally variable with a pronounced peak in July to September and a lesser increase in December to March. The annual precipitation at the experimental site averages at 410 mm y^{-1} (16 in yr^{-1}) and average daily temperatures are 24.4°C (75.9°F) in July and 10.6°C (51.1°F) in January (Lawrence 1996). The watersheds used in the study were grazed by cattle until 2006 (1975 to 2006 average 26.4 ha $animal^{-1}$ y^{-1} [65 ac $animal^{-1}$ yr^{-1}]).

Two instrumented watersheds (5 and 6) with respective areas of 4 and 3.1 ha (9.8 and 7.6 ac) located 300 m (984 ft) apart were selected for the study (table 1 and figure 1). Watershed 5 features a well-developed third order channel network with 4% main channel slope gradient. The channel network on watershed 6 is less extensive (second order), but the channel gradient is slightly steeper (6%). Channels on both watersheds are up to 1.5 m (4.9 in) deep with steep banks and occasional headcuts. Prior to dam installation, the channel on watershed 5 contained a large amount of coarse alluvium with particles 1 to 3 mm (0.03 to 0.11 in). Watersheds 5 and 6 have loamy sand soils. They are well drained and have low organic content, with a saturated hydraulic conductivity of between 50 and 150 mm h^{-1} (2 and 5.9 in hr^{-1}) (USDA 2003).

The vegetation at SRER is represented by shrubs (mesquite [*Prosopis velutina* Woot.], hackberry [*Celtis pallida* Torr.], catclaw acacia [*Acacia greggii* Gray]), cacti ([cholla *Opuntia spinisor* Engelm], prickly pear [*Opuntia engelmanni* Salm-Dyck], and fishhook barrel [*Ferocactus wisilizenii* Britt. & Rose]), and grasses (black grama [*Bouteloua eriopoda* Torr.], Lehmann lovegrass [*Eragrostis lehmanniana* Nees], Arizona cottontop [*Digitaria californica* Benth.], and Santa Rita threeawn [*Aristida glabrata* Vasey]) (Martin and Morton 1993). In 1974, prior to the commencement of runoff and sediment data collection, watershed 6 was treated to remove mesquite. Despite some initial rebound, mesquite canopy cover subsequently declined giving way to a small shrub burroweed (*Ambrosia dumosa*). Shrub cover on untreated watershed was twice that of treated by 1986 (Martin and Morton 1993).

Instrumentation and Sampling. Watersheds 5 and 6 were instrumented by the USDA Agricultural Research Service in 1975. Precipitation is measured using a high resolution weighing type rain gauges located on each of the watersheds. The watersheds are equipped with Smith-type supercritical flow flumes (Smith et al. 1981) instrumented with stage recorders and sediment samplers. The flumes are rated for flows of up to 1.4 m^3 s^{-1} (49.4 ft^3 sec^{-1}) and are designed to prevent sediment deposition on the flume floor. The stage recorders consist of a stilling well, float, and recorder. Sediment samples are collected during runoff events using a traversing slot sampler that obtains up to 20 two-liter depth integrated samples per event at predetermined time intervals ranging from 3 to 15 minutes (Nichols et al. 2008). Further details on design, calibration, and operation of the sampler can be found in Renard et al. (1986). After collection the samples were weighed, flocculated, decanted, oven dried, and weighed again to determine total sediment concentration.

Check Dam Design and Construction. The check dams were designed based on relationships developed by Heede (1978) that consider geomorphic characteristics of the channel network, such as slope and the stage of gully development. Prior to check dam construction, topographic surveys of the channel, its cross sections, and channel banks profiles were conducted using Real Time Kinematic global positioning system. Dams were built to a height of approximately two-thirds of the initial channel depth and spaced such that the resultant deposition slope would extend from the check dam to the base of the adjacent upstream dam. Deposition slopes (Sd) were calculated using the following relationship developed by Heede (1978):

$$Sd = 0.0072 + 0.0028 \times So, \qquad (1)$$

where So is the average initial channel slope. Since the sediment deposition slope is a function of the type of deposited material, which presumably was the same for the entire channel, Sd was assumed to be constant within each watershed. Tributaries were treated as continuation of the main channel, and the location of the first dam within each tributary was calculated based on the location of the nearest dam in the main channel.

Check dams were constructed in November of 2008 from loose 10 to 30 cm (4 to 12 in) rocks fit together individually by hand and stabilized with wire mesh (figure 2a). The dams were keyed into the banks and channel floor to the depth of approximately 30% of the aboveground height. The dams are semipermeable to allow runoff to go through the dam body. The dams were 0.15 to 0.6 m (0.5 to 2 in) high and up to 0.5 m (1.6 in) thick with the middle section slightly lower than the sides to create a low overfall point and direct the overflow away from the banks. A total of 27 dams (of which 12 on the main channel) were constructed on watershed 5, and 10 (7 on main channel) on watershed 6 (figure 1). Topographic surveys were conducted annually (table 4) to measure check dam geometry and quantify channel profile and morphologic changes resulting from deposition and scour. Check dams and channels were photographed at the time of surveys.

Data and Analysis. Precipitation, runoff, and sediment data were collected on watersheds starting in 1975 and continued through 2012. Precipitation was recorded at a resolution of 0.25 mm (0.01 in) at 1 minute intervals. Event runoff rate was recorded at 15 second intervals and the resolution varied from 0.1 L s^{-1} (0.03 gal sec^{-1}) at low rate to 7 L s^{-1} at 330 L s^{-1} (1.8 gal sec^{-1} at 87.2 gal sec^{-1}) rate. Event sediment yield was calculated by integrating the product of sampled sediment

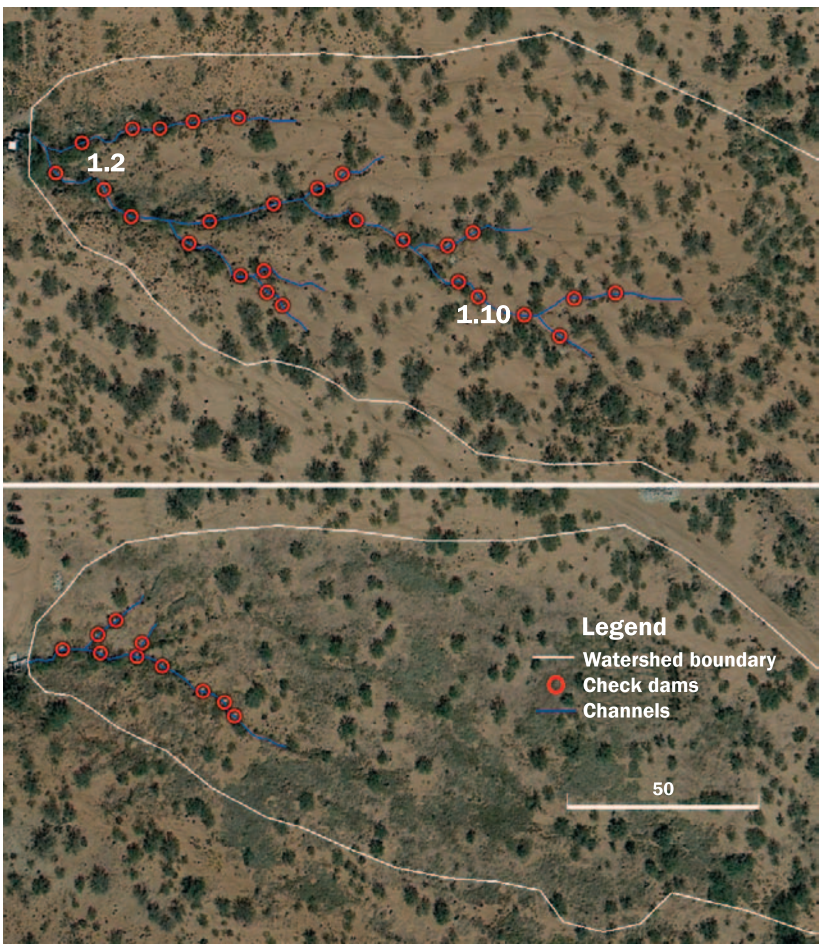
Copyright © 2014 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 69(5):414-421 www.swcs.org

Table 1
Watershed properties and soil description.

Identif-ication	Area (ha)	Elevation (m)	Average slope (%)	Main channel Order	Main channel Length (m)	Soil texture*	Clay* (%)	Erodibility (K-factor)*	Soil classification*
WS 5	4.0	1,164	3.9	3	195	Combate loamy sand	5 to 20	0.022	Coarse-loamy, mixed thermic Ustic Torrifluvents
WS 6	3.1	1,159	3.5	2	98	Comoro loamy sand	5 to 20	0.032	Coarse-loamy, mixed thermic Typic Torrifluvents

*USDA 2003.

Figure 1
Channelized portion of (a) watershed 5 and (b) watershed 6 and the location of check dams (photo taken in 2010). Labeled are check dams 1.2 that experienced scouring, and 1.10 shown in figure 2.



concentration, flow rate, and corresponding time interval. Runoff events with fewer than 3 sediment samples were considered to be inadequately sampled (Nearing et al. 2007).

The volume of the sediment retained behind the dams (check dam storage) was calculated as (Romero-Diaz et al. 2007)

$$V = 1 \div 3 \times l \times A, \quad (2)$$

where l is the length, and A is the cross sectional areas of the sediment wedge at the dam.

Three groups of variables were compiled and used in the statistical analysis: precipitation, runoff, and sediment yield. Linear regression models (PROC REG) and one-way analysis of covariance were used (SAS 2008) to describe relationship between the variables and to determine whether these relationships changed as a result of check dam construction in 2008. Obtained regression models were used to estimate sediment yield at the watershed outlet for the runoff events that either lacked sediment data or were inadequately sampled (Nearing et al. 2007). Characteristics of precipitation events were determined from the long-term historic records and their size distribution compared to that of events which occurred after 2008 (Kolmogorov-Smirnov nonparametric test). Pre and postcheck dam peak discharge data compiled from 1975 through 2012 were used to compute flood-frequency estimates. The Log-Pearson Type III frequency distribution was fit to the annual peak discharge data (Interagency Advisory Committee on Water Data 1982). In all statistical tests p = 0.05 was used, unless otherwise indicated.

Results and Discussion

Rainfall Characteristics. The average annual precipitation (P_t) over the 35 year period on watersheds 5 and 6 was 398 and 399 mm (15.6 and 15.7 in), respectively, and these values were not significantly different from each other. Precipitation in the area is seasonal with 57% of the total rainfall occurring during the monsoon season (July through September) and 20% during winter months. Rainfall events during monsoon are usually of short duration and high intensity with a single peak. Close proximity of the two watersheds to each other (300 m [984 ft]) resulted in very similar rainfall characteristics. Mean event energy (E), precipitation intensity (P_i), maximum rainfall intensity in 30 minutes (I30), and precipitation peak (P_p) on the two watersheds were not significantly different from each other. Top and bottom 10 percentile of the events accounted for 46% and 0.5% of the total precipitation, respectively. The median rainfall event was 2.2 mm (0.09 in). Average precipitation duration (P_d) during the peak of monsoon season in July was 77 minutes increasing to 170 minutes during winter storms. Comparison of rainfall event size and frequency distribu-

Copyright © 2014 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 69(5):414-421 www.swcs.org

Figure 2
Stream channel and sediment accumulation at check dam 1.10 (also see figure 1) on watershed 5 on (a) November 23, 2009, and (b) April 17, 2012.

(a)

(b)

tion before and after check dam installation (Kolmogorov-Smirnov nonparametric test) showed no significant difference between these two populations.

Runoff. Prior to December of 2008, 14% of rainfall events produced runoff on watershed 5 and 10% on watershed 6 (table 2). After the installation, this percentage decreased to 11% and 4% respectively. The I30 was overall the best predictor of event runoff volume (Q_t) on watersheds 5 and 6 as established previously using the same dataset (Polyakov et al. 2010). We used the following equation to determine whether watershed response to precipitation has changed due to installation of check dams:

$$Q_t = k + a \times I30, \qquad (3)$$

where Q_t is total event runoff, and k and a are coefficients.

For watershed 5 the analysis of covariance (table 2) showed that the slope and intercept of the linear model (equation 3) have not changed significantly due to check dams, indicating that total runoff as a function of I30 remained unaffected. The same was observed for the slope coefficient for watershed 6, however the intercept of the model increased significantly (p = 0.01). The latter means that the I30 required to initiate runoff on watershed 6 increased from 14 mm h^{-1} to 20 mm h^{-1} (0.55 in h^{-1} to 0.79 in hr^{-1}) due to installation of check dams. The former number is in better agreement with threshold values for runoff initiation reported for similar sized watersheds in the region (Osborn and Lane 1969).

Large runoff events have greater relative influence on the model (equation 3) due to their greater leverage. These events are also less likely to be influenced by check dams due to their limited runoff detention capacity. While the analysis of covariance (table 2) indicated no statistically significant change in large runoff events caused by the dams, it might underestimate the effect of these structures on small events. The increase in the intercept coefficient for postconstruction period on watershed 6 supports this hypothesis.

The range of expected event peak discharge rates was quantified for watershed 5 by calculating the flood frequency distribution (Interagency Advisory Committee on Water Data 1982) based on 34 years of measurement prior to check dam construction (table 3). Although the postcheck dam evaluation period is not of sufficient duration to statistically compare flood frequency distributions between the time periods, the long-term data provide a context for evaluating the characteristics of runoff during the study period. Although rainfall characteristics during the same period (2009 to 2012) were consistent with expectation based on analysis of the long-term precipitation data, as indicated in the previous section, the proportion of very small runoff events (recurrence interval <1 year) measured at the watershed outlet during 2009 to 2012 period was less than one-third of the proportion expected based on the prior (1975 to 2008) long-term flood frequency analysis. During the postconstruction period a greater percentage of small rainfalls failed to produce runoff that reached the watershed outlet. Check dams

Copyright © 2014 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 69(5):414-421 www.swcs.org

Table 2
Rainfall and runoff characteristics on the watersheds 5 and 6 before and after check dam installation in December of 2008. Regression coefficients for runoff and runoff peak from the watersheds ($Q_t = k + a \times I30$; $Q_p = k + a \times I30$).

Variables	Watershed 5: July of 1975 to November of 2008	Watershed 5: December of 2008 to April of 2012	Watershed 6: July of 1975 to November of 2008	Watershed 6: December of 2008 to April of 2012
Number of rainfall events	2,730	237	2,700	275
Number runoff of events	382	26	270	11
Average annual Q_t (mm y^{-1})	21.8	28.6	7.7	2.0
Average event Q_t (mm)	1.94a	3.44a	0.98a	0.61a
Q_t/P_t	0.082a	0.198b	0.035a	0.024a
Average Q_i (mm h^{-1})	1.54a	2.96b	0.69a	0.56a
Average Q_p (mm h^{-1})	5.62a	13.02b	2.65a	1.94a
Total runoff Q_t (mm)				
Intercept	–2.43a	–2.83a	–1.52a	–1.32b
slope	0.22a	0.26a	0.11a	0.05a
r^2	0.58	0.77	0.43	0.39

Notes: Numbers with the same letter within the same row and watershed are not significantly different from each other. $p = 0.05$

Table 3
Frequency analysis of runoff events on watershed 5 before (1975 to 2008) and after (2009 to 2012) check dam construction.

Recurrence Interval years	Probability of occurrence (%)	Peak discharge $m^3 s^{-1}$	Runoff events 1975 to 2008 *n*	%	Runoff events 2009 to 2012 *n*	%
100	1	1.203	1	0.2	0	0.0
50	2	0.957	0	0.0	0	0.0
25	4	0.739	1	0.2	1	2.6
10	10	0.493	3	0.7	2	5.1
5	20	0.331	7	1.6	0	0.0
2	50	0.153	27	6.2	10	25.6
1.25	80	0.068	61	13.9	8	20.5
1.05	95	0.030	103	23.5	10	25.6
1.01	99	0.015	85	19.4	4	10.3
	>99	<0.015	151	34.4	4	10.3
Total			439		39	

are more likely to reduce hydrologic connectivity between the watershed uplands, channel network, and outlet during small runoff events than during large runoff events.

Sediment Yield in Runoff. During 33 years of observation prior to check dam installation average annual sediment yield on watersheds 5 and 6 was 7.06 and 0.66 t ha^{-1} y^{-1} (2.86 and 0.27 tn ac^{-1} yr^{-1}) respectively. These results are within the range of values (0.06 to 6.4 t ha^{-1} y^{-1} [0.02 to 2.59 tn ac^{-1} yr^{-1}]) reported previously for various small watersheds in the region (Nichols 2006). The largest 10% of the storms accounted for 56% and 66% of total measured sediment yield on watershed 5 and 6, respectively. Most of the sediment yield (87%) occurred during monsoon season from July through September.

Direct sediment yield measurement was successful in approximately 30% of all recorded runoff events. Unsuccessful measurements are due to insufficient flow or under representative number of samples (less than three per continuous hydrograph). During the postinstallation period, 37 runoff events were recorded on both watersheds, 12 of which were successfully sampled. Several large events were missed due to equipment malfunction, including the largest storm in three years. Sediment yield for the unsampled events was estimated using linear regression developed using data from the sampled events (figure 3), (Nearing et al. 2007; Polyakov et al. 2010). In order to avoid bias toward larger storms that have a greater sampling success rate, a regression with zero intercept term was used (Nearing et al. 2007). Peak runoff rate was the best predictor variable for sediment yield on watershed 5 (Polyakov et al. 2010):

$$S_y = k \times Q_p, \tag{4}$$

where S_y is event sediment yield (tonnes per hectare), Q_p is peak runoff rate (millimeters per hour), and k is a regression coefficient.

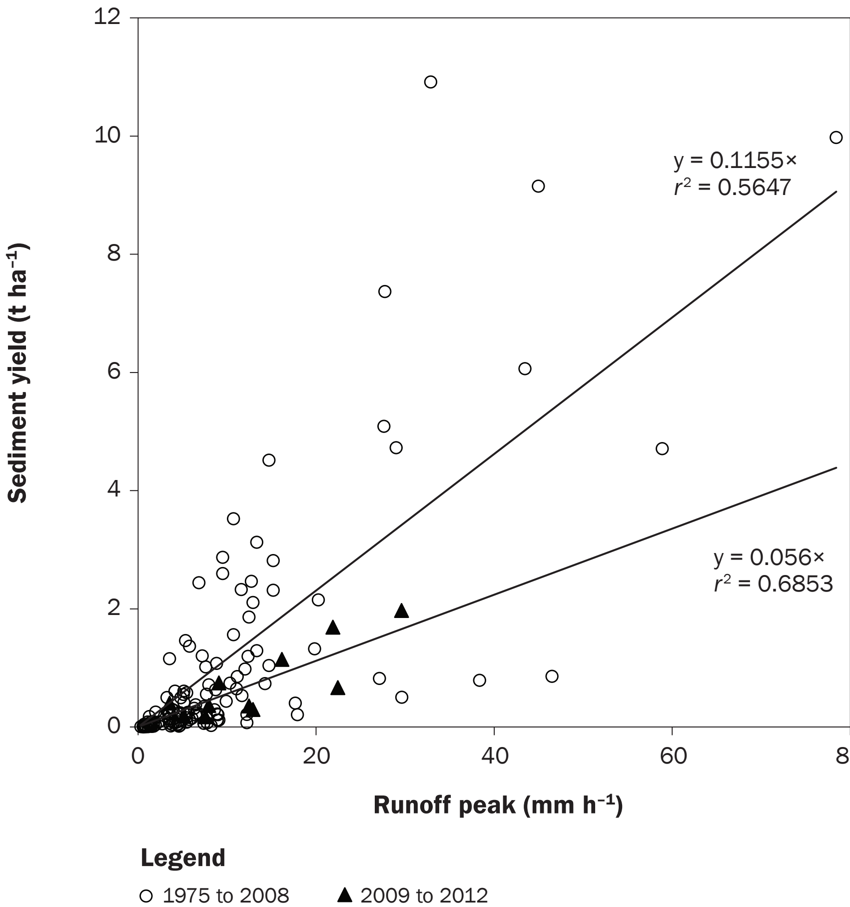
The regression slope k (equation 4 and figure 3) for watershed 5 with check dams installed was 0.056, which was a large decrease in comparison with the previous 1975 to 2008 period (0.116). However the regression slopes for the two periods were significantly different from each other only at $\alpha = 0.2$. This change indicates a twofold decline in sediment yield at the outlet due to the presence of check dams in comparison with the untreated watershed. Lack of sediment data (one sampled event) during post installation period precluded fitting a similar regression (equation 4) for watershed 6. Instead, directly measured sediment yield was used in further analysis.

Total watershed outlet sediment yield in runoff during the post installation period was 79.4 t (19.8 t ha^{-1} [8.01 tn ac^{-1}]) and 0.24 t (0.076 t ha^{-1} [0.03 tn ac^{-1}]) on watershed 5 and 6, respectively (table 4). These rates were higher than the long- term average, which was attributed to increased storm activity particularly during the 2011 monsoon season, which accounted for two-thirds of the total yield.

Copyright © 2014 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 69(5):414-421 www.swcs.org

Figure 3

Sediment yield in runoff on watershed 5 in the Santa Rita Experimental Range as affected by installation of check dams in December of 2008.



Check Dam Sediment Storage and Total Balance. During the three year study period the check dams on watersheds 5 and 6 retained 74.6 tn (18.6 t ha^{-1}) and 1.1 tn (0.4 t ha^{-1}) of sediment, respectively, as determined from topographic surveys (table 4). The amount of sediment retained by the check dams was added to the amount of sediment measured at the outlet flumes to compute the total sediment yield for the period of study. Sediment retention was directly proportional to runoff for the corresponding survey cycle and varied between 45% and 100% of the total yield decreasing slightly over time as check dams filled. Check dam sediment retention ratio for the entire period was 48.4% and 82.4% on watersheds 5 and 6, respectively (table 4).

As discussed previously watershed outlet runoff characteristics were not significantly affected by check dams based on the statistical analyses. We used equation 4 with k = 0.116, which is regression coefficient for the runoff to sediment yield relationship for 33 years of observation prior to dam construction and applied it for the period of August of 2008 to April of 2012. The modeled sediment yield estimate for this scenario where watershed was intact (163.9 tn [180.7 t]) was comparable to the sum of the actual runoff yield and check dam storage for the same period (154 tn [169.7 t]). Similarly, on watershed 6 the predicted yield for intact

Table 4

Measured and estimated sediment yield and sediment balance after check dam installation on watersheds 5 and 6.

	Number of runoff events (n)		Sediment yield in runoff (t)				
				Estimated			
Period	Total	Successfully sampled	Sampled	Precheck dams	Postcheck dams	Check dam storage (t)	Check dam retention (%)
Watershed 5							
1975 to 2008	382	123	518.0	951.2			
November 25, 2008 to November 23, 2009	4	1	1.62	6.44	3.12	6.71	68.3
November 23, 2009 to June 6, 2011	7	5	13.91	54.39	26.39	27.57	51.1
June 6, 2011 to April 17, 2012	15	5	16.54	103.12	49.94	40.34	44.7
Postinstallation total	26	11	32.07	163.94	79.40	74.62	48.4
Watershed 6							
1975 to 2008	270	57	44.6	67.05			
November 23, 2009 to June 3, 2011	4	0	0	0.40	N/A	0.83	100.0
June 3, 2011 to April 17, 2012	7	1	0.24	1.26	N/A	0.27	53.2
Postinstallation total	11	1	0.24	1.66	N/A	1.10	82.4

Copyright © 2014 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 69(5):414-421 www.swcs.org

watershed was 1.66 tn (1.83 t), while the sum of measured runoff and check dam storage was 1.34 tn (1.47 t).

Channel and Check Dam Observations. In many cases, sediment accumulated in the channels even after the check dams were backfilled to the dam crest. In such cases the depositional slope S_d (equation 1) continued to increase beyond that expected based on the initial design. For example, by 2012, S_d of the main channel on watershed 5 was three times greater (S_d = 0.023) than predicted during design stage (S_d = 0.007) and approximately 36% smaller than the initial channel slope (S_d = 0.036). As pointed out by Heede (1978), depositional slope adjustment is likely to be a function of site specific variables. However, magnitudes of gradient adjustment behind impoundments similar to those in this study have been observed on arid ephemeral channels elsewhere (Conesa-Garcia et al. 2007; Leopold 1992) where slopes were reduced by 5% to 50% depending on the initial gradient.

Initially slope reduction was associated with sediment buildup upstream and in several cases simultaneous channel erosion immediately downstream of the structures. Within 2 to 3 years, 10 out of 27 check dams on watershed 5 were partially buried by deposition from the adjacent dam located downstream. Relatively high values of S_d could be attributed to the armoring of the surface with coarser material over time. In addition, an S_d estimate might be biased because the initial channel slope on which this estimate was based was already altered by the flume acting as stable base of erosion.

These observations raise the question of the role of antecedent or legacy sediment storage in future sediment yields. Channel networks with sediment retaining structures contains large amount of loose sediment readily available for transport. With the depositional slope gradient eventually approaching that of the initial slope, the sediments behind check dams could potentially be entrained during a large runoff event depleting the system and initiating new cycle of deposition. Vegetative restoration could be a way to prevent this cycle from occurring.

In between the surveys individual check dams were filled at different relative rates and sequence; however there was no apparent relationship that tied these rates to dam locations in the stream network. How well the rocks were fitted together and check dam size might have played a role in the deposition process.

During the course of the three year experiment only one check dams on watershed 5 failed (of the 37 installed) and partially collapsed due to channel bypass and bank undercutting. A relatively low failure rates for this type of loose rock structures (Nyssen et al. 2004) was attributed to the design that employed wire mash wrap, keying into the bottom and sides of the channel, and to energy dissipation aprons downstream. Channel scouring was observed immediately downstream of several of the dams. The largest downstream scour occurred at dam 1.2 on the main channel of watershed 5 (figure 1) and totaled 1.4 tn (1.5 tn) by the June 3, 2011, survey. Over the course of the study period scour forms were subsequently refilled as sediment accumulated in response to adjacent check dams.

Repeat photography (figure 2) showed visual indication of vegetation recovery occurring around the perimeter of some of the depositional areas. This process was particularly prominent on the upper reaches of watershed 5. Channels there are relatively shallow with gently sloping overbanks that allowed formation of wide nearly flat alluvial beds without a clearly defined thalweg. Slower and less concentrated flow in these areas is expected to result in greater volume of local recharge, which is conducive to increased vegetation growth.

Summary and Conclusions

Overall check dams had no statistically significant effect on runoff volume of major events; however they reduced the number of runoff events generated by rainstorms with less than one-year recurrence interval. The amount of water that check dams can backup is small in comparison with overall runoff volume; however it is sufficient to decelerate the flow enough to induce deposition.

Sediment retention rate of the check dams was over 50% during the first three years after construction. Retention rate changed little through the duration of the study, but is expected to decrease as the impoundments fill to their total capacity. Decreased sediment load downstream of the dams might have contributed to localized scouring; however the overall effect of this process was minimal due to compensatory deposition and eventual refill of all scour forms.

As a result of depositional slopes higher than computed based on the design methods (65% of the original channel gradient) a number of check dams were partially buried. To prevent this from happening their spacing could be increased two to three times compared to the one used, such that backfilling starting at a downstream crest would only reach to the base of the next upstream dam. Optimal check dam placement is critical for ensuring adequate depositional areas while at the same time reducing cost of watershed treatment.

The low failure rate of the check dams in this study highlights the importance of implementing such design elements such as keying the structures into channel banks, stabilizing loose rocks with wire mesh, and constructing downstream energy dissipating aprons. All these features minimize the risk of collapse due to bypass or undermining.

Depositional areas behind the dams could serve as starting point for watershed restoration due to increased infiltration and accumulation of organic material. Well-established vegetation ensures that large amount of sediment deposited in the channels will not become entrained and flushed downstream during large runoff events.

Acknowledgements

The authors wish to express their appreciation to the staff of Southwest Watershed Research Center, Santa Rita Experimental Range, the University of Arizona, and the students of Tierra Seca chapter of Society for Range Management, whose dedicated efforts made this research possible.

References

Bombino, G., V. Tamburino, and S.M. Zimbone. 2006. Assessment of the effects of check-dams on riparian vegetation in the mediterranean environment: A methodological approach and example application. Ecological Engineering 27(2):134-144.

Brown, D.G., K.M. Johnson, T.R. Loveland, and D.M. Theobald. 2005 Rural land-use trends in the conterminous United States, 1950-2000. Ecological Applications 15(6):1851-1863.

Browning, D.M., S.R. Archer, G.P. Asner, M.P. McClaran, and C.A. Wessman. 2008. Woody plants in grasslands: Post-encroachment stand dynamics. Ecological Applications 18(4): 928-944.

Castillo, V.M., W.M. Mosch, C.C. Garcia, G.G. Barbera, J.A.N. Cano, and F. Lopez-Bermudez. 2007. Effectiveness and geomorphological impacts of check dams for soil erosion control in a semiarid Mediterranean catchment: El Carcavo (Murcia, Spain). Catena 70(3):416-427.

Copyright © 2014 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 69(5):414-421 www.swcs.org

Cohen, H., and L.B. Laronne. 2005. High rates of sediment transport by flashfloods in the Southern Judean Desert, Israel. Hydrological Processes 19(8):1687-1702.

Coltorti, M. 1997. Human impact in the Holocene fluvial and coastal evolution of the Marche region, Central Italy. Catena 30(4):311-335.

Conesa-Garcia, C., F. Lopez-Bermudez, and R. Garcia-Lorenzo. 2007. Bed stability variations after check dam construction in torrential channels (South-East Spain). Earth Surface Processes and Landforms 32(14):2165-2184.

Heede, B.H. 1978. Designing gully control systems for eroding watersheds. Environmental Management 2(6):509-522.

Interagency Advisory Committee on Water Data. 1982. Guidelines for determining flood-flow frequency: Bulletin 17B of the Hydrology Subcommittee. Reston, VA: Office of Water Data Coordination, US Geological Survey.

Lawrence, P.A. 1996. The role of data sources and simulation model complexity in using a prototype decision support system. *In* School of Renewable Natural Resources, 332. Tucson, AZ: University of Arizona.

Lenzi, M.A., and F. Comiti. 2003. Local scouring and morphological adjustments in steep channels with check-dam sequences. Geomorphology 55(1-4):97-109.

Leopold, L.B. 1992. Base level rise: Gradient of deposition. Israeli Journal of Earth Science 41:57-64.

Martin, S.C., and H.L. Morton. 1993. Mesquite control increases grass density and reduces soil loss in southern Arizona. Journal of Range Management 46(2):170-175.

McClaran, M.P., D.M Browning, and C. Huang. 2010. Temporal Dynamics and Spatial Variability in Desert Grassland Vegetation. *In* Repeat Photography: Methods and Applications in the Natural Sciences, eds. R.H. Webb, D.E. Boyer, and R.M. Turner, 145-166. Washington, DC: Island Press.

McClaran, M.P., P.F. Folliott, and C.B. Edminster. 2003. Santa Rita Experimental Range: 100 Years (1903 to 2003) of accomplishments and contributions. Tucson, AZ: USDA.

Mishra, A., J. Froebrich, and P.W. Gassman. 2007. Evaluation of the SWAT model for assessing sediment control structures in a small watershed in India. Transactions of the American Society of Agricultural and Biological Engineers 50(2):469-477.

Molina, A., G. Govers, J. Poesen, H. Van Hemelryck, B. De Bievre, and V. Vanacker. 2008. Environmental factors controlling spatial variation in sediment yield in a central Andean mountain area. Geomorphology 98(3-4):176-186.

Nearing, M.A., M.H. Nichols, J.J. Stone, K.G. Renard, and J.R. Simanton. 2007. Sediment yields from unit-source semiarid watersheds at Walnut Gulch. Water Resources Research 43(6)W06426, doi:10.1029/2006WR005692.

Nichols, M.H. 2006. Measured sediment yield rates from semiarid rangeland watersheds. Rangeland Ecology & Management 59(1):55-62.

Nichols, M.H., K. McReynolds, and C. Reed. 2012. Short-term soil moisture response to low-tech erosion control structures in a semiarid rangeland. Catena 98:104-109.

Nichols, M.H., J.J. Stone, and M.A. Nearing. 2008. Sediment database, Walnut Gulch Experimental Watershed, Arizona, United States. Water Resources Research 44(5):W05S06, doi:10.1029/2006WR005682.

Nyssen, J.M., M. Veyret-Picot, J. Poesen, J. Moeyersons, M. Haile, J. Deckers, and G. Govers. 2004. The effectiveness of loose rock check dams for gully control in Tigray, northern Ethiopia. Soil Use and Management 20(1):55-64.

Osborn, H.B., and L. Lane. 1969. Precipitation-Runoff Relations for Very Small Semiarid Rangeland Watersheds. Water Resources Research 5(2):419-425.

Parsons, A.J., A.D Abrahams, and J. Wainwright. 1996. Responses of interrill runoff and erosion rates to vegetation change in southern Arizona. Geomorphology 14(4):311-317.

Polyakov, V.O., M.A. Nearing, M.H. Nichols, R.L. Scott, J.J. Stone, and M.P. McClaran. 2010. Long-term runoff and sediment yields from small semiarid watersheds in southern Arizona. Water Resources Research 46:W09512, doi:10.1029/2009WR009001.

Porto, P., and J. Gessler. 1999. Ultimate bed slope in calabrian streams upstream of check dams: Field study. Journal of Hydraulic Engineering-American Society of Chemical Engineers 125(12):1231-1242.

Renard, K.G., L.J. Lane, J.R. Simanton, W.E. Emmerich, J.J. Stone, M.A. Weltz, D.C. Goodrich, and D.S. Yakowitz. 1993. Agricultural impacts in an arid environment. Hydrological Science and Technology (9):145-190.

Renard, K.G., J.R. Simanton, and C.E. Fancher. 1986. Small watershed automatic water quality sampler. *In* 4th Federal Interagency Sedimentation Conference, Subcommitee 1, 51-58, Las Vegas, Nevada.

Romero-Diaz, A., F. Alonso-Sarria, and M. Martinez-Lloris. 2007. Erosion rates obtained from check-dam sedimentation (SE Spain). A multi-method comparison. Catena 71(1):172-178.

SAS. 2008. SAS/STAT 9.2 User's Guide. Cary, NC: SAS Institute Inc.

Sheppard, P.R., A.C. Comrie, G.D. Packin, K. Angersbach, and M.K. Hughes. 2002. The climate of the US Southwest. Climate Research 21(3):219-238.

Smith, R.E., D.L. Chery, K.G. Renard, and W.R. Gwinn. 1981. Supercritical flow flumes for measuring sediment-laden flow. USDA Agricultural Research Service Technical Bullitin 1655.

Sougnez, N., B. van Wesemael, and V. Vanacker. 2011. Low erosion rates measured for steep, sparsely vegetated catchments in southeast Spain. Catena 84(1-2):1-11.

USDA. 2003. Soil Survey of Cochise County, Arizona, Douglas-Tombstone Part. Washington, DC: USDA Agricultural Research Service.

Xu, H.X. 2005. Temporal variation of river flow renewability in the middle Yellow River and the influencing factors. Hydrological Processes 19(9)1871-1882.

Copyright © 2014 Soil and Water Conservation Society. All rights reserved.
Journal of Soil and Water Conservation 69(5):414-421 www.swcs.org