Plant Ecology of an Arid Basin Tres Alamos-Redington Area Southeastern Arizona

GEOLOGICAL SURVEY PROFESSIONAL PAPER 485-D

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By ROBERT C. ZIMMERMANN

VEGETATION AND HYDROLOGIC PHENOMENA

GEOLOGICAL SURVEY PROFESSIONAL PAPER 485-D

A study of variations in the plant cover of an arid basin, primarily as related to differences in surface-flow regimen

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CONTENTS

ILLUSTRATIONS

TABLES

LIST OF PLANTS

[Scientific names after Kearney and Peebles (1960) unless otherwise indicated]

Common name	Scientific name
Acacia:	
Catclaw	*Acacia greggii* Gray
Chihuahuan whitethorn.	*vernicosa* Standl.
Whitethorn	*constricta* Benth.
Agave:	
Mountain	*Agave schottii* Engelm.
Palmer	*palmeri* Engelm.
Alder, Arizona	*Alnus oblongifolia* Torr.
Allthorn	*Koeberlinia spinosa* Zucc.
Arrowweed	*Pluchea sericea* (Nutt.) Coville
Ash, Arizona or velvet	*Fraxinus velutina* Torr.
Barrel cactus	*Ferocactus wislizeni* (Engelm.) Britt. & Rose.
Beargrass	*Nolina microcarpa* Wats.
Brickellia	*Brickellia californica* (Torr. & Gray) Gray *floribunda* Gray
Brittlebush	*Encelia farinosa* Gray
Buckthorn	*Rhamnus betulaefolia* Greene.
Bumelia	*Bumelia lanuginosa* (Michx.) Pers.
Burrobrush	*Hymenoclea monogyra* Torr. & Gray
Bur-sage, white	*Franseria dumosa* Gray
Buttonbush	*Cephalanthus occidentalis* L.
Cactus:	
Christmas	*Opuntia leptocaulis* DC.
giant or saguaro	*Carnegiea gigantea* (Engelm,) Britt. & Rose
Carlowrightia	*Carlowrightia linearifolia* (Torr.) Gray
Cassia	*Cassia covesii* Gray *leptocarpa* Benth.
Cholla	*Opuntia fulgida* var. *mammillata* (Schott) Coult. *versicolor* Engelm.
Coral bean	*Erythrina flabelliformis* Kearney
Cottonwood, Fremont	*Populus fremontii* Wats.
Creosotebush	*Larrea tridentata* (DC.) Coville
Crucillo, Mexican or squaw-bush	*Condalia spathulata* Gray
Cylindropuntia	*Opuntia* sp.
Desertbroom	*Baccharis sarothroides* Gray
Desert-honeysuckle	*Anisacanthus thurberi* (Torr.) Gray
Desert-willow	*Chilopsis linearis* (Cav.) Sweet
Elderberry, Mexican	*Sambucus mexicana* Presl
Encelia	*Encelia frutescens* Gray
False-mesquite	*Calliandra eriophylla* Benth.
Fig	*Ficus carica* L. (Fernald, 1950)
Fir:.	
Douglas	*Pseudotsuga menziesii* (Mirbel) Franco
white	*Abies concolor* (Gordon & Glendinning) Hoopes
Grama	*Bouteloua* sp.
Grape, Arizona	*Vitis arizonica* Engelm.
Graythorn	*Condalia lycioides* (Gray) Weberb.
Hackberry:	
hackberry or palo-blanco.	*Celtis reticulata* Torr.
desert	*pallida* Torr.
Honeysage or lippia	*Aloysia wrightii* (Gray) Heller.
Hopbush	*Dodonaea viscosa* Jacq.
Indigobush	*Amorpha fruticosa* L.
Jimsonweed	*Datura meteloides* DC.
Jointfir	*Ephedra trifurca* Torr.
Juniper:	
alligator	*Juniperus deppeana* Stend.
one-seed	*monosperma* (Engelm.) Sarg.
Lycium	*Lycium berlandieri* Dunal *exsertum* Gray.
Manzanita	*Arctostaphylos pungens* H.B.K.
Menodora	*Menodora scrabra* Gray.
Mesquite	*Prosopis juliflora* var. *velutina* (Woot.) Sarg.
Mimosa	*Mimosa biuncifera* Benth.
Muhly	*Muhlenbergia* sp.
Mulberry, Texas	*Morus microphylla* Buckl.
Oak:	
Arizona white	*Quercus arizonica* Sarg.
Emory	*emoryi* Torr.
Mexican blue	*oblorgifolia* Torr.
scrub	*turbinella* Greene.
Ocotillo	*Fouquieria splendens* Engelm.
Osage-orange	*Maclura pomifera* (Raf.) Schneid. (Fernald, 1950).
Paloverde:	
blue	*Cercidium floridum* Benth.
foothill or green	*microphyllum* (Torr.) Rose & Johnston.
Pine:	
ponderosa	*Pinus ponderosa* Lawson.
Southwestern white.	*reflexa* Engelm.
Platyopuntia	*Opuntia* sp.
Poison-ivy	*Rhus radicans* L.
Pricklypear	*Opuntia engelmannii* Salm-Dyck *phaeacantha* Engelm.
Rabbitbrush	*Chrysothamnus nauseosus* (Pall.) Britton.
Ragweed, canyon	*Franseria ambrosioides* Cav.
Russian-thistle	*Salsola kali* L.
Saguaro, giant cactus.	*Carnegiea gigantea* (Engelm.) Britt. & Rose.
Saltbush, four-wing	*Atriplex canescens* (Pursh.) Nutt.
Saltcedar, five-stamen	*Tamarix pentandra* Pall.
Sandpaperbush	*Mortonia scabrella* Gray

Common name	Scientific name
Seepwillow, batamote	*Baccharis glutinosa* Pers.
Soapberry	*Sapindus saponaria* L.
Sotol	*Dasylirion wheeleri* Wats.
Spruce, Engelmann	*Picea engelmanni* Parry
Squawbush	*Rhus trilobata* Nutt.
Sumac:	
sumac	*Rhus choriophylla* Woot. & Standl.
littleleaf	*microphylla* Engelm.
Sycamore, Arizona	*Platanus wrightii* Wats.
Tarbush	*Flourensia cernua* DC.
Three-awn	*Aristida* sp.
Tree tobacco	*Nicotiana glauca* Graham
Trumpetbush	*Tecoma stans* (L.) H.B.K.
Walnut, Arizona	*Juglans major* (Torr.) Heller
Willow:	
black or Goodding	*Salix gooddingii* Ball.
Bonpland	*bonplandiana* H.B.K.
yew-leaf	*taxifolia* H.B.K.
Yucca or palmilla	*Yucca elata* Engelm.
Zinnia:	
yellow desert	*Zinnia grandiflora* Nutt.
white desert	*pumila* Gray

PLANT ECOLOGY OF AN ARID BASIN, TRES ALAMOS–REDINGTON AREA SOUTHEASTERN ARIZONA

By ROBERT C. ZIMMERMANN

ABSTRACT

The area studied includes about 750 square miles of the middle reach of the San Pedro Valley in Cochise, Pima, and Graham Counties, southeastern Arizona. The San Pedro Valley is in the Gila-Colorado drainage basin in the Basin and Range physiographic province. The reach studied is flanked by mountains locally more than 8,000 feet high and by gently sloping valley fill several miles wide and in places more than 1,000 feet thick. Average annual rainfall is about 12 inches. Flow regimens are mainly ephemeral storm runoff and perennial or less continuous flows that probably last at least 6 months in most years. Other flow categories used for convenience are "persistent pools," or pools that last for at least 1 month beyond storm runoff, and intermittent flows that last more than 3 days but less than 2 months. The flow categories used may be valid only for the fall, winter, and early spring of most years. In the summer, despite heavy storm runoff, base flow disappears in many reaches. After exceptionally heavy rainfall in December 1965, flows lasting more than 2 weeks occurred in some reaches previously classified as having only ephemeral regimen.

The vegetation ranges from shrubs and cactuses at an altitude of about 3,000 feet to spruce-fir forests at about 8,000 feet. Striking variations in the vegetation occur, however, at the same altitude, presumably because of differences in moisture regimens in different substrates. For example, relatively undissected slopes underlain by deep, friable loams support small trees, mainly mesquites and acacias, and a grass cover, whereas dissected slopes underlain by cohesive older valley fill support only stands of shrubs, mainly creosotebushes, generally not floored by grasses.

The vegetation growing on valley floors ranges from stands of shrubs with the same species composition as those growing on adjacent uplands to a closed-canopy forest composed mainly of trees that grow only on bottom lands. In general, valley floors support many species, referred to as valley-floor species, that were not seen on uplands. Examples of these are ash, walnut, desert-willow, seepwillow, cottonwood, hackberry, and sycamore. The proportion of valley-floor species to other species along a stream probably reflects relative moisture conditions on the valley floor.

Drainage area, geology, and flow regimen are probably the three most important controls in the distribution of valley-floor vegetation. With uniform basin geology and ephemeral flow regimen, the differentiation between valley-floor and upland vegetation increases with increasing drainage area, though not indefinitely. On bedrock, differences between valley-floor vegetation and the plant cover of adjacent uplands occur at points where the drainage area is far less than on unconsolidated valley fill. Sustained flows, or flows other than ephemeral, eliminate the effect of drainage area and geology on valley-floor vegetation. This is illustrated by the similarity between the vegetation growing along large streams with base flows and that growing near springs or seeps. Quality of water also seems to affect the distribution of plants on valley floors. This is suggested by differences between the vegetation of the San Pedro River, a stream draining more than 2,000 square miles of arid basin, and that of tributaries draining less than 150 square miles and flowing only a short distance from humid mountains.

The distribution of vegetation along a stream with headwaters on bedrock, a middle reach in a basin underlain by thick fill, a lower-middle reach in a constricted canyon, and a lower reach on valley fill is illustrative of the most common variations in valley-floor vegetation found in tributaries of the study area. In the headwaters, the vegetation on the valley floor is similar to that of the uplands. Where the drainage area is between 1 and 2 square miles, valley-floor species have their uppermost stations. With increasing drainage area, the valley floor widens, and aquifers in the alluvium sustain base flows. Given an optimum combination of valley-floor width, thickness of alluvium, and sustained flows, the vegetation may be a closed-canopy forest composed of cottonwood, black willow, ash, walnut, sycamore, and hackberry. Where the stream crosses the basin underlain by thick fill, flow regimen is usually intermittent. The vegetation in such a reach usually consists of species characteristic of reaches with perennial or semiperennial flows mixed with species common along ephemeral streams. Thus in a reach with flow regimen intermediate between ephemeral and semiperennial, the valley-floor vegetation is also intermediate in species composition. In the constricted bedrock canyon, flow regimen may be perennial, but the alluvium may be thin or almost missing; flood damage to plants may be severe owing to the small cross-sectional area of the channel. As a result, canyons commonly support little or no woody vegetation. Downstream from the mountain front, the vegetation usually changes abruptly at the point where base flows disappear in the valley fill. Individual ashes or sycamores, or other species common in wet sites, may grow downstream from the canyon mouth. The establishment of these plants is apparently related to the slow advances and retreats of flows out of the bedrock canyon in the winter and

spring. Trees like ash may also become established in reaches with ephemeral flow regimen as a result of infrequent heavy and sustained runoff in these reaches. Such runoff occurred after the record rainfall of December 1965. In general, the number of valley-floor species decreases away from the mountain front and approaching the mainstem, despite increasingly shallow ground water. This decrease is probably related to channel losses, as most of the runoff is lost near the canyon mouth. Shallow ground water does not alter the composition of the valley-floor vegetation because this composition is primarily determined by the duration of surface flow at the germination-seedling stage.

In the study area, water tables deeper than 40–50 feet probably do not sustain plant life. This is indicated mainly by the aspect of mesquite—probably the deepest rooting species—in areas with different ground-water depths. Most plants probably have root zones within the top 20–30 feet of the substrate. Most of the valley-floor vegetation in the study area appears to grow independently of regional water tables, as these are in most reaches deeper than 40 feet. The species that seem to require shallow ground water for survival during at least part of the year are few and probably cover too small an area to affect the regional hydrology.

The variations in the vegetation of the San Pedro Valley can be related largely to easily recognized differences in moisture regimens. Some variations, however, seem to reflect flow conditions that probably occur every year but that are not immediately apparent. More rarely, distributions of plants may be related to flow events with recurrence intervals of perhaps as much as 20 years. Variations in the plant cover can thus be explained in terms of current conditions or processes, though the processes may occur either frequently or infrequently. The study of the vegetation of the San Pedro Valley supports a uniformitarian view of the development of the botanical landscape.

INTRODUCTION

In the San Pedro Valley, an arid basin of southeastern Arizona, striking variations in the vegetation coincide with differences in the physical landscape. Some bedrock canyons support tall, closed-canopy forests composed of trees belonging to genera commonly found in humid regions. A few hundred yards downstream from the canyons, however, where the stream emerges onto thick, unconsolidated intermontane fill, valley-floor vegetation may consist of thickets composed only of plants characteristic of the Sonoran Desert. Other bedrock canyons are almost devoid of woody vegetation. On the other hand, ephemeral streams located on the unconsolidated fill but with drainage areas exceeding 10 square miles may be lined with dense stands of trees that do not grow on the desert uplands. Many other variations in the valley-bottom vegetation occur, depending upon the size and geology of the drainage basin, and on the flow regimen.

Striking differences in the plant cover are not confined to valley floors. Valley flanks underlain by deep loam support trees and a grass cover, whereas slopes located at the same altitude but underlain by dissected deposits are mantled only by open stands of shrubs. In general, most plant distributions of the San Pedro Valley can be explained in terms of easily recognized variations in moisture availability, such as perennial as opposed to ephemeral flow regimen. Other variations in the plant cover are, however, apparently related to less obvious differences in hydrology, such as flows occurring at infrequent intervals.

The area studied is in the San Pedro Valley of southeastern Arizona, between Tres Alamos and Redington (fig. 1). Most of this area is in Cochise County; only its western and northern fringes are in Pima and Graham Counties, respectively. The area, about 30 miles long and 25 miles wide, hereafter referred to as the Tres Alamos–Redington area, is part of an intermontane basin with predominantly ephemeral drainage. Field studies were made in December 1963 and in the fall, winter, and early spring of 1964–65. Another 3 weeks was spent in the field in August–September of 1965, during part of the 1965 summer runoff season. In late December 1965 and early January 1966 the area was again visited because of unusually heavy rainfall and runoff.

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In Tucson, Ariz., Mr. Maurice E. Cooley of the U.S. Geological Survey provided invaluable help with regard to the valley-fill geology of the study area. Mrs. Natalie D. White, U.S. Geological Survey, and Mr. Richard J. Shaw, Department of Agricultural Engineering, University of Arizona, kindly made the ground-water data available. The writer is also indebted to Dr. Raymond M. Turner, U.S. Geological Survey, and Dr. James R. Hastings, Institute of Atmospheric Physics, University of Arizona, for help, criticism, and encouragement.

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PHYSICAL SETTING

TOPOGRAPHY

The San Pedro Valley is a northwest-trending structural trough in northern Sonora, Mexico, and southeastern Arizona. The San Pedro River, which heads in Sonora, is part of the Gila-Colorado drainage system. According to Fenneman (1931), the San Pedro Valley is in the Mexican Highland section of the Basin and Range province of the Intermontane Plateaus division.

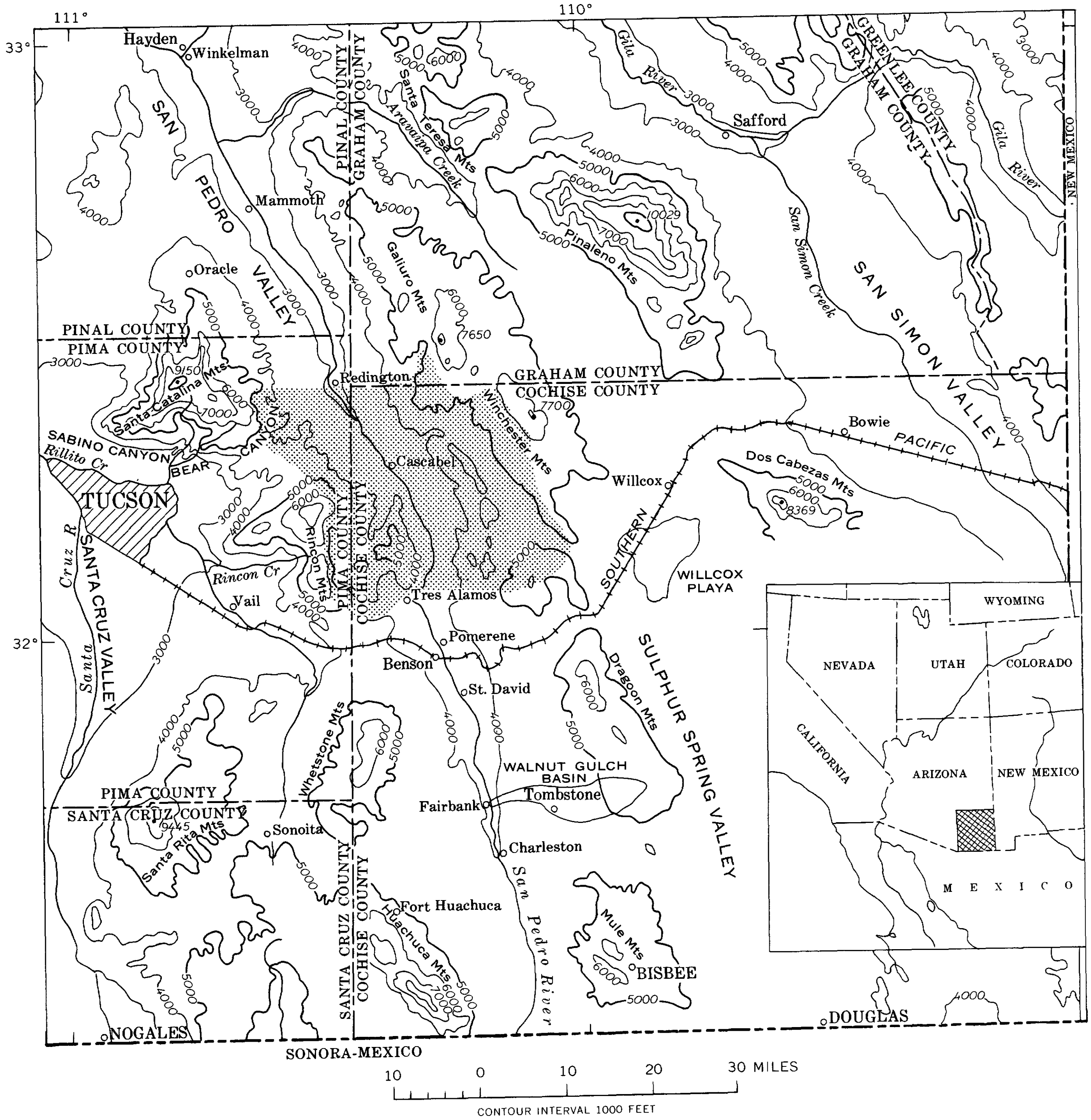

FIGURE 1.—Location of study area (stippled) and Walnut Gulch.

The Tres Alamos-Redington area is bordered on the east by the Galiuro and Winchester Mountains, and on the west by the Santa Catalina and Rincon Mountains (pl. 1). The Santa Catalina Mountains are separated from the Rincon Mountains by the Redington Pass, and the Winchester Mountains are separated from the main axis of the San Pedro Valley by a high basin, part of which is known as Allen Flat, by the southern end of the Galiuro Mountains, and by the Johnny Lyon Hills. The Little Dragoon Mountains form part of the southeast boundary of the study area. West of the San Pedro River, parts of the Rincon Mountans are separated from the main valley axis by a high basin known as Happy Valley and by the Little Rincon Mountains.

The San Pedro Valley is floored by thick valley fill, in places at least 1,950 feet thick near the valley axis (Heindl, 1963, p. E22–E23). In the study area, the valley fill averages about 6 miles in width and it slopes toward the valley axis at between 150 and 250 feet per mile.

The altitudes of the San Pedro Valley bottom in the study area range from 2,890 feet at Redington to 3,456 feet at Tres Alamos. At the break in slope between the mountains and valley fill, altitudes range from about 3,500 to about 4,500 feet. The reach studied is asymmetric; the west valley flank is steeper and higher than the east flank. The Rincon Mountains west of the San Pedro River have a maximum altitude of 8,666 feet. East of the San Pedro River, the highest altitudes within the study area are 7,328 feet in the Galiuro Mountains and 7,631 feet in the Winchester Mountains. Average maximum altitudes are about 5,500 feet east of the river and about 6,500 feet west of the river.

Local relief on the valley fill ranges from less than 50 to 300 feet over a distance of half a mile along entrenched tributaries, as along Redfield Canyon in secs. 32 and 33, T. 11 S., R. 19 E. In areas of conglomeratic valley fill, as in sec. 7, T. 14 S., R. 20 E., streams have cut canyons as much as 80 feet deep and only 6–10 feet wide.

The San Pedro River flows northwestward and joins the Gila River at Winkelman (fig. 1). The total drainage area of the river is 4,483 square miles (Arizona State Land Dept., 1963, p. 68); at the Redington gaging station, the drainage area is 2,939 square miles (U.S. Geol. Survey, issued annually). The channel of the San Pedro River is generally entrenched 20–30 feet below a presumed pre-1880 flood plain, now a terrace. (See Bryan, 1925, p. 342.)

The tributaries of the San Pedro River in the study areas have drainage areas of less than 150 square miles, and their mainstems are less than 25 miles long (table 1). Tributaries longer than about 6 miles have steep headwaters located in mountains and gently sloping lower reaches located on valley fill. Several tributaries have maximum basin elevations exceeding 7,000 feet, and several of these streams descend more than 4,000 feet in less than 20 miles.

BEDROCK GEOLOGY

The bedrock geology of the Tres Alamos–Redington area is complex as it includes Precambrian metamorphic rocks, Paleozoic and Mesozoic sedimentary rocks, and Tertiary and Quaternary volcanic units. The geology is further complicated by extensive faulting (Cooper and Silver, 1964, p. 96–126; Creasey and others,

TABLE 1.—*Basin dimensions of selected tributaries of the San Pedro River in the Tres Alamos-Redington area*

Tributary	Drainage area (sq mi)	Altitude (feet)			Approximate length of mainstem (miles)	Distance between mountain front and San Pedro River (miles)
		Maximum in basin	Minimum, in basin (approx)	Maximum of mainstem, (approx)		
Right, north to south:						
Redfield Canyon	61.5	7,094	2,890	6,300	22.0	6.5
Soza Wash	28.5	5,108	3,000	4,300	9.0	4.5
Hot Springs Canyon [1]	114.3	7,631	3,125	[1] 7,300	26.0	4.5
Teran Wash	16.3	5,218	3,175	4,350	6.5	2.5
Kelsey Canyon	18.8	5,350	3,200	5,350	17.0	2.5
Great Bajada Wash [2]	2.8	4,816	3,250	4,750	7.0	5.0
Tres Alamos Wash	134.8	6,729	3,450	4,750	24.3	[3] 10.5
Left, north to south:						
Buehan Canyon	51.3	7,122	2,850	5,500	12.5	1.3
Soza Canyon	46.0	7,145	3,000	5,800	11.0	[4] 4.0
Roble Canyon	13.5	5,970	3,100	4,350	6.0	3.5
Paige Canyon	64.5	8,482	3,125	7,600	16.0	1.8
Redrock Creek	11.3	6,090	3,300	5,500	7.5	3.0
Keith Ranch Creek [5]	6.5	6,090	3,400	5,300	6.0	4.5
Ash Creek	51.8	7,786	3,400	4,750	13.5	3.8

[1] Davis Canyon was assumed to be the headwater reach of Hot Springs Canyon.
[2] Name arbitrarily assigned to unamed stream.
[3] As Tres Alamos Wash does not leave a mountain front at near a right angle, this value represents the distance between the last point, in a downstream direction flanked by bedrock and the San Pedro River.
[4] The lower 1 mile of Soza Canyon is entrenched in bedrock.
[5] Name arbitrarily assigned to unamed stream.

1961; Heindl, 1963, p. E27). Many of the rock units have not yet been assigned to formations.

East of the San Pedro River, the Galiuro and Winchester Mountains consist mostly of Tertiary volcanics, mainly rhyolite and andesite (Arizona Bureau of Mines, 1959). Cretaceous or early Tertiary sedimentary rocks, mainly sandstone, shale, and conglomerate, crop out in the southern part of the Galiuro Mountains, primarily in the basins of Teran Wash and Kelsey Canyon (Arizona Bureau of Mines, 1959). These volcanic and sedimentary rocks are generally resistant to erosion and form either tablelands or jagged hills and mountains. Sedimentary rocks, such as Mississippian Escabrosa Limestone and Cambrian Bolsa Quartzite, also form the peaks of the Johnny Lyon Hills and of the Little Dragoon Mountains. In contrast, the Precambrian Johnny Lyon Granodiorite that underlies most of the Johnny Lyon Hills easily weathers into granular form (Cooper and Silver, 1964, p. 27), resulting in rounded hills and flat mesas.

West of the San Pedro River, in the Little Rincon, Rincon, and Santa Catalina Mountains, quartzose granitic rocks, granite gneiss, and schist predominate (Arizona Bureau of Mines, 1959; Creasey and others, 1961). The granite generally exfoliates into rounded boulders. The schist underlies steep, straight slopes covered with flaggy weathered rock. The largest outcrops of sedimentary rock west of the river are low limestone hills in the lower Buehman and Paige Canyon basins (Arizona Bureau of Mines, 1959; Wilson and others, 1960). The limestone outcrops are conspicuous as white or bluish areas, covered with little weathering material.

Bedrock also crops out in the valley fill along the San Pedro River. Johnny Lyon Granodiorite forms a series of low, rounded hills at The Narrows (pl. 1; Cooper and Silver, 1964, p. 26). Smooth, hard conglomerate composed primarily of reddish-brown volcanic fragments is exposed along the San Pedro River between Roble Canyon and the Pima-Cochise County line.

VALLEY-FILL GEOLOGY

The thick alluvium that fills the basins of southern Arizona, including the San Pedro Valley, has long been considered undifferentiated Gila Conglomerate (fanglomerate) of late Tertiary and early Quaternary age (Gilbert, 1875; Bryan, 1926; Knechtel, 1936; Creasey and others, 1961). The lumping of heterogeneous materials, including unconsolidated deposits, in this formation has been criticized, but agreement on the differentiation of the alluvium has not yet been achieved. (See Heindl, 1963, p. E14.) Pending a revision of the Cenozoic alluvial geology of southern Arizona, the informal terminology and classification used by M. E. Cooley, U.S. Geological Survey, (oral commun., 1964) is probably the most convenient and up-to-date description of the valley fill in the study area. The alluvial units currently recognized in the San Pedro Valley are described in table 2.

Descriptions of the valley-fill geology and paleontology in or near the Tres Alamos–Redington area are contained in works by the Arizona State Land Dept. (1963), Chew (1952), Cooper and Silver (1964), Creasey (1965), Creasey, Jackson, and Gulbrandsen (1961), Gazin (1942), Gidley (1922), Gilluly (1956), Heindl (1963), Kottlowski, Cooley, and Ruhe (1965),

TABLE 2.—*Valley-fill geology of the Tres Alamos–Redington area*

[After M. E. Cooley, oral commun., 1964]

Designation and age	*Description, location, and remarks*
Recent alluvium	Clay, silt, sand, and gravel. Channels and valley floors of the San Pedro River and its tributaries.
Middle(?) to late(?) Pleistocene terrace alluvium.	Predominantly sandy to bouldery brown alluvium; commonly only gravel veneers one particle thick. In places cemented. Overlies terraces underlain by basin fill or deformed gravels. At least 20 feet thick downslope from granodioritic mountain fronts. Previously described as "Tres Alamos formation" (Montgomery, 1963), as "Sacaton formation" (Heindl, 1963), and as "pediment gravels" (Creasey, 1965; Cooper and Silver, 1964).
Late Pliocene to early Pleistocene basin fill.	Predominantly fine-grained (clay and silt) pink to reddish-brown deposit. Basally and near mountain fronts coarser (sand to boulders). Contains in places caliche, mudstone, tuff, gypsum, and some diatomaceous deposits. Cohesive, commonly erodes into badlands. Underlies the level terraces (load dip not exceeding 3°) and terrace remnants of the middle and upper San Pedro Valley. Large exposures near Benson, where the basin fill is also fossiliferous. Overlies the deformed gravels unconformably. Often described as "lake beds." Previously described as "Quiburis formation" (Heindl, 1963) and as "Benson Beds" (Montgomery, 1963).
Pliocene deformed gravels	Variably cemented, tilted gravels and cobbles. Pink, conglomeratic, and cliff forming downslope from limestone outcrops; gray and poorly cemented elsewhere, especially where the gravels are granitic. Middle and lower San Pedro Valley, usually exposed between the mountain fronts and the younger alluvium located near the San Pedro River. Previously described as "Tertiary conglomerates" (Montgomery, 1963) and as "San Manuel formation" (Heindl, 1963).

Lance (1959, 1960), Melton (1965), Montgomery (1963), and Smith (1963). Interpretations of the Cenozoic geomorphic history of the San Pedro Valley and of southern Arizona are given in the works of Bryan (1926), Heindl (1963), Kottlowski, Cooley, and Ruhe (1965), Melton (1959–60; 1965), and Tuan (1959, 1962). The presence in the San Pedro Valley of a number of surfaces or terraces underlain by valley fill (fig. 2) has led to speculation concerning the sequence of erosion and aggradation in the valley since the late Tertiary (Bryan, 1926; Heindl, 1963). In one interpretation (Bryan, 1926), the San Pedro Valley is cited as a classical example of partial peneplanation in an arid basin.

FIGURE 2.—Terraces (1, 2) along the lower reach of Tres Alamos Wash. Level 2 is the pre-1880(?) flood plain of the San Pedro River. View toward west and Little Rincon and Rincon Mountains.

SOILS

The soils of the San Pedro Valley belong to the Red Desert, Noncalcic Brown, Reddish Brown, and Arid Lithosol soils groups (U.S. Dept. Agriculture, 1938, map). No systematic soil survey is available for the Tres Alamos–Redington area. Most of the soils of the study area can nevertheless be assigned to two series that are widely distributed in Arizona. The soils of the San Pedro River bottom lands probably belong primarily to the pink Gila loam series, whereas those of the valley flanks belong mainly to the brown or reddish-brown White House series (M. L. Richardson, Soil Conserv. Service, oral commum., 1964; S. W. Buol, Dept. Agricultural Chemistry and Soils, Arizona Univ., oral commun., 1965).

The Gila silty and sandy loams are calcareous and have surface pH's of about 8 (M. L. Richardson, oral commun., 1964). Along the San Pedro River local "alkali flats" or salt efflorescences have pH values, judging from data obtained in studies of similar alkali flats of the Willcox playa, that commonly reach and exceed 9. The White House soil series consists of deep dark- to reddish-brown sandy and gravelly loams developed mainly on thick terrace alluvium or fan alluvium (Nat. Coop. Soil Survey, USA 1964). The upper horizons of the White House soils are generally noncalcic, and surface pH is as low as 5.5.

In common with other arid and semiarid areas of the Western United States, the Tres Alamos–Redington area is underlain in places by caliche of varying thickness and depth. (See Carpenter and Bransford, 1924, p. 247.) This carbonate deposit seems to underlie only a small fraction of the area. Probably half of the study area consists of bare rock and eroded valley-fill deposits on which little or no soils has developed.

CLIMATE

The climate of the Tres Alamos–Redington area is warm and arid. The mean annual temperature is about 63° F, and the annual excess of pan evaporation over precipitation, as judged from records at stations in southeastern Arizona, is 70–80 inches (data from U.S. Weather Bur.).

Temperatures recorded at Benson (fig. 1) range from 10° to 115° F. The study area probably has no days with mean maximum daily temperatures below 32° F, as neither Benson (alt 3,635 ft) nor Tucson (alt 2,410 ft) have such days. Seasonal mean temperatures in the study area are shown in table 3.

TABLE 3.—*Seasonal mean temperatures in the Tres Alamos–Redington area*

[After J. R. Hastings, Inst. Atmospheric Physics, Arizona Univ., unpub. map data]

Season	*Temperature (°F)*
Winter (Dec.–Feb.)	47
Spring (Mar.–May)	61
Summer (June–Aug.)	79
Fall (Sept.–Nov.)	64

The average annual precipitation on the valley floor of the study area is about 12 inches. At Benson, average annual precipitation has been as follows: 1881–1930, 10.12 inches; 1931–52, 9.81 inches; 1953–64, 11.60 inches (data from U.S. Weather Bureau). Precipitation at Benson has ranged from 4.17 inches in 1924 to 22.58 inches in 1905. At Redington, annual precipitation since records began in 1941 has ranged from 5.48 inches in 1950 to 18.36 inches in 1951.

Annual precipitation in the mountains surrounding the study area averages about 30 inches on the summits of the Rincon and Santa Catalina Mountains, 20 inches on the Galiuro and Winchester Mountains, and 18 inches in the Redington Pass area and on the summit of the

Little Dragoon Mountains (Arizona Univ., Inst. Atmospheric Physics, 1959, map 1).

Precipitation in the San Pedro Valley occurs mainly from late July through early September and from late December through early March. Summer rainfall accounts for 40 percent and winter precipitation for 24 percent of the average annual precipitation in the middle San Pedro Valley (J. R. Hastings, Inst. Atmospheric Physics, Arizona Univ., unpub. map data). Precipitation in the valley is caused primarily by the penetration of moist subtropical-tropical air masses into southern Arizona in the summer and by the southward migration of polar fronts in the winter (Sellers, 1960, p. 22–23). Most of the summer rains fall during short-lived local convectional storms; in contrast, winter rains, which are caused by the passage of cyclonic storms and related fronts, are generally of regional occurrence, and may last for several days. Occasionally, heavy rainfall in southern Arizona is caused by storms that originate as tropical hurricanes (Sellers, 1960, p. 22) or by closely following winter cyclones such as occurred in December 1965 (data from U.S. Weather Bureau). In terms of regional climatology and surface hydrology, the San Pedro Valley is marked by unusually intense summer thunderstorm activity and by unusually large volumes of runoff, especially when compared with western Mexico (Kennon, 1954, p. 11; Kennon and Peterson, 1960, p. 94, fig. 20).

FLOW REGIMENS

In the study area, the streamflow data available prior to the study were the gaging record of the San Pedro River at Redington (U.S. Geol. Survey, issued annually) and the "wash," "intermittent," and "perennial" stream classification shown on the topographic sheets. These data, insufficient for the purposes of the study, were supplemented by observations of flow duration made from early October 1964 to early April 1965, in late August–early September 1965, and in late December 1965–early January 1966. The observations made from October 1964 to April 1965 were the basis for a classification of flow regimens used for convenience in the study. The streamflow data for the summer of 1965 and for December 1965–January 1966 are discussed below in terms of deviation from that classification.

In the fall, winter, and early spring of 1964–65, most of the streams of the study area had flows lasting only a few hours. Streams or reaches of streams in which only storm runoff lasting less than 3 days was seen were mapped as having ephemeral flow regimen (pl. 1). In some ephemeral streams located on bedrock, however, pools of water persisted for at least 1 month beyond the end of storm runoff. These persistent pools also were mapped (pl. 1).

In some reaches of tributaries and of the San Pedro River, flows lasting more than 3 days but less than 2 months were also observed during fall, winter, and spring of 1964–65. Reaches with flows of this duration were mapped as having intermittent flow regimen (pl. 1). In tributaries, most of these flows were observed immediately downstream from bedrock canyons with semi-perennial or perennial regimen (table 4). Intermittent flows downstream from canyons apparently occur whenever base flows in canyons are augmented by prolonged frontal precipitation or snowmelt in the mountains, and flows that usually end at the mountain front slowly advance into the lower reaches located on valley fill, where they are absorbed.

TABLE 4.—*Length of flow downstream from bedrock canyons for selected streams*

[All dates are for 1965. ×, to San Pedro River]

Stream	End of flow (distance from canyon mouth, miles)				
	Jan. 22	Jan. 28	Feb. 6	Feb. 8	Feb. 9
Buehman Canyon	×	0.05	------	×	×
Redfield Canyon		1.3	------	×	------
Soza Canyon	1.0	------	------	1.5	------
Hot Springs Canyon	×	------	1.25	2.25	1.75
Paige Canyon					1.0

The occurrence of intermittent flows in reaches immediately downstream from bedrock canyons suggests that Buehman Canyon, unlike other tributaries, frequently discharges into the San Pedro River for several consecutive days. Buehman Canyon is the only large tributary in the study area that leaves the mountain front as near as 1.25 miles to the San Pedro River (pl. 1). The occurrence of sustained [1] discharges in the lower part of Buehman Canyon was confirmed by observations (table 5). Buehman Canyon is the only tributary in the study area observed to have intermittent flow regimen in the entire reach between the mountain front and the San Pedro River. Table 5 also shows the contrast between Buehman and Redfield Canyons in terms of flows reaching the San Pedro River in the winter of 1964–65. Redfield Canyon, the tributary directly opposite Buehman Canyon (pl. 1), crosses 6.5 miles of valley fill before reaching the mainstem. The greater frequency of flows in Redfield Canyon in the summer (table 5) probably reflects greater incidence of convective storms over its drainage basin. The absence of intermittent flows in the lower part of Buehman Canyon in the summer (table

[1] As used in the present study, the expression "sustained" discharges or flows refers to all flows that last more than 3 consecutive days.

5) is probably related, on the other hand, to the contraction of base flows in the bedrock canyon in the summer (p. D9).

TABLE 5.—*Days on which Buehman and Redfield Canyons discharged into the San Pedro River, December 29, 1964, to August 18, 1965*

[Observations made by Mr. C. S. Ronquillo, Redington]

Date	Redfield Canyon	Buehman Canyon	Date	Redfield Canyon	Buehman Canyon
1964			*1965*—Con.		
Dec. 29		×	Feb. 9		×
30		×	10	×	×
31		×	11	×	×
1965			12	×	×
Jan. 21		×	13	×	×
22		×	July 11	×	--------
23		×	22	×	--------
24		×	24	×	--------
25		×	Aug. 2	×	--------
26		×	14		×
Feb. 7	×	×	15	×	--------
8	×	×	18	×	×

NOTE.—The precipitation at Redington was 0.90, 0.40, 0.78, and 0.29 inch on Dec. 29, Jan. 21, Feb. 7, and Feb. 10, respectively. On Feb. 10 there was also heavy snowfall in the mountains.

Many reaches of tributaries and most of the San Pedro River in the study area had flows that lasted more than 2 months (pl. 1). These flows, called semiperennial here, probably lasted from October 1964 to April 1965. Most of these flows were not checked in December 1964, but as rain fell and as base flows were generally high in southeastern Arizona during that month (U.S. Geol. Survey, issued annually), it is probably safe to assume that semiperennial flows lasted at least 6 months.

The perennial flows shown on plate 1 are those indicated as such on the topographic sheets. In reality there may not be much difference in duration between perennial and semiperennial flows. For example, the San Pedro River is shown on the Redington quadrangle sheet as having perennial flow at the Redington gaging station. The gaging record (U.S. Geol. Survey, issued annually) shows, however, that in many years the river is dry for 2 months or more, usually in May and June. In the study area, the perennial flows are probably those semiperennial flows that are least likely to dry up.

Variation in discharge of semiperennial and perennial flows measured in the fall, winter, and spring of 1964–65 is shown in table 6. These discharges are based on crude measurements of cross-sectional area and velocity of flow.

In tributaries, perennial and semiperennial flows are generally confined to upper or middle reaches located on bedrock. Most lower reaches or tributaries are located on valley fill and have ephemeral flow regimen (pl. 1). Soza Canyon is the only large tributary whose extreme lower reach is on bedrock (pl. 1) and whose underflow

TABLE 6.—*Selected discharges in streams with perennial and semiperennial flows in the Tres Alamos–Redington area, October 1964 to April 1965*

[Location of discharge measurements shown on plate 1. SP, semiperennial flow; P, perennial flow]

Stream	Location	Date	Discharge (cfs)	Flow regimen
		1964		
Ash Creek	1	Oct.–Nov.	01. -0. 3	SP
		1965		
	2	Jan. 31	. 4	SP
Buehman Canyon	3	Jan. 28	. 3	SP
	4	Mar. 12	6. 0	SP
Hot Springs Canyon	5	Feb. 9	8. 4	P
Redfield Canyon	6	Jan. 28	3. 9	P
Soza Canyon	7	Feb. 8	10. 0	SP
	7	Apr. 6	. 3	SP

emerges near the confluence with the San Pedro River either as seepage or as a short but well-defined stream (fig. 3). Soza Canyon is thus the only tributary in the study area that visibly discharges into the San Pedro River on a semiperennial basis. On March 12, 1965, the total seepage from Soza Canyon was estimated as 2.5 cfs (cubic feet per second). The inflow from Soza Canyon may account for the approximately 2 cfs difference in base flow in the San Pedro River between a point near Soza Canyon and the Redington gaging station, about 1.5 miles farther downstream (U.S. Geol. Survey open-file report).

FIGURE 3.—Soza Canyon at the confluence with the San Pedro River (foreground). The underflow emerges as a short stream. The conglomerate crops out above the terrace in the background. August 30, 1965.

The flow in the extreme lower reach of Soza Canyon probably is caused indirectly by the bedrock, which tends to force ground water to the surface. The perennial flow in the San Pedro River near Soza Canyon probably has a similar cause. The length of this perennial flow in the river coincides with the length of the bedrock outcrops near the valley axis (pl. 1). In the absence of bedrock, the underflow from tributary basins generally flows into the main San Pedro Valley aquifer at a steep angle a short distance from the mountain front (pl. 1). Near the mouths of most tributaries, ground water can be found by digging to the level of the bed of the San Pedro River. In Soza Canyon, however, excavations on March 10, 1965, revealed the following ground-water depths:

Distance from the San Pedro River (ft.)	*Height of Soza Canyon bed above river bed (in.)*	*Ground-water depth (in.)*
22.5	30	18
220.0	72	39
620.0	120	84

The distribution of flow regimens shown on plate 1 may be that present in most years in fall, winter, and early spring. The period October 1964–April 1965 was not marked by unusual precipitation and the points of appearance and disappearance of perennial and semiperennial flows were not random, but rather coincided with bedrock to valley-fill contacts. This distribution is probably not representative of flow conditions in the summer. On September 8, 1965, after about 1 week of storms and flash floods indirectly caused by a hurricane located off Baja, California, most streams in the study area were dry. On that date, the flows were primarily perennial; in contrast, considerable portions of the semiperennial flows mapped the previous fall, winter, and early spring had disappeared (pl. 1). These changes in streamflow between the cool and the hot times of the year are not unusual. As shown by the gaging records (U.S. Geol. Survey, issued annually) of streams in southeastern Arizona, streamflow declines every year after about the middle of April, presumably because water tables decline. Figure 4 shows the decline of the water table in the middle reach of Ash Creek between late January and August 1965. From May to about the middle of July many streams in southeastern Arizona are dry. After the middle of July, convective storms (p. D7) cause most of the runoff experienced annually in southeastern Arizona (U.S. Geol. Survey, issued annually). However, as observed in the study area and as confirmed by gaging records, the summer storm runoff is of brief duration and does not contribute much to restore extensive base flows. The gaging records of such Tucson basin streams as Sabino, Bear, Rincon, and Tanque Verde Creeks show the tendency of flow to disappear even between frequently recurring summer floods.

Occasionally, winter precipitation and runoff in southern Arizona equal or exceed those caused by summer convective storms. Heavy winter runoff occurs at a time, however, when water tables are already high and base flows most extensive. Thus, unlike the annual summer flash floods, it may cause sustained flows to extend into reaches that usually have ephemeral flow regimen.

Heavy precipitation and runoff occurred in December 1965 and January 1966, during and after several cyclonic disturbances that reached southern Arizona (data from U.S. Weather Bureau). At Redington, the 6.88 inches of rain that fell in December 1965 was the largest amount measured in that month since records began in 1941. At Benson and near Oracle, about 13 miles north of Redington, December precipitation amounted to 4.53 and 10.43 inches respectively. The amount measured near Oracle (alt 4,540 ft) was the largest registered for any month since records began in 1893.

The unusually heavy December rains caused extensive flooding along the Salt, Gila, Santa Cruz, and San Pedro Rivers and along Rillito Creek on December 22–23, 1965 (Associated Press, Dec. 24, 1965; U.S. Geol. Survey, issued annually). Near Solomon, at the head of the Safford Valley, the Gila River peaked at 43,000 cfs on December 22. In the lower San Pedro River, a peak discharge of 16,800 cfs occurred at and near Winkelman on Dec. 22 or Dec. 23. This was probably the largest peak discharge recorded in the lower San Pedro River since the early 1950's (U.S. Geol. Survey, issued annually). In southeastern Arizona, the last time the maximum annual peak discharges occurred on a near-regional basis in the winter was in December 1940 (U.S. Geol. Survey, issued annually).

In the study area, the primary result of the heavy rainfall that occurred mainly on December 9–18 and 23, 1965, was sustained and heavy runoff in the usually ephemeral lower reaches of large tributaries (pl. 1). As shown in figure 4, the duration of flow in these lower reaches is roughly related to the length of base flows in the tributaries as observed between October 1964 and April 1965. Streams such as Soza, Hot Springs, Redfield, Paige, and Buehman Canyons, which have long bedrock canyons with base flows, discharged for at least 2 weeks into the San Pedro River. Other tributaries with less extensive base flows either flowed for only 1 week to the mainstem (Ash Creek, Soza Wash) or had no flows in their lower reach (Kelsey Canyon). Ash Creek flowed again to the mainstem on December 30, 1965. Tres Alamos Wash, the largest tributary in the study area, did not flow at all.

The heavy rainfall and prolonged runoff caused certain generally ephemeral reaches to carry base flows. The part of Redrock Creek located on bedrock, for example, became saturated, and as late as January 3, 1966, short (50–200 ft.) flows were still present in this stream

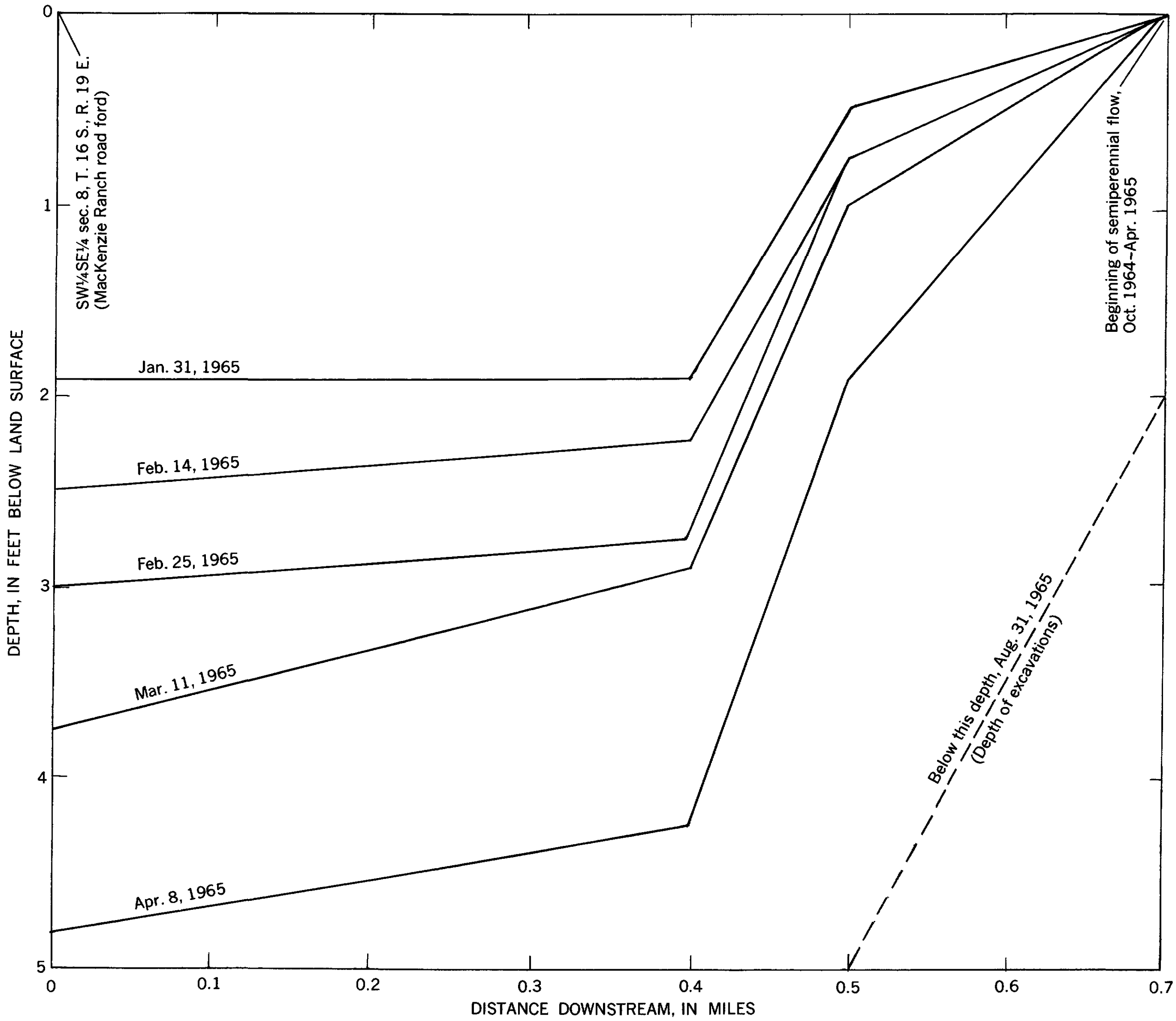

FIGURE 4.—Ground-water depths in the alluvium of Ash Creek.

(pl. 1). In the lower reach of Ash Creek, a perched aquifer formed on a lens of compacted clay in the SE¼, sec. 1, T. 16 S., R. 19 E., was maintaining a base flow as late as January 4, 1966.

On January 7, 1966, the flow in the lower reach of Soza Canyon ended at a point about 1 mile downstream from the canyon mouth. However, in the extreme lower reach entrenched in bedrock, the underflow, which usually emerges a few feet from the San Pedro River (fig. 3), came to the surface at a point about 0.5 mile from the river (fig. 5). This type of interrupted flow was not observed in the lower reaches of the other tributaries in the study area. On the other hand, on January 7, 1966, Buehman Canyon (p. D7) was the only tributary still flowing as near as about 0.25 mile to the San Pedro River.

The unusual flow events [2] of December 1965–January 1966 partly invalidate the flow regimens based on observations made the previous fall, winter, and early spring. In December 1965–January 1966, many reaches of streams previously described as having ephemeral flow regimen qualified for the next higher category of flow duration, or intermittent regimen. Events such as those of December 1965–January 1966 indicate the need for caution in categorizing processes on the landscape.

[2] Sustained flow in, for example, the lower reach of Ash Creek was apparently last seen in the 1940's (Mr. George Sherman, foreman, Tres Alamos Ranch, oral commun., 1966).

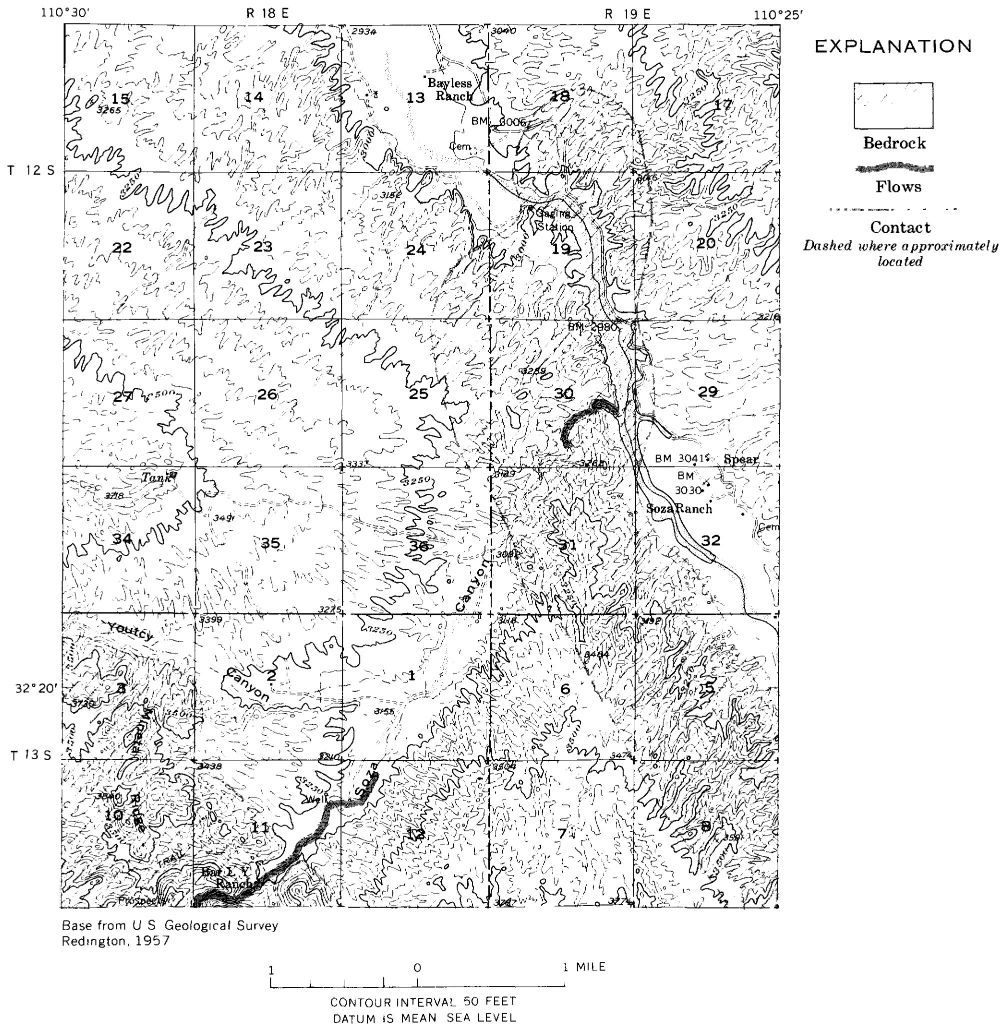

FIGURE 5.—Flows in the lower reach of Soza Canyon on January 7, 1966.

The classification of streams based on the field checks of October 1964–April 1965 (pl. 1) was nevertheless used because it seems to provide a convenient indirect measure of relative moisture conditions during at least the cool part of 1 year.

VEGETATION

GENERAL DESCRIPTION

Most of the Tres Alamos–Redington area supports a vegetation composed of shrubs, small trees, and conspicuous cactuses, including the columnar giant cactus. (Scientific names of plants are given in the list on p. v–vi.) When this vegetation is in full foliage, as in summer and early fall, the San Pedro Valley appears from a distance to have a continuous plant cover, especially in years of unusually extensive grass and ephemeral growth. The vegetation of the valley consists, however, primarily of stands of shrubs or of small-tree savannas sufficiently open to allow easy movement. Shrubs are woody plants with several stems of approximately equal size emerging from the ground. A savanna is a stand of trees, or plants with a single stem and branches off the ground, not forming a closed canopy and generally floored by grasses. Most of the common and conspicuous plants belong to the families Leguminosae and Cactaceae. Others are creosotebush (Zygophyllaceae), ocotillo (Fouquieriaceæ), yucca and beargrass (Liliaceæ), honeysage (Verbenaceae), and agave (Amaryllidaceae). The valley floors of the study area commonly support bottom-land forests consisting of trees of such familiar North American–Eurasian genera as ash, alder, cottonwood, hackberry, mulberry, sycamore, sumac, walnut, and willow. In contrast, the vegetation growing outside the valley floors consists largely of species and genera not found outside the southwestern United States and nothern Mexico, or even outside the boundaries of the Sonoran Desert (Shreve, 1951).

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Above an altitude of 4,500–5,000 feet, the main vegetation form is an open oak woodland, usually containing juniper, manzanita, and cypress. Above the oak woodland, at altitudes of more than 6,000 feet, the mountains support a coniferous forest composed mainly of pines. Above the pine forest is a forest of spruce and fir.

FLORISTIC REGIONS AND PREVIOUS WORK

The flora in the Tres Alamos–Redington reach of the San Pedro Valley growing below 4,500 feet belongs to three regions long recognized (Harshberger, 1911; Shreve, 1951; Benson and Darrow, 1954; Shreve and Wiggins, 1964). They are: The Sonoran Desert, the Desert Grassland, and the Chihuahuan Desert. Above 4,500 feet, the oak woodland, the pine forests, and the spruce-fir forests have been assigned to "Arizona chaparral," "western xeric evergreen forests," and "northern mesic evergreen forests" (Kearney and Peebles, 1960, p. 13–14).

The plant life of most of the study area below 3,200 feet belongs to the Arizona Upland subdivision of the Sonoran Desert floristic region, which is marked by the abundance of paloverde, mesquite, ocotillo, saguaro, barrel cactus, brittlebush, and many species of cylindropuntias (chollas) and platyopuntias (pricklypear) (Shreve and Wiggins, 1964, v. 1, p. 50). The southern, or upper, boundary of the Sonoran Desert in the study area varies, depending upon whether the range of the saguaro or that the green and blue paloverde is used to delimit this floristic region (fig. 6). The ranges of these two species have their southernmost, or uppermost, point on the west valley flank.

The southernmost part of the study area and Allen Flat are in the Desert Grassland, which is characterized by open stands of mesquite, acacias, yucca, and beargrass, which are usually floored by grasses such as grama, three-awn, and muhly (Benson and Darrow, 1954, p. 18). The term "savanna" is perhaps a more apt description of the vegetation form in the Desert Grassland.

The San Pedro Valley contains what are probably the westernmost areas of occurrence of Chihuahuan Desert plants (Benson and Darrow, 1954, p. 16). The Chihuahuan species (Chihuahuan whitethorn acacia, sandpaperbush, allthorn, and tarbush) are confined largely to calcareous subtrates of the San Pedro Valley (Benson and Darrow, 1954, p. 16). Sandpaperbush, for example, grows in large stands on the limestone outcrop in T. 12 S., R. 18 E., along the Tucson-Redington (Redington Pass) road. The ranges of three of the Chihuahuan species present in the study area were mapped (fig. 6).

No published ecological or botanical work dealing specifically with the Tres Alamos-Redington area exists. General references to the floristics and life forms of the study area are contained in standard works on the flora and vegetation of Arizona (Kearney and Peebles, 1960), on the Sonoran Desert (Shreve, 1951; Shreve and Wiggins, 1964), and on the Southwestern desert woody flora (Benson and Darrow, 1954). These works also include information and the presence of individual species in the San Pedro Valley.

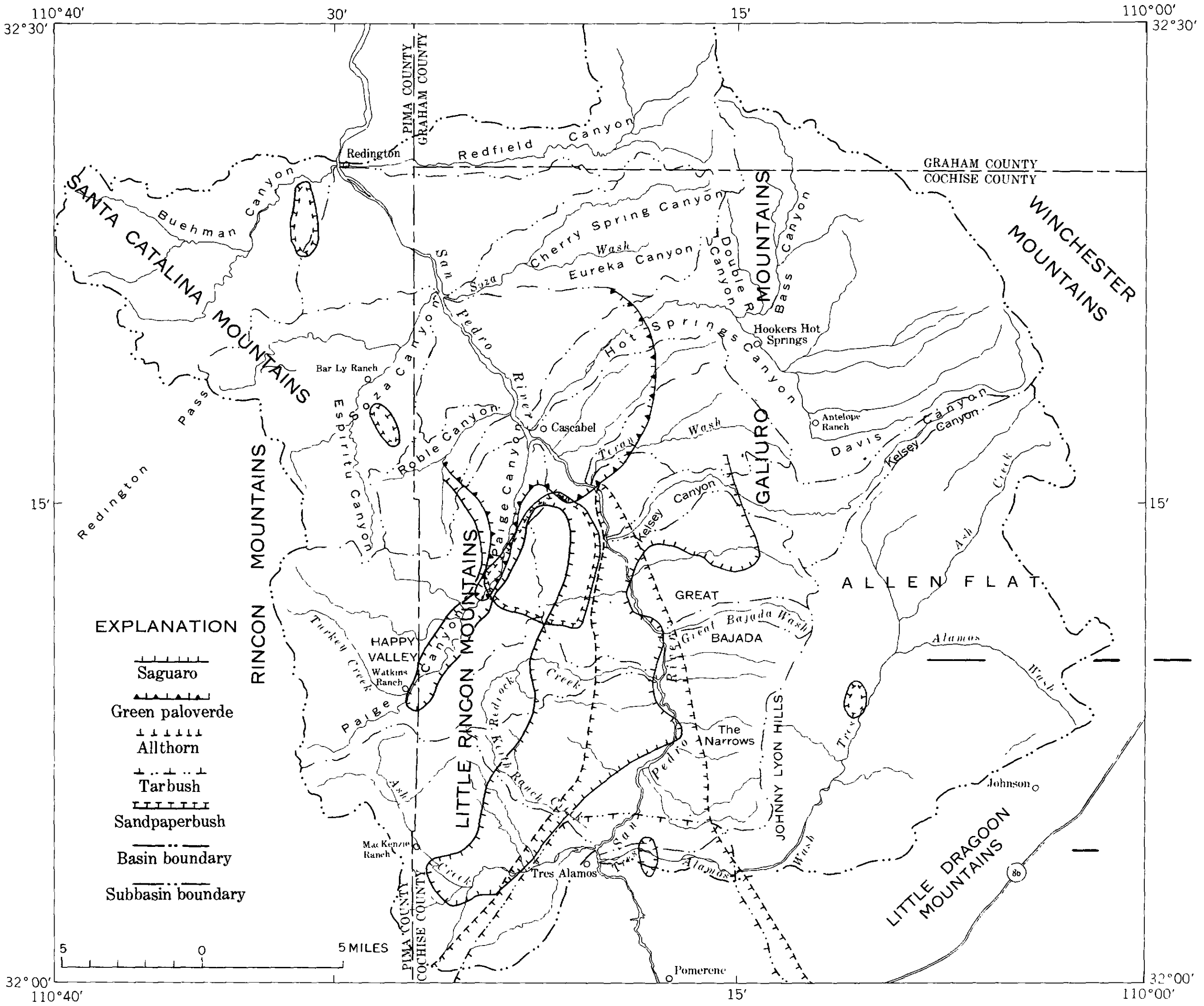
METHODS OF STUDY

The description of the vegetation of the Tres Alamos–Redington area is based on spot sampling and on continuous mapping of the ranges of selected species (pl. 1). The vegetation described consists mainly of woody plants at least 2 feet tall when full grown. Some nonwoody plants (cactuses, agaves, yuccas, and beargrass) were included along with small woody species (for example, desert zinnia), because of their abundance or conspicuousness, or both. Spot sampling consisted of noting the presence of species, the basic units of vegetation, in sight at a point. The importance, or abundance, of a particular species was indirectly determined by noting the percentage of sampling points at which the species was tallied in relation to the total number of sampling points ("frequency of occurrence").

The vegetation was also sampled by means of 21 basal area plots located in 20 selected reaches of tributary streams and on one interfluve (pl. 1). "Basal area" is a forestry term that denotes the sum of the cross-sectional area of tree boles, expressed in square feet, in a given area. It is a measure of woody vegetation, and, as used in the study, of the relative local abundance of species. The basal area plots consisted of strips 50 feet wide and 1,056 feet (0.2 mile) long, designed to include representative reaches of valley floors while excluding overlap onto side slopes. Area of the plots is 52,800 square feet, or 1.2 acres. Within the plots, all plants with a circumference of at least 6 inches, at breast height (4.5 feet) for trees and at ground level for shrubs, were tallied.

VARIATION IN THE VEGETATION OF THE UPLANDS

In the study area, large differences in the vegetation of the uplands, or habitats other than valley floors, occur primarily with altitudinal differences. Thus, for example, the paloverde woodland and the succulents characteristic of the Sonoran Desert (Shreve, 1951, pls. 9, 11) present near Redington are 5,000 feet lower than the spruce-fir forest growing on the summit of the Rincon Mountains. Smaller variations in the vegetation,



Base from U.S. Geological Survey topographic quadrangles, 1:62,500

FIGURE 6.—Ranges of selected species.

for example, the difference between the Sonoran Desert vegetation growing near Redington and the Desert Grassland found on Allen Flat, are probably also due to temperature and moisture differences caused by differences in altitude. Allen Flat is 1,500–2,000 feet higher than Redington. Variations in the vegetation coincident with climatic differences at various altitudes were described for the Santa Catalina Mountains (Shreve 1915). In the study area, however, variations in the vegetation of the uplands occur at the same altitudes. These variations are probably due mainly to moisture differences caused by different substrates and topography.

Variations in the plant cover coincident with differences in topography are conspicuous on the eastern flank of the San Pedro Valley in the Happy Valley quadrangle (fig. 7). There, the relatively undissected part of the valley flank, shown on the topographic sheet by regular, widely spaced contour lines, supports a savanna composed of trees about 10–15 feet tall and largely floored by a continuous grass cover (fig. 8). When in full foliage, this savanna appears dark green from a distance. It is composed primarily of mesquite, catclaw acacia, and yucca, and is most extensive in T. 14 S., where the largest relatively undissected valley flank is located.

The dissected parts of the valley flank are, in contrast, mantled by shrubs generally above 5 feet tall (fig. 9). The vegetation growing on the dissected valley flanks

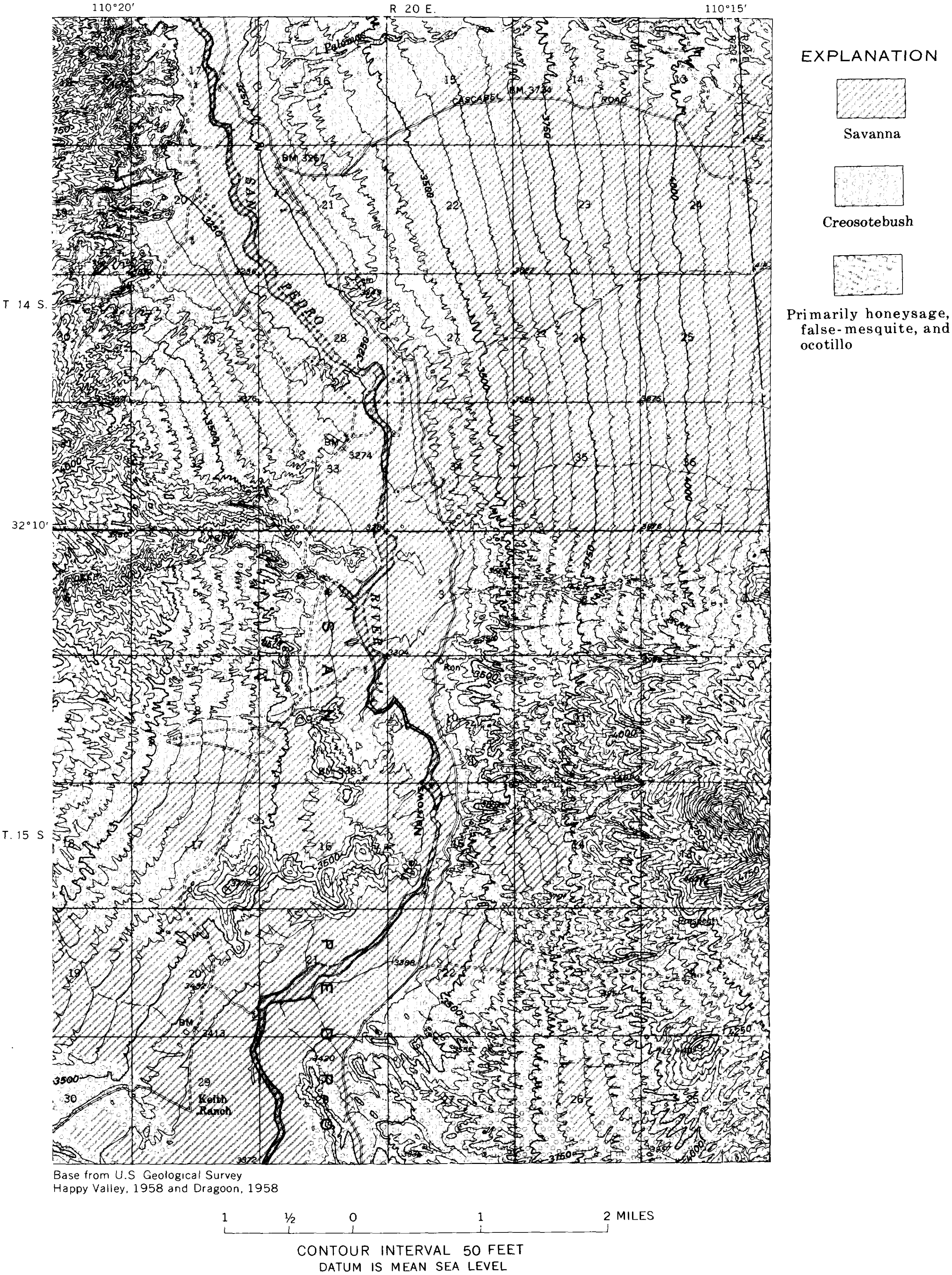


Figure 7.—Vegetation of the uplands in Tps. 14 and 15 S., R. 20 E.

FIGURE 8.—Savanna composed primarily of mesquite, yucca, and catclaw acacia growing in T. 14 S., R. 20 E. Note the grass cover and the smoothness of the slope. The substrate is sandy to gravelly loams overlying gravelly to cobbly terrace alluvium. View toward northeast; south end of the Galiuro Mountains in distance. August 1965.

FIGURE 9.—Shrubs growing on dissected valley flank in Tps. 15 and 16 S., R. 20 E. Shrubs are mainly creosotebushes. The substrate is basin fill (table 2). View toward southeast and Dragoon Mountains. August 1965.

is distinctly olive green all year and is usually not floored by grasses. This vegetation owes its appearance primarily to the abundance of creosotebush, an evergreen shrub that was not observed in the savanna (fig. 7).

The savanna and the creosotebush also grow on relatively undissected valley flanks—hereafter referred to as smooth slopes—and on dissected flanks west of the San Pedro River (fig. 7). They were not observed on the bedrock cropping out near The Narrows or on the bedrock of the lower mountain fronts in T. 15 S. These bedrock outcrops are mantled primarily by shrubs such as honeysage, false-mesquite, and mimosa, and by cactuses such as saguaro, cholla and pricklypear.

The differences in species composition between the vegetation growing on the smooth slopes and that growing on the dissected flanks are shown in table 7 and figure 10. On the smooth slopes, mesquite, catclaw acacia, graythorn, and lycium—plants that are common along streams (p. D20–D27)—are more common than on the dissected valley flanks. Mesquite and catclaw acacia also grow as small trees on the smooth slopes, but on the dissected slopes they are generally shrubs less than 6 feet tall. The smooth slopes also support desert-honeysuckle and desertbroom (table 7), species common along streams (Kearney and Peebles, 1960, p. 801, 883) and apparently absent on the dissected slopes. In general, the form and species composition of the vegetation growing on the smooth slopes suggests higher moisture levels than on the dissected slopes. This hypothesis is supported by the differences in surficial substrates of these two topographic forms.

The smooth slopes mantled by the savanna are underlain by brown coarse terrace alluvium which has buried fine-grained reddish-brown (pink when dry) basin fill

TABLE 7.—*Species present on smooth slopes and on dissected flanks of the San Pedro Valley in Tps. 14 and 15 S., R. 20 E.*

Species	Smooth Slopes	Dissected flanks
Desertbroom	X	--------
Desert-honeysuckle	X	--------
Catclaw acacia	X	X
Whitethorn acacia [1]	X	X
Palmer agave	X	X
Mountain agave	X	X
Four-wing saltbush	X	X
Carlowrightia	X	X
Saguaro	X	X
Desert-hackberry	X	X
Blue paloverde	X	X
Graythorn	X	X
Jointfir	X	X
Barrel cactus	X	X
Ocotillo	X	X
White bur-sage	X	X
Allthorn	X	X
Lycium (*Lycium berlandieri*?)	X	X
Lycium (*L. exsertum*?)	X	X
Pricklypear (*Opuntia engelmannii*)	X	X
Pricklypear (*O. phaeacantha*)	X	X
Cholla (*O. fulgida* var. *mammillata*)	X	X
Cholla (*O. versicolor*)	X	X
Christmas cactus	X	X
Mesquite	X	X
Yucca	X	X
Yellow desertzinnia	X	X
White desertzinnia	X	X
Brickellia (*Brickellia californica*)		X
False-mesquite		X
Cassia (*Cassia covesii*)		X
Mexican crucillo		X
Brittlebush		X
Encelia		X
Tarbush		X
One-seed juniper		X
Creosotebush		X
Menodora		X
Russian-thistle		X

[1] Chihuahuan whitethorn acacia may also be present. Fieldwork was carried out during the "leafless stage," when positive identification of these two closely related species is difficult.

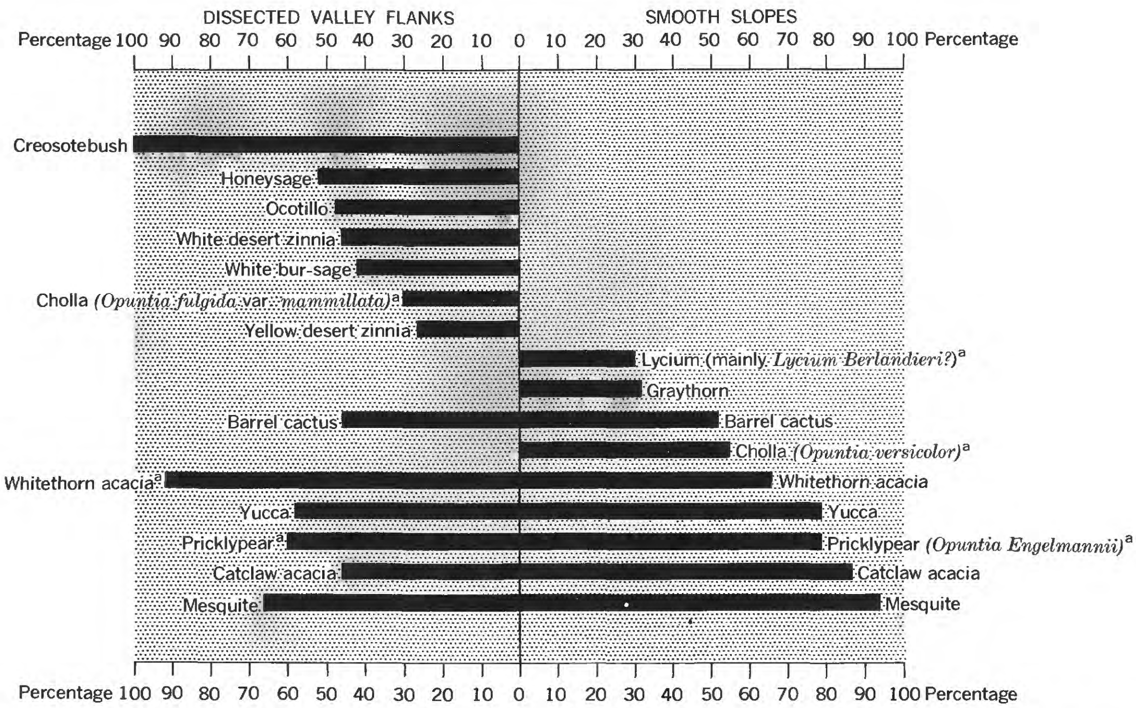


FIGURE 10.—Frequency of occurrence of species with more than 25 percent frequency on dissected valley flanks and smooth slopes in the Happy Valley quadrangle. Total number of plots on smooth slopes and on dissected valley flanks is 53 and 50, respectively.

[a] Owing to difficulties in identification, especially of young plants, the percentage indicated should be considered tentative.

(table 2). These deposits are well exposed along the escarpment in the NE¼, sec. 30, T. 15 S., R. 20 E., reached by the Keith Ranch road. Deep dark-brown sandy to gravelly loams have developed on this alluvium. These loams, which are in places at least 6 feet thick, belong to the White House series (S. W. Buol, Dept. Agricultural Chemistry and Soils, Arizona Univ., oral commun., 1965). (See Nat. Coop. Soil Survey, USA, 1964). Deep dark-brown loams were not seen in the dissected portion of the valley fill, where the stands of creosotebush and other species occur. The presence of thick dark soils on terrace alluvium or other more recent coarse material and the absence of these soils on other deposits, primarily fine-grained older valley-fill units, is apparently characteristic of the San Pedro Valley. This relationship has been observed in the Curtis–San Juan area, about 10 miles south of Tres Alamos (Smith, 1963, p. 44–47), near Tombstone (fig. 1; Renard and others, 1964, p. 472), and near Mammoth, about 15 miles north of Redington (Creasey, 1965, p. 24).

In the Happy Valley quadrangle, smooth slopes, underlain by terrace alluvium at least 20 feet thick and by deep, friable loams, occur primarily downslope from granitic-granodioritic mountain fronts (Arizona Bureau of Mines, 1959). The largest of these smooth areas, in T. 14 S., R. 20 E., is downslope from an outcrop of granodiorite that has been eroded into a mesa (Cooper and Silver, 1964, p. 26). This granodiorite "disintegrates readily into fragments 2 to 10 mm in diameter" and is only locally resistant to weathering where it is either "altered and silicified" or apparently "more resistant as a result of structural complications" (Cooper and Silver, 1964, p. 26–27). The depth of weathering of the granodiorite underlying the upper part of the slope in T. 14 S. is indicated by the driller's log of well (D–14–21) 19 cad (U.S. Geol. Survey, Tucson, unpub. well records). This log shows "decomposed granite" to a depth of 20 feet, "medium hard granite" between 20 and 200 feet, and "hard granite" below 200 feet. The availability of large amounts of noncohesive-weathering material downslope from granite or granodiorite probably causes washes to braid or shift channels frequently (See Leopold and others, 1964, p. 284–295.)

On the smooth slopes of the Happy Valley quadrangle it is commonly difficult to distinguish between wash bed and interfluve. (See Tuan, 1959, p. 88.) Thus, braiding and channel shifting in noncohesive material may produce and maintain the smooth slopes by distributing material evenly on a surface. These processes probably also tend to disperse moisture throughout a slope. In contrast, on a dissected slope, runoff is concentrated in a more fixed channel network, and a greater proportion of this runoff is probably shed from the slope. In summary, the interrelationship between rapid weathering of crystalline rocks, deposition of coarse or relatively coarse material, and formation of deep loams seems to have resulted in a relatively moist upland habitat. This habitat is sufficiently moist to support small trees in an area where, in an average year, only 12 inches of rain falls.

The dissected valley flanks in the Happy Valley quadrangle are underlain mainly by basin fill and by cemented or partly cemented deformed gravels (table 2). Soils are almost completely lacking on these deposits. The basin fill is a predominantly fine grained deposit high in clays and silts that commonly forms nearly vertical banks tens of feet high along entrenched washes. The basin fill is marked by low surface and subsurface permeability.

After summer storms, water was seen standing on surfaces underlain by basin fill for at least 2 hours after the end of precipitation. A similar puddling of water was not observed on the White House loams. In The Narrows–Tres Alamos area, the basin fill has such low subsurface permeability that it is not considered to be an aquifer (Montgomery, 1963, p. 25). At St. David and Benson, immediately south of the study area (fig. 1), artesian ground water results from the confining effect of basin fill overlying more porous aquiferous deposits (Halpenny and others, 1952, fig. 8). The low permeability of the basin fill is also shown by the results of a field test of infiltration. The test consisted of measuring the length of time water remained at the surface after 12 ounces of water was poured from a constant height of 15 inches. The mean and median times for 93 observations made in sec. 33, T. 14 S., R. 20 E., sec. 25, T. 15 S., R. 19 E., and secs. 4, 28, and 31, T. 15 S., R. 20 E., were 43.5 and 40 seconds. Corresponding values for 100 tests made on the White House loams in secs. 23, 25, 28, 33, and 35, T. 14 S., R. 20 E., and secs. 17, 18, 19, 22, and 30, T. 15 S., R. 20 E. were 20.8 and 20 seconds.

The deformed gravels are either cliff forming or have been eroded into badlands, depending upon the degree of cementation. They are commonly trenched by canyons tens of feet deep and less than 10 feet wide (p. D4). Areas underlain by the deformed gravels are probably also marked by low infiltration and rapid runoff.

Vegetation growing on the dissected valley flanks is adjusted to low moisture levels, perhaps the lowest in the study area. However, the abundance of certain species growing on the dissected valley flank may or may not be directly related to moisture regimen. For example, the creosotebush is abundant on these valley flanks, but it also grows in the channel of the San Pedro River. On valley floors or where the land is irrigated, the creosotebush is commonly more than 10 feet tall (Dalton, 1961, fig. 2). Creosotebush is commonly on calcareous substrates (Benson and Darrow, 1954, p. 219) but transplanted creosotebushes "continued to grow and thrive" in washed silica sand (Dalton, 1961, p. 92). No satisfactory explanation can be offered for the distribution of this plant in the study area. Perhaps the distribution of this shrub is controlled at the germination-seedling stage of growth, particularly by the pH of the substrate. (See Dalton, 1961, p. 51.)

The high frequency of occurrence (52 percent) of honeysage on dissected valley flanks reflects the common occurrence of this plant on slopes with an angle of more than about 15°. On side slopes, this shrub is commonly so abundant as to impart a distinctive grayish-green (gray in winter, grayish white when the shrubs are in bloom) color and fluffy aspect to the vegetation as seen from a distance. The occurrence of stands of honeysage on side slopes and the absence of these stands on level surface is particularly striking at the edge of terraces underlain by basin fill (fig. 11). Honeysage is also common on bedrock side slopes (p. D15) and on sandy wash floors. It is rare on the gentle, smooth slopes underlain by loams. The field relations of honeysage suggest that this shrub requires well-drained substrates for survival.

Ocotillo, a striking plant commonly more than 20 feet tall with showy red flowers in spring and early summer, is common on outcrops of deformed gravels and cemented terrace gravels (fig. 12) and in areas of surficial caliche or caliche at depths probably not exceeding 5 feet. Caliche is fairly common within the outcrop area of the basin fill (table 2). Ocotillo is rare on the deep loams that underlie the smooth slopes.

As the ocotillo is also common on bedrock outcrops regardless of bedrock type, it is suggested that this species grows abundantly only in areas where consolidated material provides an anchorage. Thus, ocotillo seedlings grow in areas underlain by fine-grained deposits where adult ocotillos do not grow. Toppled adult ocotillos and saguaros are a common sight in the study area, regardless of substrate; apparently both of these species topple easily because they are top heavy. The relationship between ocotillo and consolidated substrate may explain the presence of vast—in places, square miles—stands of this plant in the north half of the Tres Alamos–Redington area, where the largest outcrops of the Pliocene cemented gravels occur (pl. 1).

VARIATION IN THE VEGETATION OF VALLEY FLOORS

The vegetation growing on the valley floors of tributary washes, creeks, and canyons, and of the San Pedro River ranges from stands of shrubs with the same species composition as those growing on the adjacent

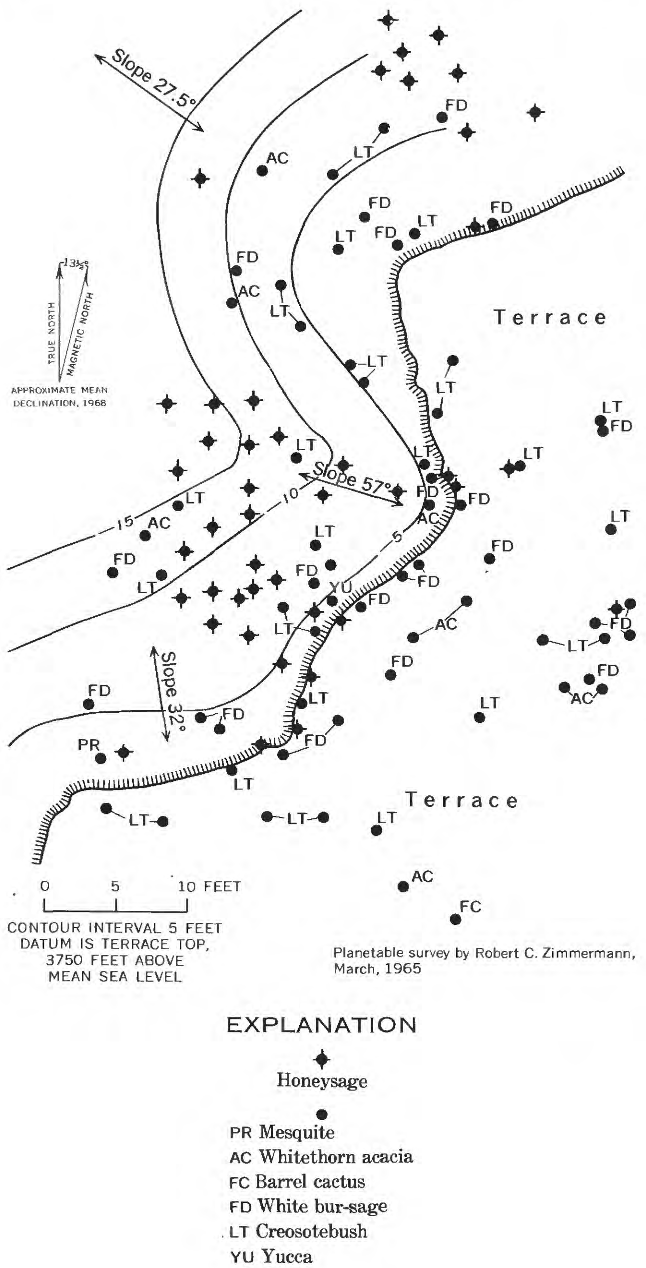


FIGURE 11.—Distribution of honeysage at the edge of a terrace in the NE¼ sec. 10, T. 16 S., R. 20 E.

FIGURE 12.—Ocotillo (tall plants) growing on partly cemented gravels in sec. 24, T. 15 S., R. 20 E. Other shrubs are creosotebush, cholla, and honeysage.

FIGURE 13.—Wash with ephemeral flow regimen, located on basin fill in the SE¼, sec. 18, T. 12 S., R. 19 E. Both side slopes and wash floor support saguaro, foothill paloverde, creosotebush, mesquite, catclaw acacia, barrel cactus, and yellow desertzinnia.

FIGURE 14.—Bottom-land forest along the San Pedro River near the mouth of Soza Wash. Most of the trees are cottonwoods.

uplands (fig. 13) to a closed-canopy forest as much as 80 feet tall, composed mainly of trees that grow only on valley bottoms (fig. 14). Many intermediate types of valley-bottom vegetation differ from these two extremes both in species composition and in height and density of the plants.

The valley-floor vegetation includes many species that were observed only on valley bottoms or, rarely, on side slopes marked by springs or seeps. These plants (table 8) are referred to as "valley-floor species," to distinguish them from those plants that grow on both uplands and valley floors. Many valley bottoms of the study area do not support any valley-floor species.

VALLEY-FLOOR VEGETATION UNDIFFERENTIATED FROM THAT OF ADJACENT UPLANDS

The vegetation growing along an ephemeral wash tributary to Tres Alamos Wash may serve as an example of valley-floor vegetation composed of the species that grow on the surrounding uplands. The wash drains about 1 square mile underlain by dissected basin fill (table 2), located mostly in secs. 1 and 2, T. 16 S., R. 20 E. The species growing on the wash floor and on the side slopes at three sampling points (202, 203, and 204, pl. 1) are listed in table 9. Dimensions of the channel and valley bottom at the three sample locations respectively, are: Width of channel, 10, 12, and 3 feet; total width of valley bottom, 70, 12, and 3 feet. None of the plants tallied along this wash is a valley-floor species (table 8).

TABLE 8.—*List of valley-floor species*

Alder, Arizona
Arrowweed
Ash, Arizona or velvet
Brickellia [1]
Buckthorn
Bumelia
Burrobrush
Buttonbush
Cassia (*Cassia leptocarpa*)
Cottonwood, Fremont
Cypress, Arizona [2]
Desert-willow
Elderberry, Mexican
Grape, Arizona
Hackberry, paloblanco
Hopbush
Indigobush
Mulberry, Texas
Oak, Arizona white [3]
  Emory [3]
Oak, Mexican blue [3]
  scrub [3]
Poison-ivy
Rabbitbrush [4]
Ragweed, canyon
Saltcedar, five-stamen
Seepwillow, batamote
Soapberry [5]
Squawbush
Sumac
Sumac, littleleaf [3]
Sycamore, Arizona
Tree tobacco
Trumpetbush
Walnut, Arizona
Willow, black or Goodding
  Bonpland
  yew-leaf

[1] Possibly *Brickellia floribunda*.
[2] Above 4,200 feet; also on uplands underlain by bedrock.
[3] Above 4,000 feet; also on uplands underlain by bedrock.
[4] Above 4,500 feet; also on uplands.
[5] On talus slopes above 5,000 feet.

BOTTOM-LAND CLOSED-CANOPY FOREST

The reaches of Paige Canyon and Turkey Creek located in Happy Valley, a high basin underlain by unconsolidated fill, pl. 1), support a closed-canopy forest composed primarily of sycamore and cottonwood mixed with ash, walnut, hackberry, and mesquite (table 10). This bottom-land forest has a basal area (tables 11 and 12) comparable to that of forests in the humid Eastern United States. (See Hack and Goodlett, 1960, p. 21.) The reaches of Paige Canyon and Turkey Creek in Happy Valley have fairly gentle slopes (50–100 ft. per mile), are wide (more than 100 ft.), and have semiperennial and intermittent flow regimens (fig. 4).

TABLE 9.—*Valley-floor (VF) and side-slope (SS) vegetation of a tributary of Tres Alamos Wash at locations 202, 203, and 204 (pl. 1)*

Species	Location 202		Location 203		Location 204	
	VF	SS	VF	SS	VF	S
Whitethorn acacia	X	X	X	X	X	X
Catclaw acacia	X	X				
Honeysage	X	X	X	X	X	X
Mexican crucillo			X		X	X
Barrel cactus	X					
Tarbush			X			
Octotillo	X			X		
White bur-sage	X	X	X	X	X	X
Allthorn			X	X		
Creosotebush	X	X	X	X	X	X
Lycium (*Lycium berlandieri*?)	X					
Cholla (*Opuntia versicolor*)	X		X			
Mesquite	X	X	X	X	X	
Yucca	X	X	X	X		
Yellow desertzinnia			X			X
White desertzinnia				X		

TABLE 10.—*Species composition of valley-bottom vegetation of Paige Canyon near Watkins Ranch*

Cassia [1]
Hackberry [1]
Rabbitbrush [1]
Ash [1]
Walnut [1]
One-seed juniper
Pricklypear (*Opuntia engelmannii*)
Sycamore [1]
Cottonwood [1]
Mesquite
Black willow [1]
Arizona grape [1]

[1] Denotes valley-floor species as defined on page D18.

TABLE 11.—*Basal area in plot located along Paige Canyon at locality 6 (pl. 1)*

Species	*Basal area (sq ft)*
Sycamore	132.66
Walnut	9.70
Ash	8.65
Cottonwood	5.31
Hackberry	.29
Mesquite	.90
Total basal area	156.70

TABLE 12.—*Basal area in plot located along Turkey Creek at locality 5 (pl. 1)*

Species	*Basal area (sq ft)*
Sycamore	64.70
Cottonwood	[1] 57.09
Ash	2.41
Walnut	2.17
Mesquite	.49
Total basal area	126.86

[1] Contributed by four trees.

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VARIATION IN THE VEGETATION OF EPHEMERAL STREAMS

The two foregoing examples have shown the striking difference in valley-floor vegetation between a small ephemeral wash and two streams with longer lasting flows. Variations in the valley-floor vegetation occur, however, between streams that have ephemeral flow regimen but different drainage areas. These variations also serve as examples of vegetation types intermediate between the two extremes described above.

The valley-floor vegetation of Great Bajada Wash at the location of basal-area plot 10 (pl. 1), where this ephemeral stream has a drainage area of about 2.8 square miles, has the same species composition as that growing on the adjacent uplands. Compared to the vegetation on the uplands, that along the wash has seven times as much basal area, is taller, and has a greater proportion of catclaw acacia (table 13). The vegetation in plot 10 is representative of the valley-floor vegetation growing along Great Bajada Wash between this plot and the San Pedro River. Total drainage area of Great Bajada Wash is 3.8 square miles.

TABLE 13.—*Basal area of valley-floor and upland vegetation along Great Bajada Wash at locations 10 and 11 (pl. 1)*

[Drainage area at location 10 is 2.8 square miles]

	Basal area (sq ft)	
	Valley floor (10)	Upland (11)
Catclaw acacia	9. 73	0. 05
Mesquite	2. 93	1. 68
Whitethorn acacia	2. 18	. 36
Total basal area	14. 84	2. 09
Maximum height of vegetation (ft)	12. 00	8. 0

In contrast, the vegetation growing along the ephemeral lower reach of Roble Canyon, at a point where the drainage area is about 12.25 square miles (loc. 74, pl. 1), includes two species—desert-willow, a tree, and burrobrush—that were seen only on valley floors. Other species at location 74 (pl. 1) are: catclaw acacia, whitethorn acacia, blue paloverde, graythorn, pricklypear (*Opuntia engelmannii*), and mesquite. In plot 19, near location 74, the basal area is also almost four times that measured along Great Bajada Wash at location 10. (Compare tables 13 and 14.) The data for plot 19 also show that the basal area of vegetation growing along an ephemeral stream can be as much as half that of the bottom-land forest of Turkey Creek (table 12). A basal area exceeding 50 square feet was also measured in the middle reach (location 18) of Teran Wash, where this ephemeral stream has a drainage area of about 14 square miles (table 15). The vegetation of Roble Canyon and Teran Wash at locations 18 and 19 consists primarily of thickets of mesquite and catclaw acacia about 20–30 feet tall, mixed with burrobrush, graythorn, and desert-willow. This vegetation is characteristic of ephemeral streams with more than about 10 square miles of drainage area. Such streams also commonly support hackberry (pl. 2), a tree present along Roble Canyon and Teran Wash but not in plots 18 and 19.

TABLE 14.—*Basal area of valley-floor vegetation of Roble Canyon at location 19 (pl. 2). Drainage area is about 12.3 square miles*

[Maximum height of vegetation about 30 feet]

Species	Basal area (sq ft)
Catclaw acacia	30. 38
Mesquite	27. 43
Desert-willow	3. 02
Whitehorn acacia	9. 91
Graythorn	. 18
Blue paloverde	. 07
Burrobrush	. 03
Total basal area	71. 02

TABLE 15.—*Basal area of valley-floor vegetation of Teran Wash at location 18 (pl. 2). Drainage area is about 14 square miles*

[Maximum height of vegetation about 30 feet]

Species	Basal area (sq ft)
Mesquite	52. 84
Catclaw acacia	5. 63
Total basal area	58. 47

The botanical data for Great Bajada Wash, Roble Canyon, and Teran Wash show that the larger the drainage area, the denser and taller the valley-floor vegetation of ephemeral streams. Streams with drainage areas the size of those of Roble Canyon (total drainage area 13.5 sq mi) and of Teran Wash (total drainage area 16.3 sq mi) also support species that were observed only on valley floors. Comparison of the vegetation of Roble Canyon and Teran Wash with that of Turkey Creek (drainage area about 8 sq mi) shows, on the other hand, the importance of flow regimen in determining the aspect and species composition of valley-floor vegetation irrespective of drainage area. Plate 2 also shows that the upper reach of Great Bajada Wash, at a point where the drainage area is about 1 square mile, supports hackberry, desert-willow, and soapberry, three valley-floor trees that do not grow at location 10 (drainage area 2.8 sq mi), farther downstream. The upper reach of Great Bajada Wash is located on bedrock. Thus, drainage area, flow regimen, and geology affect the distribution of species on the valley floors.

The effect of drainage area and geology on the distribution of plants, whatever the ultimate causal relation, is eliminated by sustained flows. This is illustrated by the vegetation growing near Kiper Spring, SW¼, sec. 10, T. 16 S., R. 19 E., on a slope underlain by basin fill and marked by seepage. This vegetation consists of cottonwood, ash, black willow, walnut, hackberry, buckthorn, Texas mulberry, mesquite (about 35 ft tall), Arizona white oak, and Emory oak. The seepage area also supports fig and osage-orange, two exotic species that were probably dispersed from a nearby abandoned ranch.

VALLEY-FLOOR VEGETATION OF TRES ALAMOS WASH AND ASH CREEK

The valley-floor vegetation of Tres Alamos Wash and Ash Creek, the two streams that form the south boundary of the study area, was sampled from the headwaters of the mainstem to the confluence with the San Pedro River. The data for these two streams show the entire range of variation in the valley-floor vegetation along two streams, as well as the botanical contrast between two tributaries with similar mainstem elevations (table 1) but greatly dissimilar basin topography, geology, and flow regimens (pl. 1). Tres Alamos Wash is located on gently sloping valley fill and has ephemeral flow regimen throughout its course. Ash Creek, with steep headwaters located on bedrock, has flow regimens ranging from semiperennial to ephemeral. Although Ash Creek has a drainage area (51.75 sq mi) less than one-half that of Tres Alamos Wash (134.75 sq mi), its valley-floor vegetation includes more valley-floor species and is generally taller and denser than that of the larger tributary across the San Pedro River.

The valley-floor vegetation of the headwaters of Tres Alamos Wash on Allen Flat is composed mostly of mesquite, yucca, and beargrass, plants which are common in the Desert Grassland (p. D12) that occupies that high basin. Valley-floor species such as hackberry, desert-willow, and rabbitbrush were seen only at and downstream from a point where the drainage area is about 12 square miles (pl. 2; table 16). The largest number of valley-floor species grow in the middle reach flanked by the bedrock of the Johnny Lyon Hills. In the lower reach located on valley fill, the number of valley-floor species is smaller (table 16; pl. 2). The density and maximum height of the vegetation are least on Allen Flat, greatest in the middle reach flanked by bedrock, and relatively low in the lower reach (table 17). The vegetation of the lower reach consists primarily of the mesquite and catclaw acacia thickets characteristic of large ephemeral streams.

The valley-floor vegetation of Tres Alamos Wash is another example of vegetation increasingly differentiated from that of the uplands with increasing drainage area. However, in a basin underlain by unconsolidated deposits and with low relief such as Allen Flat,

TABLE 16.—*Species present on the valley floor of Tres Alamos Wash at selected locations (pl. 1)*

[Figures in parentheses are approximate drainage areas (sq mi) at sampling points]

Species	Locations [1]			
	22(4.5)	19(15)	45(110)	16(134)
Beargrass	X			
Yucca	X	X		
Mesquite	X	X	X	X
Rabbitbrush [2]		X		X
Hackberry [2]		X	X	
Desert-willow [2]		X	X	
Ash [2]			X	
Littleleaf sumac [2]			X	
Soapberry [2]			X	
Whitethorn acacia			X	
Graythorn			X	
Walnut [2]			X	X
Burrobrush [2]			X	X
Catclaw acacia			X	X
Cholla (*Opuntia versicolor*)				X
Pricklypear (*O. engelmannii*)				X
Lycium (*Lycium berlandieri*?)				X
Creosotebush				X
Desertbroom				X

[1] Sampling points listed in order from headwaters to confluence with San Pedro River.
[2] Valley-floor species (p. D18–D19). Rabbitbrush was observed only on valley floors on Allen Flat.

TABLE 17.—*Basal area of valley-floor vegetation of Tres Alamos Wash in upper (plot 17), middle (plot 16), and lower (plot 12) reaches (pl. 1)*

[Figures in parentheses are approximate drainage areas (sq mi) at the site of the basal-area plots]

Species	Basal area (sq ft)		
	17(60)	16(110)	12(132)
Mesquite	0.07	34.19	26.39
Walnut [1]		20.07	
Hackberry [1]		16.14	
Catclaw acacia		9.49	8.35
Ash [1]		1.84	
Desert-willow [1]		.73	
Whitethorn acacia		.17	.97
Littleleaf sumac [1]		.11	
Burrobrush [1]		.07	.39
Total basal area	0.07	82.81	36.10
Maximum height of vegetation (ft)	8	40	20

[1] Valley-floor species (p. D18–D19).

this differentiation occurs gradually, as large drainage areas are indirectly required to support valley-floor species. Tables 14, 15, and 17 also show that the basal area of the vegetation of Tres Alamos Wash at a point where the drainage area is about 60 square miles (plot 17) is a fraction of the basal area measured along Roble Canyon and Teran Wash at points where the drainage area is less than 15 square miles. In contrast to Tres Alamos Wash, Roble Canyon and Teran Wash have steeper headwaters located on bedrock. The presence of dense tree vegetation in the middle reach of Tres Alamos Wash flanked by bedrock suggests that geology affects the distribution of plants without causing a visible difference in flow regimen.

The vegetation of the lower reach of Tres Alamos Wash indicates that, beyond a point where the drainage area is a certain size, the size of the catchment basin does not affect the composition and form of the vegetation. Comparison of the basal area data for Tres Alamos Wash in plot 12 with those for Great Bajada Wash, Roble Canyon, and Teran Wash (tables 13, 14, 15, and 17) reveals that the density of thickets along ephemeral streams does not increase indefinitely with increasing drainage area. The basal area measured at a point where the drainage area is more than 100 square miles (Tres Alamos Wash, plot 12; table 17) may even be less than that measured at points where the drainage area is less than 15 square miles (Roble Canyon and Teran Wash; tables 14, 15). In general, there is considerable botanical variation between a stream with a drainage area of less than 3 square miles (Great Bajada Wash, table 13) and streams draining more than 10 square miles (Roble Canyon, Teran Wash; tables 14, 15). However, the vegetation of streams with drainage areas of more than 10 or more than 100 square miles may have about the same density and species composition.

The valley-floor vegetation of Ash Creek includes valley-floor species at points where the drainage area is between 2 and 3 square miles (pl. 2) and, at most locations farther downstream, a greater number of these species than the vegetation of Tres Alamos Wash (tables 16, 18). The contrast between the valley-floor vegetation of Ash Creek and that of Tres Alamos Wash is also shown by the basal-area data given in table 19. At comparable distances from the San Pedro River, the valley-floor vegetation of Ash Creek is consistently taller and denser than that of Tres Alamos Wash, despite smaller drainage areas. In the ephemeral lower reaches, at distances from 3 to 4 miles from the river, the botanical differences between the two tributaries are not as pronounced, although the dense stands of hackberry and walnut present along Ash Creek are not found in the corresponding reach of Tres Alamos Wash. The lower reach of Ash Creek also supports ash, seepwillow, and large individual walnut trees (fig. 15). Ash and seepwillow were not seen along the lower Tres Alamos Wash, and the walnut along the lower 8 miles of this stream is generally a shrub less than 15 feet tall. In common with the vegetation of other tributaries, the vegetation of the lower reach of Ash Creek has, however, a progressively smaller number of valley-floor species in a direction approaching the San Pedro River (fig. 20).

The valley-floor vegetation of Ash Creek, especially when compared with that of Tres Alamos Wash, indicates that geology, by either concentrating or dispersing moisture, strongly affects the distribution of plants. Bedrock, for example, seems to compensate for small drainage areas. On bedrock, valley-floor species occur at points where the drainage area is smaller than in basins underlain by unconsolidated deposits. On bedrock, streams may also have sustained flows. Reaches

TABLE 18.—*Species present on the valley floor of Ash Creek at selected locations*

Location (pl. 1)	67	64	59	66	9
Flow regimen [1]	PP	PP	I	SP	E
Approximate drainage area (sq mi)	2	4	21	31	50
Sotol	X				
Coral bean	X				
Beargrass	X	X			
Emory oak	X	X			
Scrub oak	X	X			
Manzanita	X	X			
Seepwillow [2]		X	X	X	
Buttonbush [2]		X	X	X	
Ash [2]		X	X	X	X
Hackberry [2]			X		
Sycamore [2]			X		
Cottonwood [2]			X		
Yew-leaf willow [2]			X		
Black willow [2]			X	X	
Desert-willow [2]			X		X
Walnut [2]			X	X	X
Catclaw acacia			X	X	X
Mesquite			X	X	X
Indigobush [2]				X	
Texas mulberry [2]				X	
Buckthorn [2]				X	
Poison-ivy [2]				X	
Arizona grape [2]				X	
Desert hackberry				X	
One-seed juniper				X	
Lycium (*Lycium berlandieri?*)				X	
Arizona white oak [2]				X	
Rabbitbrush [2]					X
Burrobrush [2]					X

[1] PP, persistent pools; I, intermittent; SP, semiperennial; E, ephemeral.
[2] Valley-floor species (p. D18–D19).

FIGURE 15.—Valley-floor vegetation of Ash Creek near location 77 (pl. 1). Trees are mainly walnut, mesquite, and desert-willow. Large walnut in the center of the picture has a diameter at breast height (4.5 ft) of 5 feet. The water table in this reach of Ash Creek is about 60 feet deep.

TABLE 19.—*Basal area (sq ft) of valley-floor vegetation of Tres Alamos Wash (TA) and Ash Creek (A) at selected locations*

Distance from river (miles)	9		6–7				3–4		
Stream	TA	A	TA		A		TA	A	
Plot No.	15	4	14	13	3	1	12	7	8
Flow regimen [1]	E	SP	E	E	I	I	E	E	E
Catclaw acacia	5.67		10.68	1.28		0.89	8.35		0.98
Mesquite	3.77		8.72	2.91		.22	26.39	6.08	9.01
Desertbroom	.04								
Whitethorn acacia							.97		
Burrobrush [2]	.19		.19	.46			.39		8.49
Desert-willow [2]	3.26			.10		.02			28.89
Walnut [2]	.45		1.12	.18		1.06			
Graythorn									.18
Emory oak		5.34							
Arizona white oak		2.65							
Mexican blue oak		2.22							
Scrub oak		1.59							
Arizona cypress		.50							
Mimosa		.22							
Ash [2]		16.06			59.03	6.07			
Sycamore [2]		8.10				36.75			
Hackberry [2]		5.86			.61	3.87		31.13	.13
Black willow [2]						3.41			
Cottonwood [2]					2.0				
Total basal area	13.38	42.54	20.71	4.93	61.64	52.29	36.10	37.21	47.68

[1] E, ephemeral; I, intermittent; SP, semiperennial.
[2] Valley-floor species (p. D18–D19).

with these flows support many species that do not grow along streams with ephemeral regimen. The geology and topography of upper basins also seem to indirectly affect moisture levels in lower reaches. This is suggested by the botanical differences between the lower reaches of Ash Creek and Tres Alamos Wash. These lower reaches are both located on gently sloping valley fill. The lower reach of Ash Creek, a stream with headwaters in steep mountains, supports more valley-floor species and denser vegetation than the corresponding reach of Tres Alamos Wash. Tres Alamos Wash rises in a relatively level basin underlain by valley fill. The effect of the geology and topography of the upper basins on the flow in the lower reaches was observed in December 1965, when concentration of runoff in the headwaters of Ash Creek resulted in sustained flows in the lower reach of this stream (pl. 1); in contrast, the mainstem of Tres Alamos Wash did not flow at all.

TABLE 20.—*Species present at selected locations along Kelsey Canyon*

Location (pl. 1)	13	10	40	57
Flow regimen [1]	E	E	SP	E
Cholla (*Opuntia versicolor*)	X			
Yucca		X		
Rabbitbrush [2]		X		
Desert-willow [2]		X		
Littleleaf sumac [2]		X	X	
Mesquite		X	X	X
Catclaw acacia		X		X
Seepwillow [2]			X	
Hackberry [2]			X	
Ash [2]			X	
Cottonwood [2]			X	
Saltcedar [2]			X	
Desertbroom			X	
Blue paloverde			X	
Burrobrush [2]				X
Whitethorn acacia				X
Pricklypear (*Opuntia engelmannii*)				X

[1] E, ephemeral; SP, semiperennial.
[2] Valley-floor species (p. D18–D19).

KELSEY CANYON

In Kelsey Canyon, as in Tres Alamos Wash, the number of valley-floor species increases with increasing drainage area of the upper reach, reaches a maximum in the middle reach located on bedrock, and then decreases in the lower reach located on valley fill (table 20). In the lowest reach, near the confluence with the San Pedro River, burrobrush is apparently the only valley-floor species growing in the channel and flood plain of Kelsey Canyon. Kelsey Canyon and Tres Alamos Wash both rise on Allen Flat. In contrast to the middle reach of Tres Alamos Wash, that of Kelsey Canyon has semi-perennial flow regimen. This reach supports cottonwood, seepwillow, and saltcedar, species that were not seen in the middle reach of Tres Alamos Wash (table 16, loc. 45). The middle reach of Kelsey Canyon is also the only known station of saltcedar away from the San Pedro River channel in the study area.

LOWER REACH OF HOT SPRINGS CANYON

The preceding examples have shown that streams located on bedrock commonly have sustained flows, or flows other than ephemeral, and that these streams generally support many valley-floor species and dense and tall woody vegetation. However, not all reaches located on bedrock and having sustained flows support dense vegetation sharply differentiated from that growing on the adjacent uplands. For example, reaches of Hot Springs Canyon that have perennial flow support only low thickets of mesquite and burrobrush (fig. 16). In the lower reach of Hot Springs Canyon, tall vegetation containing many valley-floor species and having a basal area comparable to that measured along Paige Canyon or Turkey Creek (tables 11 and 12) grows near the canyon mouth, where the valley floor widens and perennial flow ends (table 21). Thus the width of the valley floor also seems to control the distribution of valley-floor vegetation.

FIGURE 16.—Reach of Hot Springs Canyon with perennial flow at location 51 (pl. 1). Valley-floor vegetation consists of mesquite and burrobrush.

Farther downstream from the canyon mouth, the vegetation along Hot Springs Canyon consists mainly of the mesquite and catclaw acacia thickets characteristic of reaches with ephemeral flow regimen (table 22). The changes in the vegetation of the lower Hot Springs Canyon, at the transition from bedrock canyon having sustained flows to a wide reach located on valley fill and having ephemeral flow regimen, occur with some variations along all tributaries at the point where the streams leave the mountain front. The changes in valley-floor vegetation at or downstream from the mountain front–valley fill contact are probably the most striking examples in the study area of the effect caused by differences in geology and flow regimen on vegetation.

TABLE 21.—*Basal area of valley-floor vegetation of Hot Springs Canyon at location 21 (pl. 1)*

[Approximate maximum height of vegetation, 60 feet]

Species	*Basal area (sq ft)*
Black willow [1]	33.30
Mesquite	25.46
Ash [1]	21.87
Sycamore [1]	16.40
Cottonwood [1]	10.93
Desert hackberry	.68
Burrobrush [1]	.06
Seepwillow [1]	.02
Total	108.72

[1] Valley-floor species (p. D18–D19).

TABLE 22.—*Species present at selected locations along the lower Hot Springs Canyon*

Location (pl. 1)	51	50	47	8
Flow regimen [1]	P	P	E	E
Mesquite	X	X	X	X
Burrobrush [2]	X	X	X	X
Seepwillow [2]		X		
Hackberry [2]		X		
Ash [2]		X		
Sycamore [2]		X		
Cottonwood [2]		X		
Black willow [2]		X		
Soapberry [2]		X		
Four-wing saltbush		X		
Desert hackberry		X		
Catclaw acacia		X	X	
Walnut [2]		X	X	
Whitethorn acacia			X	
Desert-willow [2]			X	X

[1] P, perennial; E, ephemeral.
[2] Valley-floor species (p. D18–D19).

VARIATIONS IN VALLEY-FLOOR VEGETATION DOWNSTREAM FROM THE MOUNTAIN FRONT

The valley-floor vegetation of all tributaries that were sampled changes at the contact between bedrock and the valley fill. Flow regimen usually changes at this contact, as base flows commonly disappear at the point where the stream emerges onto the valley fill. The changes in the valley-floor vegetation can, however, be abrupt or gradual. An abrupt change from a tall bottom-land forest composed primarily of trees that grow only on valley floors to scattered thickets of mesquite and catclaw acacia can be seen, for example, in Redfield Canyon at the point where this stream leaves the Galiuro Mountains (fig. 17). Perennial flow in Redfield Canyon ends at the contact between the bedrock and the valley fill (pl. 1). Individual sycamores grow, however, as far as a point about half a mile downstream from the canyon mouth.

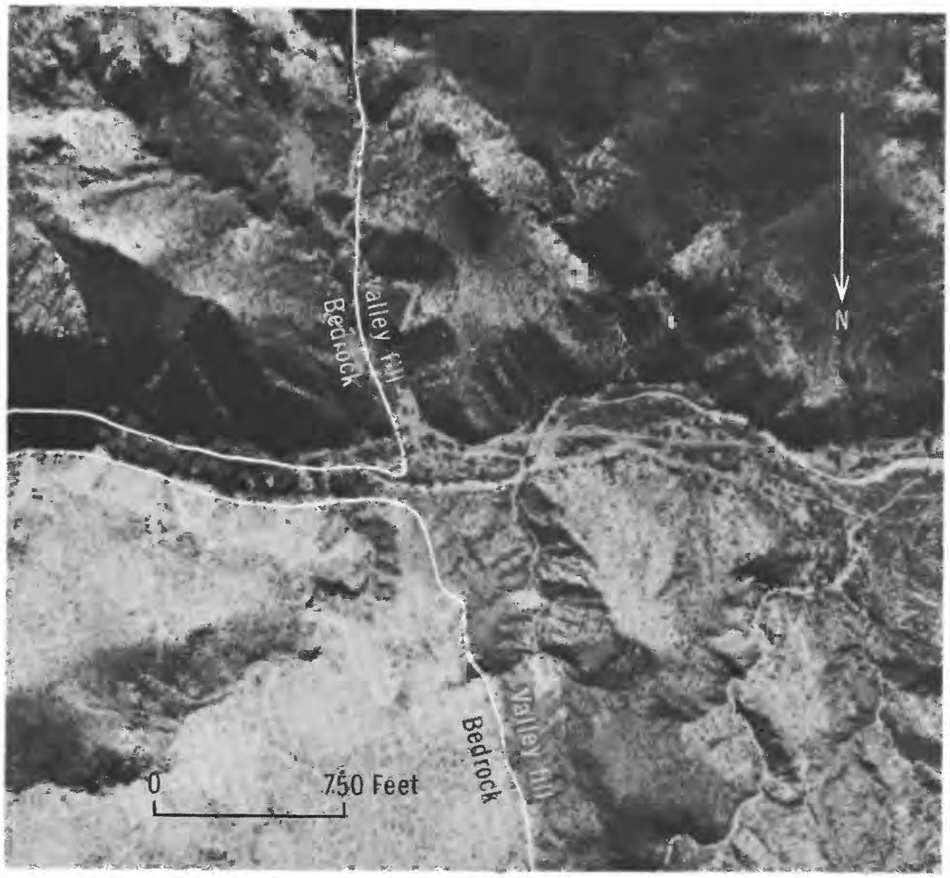

FIGURE 17.—Aerial view of Redfield Canyon at the contact between bedrock and valley fill in SE¼, sec. 34, T. 11 S., R. 19 E. Trees with rounded crowns are mainly sycamores. Direction of flow is from east to west.

In a direction approaching the San Pedro River, the valley-floor vegetation of Redfield Canyon, in common with that of other tributaries, includes a progressively smaller number of valley-floor species (table 23). Thus the valley-floor vegetation of Redfield Canyon varies most conspicuously with the change from bedrock to valley fill, at the point where perennial flow disappears. Downstream from the mountain front, in the ephemeral lower reach located on valley fill, the vegetation changes, but more gradually. These gradual changes in the vegetation suggest a gradual decrease in moisture available to plants in a direction approaching the San Pedro River. The presence of individual sycamores, or trees generally associated with sustained flows, in the reach immediately downstream from the canyon mouth suggests that this reach has a flow regimen intermediate between perennial and ephemeral.

The valley-floor vegetation of the lower reach of Paige Canyon is an example of vegetation that changes gradually downstream from a bottom-land forest composed mainly of valley-floor species to the mesquite and catclaw acacia thickets characteristic of ephemeral lower reaches. The gradual reduction in the number of valley-floor species in a downstream direction is shown in table 24. Plate 2 also shows that in the lower reach of Paige Canyon the ranges of seepwillow, ash, and sycamore

TABLE 23.—*Species present at selected locations along Redfield Canyon*

Location (pl. 1)	71	68	65	22
Distance from canyon mouth..(miles)	0	0.8	3.5	5.5
Flow regimen [1]	P	E	E	E
Alder [2]	X			
Seepwillow [2]	X			
Hopbush [2]	X			
Ash [2]	X			
Walnut [2]	X			
Sycamore [2]	X			
Cottonwood [2]	X			
Arizona grape [2]	X			
Desert hackberry	X			
One-seed juniper	X			
Hackberry [2]	X	X		
Graythorn	X	X		
Mesquite	X	X	X	X
Desert-willow [2]		X	X	
Burrobursh [2]		X	X	
Catclaw acacia		X	X	X
Cholla (*Opuntia versicolor*)		X		
Whitethorn acacia				X
Lycium (*Lycium berlandieri*?)				X

[1] P, perennial: E, ephemeral.
[2] Valley-floor species (p. D18–D19).

extend for at least 1 mile downstream from the canyon mouth. The gradual change in valley-floor vegetation of the lower reach of Paige Canyon is attributed to a more gradual reduction of moisture available to plants away from the mountain front than occurs for example, along Redfield Canyon. Paige Canyon is unique in the study area in that it does not leave the mountain front at near a right angle, but rather is flanked on one side by bedrock for about 3 miles after leaving the bedrock canyon (pl. 1).

TABLE 24.—*Species present at selected locations along the lower Paige Canyon*

Location (pl. 1)	190	188	73	72	11
Flow regimen [1]	SP	I	I	E	E
Distance from canyon mouth miles	0	1.0	1.8	2.5	3.8
Cassia [2]	X				
Cottonwood [2]	X				
Soapberry [2]	X				
Trumpetbush [2]	X				
Seepwillow [2]	X	X			
Hackberry [2]	X	X	X	X	X
Ash [2]	X	X			
Walnut [2]	X	X	X	X	
Sycamore [2]	X	X	X	X	
Burrobrush [2]		X	X	X	
Mesquite		X	X	X	X
Desert-willow [2]			X	X	X
Whitethorn acacia				X	X
Catclaw acacia				X	X
One-seed juniper				X	
Lycium (*Lycium berlandieri*?)				X	X
Pricklypear (*Opuntia engelmannii*)					X
Barrel cactus					X
Graythorn					X
Four-wing saltbush					X
Jointfir					X

[1] SP, semiperennial; I, intermittent; E, ephemeral.
[2] Valley-floor species (p. D18–D19).

Paige Canyon cuts through a narrow mountain spur in its lower reach before flowing into the San Pedro River. Most of the reach between the canyon mouth and the gap in the mountain spur was found to have intermitten flow regimen during the period October 1964–April 1965 (pl. 1). Sycamores, either solitary or in clusters, occur as far downstream as the gap in the mountain spur. Downstream from the gap, the only valley-floor trees (walnut, hackberry, and desertwillow) are those commonly found in ephemeral lower reaches of large tributaries (pl. 2). The only tributary in the study area whose extreme lower reach supports sycamore and soapberry—in addition to walnut, hackberry, and desertwillow—at points only 0.5 mile from the San Pedro River is Buehman Canyon (figs. 19, 20). Buehman Canyon is also the only tributary whose entire lower reach has intermittent flow regimen (p. D7). The valley-floor vegetation of the lower Buehman Canyon is marked, however, by the characteristic downstream reduction in the number of valley-floor species (table 25).

TABLE 25.—*Species present at selected locations along the lower reach of Buehman Canyon*

Location (pl. 1)	24	23 [1]
Flow regimen [2]	I	I
Seepwillow [3]	X	
Hackberry [3]	X	
Sycamore [3]	X	
Soapberry [3]	X	
Graythorn	X	
Desert-willow [3]	X	X
Burrobrush [3]	X	X
Walnut [3]	X	X
Catclaw acacia	X	X
Mesquite	X	X

[1] Location 23 is only 0.4 mile downstream from location 24.
[2] I, intermittent.
[3] Valley-floor species (p. D18–D19).

LOWER REACH OF SOZA CANYON

The valley-floor vegetation of the lower reach of Soza Canyon has, in common with that of other tributaries, a progressively smaller number of valley-floor species downstream from the mountain front. In the extreme lower reach of Soza Canyon, however, this number increases again (table 26). This reach also supports species (seepwillow, ash, yew-leaf willow) not commonly found in ephemeral streams or reaches of streams (pl. 2). The extreme lower reach of Soza Canyon is the only one in the study area that is located on bedrock. The changes in valley-floor vegetation that occur in the lower reach of Soza Canyon thus probably reflect a dispersal of moisture in that part of the lower reach on valley fill and relatively higher moisture levels in that part of the lower reach on bedrock. The vegetation of Soza Canyon is another example of botanical variations coinciding with geological differences; the effect of these differences is probably to alter the amount of moisture available to plants without causing, as in the middle reach of Tres Alamos Wash, a conspicuous change in flow regimen.

TABLE 26.—*Valley-floor species present at selected locations along Soza Canyon*

Location (pl. 1)	80	36	84
Flow regimen [1]	SP	E	E
Geology [2]	B	VF	B
Seepwillow	X		X
Brickellia	X		X
Buttonbush	X		
Canyon ragweed	X		X
Ash	X		X
Cottonwood	X		
Black willow	X		
Yew-leaf willow	X		X
Soapberry	X		
Arizona grape	X		
Hackberry	X	X	X
Desert-willow		X	X
Walnut		X	X
Burrobrush		X	X

[1] SP, semiperennial; E, ephemeral.
[2] B, bedrock; VF, valley fill.

VEGETATION OF THE SAN PEDRO RIVER BOTTOM LANDS

The valley floor of the San Pedro River constitutes an environment which differs considerably from the tributary valley floors previously described. In the study area, the San Pedro River drains more than 2,000 square miles of arid basin, whereas the largest tributary within the study area drains only about 135 square miles. The tributaries also flow less than 25 miles, and commonly have headwaters in humid mountains. In contrast, the San Pedro River flows about 100 miles across a basin underlain largely by unconsolidated deposits upstream from Tres Alamos. In the study area, the San Pedro River is the only stream located mainly on valley fill that has predominantly semiperennial flow regimen.

The vegetation growing within the entrenched channel of the San Pedro River is unique in the study area in that it consists primarily of thickets of saltcedar. Saltcedar was not observed, however, in a 7-mile reach near Redington (pl. 2). In November 1964, saltcedar covered 451 acres of bottom land between Tres Alamos and Redington. This area was measured from color aerial photographs taken at a time when the deciduous saltcedar was conspicuously yellow orange. Away from the San Pedro River, saltcedar occurs apparently only in the middle reach of Kelsey Canyon, where several small trees are present. Other species common along the San Pedro River are seepwillow, mesquite, cottonwood (fig. 14), and black willow (table 27).

TABLE 27.—*List of species observed within the channel of the San Pedro River*

[Figures in parentheses indicate the percentage of 31 sample plots in which the most common species grow. The sample plots were spaced about 1 mile apart between Tres Alamos and a point about 4 miles north of Redington]

Seepwillow (100)	Desertbroom
Mesquite (84)	Hackberry
Saltcedar (81)	Desert-willow
Cottonwood (58)	Ash
Black willow (52)	Burrobrush
Graythorn (32)	Walnut
Lycium (*Lycium berlandieri?*) (29)	Creosotebush
	Tree tobacco
Rabbitbrush (23)	Pricklypear (*Opuntia engelmannii*)
Catclaw acacia	
Whitethorn acacia	Cholla (*O. versicolor*)
Honeysage	Sycamore
Four-wing saltbush	Arrowweed

The channel of the San Pedro River supports two species—tree tobacco and arrowweed—that were not seen on tributary valley floors. On the other hand, many valley-floor species present along tributaries with perennial or semiperennial flow regimens were not observed along the San Pedro River, either in the study area or at higher altitudes upstream. These species are: alder, Arizona cypress, Arizona grape, brickellia, buckthorn, bumelia, buttonbush, cassia, canyon ragweed, hopbush, indigobush, littleleaf sumac, Mexican elderberry, oak, poison-ivy, soapberry, squawbush, sumac, trumpetbush, Bonpland and yew-leaf willow. Ash, walnut, hackberry, and sycamore—trees common on tributary valley floors—are relatively rare along the San Pedro River. In the study area, most of them grow in the perennial reach flanked by bedrock downstream from Cascabel (pls. 1 and 2). Except for hackberry, which grows at one location in the SE¼, sec. 33, T. 14 S., R. 20 E., none of these trees was observed south of Cascabel. Sycamore was seen at only one location, about two miles north of Redington, near the mouth of Edgar Canyon.

The difference between the vegetation growing in the channel of the San Pedro River and that of tributaries with flow regimens similar to those of the mainstem is probably due to differences in water quality between the San Pedro River and its tributaries. The water on the bottom lands of the San Pedro River is presumably more mineralized than that of tributaries. This hypothesis is supported by the presence of large salt incrustations and efflorescences along the San Pedro River. particularly south of Cascabel. In November 1964, for example, salt efflorescences in secs. 4 and 9, T. 15 S., R. 20 E., covered an area of about 10 acres near the river. These efflorescences were mapped from aerial photographs and checked on the ground. Salt efflorescences were not seen along tributaries. Of 29 published analyses of water "from representative wells and springs" in the lower San Pedro Valley, the eight samples with less than 20 percent sodium (Na)[3] were all from the underflow of tributaries such as Soza Canyon, Hot Springs Canyon, and Aravaipa Creek (fig. 1), or from valley-floor springs in tributary reaches in the mountains or near the mountain fronts flanking the San Pedro River (Halpenny and others, 1952, table 17). The average sodium content of four shallow wells sunk in the bottom lands of the San Pedro River in the study area was 44.5 percent (Halpenny and others, 1952, table 17). Total dissolved-solids content is, however, not necessarily lower away from the San Pedro River bottom lands (Halpenny and others, 1952, table 17). The waters along the San Pedro River are thus not consistently more mineralized than those of tributary basins, but the concentrations of some elements may be sufficiently higher along the river as to be toxic to some plants. Sodium content, for example, is locally so high on the bottom land of the lower San Pedro Valley that waters are not suitable for irrigation (Halpenny and others, 1952, p. 99).

[3] Presumably defined as percent Na $=\frac{(\mathrm{Na}+\mathrm{K})\ 100}{\mathrm{Ca}+\mathrm{Mg}+\mathrm{Na}+\mathrm{K}}$, where all ionic concentrations are expressed in milliequivalents per liter. (See Todd, 1959, p. 191.)

The growth of saltcedar, the characteristic plant of the San Pedro River bottom lands, may be favored by relatively high salt content of the water in and near the river. Saltcedar seems to reach its maximum volume density in areas where ground water has a dissolved-solids concentration of more than 8,000 ppm (parts per million) (Gatewood and others, 1950, p. 80). Saltcedar apparently "grows well" where the common salt (sodium chloride) content is high, although it also tolerates a wide range of water quality (Robinson, 1958, p. 16). A relationship between saltcedar growth and mineralized water is also suggested by the presence of this plant in the middle reach of Kelsey Canyon (p. D23), in an area of Cretaceous(?) and Tertiary(?) sedimentary rocks that apparently yield highly mineralized water. Water drawn from well (D–12–20) 23dc, located about 1.5 miles from the middle reach of Kelsey Canyon, had a total dissolved-solids concentration of 9,160 ppm, a total hardness as calcium carbonate of 724 ppm, and a sodium content of 89 percent (Halpenny and others, 1952, table 17).

Relatively high mineralization of water may, on the other hand, account for the absence or rare occurrence of many species along the San Pedro River. Ash, hackberry, and walnut, for example are most common along the reach having perennial flow north of Casabel (pl. 2), where the San Pedro River channel is presumably underlain at shallow depth by bedrock (pl. 1). In that reach, perennial surface flows and shallow underflow may prevent harmful accumulations of salts. Ash, sycamore, walnut, and hackberry are either absent or rare south of Cascabel, where salt efflorescences are most common. Sycamore, a tree reputed to be an indicator of "good" water (Meinzer, 1927, p. 78), is the rarest of these trees along the San Pedro River. Only three sycamores, those growing north of Redington (pl. 2), were seen between Mammoth and the Mexican border (fig. 1). Sycamore grows, however, in the headwaters of the San Pedro River in Sonora, Mexico (J. R. Hastings, Inst. of Atmospheric Physics, Arizona Univ., oral commun., 1965). In contrast, cottonwood and black willow are relatively common along the San Pedro River (table 27), which suggests that these two trees may be more tolerant of highly mineralized water.

On the San Pedro River bottom lands, the only known forest composed of walnut, hackberry, ash, sycamore, willow, and cottonwood similar to forests growing in some tributaries is outside the study area, near the mouth of Edgar Canyon in the SW¼, sec. 26, T. 11 S., R. 18 E. This location is about 2 miles north of Redington. The headwaters of Edgar Canyon are above 8,000 feet in the Santa Catalina Mountains, and the stream frequently flows in the spring as a result of snowmelt in those mountains. The occurrence of the forest near the mouth of Edgar Canyon may thus be related to a local reduction of the mineralization of water on the San Pedro River bottom lands. Such a local decrease in dissolved-solids content along a river due to inflow from tributaries has been shown for the Gila River in the Duncan basin (Halpenny and others, 1952, p. 38, pl. 4).

The presumed pre-1880 flood plain of the San Pedro River, which is generally 20–30 feet above the entrenched channel, supports mesquite forests (bosques) composed of trees about 30–35 feet tall. These forests contain scattered catclaw acacia, graythorn, lycium, pricklypear, cholla, allthorn, and other shrubby, herbaceous (commonly jimsonweed), and grassy (Gramineae) species. (See Shreve, 1951, p. 71.) The forests are being cleared to make room for irrigated agriculture. By late 1965, about 3,900 acres or about half of the mesquite forests growing on the presumed pre-1880 flood plain between Tres Alamos and Redington had been cleared. The mesquite forests grow on a surface now presumably no longer reached by channeled flow, and therefore their relation to streamflow is indirect. These forests are discussed only in connection with the role of vegetation in the regional hydrology (p. D41–D42).

SUMMARY

The vegetation of valley floors ranges from stands of shrubs that have the same species composition as the vegetation of the adjacent desert uplands to a closed-canopy forest composed mainly of trees that grow only on valley bottoms. Many intermediate types of valley-floor vegetation occur. Common examples of these are vegetation with the same species composition as that of the adjacent uplands but appreciably taller and denser and thickets of species that also occur on uplands but mixed with trees that were seen only on valley floors.

Valley floors support many species, referred to as valley-floor species, that either were not seen on uplands or were seen only on uplands below certain altitudes. Valley-floor species occur at and downstream from points with certain minimum drainage areas. With increasing drainage area, the number of these species present on the valley floor increases, the maximum usually occurring in the middle reaches of tributaries. Downstream from the mountain front, the number of valley-floor species in ephemeral lower reaches located on valley fill progressively decreases. In Soza Canyon, however, the number of valley-floor species increases again in the extreme lower reach. The extreme lower reach of Soza Canyon is the only such reach in the study area located on bedrock.

Away from the basin divide, the points of first occurrence of valley-floor species have considerably larger drainage areas on valley-fill than on bedrock. The largest number of valley-floor species and dense bottom-land forests occur in wide middle reaches flanked by bedrock and having intermittent, semiperennial, or perennial flow regimens, or near the mouths of canyons. Constricted canyons with semiperennial or perennial flows are commonly almost devoid of woody vegetation. The most conspicuous and abrupt changes in valley-bottom vegetation occur at or immediately downstream from the bedrock–valley fill contact, where forests composed mainly of valley-floor trees grade into open thickets of desert shrubs within a few tens of yards. In most large tributaries, however, individual valley-floor trees like ash or sycamore may grow half a mile or more downstream from canyon mouths. Changes in valley-floor vegetation at the bedrock–valley fill contact is either abrupt or gradual, apparently depending upon whether the change in surface-flow regimen is abrupt or fairly gradual.

The valley-floor vegetation of the San Pedro River, the mainstem in the study area, has a different species composition from that of tributaries with flow regimens similar to those of the San Pedro River. The characteristic vegetation form along the San Pedro River is thickets of the saltcedar, a species that was seen at only one location away from the mainstem.

The variations in the vegetation of valley floors have been related mainly to either concentration or dispersal of moisture, depending upon the presence of either bedrock or unconsolidated valley fill. Given uniform geology, the effect of drainage area on relative moisture levels on the valley floor is also reflected in the vegetation. As shown by the vegetation growing along Tres Alamos Wash, however, the differentiation between the vegetation of the valley floor and that of the adjacent uplands does not increase indefinitely with increasing drainage area. Beyond an optimum drainage area, the valley-floor vegetation varies in a fashion suggesting decreasing moisture availability. The vegetation along the San Pedro River, a stream draining more than 2,000 square miles, differs from that of considerably smaller tributaries presumably because differences in quality of water also affect the distribution of vegetation.

GERMINATION OF VALLEY-FLOOR SPECIES

The ranges of most plants at the adult stage probably represent contractions of their ranges at the seedling stage, as many seedlings do not survive into adulthood. The range of adult plants is evidence that conditions necessary for survival of those plants obtain in certain habitats; it is not necessarily indicative, however, of the conditions under which the plants germinated and survived the early days or weeks of growth. In the study area, variations in the plant cover seem to reflect, for example, broad hydrologic differences. Without data on germination and seedling survival, however, it is impossible to determine whether plant distributions reflect hydrologic conditions at the time plants become established, or whether distributions reflect recurrent conditions that insure the survival of adult plants. A knowledge of germination behavior also helps to identify those plants that may become established as a result of infrequent alluvial processes.

Seepwillow

Seepwillow requires sustained flows and stranding in saturated alluvium for germination and seedling survival (Horton and others, 1960, p. 16). Seepwillow seedlings survive if the sediments are saturated during the first 2–4 weeks of growth (Horton and others, 1960, p. 16). Germination occurs from late March through the summer (Horton and others, 1960, p. 16; personal observation). The seepwillow seedlings observed in the spring of 1965 were confined to saturated alluvium along semiperennial and perennial flows.

Hackberry

Hackberry seedlings were seen in the spring of 1965 in the sand of large ephemeral streams that had not flowed since the previous fall. Seedlings were also growing in saturated alluvium in reaches with sustained flows.

Ash

Ash seedlings were first seen on January 28, 1965, along the perennial flow of Redfield Canyon. Concentrations of hundreds of seedlings were seen, however, only in late March and early April, a period that may be the seasonal peak in ash germination. Ash seedlings were seen in the perennial and semiperennial reaches of Redfield Canyon, Ash Creek, Soza Canyon, Rincon Creek, Pantano Wash at the Vail gaging station, Sabino Canyon, and Buehman Canyon. Pantano Wash, Rincon Creek, and Sabino Creek are gaged streams in the Tucson basin and are included in the study as controls (p. D43–D44). In Pantano Wash at Vail, for example, ash seedlings were confined to a narrow (3 ft. or less) band of saturated sand along the perennial flow. Many seedlings were half submerged along the edge of the flow. Values of seedling density on April 5, 1965, were 26, 30, 46, 48, and 54 seedlings per square meter. Along Rincon Creek in sec. 16, T. 15 S., R. 17 E., hundreds of ash seedlings were also growing in secondary channels, dry on April 5, 1965, that were densely shaded by tangled vegetation. In places, the concentrations of seedlings ended at the end of the canopy of vegetation, at the boundary between moist and dry sand.

The distribution of ash seedlings was examined in detail along the intermittent and semiperennial middle and lower reaches of Ash Creek (pl. 1) in late March and late August, 1965. In late March, the range of seedlings coincided with the extent of the semiperennial flow; no seedlings were observed in the intermittment reach, in which no flows occurred between November 11, 1964, and March 1965. The intermittent reach supports groves of ash (table 18), presumably germinated in years of unusual sustained runoff in this reach. In late August, the range of the seedlings, by then about 4 inches high, had contracted, but not as much as the extent of semiperennial flow. (See pl. 1). Many seedlings were growing in late August in dry sand (fig. 18) near location 65, in a reach which had sustained flow in the spring.

FIGURE 18.—Ash seedlings in the channel of Ash Creek in the SW¼, sec. 9, T. 16 S., R. 19 E. These seedlings germinated in the spring of 1965, when this reach had sustained flow. August 31, 1965.

Ash seedlings, still bearing cotyledons, were growing in silt around pools in Ash Creek near location 66 in late August 1965. Thus ash germinates in the summer, but if the data for Ash Creek are representative, the range and number of summer seedlings are smaller than in the spring. No summer seedlings were seen, for example, in the semiperennial reach of Buehman Canyon, where even most of the spring seedlings had disappeared.

Ash germinates in ephemeral and intermittent reaches affected by winter discharges. Ash seedlings were seen in early April 1965 in silty depressions, but not in dry sand, in the lower reaches of Buehman and Soza Canyons. In Soza Canyon the seedlings were seen in the NW¼, sec. 12, T. 13 S., R. 18 E., at a point well within the reach wetted by winter discharges (table 4). In Buehman Canyon, ash seedlings were numerous in the NE¼, sec. 4, T. 12 S., R. 18 E. Buehman Canyon flowed to the San Pedro River for as long as 7 consecutive days during the winter of 1965 (table 5). None of the seedlings in the intermittent lower reach of Buehman Canyon was left on August 30, 1965. Survival of ash in ephemeral and intermittent reaches where it germinates as a result of slowly advancing and retreating winter discharges is apparently difficult, as also suggested by the small number of adult ashes in these reaches and by the absence of ash in many reaches subject to winter discharges.

Sycamore

Sycamore seeds were ubiquitous, beginning early in March, in the streams where this species grows. However, gemination was observed only in a slough on the flood plain of Rincon Creek in the NE¼, sec. 16, T. 15 S., R. 17 E., where, on April 5, 1965, several seedlings were emerging from a half-submerged seed ball. Sycamore seedlings about 6 inches high, apparently germinated in the spring of 1965, were seen in the semiperennial reach of Buehman Canyon in late August 1965.

Cottonwood

Germination of cottonwood was not observed in March and early April 1965. Cottonwood seed is apparently ripe in April, and it loses all viability 7 weeks thereafter (Horton and others, 1960, p. 2–3).

Black Willow

Numerous willow seedlings about 4–6 inches high were growing in the semiperennial reach of Ash Creek in sec. 9, T. 16 S., R. 19 E. and along the semiperennial reach of Buehman Canyon in late August 1965. Willow presumably germinates during a short period in the spring when seed is briefly viable (R. M. Turner, U.S. Geol. Survey, oral commun., 1965).

Saltcedar [4]

Saltcedar germinates on saturated sediment and even while seed is floating in water. Slowly receding spring and summer flows are particularly conducive to abundant germination and seedling establishment. The seedlings grow slowly and are sensitive to drying; survival seems to depend on sediment remaining saturated during the first 2–4 weeks of growth. Rapidly retreating flows and quickly drying bed and bank material are, therefore, unfavorable to saltcedar establishment. Saltcedar can, on the other hand, withstand several

[4] Data from Horton, Mounts, and Kraft (1960, p. 5, 16).

weeks of submergence. The germination and establishment of saltcedar are similar to those of seepwillow, which probably explains the similarity in the distribution of these two species along the San Pedro River. The dependence of saltcedar and seepwillow on slowly retreating flows for germination and seedling establishment may explain why these two species are apparently absent or rare in the 7-mile reach near Redington (pl. 2). This is the longest reach of the San Pedro River observed in or near the study area that has only intermittent flow regimen (pl. 1).

Observations and published data on germination and seedling establishment indicate that seepwillow, ash, sycamore, black willow, and saltcedar require substrate saturated or moistened by sustained flows, or flows other than ephemeral, in order to germinate and survive beyond the seedling stage. The same is probably also true of cottonwood. The seedlings of these species that were seen in the spring of 1965 were all growing in reaches that had experienced sustained flows in the winter of 1964–65 or in early spring of 1965. No seedlings were seen on uplands or in ephemeral streams even though seepwillow, ash, and sycamore seeds were commonly seen in these streams. In contrast, hackberry apparently can germinate and survive the seedling stage in substrates moistened only by precipitation; the distribution of adult hackberries indicates, however, that this tree can survive only on valley floors. Thus duration of surface flow seems to be an important control in the distribution of many valley-floor species because of the requirements of these species at the germination and seedling stages of growth.

Germination of ash, hackberry, cottonwood, black willow, sycamore, and probably also walnut (winter-deciduous trees) seems to occur primarily in late winter and in spring, when sustained flows are most extensive. This is also suggested by the coincidence of the ranges of ash, willow, cottonwood, and sycamore with the most extensive winter–early spring flows observed, rather than with the shorter summer flows (pls. 1 and 2). Judging from the observations of ash seedlings in Ash Creek and Buehman Canyons, the contraction of base flows in the summer apparently also destroys seedlings of trees that germinate in the spring. Thus in southern Arizona, although most of the rain and runoff occur in the summer, the establishment of many common valley-floor trees is geared to flow conditions in late winter and early spring. In contrast, the establishment of most Southwestern desert plants (mesquite, acacias, cactuses, desert-willow, creosotebush) is probably dependent mainly on summer rains.

The data on germination indicate the need to consider the seasonal changes in streamflow in order to explain distributions of valley-floor species. These data also help to interpret unusual distributions of plants. Thus, the presence of species known to require sustained flows for germination and seedling establishment (for example, ash and seepwillow) in ephemeral streams or reaches of streams suggests the occurrence of occasional sustained flows, such as those observed in December 1965–January 1966. Data on the effect of surface flow regimen or germination also help to explain why in the lower reaches of tributaries, despite progressively shallower ground water downstream, the valley floors do not support those species usually present at wet sites.

GENERAL INTERPRETATION OF THE ECOLOGY OF VALLEY-FLOOR VEGETATION

HEADWATERS LOCATED ON VALLEY FILL

Headwaters located on valley fill have ephemeral flow regimen as a result of arid climate, deep water tables, and low concentration of runoff on pervious deposits with subdued relief. (See headwaters of Tres Alamos Wash, pl. 1.) Away from the basin divide the valley-floor vegetation has at first the same species composition as the vegetation growing on the adjacent uplands. See headwaters of Tres Alamos Wash and Kelsey Canyon, tables 16, 20. With increasing drainage area, the vegetation becomes appreciably taller and denser than that of the surrounding uplands (Great Bajada Wash, table 13), though the species composition may be similar on both valley floor and uplands. Valley-floor species (p. D18–D19) have their uppermost stations along a stream at the point where the drainage area has a threshold size. In the study area, this size is about 3 square miles. The first valley-floor species seen in a downstream direction is generally burrobrush. This shrub is generally the only valley-floor species growing along washes flowing on valley fill that have a drainage area of between 3 and 6 square miles.

Along streams with a larger drainage area, valley-floor trees generally grow at and downstream from points where the drainage area exceeds 5 square miles. Hackberry, desert-willow, and walnut are seen roughly in that order downstream along the headwaters of a stream with ephemeral flow regimen. The increase in the number of valley-floor species on the valley floor of a stream flowing on valley fill apparently continues until the stream has a drainage area of 20–50 square miles. With drainage areas exceeding this size, the number and the species present remain about the same, or the number may decrease (Tres Alamos Wash, table 16). In the study area, streams with ephemeral flow regimen and flowing on valley fill apparently cannot support valley-floor trees other than hackberry, blue paloverde (at altitudes where this species grows only on valley floors), desert-willow, soapberry, and walnut, regardless of drainage area size.

The increasing differentiation between valley-floor and upland vegetation with increasing drainage area along streams with ephemeral flow regimen is attributed to increasing volumes of alluvium on the valley floor and greater storage of moisture replenished by longer lasting ephemeral flows. The differentiation has limits, however, presumably because beyond a certain point along a stream, amounts of moisture available to plants between ephemeral flows remain the same or decrease (p. D37). The increase in the number of valley-floor species and in the density of the vegetation along ephemeral streams probably cannot be directly related to an increase in discharge, especially peak discharge, or to greater frequency of discharge.

Plant distributions cannot be directly related to size of discharge because the volume of runoff in the channel is not important to plant growth. For example, a peak discharge of either 50 cfs or 1,000 cfs may saturate the entire thickness of the alluvium at a given point along an ephemeral stream. What is important to the plants is that the flow has occurred and that locally the maximum storage of moisture in the substrate has taken place. Thus only the moisture that can be stored locally is important to plants, and not surface runoff. (See Hack and Goodlett, 1960, p. 29–30.) In eastern Arizona, there is also a poor relationship between drainage area and size of discharge within the range of 1 to about 150 square miles of catchment basin (Kennon, 1954, figs. 5 and 9). Small ephemeral streams frequently have disproportionately large discharges. For example, Great Bajada Wash, a stream with a drainage area of 3.8 square miles, has had a peak discharge of 6,700 cfs (Smith and Heckler, 1955, p. 5; wash referred to by location). In contrast, the maximum discharge recorded in Sabino Creek, a stream near Tucson (fig. 1) with a drainage area of 35.5 square miles, in 40 years is only 5,100 cfs (U.S. Geol. Survey, issued annually).

Small ephemeral streams may discharge more frequently than large ephemeral streams. For example, a wash draining about 1 square mile underlain mainly by bare basin fill and located mostly in sec. 31, T. 15 S., R. 20 E. is known to have discharged three times during the winter of 1964–65, whereas Tres Alamos Wash (134.75 sq mi) last flowed on October 17, 1964. The small wash, hereafter referred to as Red Silt Wash, flowed at the road crossing in the NW¼, sec. 31, on January 31, February 7, and February 8, 1965, when 0.34, 0.03, and 0.03 inch of precipitation were recorded at Benson (data from U.S. Weather Bureau). Tres Alamos Wash is not known to have ever flowed as a result of winter rains (Frank Coons, lifetime resident of Tres Alamos area; George Sherman, foreman, Tres Alamos Ranch, oral commun., 1965).

The washes that drain the disected basin fill of T. 16 S., Rs. 20 and 21 E. (fig. 9) also seem to flow more frequently than Tres Alamos Wash and to have unusually large peak discharges. These washes are regarded by residents of Pomerene as flood hazards (Mrs. F. Gillespie, Wagner Ranch, oral commun., 1964). Partial flooding of Pomerene by some of these washes was observed on October 16–17, 1964, August 29, 1965, and September 4, 1965. In contrast, on September 4, 1965, Tres Alamos Wash did not flow at all, despite a series of storms over its basin. On October 16–17, 1964, and August 29, 1965, the peak discharges observed in washes in the NW¼, sec. 27, T. 16 S. and the SW¼, sec. 21, T. 16 S., R. 20 E., were estimated to exceed the peak discharge in Tres Alamos Wash by several hundred cubic feet per second.

Another example of a small stream flowing on valley fill (mainly basin fill) and having unusually large and frequent discharges is Tucson Arroyo in Tucson. The original drainage area of this stream was 27 square miles; this was reduced to 8.2 square miles by flood-control structures (U.S. Geol. Survey, 1964, open-file report). The maximum discharge on record in this stream is 5,000 cfs, measured after the drainage area had been reduced to 8.2 square miles. Since 1940, Tucson Arroyo has had at least six peak discharges exceeding 2,500 cfs (U.S. Geol. Survey, issued annually). In contrast, in Sabino Creek (35.5 sq mi) only four discharges have exceeded 2,500 cfs since 1932 (U.S. Geol. Survey, issued annually). Small ephemeral streams thus may have relatively frequent and large discharges. The valley floors of these streams commonly support vegetation with the same species composition as that growing on the adjacent uplands (Red Silt Wash; Great Bajada Wash on valley fill; washes in T. 16 S., Rs. 20 and 21 E.). Apparently large and fairly frequent ephemeral flows alone do not cause large amount of moisture to be available to plants.

With increasing drainage area, valley floors of streams located on valley fill have increasingly larger volumes of alluvium. The alluvium or Recent fill is generally more porous than the underlying older valley fill (table 2; fig. 19). This difference in texture alone partly explains why the valley floors of small ephemeral streams that seldom flow support vegetation different from that growing on the adjacent uplands underlain by valley fill (Great Bajada Wash, table 13). For example, on the morning after the storms of August 29, 1965, the sandy alluvium of small washes on the smooth slope in T. 14 S. (fig. 7) was wet to a depth of at least 3 feet, whereas

FIGURE 19.—Red Silt Wash in the NW¼, sec. 31, T. 15 S., R. 20 E. Width of the channel is 6 feet. Average and maximum depths of the alluvium are 9 and 11 inches. The dark deposit is basin fill (table 2).

the loams of the adjacent uplands were visibly moist only to depths ranging from 3 to 6 inches. Thus, even where the drainage area is small, concentrated runoff and porous alluvium result in higher moisture levels on valley floors than on uplands underlain by unconsolidated older valley fill or by soils.

The larger the volume of alluvium, presumably the larger the amount of moisture stored. In the middle reach of Tres Alamos Wash, for example, the Recent fill is probably tens of feet thick (Cooper and Silver, 1964, pl. 2, sec. G–G′). As the channel width of the middle reach of this wash generally exceeds 50 feet, plants growing in the reach can tap a large volume of moist substrate. In March 1965, the alluvium of Tres Alamos Wash at location 45 (pl. 1) was sufficiently moist at depths below 2 feet to leave a film of moisture on the blade of a shovel. Tres Alamos Wash received moisture only from precipitation during the winter and spring of 1964–65. In contrast, in March 1965, the thin alluvium of Red Silt Wash (fig. 19) was dry to the touch. The middle reach of Tres Alamos Wash supports five valley-floor tree species, whereas the vegetation lining Red Silt Wash has the same species composition as that growing on the surrounding uplands.

With increasing drainage area and volumes of runoff and alluvium, the duration of ephemeral flows increases. (See Kincaid and others, 1966, p. 387.) The sequence of events observed in or near Tres Alamos Wash at the Pomerene-Cascabel road ford during a storm is shown in table 28. The streamflow record of Walnut Gulch, a stream about 25 miles south of Tres Alamos (fig. 1), indicates, for example, that flows lasting 10 hours or more apparently do not occur in tributaries with a catchment area of less than 5 square miles (U.S. Agr. Research Service, 1963, p. 63.1). This difference in flow duration probably causes differences of moisture storage on the valley floors, which, in turn, affect the distribution of vegetation. For example, walnut was observed only along the mainstem and tributaries of Walnut Gulch at and downstream from points where the drainage area is about 5 square miles.

TABLE 28.—*Flow events in and near Tres Alamos Wash at the Pomerene-Cascabel road on August 29, 1965*

Time (p.m.)	*Event*
4:00	Start of precipitation.
4:04	First runoff on compacted road bed.
4:08	Flood in Tres Alamos Wash reaches road ford; initial bore about 6 inches high.
4:15	Peak discharge in Tres Alamos Wash; estimated at 300–500 cfs.
4:40	Peak apparently sustained until this time; rapid decline thereafter.
4:55	End of precipitation; flow in Tres Alamos Wash levels off at about 15 cfs.
5:00	First-order streams in the vicinity dry.
6:40	End of flow in Tres Alamos Wash; total duration of flow 2 hours 32 minutes.
7:00	Alluvium in Tres Alamos Wash still saturated below 1 foot of depth.

The increase in the number of valley-floor species along ephemeral streams and in the density of valley-floor vegetation with increasing drainage area is probably related to an increasing "valley storage" which is difficult to measure directly. The increase in this moisture storage on the valley floor is due to longer lasting ephemeral flows wetting progressively larger volumes of alluvium. With increasing drainage area, the period required for the depletion of moisture between ephemeral flows is thus correspondingly longer.

HEADWATERS LOCATED ON BEDROCK

Headwater basins located on bedrock contain greater concentrations of moisture than do headwater basins underlain by valley fill. Steep side slopes and valley floors underlain by bedrock either at the surface or at shallow depth contribute to the concentration of runoff and to the retention of water at or near the surface of valley floors. Within 1–2 miles from the drainage divide, a stream located on bedrock may have pools of water that has been retained for months beyond storm discharges, or it may have intermittent flow regimen (headwaters of Ash Creek, Keith Ranch Creek, and of Davis Canyon, pl. 1). As a result, headwater reaches located on bedrock support valley-floor species at points where the drainage area is less than 3 square miles (Ash Creek, Keith Ranch Creek, and two creeks immediately south of Keith Ranch Creek; figs. 19, 20). Sustained flows or persistence of water at the surface also allows species like seepwillow, ash, and buttonbush to germinate and become established. Thus, headwaters located on bedrock not only support valley-floor species at points where the drainage area is less than in basins underlain by valley fill, but these species are generally different from those growing on unconsolidated deposits. Even without sustained flows, headwater reaches located on bedrock may support valley-floor trees at points where the drainage area is less than 3 square miles (upper reach of Great Bajada Wash, pl. 2).

If a stream leaves the bedrock of its upper basin to flow onto the valley fill, the valley-floor vegetation growing on valley fill is generally different from that growing in the reach located on bedrock (Keith Ranch Creek, two creeks immediately south of Keith Ranch Creek, and Great Bajada Wash, pl. 2). At the bedrock-valley fill boundary, flow and water regimen generally change from intermittent or persistent pools to ephemeral. As a result, the range of species dependent on prolonged saturation of the surficial substrate for germination (for example, ash and seepwillow) generally ends at that geologic contact. The range of these species may, however, extend for several miles onto the valley fill (Davis Canyon and tributaries of Tres Alamos Wash draining the Winchester Mountains, pl. 2) if frequent sustained flows extend onto the valley fill (fig. 4). These flows apparently cause a saturation of the alluvium of sufficient duration for species like ash and seepwillow to become established.

Trees that grow in headwater reaches located on bedrock and having ephemeral flow regimen may not grow downstream from the bedrock–valley fill contact, despite increasing drainage area. (See the ranges of hackberry, desert-willow, and soapberry along Great Bajada Wash, pl. 2.) The dispersal of moisture that occurs on valley fill presumably prevents the survival of these trees. On the other hand, if the headwater basin underlain by bedrock is sufficiently large (2 square miles or more), the lower reach located on valley fill may support valley-floor trees not generally found in ephemeral streams of comparable drainage area but with basins underlain mainly or entirely by valley fill. (See the ranges of hackberry and desert-willow in the lower reaches of Keith Ranch Creek and two creeks immediately south of it and of walnut in the lower reach of Redrock Creek, pl. 2.) This relationship is strikingly shown by the difference in valley-floor vegetation between the lower reaches of streams draining the Little Rincon Mountains and the lower reaches of the streams draining the west flank of the Johnny Lyon Hills (pl. 2).

Steep headwater basins several square miles in area and underlain by bedrock presumably concentrate runoff sufficiently to support, indirectly, valley-floor trees in the lower reaches flowing on unconsolidated deposits. (See also the contrast between the vegetation of Davis Canyon, which has headwaters on bedrock, and that of Kelsey Canyon, which rises on the valley fill of Allen Flat, pl. 2.) Unusually heavy rainfall in winter or spring (p. D9–D10) can also cause such lower reaches to have flows lasting several weeks (pl. 1). These infrequent sustained flows may explain the presence of, for example, ash in Davis Canyon on Allen Flat in a reach that generally has ephemeral flow regimen (pls. 1 and 2).

Along a stream located entirely on bedrock, valley-floor configuration will gradually change downstream from a V-shape to a box shape. Alluvium will accumulate on the valley floor, and aquifers in the alluvium maintain either perennial or semiperennial base flows (Ash Creek, Paige Canyon, Hot Springs Canyon). Concurrently with these physical changes, changes in the valley-floor vegetation occur in a downstream direction. Trees like sycamore, cottonwood, willow, and walnut grow on the valley floor, and, where the valley bottom is sufficiently wide, form a closed-canopy forest (Ash Creek, Davis Canyon, Paige Canyon). The downstream changes in valley-bottom vegetation are probably related to increased moisture storage in greater volumes of alluvium, larger surfaces on which trees can grow, and reduced flood damage with increasing valley-floor width and decreasing slope.

Judging from distributions, some valley-floor trees seem more sensitive than others to amounts of alluvium present and to constriction of the valley floor, whatever the ultimate physiologic effect of these physical conditions. Ash, for example, seems least sensitive, as it is usually the first valley-floor tree seen downstream from the basin divide (Ash Creek, Keith Ranch Creek, two creeks south of Keith Ranch Creek, and Davis Canyon); hackberry, as suggested by its distribution, requires conditions roughly similar to those for ash (pl. 2). Sycamore and cottonwood, on the other hand, are probably most sensitive, as suggested by their absence in several well-watered but relatively narrow canyons (Buehman Canyon, Ash Creek in the canyon cut across the mountain spur, Paige Canyon, pls. 1 and 2). The presence or absence of these trees may be determined by their ability to resprout after flood damage, by the volume of alluvium present, and by the effect of the alluvium as an "equalizer" in smoothing out fluctuations in moisture caused by precipitation and runoff.

The densest and tallest valley-floor forests composed almost entirely of valley-floor trees occur in level, wide reaches with sustained flows (Paige Canyon and Turkey Creek in Happy Valley basin). In these reaches, establishment and survival are presumably favored because large areas of valley bottom are reworked and wetted by sustained flows, moisture is stored in thick alluvium and is replenished by frequent or perennial surface flow or shallow underflow, and the force of floods is spent over a wide channel and flood plain.

MIDDLE REACH LOCATED ON BEDROCK

Some streams flowing almost entirely on valley fill and with ephemeral flow regimen may have a short reach located on or flanked by bedrock. In the study area, the stream that best fits this description is Tres Alamos Wash (pl. 1). An increase in the number of valley-floor species present and in the density and height of the vegetation occurs in such a reach located on bedrock (Tres Alamos Wash, tables 16, 17). The effect of the bedrock is probably to increase the local runoff from side slopes and to form a partial seal under the alluvium, thus increasing moisture levels on the valley floor. In the middle reach of Tres Alamos Wash there is no evidence that the bedrock under the alluvium acts as an aquiclude for a permanent or semipermanent perched aquifer (log of well D–15–21/27bad). No sustained flow has ever been seen in this reach (Mr. Thomas Moorhead, Cross X Ranch, oral commun., 1965). The bedrock may, however, partly prevent deep percolation of moisture after ephemeral flows. At one point in the NW¼, SE¼, sec. 22, T. 15 S., R. 21 E., for example, excavation showed that bedrock underlies the alluvium in the middle of the channel at a depth of 2.5 feet. Water that was poured into the excavation remained on the bottom for as long as the excavation was kept open, about 15 minutes. Elsewhere in the middle reach of Tres Alamos Wash near location 45, the bedrock was at depths greater than 6 feet, and water that was poured into the excavations quickly drained away.

The middle reach of Tres Alamos Wash supports ash, a tree whose presence suggests sustained flows (p. D29–D31). Judging from locations, these trees probably became established either near pools of water on the exposed bedrock along the channel and subsequently sent roots down rock fractures or as a result of sustained flows from tributaries draining the Little Dragoon Mountains and Johnny Lyon Hills (pl. 1). Ash thus germinated apparently can survive only in the thick alluvium of Tres Alamos Wash and not in that of the local tributaries.

A stream whose basin geology is similar to that of Tres Alamos Wash basin is Walnut Gulch, a tributary of the San Pedro River about 25 miles south of Tres Alamos (fig. 1). Walnut Gulch has mainly ephemeral flow regimen. Most of Walnut Gulch basin is on a gently sloping valley flank underlain mainly by valley fill (Gilluly, 1956, pl. 5). About 2 miles northwest of the city of Tombstone, however, about 1.5 miles of the middle reach of Walnut Gulch is on an intrusive mass of bedrock.[5] In this reach, the channel consists of a series of troughs in the bedrock, filled with alluvium 6–30 feet thick.

The regional water table of the area is about 200 feet deep. As flash floods move down Walnut Gulch transmission losses occur, perhaps of as much as 80 acre-feet per mile. In the reach located on bedrock, these losses from surface runoff fill the troughs in the bedrock and form a perched aquifer. This aquifer has persisted for as long as 309 days without replenishment from surface runoff, although during dry spells it may break up into a series of small water pockets. Given sufficient recharge, the perched aquifer occasionally reaches the surface, and a base flow is maintained for months beyond the last runoff event. These occasional base flows probably enable cottonwood, seepwillow, and black willow to become established. These species were not seen in any other reach of Walnut Gulch. The shallow ground water may also insure the survival of cottonwood and willow. However, these trees tolerate a water table at least 7 feet below the surface of the channel, as the perched water table has dropped to a level at least that deep.

The middle reaches of Tres Alamos Wash and Walnut Gulch have similar geology. It is also conceivable that perched aquifers occasionally form in the middle reach of Tres Alamos Wash for brief periods. The difference in valley-floor vegetation between the two reaches shows primarily the effect of surface-flow regimen on the distribution of plants on valley floors.

MIDDLE REACH LOCATED ON VALLEY FILL

Streams flowing primarily on bedrock may, in places, cross valley fill sufficiently thick to cause differences in flow regimen and valley-floor vegetation. If the stream

[5] Except for the vegetation, the discussion of this reach is based on Renard, Keppel, Hickey, and Wallace (1964, p. 471–473).

has a low semiperennial base flow, this flow will not usually be maintained in the reach underlain by valley fill. Ash Creek is one such stream; Paige Canyon, on the other hand, is a stream crossing a basin underlain by valley fill, but the semiperennial flow is maintained in the basin (pl. 1). Reaches located on valley fill but not far from bedrock or semiperennial flow are generally characterized by intermittent flow regimen (Turkey Creek, Ash Creek, pl. 1). These reaches are dry most of the year but probably have sustained flows annually owing to the downstream extension of semiperennial flow or to shallow ground water rising to the surface. In the intermittent middle reach of Ash Creek, for example, ground water was at the surface of the channel between October 17 and November 11, 1964, after an unusually heavy and late series of convective storms, and in early January 1966, after the record rainfall of December 1965 (p. D9).

Reaches with intermittent flow regimen are habitats intermediate between ephemeral streams and streams with semiperennial or perennial flow. The valley-floor vegetation of reaches with intermittent flows shows an adjustment to these intermediate conditions, as it usually consists of a mixture of species characteristic of streams with ephemeral flows as well as those with perennial or semiperennial flows (middle reach of Ash Creek, table 18). The occasional sustained flows probably allow species like ash, seepwillow, sycamore, cottonwood, and black willow to become established, and the relatively shallow water table probably enables some of these species to survive. On the other hand, species that are most common in reaches with deep water tables but rare along streams with semiperennial or perennial flows (desert-willow, desertbroom, catclaw acacia, graythorn, burrobrush), are also common were flows are intermittent. Thickets of mesquite and catclaw acacia mixed with desert-willow, walnut, ash, sycamore, and seepwillow are probably the most common type of vegetation in reaches with intermittent flows (Turkey Creek and lower reach of Paige Canyon, table 24, pl. 2). Desert-willow grows with ash, walnut, and seepwillow in the reach of Redrock Creek located in a small high basin (pls. 1 and 2). Sustained flows in that reach of Redrock Creek were seen only following the heavy rainfall of December 1965 (p. D9–D10; pl. 1). Thus vegetation that suggests intermittent flow regimen may reflect sustained flows that may not occur every year.

BEDROCK CANYON IN MIDDLE TO LOWER REACH

Most of the large tributaries in the study area flow in narrow, deeply entrenched canyons before emerging onto the valley fill of the lower valley flank. These canyons commonly support few valley-floor species. Trees like sycamore and cottonwood are commonly absent in canyons that support other woody vegetation (pl. 2). Given sufficient constriction of the canyon floor, vegetation may be almost entirely missing.

In canyons, concentration of runoff and confinement of ground water at shallow depth may be such that perennial flow is maintained even in a warm, arid climate (pl. 1). With increasing constriction of the valley floor, however, the amount of alluvium decreases, or alluvium may be almost entirely missing, and with the reduction of the cross-sectional area the destructiveness of floods increases. Insufficient substrate for growth and flood damage may partly explain why narrow but well-watered canyons commonly support little or no woody vegetation.

LOWER REACH LOCATED ON VALLEY FILL

The lower reaches of most tributaries in the study area have ephemeral flow regimen, as ground water generally occurs at depths exceeding 100 feet within half a mile downslope from the mountain front (pl. 1). At the bedrock–valley fill boundary, the valley-floor vegetation commonly changes abruptly (fig. 17), as the change from sustained surface flows to ephemeral flow regimen apparently prevents the establishments on the valley fill of those species that require prolonged saturation of the substrate for germination and seedling survival. Deep water tables downstream from the mountain front may also prevent the survival of some species, possibly black willow, cottonwood, and sycamore. Sycamore and ash may, however, occur as far as half a mile to several miles downstream from the mountain front (pl. 2). The occurrence of these trees in reaches that are dry most of the year is attributed to the slow advance and retreat—often occurring over a period of several days—of winter or spring flows emerging from bedrock canyons (table 4). These sustained flows presumably saturate the alluvium for periods sufficiently long for the germination of ash and sycamore. The flows may also replenish moisture in the alluvium with sufficient regularity to insure the survival of these trees in a reach located on unconsolidated deposits.

If a stream is flanked on one side by bedrock for some distance after leaving the bedrock canyon, the changes in surface flow regimen and in valley-floor vegetation in the lower reach are more gradual than along a stream that leaves the mountain front at near a right angle. This can be seen in the lower reach of Paige Canyon (table 24; pl. 2), where intermittent flow regimen and ground water less than 40 feet deep occur for about 3 miles downstream from the canyon mouth (pl. 1). These hydrologic conditions are probably directly or indirectly the result of bedrock close to the surface of the valley bottom. The vegetation in the lower reach of Paige Canyon, a bottom-land forest composed mainly of valley-floor trees gradually replaced downstream by thickets of plants common along ephemeral streams probably reflects a gradual decrease in moisture availability.

In lower reaches located on valley fill, the number of valley-floor species decreases downstream, despite increasingly shallower ground water in the extreme lower reach (pls. 1 and 2). In general, in a downstream direction the valley-floor vegetation contains an increasing number of species that also grow on adjacent uplands. These changes in vegetation, which suggest a decrease in moisture available to plants away from the mountain front, are probably due to channel losses. In the San Pedro Valley, about half of the runoff emerging from the mountain valleys is probably lost immediately downstream from the mountain front to deep percolation in the valley fill (Halpenny and others, 1952, p. 17).

In Walnut Gulch basin, about 25 miles south of Tres Alamos (fig. 1), channel losses of 25 acre-feet per mile have been measured in dry channels, and a maximum rate of loss of 80 acre-feet per mile has been computed on the basis of the texture and amount of alluvium present (Keppel and Renard, 1962, p. 59, 67). The extreme lower reaches of tributaries do not support species characteristic of wet habitats despite shallow ground water, presumably because the species composition of the valley-floor vegetation is primarily determined at the germination-seedling stage of growth by surface flow regimen. In the study area, the lower reach located on valley fill in which sycamore, seepwillow, and ash grow close to the mainstem is also the only reach that has intermittent flow regimen (Buehman Canyon, pls. 1 and 2). These intermittent flows are, in turn, caused by the proximity of the bedrock canyon and semiperennial flow to the mainstem.

EXTREME LOWER REACH LOCATED ON BEDROCK

In the study area, Soza Canyon crosses valley fill after leaving the mountain front but again flows on bedrock before reaching the San Pedro River (pl. 1). The lower reach of Soza Canyon has ephemeral flow regimen, but the underflow in this stream is exceptionally shallow and frequently reaches the surface upstream from the confluence with the San Pedro River (fig. 3). The lower reach of Soza Canyon is the only such reach in the study area in which the number of valley-floor species decreases away from the mountain front and then increases again in the reach located on bedrock (table 26).

The valley-floor vegetation of the extreme lower reach of Soza Canyon grows in a reach with unusually shallow underflow. However, the presence of shallow ground water that never reaches the surface does not seem to alter the composition of valley-floor vegetation. Ash, seepwillow, and yew-leaf willow, species present in the lower reach of Soza Canyon, also grow in the middle reach of Ash Creek, where the water table may be 30–40 feet deep (pls. 1 and 2). The presence of ash and seepwillow suggests sustained discharges, but until the unusually heavy runoff of December 1965–January 1966, no such discharges had been seen in the lower reach of Soza Canyon, except near the confluence with the San Pedro River.

One explanation for the presence in the lower reach of Soza Canyon of plants usually associated with sustained flows is suggested by the distribution of the plants. Groups of seepwillows and ashes are common near the mouths of small tributaries draining the bare conglomerate side slopes of the reach and near the break in slope between the bed of Soza Canyon and the side slopes. This distribution suggests that the species become established in response to flow events in the tributaries rather than to those in Soza Canyon itself. Small alluvial cones in the bed of Soza Canyon near the mouths of tributaries draining only several acres also suggest more frequent discharges than occur in Soza Canyon. Runoff from the conglomerate side slopes was observed on several occasions during the winter of 1964–65, in August 1965, and in January 1966. On these occasions, small tributaries flowed after light rainfall that did not cause runoff elsewhere (fig. 20). These tributaries commonly support maidenhair fern (*Adiantum* sp.) and Texas mulberry, plants usually found at wet sites. Thus concentration of runoff on the bedrock side slopes may cause flows or seepage sufficient to allow ash or seepwillow to germinate in the bed of Soza Canyon. These species may survive only in the presumably thick alluvium of Soza Canyon.

An alternative explanation for the unusual vegetation of the lower Soza Canyon became apparent as a result of the exceptionally heavy runoff of December 1965–January 1966 (p. D9–D10). Ash, seepwillow, and yewleaf willow may become established in the extreme lower reach of Soza Canyon whenever unsually prolonged winter runoff causes the underflow to reach and stay at the surface for periods of weeks. Or the valley-floor vegetation in the extreme lower reach of Soza Canyon may reflect a combination of unusually high concentration of runoff on bare conglomerate slopes and infrequent sustained flows due to saturation of the alluvium. The growth of ash, seepwillow, and yew-leaf willow, as well as that of other plants, is probably also favored by the presence of the permanent shallow underflow.

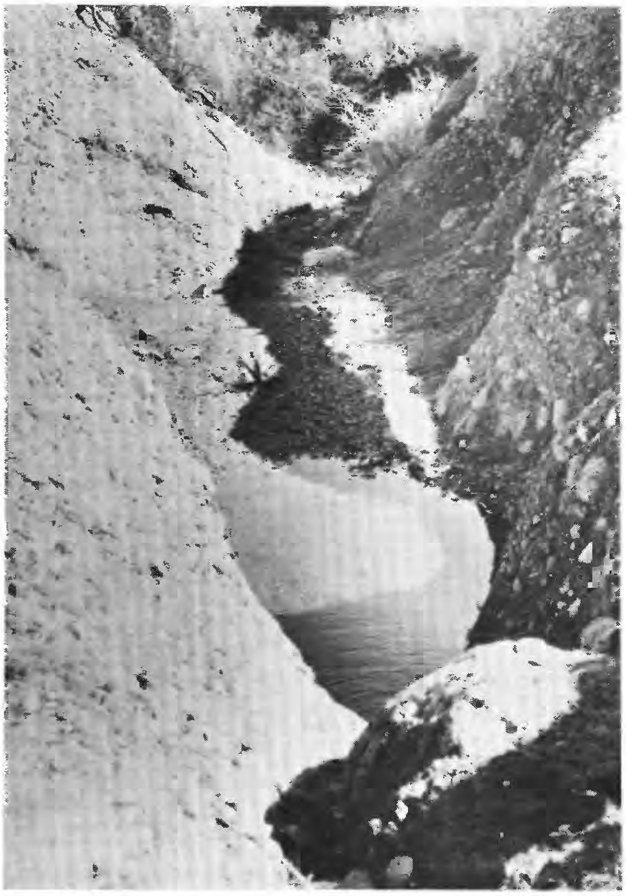

FIGURE 20.—Flow in small tributary of Soza Canyon in the SE¼, sec. 30, T. 12 S., R. 19 E. Note bare conglomerate side slopes. January 1966.

Another unique botanical feature of the lower Soza Canyon is the presence of black willow at points as far as 220 feet from the confluence with and 6 feet above the San Pedro River. Black willow is a common tree along the San Pedro River. The willows growing in the extreme lower reach of Soza Canyon may have become established as a result of flood waters from the San Pedro River backing up into this tributary. The backing up of flood waters probably occurs in all the lower reaches of tributaries; however, willow germinated under these circumstances may survive in Soza Canyon only because of the unusually shallow underflow in this tributary. These willows may have also become established at times of heavy runoff, when the point of emergence of the underflow shifted upstream because of saturation. Such a shift occurred in January 1966.

SUMMARY

The many variations in valley-floor vegetation observed in the study area have been explained by means of the adjustments between geology, hydrology, and plants found in selected valley-floor environments. These adjustments can be further summarized as follows:

On bedrock, runoff is concentrated, and on valley floors ground water is confined and either held at shallow depth or forced to the surface. The shallow ground water sustains base flow. Small drainage areas are required to support valley-floor species. Sustained surface flows enable many valley-floor species to germinate and become established on saturated alluvium. Shallow ground water or frequent recharge in the alluvium insures the survival of some of these species. Given an optimum combination of volume of alluvium, valley-floor width, and sustained flows, streams flowing on bedrock may support a closed-canopy forest, composed mainly of valley-floor trees, whose density, stem development, and height are comparable to those of forests in humid areas.

A "law of diminishing returns" applies to the distribution of valley-floor vegetation along streams located on bedrock. Where entrenchment in bedrock concentrates runoff and confines ground water sufficiently to maintain a perennial or nearly perennial flow even in a warm, arid climate, the amount of alluvium generally is small, and flood damage due to the constriction of the valley bottom is great. As a result, well-watered canyons are commonly devoid or almost devoid of woody vegetation.

On valley fill, runoff is less concentrated than on bedrock, and evaporation or deep percolation of runoff results in deep water tables. Flow regimen is usually ephemeral. Relatively large drainage areas are required to concentrate moisture sufficient to support the growth of valley-floor species. The absence of sustained surface runoff greatly limits the number of valley-floor species that can germinate and become established along ephemeral streams. Deep ground water or infrequent recharge may prevent the growth of some species.

A "law of diminishing returns" also applies to the distribution of valley-floor vegetation along ephemeral streams flowing on valley fill. The number of valley-floor species and the density of vegetation increase as drainage area and attendant moisture storage increase. However, beyond a threshold drainage area size—between 20 and 50 square miles—the number of valley-floor species and the density remain about the same or decrease, as presumably there is a limit to the amount of moisture that can be stored within reach of plant roots on the valley floors between ephemeral flows. Channel losses also increase with increasing length of the channel system. As a result, the lower reaches of large ephemeral streams presumably carry smaller and shorter lasting flows that recharge the alluvium less than do larger discharges upstream.

Streams flowing on valley fill but with a drainage area of thousands of square miles may, on the other hand, have base flows. The water of streams draining large arid basins is, however, appreciably more mineralized than the water of tributaries draining less than 150 square miles. Quality of water may partly account for the differences between the valley-floor vegetation of a stream the size of the San Pedro River and that of tributaries with similar flow regimens.

The main changes in valley-floor vegetation occur at the point where the surface flow regimen changes from sustained flow to emphemeral storm runoff. Thus differences in duration of surface flow are probably the main cause of variations in valley-floor vegetation. The duration of surface flows determines the moisture levels in the superficial layers of the alluvium, and these in turn determine which species can germinate and survive the seedling stage. Many more species can become established in substrate saturated by sustained flows than in substrate wetted by the occasional storm runoff. The composition of the valley-floor vegetation is no doubt also determined by differential survival of plants on valley bottoms with different moisture regimens at and below the surface.

SELECTED ASPECTS OF VALLEY-FLOOR PLANT ECOLOGY

VALLEY-FLOOR VEGETATION, ROOTING DEPTHS, AND GROUND-WATER WITHDRAWALS

Valley bottoms support vegetation generally different from that growing on uplands presumably because of greater concentration of moisture in the drainage system. Valley-floor vegetation may, however, depend for growth on moisture in the alluvium or on moisture drawn from the water table. The exact source of moisture used by plants is difficult to determine. Nevertheless, plant geography may help determine the proportion of valley-floor vegetation that is, with reasonable certainty, independent of the water table for its growth. The method of analysis has been to review data on rooting depth of desert plants and on the capillary rise from saturated layers so as to determine depths below which ground water is not withdrawn by plants. Given these depths and maps of plant distributions and of water tables, the proportions of seemingly phreatophytic and nonphreatophytic valley-floor vegetation can be determined.

ROOTING DEPTHS

The maximum and average rooting depths of wild-growing plants are not well known. Even if these depths were known, it would be risky to assume a rooting depth for a particular plant at a particular location in the field, as vertical and lateral development of roots is highly individualized (Russell, 1961, p. 452–454). The plasticity of root systems has limits, however, and the data shown in table 29 provide perspective on these limits. The maximum vertical length of roots of most desert plants is probably less than 50 feet and more commonly less than 30 feet. Rooting depths exceeding 60 or even 100 feet seem to occur only in dune sand or in fractured rock (Meinzer, 1927, p. 55; Oppenheimer, 1960, p. 109); reports of such depths, however, are usually not well documented (see Oppenheimer, 1960, p. 109).

Deep penetration of roots is usually prevented by compacted substrates, poor drainage, and poor aeration (Kramer, 1949, p. 123). Withdrawals of moisture from deep layers by plants is also made difficult by low temperatures. The lower the temperature, the greater the suction of water in the soil, so that net diffusion of water into the plant ceases earlier at depth, even though more water may be available than at the surface (Gardner, 1960, p. 52; Meyer and others, 1960, p. 126–128). At depth, realtively low temperatures, as well as low oxygen concentrations, may also affect the physiology of root cells in such a way as to impede diffusion of water into the plant (Meyer and others, 1960, p. 126–127). In an arid area, high salt content at depth may be an additional obstacle to water absorption by plants (Wadleigh, 1955, p. 360–361). The main advantage of deep rooting, tapping of moisture from large volumes of substrate, is thus increasingly offset with increasing depth by low temperatures, poor aeration, salinity, and metabolic changes in the root cells. As a result, even desert plants have roots that rarely exceed a few tens of feet. Regardless of rooting depth, plants tend to dry out the superficial layers of the substrate—where most of the roots are—before withdrawing water from greater depths and horizontal distances (Gardner, 1960, p. 54; Meyer and others, 1960, p. 113; Russell, 1961, p. 406–409). One study found that orchard trees growing on permeable well-drained soils were able to withdraw water at levels 9–12 feet deep, but that wilting and other ill effects due to drought set in if the top 6 feet of soil was dried out to the wilting coefficient (Russell, 1961, p. 406).

In the study area, mesquite is probably the deepest rooting species. Along the cut banks of the San Pedro River, exposed mesquite tap roots are commonly 30 feet long, and in places are 35–40 feet long. It is probably conservative to assume that mesquite roots rarely exceed vertical lengths of 40–45 feet, especially in the fine-grained compacted deposits characteristic of the San Pedro River bottom lands. Comparison of the Happy Valley quadrangle topographic map (1958) with a map of average ground-water depths (pl. 1) reveals that

TABLE 29.—*Maximum rooting depths observed in arid and semiarid areas of the world*

Common name, genus, or species	Location	Rooting depth (ft)	Source and remarks
Catclaw acacia	Southern Arizona	18+	Personal observation.
Acacia raddiana	Near East	7.5	Zohary (1961, p. 201).
Acacia sp	do	4.5	Oppenheimer (1960, p. 109).
Alfalfa	Irrigated western United States(?).	33.0	Kramer (1949, p. 122)
Do	do	66.0	Meinzer (1927, p. 55); not well documented.
Apple (*Malus*)	Nebraska	30.0	Kramer (1949, p. 122); in loess.
Four-wing saltbush	Southern Arizona	15+	Personal observation.
Atriplex halimus	Near East	25.0	Zohary (1961, p. 201).
Seepwillow	Arizona	1.9	Gary (1963, p. 312); average maximum depth.
Do	do	4+	Personal observation.
Most cactuses	Southern Arizona	1.0	Cannon (1911).
Hackberry	do	15+	Personal observation.
Desert-willow	do	4+	Personal observation. Lateral roots about 4 in. in diameter and at least 30 ft long.
Ash	do	7+	Personal observation.
Guayule (*Parthenium argentatum*).	Texas	16.0	
Walnut	Southern Arizona	7.0	Personal observation. *Juglans* noted for deep roots in both Old and New Worlds (Oppenheimer, 1960, p. 110).
Creosotebush	Arizona	6.3	Cannon (1911, p. 60).
Arrowweed	do	4.3	Gary (1963, p. 312); average maximum depth.
Cottonwood	Southern Arizona	7+	Personal observation.
Prosopis farcata	Near East	45.0	Oppenheimer (1960, p. 109).
Mesquite	Arizona	175.0	Phillips (1963, p. 424); on alluvial fan or pediment.
Do	do	30–40?	Cannon (1911, p. 8, 80).
Do	do	22+	Gatewood and others (1950, p. 9).
Do	Southern Arizona	30+	Personal observation.
Retama raetam	Near East	60.0	Zohary (1961, p. 201); in dune sand.
Tamarix aphylla	do	30.0	Zohary (1961, p. 201).
T. gallica	do	7.5	Do.
T. pentandra	Arizona	12.0	Gary (1963, p. 312); average maximum depth.
Tamarix or *Acacia*	Suez Canal excavation	90.0	Oppenheimer (1960, p. 109); not well documented.
Various species	Campos Cerrados, Brazil	55–58	Oppenheimer (1960, p. 109).
Do	Caspian Sea area, U.S.S.R	45.0	Do.
Welwitschia mirabilis	South Africa	55.0	Do.
Black willow	Southern Arizona	7.0	Personal observation.

the mesquite forests of the San Pedro River bottom lands (p. D28) as depicted on the topographic map coincide areally with ground-water depths of about 45 feet or less. This relationship is particularly evident in secs. 31 and 32, T. 15 S., R. 20 E., where both shallow ground water and mesquite forests "bulge" away from the river on the two maps. In general, away from the river where water-table depths exceed 40 feet, the closed-canopy mesquite forests about 30–35 feet tall are replaced within 50–100 feet by open stands of shrubs or by the savanna described on page D13. This observation agrees with earlier descriptions by Cannon (1913, p. 421) and by Meinzer (1927, p. 43–54).

In the Tres Alamos–Redington area, as elsewhere, the bulk of the roots of most plants and thus the zone of maximum moisture withdrawals are probably in the superficial layers. However, in an arid basin such as the San Pedro Valley this zone may be as much as 25 feet thick, as opposed to a maximum thickness of perhaps 10 feet in humid areas.

CAPILLARY RISE

The capillary rise generally is a fraction of an inch in gravel, 1 foot in sand, and several feet in clay (Todd, 1959, p. 22). Figures of less than 1 foot (0.1 m) in gravel, 1–3.3 feet (0.1–1 m) in sand, and 6–12 feet (2–4 m) in clay have also been given (De Wiest, 1965, p. 200). The capillary fringe is usually included in the zone of saturation (De Wiest, 1965, p. 143), but most of the fringe is only partly saturated (Lambe, 1951, p. 424). The transition from saturation, or ground water to soil moisture thus occurs in a short distance above the water table.

The capillary rise is probably negligible under field conditions, especially in areas of water tables several tens or hundreds of feet deep (Meyer and others, 1960, p. 106–107). Under laboratory conditions, water can move upward at "appreciable rates" from water tables as deep as 7 meters, about 25 feet (Gardner, 1960, p. 50). The capillary rise observed in sand models in laboratories is, however, "disproportionately large compared to that occurring under field conditions" (Todd, 1959, p. 308). The capillary rise is of only limited value to plant life. In moist soils, water normally cannot rise more than about 1 meter (3.3 ft) at a rate sufficient to sustain a transpiring plant (Gardner, 1960, p. 50; Russell, 1961, p. 409). To be of use to terrestrial plants, water tables must be immediately below the root zone

(Gardner, 1960, p. 54; Kramer, 1949, p. 47; Meyer and others, 1960, p. 120).

PLANT GROWTH AND SOURCES OF MOISTURE

The data presented above provide some perspective on the relationship between rooting depths and withdrawal of moisture from saturated layers in arid areas. The data suggest that desert plants generally have root zones in the top 25 feet of substrate, althought some are more deeply rooted. In the study area it is doubtful that rooting depths, including those of mesquite, exceed 40 or 50 feet. (See Meinzer, 1927, p. 43, 77.) Thus water tables deeper than about 45 feet probably do not support plant life.

Physical and biological processes also set a limit to the depth from which plants can withdraw moisture. Deep water tables do not seem to affect the growth of adult plants or the distribution of valley-floor species. The ranges of many of these species are largely determined at the germination-seedling stage by a matching of physiologic requirements with conditions of surface flow. The small number of valley-floor species along ephemeral streams, even where ground water is shallow, indicates the importance to plant life of moisture conditions at or near the surface.

If it is true that water tables deeper than 50 feet are not tapped by plants, and that even where ground water is nearer the surface the plants still obtain most of their moisture from the upper part (20 ft?) of the root zone, then most of the valley-floor vegetation in the study area grows independently of regional water tables (pls. 1 and 2). In addition, species that may withdraw moisture from the water table in some reaches where ground water is shallow also grow in reaches where water tables are more than 100 feet deep. Examples are such common valley-floor trees as ash, desert-willow (p. D42–D43), mesquite, catclaw acacia, walnut, hackberry, and soapberry. In general, observations of water levels in wells have suggested that ground-water drafts by most species in the Western United States decrease "substantially" beyond a depth as shallow as 7 feet (Robinson, 1958, p. 27). Data on the effect of plant growth on ground-water levels deeper than 7 feet are, however, "meager" (Robinson, 1958, p. 22).

In the study area, the vegetation that is most certainly dependent only on soil moisture for most of its growth is by no means negligible. In the middle reach of Tres Alamos Wash, for example, the basal area measured where ground water is about 300 feet deep (well D–15–21/27bad) amounts to 82 square feet per 1.2 acres, or more than was measured along the semiperennial and intermittent reaches of Ash Creek (table 19). In one plot (20, pl. 1) in the ephemeral lower reach of Soza Canyon, the vegetation growing where the water table is about 90–100 feet deep has a basal area of 72 square feet per 1.2 acres, contributed mainly by mesquite and catclaw acacia. Maximum basal area measured in the study area is 156 square feet per 1.2 acres in a reach of Paige Canyon where ground-water levels probably fluctuate between the surface and 20 feet of depth. The large walnut and other tall vegetation shown in figure 21 grow in a reach where ground water is about 60 feet deep.

The vegetation growing in the reaches of Tres Alamos Wash and Soza Canyon described above probably depends for growth on pellicular and gravitational water (Todd, 1959, p. 18) or on small perched aquifers replenished by precipitation and occasional storm runoff. It is not known whether vegetation prevents a periodical recharge, however slight, to ground water by withdrawing moisture that conceivably could accumulate beyond the field capacity of the alluvium. Where the zone of aeration is several hundred feet thick, ground-water recharge is probably negligible even without vegetation, except locally and infrequently following unusually heavy runoff (Arizona State Land Dept., 1963, p. 39–47). In the study area, plants probably affect ground-water conditions not so much by preventing ground-water recharges as by withdrawing moisture from shallow saturated layers. Field evidence suggests, however, that plants may or may not depend on ground water for growth even in areas of shallow water tables.

As described on page D40, the mesquite forests growing on the bottomlands of the San Pedro River coincide areally with ground water generally no deeper than about 40–45 feet. The roots of mesquite are capable of reaching water tables at least that deep. The bulk of the roots are, however, in the first 20–25 feet below the surface, as can be easily seen along the cut banks of the San Pedro River. Moisture in the upper 20–25 feet is recharged largely during floods, when the San Pedro River becomes an influent stream (Arizona State Land Dept., 1963, p. 74–75), and by rainfall. Thus if the presence of dense and tall mesquite forests is clearly an indication of higher moisture levels, it is not incontrovertible evidence of heavy and constant withdrawals of moisture from the water table. The dense growth of mesquite may be due primarily to more regular moisture recharge by the rising and falling river than occurs on surfaces higher above the valley bottom. The mesquite forests may depend for growth mainly on bank storage below the amount required for saturation. The absence of large groves of mesquite in reaches of tributaries where the water table is permanently shallow (tables 11, 12) and the presence of dense mesquite thickets in reaches where the water tables are deep (tables 14, 15,

17) also suggest that mesquite is relatively intolerant of shallow ground water. Within the study area, however, the vast and dense bottom-land mesquite forests along the San Pedro River are probably the heaviest consumers of moisture, including moisture withdrawn from the water table. These forests are being cleared to make room for agriculture (p. D28).

Of the large valley-floor trees in the study area, cottonwood, black willow, sycamore, and alder grow primarily in areas where ground water is generally less than 40 feet deep (see Meinzer, 1927, p. 56–59, 62). These are all species known or thought to germinate and become established only in sediment saturated at the surface for periods of perhaps more than 1 or 2 weeks. In the intermittent middle reach of Ash Creek, cottonwood, black willow, and sycamore grow where water tables may decline, at least in late spring and early summer, to about 30–40 feet below the valley floor (wells D–16–19/8cbb, 17aba). As these trees are probably shallow rooted (maximum depth 20 feet?; fig. 21), even they may depend for growth during at least part of the year only on moisture in the alluvium. These trees probably grow most vigorously in late spring and summer, when the water tables reach their annual low point. It is possible, of course, that the trees contribute to that decline. Cottonwood also occurs on Allen Flat in a tributary of Tres Alamos Wash (fig. 19), where ground-water depths exceed 300 feet (wells D–13–22/28bca, 28).

FIGURE 21.—Root mass of a cottonwood that grew beside a stream with semiperennial flow. The root mass is about 5 feet thick and 15 feet wide.

The importance of shallow ground water to plant growth may lie primarily in the maintenance of more frequent and regular surface flows and thus in the more frequent recharge of moisture to the surficial layers of the substrate. It is not ruled out, however, that some species at some stage of the life cycle—especially 60- to 80-foot tall cottonwoods and sycamores—cannot survive in the arid climate of the San Pedro Valley unless they can withdraw moisture from saturated layers during at least part of the year. On the tributary valley floors of the study area, the species suspected of withdrawing moisture from the water table probably do not cover a sufficient area to appreciably affect the regional hydrology. The same may also be true of the saltcedar growing in the channel of the San Pedro River (p. D27). These plants also grow where water is at or near the surface and presumably would be lost through evaporation were there no plants present.

DISTRIBUTION AND ECOLOGY OF DESERT-WILLOW

The distribution of desert-willow, a common valley-floor tree, is generally mutually exclusive with that of perennial and semiperennial flow and of bedrock (pls. 1 and 2). Thus in a desert area, trees that grow only on valley floors may not necessarily grow where there is shallow ground water. Desert-willow grows in the lower reaches of large tributaries, along most of Tres Alamos Wash, and in middle and upper reaches with intermittent or ephemeral flow regimen (middle reach of Ash Creek, Hot Springs Canyon between Antelope Ranch and Hookers Hot Springs, along Redrock Creek in small high basin, and along Turkey Creek in Happy Valley; pl. 2). Desert-willow was not seen along Davis Canyon in Allen Flat, a reach marked by bouldery alluvium. Desert-willow also grows along the San Pedro River on flood plains at least 100 feet wide; it is particularly abundant near Cascabel (pl. 2), where the channal of the San Pedro River is commonly more than 500 feet wide. Desert-willow grows primarily in wide (more than 50 feet) sandy to gravelly beds, commonly where water tables are hundreds of feet deep. (See Meinzer, 1927, p. 57.)

A clue to the ecology of desert-willow is provided by data on the germination of this species. Under controlled conditions, desert-willow seeds germinate faster if kept buried in wet sand for several days; in addition, for best results in germination tests, temperatures above 80° F are "preferable" (U.S. Forest Service, 1948, p. 137). The best conditions for the germination of desert-willow may thus obtain in the sandy channels of ephemeral streams subject to flash floods in the summer, where seeds are buried in reworked alluvium and subsequent temperatures are high. Conditions for germination are presumably least favorable in canyons, where shade and sustained surface flows probably keep the temperature of the alluvium below that of sediment in wide, open channels. As desert-willow generally grows in reaches where ground water is deeper than 40 feet, intolerance of permanently shallow water tables may also control the distribution of this tree.

Desert-willow generally grows downstream from points where sustained or flood runoff is dispersed or absorbed. This tree is commonly absent in reaches immediately downstream from the mountain front (pl. 2), where sustained flows frequently advance and retreat and where presumably the maximum transmission losses occur during flash floods. Desert-willow is common in reaches with intermittent flows. These are primarily reaches in which flows cannot be maintained throughout most of the year because of the presence of thick alluvium.

Other species which, on valley bottoms, have a distribution similar to that of desert-willow are catclaw acacia, burrobrush, and desertbroom. The germination requirements of these species may also be best met on wide, sandy channels wetted and reworked by the occasional summer flood. These species, like desert-willow, could also be intolerant of prolonged saturation of the superficial layers of the alluvium.

VALLEY-FLOOR VEGETATION OF GAGED STREAMS IN THE TUCSON BASIN

The valley-floor vegetation of five gaged streams in the Tucson basin, the next basin west of the San Pedro Valley, was sampled near the gaging site in order to obtain partial control data for the relationships established in the study area. The variations in the vegetation (table 30) of the streams, whose hydrologic characteristics are shown in table 31, are similar to those observed in the Tres Alamos–Redington area in streams with comparable physical characteristics. Table 30 shows the species present at the gaging sites of the five different streams sampled; the tabulation of the species thus does not reflect any distribution of vegetation from upper to lower reach as in earlier tables. The variations in valley-floor vegetation observed in the Tucson basin confirm primarily the importance of surface flow duration as a control in the distribution of plants. However, as in the study area, amounts of alluvium present and quality of water also seem to influence the composition of valley-floor vegetation.

Bear Creek

The channel of Bear Creek at and upstream from the gaging station is cut into the Catalina gneiss, and only scattered, thin alluvial deposits are present (M. E. Cooley and A. M. Saltnass, U.S. Geol. Survey, unpub. data). The flow regimen of Bear Creek is semi-perennial, and the valley-floor vegetation is similar to that of semi-perennial streams in the study area (Ash Creek, Paige Canyon). Sycamore is absent from Bear Creek near the gaging station, as it is from many reaches of the study area that have only small amounts of alluvium (p. D34–D36).

TABLE 30.—*Species present at gaging sites of streams in the Tucson basin*

Stream Flow regimen [1]	Sabino Creek SP	Bear Creek SP	Rincon Creek I-SP	Pantano Wash P	Rillito Creek E-I
Seepwillow [2]	X	X	X	X	
Ash [2]	X	X	X	X	
Cottonwood [2]	X	X	X	X	
Black willow [2]	X	X	X	X	
Hackberry [2]	X		X	X	
Hopbush [2]	X	X			
Sycamore [2]	X				
Emory oak [2]	X				
Mexican blue oak [2]	X				
Buckthorn [2]	X				
Soapberry [2]	X				
Arizona grape [2]	X				
Bonpland willow [2]	X				
Desert-hackberry	X				
Sotol	X				
Mimosa	X				
Pricklypear (*Opuntia engelmannii*)	X	X			
Cholla (*O. versicolor*)	X	X			
Mesquite	X	X	X	X	X
Desertbroom [2]	X	X	X		X
Buttonbush [2]		X			
Cassia [2]			X		
Arizona cypress [2]			X		
Burrobrush [2]			X		X
Walnut [2]			X		X
Yew-leaf willow [2]			X		
Catclaw acacia			X		X
Blue paloverde [2]					X
Desert-willow [2]					X
Lycium (*Lycium berlandieri*?)					X
Creosotebush					X

[1] E, ephemeral; I, intermittent; SP, semiperennial; P, perennial.
[2] Valley-floor species at the particular altitude.

Pantano Wash at Vail

Flow in Pantano Wash at the Vail gaging station is perennial because a dam built across the bedrock constriction at the gaging site forces ground water to the surface (U.S. Geol. Survey, issued annually). Pantano Wash is primarily a "lowland" stream in the Tucson basin, as it skirts around the western flank of the Rincon Mountains (fig. 1). The valley-floor vegetation at the Vail gaging site is similar to that of the San Pedro River in the perennial reach flanked by conglomerate (p. D28). No saltcedar was observed, however, along Pantano Wash near Vail. Sycamore and shrubs characteristic of perennial or semi-perennial mountain streams (for example, buttonbush, hopbush, buckthorn, yew-leaf willow) were not seen in Pantano Wash.

About half a mile downstream from the gaging station, Pantano Wash has a wide (100–150 feet), sandy channel flanked by bedrock. Flow regimen is either intermittent or ephemeral. The valley-floor vegetation includes hackberry, walnut, and ash mixed with thickets of mesquite, catclaw acacia, graythorn, and desertbroom. At the same location, a leaky irrigation pipe 6–10 feet above the stream is paralled by seepwillow, black willow, tree tobacco, ash, and walnut. Black willow and

TABLE 31.—*Hydrologic characteristics of gaged streams in the Tucson basin*

[Data from U.S. Geol. Survey, issued annually]

Stream	Drainage area at gaging station (sq mi)	Average annual discharge (cfs)	Average annual peak discharge (cfs)	Maximum discharge known (cfs)	Annual number of days of no flow			Flow regimen [1]
					Maximum	Minimum	Mean	
Bear Creek [2]	16.3	4.2	329	575	254	62	155	SP
Pantano Wash at Vail [3]	457.0	7.0	6,603	38,000	0	0	0	P
Rillito Creek [4]	918.0	16.0	5,380	24,000	356	320	334	E–I
Rincon Creek [5]	44.8	4.0	2,176	8,250	322	137	236	I–SP
Sabino Creek [6]	35.5	11.3	1,725	5,100	120	17	66	SP

[1] P, perennial; SP, semiperennial; I, intermittent; E, ephemeral.
[2] Period of record water years 1960–1965.
[3] Period of record water years 1960–1965.
[4] Average annual and maximum known discharge for 57-year period; all other data for period 1950–1965.
[5] Period of record water years 1953–1965.
[6] Average annual and maximum known discharge for 40-year record; all other data for period 1950–1965.

tree tobacco are species characteristic of streams with semiperennial or perennial flows.

About a mile downstream from the gaging station, Pantano Wash flows on valley fill, and its regimen is ephemeral. The regional water table in the area is about 430 feet deep (Arizona Univ., Agr. Eng. Dept., unpub. data, 1964). The species along Pantano Wash are those characteristic of ephemeral streams in the Tres Alamos-Redington area: catclaw acacia, desertbroom, desert-hackberry, blue paloverde, desert-willow, graythorn, burrobrush, creosotebush, lycium (*Berlandieri?*), and mesquite.

Rillito Creek

At the gaging station near the Oracle Road, Rillito Creek flows on valley fill, and flow regimen is ephemeral. The regional water table in the area of the gaging site is about 90 feet deep (Arizona Univ., Agri. Eng. Dept., unpub. data, 1964). The valley-floor vegetation of Rillito Creek is similar to that of ephemeral streams in the study area such as Tres Alamos Wash, despite the large difference in drainage area. The drainage area of Rillito Creek at the Oracle Road gaging station is 918 square miles.

Flows lasting as long as several weeks occasionally occur in Rillito Creek at the Oracle Road gaging station. Such flows occured, for example, in the spring of 1958 (U.S. Geol. Survey, issued annually) and in December 1965–January 1966 (personal observation). These occasional sustained flows probably account for the presence of seepwillow, black willow, cottonwood, and saltcedar as far downstream as a point about 3 miles upstream from the gaging station. In 1966, the reach that supports these species was still flowing on January 9 and probably flowed for several additional days, whereas flows at the Oracle Road gaging station ceased about 6 days earlier. This difference in flow duration, whatever its average or extremes, apparently prevents the establishment or survival at the Oracle Road gaging station (alt 2,284 ft) of species characteristic of streams or reaches with sustained flows.

The difference in duration of flow in Rillito Creek at the Oracle Road gaging station and at Wrightstown, about 8 miles upstream, is shown by the few comparable data available (fig. 22). The sustained flow in Rillito Creek at Wrightstown is caused primarily by inflows from semiperennial mountain streams, such as Sabino Creek, in winter and early spring. At Wrightstown, the valley-floor vegetation of Rillito Creek includes cottonwood, willow, seepwillow, saltcedar, and ash. At the Oracle Road gaging station, the vegetation is, as noted above, characteristic of ephemeral streams.

Sabino Creek (Canyon) and Rincon Creek

Sabino Creek has semiperennial flow regimen and is nearly perennial in some years. Rincon Creek, on the contrary, frequently qualifies as having only intermittent flow regimen as defined in the present study. This hydrologic difference may account for the smaller number of valley-floor species near the Rincon Creek gaging station as compared to the number in Sabino Canyon. In Rincon Creek, the sycamore grows to a point about 1.5 miles upstream from the gaging station.

DISCUSSION

Study of the vegetation in the middle reach of the San Pedro Valley has shown that variations in this vegetation can be explained largely in terms of current recognizable differences in the surface hydrology of the area. Geology and topography are important indirect causes of the variations in the plant cover because they determine the hydrologic differences by either concentrating, retaining, or dispersing moisture. In an arid region, variations in the vegetation coextensive with topographic or geologic units are commonly striking, presumably because plants are more dependent on long-term moisture storage in the substrate than in humid

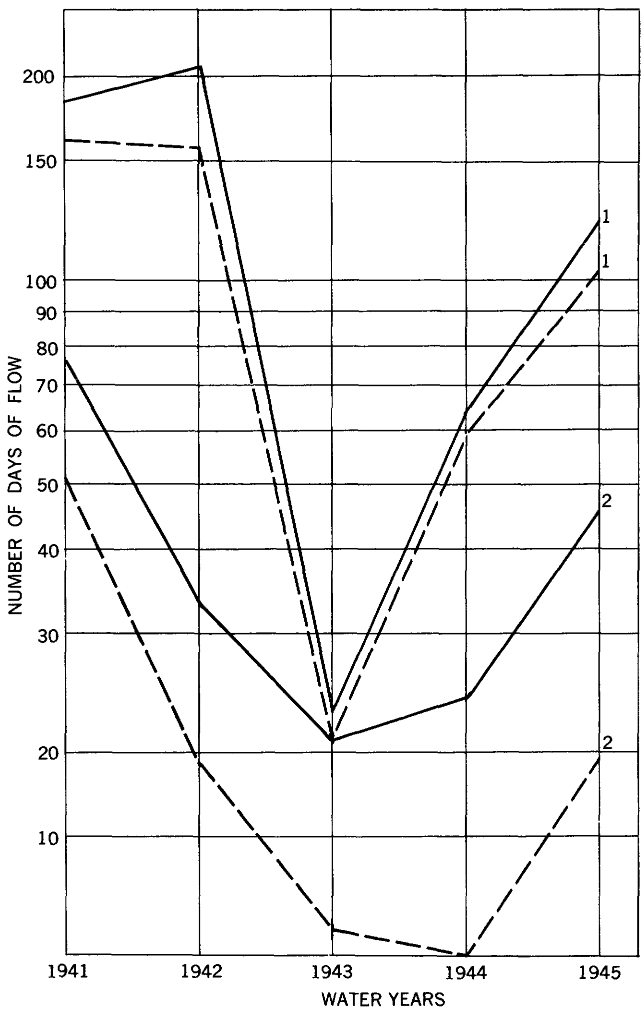

FIGURE 22.—Number of days of flow in Rillito Creek near Wrightstown (1) and at the Oracle Road gaging station (2) in 1941–45. The two stations are about 8 miles apart; Wrightstown is the upstream station. Solid lines indicate total annual number of days of flow, dashed lines total number of days of flow in winter and spring, December 21 through June 21. Data from U.S. Geol. Survey, issued annually.

regions. Where the rainfall is more frequent and abundant, the differences in plant life between habitats at different topographic locations or with different geology are considerably reduced. Hence, in humid regions the contrasts in vegetation between, for example, valley floors and uplands or valley floors with different flow regimens are less conspicuous.

On the valley floors of the study area, the vegetation varies primarily with flow conditions that are probably present most of the time. These are the perennial flows, the semiperennial flows that can be recognized as such mainly in the dry early summer, and the absence of flow save during a few hours following convective storms in the summer in those streams that have ephemeral flow regimen. However, variations in the vegetation also coincide with flows that are average, in the sense that they probably occur annually, but that are not as readily apparent from field inspection as the flow regimens described above. Such flows have been called intermittent because they are intermediate in duration between ephemeral and semiperennial flows. These flows seem to occur mainly as a result of prolonged frontal precipitation in the winter and early spring. The distribution of some plants in the San Pedro Valley also seems to reflect flow events that are not normal; they may have a recurrence interval of perhaps as much as 20 years. An example of such a distribution is the presence of ash, a tree generally associated with sustained flows, in streams with ephemeral flow regimen. Ash may become established in these streams as a result of unusually heavy and sustained runoff, as occurred in December 1965 and January 1966.

Some of the relationships between plants and environment observed in the San Pedro Valley were described in earlier studies of desert vegetation. In the Sonoran Desert, the occurrence of distinctive types of vegetation in streams with different flow regimens, volumes of alluvium, or altitudes of headwaters was recognized by Shreve (1951, p. 69–72). Shreve (1915, p. 19–21) also noted that the differential extension of canyon vegetation away from a desert mountain range such as the Santa Catalina Mountains depends indirectly on the size of the stream, the volume of its flow, and on how far this flow is maintained away from the mountain front. In the Egyptian desert, the presence of certain species on valley floors is apparently related to the size of the catchment basin (Kassas and Girgis, 1964, p. 117). A sorting of distinctive assemblages of species in different valley-floor habitats with different moisture regimens was described in studies of the Hoggar and Tibesti massifs of the Sahara desert (Quézel, 1954; 1958). In the Hoggar massif, abundant regeneration of tree species occurred in wadis following unusually heavy rains and sustained runoff (Quézel, 1954, p. 8–9, 47, 109). Such trees survive subsequent years of drought (Quézel, 1954, p. 47). The establishment of trees on the valley bottoms of the Hoggar massif is apparently related mainly to infrequent flow events.

The study of the vegetation of the San Pedro Valley supports the view that the plants are constantly adjusting to a dynamic environment. (See Hack and Goodlett, 1960, and Heinselman, 1963, for statements on humid regions.) In a desert, as elsewhere, plants are adjusted to the environment at any given time, for growth cannot occur under any other circumstances. On the other hand, in a desert the establishment, and, hence, the distribution, of plants may be related to processes of widely different frequency of occurrence. Some distributions may be related to processes that favor the establishment of plants but may not recur during the lifespan of the same plants.

REFERENCES

Arizona Bureau of Mines, 1959, Geologic map of Cochise County, Arizona: Tucson, Arizona Univ.

Arizona State Land Dept., 1963, Annual report on ground water in Arizona spring 1962 to spring 1963: Water Resources Rept. 15, 136 p.

Arizona Univ., Inst. Atmospheric Physics, 1959, Report on the meteorology and climatology of arid regions, no. 7, Arizona statewide rainfall.

Benson, L., and Darrow, R. A., 1954, The trees and shrubs of the southwestern deserts: Arizona Univ. Press and New Mexico Univ. Press, 437 p.

Bryan, Kirk, 1925, Date of channel trenching (arroyo cutting) in the arid Southwest: Science, v. 62, p. 338–344.

——— 1926, San Pedro Valley, Arizona, and the geographic cycle (abs.): Geol. Soc. America Bull., v. 37, p. 169–170.

Cannon, W. A., 1911, Root habits of desert plants: Carnegie Inst. Washington Pub. 131, 96 p.

——— 1913, Some relations between root characters, ground water and species distribution: Science, v. 37, p. 420–423.

Carpenter, E. J., and Bransford, W. S., 1924, Soil survey of the Benson area, Arizona: U.S. Dept. Agriculture Bur. of Soils, advance sheets, field operations of the Bur. of Soils, 1921, p. 247–280.

Chew, R. T., III, 1952, The geology of the Mineta Ridge area, Pima and Cochise Counties, Arizona: Arizona Univ., M.S. thesis, 53 p.

Cooper, J. R., and Silver, L. T., 1964, Geology and ore deposits of the Dragoon quadrangle, Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 416, 196 p.

Creasey, S. C., 1965, Geology of the San Manual area, Pinal County, Arizona: U.S. Geol. Survey Prof. Paper 471, 64 p.

Creasey, S. C., Jackson, E. D., and Gulbrandsen, R. A., 1961, Reconnaissance geologic map of parts of the San Pedro and Aravaipa Valleys, south-central Arizona: U.S. Geol. Survey Mineral Inv. Map MF–238.

Dalton, P. D., 1961, Ecology of the creosote-bush *Larrea tridentata* (DC) Cov.: Arizona Univ., unpub. Ph. D. dissert., 162 p.

De Wiest, R. J. M., 1965, Geohydrology: New York, John Wiley & Sons, Inc., 366 p.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill Book Co., 534 p.

Fernald, M. L., 1950, Gray's manual of botany [8th ed.]: New York, Am. Book Co., 1632 p.

Gardner, W. R., 1960, Soil water relationships in arid and semiarid conditions, *in* UNESCO, Plant-water relationships in arid and semi-arid conditions, reviews of research: Paris, p. 37–61.

Gary, H. L., 1963, Root distribution of five-stamen tamarisk, seep-willow, and arrow-weed: Forest Science, v. 9, p. 311–314.

Gatewood, J. S., Robinson, T. W., Colby, B. R., Hem, J. D., and Halpenny, L. C., 1950, Use of water by bottom-land vegetation in lower Safford Valley, Arizona: U.S. Geol. Survey Water-Supply Paper 1103, 210 p.

Gazin, C. L., 1942, The late Cenozoic vertebrate faunas from the San Pedro Valley, Arizona: U.S. Natl. Mus. Proc., v. 92, no. 3155, p. 457–518.

Gidley, J. W., 1923, Preliminary report on fossil vertebrates of the San Pedro Valley Arizona, with descriptions of new species of Rodentia and Lagomorpha: U.S. Geol. Survey Prof. Paper 131–E, p. 119–131.

Gilbert, G. K., 1875, Report on the geology of portions of Nevada, Utah, California, and Arizona: U.S. Geog. and Geol. Surveys West of 100th Meridian Rept. (Wheeler), v. 3, p. 501–567.

Gilluly, James, 1956, General geology of central Cochise County, Arizona: U.S. Geol. Survey Prof. Paper 281, 169 p.

Hack, J. T., and Goodlett J. C. 1960 Geomorphology and forest ecology of a mountain region in the central Appalachians: U.S. Geol. Survey Prof. Paper 347 66 p.

Halpenny, L. C., and others, 1952, Ground water in the Gila River basin and adjacent areas Arizona—a summary: U.S. Geol. Survey open-file report, 224 p.

Harshberger, J. W., 1911, Phytogeographic survey of North America: New York, G. E. Stechert, 790 p.

Heindl, L. A., 1963, Cenozoic geology in the Mammoth area Pinal County, Arizona: U.S. Geol. Survey Bull. 1141–E, 41 p.

Heinselman, M. L., 1963, Forest sites, bog processes, and peatland types in the glacial Lake Agassiz region, Minnesota: Ecolog. Monographs, v. 33, p. 327–374.

Horton, J. S., Mounts, F. C., and Kraft, J. M., 1960, Seed germination and seedling establishment of phreatophyte species: U.S. Dept. Agriculture, Forest Service, Rocky Mountain Forest and Range Expt. Sta. Paper 48, 26 p.

Kassas, M., and Girgis, W. A., 1964, Habitat and plant communities in the Egyptian Desert. V. The limestone plateau: Jour. Ecology, v. 52, p. 107–119.

Kearney, T. H., and Peebles, R. H., 1960, Arizona flora: Berkeley and Los Angeles, California Univ. Press, 1085 p.

Kennon, F. W., 1954, Magnitude and frequency of summer floods in western New Mexico and eastern Arizona: U.S. Geol. Survey open-file report, 15 p.

Kennon, F. W., and Peterson, H. V., 1960, Hydrology of Cornfield Wash, Sandoval County, New Mexico, 1951–55: U.S. Geol. Survey Water-Supply Paper 1475–B, 103 p.

Keppel, R. V., and Renard, K. G., 1962, Transmission losses in ephemeral stream beds: Am. Soc. Civil Engineers Proc., Jour. Hydraulics Div., v. 88 (HY3), p. 59–68.

Kincaid, D. R., Osborn, H. B., and Gardner, J. L., 1966, Use of unit-source watersheds for hydrologic investigations in the semi-arid Southwest: Water Resources Research, v. 2, p. 381–392.

Knechtel, M. M., 1936, Geologic relations of the Gila conglomerate in southeastern Arizona: Am. Jour. Sci., 5th ser. v. 31, no. 182, p. 81–92.

Kottlowski, F. E., Cooley, M. E., and Ruhe, R. V., 1965, Quaternary geology of the Southwest, *in* Wright, H. E., Jr., and Frey, D. G., eds., The Quaternary of the United States: Princeton Univ. Press, p. 287–298.

Kramer, P. J., 1949, Plant and soil water relationships: New York, McGraw-Hill Book Co., 347 p.

Lambe, T. W., 1951, Capillary phenomena in cohesionless soils: Am. Soc. Civil Engineers Trans., v. 116, p. 401–432.

Lance, J. F., 1959, Geologic framework of arid basins in Arizona: Geol. Soc. America Bull., v. 70, p. 1729–1730.

——— 1960, Stratigraphic and structural position of Cenozoic fossil localities in Arizona: Arizona Geol. Soc. Digest, v. 3, p. 155–160.

Leopold, L. B., Wolman, M. G., and Miller, J. P., 1964, Fluvial processes in geomorphology: San Francisco and London, W. H. Freeman and Co., 522 p.

Meinzer, O. E., 1927, Plants as indicators of ground water: U.S. Geol. Survey Water-Supply Paper 577, 95 p.

Melton, M. A., 1959–1960, Origin of the drainage and geomorphic history of southeastern Arizona: Arizona Univ., Arid Lands Colloquia, p. 8–16.

——— 1965, The geomorphic and paleoclimatic significance of alluvial deposits in southern Arizona: Jour. Geology, v. 73, p. 1–38.

Meyer, B. S., Anderson, D. B., and Böhning, R. H., 1960, Introduction to plant physiology: Princeton, N. J., Van Nostrand, 541 p.

Montgomery, E. L., 1963, The geology and ground water investigation of the Tres Alamos dam site of the San Pedro River, Cochise County, Arizona: Arizona Univ., M.S. thesis, 61 p.

National Cooperative Soil Survey, USA, 1964, White House Series: U.S. Soil Conserv. Service revised soil series description.

Oppenheimer, H. R., 1960, Adaptation to drought: xerophytism, *in* UNESCO, Plant-water relationships in arid and semi-arid conditions—reviews of research: Paris, p. 105–138.

Phillips, W. S., 1963, Depth of roots in soil: Ecology, v. 44, p. 424.

Quézel, Pierre, 1954, Contribution à l'étude de la flore et de la végétation du Hoggar: Algiers Univ. Inst. Recherches Sahariennes, Monographies Régionales 2, 164 p.

——— 1958, Mission botanique au Tibesti: Algiers Univ., Inst. Recherches Sahariennes, Mem. 4, 357 p.

Renard, K. G., Keppel, R. V., Hickey, J. J., and Wallace, D. E., 1964, Performance of local aquifers as influenced by stream transmission losses and riparian vegetation: Am. Soc. Agr. Engineers Trans., v. 7, p. 471–474.

Robinson, T. W., 1958, Phreatophytes: U.S. Geol. Survey Water-Supply Paper 1423, 84 p.

Russell, E. W., 1961, Soil conditions and plant growth: London, Longmans, 688 p.

Sellers, W. D., ed., 1960, Arizona climate: Arizona Univ., Inst. Atmospheric Physics, 60 p.

Shreve, Forrest, 1915, The vegetation of a desert mountain range as conditioned by climatic factors: Carnegie Inst. Washington Pub. 217, 112 p.

Shreve, Forrest, 1951, Vegetation of the Sonoran Desert: Carnegie Inst. Washington Pub. 591, 192 p.

Shreve, Forrest, and Wiggins, I. L., 1964, Vegetation and flora of the Sonoran Desert: Stanford Univ. Press, 2 vols., 1740 p.

Smith, D. G., 1963, Pleistocene geology and geomorphology of the San Pedro Valley, Cochise County, Arizona: Arizona Univ., M.S. thesis, 73 p.

Smith, Winchell, and Heckler, W. L., 1955, Compilation of flood data in Arizona 1862–1953: U. S. Geol. Survey open-file report, 113 p.

Todd, D. K., 1959, Ground water hydrology: New York, John Wiley & Sons, Inc., 336 p.

Tuan, Yi-Fu, 1959, Pediments in southeastern Arizona: California Univ. Pub. Geog., v. 13, p. 1–163.

——— 1962, Structure, climate, and basin land forms: Assoc. Am. Geographers Annals, v. 52, p. 51–68.

U.S. Agricultural Research Service, 1963, Hydrologic data for experimental watersheds in the United States 1956–59: U.S. Dept. Agriculture Misc. Pub. 945.

U.S. Dept. of Agriculture, 1938, Soils and men: Yearbook of Agriculture, 1232 p.

U.S. Forest Service, 1948, Woody-plant seed manual: U.S. Dept. Agriculture Misc. Pub. no. 654, 416 p.

U.S. Geological Survey, issued annually, Surface-water supply of the United States, Part 9, Colorado River basin: U.S. Geol. Survey Water-Supply Papers.

U.S. Geological Survey, issued annually after water year 1960, Surface-water records of Arizona: U.S. Geol. Survey open-file reports.

Wadleigh, C. H., 1955, Soil moisture in relation to plant growth, *in* U.S. Dept. Agriculture, Water: Yearbook of Agriculture, p. 358–361.

Wilson, E. D., Moore, R. T., and O'Haire, R. T., 1960, Geologic map of Pima and Santa Cruz Counties, Arizona: Arizona Univ., Arizona Bur. Mines.

Zohary, Michael, 1961, On hydro-ecological relations of the Near East desert vegetation, *in* UNESCO, Plant-water relationships in arid and semi-arid conditions (Proc. Madrid Symposium): Paris, p. 199–212.

INDEX

[Italic page numbers indicate major references]

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