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Runoff Water Quality from Varying Land Uses in Southeastern Arizona

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Highlight: Surface runoff waters from three kinds of activity on rangeland were examined for suspended solids and some indicator chemical constituents. We compared ungrazed brush-covered rangeland with recently subdivided rangeland, originally and still partly brush-covered, but whose surface was disturbed by man's urbanizing influence. Water quality indicators showed the urbanized watersheds had poorer water quality. Comparisons between the two brush-covered watersheds and a third—grass-covered and grazed—were made only on the runoff water's dissolved constituents. Despite the grazing activity, the waters were of better quality.

A contrast in the geology between the grass and brush areas suggested that mineral sources affected qualitative changes in the dissolved solids. Calcareous soils produced waters higher in Ca and total dissolved solids and lower in other cations. Phosphate in runoff averaged higher from the grass-covered, noncalcareous area than from the brush-covered calcareous watershed. We hypothesize now that the phosphate originated from soil sources, rather than from grazing activity. Nitrate levels were comparable in runoff from all the nonurban areas, but increased in runoff from the semiurban area. Thus, the nonagricultural complex of activities associated with a housing development was more detrimental to water quality than those from undisturbed or grazed rangelands.

The need for water quality data, chemical as well as sediment, has become acute because of recent legislation such as the 1972 Federal Water Pollution Control Act Amendments. Such data for rangeland areas are especially lacking. The impact of grazing on chemicals in runoff is also needed for the preparation of Environmental Impact Statements (EIS) on public lands.

Runoff from intense thunderstorms in the arid and semiarid rangelands of the southwestern United States has been studied extensively with special emphasis on sediment production. Information published, however, on the chemical quality in such water has been minimal. Gregory and Ffolliott (1976) discussed runoff water quality from a forested range on sedimentary rock in northern Arizona. Urban runoff waters from rains, presumably similar to those at Tombstone, falling on parts of Tucson (100 km northwest) were examined in detail (Dharmadhikari 1970; Mische 1971; and Popkin 1973). The drainage basin above Charleston, 14 km upstream from the mouth of Walnut Gulch, has been partly monitored for conductance since 1964 (U.S. Geology Survey 1974).

To identify and control sources of nonpoint pollution control, we collected surface runoff samples in 1974 at Walnut Gulch Experimental Watershed, near Tombstone, Ariz., to examine the water quality of a southeastern Arizona rangeland area with varying soils and vegetation under year-round grazing by cattle (chiefly Herefords). In this paper, we present information regarding ranges in concentration of various ions in runoff from select soils, vegetations, and land-use units. This data and the associated observations should be valuable to those concerned with nonpoint pollution control in the arid and semiarid regions associated with agriculture.

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Description of Experimental Areas

Figure 1 shows the location of three small watersheds (all included within the 150-km^2 Walnut Gulch Experimental Watershed), each containing within their boundaries uniform plant communities, uniformly distributed soil series (or complexes), and presumably receiving uniform rain during an event. The 98-gage watershed raingage network includes a gage at each of the three small watersheds. Mean annual rainfall is 350 mm, 230 mm of which occurs from June to September, corresponding to the runoff season. Runoff for the three locations, as well as at the outlet of the entire area, is ephemeral and measured and recorded continuously, using precalibrated measuring devices. Further background information on the entire experimental area can be found in Renard (1970).

Watershed No. 112, located in the upper elevations of the Walnut Gulch watershed is heavily-grazed and grass-covered (Table 1). Despite the heavy stocking rate (probably more than 4 cow-calf animal units/km^2/year with continuous grazing), erosion is not excessive at this site, as was shown by Osborn et al. (1977). Watershed No. 121 is a recently urbanized area (current housing density is about 1 family dwelling/ha), with brush-covered calcareous soils. Watershed No. 104 is a similar brush-covered, calcareous soil area, where grazing and other man-related activities have been excluded for 15 years. Erosion was considerable from this area (Osborn et al. 1977).

The wide variations in soils and, perhaps, vegetation (a mixture of desert shrubs and grasses) on the Walnut Gulch Watershed are often reflected in the chemical characteristics of the flow along different channel segments of these ephemeral stream channels. Creosotebush (*Larrea divaricata* Cav.) and whitehorn (*Acacia constricta* Benth.) dominated the vegetative cover of the brush-covered watersheds (Nos. 104 and 121), with vegetation basal areas of 2% and a 40% crown cover. Blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) and sideoats grama (*Bouteloua curtipendula* Michx.) dominated the vegetative cover of Watershed No. 112, where vegetation basal area is 5% with a 50% crown cover.

The soil series on the small watersheds are all complexes of two soil series each. These series are the same for watersheds

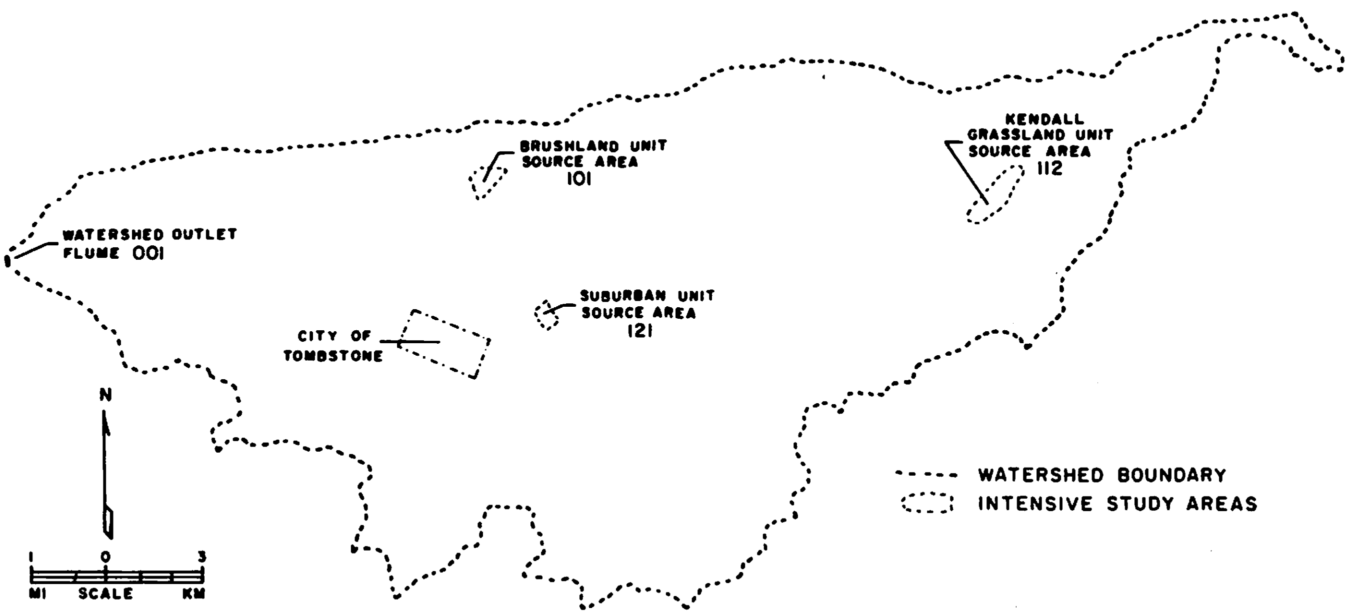

Fig. 1. *Walnut Gulch watershed and the unit source areas (small watersheds) contained therein.*

Nos. 104 and 121, although the percentages of each series within these watersheds are probably different (Table 1).

All series are formed on geologic material of old valley plains or alluvium, made of gravelly loamy materials. The Bernardino, the only soil series with a well developed neutral-to-slightly acid argillic horizon, has a Cca horizon within 0.5 m of the surface.

Table 1. Watershed characteristics.

Watershed no.	Drainage area (ha)	Vegetation	Soils	Land use
1	15,000	mixed grass-brush	70% Calcareous	Mixed
121	5.26	brush	Rillito-Laveen gravelly loam	Suburban
112	1.86	grass	Bernardino-Hathaway gravelly loam	Grazed
104	4.54	brush	Rillito-Laveen gravelly loam	Ungrazed

Methods of Runoff Collection and Analysis

Water samples were collected from the three small watersheds using a Chickasha-type sampler (Miller et al. 1969), which collects samples throughout flow events with 3- to 10-min sampling intervals. At the outlet of Walnut Gulch (watershed No. 1), samples were usually collected by wading above the supercritical measuring flume with a US D-48 hand sampler. During high discharges, a US P-63 sampler was lowered from a cableway car to obtain depth-integrated samples throughout the flow. All samples were collected in glass or plastic bottles.

Sediment concentrations were determined by centrifuging, drying, and weighing the suspended sediment. The supernatant liquid, removed from the water/sediment aliquot, provided the source liquid for determining electrical conductivity (EC) with a standard Wheatstone bridge, pH electrometrically, and all other ionic constituents. The major cations were determined using an atomic absorption spectrophotometer. The HCO_3 concentrations were obtained by electromatic titration to a pH 4.5 endpoint. The PO_4-P in the supernatant was determined by the Murphy-Riley ascorbic acid method, while NO_3-N was determined using the phenoldisulfonic method. Aliquots for the N determination were taken within 24 hours

Table 2. Minimum, maximum, and mean values of various quality parameters measured on Walnut Gulch in 1974.

Parameter	Units	121[1]			112[2]			104[3]			001[4]		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
pH		7.8	8.7	8.34	7.0	7.59	7.48	7.4	8.9	8.17	7.4	8.5	8.21
EC	µmhos/cm	85	167	123	60	159	92.5	80	196	103	77	216	156
SUM CATIONS	me/L	0.72	1.80	1.31	0.60	1.02	0.89	0.74	1.94	1.03	1.17	2.10	1.55
NO_3-N	ppm	.03	1.09	0.62	.20	.67	0.30	.08	.57	0.24	.01	.72	0.23
PO_4-P	ppm	.007	.50	0.06	.05	.70	0.22	.001	.25	0.03	.001	.16	0.05
HCO_3	ppm	53	119	70.7	24	45	38.5	31	120	58.8	53	109	78.8
Na	ppm	.65	3.05	1.87	.92	2.00	1.87	.56	3.65	1.50	1.20	2.40	2.08
K	ppm	1.60	7.15	4.39	4.0	11.5	5.03	1.6	5.4	2.52	2.8	5.6	3.75
Ca	ppm	10.9	29.2	20.9	7.1	13.8	12.3	12.0	28.0	16.5	17.0	34.0	25.1
Mg	ppm	0.52	1.27	0.88	0.48	1.04	0.77	0.49	2.38	1.00	0.93	2.05	1.32

[1] Based on 107 samples — Recently urbanized (1 family dwelling/ha).
[2] Based on 33 samples — Heavily grazed, grass-covered watershed.
[3] Based on 121 samples—Grazing and other man-related activities excluded for 15 years.
[4] Based on 65 samples—Outlet of the entire watershed.

and dried, but P was determined after the runoff season ended. While exhaustive tests on P losses during storage have not been made, we felt this delay did not affect observed P concentrations in these waters.

Results

Table 2 summarizes the data from all samples collected in 1974 from the three small watersheds (Nos. 121, 104, and 112) and from the total watershed outlet (No. 1).

Figure 2 shows the relationships between discharge, sediment concentration, and EC of the supernatant solution for the first runoff event of the summer rainy season at each of the two small watersheds, Nos. 104 and 121.

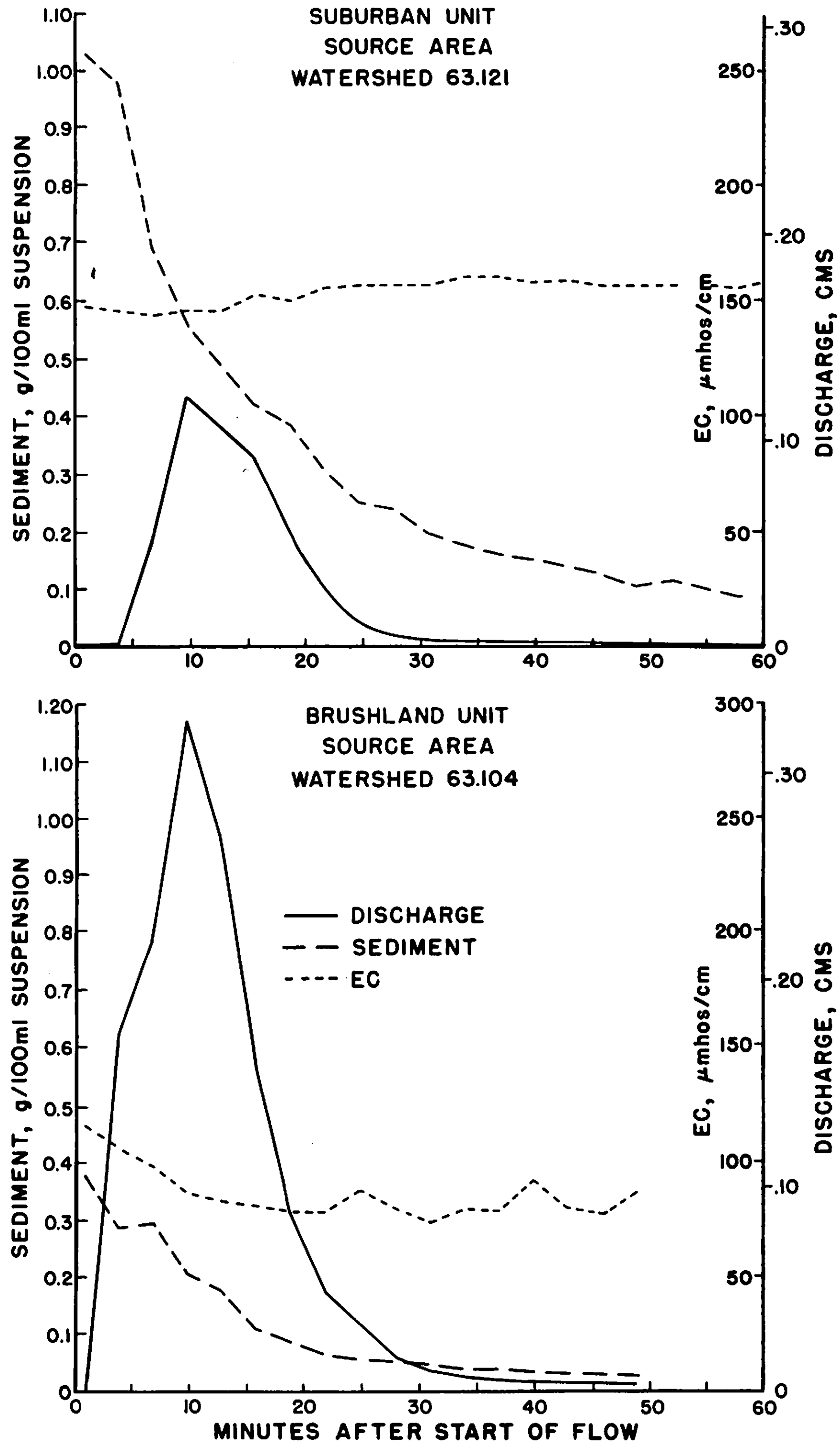

Fig. 2. *Discharge, percent sediment, and electrical conductivity of flows through station No. 121 (July 28, 1974) and No. 104 (July 19, 1974).*

These events were selected because samples were obtained throughout the duration of the flows, and because they were high runoff volume events. The runoff event at watershed No. 104 was the largest of the year; the event at No. 121 was the third largest.

As shown by Henderson (1966) and Vanoni (1975), sediment concentration tends to correlate with water discharge within a given event. In comparing the two events in Figure 2, the sediment at watershed No. 121 probably includes a higher percentage of sand as compared with that at No. 104, where a settling pond was maintained, causing some sand-sized aggregate deposition immediately above the measuring and sampling area. EC was correlated with instantaneous volume and sediment concentration, suggesting that the ions carried in solution were probably associated with the sediment or were affected by the same detaching mechanisms. This was not true, however, for watershed No. 121, where we found a 50% higher salt content, which could have been caused by real although nonascribable differences in soils and geology and by increasingly numerous disturbances, such as roads, buildings, and animals.

Figures 3 and 4 illustrate variation in some water quality parameters during individual flow events at watersheds Nos. 104 and 121. We encountered similar variability at the other stations for individual flow events. Early and late season concentrations were comparable, indicating that seasonal variability was not a strong factor affecting sediment concentration or EC (Figs. 3 and 4). Figures 3a and 4a show the peak runoff from the various flows at the ungrazed and suburban watersheds over one runoff season. Peak runoff, an index of rainfall intensity and duration, usually correlated well with the total volume of runoff per event (Osborn and Laursen 1973). Peak runoff can be compared with other parameters measured during these same flows. Sometimes, two separate events occurred the same day (shown by a break at the height of the smaller flow line). The disturbed area, watershed No. 121, had a high, stable concentration, regardless of flow volumes. The sediment discharged from watershed No. 121 was comparable with the highest sediment loads cited by Dharmadhikari for an industrial watershed in Tucson (1970). He indicated that as an urban area becomes "settled," with proportionally more pavement and less disturbed land, suspended sediment decreases. Our values may be partially attributed to the more recent exposure and generally steeper slopes at watershed No. 121 than those at Tucson. Popkin (1973) noted that McGauhey (1968) gave 50 mg suspended sediment/l as a limit for potable water. Most runoff waters from urban, semiurban, or agricultural rangelands would not meet this criterion without treatment, such as detention and addition of alum.

Figures 3c and 4c show that all but one flow at No. 121 had ECs greater than 125 μmhos/cm, but less than 175 μmhos/cm. Those flows at No. 104 were all under 125 μmhos/cm with one exception. These two anomalous records, together with a lack of seasonal trend at either watershed, suggest that many variables affected the total dissolved solids in these waters.

Dharmadhikari's study (1970) of the Tucson watersheds indicated complex urban activities may cause even further deteriorations in conductance (increased total dissolved solids). Runoff from the industrialized area in his study showed still further deterioration in the dissolved load. Unlike EC, the NO_3 concentrations varied consistently at both locations (Figs. 3d and 4d) with threefold differences in NO_3 concentrations between the disturbed (No. 121) and undisturbed (No. 104) watersheds, respectively, and with early-season flows containing higher NO_3 concentrations than late-season flows by a factor of two, independent of flow discharge rates, sediment, and EC. These high early-season NO_3 concentrations in the runoff water could have reflected the microbial activity in the soil, resulting in nitrification of organic materials made available during the preceding winter and spring. Another possible explanation is that all of the ingredients required for nitrification were available, but plant uptake is lower early in the runoff season.

The seasonal values of phosphate in the runoff water (Figs. 3e and 4e) do not resemble those for NO_3. Each area contributed a relatively constant amount of P per event with the disturbed watershed contributing consistently higher amounts. The correlation between sediment and P was better than that between sediment and NO_3 or EC. Actually, a multifactor relationship could exist: P concentrations were highest when flow rates were lowest and sediment concentrations were highest. Thus, the amount of P per event might tend to be a fixed amount, or at least a discontinuous function of flow volume. Given a threshold amount of runoff, a relatively fixed increment of P is dislodged from the soil surface.

Figure 5 shows in detail the relationships between EC and sediment concentration at three sites. From these relationships, a minimum discharge, or conditions that lead to a threshold, apparently gave sediment concentrations at watershed No. 121 that were comparable to concentrations obtainable at No. 104. Under these low discharge rates, EC can decrease slightly, but otherwise the insensitivity of EC to sediment concentration is shown by those samples, which averaged over 3 g/l. The lack of pattern for all other EC vs sediment concentration relations is evident, but for most cases, when flows

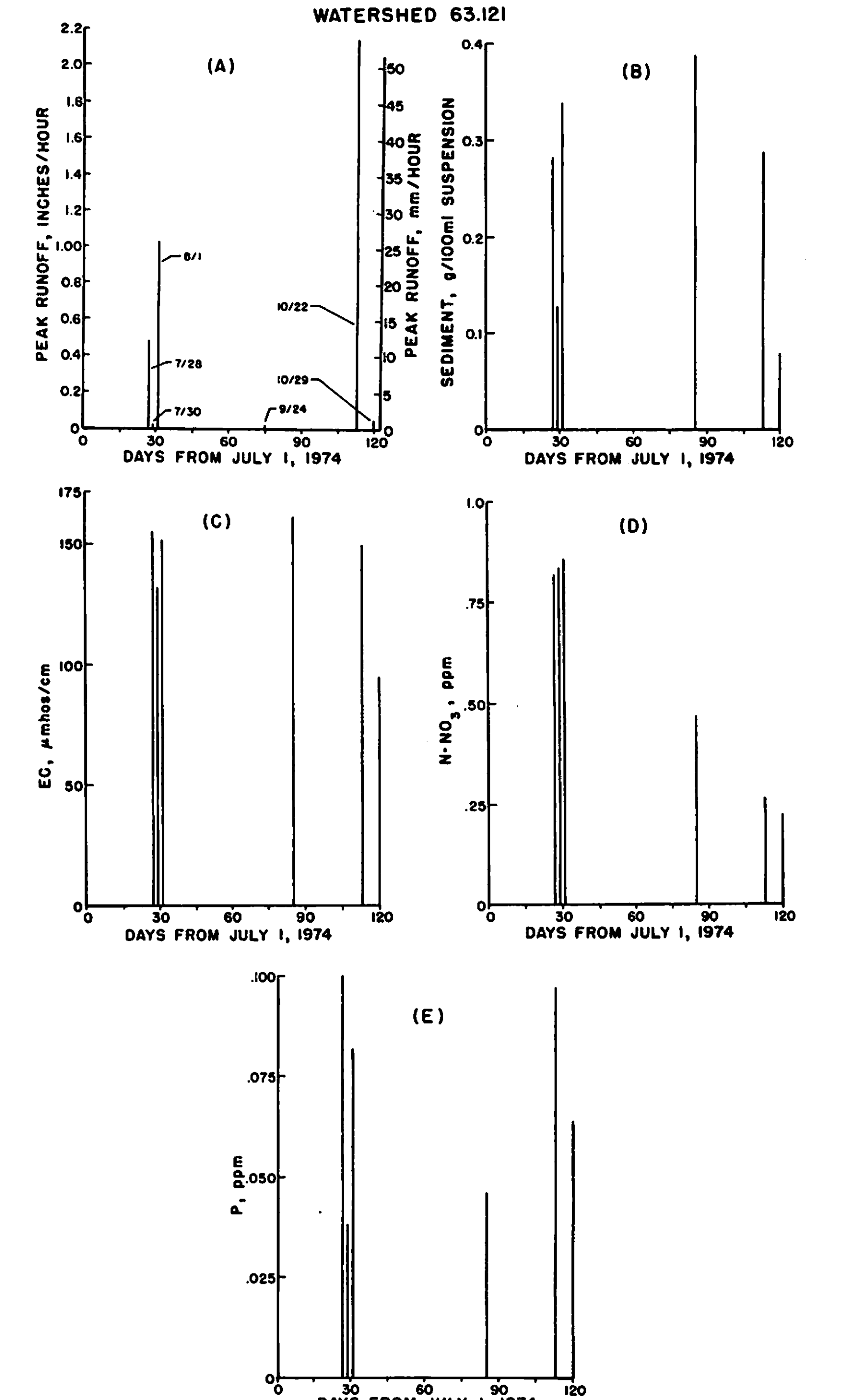

Fig. 3. *Some water quantity and quality parameters of flows at gaging station No. 121 during 1974.*

occurred in several places on the same day, the ranking in ECs is very close. From this, we can infer that the quality of rainwater varies between storms, and the contribution of soil salinity is not sufficient to mask the atmospheric contribution to total dissolved solids in the water. Even in the Tucson runoff waters, Dharmadhikari (1970) observed less variance within storm samples than between sets of storm samples.

Similar water quality variables were measured by Stephenson (1975) on the Reynolds Creek Experimental Watershed near Boise, Idaho. These data were compared with values obtained on Walnut Gulch. Interestingly, the EC, K, and Na concentrations in Walnut Gulch runoff waters were comparable with that at the outlet of Reynolds Creek. However, Mg concentrations were usually lower and Ca concentrations higher in southeastern Arizona because of $CaCO_3$ in the soil. This $CaCO_3$ also influences orthophosphate solubility, causing P concentrations to decrease by an order of magnitude (relative to those from Idaho) in water originating in the calcareous parts of Walnut Gulch.

Within Walnut Gulch, the presence or absence of surface $CaCO_3$ in a small watershed allowed us to separate, on the basis of pH, limey areas which invariably have water whose supernatant liquid has a pH greater than 7.4. Overland flows sampled at site No. 112 never had Ca concentrations greater than 14 ppm, while that from other areas rarely had such low Ca concentrations. A concentration of 4- to 5-ppm K separated the calcareous from non-calcareous areas except for the urbanized watershed, which seemed to often resemble the non-calcareous areas in K and P concentrations. The NO_3-N concentrations from the urbanized area generally exceeded those measured on the other areas.

The limited data collected and analyzed indicate that any Walnut Gulch runoff water would be safe for livestock in its present form, based on the standards given by McKee and Wolf (1963), although Weeth (1973) cautioned against blanket acceptance of such standards without more research. The chemical constituents examined and reported on in this paper indicated that the water would probably be excellent for human consumption and irrigation after it was treated to remove

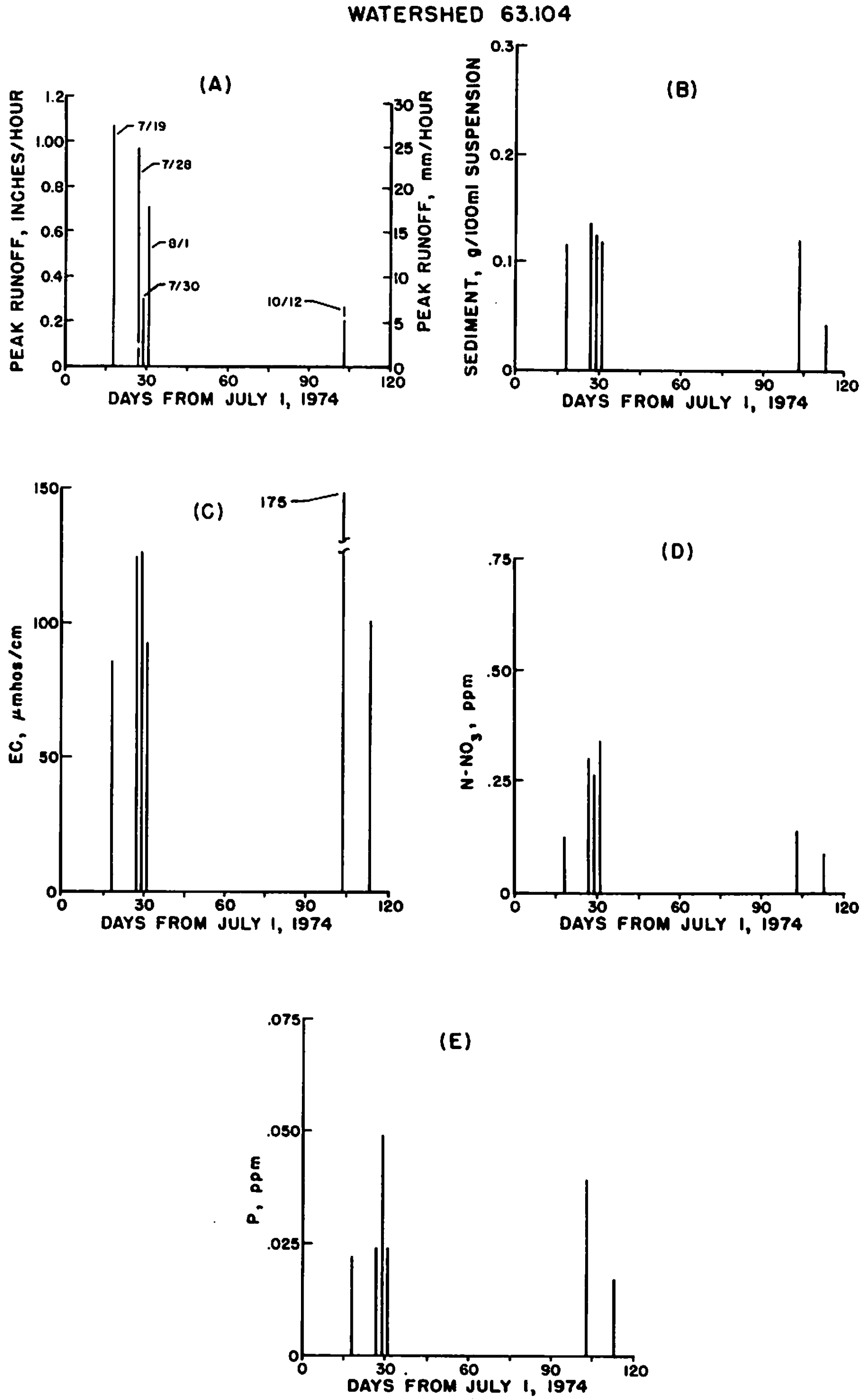

Fig. 4. *Some water quantity and quality parameters of flows occurring at gaging station No. 104 during 1974.*

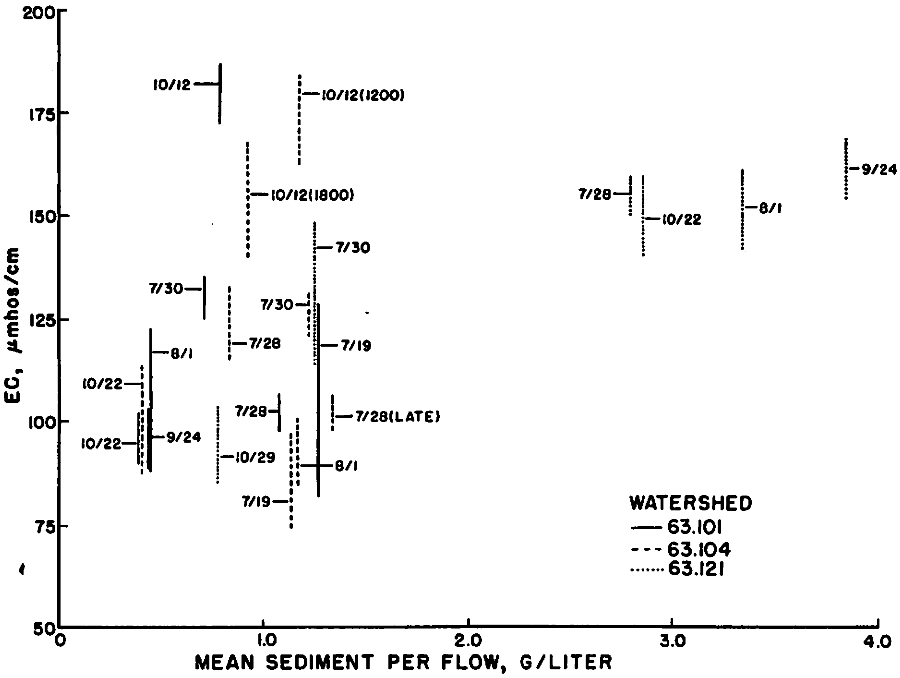

Fig. 5. *Electrical conductivity (EC) plotted as a function of the mean value of sediment per flow on the day and month (and time, if two flows occurred on the same day). Mean EC is at the mid-point of bar and the total vertical distance is two standard deviations from the mean, thus including about ⅔ of the EC values obtained for a flow. Note the proximity of EC values for different locations on the same day.*

excessive suspended sediment from the source areas. Additionally, most surface runoff waters require chlorination to make them safe for recharge.

Literature Cited

Dharmadhikari, V. V. 1970. Quality of runoff from diversified urban watersheds. MS Thesis. Univ. of Arizona, Tucson. 107 p.

Gregory, P. W., and P. F. Ffolliott. 1976. Water quality of stream flow from forested watersheds on sedimentary soils. *In:* Chery, D. L. (Ed.). Hydrology and Water Resources in Arizona and the Southwest. 29 April-1 May. 5:93-95.

Henderson, F. M. 1966. Open Channel Flow. The Macmillan Co., New York, N.Y. 522 p.

Miller, G. E., P. B. Allen, N. H. Welch, and E. D. Rhoades. 1969. The Chickasha sediment sampler. U.S. Dep. Agr., Agr. Res. Serv. ARS 41-150. 14 p.

Mische, E. F. 1971. The potential of urban runoff as a water resource. PhD Thesis. Univ. of Arizona, Tucson. 179 p.

McGauhey, P. H. 1968. Engineering Management of Water Quality. McGraw-Hill Book Co., Inc., New York, N.Y. 295 p.

McKee, J. E., and H. W. Wolf. 1963. Water quality criteria. The Resources Agency of Calif. State Water Control Bd. Pub. No. 3-A.

Osborn, H. B., and E. M. Laursen. 1973. Thunderstorm runoff in southeastern Arizona. J. Hydraul. Div., Proc. ASCE 99(HY7):1129-1145. July.

Osborn, H. B., J. R. Simanton, and K. G. Renard. 1977. Use of the universal soil loss equation in the semiarid Southwest. Soil Erosion Symposium Special Pub. 21. Soil Conserv. Soc. Amer. p. 41-49.

Popkin, B. P. 1973. Effect of mixed-grass cover and native-soil filter on urban runoff quality. MS Thesis. Univ. of Arizona, Tucson. 112 p.

Renard, K. G. 1970. The hydrology of semiarid rangeland watersheds. U.S. Dep. Agr., Agr. Res. Serv. ARS 41-162. 26 p.

Stephensen, G. R. 1975. Water quality characteristics of the hydrologic flow region of the Reynolds Creek experimental watershed. *In:* ARS-BLM Cooperative Studies Reynolds Creek Watershed. Interim report No. 5. Cooperative Agreement No. 14-11-0001-4162 (N). p. 54-67. N. W. Watershed Research Center, U.S. Dep. Agr., Agr. Res. Serv., Boise, Ida.

U.S. Geological Survey Staff. 1974. Water resources data for Arizona, part 2: quality of water records. U.S. Dep. Int., U.S. Geo. Surv. 192 p.

Vanoni, V. A. 1975. Sedimentation engineering. Amer. Soc. Civil Eng. Manuals and Reports on Engineering Practice No. 54. New York, N.Y. 745 p.

Weeth, H. J. 1973. Non-applicability of federal water quality standards when applied to cattle. *In:* Mayland, H. F. (Ed.). Water-Animal Relations Proc. p. 9-14. Water-animal relations committee, Kimberly, Ida.