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# AQUATIC INVENTORY OF THE UPPER BILL WILLIAMS DRAINAGE, YAVAPAI AND MOHAVE COUNTIES, ARIZONA

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# INTRODUCTION

In compliance with the National Environmental Policy Act (NEPA) of 1970, the U.S. Bureau of Land Management (BLM) is required, by law, to address the resources and impacts of land use on National Resource Lands in the form of an Environmental Statement.

Extensive wildlife inventories were first implemented on public lands following the October 1973 lawsuit filed in the Federal District Court of the District of Columbia by the Natural Resources Defense Council and other conservation groups. It was successfully argued that the evaluation of livestock grazing on public lands, first filed by BLM with the Council on Environmental Quality, was too general in content to properly address localized impacts, and therefore did not comply with NEPA.

It is estimated that 310 stream miles and over 11,800 acres of riparian woodland are administered by the BLM in Arizona (Hoeft, 1978). In an effort to comply with the court decision, it became the purpose of this study to provide aquatic habitat and water quality information to the Phoenix District Office of the Bureau of Land Management. These baseline data are to serve as an information source to be utilized in the management plans for terrestrial and aquatic resources on public lands.

## DESCRIPTION OF THE STUDY AREA

An aquatic inventory was completed during the winter of 1978-79 for perennial drainages of the BLM Hualapai and Aquarius Planning Units in Mohave and Yavapai counties, Arizona (Figure 1). The study area was collectively regarded as the upper Bill Williams basin, upstream from Alamo Reservoir (Figure 2), an area largely neglected with the exception of sporadic collecting by personnel of the University of Michigan, Arizona State University, and Prescott Center College. The drainage area is characterized by low order desert streams with riffles, pools, runs, and during low flow periods, intermittent reaches. The waters support a variety of native and introduced fish plus a diverse invertebrate assemblage.

A warm, semiarid climate prevails with variable annual precipitation of 11 to 18 in. (Wendt, et al. 1976). Rainfall generally follows a bimodal pattern in summer and winter, separated by relatively dry periods in spring and autumn. Summer precipitation is associated with an influx of moist tropical air masses from the south. In winter, Pacific storms enter the area from the west. They are less intense than sporadic summer thundershowers, but of longer duration, with snow commonly occurring at upper elevations. Snow usually falls from mid-November at elevations above 5,000 ft. and is rare after the first of May (Wendt, et al. 1976).

Fig. 1. LOCATION OF THE HUALAPAI AND AQUARIUS PLANNING UNITS, MOHAVE AND YAVAPAI COUNTIES, ARIZONA.



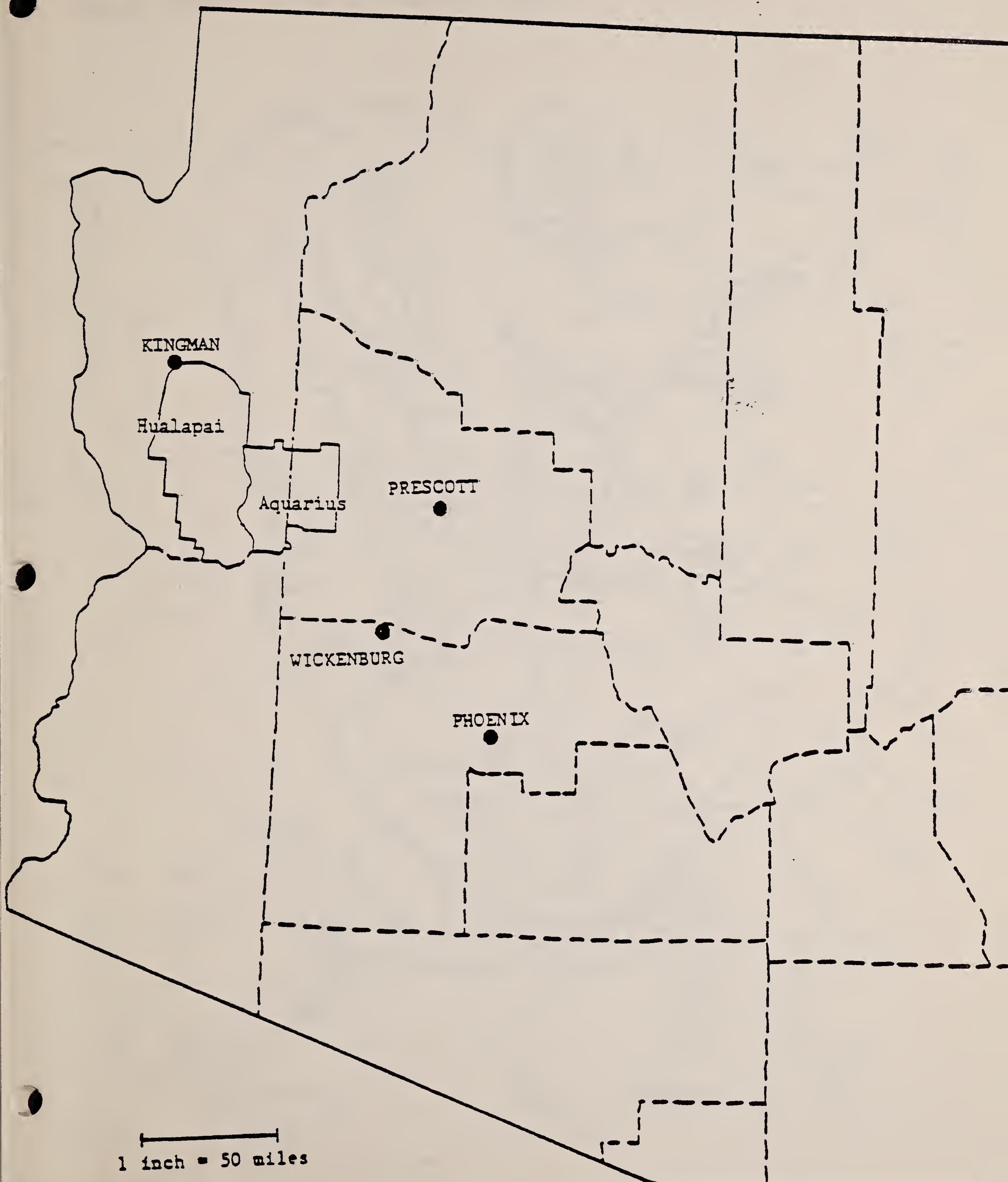
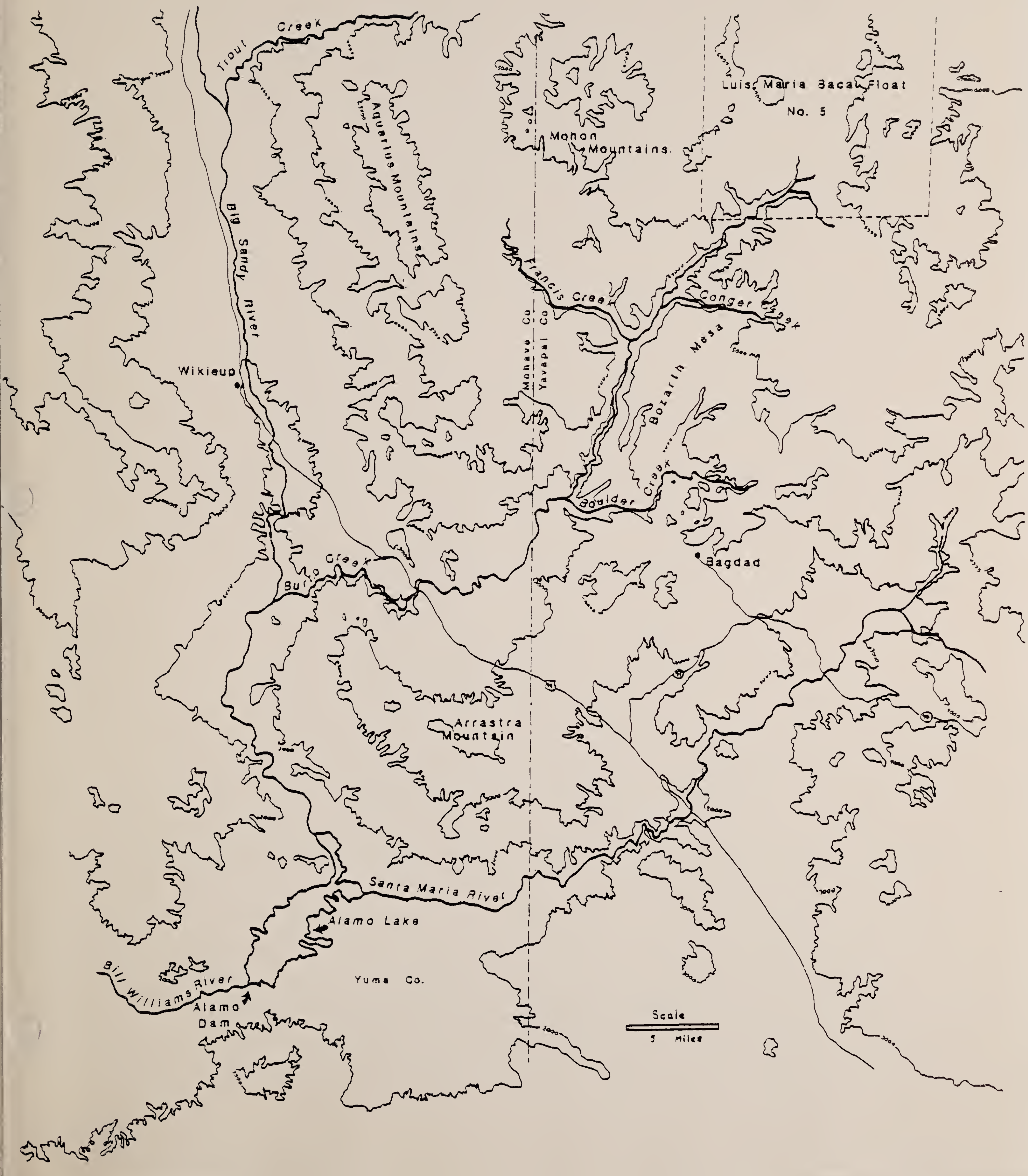


Fig. 2. UPPER BILL WILLIAMS DRAINAGE, ARIZONA.



# METHODS

A total of 64 stations was sampled on 3 major watersheds between December 1978 and February 1979. Each of the watersheds, Santa Maria River, Burro Creek, and Big Sandy River, was distinctive, and data are separately presented. Legal descriptions of sampling sites are included in Appendix 1. More than 168 stream-miles were surveyed, with sampling stations positioned at roughly equivalent, 2.5-mile intervals along each watercourse, depending on access. Stations were designated on U.S. Geological Survey (USGS) topographic maps prior to field investigations, to eliminate bias, and included federal, state, and private lands due to multi-ownership status of the planning units. Each station was sampled through a 60-ft. reach to insure uniformity in sampling, and was subsequently classified as either a pool, run, or riffle using the following criteria:

- pool - deeper, placid, and slower-moving section of a stream;
- run - shallow trough, generally sand and/or gravel substrate, smooth laminar flow of slow to moderate velocity (intermediate between a pool and a riffle);
- riffle - shallow waters with moderate to high velocity but not necessarily high discharge, flow more turbulent, generally pebble, cobble, or larger substrate.

Instantaneous discharges were estimated using the Embody (1927) cork-float method, for which width, stream velocities, and depths are obtained, the last two at selected intervals across the station. A visual approximation of substrate types was categorized following Hynes (1970) and stream gradients were estimated through use of an Abney level. Description of the riparian vegetation types (Brown and Lowe, 1974a and 1974b; Brown, *et al*. 1979) and condition was

recorded for each transect in addition to a narrative for adjacent, non-riparian climax communities. Any land use impacts, e.g. livestock grazing or mining operations, were added to the reach description. Field notes and maps are on file at the Phoenix District Office of BLM.

Water quality was monitored at each station through use of Hach Model CA-10WR and NI-12 field test kits; water temperatures were measured with a pocket thermometer (°F). Chemical parameters included dissolved oxygen (DO, mg/l), carbon dioxide ($CO_2$, mg/l), hydrogen-ion concentration (pH), and nitrate-nitrogen ($NO_3^-$-N, mg/l). In addition, water samples from selected stations were analyzed at the Water Quality Branch (Fisheries Management Division) of the Arizona Game and Fish Department for chloride ($Cl^-$ mg/l), hardness (as $CaCO_3$ mg/l), ammonia ($NH_4^+$ mg/l), phosphate-phosphorus ($PO_4^{\equiv}$-P mg/l), sulfate ($SO_4^=$ mg/l), turbidity (Jackson Turbidity Units [JTU]), and total dissolved solids (TDS). Other information with regards to water quality was obtained from monthly sampling by the USGS under contract with the Arizona State Office of BLM.

Macrofaunal sampling of benthic communities was undertaken to define associations of macroinvertebrate species in each watershed. The sampling approach was not intended to meet statistical requirements for quantification, but rather to identify trends in distribution and diversity with inference to environmental stresses or quality. Wherever possible, specimens were identified to the species level (Appendix 2).

Fish were collected by 115 volt, A.C., backpack electrofishing equipment and 1/8-inch mesh seines. Specimens were preserved in 10% formalin and later transferred to 50% isopropynol. Identifications followed Minckley (1973); all specimens were deposited in the Collection of Fishes, Arizona State University, Tempe.

# RESULTS AND DISCUSSION

## Santa Maria River

Description.

The Santa Maria River originates at the confluence of Sycamore and Kirkland creeks at 2,650 ft. elevation, and flows southwest approximately 41 miles to enter Alamo Lake at 1,170 ft. The river is accessible at various points by maintained and unimproved dirt roads and at two locations *via* U.S. Highway 93 and State Highway 96. Drainage area of the watershed is estimated at 1,520 square miles (pers. comm. Paul Rohne, Jr., USGS, Phoenix District Files).

The Santa Maria River is characterized by broad, shallow, sandy-bottomed runs, with few riffles and low gradient. Average width during our period of study was 132.5 ft. (range 65.1 to 256.2 ft.) with mean depth and gradient 11.2 in. (range 2.5 to 25 in.) and $0.98^{\circ}$ (range 0.5 to $1.5^{\circ}$), respectively. Pools and eddies were rare, occurring only in areas where the open floodplain has been constricted by narrow canyons.

Flow was swift and laminar, averaging 2.5 ft./sec. (range 1.6 to 5.5 ft./sec.). In an 11-year period from 1966 to 1977, average discharge at USGS gaging station No. 4249 (located 12 miles upstream from the confluence with Big Sandy River) was 37.5 $ft.^3$/sec. or 27,170 acre-ft./yr. The drainage is subject to spates, with the highest measured discharge, 30,000 $ft.^3$/sec., recorded in February 1978. During summer months, surface flow is not sustained and the stream is reduced to a series of disconnected pools (USGS, 1977).

The drainage dissects Precambrian metamorphics and recent Tertiary sediments. Adjacent slopes are moderate to steep, with well-drained, shallow soils over granitic hills and mountains. The soil surface is generally rocky to gravelly, and loosely compacted, with numerous rock outcrops.

Stream substrate consisted of mixed recent alluvium, mostly unstabilized sand and gravel, weathered from a wide variety of geologic materials. Alluvial sediments are generally fine grained and level to gently sloping within the floodplain, with cobble present locally. Banks were often cut, but stabilized by rooted plants, _e.g._ Bermuda grass (_Cynodon dactylon_).

Riparian vegetation was sparse, and characterized by mesquite (_Prosopis velutina_) bosques with seep willow (_Baccharis salicifolia_) bordering the stream, or occurring in the form of small stands of Goodding willow (_Salix gooddingii_) and cottonwood (_Populus fremonti_), with mesquite bosque as an understory.

Palo verde-saguaro (_Cercidium microphyllum_, _Cereus giganteus_) desertscrub was the dominant, non-riparian vegetative community along the Santa Maria River. Codominant species typical of the area included creosote bush (_Larrea divaricata_) and buckhorn cholla (_Opuntia acanthocarpa_).

_Water Quality_.

Interpretation of chemical analyses is severely limited by the "one shot" approach of point localities. When physical/chemical parameters are not monitored over time, they obviously cannot account for diurnal or seasonal fluctuations in macronutrients and major cations and anions. Limited sampling can, however, identify point sources of pollution and do provide for evaluation of the system for a given period of time. Observations of the physical/chemical quality as related to requirements of the aquatic communities are therefore restricted to our winter sampling period (Table 1).

The temperature regime of a system is significant in governing the suitability of a habitat for aquatic organisms, and is obviously most extreme during the summer in desert areas. There are optimal or preferred temperatures

Table 1. CHEMICAL/PHYSICAL DATA FOR THE SANTA MARIA RIVER, ARIZONA; MEANS FOLLOWED BY RANGES (IN PARENTHESES). *

| | | |
|---|---|---|
| Drainage area ($mi.^2$) | 1,520.0 | |
| Mean width (ft.) | 132.5 | (65.1 - 256.2) |
| Mean depth (in.) | 11.2 | (2.5 - 25.0) |
| Mean stream gradient | $0.98^{o}$ | ($0.5 - 1.5^{o}$) |
| Mean stream velocity (ft./sec.) | 2.5 | (1.6 - 5.5) |
| Mean discharge ($ft.^3$/sec.) ** | 37.5 | (0 - 30,000) |
| Turbidity (JTU) | 17.2 | (8 - 24) |
| Total Dissolved Solids (TDS), mg/l | 214 | (180 - 240) |
| Total Hardness, mg/l as $CaCO_3$ | 492 | (360 - 740) |
| Water Temperature, $^{o}F$ | 50 | (41 - 58) |
| pH | 8.3 | (7.5 - 8.5) |
| Dissolved Oxygen (DO), mg/l | 11 | (9 - 12) |
| Carbon Dioxide ($CO_2$), mg/l | 17 | (15 - 20) |
| Ammonia ($NH_4^+$), mg/l | 0.19 | (0.1 - 0.3) |
| Nitrate-nitrogen ($NO_3^-$-N), mg/l | 2.1 | (1.5 - 3.0) |
| Total Phosphate ($PO_4^{\equiv}$-P), mg/l | 0.34 | (0.18 - 0.53) |
| Sulfate ($SO_4^{=}$), mg/l | 29.7 | (24.8 - 35.6) |
| Chloride ($Cl^-$), mg/l | 3.9 | (3.55 - 5.32) |

* Diurnal samples at 11 stations, 5 February 1979 to 9 February 1979.

** USGS water resources data for record period, April 1966 to 1977.

as well as lethal minima and maxima, depending on the organism. Daytime water temperatures in the Santa Maria River were well within tolerable limits, ranging between 41 and 58°F during our winter sampling period. High temperatures are likely to approach or exceed extremes of tolerance for some species in summer due to lack of cover from a riparian corridor of vegetation, lack of canyon shading, turbidity, and low discharges.

Turbidity levels are difficult to evaluate because of the broad spectrum of tolerance exhibited by aquatic organisms. Turbidity relates to the amount of suspended and dissolved particles which affect water transparency, and (as measured in JTU) reflects the ability of natural waters to either scatter or absorb light. Turbidity ranged between 8 and 24 JTU, with variance due to changing amounts of streamload in the form of suspended sand particles. The turbidity range for the Santa Maria River was in compliance with the Arizona standard for warm-water fishery habitat (<50 JTU).

TDS is a measure of total concentration of solutes. It is an important property of water relating to the salt balance of organisms, and is often used as an index of pollution. TDS values were below 400 mg/l, the maximum level considered optimal to support a mixed fish fauna by McKirdy (1968). Values ranged between 180 and 240 mg/l (mean 214 mg/l).

Hydrogen-ion concentration (pH) was almost uniform throughout the samples, ranging between 7.5 and 8.5 during the day, but is expected to vary seasonally and diurnally in relation to photosynthetic activity and respiration rates of aquatic biota. These hydrogen-ion values met current and proposed water quality criteria (pH 6.5 - 9.0) of the Arizona Water Quality Control Council (AWQCC) for aquatic life and wildlife uses. In addition to alkaline pH, waters were hard (mean 492 mg/l as $CaCO_3$).

Atmospheric oxygen is abundant (20.9% by volume) and is readily absorbed into water, depending on temperature, salinity, and pressure. Sources of dissolved oxygen in water are biologic dehydrogenation of water during photosynthesis and atmospheric exchange at the water surface. Substantial respiration by higher plants, algae, animals, and aerobic bacteria of decay are responsible for the loss of dissolved oxygen from water. Decreased DO may also be attributed to the organic import during such events as autumn leaf-fall or decreased photosynthetic rates during increased light extinction associated with high turbidity, e.g. spates.

As with pH, DO values are to be expected to change with photosynthesis and respiration over time. DO varied from 9 to 12 mg/l in daytime sampling, the minimum of which exceeded the state minimum standard (6.0 mg/l) for oxygen concentration in surface waters for aquatic life and wildlife uses. However, amounts of oxygen required by aquatic organisms is largely a function of temperature which governs their metabolic rates (Moore, 1942), and sometimes conditions might be expected to approach critical levels.

Oxygen and $CO_2$ are inversely related in aquatic ecosystems because of photosynthetic and respiratory activities. Most $CO_2$ is produced as respiration of aerobic organisms and by anaerobic decomposition of autochthonous organic material by bacteria. Because of the high coefficient of solubility, $CO_2$ can also enter an aquatic system directly by diffusion from the atmosphere or secondarily from rainfall. Other sources include subterranean waters which have been exposed to organic materials and bacterial respiration in the soil and enter via springs and seeps. In most aquatic systems gaseous $CO_2$ occurs with alkali metals or alkaline earth metals and combines with them to form bicarbonate ($HCO_3^-$) and carbonate ($CO_3^=$) compounds. The

$CO_3^{=}$ - $HCO_3^-$ ion system is a dominant buffering factor in aquatic systems, resisting changes in hydrogen-ion concentrations. The amounts of $CO_2$ above that bound in $HCO_3^-$ and $CO_3^{=}$ varied from 15 to 20 mg/l during the day in the Santa Maria River, which are values within the restrictive range (<20 mg/l) prescribed for good fish and aquatic life production by McKirdy (1968).

$NH_4^+$ is an important nitrogenous end product of heterotrophic bacterial breakdown. Aquatic animals also commonly excrete $NH_4^+$ as a waste product of metabolism, but contribute far less to the system than bacteria. Ammonia is extremely soluble and can be present in any of three forms: a gas, $NH_3$; an ion, $NH_4^+$; or in undissociated states such as $NH_4OH$. Toxic effects of ammonia rarely manifest themselves in lotic situations because it is usually swept away from organisms by surface flow. In most natural waters, the pH range is such that the ionized fraction, $NH_4^+$, of ammonia predominates and the $NH_4^+/NH_3$ ratio is maintained in equilibrium. In dilute, highly alkaline waters, the equilibrium shifts towards $NH_3$, the more toxic fraction. $NH_4^+$ ion has little or no toxicity to aquatics but levels of $NH_3$ in the range of 0.20 to 2.0 mg/l are toxic to some species of freshwater aquatic life (European Inland Fisheries Advisory Commission, 1970). The standard adopted by the AWQCC (1979) for aquatic life and wildlife use of surface waters is 0.02 mg/l $NH_3$; ammonia ($NH_3$ + $NH_4^+$) values for the Santa Maria River ranged between 0.10 and 0.30 mg/l.

Free nitrogen is largely unavailable to higher plants and animals until it undergoes the processes of ammonification and nitrification. $NO_3^-$ is the most fully oxidized and common form of nitrogen in lotic waters, entering the watershed from rainfall and particulate sources associated with runoff, where it is released to the system. Because $NO_3^-$ is the most available form for

plant growth, it is assimilated rapidly by autotrophs and may decline to undetectable levels in an aquatic system, especially during diurnal activity periods. This has caused recent concern among aquatic ecologists, since areas of exceptional plant growth were discovered to act as nutrient traps. Little nitrate may pass such a point and lower reaches of desert streams may become nitrogen limited (Fisher and Grimm, 1979). Nutrient levels for $NO_3^-$-N were at desirable levels for aquatic production in the Santa Maria River (range 1.5 to 3.0 mg/l), and did not exceed the Environmental Protection Agency (EPA, 1977a) standard for maximum concentration (5.0 mg/l).

Phosphorus is seldom found in significant concentrations in natural waters. Unlike nitrogen, phosphorus is less abundant in the lithosphere and does not have an immediate atmospheric store. Phosphorus occurs as simple ionic orthophosphate, $PO_4^{\equiv}$, and as bound $PO_4^{\equiv}$ in soluble and particulate form. Igneous rocks are the main source of orthophosphate, the oxidized form of phosphorus which is immediately available to autotrophic plants. Although rapidly taken up and concentrated by aquatic organisms, it can also be recycled through decay and demineralization of organic material by bacterial action. Traditionally, phosphorus has been considered the major limiting factor for primary production and has been measured as total $PO_4^{\equiv}$-P. Total $PO_4^{\equiv}$-P values for the Santa Maria River were fairly stable throughout the drainage (range 0.18 to 0.53 mg/l). However, these values were higher than not-to-exceed standards set by the EPA (0.06 mg/l).

High $PO_4^{\equiv}$-P is characteristic of desert streams (pers. comm. W. L. Minckley, Arizona State University), as is its relative stability (Fisher and Grimm, 1979). Nutrient limitation may be a single compound, when if absent, suppresses growth of plants even if other nutrients are over-abundant. Thus,

in the absence of $NO_3^-$-N, high $PO_4^{\equiv}$-P has little significance. There seems a real danger in Arizona streams, if $NO_3^-$-N is made available through input of sewage or other sources, that accelerated eutrophication might prevail.

$SO_4^=$ occurs naturally in water, particularly in the American Southwest as a result of leachings from calcium sulfate ($CaSO_4$) or metal sulfides, especially pyrite ($FeS_2$). As the most oxidized form of sulfur, the $SO_4^=$ ion is usually second to carbonate as a principle anion in freshwater and in soil. Aside from edaphic sources, it is a pollutant from acid mine drainage, combusion of fossil-fuels, and pulp and paper mill wastes. Unusually high $SO_4^=$ and sulfite ($SO^=_3$) levels are an important index of industrial water pollution. Sulfur in its most reduced state, hydrogen sulfide ($H_2S$), results in abiotic conditions because of its inactivation of the enzyme cytochrome oxidase in aerobic organisms. Sulfate levels in the Santa Maria River varied between 24.8 and 35.6 mg/l (mean 29.7 mg/l), significantly below maximum levels (90 mg/l) suggested for aquatic life by McKirdy (1968).

Chlorine is presnt in practically all natural waters as the dissociated ionic form, chloride ($Cl^-$). Chloride is the third most common anion present in rivers and lakes and is derived mostly from edaphic evaporites. Other sources may include contamination from domestic sewage and livestock. It is important in the osmoregulation of aquatic organisms and for its minor effect on the solubility of oxygen. Chloride varied between 3.55 and 5.32 mg/l (mean 3.9 mg/l), representing values well within the suggested range (<170 mg/l) for good fish production (McKirdy, 1968).

## Macroinvertebrates.

Macroinvertebrates have been widely used as biological indicators of environmental quality, often reflecting instability better than any

chemical/physical parameter. They are subjected to stresses which are largely non-selective for any given species, but affect the entire aquatic community. Although there are intolerant or sensitive species, Cummins (1964, 1974) warns that no single organism can be referred to as the indicator of pollution, and insists that specific assemblages or functional groups of organisms must be used for environmental assessment. In general, a more diverse community, the greatest number of individuals distributed evenly over several species, is desirable to assure structural stability.

Many factors regulate occurrence and distribution of aquatic invertebrates, but composition of the stream bottom appears to be a major controlling factor (Thorup, 1966). Most macroinvertebrates require a suitable habitat of stable gravel, mixed rubble or organic debris. It is not therefore surprising that clean, shifting sands of the Santa Maria River were relatively depauperate in benthic fauna. Diversity was low and populations appeared clustered in distribution, depending on available microhabitat. Only 21 taxa were collected in the drainage, with a range of 4 to 15 taxa per sample. The most frequently encountered species included the odonate, Progomphus borealis, the hydrophilid beetle, Tropisternus ellipticus, and members of the dipteran family Chironomidae (Appendix 3), all of which are indicative of physically-stressed communities where siltation, fluctuating flow, and scouring are common.

Macroinvertebrate populations of the Santa Maria River varied with the seasonality of catastrophic events associated with spates. High flow resulted in a temporary net loss in benthic density and diversity. Cobble/rubble substrates that offer temporary shelter for the benthic community, were essentially absent in the Santa Maria River. Flow fluctuations in addition to substrate scouring and abrasion can reduce biomass upwards to 95 and 99%

(Gray, 1979). However, with the exception of extremely high discharges, spates normally do not result in net reduction of species, and may actually contribute to diversity through drift of rare taxa from upstream. Depending on ambient temperature, turnover rate is high and the benthic fauna rapidly recovers following spates. Streams are primarily repopulated by downstream drift and aerial transport of ovipositing adults, which may be present throughout the year (Williams and Hynes, 1976). Other recolonization pathways include upstream migration and vertical emergence through the substrate. All four pathways may be used by members of the same taxa, although various taxonomic groups may have preferred directions from which they recolonize disturbed areas. Importance of any particular mode of recolonization may vary seasonally, reflecting life cycles of the organisms involved.

Ichthyofauna.

Seven species of fishes representing four families were collected from the Santa Maria River (Table 2). This represents two species, *Gila robusta robusta* and *Pantosteus clarki*, not known from previous museum records (Arizona Game and Fish Department, Phoenix). These native species are certainly not new to the ichthyofauna, but previous collections were sparse and at points of easy access across sandy runs, habitat not conducive to populations of either species. Four of the seven fishes are native to the drainage, and none merits special attention afforded threatened, endangered, or sensitive species on federal and state lists.

Fish habitat in the Santa Maria River is marginal at best and homogeneity of the system is obvious. The depauperate fish fauna can be attributed to a lack of habitat diversity rather than any chemical/physical parameter. Fishes

Table 2. SANTA MARIA RIVER FISH COLLECTIONS.

| | Total Length (range in mm) | Percentage of Occurrence | Total N |
|---|---|---|---|
| Family Cyprinidae | | | |
| *Agosia chrysogaster* - longfin dace * | 24 - 83 | 97.1 | 1,324 |
| *Gila robusta robusta* - roundtail chub * | 32 - 56 | 0.9 | 12 |
| *Notropis lutrensis* - red shiner | 31 - 85 | 1.2 | 16 |
| Family Catostomidae | | | |
| *Catostomus insignis* - Gila sucker * | 86 | 0.1 | 1 |
| *Pantosteus clarki* - Gila mountain-sucker * | 55 - 95 | 0.3 | 4 |
| Family Centrarchidae | | | |
| *Chaenobryttus cyanellus* - green sunfish | 77 - 114 | 0.4 | 5 |
| Family Ictaluridae | | | |
| *Ictalurus melas* - black bullhead | 210 - 212 | 0.1 | 2 |
| | | | 1,364 |

* Native fishes

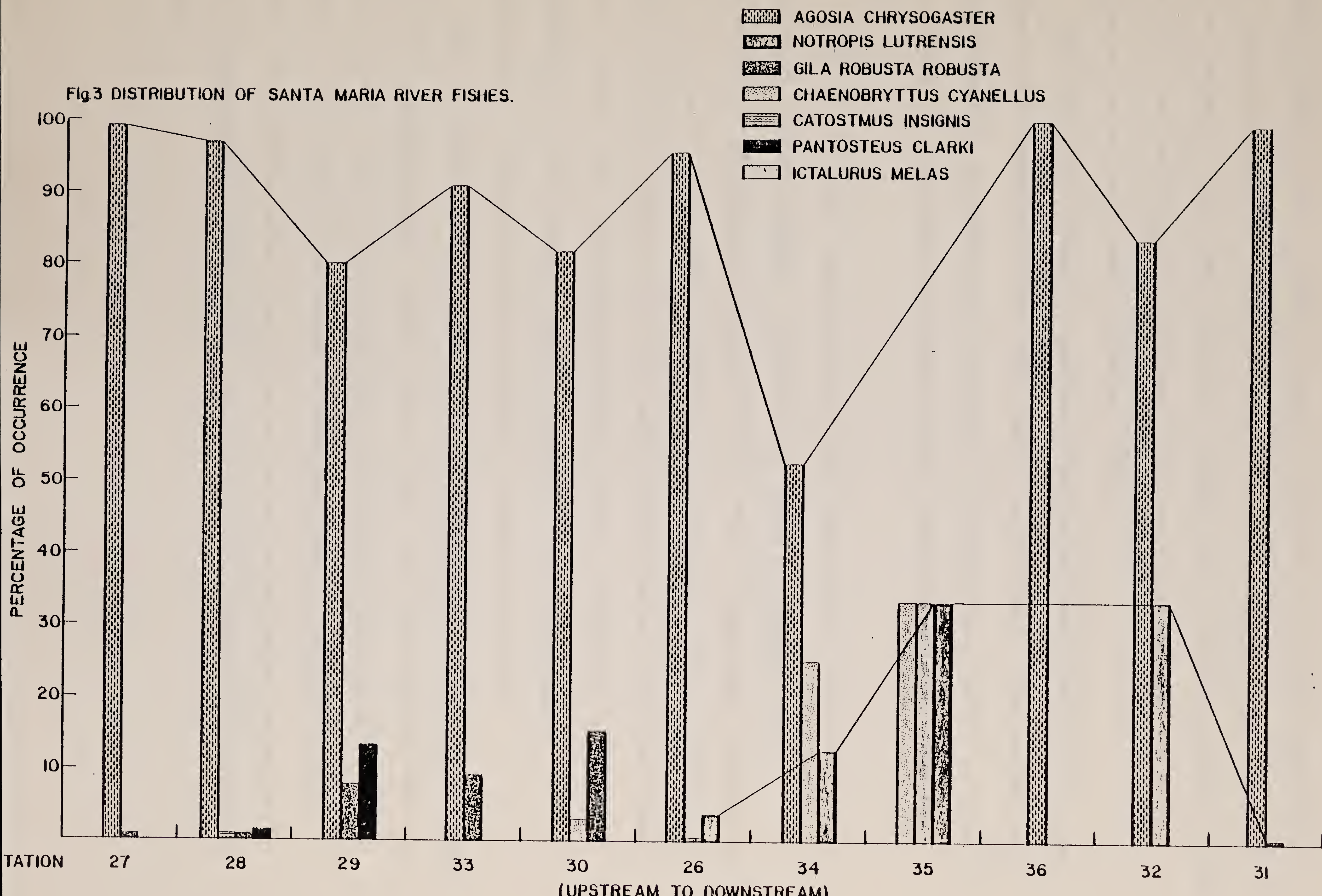
must contend with such environmental perturbations as increased turbidity, shifting substrates and scouring from spates, elevated summer temperatures, lack of vegetative cover, seasonal intermittency of flow, and a low benthic prey-base.

However severe conditions may appear, the Santa Maria River remains prime habitat for longfin dace (Agosia chrysogaster), the most ubiquitous Southwestern minnow (Minckley and Barber, 1970). Overhanging vegetation is scarce along the drainage and Agosia are found primarily over shallow, sandy substrate with limited cover in the form of cut banks or flood debris. Adult populations are rarely reduced as the result of spates (Minckley, 1973) and they are tolerant of elevated summer temperatures (Lowe, et al. 1967; Minckley, 1973). Spawning is protracted in saucer-shaped nests in the sand throughout much of the year and tuberculate males were collected as early as February.

Agosia are diuranal feeders and opportunistic omnivores. In Aravaipa Creek, Arizona, major food items in addition to algae and detritus included aquatic insects, primarily baetid mayfly nymphs and chironomid dipterans associated with drift (Schreiber, 1978). Detritus, filamentous green algae, e.g. Cladophora sp., and diatoms epiphytic on Cladophora, were the predominant diet of Agosia in Sycamore Creek, Arizona (Grimm, et al. 1979).

Agosia persist throughout the drainage and clearly dominate the Santa Maria River (Figure 3). They were collected at almost every station and represented more than 97% of all fishes collected. Total lengths ranged between 24 and 83 mm. indicating the presence of two strong year classes and a high level of reproductive success.

Red shiner (Notropis lutrensis) was the next most abundant species, but only accounted for 1.2% of the total collection. Red shiners are introduced,


AGOSIA CHRYSOGASTER
NOTROPIS LUTRENSIS
GILA ROBUSTA ROBUSTA
CHAENOBRYTTUS CYANELLUS
CATOSTMUS INSIGNIS
PANTOSTEUS CLARKI
ICTALURUS MELAS
Fig.3 DISTRIBUTION OF SANTA MARIA RIVER FISHES.
PERCENTAGE OF OCCURRENCE
100
90
80
70
60
50
40
30
20
10
TATION
27
28
29
33
30
26
34
35
36
32
31
(UPSTREAM TO DOWNSTREAM)

largely a result of bait bucket transfers, from east of the Rocky Mountains. They are also omnivorous and occupy similar habitat as *Agosia*, but obviously in smaller numbers. They spawn from March through June in laminar runs over gravel substrate, but unlike *Agosia*, broadcast their ova indiscriminately over the bottom and do not build nests (Minckley, 1972).

Red shiners were absent at upstream stations and most common at the lower reaches where interactions from other species were reduced. They exhibit wide physico-chemical tolerances and are capable of exploiting a variety of habitats unfavorable to other more specialized species (Matthews and Hill, 1977 and 1979).

Some of the native species were far more restricted in their habitat preferences than was *Agosia*. Roundtail chub (*Gila r. robusta*), Gila mountain-sucker (*Pantosteus clarki*), and Gila sucker (*Catostomus insignis*) were only collected in areas where a riffle/pool habitat was present. Adult Gila suckers typically inhabit deep, quiet pools rather than more turbulent areas such as riffles where Gila mountain-sucker prevails. Roundtail chubs are intermediate to the suckers in habitat selection, with large adults concentrating in suitable pools and smaller juveniles on riffles.

Both introduced species, green sunfish (*Chaenobryttus cyanellus*) and black bullhead (*Ictalurus melas*), prefer areas of quiet water and undercut banks with limited cover. Both fish are omnivorous and relatively intolerant to other species. Their populations are not at adequate levels to support a sport fishery in the Santa Maria. Numbers were few and overall size diminutive. Total lengths rarely exceeded what might be considered desirable by fishermen (Table 2).

Multiple-use.

Water quality for the Santa Maria River may be considered good, meeting or exceeding federal and state surface water standards, with a few notable exceptions. Low standing crops and diversity of the ichthyofauna and of macroinvertebrate populations may be attributed to physical characteristics inherent to the drainage rather than anything artificial or biologically induced. Indeed, there was little in the way of impact from current utilization of the watershed.

Livestock grazing is limited and primarily restricted to yearlong cow - calf operations, where numbers are regulated by appropriate federal and state land-management agencies. Cattle were observed at various localities throughout the Santa Maria watershed, and may represent significant management problems if successful regeneration of riparian species is suppressed by grazing. In addition, 500 to 600 feral burros are in the vicinity of Alamo Lake (BLM, 1979) and several individuals were frequently encountered along the Santa Maria River during the course of this study. Burros present more serious problems to land management in that they are more destructive grazers and prolific breeders than cattle, their numbers are not well regulated, and they are afforded protection status by the federal government under the Wild Horse and Burro Act of 1971. In addition to livestock and burro grazing, other agricultural uses include diversions for irrigation of approximately 5,300 acres (USGS, 1977). The primary source of this water is from pumping of ground water contained within the shallow alluvium aquifer at depths between 10 and 200 feet.

Little is provided in the way of desert recreation for the outdoor activist. There are no established campground or picnic areas along the Santa Maria River, thus activities are limited to primitive camping, off-road

driving, and some rockhounding. Hunting and observation of wildlife, particularly birds, is probably enjoyed by few participants in the Santa Maria vicinity.

The bird fauna is relatively dense and extremely diverse along desert streams (Carothers, et al. 1974; Carothers and Johnson, 1975). The Santa Maria represents significant habitat for migrating ducks and wintering Canada geese and to many piscivorous birds such as great blue herons (Ardea herodias) and common mergansers (Mergus merganser) which prey heavily on fish populations. Occasionally, bald eagles (Haliaeetus leucocephalus) were observed above the drainage, presumably in search of piscine prey.

By far the greatest threat to integrity of the Santa Maria watershed may be forthcoming. Plans are fully implemented for reopening of the Anderson Uranium Mine, which includes land downstream from the U.S. Highway 93 bridge, and adjacent to the Santa Maria River. The mine was first opened in 1955 during the height of the uranium boom and later sold to the Union Minerals Exploration Company in the mid-1970s. As other mining interests begin to move into the area, it remains unclear what environmental consequences to the aquatic ecology of the Santa Maria may be involved. Union Minerals expects to employ 350 permanent employees and create an around-the-clock yearly mill and mine operation (BLM, 1979).

Several points become pertinent in assessing potential environmental impacts. Sedimentation is likely to become a problem in the area, which is heavily dissected by small ephemeral washes that drain into the Santa Maria River. Open-pit operations could easily contribute copious amounts of sediment to the normal streamload and increase some chemical/physical parameters, e.g. heavy metals, radionuclides, TDS, turbidity, conductivity, etc., to levels

unfavorable for aquatic life. This is especially true if operations are proximal to the river since "the lake beds near the Santa Maria River are host rocks for the uranium ($U_3O_8$) mineralization at the Anderson Mine" (BLM, 1979). Other questions arise concerning final disposition and location of mill tailings and how they will affect runoff quality or percolation into the water table. It is yet unclear as to what volumes of water will be necessary to maintain an operation of this magnitude, nor where it will come from, surface diversions or ground water. Withdrawals of either kind will certainly affect instream flows, which may be detrimental to an aquatic community in an already intermittent system. It is important to monitor the Santa Maria River for chemical/physical and biological features prior to and during the operation of the Anderson Mine. This should be done in cooperation with the USGS and facilitated by the permanent gaging station (No. 4249) located just 2.75 miles downstream from the property boundary of the mine.

# Burro Creek

## Description.

Burro Creek begins at the confluence of Pine Creek and Cabin Wash in the Luis Maria Baca Float No.5, an old Spanish land grant dating to January 1821. It flows approximately 57 miles southwest from an elevation of 4,380 ft. to its confluence with the Big Sandy River, 20.5 miles above Alamo Lake at 1,510 ft. Burro Creek and its perennial tributaries collectively drain the Mohon and Aquarius Mountains and the western half of the Santa Maria Mountains. The total watershed is estimated to be 687 square miles (pers. comm. Paul Rohne, Jr., USGS, Phoenix District Files), and includes numerous springs and seeps.

Topography varies from moderately steep hills and mountains, cut canyons with near vertical escarpments, to nearly level basaltic mesas. Access to Burro Creek is restricted to a few maintained and unimproved dirt roads, and *via* U.S. Highway 93. Due to the limited approach to Burro Creek and its tributaries, it was necessary to use a helicopter for access to many of the sampling stations.

Geology is variable throughout the drainage and rock outcrops are common. At its point of origin, Burro Creek has incised into recent Tertiary volcanics. The headwaters are located within nearly level to moderately sloping soils on basaltic uplands. These volcanic mesas are characterized by rocky, clay-loam surfaces that support mainly grasses, but juniper (*Juniperus osteosperma*) and pinyon pine (*Pinus monophylla*) are present at the higher elevations. Average annual air temperature is 45 to 57°F and precipitation varies between 12 and 16 in. (Wendt, *et al*. 1976). Riparian vegetation in the upper reaches includes various mixed broadleaf species such as sycamore (*Platanus wrightii*), velvet

ash (*Fraxinus pennsylvanica*), Arizona alder (*Alnus oblongifolia*), and Arizona walnut (*Juglans major*).

At intermediate elevations, non-riparian climax communities consist largely of desert grassland where prickly pear (*Opuntia phaeacantha*), Mohave thorn (*Canotia holacantha*), and snakeweed (*Gutierrezia sarothrae*) are often dominant. Chaparral species such as scrub oak (*Quercus turbinella*), sugar sumac (*Rhus ovata*), and mountain mahogany (*Cercocarpus montanus*) exhibit aspect dominance and are found on the north-facing slopes of the drainage. The riparian woodland below 3,600 ft. is dominated by cottonwood and Goodding willow, with a seep willow understory. Cottonwood/willow stands vary from a few individuals to full galleries with bosque species such as mesquite, catclaw (*Acacia greggii*) and graythorn (*Zizyphus obtusifolia*) present on the upper terraces of the floodplain.

At lower elevations, average annual precipitation is reduced to 8 to 12 in. and mean annual air temperature is 57 to 67°F (Richmond and Richardson, 1974). Soils are shallow and of granitic origin in areas of strongly sloping to steep foothills, mountains, and rock outcrops. The soil surface is mostly gravelly to cobbly loam except at the confluence of the Big Sandy River where soils become a deeper series of finer sediments in mixed, recent alluvium. The lower elevations support a wide variety of desert shrubs, leaf succulents, and cacti. Saguaro, foothill palo verde, teddy bear cholla (*Opuntia bigelovii*), and creosote bush are frequently dominant. Low elevation riparian vegetation becomes a series of scattered stands of mesquite, catclaw, burro brush (*Hymenoclea monogyra*), and seep willow. Tamarisk (*Tamarix chinensis*) has

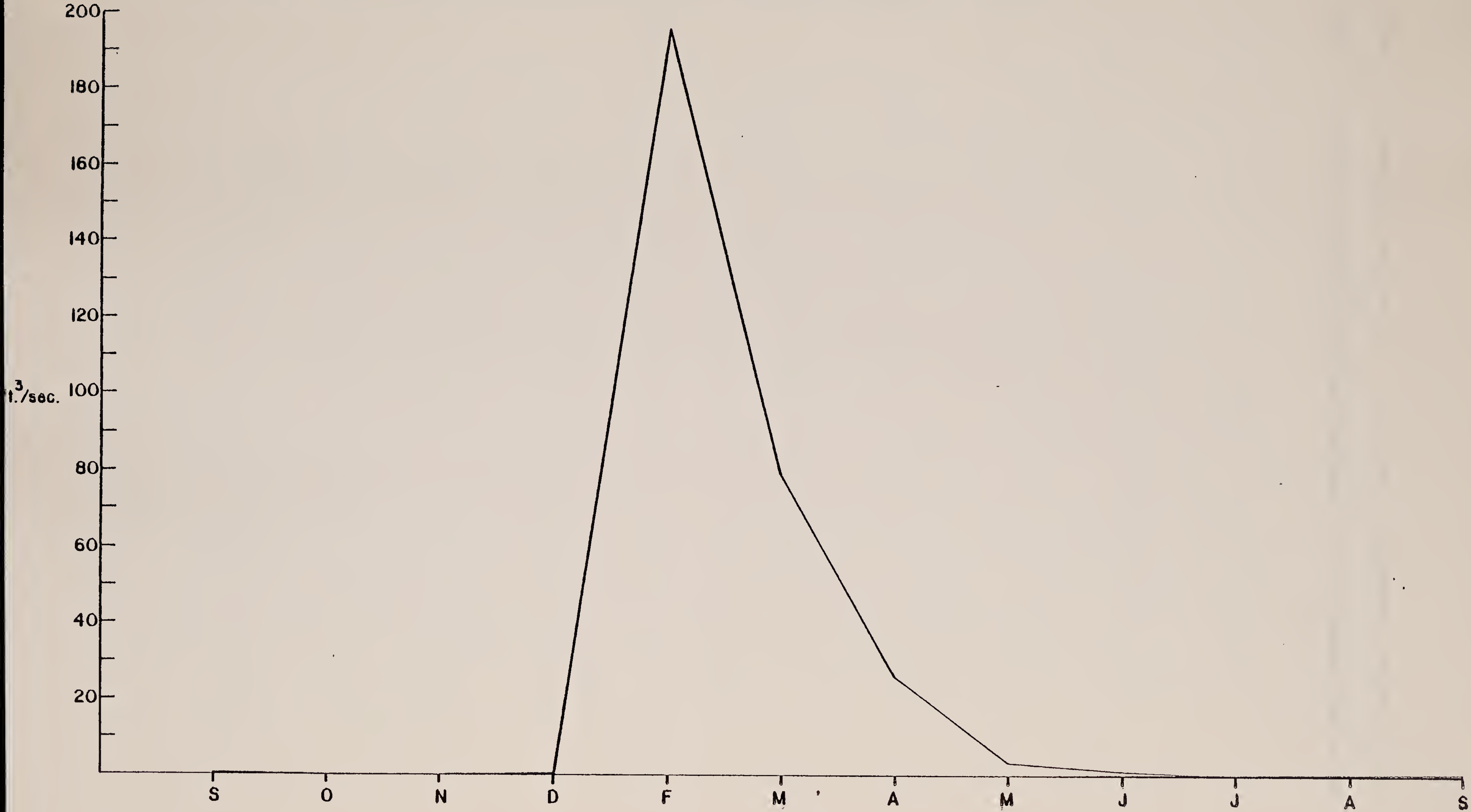
begun to invade Burro Creek along its lower reaches, probably gaining access from the Big Sandy where this exotic is common. Sporadic flash flooding uproots seedlings and helps maintain this introduction at reduced numbers.

Burro Creek is an extremely heterogenous system for aquatics. Riffle, run, and pool habitats are well represented, but during the drier months of summer, much of the stream becomes reduced to intermittent pools. Mean depth over riffle/run habitats was 15.6 in. (range 5 to 35 in.) and many pools were more than 15 to 20 ft. deep. Average width of Burro Creek was 52.2 ft. (range 23.3 to 189 ft.) and mean gradient was equal to 1.27$^{o}$ (range 0.5 to 2.5$^{o}$).

Flow was swift and often turbulent, averaging 1.2 ft./sec. (range 0.33 to 4.69 ft./sec.). Burro Creek is normally not monitored for discharge and lacks a permanent USGS gaging station. Some information is available under contract between the BLM State Office and USGS, where instantaneous discharge, among other parameters, was determined on a monthly basis between September 1977 and September 1978 (Figure 4). Mean discharge was equal to 25.5 ft.$^3$/sec. but varied between little or no flow (0.02 ft.$^3$/sec.), to a maximum of 195 ft.$^3$/sec. Spates are normally associated with the winter precipitation peak, December through February, and elevated flows are again present during spring runoff.

Bottom substrate presented a mix of particle-sizes throughout the drainage. Small basaltic boulders and rubble were prevalent in the headwaters, whereas smaller cobble became the dominant bottom type at the intermediate reaches. In lower reaches where gradient was reduced, cobble was often intermixed with unstabilized sand and gravel. In some areas, Burro Creek had exposed and cut bedrock, scouring the bottom clean of any debris. Banks were often cut, but

Fig. 4 INSTANTANEOUS DISCHARGE DATA FOR BURRO CREEK, PERIOD OF RECORD: SEPT. 1977 – SEPT. 1978.



stabilized by rooted, overhanging vegetation. In other instances, banks either consisted of a jumble of cobble and boulder over bedrock, or the sheer faces of canyon walls.

Water Quality.

Water quality data for Burro Creek was mostly within optimal standards of compliance with the EPA and the AWQCC (Table 3). $NO_3^-$-N declined throughout the system, presumably the result of assimilation by aquatic autotrophs. Total $PO_4^{\equiv}$-P values were elevated above EPA (1977a) standards as a result of extensive orthophosphate stores located within the igneous rocks of the headwaters. Water was alkaline (pH range 8.0 to 9.5) and varied little, mostly diurnally. DO was high and stable. Water temperatures were suitable for aquatic life and annual variations are expected to be minimal, ameliorated by canyon shading and riparian vegetation. Burro Creek may, however, receive some thermal loading from natural geothermal sources located within Francis Creek. Hot springs and seeps are common in that drainage and contribute significant amounts of water to the watershed. Water temperature measured at one springhead on January 4th was constant at 85°F; temperature of the creek below was 53°F.

Our water quality data, in addition to information obtained under Contract No. YA-515-IA7-41 with USGS, identified the Cyprus-Bagdad open-pit copper mine as a point-source of toxic effluents and inorganic sediment loads for Burro Creek. Mine wastes reach Burro Creek _via_ Boulder Creek, a perennial 90-square-mile watershed confluent with Burro Creek 5.25 miles below the mine. Contaminants enter Boulder Creek through leaching of ore tailings, runoff from exposed overburden, and direct discharge from the tailings pond located in Copper Creek. Toxicity of copper mine effluents, especially heavy metals such as copper and zinc, has been well documented in the literature (Pentelow and Butcher, 1938; Hynes, 1960; Follett and Wilson, 1969; Warnick and Bell, 1969; Gammon, 1970; Whitton, 1970; Rehwoldt, _et al_. 1973; Rathbun, 1973-75; Sylva, 1976; Lewis, 1977a, 1977b, and 1978; Lewis and Burraychak, 1979).

Table 3. CHEMICAL/PHYSICAL DATA FOR BURRO CREEK, ARIZONA; MEANS FOLLOWED BY RANGES (IN PARENTHESES). *

| | | |
|---|---|---|
| Drainage area (mi.$^2$) | 687.0 | |
| Mean width (ft.) | 52.2 | (23.3 - 189) |
| Mean depth (in.) | 15.6 | (5 - 35) |
| Mean stream gradient | 1.27° | (0.5 - 2.5°) |
| Mean stream velocity (ft./sec.) | 1.2 | (0.33 - 4.69) |
| Mean discharge (ft.$^3$/sec.) ** | 25.5 | (0.02 - 195) |
| Turbidity (JTU) | 82 | (62 - 100) |
| Total Dissolved Solids (TDS), mg/l | 88 | (60 - 130) |
| Total Hardness, mg/l as $CaCO_3$ | 516 | (200 - 920) |
| Water Temperature, °F | 44 | (38 - 51.5) |
| pH | 8.6 | (8.0 - 9.5) |
| Dissolved Oxygen (DO), mg/l | 13 | (10 - 18) |
| Carbon Dioxide ($CO_2$), mg/l | 12 | (5 - 17.5) |
| Ammonia ($NH_4^+$), mg/l | 0.42 | (0 - .73) |
| Nitrate-nitrogen ($NO_3^-$-N), mg/l | 2.0 | (0 - 4.0) |
| Total Phosphate ($PO_4^{\equiv}$-P), mg/l | 0.66 | (0.24 - 2.8) |
| Sulfate ($SO_4^{=}$), mg/l | 82.5 | (17 - 195) |
| Chloride ($Cl^-$), mg/l | 17.1 | (3.55 - 35.5) |

* Diurnal samples at 26 stations, 1 December 1978 to 16 February 1979 (includes samples from below the confluence of Boulder Creek).

** USGS water resources data under Contract No. YA-515-IA7-41 for record period, September 1977 to September 1978.

Marked disparities exist among physical/chemical parameters examined for Burro and Boulder creeks in the vicinity of the mine (Table 4). Most obvious are increases in $SO_4^=$, $Cl^-$, and total hardness downstream from the mine. $SO_4^=$ averaged 20.1 mg/l in Burro Creek above the confluence with Boulder Creek, and 113.8 mg/l below. Effluent from the mine draining into Boulder Creek was at 640 mg/l $SO_4^=$, far exceeding Arizona's drinking water and aquatic life standards (250 mg/l) and considerably higher than the 90 mg/l limit considered optimal for fish and other aquatic life by McKirdy (1968). Mean $Cl^-$ levels were 4.1 mg/l above the Boulder Creek confluence and 23.6 mg/l below, with 49.7 mg/l recorded from the mine effluents. Mean total hardness values increased 43% below the confluence of Boulder Creek, 343 mg/l above and 602 mg/l below. Total hardness in water entering Boulder Creek from the mine was 1,200 mg/l.

The EPA (1977b) has established point-source discharge guidelines for copper mines which limit total suspended solids, copper, zinc, lead, mercury, and pH levels in discharge waters. In addition, the state of Arizona has applicable specific standards for protected uses such as aquatics and wildlife (AWQCC, 1979). Under both state and federal laws, copper mines and mills which utilize various leaching processes in their operation are prohibited from discharging pollutants. In addition to our own observations, copper levels up to 8.0 mg/l were recorded by the Arizona State Department of Health Services in the spring of 1977 which clearly indicated violation of the state and federal water quality standards. The cummulative effects of toxic effluents and increased sedimentation are the responsible agents for the poor quality and instability of the aquatic ecosystem below the mine. The unsuitability of habitat results in reduced biomass and diversity of the aquatic community.

Table 4. SELECTED CHEMICAL PARAMETERS OF THE BURRO CREEK AND BOULDER CREEK CONFLUENCE.

| | Burro Creek stations above the Boulder Creek confluence N = 6 | Burro Creek stations below the Boulder Creek confluence N = 12 | Cyprus-Bagdad effluent N = 1 |
|---|---|---|---|
| Sulfate ($SO_4^{=}$) | mean 20.1 mg/l<br>range 17 - 22 mg/l | mean 113.8 mg/l<br>range 91 - 195 mg/l | 640 mg/l |
| Chloride ($Cl^-$) | mean 4.1 mg/l<br>range 3.6 - 5.3 mg/l | mean 23.6 mg/l<br>range 17.8 - 31.9 mg/l | 49.7 mg/l |
| Total Hardness mg/l as $CaCO^3$ | mean 343 mg/l<br>range 200 - 500 mg/l | mean 602 mg/l<br>range 400 - 920 mg/l | 1200 mg/l |
| Phosphate-phosphorus ($PO_4^{\equiv}$-P) | mean 0.30 mg/l<br>range 0.24 - 0.34 mg/l | mean 0.84 mg/l<br>range 0.25 - 2.8 mg/l | 0.98 mg/l |

One of the more interesting hydrologic phenomena of desert basins is flash flooding. Several opportunities to observe such catastrophic events presented themselves during the course of this study. In most cases, rain for several days previous to the flood saturated shallow soils of the watershed to a point allowing sheet runoff. In one instance, warm rains melted the snowpack at the upper elevations and resulted in a flooding event.

Selected chemical/physical parameters for a flood event on Burro Creek are compared in Table 5 to values recorded a month before during normal flow. During flooding, flow was extremely turbulent and water was highly turbid with fine suspended sediment. Large particles such as rubble and small boulders could be heard colliding as they were transported along the bottom. Flood debris included organic materials as large as tree limbs and trunks. TDS and specific conductance declined by dilution in the flood waters, whereas total hardness, $NO_3^-$-N, and $PO_4^{\equiv}$-P increased, presumably as a result of the influx of particulate materials. Fisher and Minckley (1978) similarly reported peak concentrations of suspended solids, $NO_3^-$-N, and $PO_4^{\equiv}$-P at the leading edge of a flood wave. They also found a general decline in suspended solids and conductivity during a flood in Sycamore Creek, Arizona.

Water levels in Burro Creek were observed to rise 17 to 20 ft. on canyon walls near the headwaters and even higher further downstream after input from additional tributaries. High discharge receded gradually over time and resumed near-normal flow levels within a few hours.

Table 5. COMPARISON OF SELECTED CHEMICAL/PHYSICAL PARAMETERS FOR BURRO CREEK BELOW U.S. HIGHWAY 93 (T14N R11W NW 1/4 Sec. 30, elevation 1,880 ft.).

| | Normal Flow 12 December 1978 1220 hr | Flood Event 18 January 1979 0940 hr |
|---|---|---|
| Discharge (ft.$^3$/sec.) | 38[a] | 14,400[b] |
| Temperature, $^{o}$F | 46 | 44 |
| pH | 9.0 | 7.8 |
| Turbidity, JTU | 82[c] | 300 |
| Total Dissolved Solids, mg/l | 88[c] | 60 |
| Conductivity, mmho/cm | 337[c] | 115 |
| Total Hardness, mg/l as $CaCO_3$ | 920 | 1,160 |
| Dissolved Oxygen, mg/l | 16 | 19 |
| Carbon Dioxide, mg/l | 17.5 | 7.5 |
| Total Phosphates, mg/l | 0.41 | 2.2 |
| Nitrate-nitrogen, mg/l | 2.0 | 2.5 |
| Ammonia, mg/l | 0.5 | 1.66 |
| Sulfate, mg/l | 110 | 96 |
| Chloride, mg/l | 21.3 | 3.55 |

a 6 December 1978 (USGS Contract No. YA-515-IA7-41).
b 17 January 1979 (USGS Contract No. YA-515-IA7-41).
c Mean value for Burro Creek stations above U.S. Highway 93.

Macroinvertebrates.

The Burro Creek watershed supported the largest variety and highest density of aquatic invertebrates sampled in the upper Bill Williams drainage, accounting for 41 of 62 total taxa identified during the study, and including members of 9 of the 10 aquatic orders (Appendix 3).

The macroinvertebrate fauna in Burro Creek was clearly dominated by two members of the Plecoptera order, *Mesocapnia frisoni* and *Mesocapnia arizonensis*, one tricopteran, *Hydropsyche* sp., one odonate, *Progomphus borealis*, and one coleopteran, *Tropisternus ellipticus*. All five species occur throughout the drainage in great numbers and are highly tolerant of the widely varying physical and chemical conditions that exist there.

*Progomphus borealis* is a member of the dragonfly family Gomphidae and is distributed throughout western United States and Mexico. *Progomphus* was collected throughout Burro Creek from sandy shallows associated with cut runs. Adult dytiscid beetles, *Tropisternus ellipticus*, were also abundant in shallow, sandy runs near cut banks, and in side pools among aquatic macrophytes.

*Hydropsyche* sp. was the dominant caddisfly in Burro Creek, and was confined to riffle areas where stable substrate provided points of attachment for silken nets. Nets are used by the larvae as a food capturing device in which detritus and other drift items are trapped. The hydropsychid diet is highly faculative and depends on the particular species and habitat. In general, early instars are primarily herbivore-detritivores, while older instars are more carnivorous (Wiggins, 1977).

The two capniid stoneflies, *Mesocapnia frisoni* and *Mesocapnia arizonensis*, were collected from riffles on Burro Creek to its confluence with the Big Sandy River. *Mesocapnia* is essentially a southwestern genus, and both species feed on

leaf-detritus or shred fallen leaves and must rely heavily on autumn leaf-fall from riparian vegetation as their food source. They are indicative of high quality environments and occur in great enough numbers, at least above the inflow of Boulder Creek, to constitute a major dietary item for fishes. Most capniid species emerge in winter or early spring (Baumann, et al. 1977). Adults in Francis and Burro creeks emerged as early as February.

Other significant components of the benthic community included three rheophilic species, Baetis sp., Simulium sp., and Corydalus cognata. All three were confined to shallow, flowing water and were found on or under stones or among vegetation in the riffles. They are easily dislodged during spates and constitute a substantial portion of the catostrophic drift. In normal flow periods, "behavioral drift" is part of the life cycle of many species of Simuliidae, Ephemeroptera, Plecoptera, and Chironomidae, which continually distribute themselves downstream. Many active drifters exhibit some type of diel periodicity. Insects that drift at night avoid predation by sight-feeding fish. One other form of drift in the Burro Creek watershed, includes the incidental drift of terrestrial insects. This is a significant component of the drifting invertebrate fauna in areas with dense, overhanging riparian vegetation. Terrestrial drift supplements the aquatic prey-base and helps maximize fish production (see Waters, 1961 and 1973, for a review of the drift of stream insects).

Because of the short period of sampling, field investigations of Burro Creek macroinvertebrates did not account for the seasonality of life histories inherent to benthic communities. Most temperate aquatic insects are characterized by a univoltine life cycle in which a single generation is produced each year. Invertebrates with multivoltine life cycles, more than one generation a year, are relatively scarce in temperate running-water ecosystems

(Hynes, 1970). As a result, single period sampling can only underestimate the actual fauna since many organisms are present only at certain and often limited seasons. Another difficulty encountered results from problems in identification of immature insects. Many taxonomic keys are available only for adult organisms and positive identification of immature stages to the specific level is impossible without rearing them to adulthood. As a result, many species were identified only to the generic level and many additions to the recorded macroinvertebrate fauna may therefore be expected.

Presently, samples from much of Burro Creek and its tributaries indicate a high quality, diverse macroinvertebrate community capable of adequately sustaining the fishery. Many species were uniformly and abundantly distributed throughout the drainage and others exhibited more limited distributions. Almost all species have some kind of habitat preference and whole families were confined to riffles, e.g. Simuliidae, Corydalidae, Hydropsychidae, Helicopsychidae, Psephenidae and Elmidae, while others were in slower-moving pools and runs, e.g. Belostomatidae, Naucoridae, Gyrinidae, Dytiscidae, Hydrophilidae, Gerridae, Microveliidae, and Gomphidae. Only downstream from the inflow of Boulder Creek were invertebrates rare, and in Boulder Creek itself.

Ore tailings were contiguous with Boulder Creek and water was visibly turbid. Reaches below the effluent outfall on Boulder Creek were essentially abiotic and devoid of any kind of invertebrates, algae, or fishes. Only the most tolerant macroinvertebrates such as belostomatids and dytiscids were present in the zone of recovery in Boulder Creek below the Cyprus-Bagdad mine. Aquatic insects have the capability of recolonizing rapidly because of their mobility (Warnick and Bell, 1969; Rhewoldt, et al. 1973), yet those in Boulder Creek were in an early stage of recovery and avoided the main channel, with most located in protected side-pools.

The toxicity of effluents is typically reduced either by dilution or precipitation of metallic salts, with the aquatic biota increasing in diversity and biomass as distance from the mine increases.

Mortality in aquatic communities has been reported from other Arizona watersheds, i.e. Mineral Creek (Rathbun, 1974 and 1975) and Lynx Creek (Follett and Wilson, 1969) and Lewis and Burraychak (1979) reported on destruction and recovery of aquatic life in the lower reaches of Pinto Creek following contamination by mine effluents. Clearly, heavy metals and other chemical effluents alter water quality and reduce biotic diversity and density, but metals are precipitated in hard waters and may not be as detrimental to the aquatic biota as is the actual physical effects of total suspended solids and stream sedimentation. Indeed, the major water quality problem associated with most surface mines is with sedimentation resulting in increased turbidity and reduced primary productivity, scouring and abrasion of benthic organisms, and altered or buried natural substrates. Productivity of aquatic communities may be reduced in ways other than direct mortality. Loss of a heterogeneous substrate of cobble or rubble may result in loss of habitat for invertebrates and a net reduction in diversity and biomass of the benthic fauna (Hynes, 1970).

Ichthyofauna.

Nine species of fish representing four families were collected from Burro Creek and its tributaries (Tables 6 and 7). All had been previously recorded from the drainage and none was either state or federally listed. In addition, personnel from Prescott Center College collected 2, 5-cm. specimens of smallmouth bass (Micropterus dolomieui) from the upper reaches, near the confluence of Hellzapoppin' Creek, in April 1977. It is common practice for ranchers to stock ponds and cattle tanks in the area, and the fish probably represented escapees resulting from flooding. Absence of the species in our collection indicates that smallmouth bass have not reproduced or become established. Diversity of the fish fauna tended to increase in the lower reaches of Burro Creek with the marked increase in percentage of introduced species. The headwaters, including Francis and Conger creeks, were almost exclusively occupied by native fishes (Table 7).

The speckled dace (Rhinichthys osculus) was the most prevalent species in upper reaches of the Burro Creek system (Figure 5). It exhibited a proclivity for swift riffles, and was rarely collected from shallow pools or runs near cut banks. Schreiber (1978) reported speckled dace in Aravaipa Creek, Arizona, feeding exclusively on rheophilic insects. Major food items included ephemeropteran nymphs (>70% by volume) and simuliid dipteran larvae. Speckled dace rarely feeds at the surface, but actively forages over the bottom.

At downstream stations, speckled dace declined in numbers and longfin dace became dominant. Longfin dace were collected near cut banks adjacent to riffles in reduced currents. Numbers per collection steadily increased, peaking just upstream from the confluence of Burro and Boulder creeks, where introduced

Table 6. BURRO CREEK FISH COLLECTIONS.

| | Total Length (range in mm) | Percentage of Occurrence | Total N |
|---|---|---|---|
| Family Cyprinidae | | | |
| *Agosia chrysogaster* - longfin dace * | 28 - 81 | 10.6 | 380 |
| *Gila robusta robusta* - roundtail chub * | 21 - 119 | 15.0 | 540 |
| *Rhinichthys osculus* - speckled dace * | 35 - 82 | 5.7 | 106 |
| *Notropis lutrensis* - red shiner | 21 - 74 | 43.7 | 1,570 |
| *Cyprinus carpio* - carp | 63 - 358 | 5.8 | 209 |
| Family Catostomidae | | | |
| *Catostomus insignis* - Gila sucker * | 55 - 285 | 5.0 | 180 |
| *Pantosteus clarki* - Gila mountain-sucker * | 47 - 173 | 5.3 | 191 |
| *Catostomus insignis* x *Pantosteus clarki* - hybrid * | 128 | 0.03 | 1 |
| Family Centrarchidae | | | |
| *Chaenobryttus cyanellus* - green sunfish | 29 - 168 | 4.8 | 171 |
| *Micropterus dolomieui* - smallmouth bass ** | 50 | | 2 |
| Family Ictaluridae | | | |
| *Ictalurus natalis* - yellow bullhead | 46 - 274 | 4.1 | 146 |
| | | | 3,594 |

* Native fishes

** Two 5-cm. specimens collected by personnel of Prescott Center College at the confluence of Hellzapoppin' Creek and Burro Creek in April 1977.

Table 7. BOULDER CREEK, FRANCIS CREEK, AND CONGER CREEK FISH COLLECTIONS.

| | Total Length (range in mm) | Percentage of Occurrence | Total N |
|---|---|---|---|
| BOULDER CREEK | | | |
| Family Cyprinidae | | | |
| Agosia chrysogaster - longfin dace * | 56 - 93 | 30.3 | 69 |
| Gila robusta robusta - roundtail chub * | 41 - 164 | 25.9 | 59 |
| Notropis lutrensis - red shiner | 85 | 0.4 | 1 |
| Family Catostomidae | | | |
| Catostomus insignis - Gila sucker * | 67 - 172 | 28.5 | 65 |
| Pantosteus clarki - Gila mountain-sucker * | 78 - 138 | 5.3 | 12 |
| Family Centrarchidae | | | |
| Chaenobryttus cyanellus - green sunfish | 40 - 189 | 9.6 | 22 |
| | | | 228 |
| FRANCIS CREEK | | | |
| Family Cyprinidae | | | |
| Gila robusta robusta - roundtail chub * | 50 - 80 | 24.8 | 34 |
| Rhinichthys osculus - speckled dace * | 38 - 90 | 20.4 | 28 |
| Family Catostomidae | | | |
| Catostomus insignis - Gila sucker * | 79 - 112 | 4.4 | 6 |
| Pantosteus clarki - Gila mountain-sucker * | 50 - 170 | 50.4 | 69 |
| | | | 137 |
| CONGER CREEK | | | |
| Family Cyprinidae | | | |
| Agosia chrysogaster - longfin dace * | 54 - 63 | 50.0 | 4 |
| Gila robusta robusta - roundtail chub * | 55 - 89 | 37.5 | 3 |
| Rhinichthys osculus - speckled dace * | ASU 2354 ** | | |
| Family Catostomidae | | | |
| Catostomus insignis - Gila sucker * | 90 | 12.5 | 1 |
| Pantosteus clarki - Gila mountain-sucker * | ASU 2352 ** | | |
| | | | 8 |

* Native fishes

** Collections by personnel of Arizona State University 3 miles above the confluence of Burro Creek (24 May 1966).

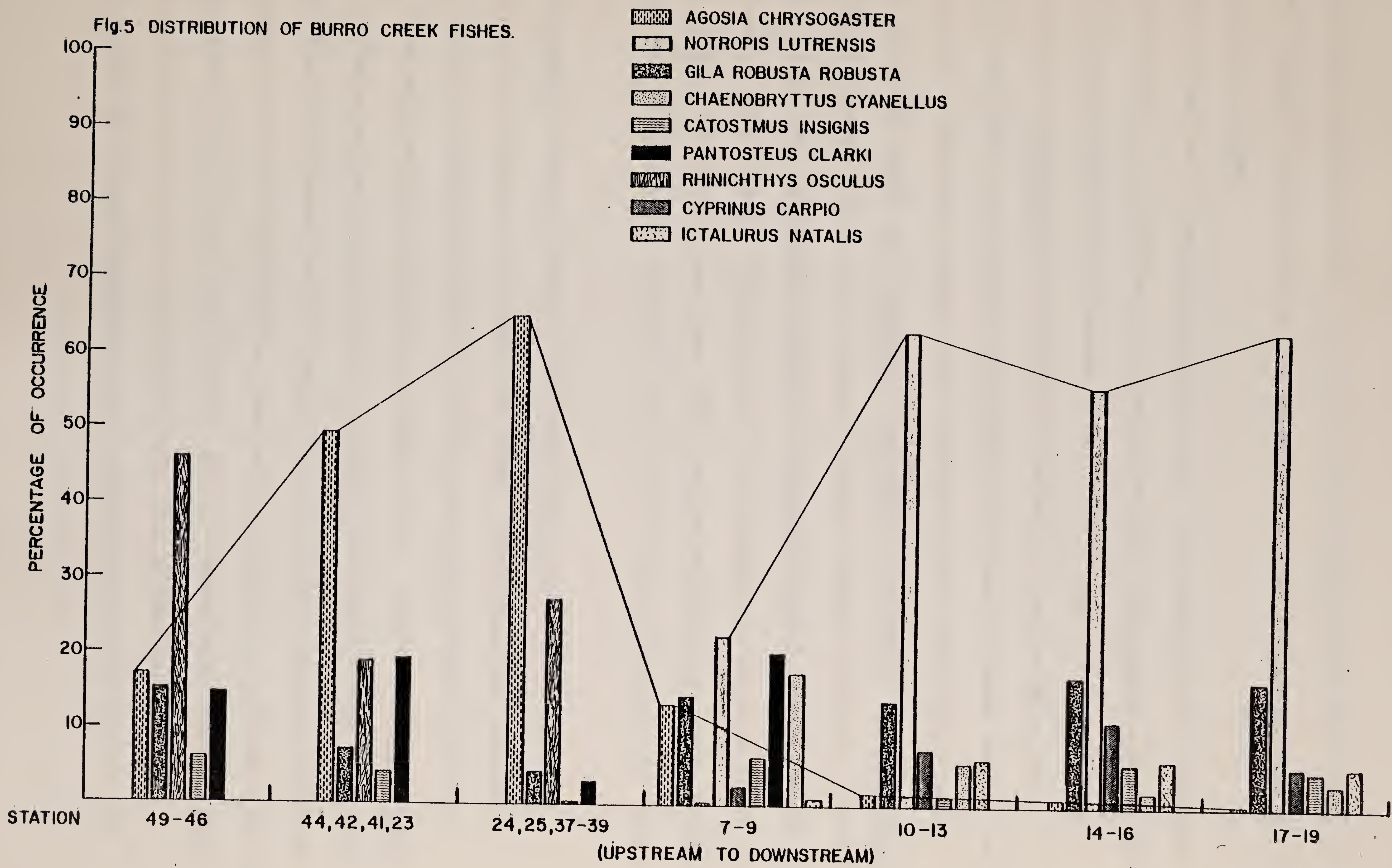


Fig.5 DISTRIBUTION OF BURRO CREEK FISHES.
AGOSIA CHRYSOGASTER
NOTROPIS LUTRENSIS
GILA ROBUSTA ROBUSTA
CHAENOBRYTTUS CYANELLUS
CATOSTMUS INSIGNIS
PANTOSTEUS CLARKI
RHINICHTHYS OSCULUS
CYPRINUS CARPIO
ICTALURUS NATALIS
PERCENTAGE OF OCCURRENCE
100
90
80
70
60
50
40
30
20
10
STATION
49-46
44,42,41,23
24,25,37-39
7-9
10-13
14-16
17-19
(UPSTREAM TO DOWNSTREAM)

species first became apparent. Below that point, _Agosia_ declined rapidly in abundance suggesting that they do not compete well with introduced species that occupy similar niches.

Gila sucker was collected throughout Burro Creek owing to the continued presence of pools. In contrast, Gila mountain-sucker (_Pantosteus clarki_) was rarely collected below the confluence of Burro and Boulder creeks. It is unclear whether _Pantosteus_ is intolerant of effuents from the mine, the non-native species, or was simply exhibiting preference for upper reaches where shallow riffles were more common. Gila mountain-suckers feed primarily on filamentous green algae, _e.g._ _Mougeotia_, _Spirogyra_, _Cladaphora_, and _Oedogonium_ and attached diatoms, which they scrape off cobble riffles (Schreiber, 1978). One hybrid specimen, _Catostomus insignis_ x _Pantosteus clarki_, was collected from Burro Creek. These species hybridize at a low frequency in the Gila River basin (Hubbs, _et al_. 1943; Miller and Lowe, 1964; Barber and Minckley, 1966; Smith, 1966) and the frequency was similarly low (0.19%) in the upper Bill Williams drainage.

_Pantosteus_ in Burro, Francis, and Trout creeks, is morphologically variable, and may consist of at least two forms. Discriminating characters in identification of mountain-suckers of the Bill Williams drainage have been lateral-line and predorsal scale counts (Smith, 1966). Typically, _Pantosteus clarki_ is characterized by fewer than 75 lateral-line scales (range 61 to 84) and fewer than 25 predorsal scales (range 13 to 33). Specimens from the upper Bill Williams basin have finer scales, lateral line range 72 to 104 (N = 86) and predorsal scales 23 to 36 (N = 127) (Smith, 1966). These characters obviously overlap with the typical Gila River basin form, but extreme variation may indicate mixing of a local population of _P. clarki_ with an unrecognized form

with which it is sympatric. Smith (1966) chose not to recognize any such form from the Bill Williams system, and they (plus populations from the Virgin River and elsewhere) were collectively grouped into a single species. It is our field impression that two forms of Pantosteus exist in the Burro Creek drainage, but their identification is well beyond the scope of this study. Investigations into the variance among discriminating characters should be pursued making use of all available taxonomic tools, e.g. electrophoretic analyses of hemoglobins, serum esterases and transferrins, karyotyping, and examination of the osteological, morphometric, and meristic characters (see Smith and Koehn, 1971, for further discussion).

In general, the lower reaches of Burro Creek were characterized by wide, gravelly runs with cut banks separated by large and often deep pools. Riffles were less common than upstream and introduced fishes responded favorably to the pool/run habitats. Red shiner clearly dominated all lower Burro Creek stations representing 43.7% of the total fishes collected. It was present in largest numbers in runs and backwater areas.

Green sunfish and yellow bullhead (Ictalurus natalis) were common near cut banks with overhanging vegetation and in protected areas under submerged boulders. These two species attain lengths and weights in larger pools that provide limited angling opportunities for the fishing public.

Carp (Cyprinus carpio) were common in the lower portions of Burro Creek and were observed as far upstream as the confluence of Burro and Francis creeks. Large adults (>2.0 ft. total length) were in the deepest pools and smaller adults and juveniles were more frequently collected from beneath undercut banks. According to Minckley (1973), carp are extremely fecund (100,000 to 2,000,000 ova per female) and spawn in Arizona from late February through June or July. Carp are enjoyed by fishing enthusiasts and are popular prey to bow fishing.

Only one native species, the roundtail chub, was common in the lower Burro Creek reaches. This may have been in response to a preponderance of deep pools where large adults tended to congregate. Roundtail chubs are opportunistic omnivores and feed on terrestrial and aquatic invertebrates, algae, and on occasion, other fishes (Vanicek and Kramer, 1969; Neve, 1976; Schreiber, 1978).

One of the more interesting characteristics of roundtail chubs in the Burro Creek system is a high incidence of lateral blotching. Rinne (1976) postulated that color polymorphism in this population may reflect the influence of more northern populations of *Gila r. jordani* during Pluvial times.

The only stocking record available for the Burro Creek drainage is for 200 individuals of cichlids (*Tilapia* sp.) at the confluence of Burro and Francis creeks on 28 May 1968 (pers. comm., Tom Liles, Arizona Game and Fish Department, Kingman). The introduction was of 3- to 6-inch fish, probably *Tilapia zillii*, from the Page Springs Hatchery and was conducted by personnel from the Arizona Game and Fish Department. The genus *Tilapia* is native to freshwaters of Africa and includes over 100 species. They have been introduced worldwide for various purposes including attempts to combat food problems in "third world" nations, weed control, vector control, and development of commercial and sport fisheries. They are resistent to disease, tolerant of high temperatures and salinity, grow rapidly and multiply abundantly, and flourish under crowded conditions. Their only major environmental restriction appears to be water temperatures of about 55°F (12.9°C) as a lower lethal limit (Hickling, 1963). For this reason alone, *Tilapia* in Burro Creek probably did not survive the winter of 1968/1969, and no longer persists there.

Incidence of parasitism was extremely high in the upper reaches of Burro Creek. All cases of parasitism occurred on native cyprinid and catostomid

fishes, and in some collections, every fish was infected with the metacercarial cysts of digenetic trematodes. The most frequently encountered metacercaria was a member of the Diplostomidae in the group Strigeoidea. Infection with this metacercaria is commonly called "black spot" or "black grub" due to encapsulation of the metacercarial cysts by melanophores of the host. Black grubs encyst in the dermis, trunk musculature, and fins of centrarchids, catostomids, and particularly cyprinids. Black spot in Burro Creek was identified as Uvulifer amblоplitis, which is reportedly widespread in the United States. There are six species of black grubs belonging to the strigeoid trematodes (Hoffman, 1955), but only the life cycles for Uvulifer amblоplitis and Crassiphiala bulboglossa are known (Hunter and Hunter, 1934; Hoffman, 1956).

All members of this group typically make use of snails, e.g. Helisoma, as the first intermediate host, fish as the second intermediate host, and piscivorous birds as the final host. Most strigeoids are host specific and Uvulifer metacercariae are long-lived, remaining up to four years in fish at 12°C (Hoffman, 1967). Black spot in Burro Creek was only observed in areas where aquatic snails, Physa virgata, were collected and high densities of belted kingfishers (Megaceryle alcyon), the reported definitive host of Uvulifer, were observed. Debilitating effects to infected fishes were not evident. Emaciation, mortality, and impairment or loss of sight have all been reported in the literature (Hugghins, 1972).

One other trematode, Gyrodactylus sp., was observed on the epidermis, gills, and fins of fishes in Burro Creek. This is a common genus of the family Gyrodactylidae that is host specific for teleost fishes. Gyrodactylus is one of

several monogenetic trematodes that have been implicated in hatchery epizootics that have resulted in severe fish kills. It causes epidermal lesions on the fish host, which may result in secondary infection of the wound by fungus. Death has been attributed to the hypersecretion of mucus from gill surfaces (Yin and Sproston, 1948). Fish in Burro Creek were not heavily parasitized by this trematode and appeared healthy with unfrayed fins. The highest incidence occurred on the caudal fin of speckled dace.

Burro Creek and its tributaries, other than Boulder Creek and a reach of the mainstream below from its inflow, support a diversified fish fauna with high standing crop. Other than mine effluents, to be discussed below, water-level fluctuations are the only major factor working against maintenance of their populations. Impacts of drought are ameliorated by deep pools which act as periodic refugia for native and introduced species alike.

Flash flooding, although spectacular, did not decimate adult populations of native fishes, which moved laterally against banks in slower moving currents or into cut, protected areas. Juveniles of native fishes and introduced species were frequently displaced downstream, and some mortality was observed. Pressures from introduced fish species have obviously altered some native populations, but patterns of distribution and abundance seem stabilized with the former group downstream and the latter toward headwater areas (Figure 5).

Fish and algae populations are less tolerant to toxic metals than are aquatic insects. Indeed, heavy metals may be toxic to fish in very low concentrations. Lewis and Burraychak (1979) observed that the lethal copper concentration for 50% mortality (LC 50) of longfin dace in Pinto Creek, Arizona, was as little as 0.86 mg/l. Zinc was most lethal (LC 50 = 0.79 mg/l) and copper-zinc combinations appeared more toxic than any metal ion alone

(LC 50 = 0.21 mg/l copper mixed with 0.28 mg/l zinc). Fish kills at or above these concentrations are not unusual. Lewis and Burraychak reported kills on two separate occasions in Pinto Creek which involved over 300,000 individual fish.

Sedimentation, attendant precipitation of salts of heavy metals or input of turbidities may cover natural substrates and vastly modify aquatic habitats (see Macroinvertebrate section). Perhaps the spectacular decline in abundance of Gila mountain-sucker downstream from Boulder Creek reflects extermination of perilithic algae (its major food source). In addition to loss or reduction of the prey-base for fish, reproduction may be severely affected by the loss of spawning areas or actual siltation of reproductive products, e.g. Agosia chrysogaster nest sites.

Agosia has a history of being the most tolerant species to environmental perturbations in the Southwest. Longfin dace was the only fish species collected at the first station below the mine (1.25 miles). Two miles further downstream, waters were less turbid, but remained discolored, and five species of fish (Agosia chrysogaster, Gila r. robusta, Catostomus insignis, Chaenobryttus cyanellus, and a few Pantosteus clarki) were obtained.

One of the less obvious effects of heavy metal contamination is the phenomenon of bioaccumulation, concentration of a substance, e.g. mercury, in successive trophic levels through the food chain (Krenkel, 1975). Metallic residues in aquatic biota are considered the best indicator of metal pollution, and are directly related to the concentration of any particular metal in solution. Hannerz (1968) found that certain fishes had the ability to concentrate mercury upwards from 3,000 to 10,000 times the level of the surrounding water. This phenomenon may rarely manifest its adverse influence

at the lower trophic levels, but becomes readily apparent when such things as direct mortality, infertility, and egg-shell thinning occur in picivorous raptor populations near point sources of heavy metal pollution (Anonymous, 1970 and 1971; Millsap, 1979).

Multiple-use.

Burro Creek was inhabited by early man, notably the Cerbat Group of the Hualapai Indians, and was first discovered by caucasions in July 1869 when named by an army scouting party from Camp Tollgate (Granger, 1960). In more recent times, the area has been used for livestock grazing and copper mining. These remain the two greatest threats to the aquatic ecology of the watershed.

Small, isolated prospects of the 1800s and early 1900s were consolidated into the present open-pit mining operation in 1955. Current mining activities are adjacent to Boulder Creek and centered around the town of Bagdad. Toxic effluents of the Cyprus-Bagdad operation as a major impact on aquatic ecosystems, has previously been discussed, but withdrawal of water from the system also warrants special attention. Refinement of a ton of copper from ore requires approximately 100,396 gallons of water, more than for any other heavy metal (Lewis and Burraychak, 1979). Arizona's open-pit copper mines produce 63% of the total annual U. S. domestic output of approximately 1.72 million tons (Anonymous, 1977). Cyprus-Bagdad currently pumps more than 1,100 gallons/minute for milling operations and municipal use from a pump located on Francis Creek 2.5 miles above its confluence with Burro Creek (BLM, 1976). Additional water for the mine is pumped and transported via pipeline from 12 wells located on the Big Sandy River north of Wikieup. Cyprus-Bagdad pumps water from the Burro Creek drainage under the Certificate of Water Rights Nos. 3713, 2206, and 1314 issued by the Arizona State Land Department, Phoenix. Application for Permit to Appropriate Water No. A3195 (priority date: September 29, 1975) is currently under review by the State Land Department pending adjudication of the water rights. If approved, this will increase withdrawals from Francis Creek by

131,400 gallons/year and raise total permissable allocations to 490,628,250 gallons/year (pers. comm., Chuck Vergith, Arizona State Land Department, Water Rights Division).

Francis Creek drains the Mohon and Aquarius mountains and is the major tributary to Burro Creek. Special consideration should be addressed to maintaining instream flows for aquatic life, riparian vegetation, and wildlife. Riparian habitat is of particular importance to many larger mammals, e.g. beaver and raccoons, and to the piscivorous birds of prey, e.g. bald eagles, black hawks (Buteogallus anthracinus), and zone-tailed hawks (Buteo albonotatus) which are present in the area.

The incompatibility which exists between livestock grazing and aquatic or riparian habitats is well documented in the literature and has been the focus of recent attention by many land management agencies (Platts, 1975; Armour, 1977; Duff, 1978; Meehan and Platts, 1978). Overgrazing can alter and degrade the quality of a watershed in a variety of ways, which collectively reduce diversity and density of the benthic community in streams (Cordone and Kelley, 1961) and result in the decline of fish productivity (Marcuson, 1977).

Removal of riparian vegetation and prevention of its regeneration by livestock grazing or trampling has been implicated in increased water temperatures, increased runoff and erosion, and reduced cover for fisheries (Alderfer and Robinson, 1947; Packer, 1953; Boussu, 1954; Sharp, et al. 1964; Lusby, 1970; and Smiens, 1975). Elimination of streamside vegetation not only results in loss of protective cover for aquatic life but may adversely affect allochthonous drift from overhanging vegetation and reduce the available prey-base. Trampling may result in bank caving and sloughing, soil compaction, reduced soil infiltration, and accelerated erosion and transfer of sediment.

Heavy sedimentation can bury and scour benthic communities, fill and eliminate pools, and result in mortality of reproductive products (Peters, 1962).

Excessive eutrophication of aquatic ecosystems by livestock defecation results in pollution and bacterial contamination (Robbins, et al. 1972). Reduced oxygen tensions and increased ammonia concentrations are indicative of organic loading by livestock. Such factors were causative agents reported by Scalf, et al. (1970) for mortality of all game fish (largemouth bass, white crappie, and channel catfish) in a 45 acre, flood control reservoir.

A potential conflict area, Burro Creek Allotment, has been identified with the overutilization of riparian vegetation (BLM, 1977). The allotment consists solely of stream bottom acerage, including adjacent canyon walls, along Burro Creek from the inflow of Francis Creek to just upstream from the Boulder Creek confluence (6,026 acres). Vertical relief is more than 1,000 ft. in some areas below Bozarth Mesa, and the slopes are rugged and steep. Cattle are gregarious and tend to congregate along the stream bottom and avoid the rougher terrain of the mesa slopes. The allottee is licensed for only 75 head of cattle, yet damage to the streamside vegetation (BLM, 1977) and fecal coliform counts as high as 200/100 ml (USGS, Contact No. YA-515-IA7-41) have been documented.

Reduction in the number of cattle or building exclosures to keep cattle from riparian vegetation is probably not the answer. Remaining livestock would continue to graze the stream bottom under the first alternative and fences are short-lived, rarely being immune to flash flooding. Grazing should be eliminated from the allotment to avoid further losses of riparian habitat and degradation of the aquatic ecosystem. Much of the allotment is inaccessible and unsuitable for cattle grazing based on slope topography alone. Riparian corridors on western ranges can no longer tolerate the abuse of improper

management of domestic livestock and impaired conditions should be met with alternative management plans. To place the special consideration afforded riparian habitats into proper perspective, consider that riparian areas represent less than 1% of the total Arizona surface area, yet support more than 70% of its wildlife species (USDA Forest Service, 1977).

Burros remain a management problem in the lower reaches of Burro Creek, but are less frequently encountered than in areas adjacent to Alamo Lake and the Santa Maria River. They present similar problems to riparian habitats as created by livestock grazing and should have their numbers "adjusted" to minimize conflicts and provide for the needs of aquatic life, wildlife, and riparian vegetation.

Other current uses of the Burro Creek watershed involve scientific collecting and recreation. Several state colleges and universities (Arizona State University, Tempe; University of Arizona, Tucson; Prescott Center College; Yavapai Community College, Prescott; Glendale Community College, Glendale; University of Michigan, Ann Arbor) have utilized the Burro Creek resources for educational and research purposes. Two localities receive the major recreational use associated with Burro Creek. Both are easily accessible and include "six-mile crossing" on east Signal Road and the BLM campground below the U.S. Highway 93 bridge. Recreational activities at these campgrounds mostly center around picnicking, fishing, wading, and camping. Other activities in more remote areas of the watershed include rockhounding, hunting, hiking, and off-road vehicle use.

Water quality data (USGS, Contract No. YA-515-IA7-41) indicate that the BLM campground may be a point source for bacterial contamination in Burro Creek. Bacteria counts monitored below the campground between September 1977 and

September 1978 averaged 275/100 ml for fecal coliforms and 224/100 ml for fecal streptococci. Water below the campground is in violation of the state water quality standard (200/100 ml) for full body contact to fecal coliforms and therefore may present a health hazard to recreationists.

## Big Sandy River

The Big Sandy River originates at the confluence of Knight and Trout creeks approximately 16.5 miles north of Wikieup, Arizona. It flows 37.8 miles south from an elevation of 2,420 ft. before entering Alamo Lake at 1,170 ft. The Big Sandy drainage is normally perennial below Wikieup and throughout Trout Creek, its major upper tributary. Trout and Knight creeks drain the Aquarius Mountains and the north half of the Mohon Mountains; Burro Creek drains the mesas to the east. The total drainage area, excluding the Burro Creek watershed, is estimated at 2,123 square miles (pers. comm., Paul Rohne, Jr., USGS, Phoenix District Files).

The Big Sandy River is in a broad, alluvial valley between granitic mountain blocks. It is almost totally accessible via U.S. Highway 93 or maintained county roads, except at the lower reaches below the old townsite of Signal. The valley fill consists of deep, loosely consolidated, mixed alluvia that are well sorted and nearly level to gently sloping within the floodplain. Mean annual precipitation is 6 to 10 in. and the mean air temperature varies between 56 and 67°F (Richmond and Richardson, 1974).

Trout Creek is similar to Burro Creek, having incised Precambrian granitic gneiss and recent Tertiary volcanics. Topography is rugged and characterized by moderate to steep slopes, deeply cut narrow canyons, and shallow well-drained soils over granitic hills and mountains. Rock outcroppings are common and access is restricted. Mean annual precipitation is 8 to 12 in. (Richmond and Richardson, 1974), and supports desertscrub vegetation typical of the low desert hillsides, e.g. palo verde and saguaro. Riparian vegetation is mostly grouped stands of either cottonwood or Goodding willow, with a seep willow understory.

Trout Creek is much narrower and deeper than the Big Sandy River and a much more heterogeneous system for aquatic life (Table 8). Riffles, runs, and pools are well represented, providing a diversity of habitats. Banks are often cut, but stable, and stream substrate varies from cobble/gravel bottoms to small boulders. Trout Creek lacks a streamflow gauge and discharge data are largely unavailable, however Davidson (1973) reports average discharge near its confluence with Knight Creek may be as much as 3 ft.$^3$/sec. or approximately 2,000 acre-ft./yr. Stream velocities recorded during the present study averaged 2.5 ft./sec. (range 1.9 to 3.3 ft./sec.).

In contrast, the Big Sandy River is characterized by lower gradient and is essentially a broad, shallow, sandy run with no pools or riffles. Average width was 183.9 ft. (range 98.8 to 347.5 ft.) with mean depth and gradient 4.5 in. (range 1.25 to 10.0 in.) and 0.45$^\circ$ (range 0.2 to 0.6$^\circ$), respectively. Flow was swift and laminar during the study period, averaging 2.2 ft./sec. (range 1.6 to 4.7 ft./sec.). In an 11-year period from 1966 to 1977, average discharge recorded at USGS gaging station No. 4244.5 (located 15 miles upstream from the confluence of the Big Sandy and Santa Maria rivers and 17 miles south of Wikieup) was 45.9 ft.$^3$/sec. or 33,250 acre-ft./yr. The drainage is subject to spates, with the highest measured discharge, 35,000 ft.$^3$/sec., recorded in March 1978.

Substrate in the Big Sandy River was characterized by loosely consolidated sand of uniform particle size. Stream sediments were continually shifting over the bottom and the water remained visibly turbid. Banks usually consisted of mixed particle sizes, but were dominated by sand which was stabilized by rooted trees, shrubs, and grasses. In other areas, the channel has been widened and deeply scoured by floodwaters, and banks have been cut up to 15 ft. in vertical

height (Davidson, 1973). Cut and undercut banks with overhanging vegetation or flood debris were common throughout the drainage and provide cover for aquatic organisms.

Riparian vegetation near Wikieup was typically dominated by dense thickets of mesquite and tamarisk, with a scattering of cottonwood and Goodding willow except where cleared for agriculture. Mesquite and tamarisk stands became thinner downstream where the banks were heavily vegetated by arrow-weed (*Pluchea purpurascens*), seep willow, and burro-brush.

Mature stands of tamarisk have invaded and displaced many native riparian species of the Big Sandy floodplain. Tamarisk was introduced into the United States during the 1820s (Horton, 1964) as an ornamental, but quickly escaped cultivation and has become established around reservoirs and along most streams and rivers in the arid Southwest. It can survive long periods of inundation and is a prolific seed producer (Warren and Turner, 1975). Seeds are produced biseasonally in Arizona (Horton, 1957; Horton and Flood, 1962; Warren and Turner, 1975) and readily germinate within 24 hours after imbibing water (Reynolds and Alexander, 1974). Its current status along the Big Sandy appears orientated towards an advanced successional stage and the trend, historically, has been the establishment of a disclimax community.

Non-riparian vegetation adjacent to the Big Sandy River includes microphyllous trees and shrubs with numerous cacti. Palo verde, saguaro, and creosote bush were the most frequently encountered desertscrub species associated with foothills, but other species, *e.g.* buckhorn cholla and teddy bear cholla, also are common.

Water Quality.

Water quality in Trout Creek and the Big Sandy River was acceptable for good aquatic production (Tables 8 and 9). Water quality parameters met or exceeded state and federal surface water standards of the AWQCC and EPA with few exceptions. Fecal coliform counts from the Big Sandy varied above and below the state standard (200/100 ml) during a 1977 to 1978 sampling by USGS, Phoenix; the mean was 120/100 ml. Total $PO_4^{\equiv}$-P levels in both the Big Sandy and Trout Creek were above the EPA (1977a) standard. The source of elevated $PO_4^{\equiv}$-P is probably particulate materials derived from runoff over Tertiary basalts of the headwaters, plus ionization of bound forms which may enter the system, as occurred elsewhere in the upper Bill Williams basin. The Big Sandy River lacked large standing crops of aquatic macrophytes and algae so that orthophosphates were not taken up and assimilated from the system. DO values in the Big Sandy were high (9 to 11 mg/l) and stable, and waters were hard (mean 880 mg/l as $CaCO_3$) and alkaline (pH = 8.5). $Ca^{++}$, $Mg^{++}$, and $HCO_3^-$ were the dominant dissolved ions, and total dissolved solids (mean 592 mg/l) and fluoride concentrations (mean 1.2 mg/l) were typically high (USGS, Phoenix, Contract No. YA-515-IA7-41, 1977/1978). Water temperatures were suitable for aquatic life but should be expected to increase in summer, with pronounced variation occurring in some areas where riparian vegetation was totally lacking. Trout Creek is subject to canyon shading which may help ameliorate summer water temperatures.

It is not known what affect withdrawal of water from the 12 wells located along the Big Sandy may have on water quality or quantity of that system. The wells are owned and operated by the Cyprus-Bagdad mining company. A series of five pumps move water through a single pipeline to the mine. Each is capable

Table 8. CHEMICAL/PHYSICAL DATA FOR TROUT CREEK, ARIZONA; MEANS FOLLOWED BY RANGES (IN PARENTHESES). *

| | | |
|---|---|---|
| Mean width (ft.) | 51.9 | (33.3 - 84.0) |
| Mean depth (in.) | 18.4 | (11.5 - 29.4) |
| Mean stream gradient | 1.25° | (1.0 - 1.5°) |
| Mean stream velocity (ft./sec.) | 2.5 | (1.9 - 3.3) |
| Mean discharge ($ft.^3$/sec.) ** | 3.0 | |
| Turbidity (JTU) | 40 | (30 - 50) |
| Total Dissolved Solids (TDS), mg/l | 140 | (130 - 150) |
| Total Hardness, mg/l as $CaCO_3$ | 700 | (600 - 800) |
| Water Temperature, °F | 41 | (38 - 44) |
| pH | 8.2 | (8.0 - 8.5) |
| Dissolved Oxygen (DO), mg/l | 11 | (10 - 12) |
| Carbon Dioxide ($CO_2$), mg/l | 13 | (10 - 15) |
| Ammonia ($NH_4^+$), mg/l | 0.22 | (0.11 - 0.33) |
| Nitrate-nitrogen ($NO_3^-$-N), mg/l | 2.5 | (2.0 - 3.0) |
| Total Phosphate ($PO_4^{\equiv}$-P), mg/l | 0.67 | (0.54 - 0.80) |
| Sulfate ($SO_4^{=}$), mg/l | 23 | (18 - 28) |
| Chloride ($Cl^-$), mg/l | 5.32 | (5.32) |

* Diurnal samples at 3 stations, 21 February 1979 to 23 February 1979.

** E. S. Davidson. 1973. Water-Resources Appraisal of the Big Sandy Area, Arizona Water Commission Bulletin 6, USGS, Phoenix. p. 29.

Table 9. CHEMICAL/PHYSICAL DATA FOR THE BIG SANDY RIVER, ARIZONA; MEANS FOLLOWED BY RANGES (IN PARENTHESES). *

| | | |
|---|---|---|
| Drainage area ($mi.^2$) | 2,123.0 | |
| Mean width (ft.) | 183.9 | (98.8 - 347.5) |
| Mean depth (in.) | 4.5 | (1.25 - 10) |
| Mean stream gradient | 0.45° | (0.2 - 0.6°) |
| Mean stream velocity (ft./sec.) | 2.2 | (1.6 - 4.7) |
| Mean discharge ($ft.^3/sec.$) ** | 45.9 | (0 - 35,000) |
| Total Dissolved Solids (TDS), mg/l | 413 | (370 - 500) |
| Total Hardness, mg/l as $CaCO_3$ | 880 | (560 - 1180) |
| Water Temperature, °F | 59 | (44 - 71) |
| pH | 8.5 | (8.5) |
| Dissolved Oxygen (DO), mg/l | 10 | (9 - 11) |
| Carbon Dioxide ($CO_2$), mg/l | 15 | (10 - 15) |
| Ammonia ($NH_4^+$), mg/l | 1.45 | (0.7 - 2.12) |
| Nitrate-nitrogen ($NO_3^-$-N), mg/l | 2.7 | (2.0 - 3.0) |
| Total Phosphate ($PO_4^{\equiv}$-P), mg/l | 2.68 | (1.94 - 3.7) |
| Sulfate ($SO_4^=$), mg/l | 67 | (52 - 80) |
| Chloride ($Cl^-$), mg/l | 47.3 | (35.5 - 71.0) |

* Diurnal samples at 10 stations, 26 February 1979 to 6 March 1979.

** USGS water resources data for record period, March 1966 to 1977.

of pumping 1,400 gallons per minute, but their operation is variable depending upon demand. Substantial withdrawals are capable of reducing instream flows, thus increasing conductivity and total dissolved solids from a lack of dilution by surface waters. Other risks include reduction or elimination of the riparian vegetation in areas where the water table is drawn down.

Macroinvertebrates.

Macroinvertebrates of the Big Sandy River mainstream were similar to those present in the Santa Maria River. There were no riffles, and bottoms were swept clean by shifting sand particles. The invertebrate fauna reflected the instability of the aquatic habitat and the influx of catastrophic drift. Much of the diversity and abundance indicated for the Big Sandy macroinvertebrate community was a result of collections from quiet backwater areas near Wikieup or, primarily, as downstream drift from productive upstream tributaries (Trout and Burro creeks).

Only 18 taxa were collected from Trout Creek but more than 35 taxa were taken from the Big Sandy River where the dominant species included the odonate, Progomphus borealis, the hydrophilid, Tropisternus ellipticus, and the naucorid, Ambrysus cf. puncticollis (Appendix 3). Many species, e.g. Baetis sp., Mesocapnia frisoni, Hydropsyche sp., Corydalus cognata, and Ambrysus spp., were present only as result of catastrophic drift during spates, particularly from Burro Creek, and would not be expected to occur in the Big Sandy River under low flow conditions.

Progomphus borealis was typically collected in sandy runs throughout the watershed. Eleven other odonates including two members of the suborder Zygoptera (damselflies), Enallagma praevarum and Ischnura barberi, were taken from backwaters connected to the mainstream of the Big Sandy. Such lentic areas offer refuge against spates and predation by fishes and supported some of the most productive and diverse invertebrate populations in the basin.

Adult Tropisternus ellipticus were abundant throughout the Big Sandy along the cut banks, and were found in shallow waters among the aquatic macrophytes and flood debris. Their distribution largely reflects their food habits, adults being herbivores and/or detritivores. Tropisternus adults and larvae are

important food sources for certain ducks, which prey upon them heavily, and other aquatic birds. They are also utilized by fish, frogs, and toads as diet items (Usinger, 1956).

The dominant ephemeropteran was _Callibaetis_ sp., a baetid mayfly typical of still or slow-moving waters. They exhibit a wide range of physico-chemical tolerances and were typically found clinging to vegetation in the backwater areas of the Big Sandy. The nymphs are herbivorous, feeding primarily on diatoms and other algae.

_Ambrysus_ is the dominant naucorid hemipteran genus in the western United States. _Ambrysus_ cf. _puncticollis_ is common in the Southwest, and in Arizona is previously known from the Colorado River drainage (LaRivers, 1951). It is relatively large in size and a voracious predator that feeds on aquatic insect larvae. Under normal circumstances, _Ambrysus_ is found in small eddies or areas of broken flow and in well-oxygenated waters with rocky, cobble bottoms. Its dominance in the lower reaches of the Big Sandy River, in habitats not typical for the species, is clearly the result of catastrophic drift from Burro Creek.

Excluding the productive backwaters, macroinvertebrate populations of the Big Sandy were depauperate with little diversity. Terrestrial drift from the dense mesquite/tamarisk stands near Wikieup was, however, relatively high, and contributed significantly to the available prey-base for the fishes, depending on season.

Ichthyofauna.

Seven species of fishes representing four families were collected from Trout Creek (Table 10). This is the first record from that stream for introduced species, green sunfish and black bullhead. Fishes in Trout Creek are distributed similarly as those in Burro Creek, with upper reaches exclusively occupied by native species and introduced forms inhabiting the lower reaches, above the confluence with the Big Sandy. All seven species were collected at the mouth of Trout Creek, but longfin dace was clearly dominant, comprising 65.6% of the total. Roundtail chub was the second-most abundant species in Trout Creek, accounting for 12.9% of the total fishes collected. Roundtail chubs dominated upper reaches of Trout Creek and occupied similar habitats to those in Burro Creek. Although Trout Creek has no salmonid populations, roundtail chubs are frequently called "Verde trout" by local residents and are probably responsible for the name of the stream. The two native suckers, and speckled dace, were present in substantial numbers throughout Trout Creek. Hybrids, *Catostomus insignis* x *Pantosteus clarki*, have previously been taken in the drainage (Arizona State University, Museum of Fishes, Catalogue No. 2357), but were not collected in the current study.

Four families and eight species of fishes were collected from the Big Sandy River (Table 10). This represents seven species more than indicated by previous museum records (Arizona Game and Fish Department, Phoenix). All former collections were made at or near Wikieup, where longfin dace predominate. Additions are probably the result of outflow from perennial tributaries to the Big Sandy during flood stages, especially Burro Creek, and they may well disappear in other than the wettest years.

Only 3 of the 8 species are native to the drainage, *Agosia chrysogaster*, *Catostomus insignis*, and *Gila r. robusta*, with the remaining introduced

Table 10. TROUT CREEK AND BIG SANDY RIVER FISH COLLECTIONS.

| | Total Length (range in mm) | Percentage of Occurrence | Total N |
|---|---|---|---|
| TROUT CREEK | | | |
| Family Cyprinidae | | | |
| *Agosia chrysogaster* - longfin dace * | 27 - 87 | 65.6 | 315 |
| *Gila robusta robusta* - roundtail chub * | 38 - 131 | 12.9 | 62 |
| *Rhinichthys osculus* - speckled dace * | 38 - 62 | 7.7 | 37 |
| Family Catostomidae | | | |
| *Pantosteus clarki* - Gila mountain-sucker * | 53 - 98 | 7.1 | 34 |
| *Catostomus insignis* - Gila sucker * | 69 - 255 | 5.6 | 27 |
| Family Centrarchidae | | | |
| *Chaenobryttus cyanellus* - green sunfish | 48 - 110 | 0.8 | 4 |
| Family Ictaluridae | | | |
| *Ictalurus melas* - black bullhead | 191 | 0.2 | 1 |
| | | | 480 |
| BIG SANDY RIVER | | | |
| Family Cyprinidae | | | |
| *Agosia chrysogaster* - longfin dace * | 26 - 88 | 50.5 | 553 |
| *Gila robusta robusta* - roundtail chub * | 43 - 85 | 2.4 | 26 |
| *Notropis lutrensis* - red shiner | 20 - 59 | 33.0 | 361 |
| *Cyprinus carpio* - carp | 81 - 110 | 0.3 | 3 |
| Family Catostomidae | | | |
| *Catostomus insignis* - Gila sucker * | 71 - 110 | 4.9 | 54 |
| Family Centrarchidae | | | |
| *Chaenobryttus cyanellus* - green sunfish | 33 - 108 | 4.9 | 54 |
| Family Ictaluridae | | | |
| *Ictalurus natalis* - yellow bullhead | 59 - 139 | 3.3 | 36 |
| *Ictalurus melas* - black bullhead | 55 - 148 | 0.6 | 7 |
| | | | 1,094 |

* Native fishes

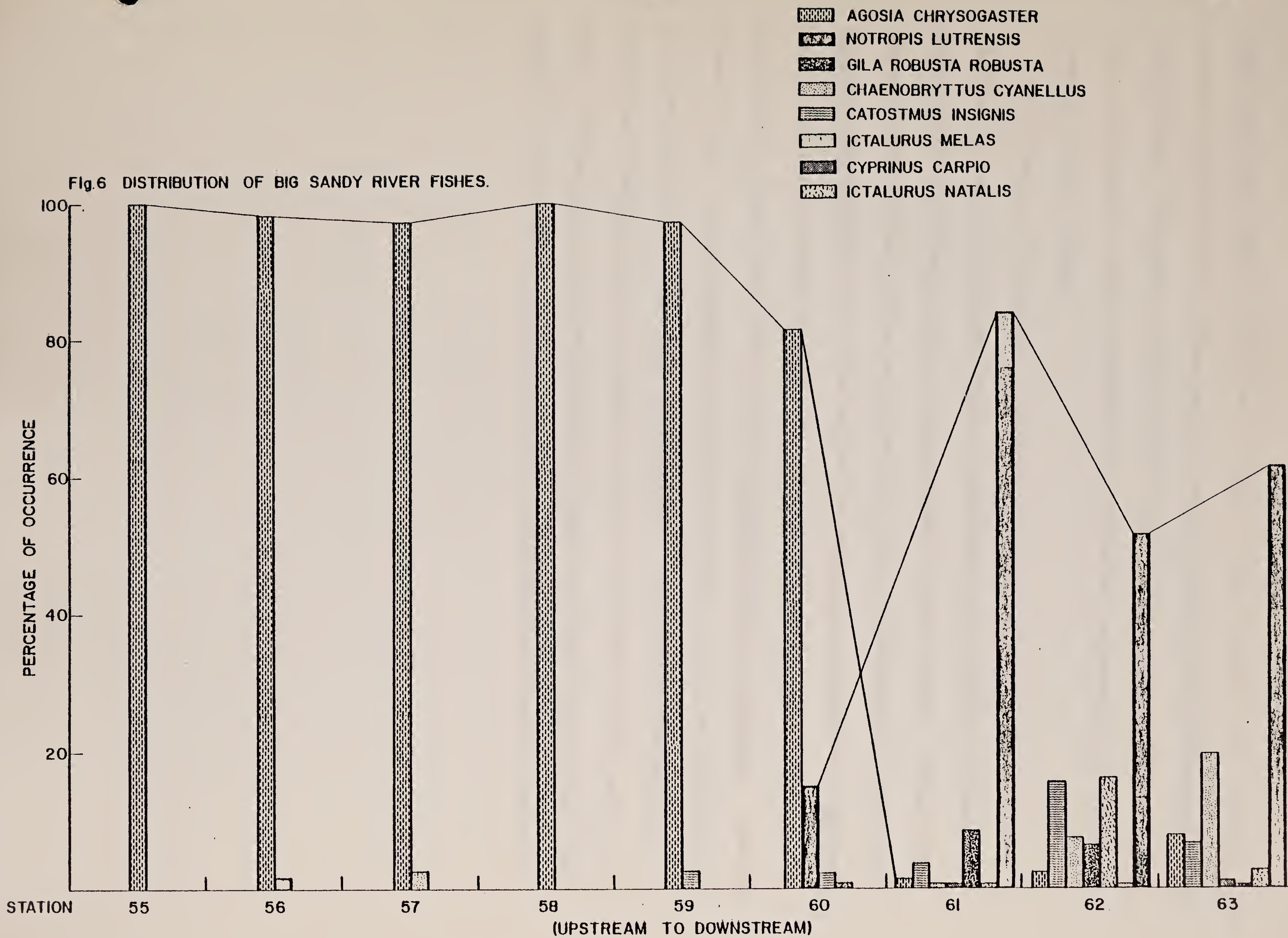
species representing elements of sport fishery or bait bucket transfers. As with Trout Creek, no member of the ichthyofauna is protected under federal or state listings for threatened, endangered, or sensitive species.

Longfin dace were the most abundant species in the Big Sandy River, accounting for 50.5% of the total samples. They occurred at every station and were associated with cut banks where cover was provided by overhanging vegetation, or were in open water, presumably foraging on the invertebrates associated with drift. Total lengths ranged between 26 and 88 mm., indicating the presence of more than one year class. Males were frequently collected in breeding condition, with nuptial tubercles present on the head, operculum, and all fins except the caudal. Females were distended posteriorly, presumably gravid with ova. Longfin dace were dominant at all upper stations above the confluence of Burro Creek and represented more than 89% of all fishes collected there (Figure 6). Its numbers declined precipitously after the confluence with Burro Creek, representing only 4.1% of the total samples from lower stations.

Red shiners exhibited their dominance below Burro Creek and accounted for 64% of all fishes collected from the lower reaches. Overall, red shiners were the second-most abundant species, representing 33% of the total fish caught in the Big Sandy River.

Although yellow bullhead and carp are common in Alamo Lake, diversity of the lower reaches of the Big Sandy River results from the outwash of Burro Creek populations, including native roundtail chub, during spates (Figure 6). A possible exception was Gila sucker, which occurred in the Big Sandy River at sites above the confluence. Gila suckers in the Big Sandy were not as robust or large (total length 71 to 110 mm.) as those which inhabited pools of Burro Creek, but were nevertheless, able to survive along cut banks and scoured areas

Fig.6 DISTRIBUTION OF BIG SANDY RIVER FISHES.



where cover and organic debris were present. They typically feed on aquatic and terrestrial drift along stream margins and pool bottoms, and infrequently visit riffle areas. Schreiber (1978) reported a generalized diet of several food items, principally baetid ephemeropteran nymphs and chironomid dipterans, in Aravaipa Creek, Arizona.

No evidence of black grub, gyrodactyliasis, or ichthyophthiriasis was recorded in any of the fishes from the Big Sandy River, whereas incidence of parasitism was extremely high in native fishes of Trout Creek. Fishes in the upper reaches of the creek were plagued with heavy infestations of black grub, *Uvulifer ambloplitis*, and to some extent the monogenetic trematode, *Gyrodactylus* sp. In addition, longfin dace at the mouth of Trout Creek were heavily parasitized by the holotrichous ciliate, *Ichthyophthirius multifilis*, commonly known as "Ich." All freshwater fishes are vulnerable to this ectoparasitic protozoa and its distribution is cosmopolitan. Ich severely impairs the epithelium forming lesions or pustules, which often result in the death of the host. Although this ciliated protozoa is common on longfin dace in the lower reaches of Trout Creek, mortality due to ichthyophthiriasis was not observed.

Multiple-use.

Water quality in the Big Sandy River and Trout Creek was within levels outlined in the federal and state surface water standards with few exceptions. Most of the water is suitable for aquatic life and irrigation, but may be fair to objectionable for use as public drinking water due to the high concentrations of TDS and fluoride.

Standing crop of the Big Sandy ichthyofauna was reduced as compared to Trout Creek, but nevertheless was significant in areas with stable, cut banks with lush, riparian vegetative cover. The apparent lack of abundance of fishes in the Big Sandy assemblage is attributable to the lack of diversity in aquatic habitat rather than any chemical/physical parameter.

Present water usage in the Big Sandy Valley is mainly for agriculture, with significantly less water use for livestock and domestic purposes. Farming along the Big Sandy River is currently geared to produce crops which can be used by cattle. More than 3,800 acres of alfalfa, grain, and pasture are irrigated regularly from pumped ground-water sources (USGS, 1977). Additional water requirements, due to changes in crop patterns or irrigation demands, are not anticipated in the area and withdrawals will probably remain at the current level. Although most surface flow is not utilized by the Big Sandy community, only 4.6 percent of the precipitation which falls within the basin leaves the area as surface and ground water flow, the remainder being lost to evapo-transpiration (Davidson, 1973).

In addition to water use for domestic, agricultural, and mining purposes, the Big Sandy drainage is used by resident and migratory wildlife and for livestock grazing. Both cattle and burros graze along the drainage and damage to the vegetation from overutilization and trampling is apparent.

Burros are more common near the lower reaches of the Big Sandy, above Alamo Lake, and their numbers remain unregulated.

Water consumption by wildlife may be negligible, but the drainage nevertheless represents significant habitat for herons, egrets, and shorebirds. It is also an important part of the flyway for migratory waterfowl.

The Big Sandy River receives little impact from public recreation. There are no opportunies available for swimming, wading, and fishing and there are no camping or picnicking areas. Hunting is important seasonally, but a sport fishery is nonexistent nor feasible, and is expected to remain so.

## Alamo Lake

A prominent hydrologic feature within the Bill Williams River Basin is the Alamo Dam and Reservoir, constructed by the U.S. Army Corps of Engineers in 1968 for flood control. The earthfill dam is approximately 39 miles upstream from the confluence of the Bill Williams and Colorado rivers and can store a maximum of 1,043,000 acre-feet of water (USGS, 1977). Surface area of the lake varies from 500 acres at minimum pool to 13,300 acres at capacity. Prior to the 1978 and 1979 winter storms, Alamo Lake averaged about 1,800 surface acres. Water levels rose more than 106 vertical feet in the last two winters, and now cover more than 7,000 surface acres. Many camping facilities were flooded and access at Brown's and Alamo crossings was eliminated. Many saguaros, cottonwoods, and Goodding willows which bordered the lake have been completely submerged.

The lake inundates the confluence of the Santa Maria and Big Sandy rivers, and the Bill Williams River now flows through release or overflow from the reservoir. Prior to construction of the dam, average annual discharge in the Bill Williams River at Alamo for the period of record (1939 to 1968) was 66,760 acre-feet with no zero-flow days. Following completion of Alamo Dam, the river averaged 76 zero-flow days a year and the average annual flow was reduced to 30,909 acre-feet (Woodward-Clyde Consultants, 1978).

Initially, Alamo Lake was stocked with largemouth bass (Micropterus salmoides), channel catfish (Ictalurus punctatus), redear sunfish (Lepomis microlophus), and yellow bullhead by the Arizona Game and Fish Department in March of 1968. Stocking of flathead catfish (Pilodictis olivaris), shellcrackers (Lepomis microlophus x Chaenobryttus cyanellus), and bullfrogs

(_Rana catesbeiana_) followed the initial stocking. Other species of fish now are established in Alamo Lake and are usually present in the creel (Table 11). Origin of their introductions is unknown, but probably occurred as the result of bait transfer and release.

In a two-day survey with 1.5-inch mesh monofilament gill nets, it was apparent that carp were abundant in the lake and reach substantial sizes. They accounted for 48.5% of the total catch and ranged in total length from 508 to 711 mm. Bluegill (_Lepomis macrochirus_) have supplanted redear sunfish, and are main forage fish for the productive bass fishery. Numerous largemouth bass juveniles were observed where the Big Sandy enters Alamo Lake, but none was taken upstream. Larger bass were collected at open-water stations throughout the lake. Large channel catfish (total length 470 to 568 mm., N = 6) were collected from the Big Sandy Arm of Alamo Lake and seemed to prefer quiet, shallow backwater areas near submerged vegetation.

Fish were in good condition, with significant fat bodies present and many of the females gravid. All fish were examined for ecto- and endoparasites. "Anchor worm," _Lernaea elegans_ (Hoffman, 1976), was the only parasite observed (N = 4). _Lernaea_ is an ectoparasitic microcrustacean which attacks or anchors, _via_ hornlike processes on the cephalothorax, to the flesh of piscine or amphibian hosts. Only the female is parasitic and like other ectoparasitic copepods, feeds on blood and tissue fluids of the host. Infected foci are commonly hemorrhagic and necrotic and heavy infestations may kill the host (Cheng, 1973). Because _Lernaea_ apparently lacks host specificity they can parasitize all freshwater fish, and frog tadpoles and salamanders. If the parasite reached epizootic levels it could be a serious menance to a freshwater fishery. Frequency of _Lernaea_ in Alamo Lake was low and did not pose such a threat.

Table 11. ALAMO LAKE FISHES.

Order Cypriniformes

Family Cyprinidae

*Carassius auratus* - goldfish

*Cyprinus carpio* - carp

*Notemigonus crysoleucus* - golden shiner

*Notropis lutrensis* - red shiner

Order Cyprinodontiformes

Family Poeciliidae

*Gambusia affinis affinis* - mosquitofish

Order Perciformes

Family Centrarchidae

*Lepomis macrochirus* - bluegill sunfish

*Lepomis microlophus* - redear sunfish *

*Lepomis microlophus* x *Chaenobryttus cyanellus* - shellcracker *

*Micropterus salmoides* - largemouth bass *

Order Siluriformes

Family Ictaluridae

*Ictalurus natalis* - yellow bullhead *

*Ictalurus punctatus* - channel catfish *

*Pilodictis olivaris* - flathead catfish *

* State introduced

Overall, Alamo Lake is an excellent warm-water fishery. The bluegill fishery is probably the best in Arizona and the bass fishery consistent from year to year. Fishermen from as far as Los Angeles, California take advantage of the healthy centrarchid population, but more than 80% of the fishing pressure comes from Maricopa County, primarily Phoenix (written comm. Tom Robinson, Arizona Game and Fish, Yuma).

## Management Alternatives

The native aquatic fauna of the American Southwest has seriously been depleted, and in some cases decimated, following land-use actions where man has either altered and degraded habitat or introduced exotic species (Miller, 1961). Relatively few areas in Arizona have escaped the development of water resources unharmed. The upper Bill Williams drainage is one of the few remaining watersheds in the state which flows relatively undisturbed by human activity. It represents an unique assemblage of desert organisms within an unique aquatic community. Management of aquatic habitat by appropriate state and federal land agencies should insure the environmental quality and stability of the ecosystem where possible. The following is a summary of management suggestions which became evident during the course of the present study:

1. Limit or eliminate grazing by livestock in riparian areas to insure bank stability and stream cover through successful regeneration and growth of streamside vegetation.
2. Reduce or adjust the feral burro population to alleviate impacts on aquatic ecosystems and the riparian vegetation.
3. Maintain instream flows to provide for needs of aquatic life, wildlife, and riparian vegetation. Discourage diversions, impoundments, or further withdrawals of groundwater.
4. Continue surveillance of water and habitat quality through monthly sampling of water chemistry and selected biological parameters. Specifically, the Santa Maria River should be monitored downstream from the Anderson Uranium Mine in regards to potential problems associated with increased sediment loads and the introduction of heavy metals or radionuclides from runoff and leaching of overburden spoils. In

Burro Creek, water chemistry should be closely monitored in the vicinity of the Cyprus-Bagdad open-pit mine, especially for heavy metal contamination. Any violation of state or federal water quality standards should be reported to the mining company and the appropriate government agency. The pattern and role of heavy metals and their accumulation through the successive trophic levels of the food chain in aquatic communities near the mine should be monitored. In particular, fish and nest products from piscivorous raptors should be analyzed for heavy metal concentrations, and relationships to surface water concentrations determined.

5. Construct a permanent streamflow gauge on Burro Creek to collect and record discharge data for the drainage. The most logical location would be at the old U.S. Highway 93 bridge which is both easily accessible and is also below all perennial tributaries which enter Burro Creek.

6. Maintain the watershed as a native non-game fishery and discourage introduction of non-native species for sport fishery purposes. The majority of the upper Bill Williams drainage does not satisfy game fish habitat requirements, although native fishes thrive in all areas of the watershed. Burro Creek represents an opportunity for introduction of game fish but is burdened with problems of intermittent flow and limited access and would scarcely capture the attention of the fishing public. Any sport fishery, therefore, is anticipated as marginal at best and to present only limited opportunities to the angler.

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APPENDIX 1. LEGAL DESCRIPTION OF INVENTORY TRANSECT LOCALITIES.

## Big Sandy River

Stat. 55 Ariz., Mohave Co., T16N R13W NW¼ Sec. 26
elev. 1920', at Wikieup

Stat. 56 Ariz., Mohave Co., T16N R13W SE¼ Sec. 35
elev. 1860'

Stat. 57 Ariz., Mohave Co., T15N R13W NE¼ Sec. 11
elev. 1800'

Stat. 58 Ariz., Mohave Co., T15N R13W NE¼ Sec. 13
elev. 1780'

Stat. 59 Ariz., Mohave Co., T15N R13W NE¼ Sec. 25
elev. 1720'

Stat. 60 Ariz., Mohave Co., T14N R13W SW¼ Sec. 12
elev. 1580', at Signal Road

Stat. 61 Ariz., Mohave Co., T14N R13W NW¼ Sec. 26
elev. 1480', below the confl. of Burro Creek

Stat. 62 Ariz., Mohave Co., T13N R13W SE¼ Sec. 16
elev. 1400', at USGS Gaging Station

Stat. 63 Ariz., Mohave Co., T12N R13W NW¼ Sec. 11
elev. 1230'

Stat. 64 Ariz., Mohave Co., T12N R12W NE¼ Sec. 32
elev. 1180'

## Alamo Lake

Stat. 65 Ariz., Mohave Co., T11N R12W NE¼ Sec. 8
elev. 1170'

Boulder Creek

| | | |
|---|---|---|
| Stat. 1 | Ariz., Yavapai Co., T15N R9W NE$\frac{1}{4}$ Sec. 24<br>elev. 3700' |
| Stat. 2 | Ariz., Yavapai Co., T15N R9W NE$\frac{1}{4}$ Sec. 16<br>elev. 3100', above confl. of Wilder Creek |
| Stat. 3 | Ariz., Yavapai Co., T15N R9W SW$\frac{1}{4}$ Sec. 29<br>elev. 2750', above confl. of Copper Creek |
| Stat. 4 | Ariz., Yavapai Co., T15N R10W SE$\frac{1}{4}$ Sec. 25<br>elev. 2640' |
| Stat. 5 | Ariz., Yavapai Co., T15N R10W SW$\frac{1}{4}$ Sec. 26<br>elev. 2550' |
| Stat. 6 | Ariz., Yavapai Co., T15N R10W NW$\frac{1}{4}$ Sec. 27<br>elev. 2460', above confl. of Burro Creek |

Burro Creek

| | |
|---|---|
| Stat. 7 | Ariz., Yavapai Co., T15N R10W SW$\frac{1}{4}$ Sec. 22<br>elev. 2460', above confl. of Boulder Creek |
| Stat. 8 | Ariz., Yavapai Co., T15N R10W SE$\frac{1}{4}$ Sec. 29<br>elev. 2440', below confl. of Boulder Creek |
| Stat. 9 | Ariz., Yavapai Co., T15N R10W SE$\frac{1}{4}$ Sec. 32<br>elev. 2280' |
| Stat. 10 | Ariz., Mohave Co., T14N R10W NE$\frac{1}{4}$ Sec. 7<br>elev. 2220' |
| Stat. 11 | Ariz., Mohave Co., T14N R10W NE$\frac{1}{4}$ Sec. 13<br>elev. 2200', below "6 mile crossing" |
| Stat. 12 | Ariz., Mohave Co., T14N R11W NE$\frac{1}{4}$ Sec. 14<br>elev. 2160' |
| Stat. 13 | Ariz., Mohave Co., T14N R11W NE$\frac{1}{4}$ Sec. 22<br>elev. 2060' |
| Stat. 14 | Ariz., Mohave Co., T14N R11W SW$\frac{1}{4}$ Sec. 17<br>elev. 1980', upstream from Hwy. 93 bridge |
| Stat. 15 | Ariz., Mohave Co., T14N R11W NW$\frac{1}{4}$ Sec. 30<br>elev. 1880', at Shipp's Ranch |
| Stat. 16 | Ariz., Mohave Co., T14N R12W NE$\frac{1}{4}$ Sec. 23<br>elev. 1800' |
| Stat. 17 | Ariz., Mohave Co., T14N R12W NE$\frac{1}{4}$ Sec. 15<br>elev. 1720' |
| Stat. 18 | Ariz., Mohave Co., T14N R12W SE$\frac{1}{4}$ Sec. 17<br>elev. 1600' |
| Stat. 19 | Ariz., Mohave Co., T14N R12W NW$\frac{1}{4}$ Sec. 19<br>elev. 1540', at Leivas Ranch above confl.<br>of the Big Sandy River |
| Stat. 23 | Ariz., Yavapai Co., T16N R9W NE$\frac{1}{4}$ Sec. 7<br>elev. 3100', above confl. of Francis Creek |
| Stat. 24 | Ariz., Yavapai Co., T16N R9W NW$\frac{1}{4}$ Sec. 18<br>elev. 3050', below confl. of Francis Creek |
| Stat. 25 | Ariz., Yavapai Co., T16N R9W NW$\frac{1}{4}$ Sec. 19<br>elev. 2950' |

Burro Creek

Stat. 37 Ariz., Yavapai Co., T15N R10W SW¼ Sec. 14
elev. 2600'

Stat. 38 Ariz., Yavapai Co., T15N R10W SE¼ Sec. 2
elev. 2760'

Stat. 39 Ariz., Yavapai Co., T16N R10W SW¼ Sec. 25
elev. 2880'

Stat. 41 Ariz., Yavapai Co., T16N R9W SW¼ Sec. 5
elev. 3180'

Stat. 42 Ariz., Yavapai Co., T17N R9W SE¼ Sec. 32
elev. 3280', below the confl. of Conger Creek

Stat. 44 Ariz., Yavapai Co., T17N R9W SW¼ Sec. 28
elev. 3320', above confl. of Conger Creek

Stat. 46 Ariz., Yavapai Co., T17N R9W NE¼ Sec. 28
elev. 3440'

Stat. 47 Ariz., Yavapai Co., T18N R9W SE¼ Sec. 35
elev. 3600'

Stat. 48 Ariz., Yavapai Co., T18N R9W NE¼ Sec. 36
elev. 3700'

Stat. 49 Ariz., Yavapai Co., T18N R8W NW¼ Sec. 20
elev. 4020'

## Conger Creek

Stat. 43 Ariz., Yavapai Co., T17N R9W SW$\frac{1}{4}$ Sec. 33
elev. 3280', above confl. of Burro Creek

Stat. 45 Ariz., Yavapai Co., T17N R9W NE$\frac{1}{4}$ Sec. 33
elev. 3440'

# Francis Creek

Stat. 20 Ariz., Yavapai Co., T16N R10W NW$\frac{1}{4}$ Sec. 1
elev. 3280', next to pump house

Stat. 21 Ariz., Yavapai Co., T16N R10W SE$\frac{1}{4}$ Sec. 1
elev. 3200'

Stat. 22 Ariz., Yavapai Co., T16N R10W NE$\frac{1}{4}$ Sec. 12
elev. 3160', above confl. of Burro Creek

Stat. 40 Ariz., Yavapai Co., T17N R10W SW$\frac{1}{4}$ Sec. 33
elev. 3560'

Stat. 53 Ariz., Mohave Co., T17N R10W SW$\frac{1}{4}$ Sec. 33
elev. 3860'

Stat. 54 Ariz., Mohave Co., T17N R11W NE$\frac{1}{4}$ Sec. 29
elev. 4120'

Santa Maria River

| | | |
|---|---|---|
| Stat. 26 | Ariz., Yavapai Co., T12N R9W NW¼ Sec. 28<br>elev. 1720' | |
| Stat. 27 | Ariz., Yavapai Co., T13N R8W SW¼ Sec. 11<br>elev. 2240', below Hwy. 96 bridge | |
| Stat. 28 | Ariz., Yavapai Co., T13N R8W NW¼ Sec. 21<br>elev. 2160' | |
| Stat. 29 | Ariz., Yavapai Co., T13N R8W SW¼ Sec. 30<br>elev. 2120' | |
| Stat. 30 | Ariz., Yavapai Co., T12N R9W SE¼ Sec. 10<br>elev. 1800', above Hwy. 93 bridge | |
| Stat. 31 | Ariz., Mohave Co., T11N R11W NE¼ Sec. 17<br>elev. 1280', above Palmerita Ranch | |
| Stat. 32 | Ariz., Mohave Co., T11N R11W SW¼ Sec. 14<br>elev. 1320' | |
| Stat. 33 | Ariz., Yavapai Co., T13N R9W NE¼ Sec. 35<br>elev. 1960' | |
| Stat. 34 | Ariz., Yavapai Co., T12N R10W NW¼ Sec. 36<br>elev. 1540' | |
| Stat. 35 | Ariz., Yavapai Co., T11N R10W SW¼ Sec. 5<br>elev. 1440' | |
| Stat. 36 | Ariz., Mohave Co., T11N R10W SW¼ Sec. 7<br>elev. 1380' | |

Trout Creek

Stat. 50 Ariz., Mohave Co., T18N R13W SE$\frac{1}{4}$ Sec. 23 elev. 2440', at confl. with Knight Creek

Stat. 51 Ariz., Mohave Co., T18N R13W NW$\frac{1}{4}$ Sec. 13 elev. 2500'

Stat. 52 Ariz., Mohave Co., T19N R12W NW$\frac{1}{4}$ Sec. 35 elev. 3200'

APPENDIX 2. TAXONOMIC LIST OF AQUATIC INSECTS FOUND IN THE UPPER BILL WILLIAMS DRAINAGE, YAVAPAI AND MOHAVE COUNTIES, ARIZONA, FROM DECEMBER 1978 TO MARCH 1979.

Order Ephemeroptera
- Family Tricorythidae
  - Tricorythodes sp. Ulmer
  - Leptohyphes sp. Eaton
- Family Leptophlebiidae
  - Choroterpes kossi Allen
  - Paraleptophlebia sp. Lestage
- Family Baetidae
  - Baetis sp. Leach
  - Callibaetis sp. Eaton
  - Pseudocloeon sp. Klapalek

Order Odonata
- Suborder Anisoptera
  - Family Gomphidae
    - Gomphus confraternus confraternus Selys
    - Progomphus borealis MacLaclin
    - Erpetogomphus compositus Hagen
  - Family Aeschnidae
    - Aeschna (Hesperaeschna) californica Calvert
  - Family Libellulidae
    - Paltothemis cf. lineatipes Karsch
    - Pachydiplax longipennis Burmeister
    - Erythemis simplicicollis Say
    - Sympetrum pallipes Hagen
    - Macrothemis sp. Hagen
    - Libellula cf. comanche Calvert
    - Libellula cf. saturata Uhler
- Suborder Zygoptera
  - Family Coenagrionidae
    - Hyponeura lugens Hagen
    - Hesperagrion sp. Calvert
    - Argia sp. Rambur
    - Enallagma cf. praevarum (Hagen)
    - Ischnura cf. barberi Currie

Order Plecoptera
- Family Capniidae
  - Mesocapnia frisoni Baumann
  - Mesocapnia arizonensis Baumann
  - Mesocapnia sp. Baumann and Gaufin

Order Hemiptera
- Family Gerridae
  - Gerris remigis Say
- Family Microvelidae
  - Microvelia gerhardi Hussey
- Family Notonectidae
  - Notonecta lobata Hungerford
- Family Belostomatidae
  - Abedus herberti Hildalgo
- Family Corixidae
  - Graptocorixa serrulata (Uhler)
- Family Gelastocoridae
  - Gelastocoris oculatus (Fabricius)
- Family Naucoridae
  - Ambrysus puncticollis Stal
  - Ambrysus occidentalis LaRivers
  - Ambrysus arizonus LaRivers

Order Diptera
- Family Tabanidae
  - Tabanus sp. Linneaus
- Family Chironomidae
  - Subfamily Tanypodinae
  - Subfamily Diamesinae
  - Subfamily Tendipedinae
    - Tribe Calopsectrini
    - Tribe Tendipedini
- Family Tipulidae
  - Tipula sp. Linneaus
- Family Simuliidae
  - Simulium sp. Latreille
- Family Culicidae
  - Culex sp. Linneaus

Order Coleoptera
- Family Gyrinidae
  - Gyrinus plicifer LeConte
- Family Hydrophilidae
  - Tropisternus ellipticus (LeConte)
  - Tropisternus lateralis (Fabricius)
  - Berosus cf. punctatissimus LeConte
  - Helochares cf. normatus (LeConte)
  - Hydrochara cf. lineata LeConte
- Family Dytiscidae
  - Hygrotus sp.$_1$ Stephens
  - Hygrotus sp.$_2$ Stephens
  - Eretes sticticus Laporte
  - Thermonectus marmoratus (Hope)
  - Laccophilus maculosus shermani Leech
- Family Haliplidae
  - Peltodytes cf. callosus (LeConte)
- Family Dryopidae
  - Helichus immsi Hinton
- Family Psephenidae
  - Psephenus minckleyi Brown
  - Psephenus murvoshi Brown

Order Megaloptera
- Family Corydalidae
  - Corydalus cognata Hagen

Order Trichoptera
- Family Hydropsychidae
  - Hydropsyche sp. Pictet
- Family Helicopsychidae
  - Helicopsyche sp. von Siebold

Order Lepidoptera
- Family Pyralidae
  - Parargyractis jaliscalis (Schaus)

APPENDIX 3. DISTRIBUTION OF AQUATIC INSECT COLLECTIONS FROM THE UPPER BILL WILLIAMS DRAINAGE, YAVAPAI AND MOHAVE COUNTIES, ARIZONA, DECEMBER 1978 TO MARCH 1979.

| Taxon | Conger Creek | Francis Creek | Boulder Creek | Burro Creek | Big Sandy River | Trout Creek | Santa Maria River |
|---|---|---|---|---|---|---|---|
| Order Ephemeroptera | | | | | | | |
| Family Tricorythidae | | | | | | | |
| *Tricorythodes* sp. | | X | | X | | X | X |
| *Leptohypes* sp. | | X | | X | | | |
| Family Leptophlebiidae | | | | | | | |
| *Choroterpes kossi* | X | | | | | | |
| *Paraleptophlebia* sp. | | X | | X | | | |
| Family Baetidae | | | | | | | |
| *Baetis* sp. | X | X | | X | X | X | |
| *Callibaetis* sp. | | | | | X | | |
| *Pseudocloeon* sp. | | | | X | | | |
| Order Odonata | | | | | | | |
| Suborder Anisoptera | | | | | | | |
| Family Gomphidae | | | | | | | |
| *Gomphus confraternus confraternus* | | X | | | | | |
| *Progomphus borealis* | | | | X | X | | X |
| *Erpetogomphus compositus* | | | | X | X | | |
| Family Aeschnidae | | | | | | | |
| *Aeschna (Hesperaeschna) californica* | | | | | X | | |
| Family Libellulidae | | | | | | | |
| *Paltothemis* cf. *lineatipes* | | | X | X | X | | |
| *Pachydiplax longipennis* | | | | | X | | |
| *Erythemis simplicicollis* | | | | | X | | |
| *Sympetrum pallipes* | | | | | X | | |
| *Macrothemis* sp. | | | | | X | | |
| *Libellula* cf. *comanche* | | | | | X | | |
| *Libellula* cf. *saturata* | | | | | X | | |

| Taxon | Conger Creek | Francis Creek | Boulder Creek | Burro Creek | Big Sandy River | Trout Creek | Santa Maria River |
|---|---|---|---|---|---|---|---|
| Suborder Zygoptera | | | | | | | |
| Family Coenagrionidae | | | | | | | |
| *Hyponeura lugens* | | | | X | | | X |
| *Hesperagrion* sp. | | | | X | | | |
| *Argia* sp. | | | | X | | | |
| *Enallagma* cf. *praevarum* | | | | X | X | | |
| *Ischnura* cf. *barberi* | | | | X | X | | |
| Order Plecoptera | | | | | | | |
| Family Capniidae | | | | | | | |
| *Mesocapnia frisoni* | | X | | X | X | X | X |
| *Mesocapnia arizonensis* | | X | | X | | | X |
| *Mesocapnia* sp. | X | X | | | | | |
| Order Hemiptera | | | | | | | |
| Family Gerridae | | | | | | | |
| *Gerris remigis* | X | | | | | | |
| Family Microvelidae | | | | | | | |
| *Microvelia gerhardi* | | | | | X | X | X |
| Family Notonectidae | | | | | | | |
| *Notonecta lobata* | X | | | | | | |
| Family Belostomatidae | | | | | | | |
| *Abedus herberti* | | X | X | X | X | X | X |
| Family Corixidae | | | | | | | |
| *Graptocorixa serrulata* | | | | X | X | X | X |
| Family Gelastocoridae | | | | | | | |
| *Gelastocoris oculatus* | | | | X | | | X |
| Family Naucoridae | | | | | | | |
| *Ambrysus puncticollis* | | | | X | X | | X |

APPENDIX 3. Continued.

| Taxon | Conger Creek | Francis Creek | Boulder Creek | Burro Creek | Big Sandy River | Trout Creek | Santa Maria River |
|---|---|---|---|---|---|---|---|
| *Ambrysus occidentalis* | | | | X | X | | |
| *Ambrysus arizonus* | | | | | X | | |
| Order Diptera | | | | | | | |
| Family Tabanidae | | | | | | | |
| *Tabanus* sp. | | X | | X | X | X | X |
| Family Chironomidae | | | | | | | |
| Subfamily Tanypodinae | | X | | X | X | X | X |
| Subfamily Diamesinae | | X | | X | X | X | X |
| Subfamily Tendipedinae | | | | | | | |
| Tribe Calopsectrini | | X | | X | X | X | X |
| Tribe Tendipedini | | X | | X | X | X | X |
| Family Tipulidae | | | | | | | |
| *Tipula* sp. | | X | | X | | X | |
| Family Simuliidae | | | | | | | |
| *Simulium* sp. | | X | | X | | X | X |
| Family Culicidae | | | | | | | |
| *Culex* sp. | | X | | X | X | | |
| Order Coleoptera | | | | | | | |
| Family Gyrinidae | | | | | | | |
| *Gyrinus plicifer* | X | | | | | | X |
| Family Hydrophilidae | | | | | | | |
| *Tropisternus ellipticus* | X | X | | X | X | X | X |
| *Tropisternus lateralis* | | | | | X | | |
| *Berosus* cf. *punctatissimus* | X | | | X | | | X |
| *Helochares* cf. *normatus* | | X | | | | | |
| *Hydrochara* cf. *lineata* | | X | | | | | |
| Family Dytiscidae | | | | | | | |
| *Hygrotus* sp.[1] | X | X | | X | X | X | X |

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APPENDIX Continued.

| Taxon | Conger Creek | Francis Creek | Boulder Creek | Burro Creek | Big Sandy River | Trout Creek | Santa Maria River |
|---|---|---|---|---|---|---|---|
| *Hygrotus* sp.[2] | | | | X | | | X |
| *Eretes sticticus* | X | X | | | | | |
| *Thermonectus marmoratus* | | X | | | | | |
| *Laccophilus maculosus shermani* | | | | X | X | | X |
| Family Haliplidae | | | | | | | |
| *Peltodytes* cf. *callosus* | | | | X | X | | X |
| Family Dryopidae | | | | | | | |
| *Helichus immsi* | | X | | X | X | | X |
| Family Psephenidae | | | | | | | |
| *Psephenus minckleyi* | | X | | X | | X | |
| *Psephenus murvoshi* | | X | | X | | X | |
| Order Megaloptera | | | | | | | |
| Family Corydalidae | | | | | | | |
| *Corydalus cognata* | X | X | | X | X | X | X |
| Order Trichoptera | | | | | | | |
| Family Hydropsychidae | | | | | | | |
| *Hydropsyche* sp. | | X | | X | X | | X |
| Family Helicopsychidae | | | | | | | |
| *Helicopsyche* sp. | | X | | X | | | |
| Order Lepidoptera | | | | | | | |
| Family Pyralidae | | | | | | | |
| *Parargyractis jaliscalis* | | | | X | | | |

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