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Bacteriological Ground Water Quality Characteristics of the Walnut Gulch Experimental Watershed

Abstract

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Transmission losses from ephemeral channels are a major ground water recharge mechanism in southwestern rangelands. Wells located near large ephemeral streams in southeastern Arizona were sampled to determine the influence of recharging storm runoff on ground water quality. The wells reacted in a cyclic pattern with fecal coliform-fecal streptococci ratios ranging from extremely low values prior to storm runoff (0.003) to high values (6.60) immediately after runoff events. The wells then quickly returned to the original low bacteria counts. This indicates a highly porous subsurface material which allows pollutants to travel long distances in extremely short time intervals. Thus, a potential exists for polluting vast quantities of ground water in alluvium filled basins in the Southwest.

Keywords: Ground water, ephemeral recharge, rangeland and urban pollution, fecal coliform-fecal streptococci, bacteria movement, pollution potential, nonpoint pollution.

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Bacteriological Ground Water Quality Characteristics of the Walnut Gulch Experimental Watershed

By K. S. Hanks, D. E. Wallace, and H. A. Schreiber[1]

Introduction

Arid land basin and range provinces are increasingly being exploited as an expanding population demands new and larger sources of potable water. Since surface water is a scarce and easily polluted commodity in the arid regions of the Southwestern United States, increasing pressure is placed on using the vast ground water reservoirs.

Walnut Gulch Experimental Watershed, a research facility operated by the Science and Education Administration- Agricultural Research (SEA-AR), U.S. Department of Agriculture, near Tombstone, Ariz., is the site of intensive research on semiarid rangelands. Water quality studies are an integral part of the comprehensive hydrologic research program underway at the watershed and offer an excellent opportunity to study water quality problems that may be associated with various rangeland uses. This research attempts to isolate the effects these uses have on the bacteriological ground water quality on the Walnut Gulch Experimental Watershed.

Ground water contamination from a variety of sources is already a well-documented problem. Industrial wastes, landfill leachate, petroleum products, chlorides (road salt and oilfield brine), and organic wastes are some of the most commonly reported ground water pollutants. Once ground waters become contaminated from any source, remedial solutions are often difficult, since ground water flow is laminar, in smooth parallel lines, and not as turbulent as is characteristic of surface flow. As a result, dilution and dispersion are slow and ineffective processes for renovation of subsurface contamination.

The rate of movement of subsurface water is influenced by the size of the voids in the earth materials and the degree to which these openings are interconnected. Hydraulic conductivity (as opposed to permeability) is a property of the earth materials and water and indicates the ability of the earth material to conduct water (Bear *1972*).[2] Sands and gravels generally have high hydraulic conductivities because the openings are large and well connected. Fine-grained deposits may filter out bacteria and reduce concentrations of some chemical constituents via the ion-exchange capacity. Silts and sands have limited exchange capacity. The amount of exchange a particular cation undergoes is a function of (1) the clay minerals involved, (2) the cations already on the clay, (3) the other cations in solution, and (4) the accompanying anions. Clay minerals are particularly common in the streambeds of most perennial streams and rivers of the Eastern United States.

Sand and gravel and fractured bedrock aquifers generally afford little or no attenuation of either bacteriological or chemical contaminants. Bedrock that is jointed or fractured permits water to move rapidly along the joint or fracture openings so that hydraulic conductivities in such rock tend to be high. Ground water movement is along fractures that are likely to be irregularly distributed. Contamination, likewise, follows the irregular fracture pattern, and monitoring wells may not give an accurate picture of the extent of contamination because the various wells may not intercept the same fracture system.

The climate of nearly a half-million square miles in the Southwestern United States is semiarid (Thornthwaite *1941*). The area under consideration, which is used principally for livestock grazing, is characterized by annual precipitation of 7 to 20 inches in two distinct seasons—summer and winter—separated by protracted periods of negligible rainfall. Storm characteristics during these two seasons differ markedly. Winter precipitation results from widespread frontal storms of low intensity. Summer rains, which produce nearly all of the runoff, typically occur as convective thunderstorms of limited areal extent, short duration, and high intensity.

Water yields from the semiarid basin and rangeland provinces are, generally speaking, very low. For the arid-zone portions of Arizona, Colorado, New Mexico, and Utah, Dorroh (*1961*) has estimated that only 2 percent of the water falling as precipitation reaches a point of downstream use. On Walnut Gulch, water yield is highly correlated with drainage area. At the outlet of the 150-km^2 area, water yield is also about 2 percent of the annual precipitation (Renard *1970*).

On Walnut Gulch, about 70 percent of the average precipitation of 11.5 inches (29.2 cm) and almost all runoff occur in the summer thunderstorm season from June through September (Osborn and Renard *1970*).

A distinctive feature of the runoff pattern in southeastern Arizona is the large transmission losses. These losses may approach over 4.0 acre-ft per mile of channel per hour of flow duration (Keppel and Renard *1962*, Wallace and Renard *1967*). Losses such as these are quite typical of many of the semiarid rangeland watersheds. These losses result from the peculiar nature of the runoff producing storms, the highly ephemeral quality of the flow events, and the porous character of the channel alluvium. Runoff generated from summer thunderstorms typically traverses an extensive network of dry and highly absorbent channels. A significant portion of the runoff water may be absorbed by the channel alluvium during the flow event.

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[2]*The year in italic, when it follows the author's name, refers to Literature Cited, p. 12.*

Whether the water lost in the channel system reaches regional ground water depends on the geology of the individual watershed considered. Where the geology is conducive to recharge to permanant aquifers, a portion of the transmission-loss water moves downward to the water table and cannot be properly throught of as a "loss."

Several agricultural practices are known to contribute to pollution of surface and ground water resources. Heavy grazing on open range usually compacts the soil, reduces infiltration, and seriously reduces the vegetative cover, all of which increases runoff. An increased contribution of sediment and nutrients to the stream channel is often the result.

Poor well construction may sometimes contribute to ground water pollution by allowing surface runoff to seep through well seals or leaking casings. When this happens, bacteria-laden surface runoff can be routed directly from surface to ground water.

The potential impact that these and other activities have on the overall quality of surface and ground water resources on public rangeland remains unexplained. Pollution originating from these activities is generally of a nonpoint source and can rarely be controlled by abatement measures practiced for point sources. Economic constrictions, as well as the harsh climate and vast acreages involved, usually preclude control by abatement common to Midwest agricultural areas.

The 1972 Federal Water Pollution Control Act Amendments (Public Law 92-500) provide the framework for establishing regulatory programs to reduce, and eventually eliminate, pollution in the Nation's navigable waters. Basic data, however, are needed for developing guidelines for identifying and evaluating the nature and extent of nonpoint pollution sources before the intended results of this act can be fully realized.

By identifying and quantifying nonpoint sources of pollution, improved management practices may result in improved water quality. Ground water quality data from western rangeland in semiarid conditions are presently needed by those agencies responsible for management and use of this public domain. Information is also needed on the water quality characteristics of rangeland watersheds under natural conditions and various land management practices.

In recent years, due to population growth and pollution of surface water sources, ground water resources have assumed greater importance as a potential source of drinking water. The semiarid basin and range region of the Southwestern United States has experienced some of the highest population growth rates in the United States. This growth has increased the demand for using the scarce water resources, and the demand is expected to increase in the near future. Ground water resources are being exploited to satisfy the growing need for agricultural, industrial, and municipal water supplies.

The general objective of this research was to determine the bacteriological ground water quality characteristics of the Walnut Gulch Experimental Watershed. Specific objectives were to determine water quality characteristics as influenced by:

1. Runoff events occurring under various agricultural management practices.
2. Urban septic tanks and sewage disposal mine shafts and associated seepage.
3. Natural soil and geologic and vegetative conditions.

It was also considered important to determine sources of nonpoint pollution and make feasible recommendations for control of nonpoint sources.

Literature Review

The vast majority of surface and subsurface water quality investigations in the literature have been concerned primarily with the chemical and physical integrity of those waters (Lin *1972*, Van der Leeden *1975*, Sewell *1972*, Everett *1976*, Miller *1974*, Scalf *1973*). Many rangeland water quality investigations have reported on bacteriological indicators in streams from high mountain watersheds (Kunkle *1967*, Skinner and Cook *1974*, Stuart and May *1971*, Walter *1967*). Only two investigations of surface bacteriological water quality on lower elevation, semidesert rangeland conditions were found in the literature (Buckhouse *1976*, Stephenson *1975*). The results of these investigations indicated that livestock grazing, public use, high runoff, irrigation return flow, and seasonal use all frequently increased indicator bacterial concentrations. These investigators also concluded that the potential public health hazard of livestock grazing on open range with gentle slopes was minimal along channel segments with steep gradients.

Regional ground water aquifers are generally considered to be biologically free environments. The earliest studies on water bacteriology were conducted in Western Europe and the Eastern United States (British Ministry of Health *1934*, Levine *1921*). During these investigations, it was established that surface water that percolated into ground water aquifers would be naturally purified through soil filtration and oxidation. Since these studies established the integrity of ground water, there was no longer a need for further investigations of this nature. From time to time, isolated situations warranted that particular well sites be closely scrutinized (Kligler *1919*), but these were usually the result of disasters of either natural or human origin.

Ground water recharge mechanisms associated with ephemeral channel recharge are complicated and still under investigation in many locations. The recharging water quality can vary tremendously, depending on geographical areas involved and local conditions. Stephenson (*1975*) demonstrated that snowmelt associated runoff events contained little or no bacteriological indicators; therefore, any runoff water reaching ground water tables would be of exceptional purity. In semiarid lands of the Southwestern United States, however, runoff events usually erode vast quantities of top soil, carrying with the runoff tremendous numbers of organisms and a variety of chemical pollutants and various pesticides.

Problems Associated with Bacteriological Indicators

The total coliform (TC) group includes many organisms indigenous to soils that are not related to fecal contamination. Because of this, it has been proposed by Geldreich (*1967*) and others that this group be passed over in favor of the fecal coliform (FC) group when assaying the role of grazing and other human-related activities on surface water quality. The authors agree with this proposition as it applies to surface water; however, in the case of ground water, the TC group has been included, since it may well be a useful bacteriological indicator as it relates to soil erosion.

There seems to be a great deal of confusion as regards the interpretation of the TC test when utilizing the Endo-type media. Water quality manuals (American Public Health Association *1971*) refer to the interpretation of colony growth characteristics in the following manner: " . . . after 24 hours incubation at 35°C, count only those colonies which are dark red and exhibit the characteristic green metallic sheen. . . . " This statement is somewhat misleading. To understand the problem involved here, we should examine the "textbook" definition of TC. According to "The Fundamentals of Medical Bacteriology and Mycology" (Myrvik *1974*), TC is defined as those bacteria which are members of the genera *Enterobacter, Klebsiella, Serratia, Hafnia, Citrobacter, Arizona,* and *Escherichia.* The genus *Escherichia* contains species most often assigned the status of FC. In addition, these bacteria and a few variants will most often produce the characteristic "green metallic sheen" on Endo media. The interpretation of colony growth characteristics on this medium, according to most professional microbiologists (Salle *1973*), is red or pink colonies with or without a green metallic sheen. It is well established that attempts to determine FC (*Escherichia*) data from TC-isolating media are impossible. Since soil coliforms, from animal feces deposition and natural soil inhabitants, are also detected on Endo medium, the test is excellent for evaluating soil-eroding runoff and for detecting the contamination potential of surface water reaching well field aquifers.

Area Description

The Southwest Watershed Research Center of SEA-AR operates the 57.7-mi² (150-km²) Walnut Gulch Experimental Watershed in southeastern Arizona (fig. 1). This watershed is located on the eastern portion of the Upper San Pedro River Valley. The study area, with isolated mountain blocks separated by a broad alluvium-filled basin, is typical of basin and range physiography (fig. 2). The alluvium that fills the intermontane basin consists of Cenozoic sand, gravel, clay, and caliche conglomerate. Previous data indicate that the alluvium is nearly 2,500 ft deep in places and contains a large volume of ground water (Libby et al. *1970*). Elevation ranges from 3,800 ft above sea level at the confluence with the San Pedro River (the western boundary) to 6,000 ft in the Dragoon Mountains (the eastern boundary). The topographic expression is that of gently rolling foothill alluvial fans incised by a youthful drainage system. The mountainous portion of the watershed consists of rock types ranging in age from pre-Cambrian to Quaternary. Fault-block mountains on the east slope westward with igneous intrusions and complexly folded and faulted sediments interrupting the smooth downward slope towards the San Pedro River. This folding and faulting has resulted in large areas of shattered rock that tend to influence infiltration in the stream channels and, consequently, the subsurface hydrology.

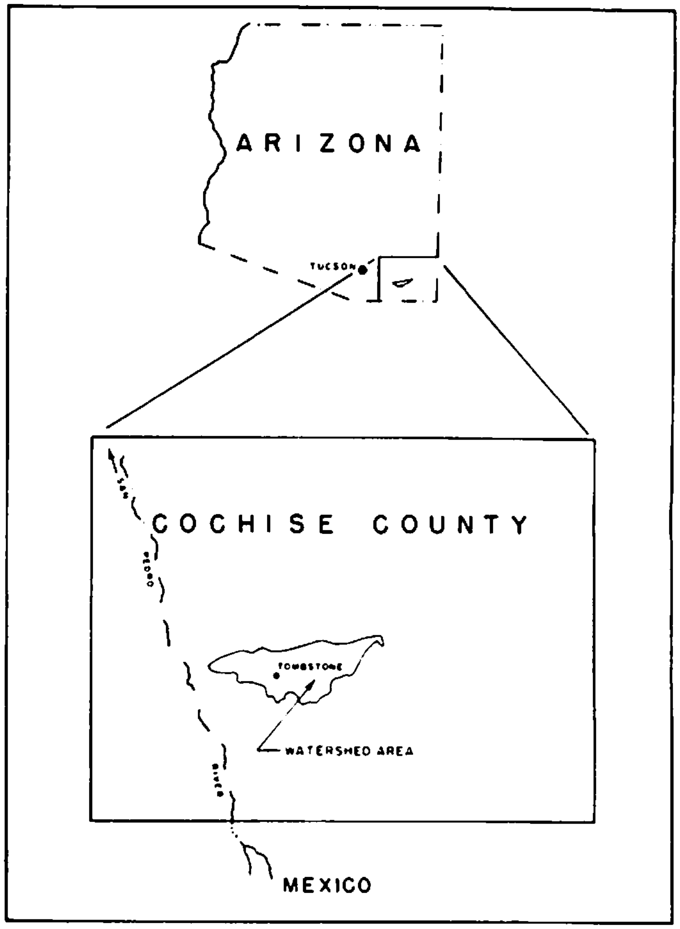

Figure 1.—Location map, Walnut Gulch Experimental Watershed.

Vegetation on approximately two-thirds of the area is predominantly desert shrubs with varying amounts of grass (lower elevation), whereas that of the remaining third is predominantly rangeland grasses (upper elevation).

Methods

Field Procedures

Bacteriological ground water sampling was dictated by the location of existing well sites on the watershed. A total of 20 well sites were sampled, and their locations are shown on figure 3. Table 1 lists some of the characteristics of each well site. Wells were sampled on a routine schedule during the major part of the year (May 1977 to August 1978), and samples were taken more frequently during periods following significant runoff events. Samples collected in the field were placed in heat-sterilized, 500-ml bottles. Samples were returned to the laboratory for microbial analysis within 2 hours of being collected. Aseptic technique was strictly adhered to throughout this research.

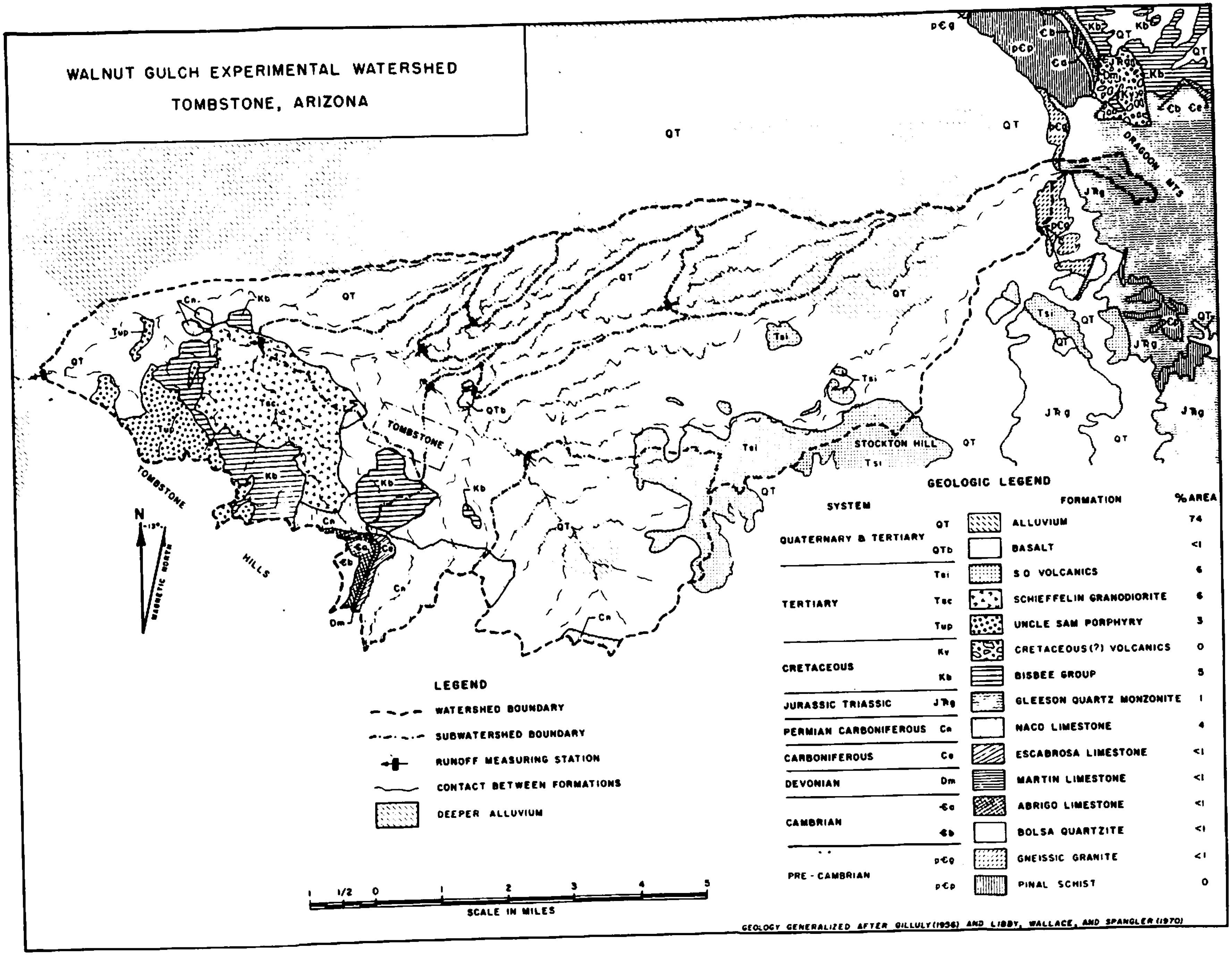

Figure 2.—Geologic map of the Walnut Gulch Experimental Watershed showing mountainous areas and extent of deeper alluvium.

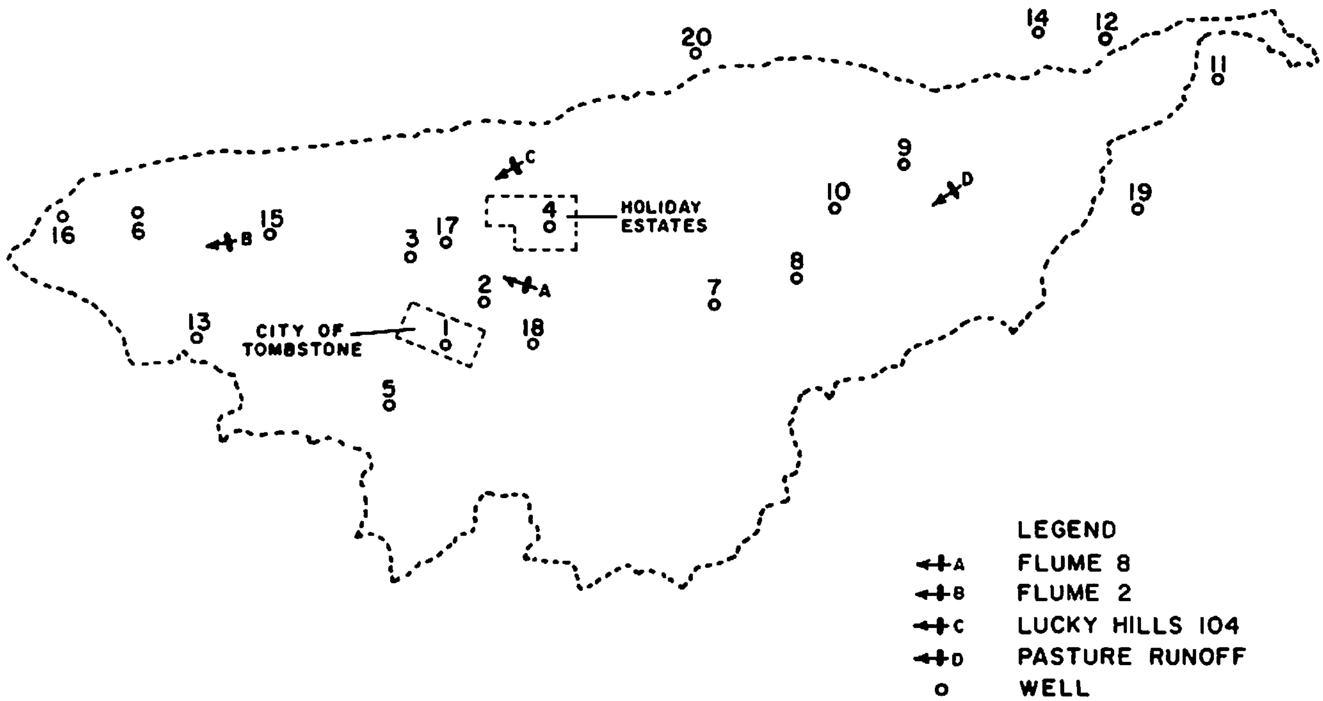

Figure 3.—Sampling site locations on the Walnut Gulch Experimental Watershed.

Table 1.—*Description of well sites*

Location site No.	Approximate depth to H_2O	No. of samples	Windmill (W) or electric pump (E)	Name of well
	Feet			
1	410	45	E	City Well 1.
2	278	43	E	City Well 2.
3	100	41	E	Little Green Ranch.
4	455	42	E	Holiday Well.
5	456	40	E	Westside Shaft.
6	255	38	E	Montijo Flat.
7	362	35	E	Cowan's Deep Well.
8	22	28	W	Cowan's Shallow Well.
9	463	37	W	Doug's Well.
10	312	25	W	Charlie's Big Windmill.
11	275	25	E	Jones' Well.
12	150	21	E	Old Home Ranch.
13	200	22	E	Escapule's Well.
14	35	26	W	Robertson's Well.
15	25	15	W	Clyne Well.
16	215	19	W	Watershed Windmill.
17	80	20	W	Lucky Hills Well.
18	200	12	E	City Well 3.
19	200	15	W	Charlie's Small Windmill.
20	432	36	W	Bennett's Well.

Laboratory Procedures

Bacterial counts were determined according to prescribed microbial methods (American Public Health Association *1971*), utilizing the membrane filter technique. M-Endo, M-FC, and KF media were used for the TC, FC, and fecal streptococcus (FS) determinations, respectively. Incubation temperatures for the FC group were maintained at 44.5°C in a standard waterbath, whereas TC and FS cultures were incubated at 35°C. Appropriate dilutions for each sample were prepared according to the degree of pollution so as to yield countable colonies in the range of 30 to 100. All reported microbial counts in this paper are expressed as numbers per 100 ml of water.

Results and Discussion

Background Watershed Water Quality

Before the impact of various water-polluting activities upon an area can be adequately assessed, it is important to determine the natural background or baseline bacteriological water quality. The present status of the ground water quality on the watershed has been necessarily influenced by rangeland management practices prior to when cattle ranchers first entered the area. Also, septic tank-leaching field sewage disposal systems are presently in use for all dwellings in the area. It is difficult, therefore, to appropriately determine the virgin bacteriological status of the ground water as it existed before settlers arrived; however, ground water recharge mechanisms were probably operable much in the same fashion then as they are today. As such, surface water recharging the ground water in years past was probably carrying with it a reasonable amount of bacteriological indicators, at least as much then as today. In the absence of livestock, it is entirely possible the watershed supported a much higher density of native wildlife, which would have included a substantial number of warm-blooded animals. Consequently, the number of fecal organisms, coliforms, and streptococci being contributed by these native fauna would have been significant. In addition, soil erosional processes constitute a continuing process. Thus, TC organisms, some of which are natural soil inhabitants, would have also been present in runoff waters and ground waters.

To best represent the background bacteriological quality of the ground water as it currently exists on the watershed, we will examine four typical wells located on the upper portion of the watershed. The wells are all hydraulically downstream from the Dragoon Mountains (a major, nearly uninhabited mountain range in the study area), and as such, recharge from the area is believed to contain very little pollution due to human activities. The wells and their site numbers are: Jones' Well (11), Doug's Windmill (9), Bennett's Windmill (20), and Cowan's Deep Well (7). Figures 4 through 7 depict the seasonal data compiled for these sample sites. The data

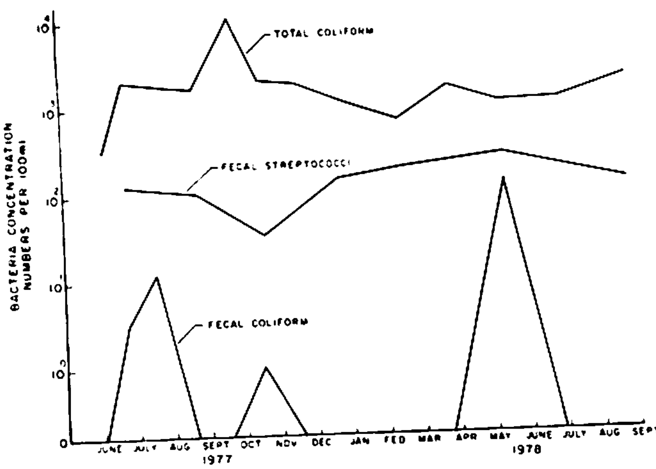

Figure 4.—Seasonal coliform concentrations, Jones' Well.

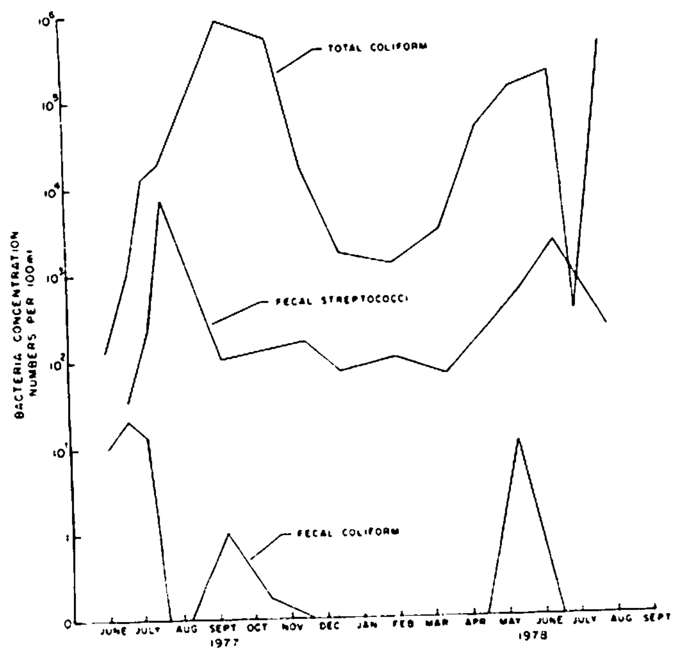

Figure 5.—Seasonal coliform concentrations, Doug's Windmill.

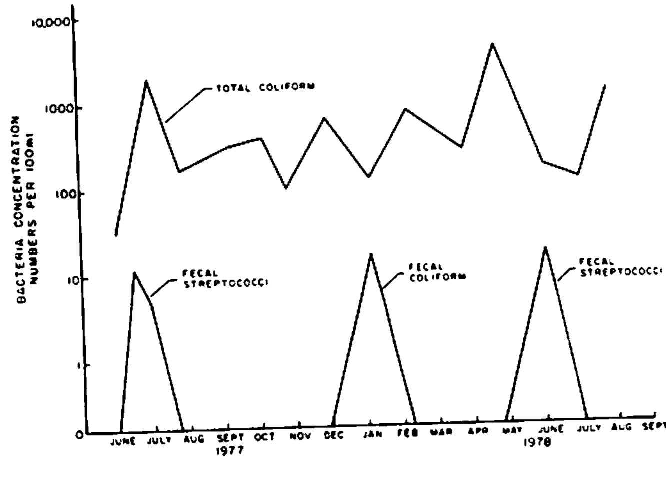

Figure 6.—Seasonal coliform concentrations, Bennett's Windmill.

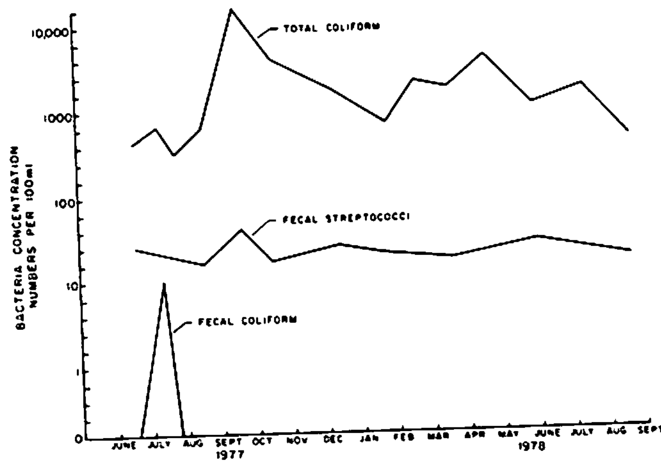

Figure 7.—Seasonal coliform concentrations, Cowan's Deep Well.

show that all these wells yield significant numbers of TC organisms all year. FS were also isolated on a routine basis, with the exception of an unexplained break in concentration in Bennett's Windmill (fig. 6). FC bacteria were isolated only occasionally. The modified seasonal cycles demonstrated by all three groups of bacteria did not seem to closely coincide with summer monsoon rainfall-runoff events. These bacterial groups are probably present in the channel alluvium to considerable depth. Any flushing of bacteria with runoff events would be dampened considerably by the time these freshly contaminated waters reach their respective well fields. Geologic investigations indicate these wells are in highly permeable alluvial deposits.

One of the principal advantages to the conjunctive use of the FC and FS as pollution indicators is that it enables a FC:FS ratio to be calculated. This ratio has been proposed as a means of estimating the origin of contamination. Geldreich (*1967*) demonstrated that a FC:FS ratio less than 0.7 usually indicates the primary source of contamination as originating from warm-blooded animals, excluding humans, whereas a ratio greater than 4.0 would primarily indicate a human source of pollution effluent. Geldreich (*1958*) recommended that the FC:FS ratio be considered valid only during the first 24 hours immediately following the discharge of micro-organisms into aquatic habitats. The reasoning is that unless the FC and FS die off at identical rates, the FC:FS ratio will gradually drift with time so as to no longer accurately reflect the original source of contamination.

McFetters and Mane (*1972*) reported that members of the FS group died off at rates differing from that of the FC. Briefly, the FS are defined as those hemolytic organisms that can be serologically typed with a prepared antigen-precipitin test and placed in Lancefield's group D. The Lancefield's group D organisms include, among others, *Streptococcus faecalis, S. bovis,* and *S. equinus.* McFetters (*1972*) reported that *S. faecalis* survived better than FC, which survived better than *S. bovis* and *S. equinus.* Reliance upon the diagnostic value of the FC:FS ratio must be carefully dealt with, especially when runoff waters are over 24 hours old.

FC:FS counts are extremely low for these four wells, thus lessening the credibility of the ratios (Geldreich *1976*); however, based on an average of only six to eight animal units per section grazing the sampled rangeland, and with the scarcity of published data on this particular subject and area, these data are believed worthy of comparison with data from higher count areas.

The Federal Water Pollution Control Act Amendments of 1972 stipulate that background levels of contamination be established whenever and wherever the situation warrants. It should never be assumed that ground water aquifers are bacteriologically free. In arid land watersheds, background levels of ground water contamination are apparently going to have to be assayed individually. Wells are usually drilled until a water table is reached that will yield a dependable source of water. To avoid excessive drilling costs, the water tables generally tapped are the ones closest to the surface. These water tables, then, also represent those most likely to experience surface water recharge. As a result, a vast number of wells may exist in contaminated aquifers (table 2).

Table 2.—*Mean values for upper watershed wells, 1977 and 1978*

Well	Site No.	TC[1]	FC[2]	FS[3]	FC:FS[4]	Water temperature	NO_3	Ph
		Numbers				°C	*Mg/L*	
Jones' Well	11	3.25×10^2	3.50×10^1	1.19×10^2	0.294	37	1.3	8.0
Doug's Windmill	9	1.67×10^5	1.10×10^1	3.10×10^3	.003	21	3.1	7.6
Bennett's Windmill	20	1.10×10^3	1.30×10^1	5.10×10^1	.241	25	3.7	7.8
Cowan's Deep Well	7	5.11×10^4	1.20×10^1	2.00×10^1	.600	21	1.9	7.8

[1]TC = total coliform.
[2]FC = fecal coliform.
[3]FS = fecal streptococci.
[4]FC:FS = fecal coliform to fecal streptococci ratio.

Sanitary bacteriological indicators are a reasonable means of detecting rechargeable aquifers, since fecal bacterial organisms are not native inhabitants to uncontaminated ground water resources. Most surface water resources, on the other hand, will generally yield small numbers of bacteriological indicators, since surface waters represent the bacteriological contributions from the entire surrounding watershed, including fecal micro-organisms.

The idea of bacteriological ground water contamination has been thought of as an ephemeral situation in most aquifers; nevertheless, the situation on the Walnut Gulch Experimental Watershed dictates that contamination is a year-round occurrence. These data represent one isolated watershed in an arid land situation. The importance of fully evaluating a contaminating syndrome such as this has to be examined in more detail with other contrasting study areas.

Bacteriological Flushing

Data obtained from the routine sampling of wells during the rainy season of the summer of 1977 suggested that rainfall-related runoff events had a profound effect upon the bacteriological quality of the water sampled from wells located in close proximity to the main drainage channel of the watershed. Early in the sampling schedule during June 1977, well site 2 (fig. 3) was sampled a number of times and was found to be free of bacteriological indicators (fig. 8). Subsequent to the numerous runoff events that summer, however, pulses of coliform bacteria occurred repeatedly in samples obtained from wells 2, 3, and 4 (figs. 8, 9, and 10, respectively). All of these wells responded in a similar fashion; nevertheless, the bacteriological expression was individual for each separate well site. Numerous hydrologic and geologic processes serve to profoundly influence each well site independently; however, the overall effects of ground water recharge through a relatively porous media can readily be observed.

All well sites sampled from the watershed contained at least a minimal number of TC organisms. The well sites located in close proximity to the main drainage channel (wells 2 and 3) yielded the lowest average coliform levels found in this field study; yet these same wells also proved to be most susceptible

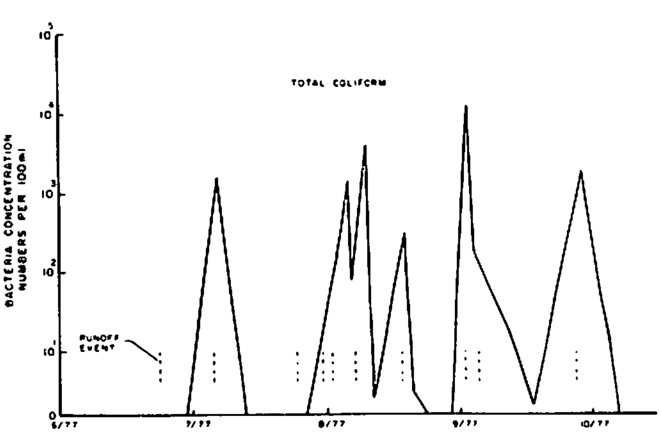

Figure 8.—Total coliform concentration, City Well 2, site 2, during the summer of 1977.

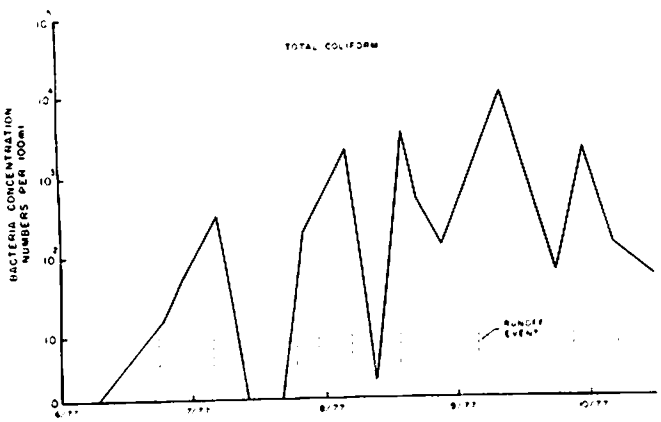

Figure 9.—Total coliform concentration, Little Green Ranch, site 3, during the summer of 1977.

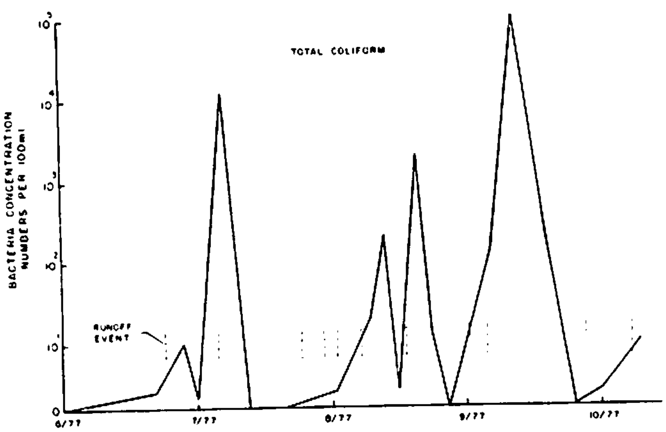

Figure 10.—Total coliform concentration, Holiday Estates Well, site 4, during the summer of 1977.

to contamination cycles associated with runoff events. This is most likely explained by the fact that these wells are located in or near the present braided-stream complex. Soil bacteria and manure deposited on the landscape by grazing animals and wildlife during dry periods are swept along by summer storm runoff and deposited in stream channels. Older buried channels and meanders intersect boulder beds and permeable sand and gravel layers in the alluvium, which can create a subsurface hydraulic connection with the present existing channel. In addition, drainage channels often aline themselves along local faultlines, which may help explain the relative speed with which these wells experience contamination following surface runoff.

To support the bacteriological data, we decided to implement a tracer study. This study involved placing an organic tracer compound, not contained in previous well water samples, into runoff water some distance upstream from the selected well sites. With the help of Glenn Thompson and the Hydrology and Water Resources Department at the University of Arizona, an organic tracer, bromodichloromethane (BCF), was obtained. On the evening of September 1, 1977, a typical convective summer thunderstorm was registered on a number of recording rain gages located on the watershed (almost 2 inches of rain in 90 min).

The watershed had had a number of rainfall-runoff events through the summer. As such, wet antecedent conditions insured a heavy runoff event. At 8:15 p.m., on the evening of September 1, 40 ml of BCF dissolved in one gallon of ethanol was metered into the runoff water, via a mariott flask, at a site approximately 1 mile upstream from well site 2. The tracer was subsequently positively isolated from well site 2 at a concentration of one part per trillion (1 p/t = 10^{12} g of tracer per ml of sample) and 3 p/t from well site 3. The samples were collected from these sites from (8:00 to 10:00 a.m.) on September 2.

Further tracer experiments, conducted during the summer of 1978, again demonstrated the presence of tracer from these same well sites. Tracer was never isolated from well sites 1, 4, 5, or 6, which are hydraulically downgradient from the inspection site. Other well sites were not tested for the presence of tracer.

Table 3 lists the bacteriological and other data obtained from the remaining wells sampled during this field study. Of all the wells listed in this table, only three sites, 1, 4, and 5, show a FC:FS ratio greater than one. Only site 4 was shown to have a ratio greater then 4.0 (6.6), which Geldreich (*1967*) recommends as the threshold indicating human fecal material as the primary source of contamination. Site 4 represents a recently constructed well and serves as the sole drinkable water supply for the Holiday Estates housing development. This currently serves a community of approximately 50 homes in the vicinity of Tombstone. The well is surrounded on all sides by individual homes and their onsite septic tanks and leaching fields. It is uncertain at this time what, if any, effects are caused by sewage leaching fields. The 6.6 FC:FS ratio must be suspect due to the extremely low indicator count values; however, as the ratio represents a mean value of 42 samplings, a fecal pollution problem may very well exist. In light of other well contamination cycles existing on the watershed, the potentials for contamination are numerous. A detailed investigation of this well will have to be undertaken before the cause and relationship of contamination can be pinpointed.

Pulses of organisms resulting from runoff events were not detected in the remainder of the wells listed in table 3; however, all wells sampled contained bacterial indicator organisms. The situation existing in these wells is apparently analogous to those wells (table 2) located on the upper portion of the watershed, which were discussed earlier. Apparently, all the remaining wells also extend into a rechargeable aquifer, as evidenced by the presence of FC organisms. The FC:FS ratio calculated for the majority of these wells indicates, again, that animal contamination and soil derived coliforms are the main sources of pollution to these well field aquifers. More information is needed in regard to the mechanisms of this recharge. The presence of indicator coliform organisms in these ground waters suggests a more commonplace condition than previously considered possible. Further research is needed to determine the depth to which recharge water and contaminating organisms occur and the rate at which these organisms migrate through ground water.

Table 3.—*Mean values for water quality samples taken during 1977-78*

Well	Site No.	TC[1]	FC[2]	FS[3]	FC:FS[4]	Water temperature	NO_3
			Numbers			*°C*	*Mg/L*
City Well 1	1	2.96×10^{3}	1.24×10^{2}	3.84×10^{1}	3.23	27	12.7
City Well 2	2	1.03×10^{3}	2.26×10^{0}	5.89×10^{1}	.038	24	3.1
Little Green Ranch	3	8.52×10^{2}	4.10×10^{0}	1.10×10^{1}	.372	24	6.2
Holiday	4	2.59×10^{3}	1.00×10^{1}	1.50×10^{0}	6.66	24	1.7
Westside Shaft	5	1.94×10^{3}	2.50×10^{0}	2.20×10^{0}	1.13	25	3.5
Montijo Flats	6	1.5×10^{4}	2.0×10^{2}	1.9×10^{3}	.105	23	2.9
Cowan's Deep Well	7	5.11×10^{4}	1.20×10^{1}	2.00×10^{1}	.600	21	1.7
Cowan's Shallow Well	8	2.00×10^{3}	2.50×10^{1}	1.97×10^{2}	.126	22	3.7
Doug's Well	9	1.67×10^{5}	1.10×10^{1}	3.10×10^{3}	.003	21	3.1
Charlie's Big Windmill	10	7.00×10^{3}	4.00×10^{0}	6.80×10^{1}	.059	23	2.7
Jones' Well	11	3.25×10^{3}	3.50×10^{1}	1.19×10^{2}	.294	36	1.4
Old Home Ranch	12	1.21×10^{3}	2.08×10^{1}	2.50×10^{2}	.083	24	5.5
Escapule's Well	13	2.00×10^{2}	1.50×10^{0}	4.50×10^{1}	.033	28	3.1
Robertson's Well	14	6.00×10^{4}	9.90×10^{1}	4.36×10^{3}	.023	22	3.5
Clyne Well	15	4.76×10^{4}	2.20×10^{1}	1.16×10^{3}	.019	20	2.1
Watershed Windmill	16	3.60×10^{3}	1.00×10^{1}	1.42×10^{2}	.070	24	3.1
Lucky Hills Well	17	2.40×10^{3}	1.50×10^{1}	2.66×10^{2}	.056	23	4.1
City Well 3	18	3.41×10^{2}	2.70×10^{0}	4.40×10^{1}	.061	23	2.7
Charlie's Small Windmill	19	2.0×10^{3}	4.1×10^{1}	2.31×10^{2}	.177	20	4.5
Bennett's Well	20	1.10×10^{3}	1.30×10^{1}	5.40×10^{1}	.241	23	3.7

[1]TC = total coliform.
[2]FC = fecal coliform.
[3]FS = fecal streptococci.
[4]FC:FS = fecal coliform to fecal streptococci ratio.

San Pedro River Runoff

The streamflow in the San Pedro River at Fairbank, Ariz. (approximate drainage area, 1,120 mi²), was sampled for indicator bacteria from June 1977 until June 1978 (fig. 11). The San Pedro River drains a total area of 4,483 mi², 696 mi² of which are in Mexico (Roeske and Werrell *1973*). Most mountains bordering the river valley rise to altitudes of 6,000 ft or more, with some peaks contributing snowmelt during a portion of the year. The stream is intermittent except for a short period during the summer when flow increases due to seasonal runoff. The nearest human habitation is a concentration of dwellings located near the river, approximately 8 miles upstream from the sampling site; otherwise, the water quality of the sampling area should not be influenced by human activity. During periods of summer runoff, TC numbers averaged 6.9×10^{5}; FC, 8.4×10^{3}; FS, 9.2×10^{3}; and the FC:FS ratio was 0.91. During periods of winter baseflow, the TC average dropped to 3.9×10^{3}; FC, 3.0×10^{1}; FS, 6.8×10^{1}, and the FC:FS ratio was 0.44. The baseflow numbers most likely represent present day approximate background bacterial levels. A high FC:FS ratio is generally indicative of a contaminated water resource; therefore, a decreasing ratio with time should indicate an improvement toward the natural or background water quality.

Figure 11 illustrates some instances during runoff events in which FC far outnumbered FS. FC:FS ratios reached 6.5 on July 1, 1977. TC organisms are always found in more abundance because they comprise a large group of organisms, and many are normal soil inhabitants. Standard plate count organisms also followed exactly the cycles demonstrated by the bacterial indicator groups. It is not surprising to see such high numbers of standard plate count organisms, since this group includes most aerobic heterotrophic bacteria. Temperature of the baseflow seems to influence microbial

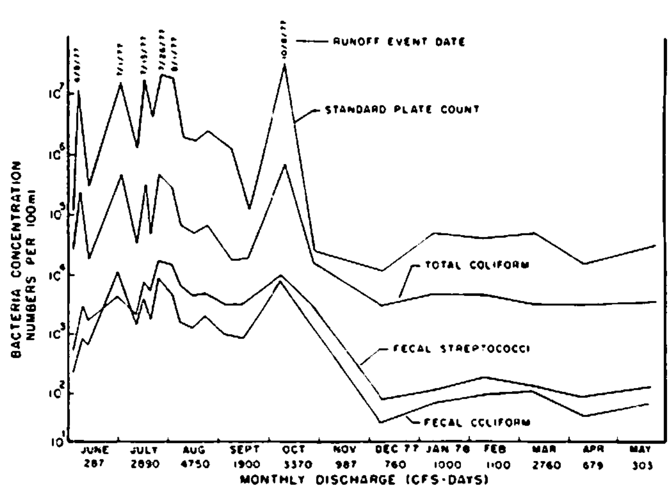

Figure 11.—Flow data in monthly cumulative cubic-feet-per-second days, San Pedro River at Fairbank, Ariz. Bacteria concentrations are shown for a 12-month period in 1977-78.

growth. All groups of bacteria organisms seemed to increase in number as water temperature increased in the spring of 1978, with an apparent change in the character of the baseflow. Further bacteriological work must be completed before any firm conclusions can be made from data of this nature.

Walnut Gulch Runoff

The Walnut Gulch Experimental Watershed is a typical, semiarid, grass-brush watershed where flow events in the drainage channels are ephemeral and are usually associated with high intensity, short duration thunderstorms. In the main drainage channels, there is little baseflow of any significance. As a result of high intensity thunderstorms on a sparsely vegetated semiarid watershed, extremely high numbers of bacterial indicators are carried by runoff water, including vast amounts of soil particulate matter.

Figure 12 illustrates the areal extent of the runoff-producing storm of July 25, 1978, at the Walnut Gulch Experimental Watershed. Figures 13 to 15 illustrate bacteria concentrations decreasing with time during flow events at three flow-measuring sites located in figure 3. The highest numbers of bacteria are present in the first part of the flow event.

ple, collected from an area that drains a portion of the urban area surrounding and including the town of Tombstone, yielded a FC:FS ratio of 5.7.

Figure 15 illustrates the runoff from a small watershed located at Lucky Hills (site C, fig. 3). This 11.2-acre site has been excluded from grazing-animal use for over 20 years, resulting in an increased forage cover and subsequent increased small animal population. This is believed to be responsible for the high FC:FS ratio at the start of the flow event. The initial flow from this watershed gave a FC:FS ratio of 2.8, which dropped to 0.32 by the end of the flow event. Again, when the FC:FS ratio falls to such a low value, this should indicate an improvement in water quality, whereas rising ratios should indicate a higher degree of bacteriological contamination in waters.

Figure 16 illustrates the increase in bacteria concentration with distance as flow proceeds downslope in a heavily grazed pasture (site D, fig. 3). Samples of runoff were taken commencing at a hilltop and at 100-ft intervals downslope in the pasture.

Bacterial accumulation may occur quickly as in rills or with the start of sheet flow. Thus, bacterial concentrations may be substantial by the time flow is concentrated into even small drainage channels.

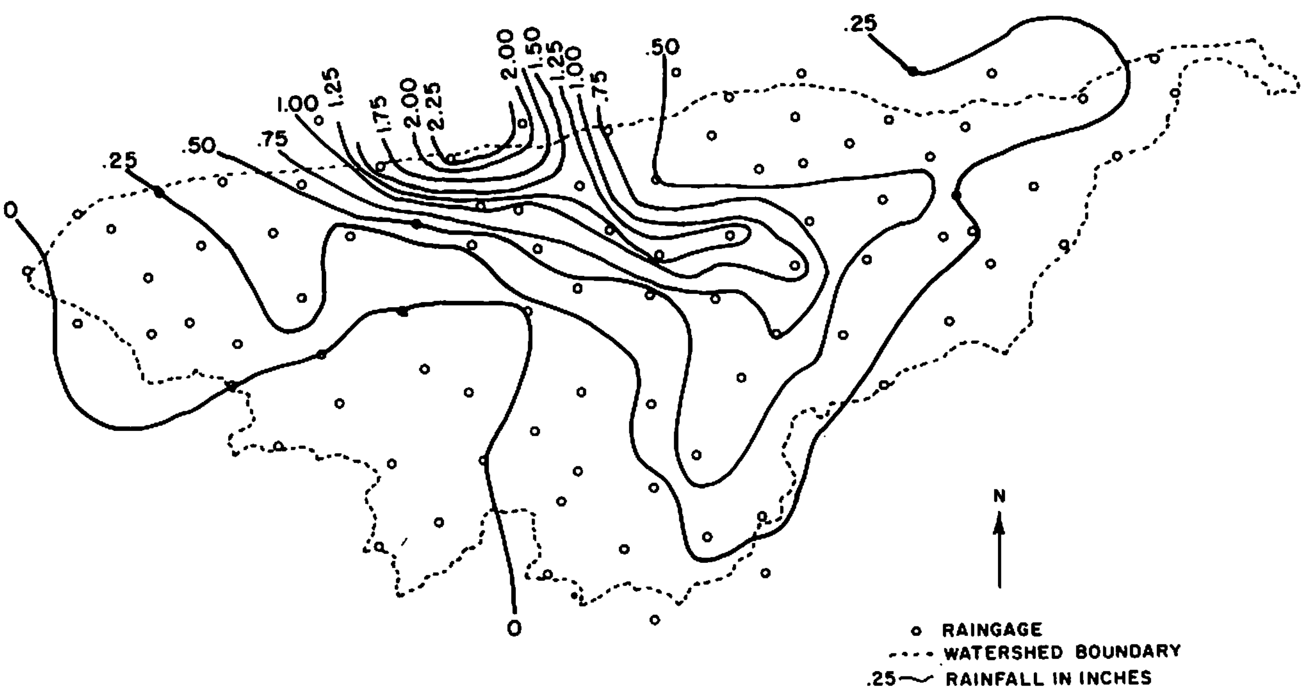

Figure 12.—Isohyetal map of July 25, 1978, storm on Walnut Gulch Experimental Watershed.

FC:FS ratios seemed to behave in an erratic manner. The initial runoff water that passed through flume 8 (site A, fig. 3) had a ratio of 1.6. As the flow event continued, the ratio decreased with time until the final sample, which had a ratio of 0.63. At flume 2 (site B, fig. 3), an initial ratio of 0.91 was measured, and the final ratio was 1.4. A rise in the ratio through a flow event could be indicative of highly contaminated additional runoff from urban areas intersecting the runoff between flume 8 and flume 2. An isolated runoff sam-

The data recorded from the baseflow in the San Pedro River and the Lucky Hills subwatershed, where the lowest FC:FS ratios were recorded, probably represent the present day natural or background bacteriological standards. Random water samples were collected from baseflow at upper Ramsey Canyon, located in the Huachuca Mountains in southeastern Arizona. This canyon is an uninhabited recreational forest area, supervised by the U.S. Forest Service, with no grazing by domestic livestock. The samples yielded FC and FS numbers comparable with the San Pedro baseflow, except that the FC:FS ratio was 0.19. Apparently, the ratio decreases as the water quality improves. In establishing bacteriological water quality standards for Arizona, more comparisons must be made to determine if ratios remain low in wilderness watersheds.

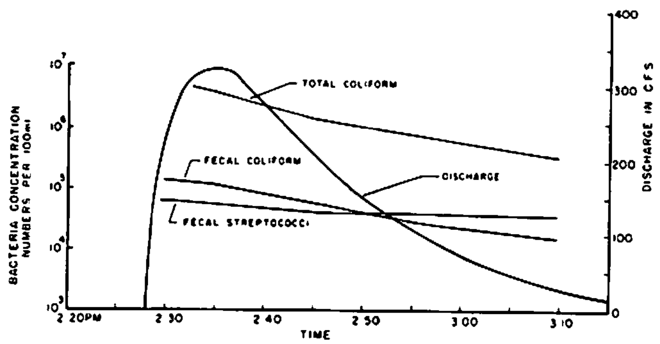

Figure 13.—Bacteria concentration fluctuations and hydrograph for flow event on July 25, 1978, flume 8 (site A, fig. 3).

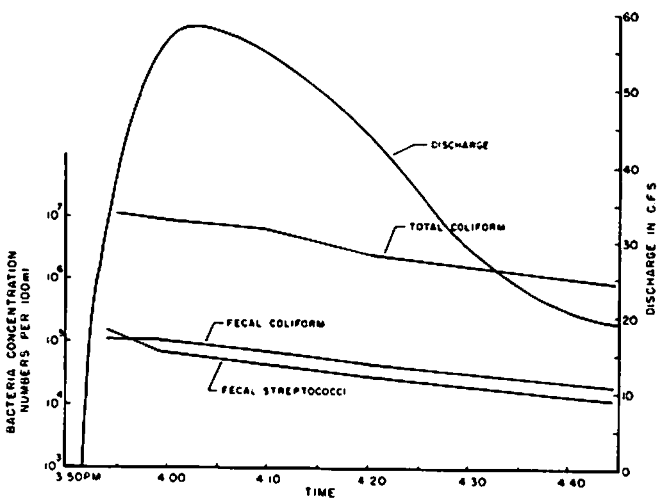

Figure 14.—Bacteria concentration fluctuations hydrograph for flow event on July 25, 1978, flume 2 (site B, fig. 3).

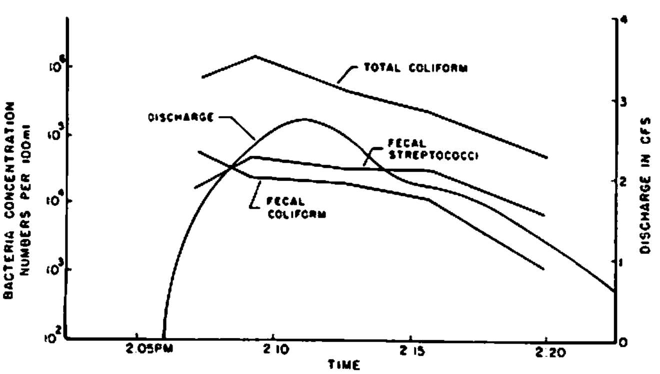

Figure 15.—Bacteria concentration fluctuations and hydrograph for flow event on July 25, 1978, Lucky Hills Watershed 4 (site C, fig. 3).

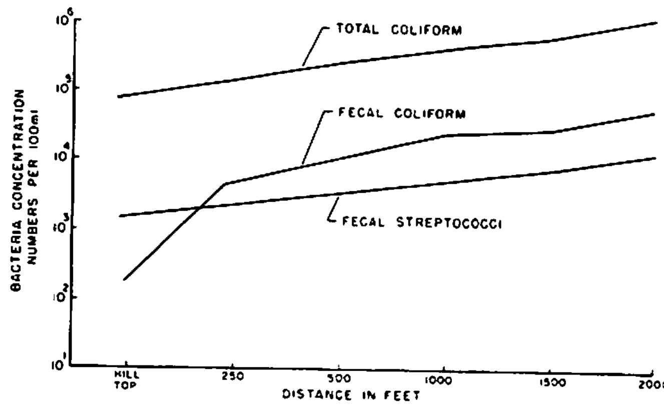

Figure 16.—Bacteria concentration with distance from the watershed divide in a heavily grazed pasture (site D, fig. 3).

Even though the concentration of TC organisms isolated in runoff water reached nearly 10^7, well water samples never exceeded 10^4 organisms. TC were measured in samples taken of the channel sediment during the dry summer months. Sampling the upper 6 ft of alluvium indicated that 10^4 TC organisms per 100 g were present in the channel. The channel sediment contained mostly moist sand and gravel. Fine-grained silts and clays from stock tank sediments yielded 10^6 TC organisms per 100 g. Apparently, the channel sediment may serve as a vast reservoir of TC organisms.

The continual presence of bacteriological indicators in the upper watershed wells (figs. 4 to 7) can be explained by the possible presence of bacteria in the channel sediment to appreciable depths; however, since runoff events seem to contaminate well water so quickly (figs. 8 to 10), it does not seem plausible that water is passing through hundreds of feet of channel sediment that quickly. Since some of these wells are located near the edge of the alluvium-filled basins, water may be penetrating quickly through the alluvium-bedrock interface or through the numerous faultlines and fractures.

City Well 1

Tombstone High School is suspected of being a potential polluter of ground water, especially between September and May, when approximately 300 students are in attendance.

Tombstone City Well 1 is located approximately 50 ft west of the Tombstone High School complex, with its associated septic tank-leaching field sewage disposal system. This well has had a previous history of contamination. In 1972, the Arizona Public Health Department temporarily closed the well due to the presence of coliform organisms above the public health standards established for drinking water supplies. The well has since been reopened and will apparently remain so as long as well water is mixed with other water sources, chlorinated, and routine water analysis is carried out. The well is positioned directly above a deep, expansive network of mine shafts and tunnels extending to a depth of approximately 600 ft. At the time of the investigation, there were no sewers in Tombstone. A number of septic tanks and leaching fields are located primarily in the residential sector, and some of the businesses in this popular tourist town discharge their sewage into various abandoned mine shafts, many of which are flooded.

Figure 17 illustrates the TC and FC data isolated from City Well 1 during the summer of 1977. Although school sessions ended in late May, TC and FC levels remained detectable until late July. A summer recreation program which utilizes the facility, coincidentally, terminated in late July. Numerous samples collected in August failed to show indicator coliforms. In contrast, coliform numbers increased markedly when school sessions began in September. During the remainder of the fall season, the well was undergoing repairs.

The mines of Tombstone are located in the same general area where wells are drilled. It is not surprising to see such a strong response of bacteria in the situation demonstrated in Tombstone. Little bacteriological attenuation can be expected in areas with extensive rock fractures, fault blocks, and extensive mine workings. Few alluvial deposits are associated with the geology under the immediate city area. Some factors may play a role in forestalling pollution of well fields, such as the presence of permeable dikes or new ground water intrusion. Tombstone's "sewage mines" apparently are capable of contaminating well field aquifers fairly quickly. Continued chlorination of these well waters will be necessary until all sewage mine waste disposal practices are terminated.

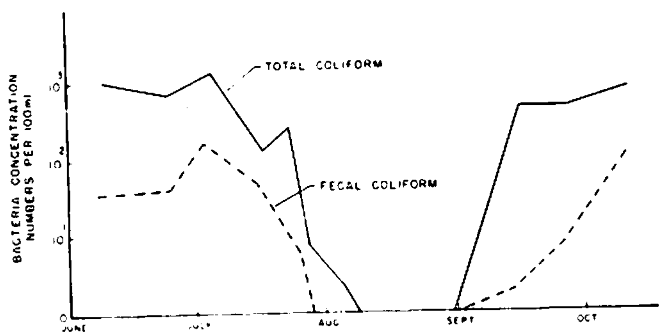

Figure 17.—Total and fecal coliform counts isolated from City Well 1, Tombstone, Ariz., during the summer of 1977.

Conclusions

Semiarid rangelands are potential sources of pollution to regional ground water in many areas of the Southwestern United States. The high intensity-short duration thunderstorms characteristic of this region promote large volumes of runoff during the summer monsoon season, although water yield may be low due to large transmission losses. Erosion and sedimentation are severe from these runoff events. A buildup of manure from grazing animals occurs in the channels and soil bacteria during the dry periods. Such accumulations are flushed into the ephemeral channels during the monsoon season. This promotes high concentration of FC and FS in the early portion of runoff, which lessens as the runoff rate decreases in the later stages of the storm. This washing action on the land surface and channels results in pulses of pollutants entering subsurface waters and wells, especially near large ephemeral channels.

This situation exists for two major reasons. First, ephemeral channels allow a buildup of manure, bacteria, and other pollutants on the soil surface and also at shallow depths. This accumulation increases until a runoff-producing storm of sufficient size carries it downslope, with a portion of it eventually infiltrating to ground water. The cycle then starts again, and continues until the next runoff event. Second, land usage practices contribute to the ground water pollution. Grazing strips the land surface of vegetative cover, promoting runoff and allowing animal wastes to concentrate in stream channel alluvium and not be efficiently used by vegetation. The concentration of animals near water sources (wells and stock tanks) promotes this overuse of the surrounding area and concentrates animal waste near the water source. Poor well construction may contribute to ground water pollution by allowing direct infiltration of bacteria-laden surface runoff to depth through improper or nonexistent well seals and leaking casings. This can often lead to a direct recharge route from surface to ground water.

Municipal sewage disposal systems, and even isolated private homes, can contribute heavily to ground water contamination. Septic tank-leaching field systems are the common sewage disposal method in southeastern Arizona. This may be a significant contributor to ground water pollution in this area, depending on local infiltration characteristics.

Background concentrations must be determined so that realistic water quality standards can be established. Ground water pollution at Walnut Gulch Experimental Watershed can originate from a variety of both point and nonpoint sources. Some of these sources have been contaminating ground water as long as infiltration and recharge processes have been actively present. Other sources, such as urban development, are new and expanding rapidly. These new sources are a major threat to future ground water quality and demand attention. Remedial measures that can be implemented now are erosion controls, reduction of overgrazing and reestablishment of vegetation on these badly abused areas.

Literature Cited

American Public Health Association. 1971. Standard methods for the examination of water and wastewater. Thirteenth edition, American Public Health Association, Inc., New York.

Babcock, H. M., and Cushing, E. M. 1942. Recharge to groundwater in a typical desert wash, Pinal County, Arizona. Transactions of the American Geophysical Union 23, Part 1, p. 49.

Bear, J. 1972. Dynamics of fluids in porous media. American Elsevier Publishing Co., New York, 764 p.

British Ministry of Health. 1934. Bacteriological examination of water supplies. Bulletin No. 71, London, England.

Buckhouse, J. C. 1976. Water quality implications of cattle grazing on a semiarid watershed in southeastern Utah. Journal of Range Management 29:109-112.

Doran, J. W., and Linn, D. M. 1979. Bacteriological quality of runoff water from pastureland. Applied and Environmental Microbiology 37(5):985-991.

Dorroh, J. H. 1961. Meteorological characteristics of the Southwest as related to water yields. *In* Symposium, Water yield in relation to environment in the Southern United States, Southwestern and Rocky Mountain Division, Arizona Association for the Advancement of Science, May 3, 1960. P. 47-50.

Everett, L. G. 1976. Monitoring groundwater quality: methods and costs. U.S. No. 600/4-76023, Santa Barbara, Calif.

Geldreich, E. E. 1958. The coliform group II. Reaction in EC medium at 45°. Applied Microbiology 6:347.

———1967. Fecal coliform concepts in stream pollution. Water Sewage Works 114:R-98.

Keppel, R. V., and Renard, K. G. 1962. Transmission losses in ephemeral stream beds. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 88(HY3):59-68.

Kligler, L. J. 1919. Non-lactose fermenting bacterial from polluted wells and sub-soil. Journal of Bacteriology 4:35.

Kunkle, S. H. 1967. Water quality of mountain watersheds. Colorado State University Paper No. 21, Ft. Collins, Colo. 27 p.

Levine, M. 1921. Bacteria fermenting lactose and their significance in water analysis. Iowa State Bulletin 62-117.

Libby, F., Wallace, D. E., and Spangler, D. P. 1970. Subsurface geology from seismic refraction studies of Walnut Gulch Experimental Watershed, Arizona. U.S. Department of Agriculture, Agricultural Research Service, ARS-41-164, 14 p. (Series discontinued; Agricultural Research Service is now Science and Education Administration-Agricultural Research.)

Lin, S. 1972. Nonpoint rural sources of water pollution. State of Illinois, Department of Registration and Education, Illinois 3, State Water Survey Circular, Urbana, Ill. 37 p.

McFeters, G. A., and Stuart, D. G. 1972. Survival of coliform bacteria in natural waters. Applied Microbiology 24(5):805-811.

Miller, D. W. 1974. Groundwater contamination in the Northeast States. U.S. No. 660/2-74-056, Boston, Mass.

Myrvik, Q. N. 1974. Fundamentals of medical bacteriology and mycology. Lea and Febiger, Philadelphia. 509 p.

Osborn, H. B., and Renard, K. G. 1970. Thunderstorm runoff at the Walnut Gulch Experimental Watershed, Arizona, U.S.A. Proceedings of the International Association of Scientific Hydrology-United Nations Educational, Scientific, and Cultural Organizations Symposium on Results of Research on Representative and Experimental Basins, Victoria University of Wellington, New Zealand, International Association of Scientific Hydrology 96:455-464.

Renard, K. G. 1970. The hydrology of semiarid rangeland watersheds. U.S. Department of Agriculture, Agricultural Research Service, ARS-41-161. (Series discontinued; Agricultural Research Service is now Science and Education Administration-Agricultural Research.)

Roeske, R. H., and Werrell, W. L. 1973. Hydrologic conditions in the San Pedro River Valley, Arizona 1971. Arizona Water Commission Bulletin No. 4, U.S. Geological Survey, Phoenix, Ariz.

Salle, A. J. 1973. Fundamental principles of bacteriology. McGraw-Hill, Inc. 1093 p.

Scalf, M. R. 1973. Groundwater pollution in the South-Central States. U.S. No. R-2, 73-268, Atlanta, Ga.

Schepers, J. S., and Doran, J. W. 1980. Effect of grazing management on the chemical and microbiological aspects of the environment. Proceedings of the Nebraska Forage and Grassland Council, Winter Meeting, Jan. 17, 1980, East Campus Union, University of Nebraska, Lincoln, Nebr.

Sewell, J. I. 1972. Effects of agricultural land use on the quality of surface runoff. Tenn. Farm and Home Science, Progress Report No. 82.

Skinner, Q. D., and R. D. Cook. 1974. Effect of summer use of a mountain watershed on bacterial water quality. Journal of Environmental Quality 3:329-335.

Stephenson, G. R. 1975. Water quality investigations on the Reynolds Creek Watershed. Interim Report No. 12-14-5001-6028. Bureau of Land Management, 73 p.

Stuart, D. G., and B. R. May. 1971. Effects of multiple use on water quality of high mountain watersheds: bacteriological investigations of mountain streams. Journal of Applied Microbiology 22:1048-1054.

Thornthwaite, C. W. 1941. Atlas of climatic types of the United States, 1900-1939. U.S. Department of Agriculture, Miscellaneous Publication No. 241, 7 p.

Van der Leeden, Fritz. 1975. Groundwater contamination in the Northwest States. U.S. No. 660/3-75-018, Corvallis, Oreg.

Wallace, D. E., and Renard, K. G. 1967. Contribution to regional water table from transmission losses in ephemeral streambeds. Transactions of the American Society of Agricultural Engineers 10(6):786-792.

Walter, W. G. 1967. Microbiological and chemical studies of an open and closed watershed. Journal of Environmental Health 30:157-163.

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