SENSITIVITY OF AN ARIZONA WATERSHED TO RESERVOIR DENSITY

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Over the past 20 years, Arizona has been embroiled in two massive water rights adjudications on the Gila River and the Little Colorado River watersheds. The Arizona Attorney General's Office, which represents client agencies as claimants in these cases (Game and Fish, Parks, State Land, etc.), undertook a project to evaluate the impact of stockwatering ponds (stockponds) on the hydrology of the Walnut Gulch Experimental Watershed (WGEW), which surrounds the town of Tombstone in southeastern Arizona (Figure 1). That research resulted in expert witness testimony at hearings held in 1994 to determine the *de minimis* issue on the Silver Creek and San Pedro subwatersheds (Young and Dozer 1988, Milne and Young 1989, Young 1994a, 1994b). This paper is based on the research originally presented to the courts in those cases (Superior Court 1994).

Hydrologic Model Description

The model used in this study (TSPLOSS) is an adaptation of the TLOSS6 numerical model developed at the Agricultural Research Service (ARS)–Southwest Watershed Research Center. The model is based on, and calibrated to, empirical data collected over many decades from the WGEW (Lane 1972, 1983).

The model represents the watershed with three types of elements: upland areas, lateral areas, and channel segments. In this manner the watershed is divided into several small drainage areas that are linked through channel segments. An SCS curve number (CN) is given to each designated drainage area to quantify the effects of storage factors, interception losses, infiltration losses, and evapotranspiration losses. Excess rain falling over a drainage flows from the upland area to the head of the channel segment and from the laterals uniformly into the channel along its reach. Because of infiltration losses into the channel alluvium, the total volume of runoff decreases as water flows down a channel reach (Keppel and Renard 1962, Peterson 1962, Lane 1972, 1983, 1985, Renard and Keppel 1992).

Each lateral and upland area is described by its acreage and a CN. The channel segment is characterized by its length (miles), its average width (feet), and the effective hydraulic conductivity of its bed material (inches per hour). Each channel segment can be associated with one upland area, two lateral areas, and two inflow channels. Each stockpond in the watershed is associated with a specified element, either a drainage area or channel segment, and described with a retention volume (Lane 1983, 1985).

The 60 mi^2 Walnut Gulch watershed used in this study contains an ephemeral stream that is part of southeastern Arizona's San Pedro River drainage system (Figure 1). The model represents the watershed with 151 elements: 46 channel segments, 13 upland areas, and 92 lateral areas. The drainage area contains 14 stockponds (Table 1) which are, with one exception, associated with upland areas. The single exception is associated

Table 1. Data for stockponds located on WGEW used in the TSPLOSS model.

SP #	Volume (af)	Contrib.	Watershed (acs)	Curve Number
201	3.44	U143	53	87
207	8.73	LAT56[1]	268	89
208	4.59	U82	278	90
210	7.8	U96	163	90
212	19.29	U50	806	89
213	2.11	U46	365	89
214	14.92	U78	386	90
215	4.59	U26	80	91
216	3.9	U71[2]	385	93
218	9.4	U71[3]	<385>	[93]
220	1.95	U36	128	95
221	10.9	U4	164	91
223	2.53	U130	110	92
226	0.37	U61	85.1	89

[1]Functions as an UPLAND area.
[2]In-line tanks; total contrib. area = 365 acs.
[3]Can be treated as one tank with 13.3 af capacity.

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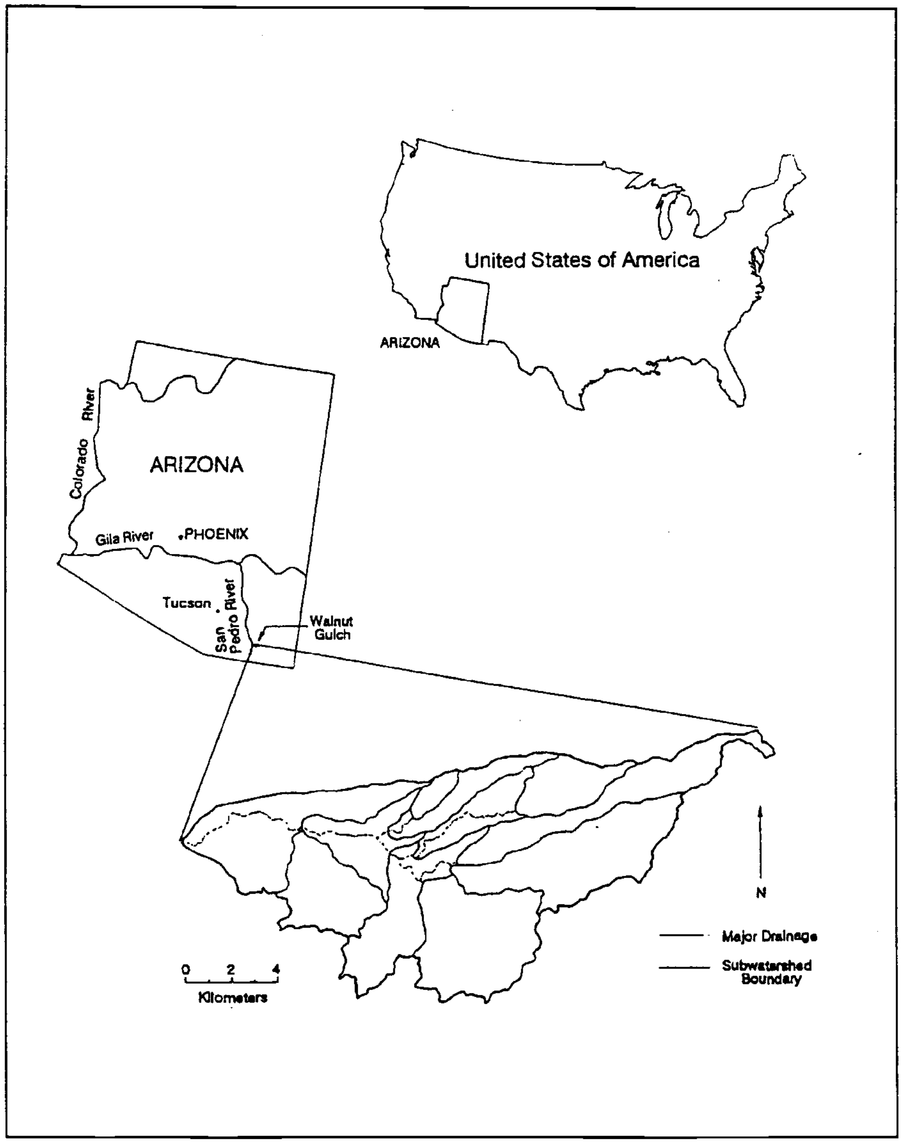

Figure 1. Map showing location of Walnut Gulch Experimental Watershed (adapted from Renard et al. 1993).

with a lateral area [LAT 56] (Young 1994a, 1994b, Young and Lang 1996).

The original modeling effort attempted to answer the following questions regarding the effects of stockpond retention on downstream water users:

1. For specified rainfall events, how is watershed production and stockpond retention used to help define de minimis (insignificant) effects?

2. What is the effective retention (ER) for specified rainfall events?

3. How do transmission losses affect stockpond retention?

4. What events are most and least affected by the presence of stockponds, and what is their recurrence interval?

5. What is the sensitivity of the model to variations in estimates of stockpond densities, the curve number (CN), and channel bed hydraulic conductivity (K)?

Model Scenarios

Four scenarios were run to simulate four different rainfall events, plus a hypothetical sudden release of all the stockponds in the system. Runs 1–3 simulate rainfall over only a part of the watershed. These simulations represent the short duration, random multicellular convective storms that are characteristic of summer rainfall on the WGEW. Run 4 simulates a rainfall event that would be typical of a winter weather pattern on the watershed. In this simulation, the rainfall is applied to the entire area of the watershed.

Description of Model Output

The water balance for the model consists of one input—rainfall (P)—and four possible outputs: runoff (R), overland flow losses (OL), transmission losses (TL), and stockpond retention losses (SPL). Overland flow losses are dictated by the curve number (CN) and cover a variety of losses, including overland infiltration, evapotranspiration, and interception. If conservation of mass is assumed, then inflow to the system must equal outflow from the system, and P = R + OL + TL + SPL (Young 1994a, 1994b, Young and Lang 1996).

Model output provides the water balance for each simulation. For every storm simulated, two runs are performed on the watershed: one that assumes that there are no stockponds in the system, and another that assumes all of the ponds specified are in the system and are empty at the beginning of the storm. Even though losses to the water budget for a given storm may be attributed to stockpond retention, if all the water would have been lost anyway to another sink, such as transmission loss, then the volume effectively retained would be zero. Effective retention is the ratio of effective retention to possible retention, and is expressed as percentage in Figure 2 (Young 1994a, 1994b, Young and Lang 1996).

Results of Model Runs

- For each run a rainfall depth exists where the stockpond retention reaches a maximum and remains constant as rainfall depth increases further (Young 1994a, 1994b, Young and Lang 1996).
- Effective retention (ER) for a single event is always less than one. This is due to the effects of channel transmission losses (ER = volume of water retained/cumulative volume of all tanks; Young 1994a, 1994b, Young and Sejkora 1995, Young and Lang 1996). See Table 2.

Table 2. Maximum effective retention (ER) for Runs 1–4.

Run No.	Max. ER
1	0.15
2	0.21
3	0.38
4	0.35

- The model results show that no matter to what degree the stockponds fill, even if they completely fill and spill over, some of the water they retain would be lost to channel bed infiltration if the stockponds were not there (Young 1994a, 1994b, Young and Lang 1996).

Results and Discussion

Four properties of the watershed are presented in Table 3: the area receiving rainfall, the area receiving rainfall that drains to stockponds, the percentage of the area being rained upon that drains to stockponds, and *the ratio of the cumulative stockpond volume to the area receiving rainfall*.

Stockpond density is a measure of the potential for stockponds in a system to retain water with respect to the watershed's ability to produce water (Young 1994a, 1994b, Young and Lang 1996). It is represented in Table 3 as a ratio of the cumulative retention of all the stockponds in the rained-on portion of the watershed to the normalized area of the watershed.

A normalized area would have to take into consideration the variability of CN spatially over the watershed. A large area associated with a low CN may produce the same amount of water for a given event as would a much smaller area with a higher CN. If variability of CN is small throughout the watershed, then normalization may not be necessary. This was deemed to be the case for the WGEW as represented here, and therefore the values in Table 3 are already considered normalized (Young 1994a, 1994b, Young and Lang 1996).

Due to the limits of measurement accuracy with respect to watershed production and stockpond volumes, any rainfall event that results in less than 10 percent of the watershed production being retained could be considered de minimis. Therefore, 10 percent was arbitrarily selected as a threshold amount in this study. The results of Runs 1–4 show that Run 1 retained more than 10 percent of the watershed production for a larger range of events than did the other three simulations (Figure 2 and Table 4). Table 4 illustrates that the stock-

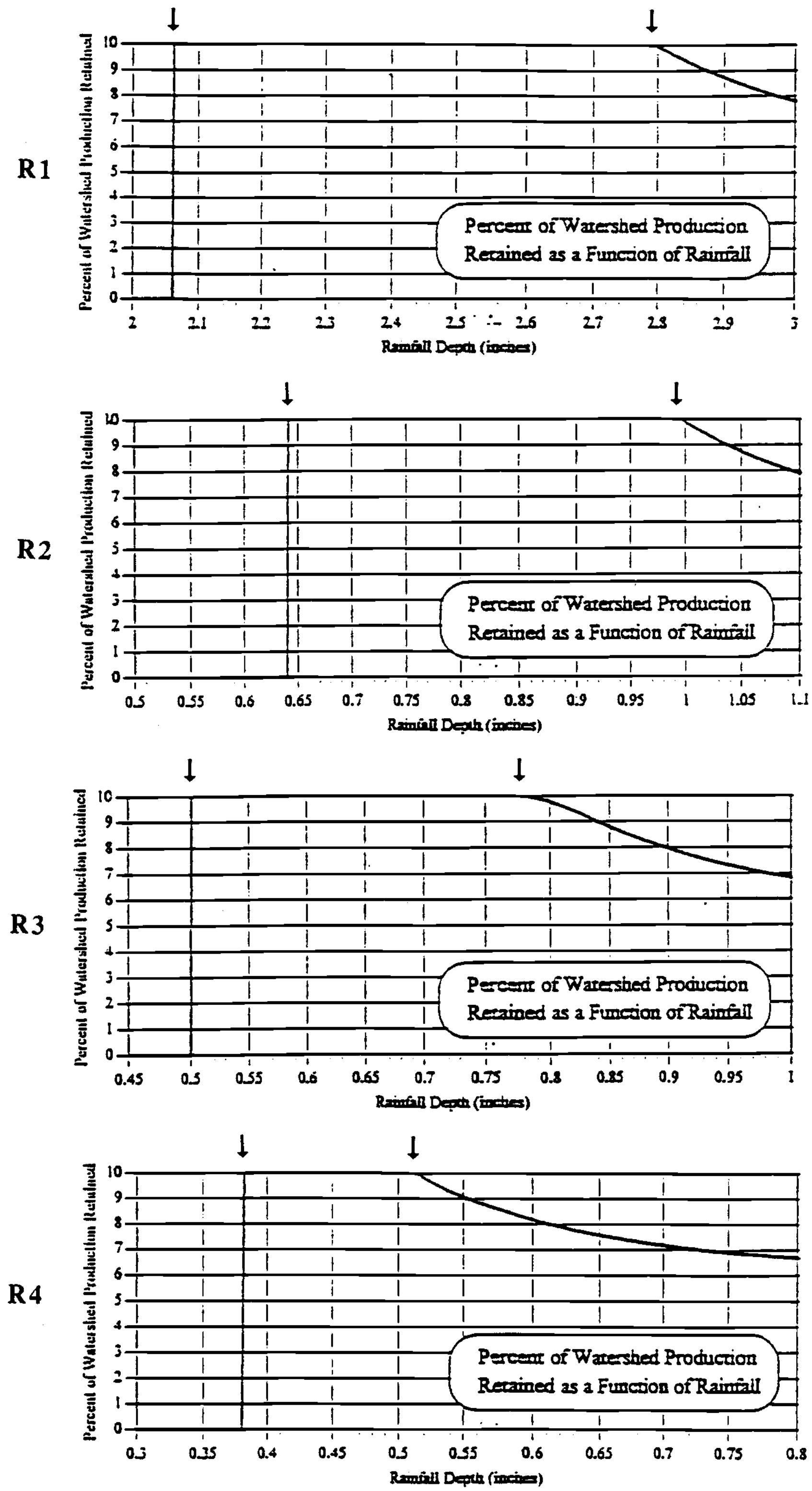

Figure 2. Graphs of percent of watershed production retained as a function of rainfall for model runs R1, R2, R3, and R4 on the Walnut Gulch Experimental Watershed (arrows indicate range of rainfall depth where watershed production retained is ≥ 10%).

Table 3. Statistical Properties of the Walnut Gulch Experimental Watershed.

Run No.	Description (Areas Receiving Rainfall)	Area Receiving Rainfall (acres)	Area Draining to Stock-ponds (acres)	Percent of Area Draining to Stockponds	Cum. Vol. (ac/ft) / Rainfall Area x 100
1	S1	2213	164	7.4	4.93
2	S1, S2, S3, S4	11976	757	6.3	2.57
3	S5	8304	774	9.3	2.65
4	Total Watershed	38607	3271	8.5	2.45

Table 4. Ranges of rainfall impounded that are >10% of watershed production.

Run No.	Rainfall Range (in.)	Retention >10% (in.)	Stockpond Density
1	2.06–2.79	0.73	4.93
2	0.64–0.995	0.36	2.57
3	0.50–0.78	0.28	2.65
4	0.38–0.565	0.19	2.45

pond density for Run 1 was almost twice that of the other three runs.

Stockpond density was plotted against the range of retention greater than 10% of total watershed production (see Figure 3). It is doubtful that the relationship is linear in nature, as depicted. Whether this is a true representation of the relationship between stockpond density and retention is not known, nor is the relationship fully understood at this time. However, it is a starting place for further investigation.

Although the results here are not conclusive due to the small area involved in Run 1, stockpond density may prove to be significant in situations that involve high densities over larger areas. This requires further investigation. The model should be tested further to determine the break-point density at which cumulative impact of small impoundments would have "significant impact" on watershed production.

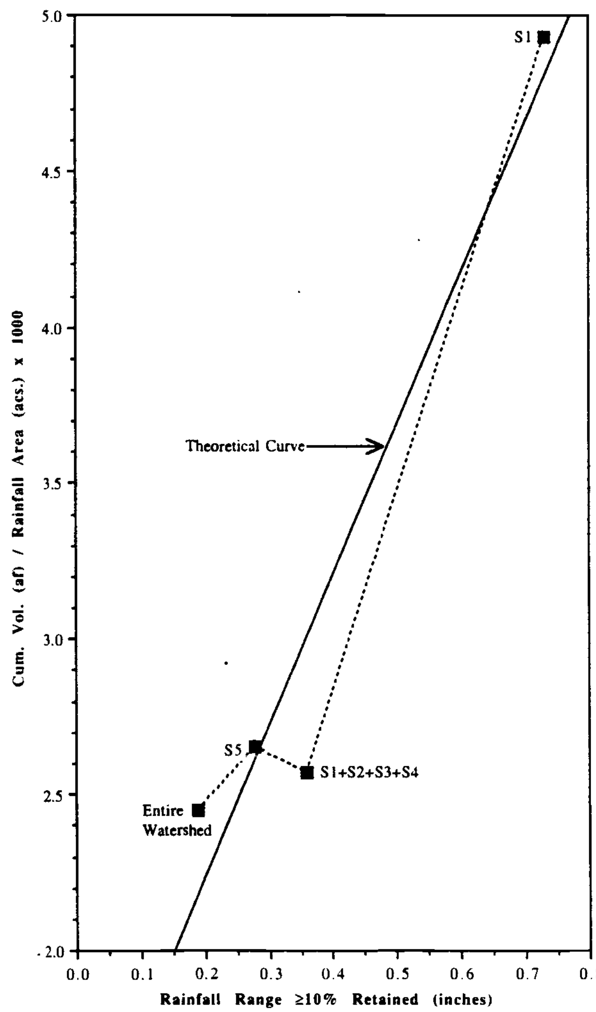

Figure 3. Graph of stockpond density vs. retention for the Walnut Gulch Experimental Watershed.

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