1.0 INTRODUCTION

Effluent-dependent waters, aquatic environments that have been created as a result of the discharge of treated effluent to an otherwise dry or intermittent streambed, represent unique aquatic ecosystems. This report, the Habitat Characterization Study, represents the completion of a two-year effort to characterize the habitats of selected effluent-dependent waters across the arid western United States ("arid West"). Funded by the Arid West Water Quality Research Project (WQRP or "project"), the Habitat Characterization Study was commissioned to identify the physical, chemical, and biological characteristics that collectively structure the habitat of selected effluent-dependent waters. It is believed that this effort represents the first attempt to focus data gathering efforts on this type of aquatic ecosystem.

Ten effluent-dependent waters, representing a broad range of ecoregions, watershed sizes, and degrees of urbanization, were evaluated using historical and site reconnaissance-level data to document ecosystem attributes. These waterbodies serve as case studies of effluent-dependent waters in the arid West. As originally designed, a projected outcome of the Habitat Characterization Study was the establishment of a habitat characterization scheme based on the physical, chemical, and aquatic and terrestrial biological attributes of effluent-dependent waters. It was believed that this outcome could provide the basis for making decisions on how different types of effluent-dependent waters should be protected and regulated. However, as the project progressed, it became apparent that effluent-dependent waters as a whole are a distinct class of waterbody (i.e., as a group, effluent-dependent waters share more in common with each other than with any other types or classes of waterbodies).

The finding that effluent-dependent waters represent a distinct waterbody class has significant implications regarding the implementation of water quality programs in these created ecosystems. These implications range from potential limitations on what is biologically attainable in the aquatic community to the economics of wastewater treatment. Accordingly, as part of this final report, the project team has presented results, not only from a technical perspective, but also from a regulatory and economic perspective. In the chapters that follow, the results of the review of historical and site reconnaissance data are presented to first ground the reader in the physical, chemical, and biological characteristics of effluent-dependent waters. Subsequent to that presentation, the technical results are discussed in an economic and regulatory context that includes a recommendation that a specific designated use be established to recognize the uniqueness of effluent-dependent water ecosystems. Finally, closing this report, recommendations are provided for future research to build upon the findings of this project.

1.1 ARID WEST WATER QUALITY RESEARCH PROJECT

1.1.1 Overview

The WQRP began as an idea in the early 1990s that developed out of concerns regarding the applicability of national water quality criteria to western ephemeral and effluent-dependent waters (Baumgartner et al. 1993). Two key issues were originally identified: (1) national water quality criteria were based on aquatic species not necessarily representative of species typically

resident in ephemeral and effluent-dependent streams; and (2) the methods provided by the U.S. Environmental Protection Agency (EPA) to modify national water quality criteria for use in effluent-dependent and ephemeral streams were not readily applicable primarily because of the lack of basic data on organisms of importance in arid West waters. With these concerns in mind, efforts were initiated to demonstrate the need for the establishment of a program to develop standards and criteria applicable to the arid West, similar to regional programs established for the Great Lakes and coastal marine waters.

These efforts resulted in the establishment of the WQRP in 1995, the result of a $5,000,000 federal appropriation (Public Law 103-327) and the establishment of an Assistance Agreement between EPA and Pima County, Arizona. The establishment of the Agreement provided a significant opportunity for Pima County, EPA Region 9, and others throughout the arid West to work cooperatively to conduct the scientific research necessary to develop appropriate water quality criteria and standards for the region and improve the scientific basis for regulating wastewater and stormwater discharges in the arid and semi-arid West. [Note: Throughout this document references to the arid West include both the arid and semi-arid areas.]

Since the establishment of the WQRP, three projects have been funded and additional projects are planned. As projects have been implemented and completed, the WQRP has shared project results as well as their implications in a variety of forums. This outreach effort is leading to a broader understanding of water quality issues unique to the arid West and growing support for the establishment of a regional approach for the development and implementation of water quality standards. This growing support recently resulted in an additional federal appropriation of $500,000 that will be applied towards additional research projects. Increased support of the WQRP also has been fueled by an increasing interest in recognizing the ecological benefit of effluent-supported riparian habitats in the West. Moreover, it is being recognized that as the cost of wastewater treatment climbs and the quality of effluent improves, the competition and value of treated wastewater will likewise increase to the extent that treated wastewater, which could be used to support riparian habitat and wildlife, likely will be diverted to other urban uses. This is especially a concern for areas of the arid West where riparian and wildlife habitats are already limited. Thus, an ongoing purpose of the WQRP is to provide critical data to support efforts to address these unique western water quality concerns and provide innovative solutions.

1.1.2 WQRP Research Agenda: Establishing a Project Road Map

The arid West comprises many different interests, stakeholders, and water quality concerns. Accordingly, it was recognized at the onset of the project that it would be essential to establish a research agenda representative of the issues and concerns prevalent in the arid West. To develop this agenda, the WQRP organized and hosted a conference in Tucson, Arizona in 1997 (the full conference summary may be viewed at the WQRP website, which can be accessed at http://www.co.pima.az.us/wwm/wqrp/index.html). The purpose of this conference was to bring together people with interests in arid West water quality issues to identify water quality concerns within four general areas: habitats of concern, biological and ecological criteria and standards, chemical criteria and standards, and whole effluent toxicity (WET) testing. More than 100 conference participants, representing federal, state, local and tribal government agencies, wastewater dischargers, and university researchers, attended specialized sessions devoted to

identifying research needs under each of these areas and formulating specific questions that would provide the foundation for the research agenda. As a result of this effort, the following general research needs were identified:

Habitats of Concern

- Establish the basic descriptions of environmental conditions (physical, chemical, and biological), that would define beneficial use of effluent-dependent and ephemeral arid stream habitats, which have been attained and preserved under existing discharge conditions. Consideration should be given to the effect that historical discharges and conditions may have had on current uses. The influence of stormwater flows was recognized as a major consideration in defining effects on habitats in arid environments.

- Identify the types of habitats that currently exist below effluent discharge and stormwater discharge points. Quantify and analyze the community structure as a function of habitat and ecosystem structure.

- Evaluate attainable environmental benefits of arid ephemeral stream habitats affected by discharges of treated effluents and stormwater. Determine the environmental benefits of habitats associated with effluent-dependent watercourses.

- Determine the resiliency of arid West stream habitats to variation in water quality indicators (including chemical species), and effects on beneficial uses.

Biological/Ecological Criteria and Standards

- Determine the variability of biological communities of arid effluent-dependent waters and ephemeral streams.

- Define the range of biologically acceptable reference conditions for arid effluent-dependent and ephemeral streams that offer net ecological benefit.

- Define the differential response of biological communities to stormwater from natural landscape drainage, agricultural lands, and municipal environments.

WET Testing

- Identify conditions in arid ecosystem ephemeral and effluent-dependent streams appropriate for WET testing application in arid regions, including in relation to stormwater flows.

- Assess the sensitivity of current test species to typical chemical and physical characteristics of effluent-dependent and ephemeral source waters in the arid West. Improve the test protocol, including solution matrix effects, rearing environment, and selection of native arid species in order to separate effects of effluents from effects of natural conditions, including stormwater flows. The relationship of test results to

observed measures of downstream biological integrity needs to be established for representative stream segments.

- Determine the correlation between test response of current test species and native species of typical arid effluent-dependant and ephemeral streams including "toxic" events.

Chemical Criteria and Standards

- Determine chemical quality indicators (nutrients, metals, and organics) thresholds and exposure conditions (frequency, duration, and intensity of stress) needed to maintain existing arid West ephemeral and effluent-dependent stream environmental benefits.

Based on input received from the 1997 WQRP Conference, WQRP staff prepared an EPA Workplan to address federal funding requirements and provide a basis for the selection and implementation of WQRP-funded research (the current EPA-approved WQRP Workplan may be viewed at http://www.co.pima.az.us/wwm/wqrp/index.html).

1.1.3 WQRP Infrastructure: Ensuring Sound Science

Since its founding, WQRP activities have been conducted under a strict organizational structure to help the project achieve several key outcomes, as follows: (1) research proposals and project results are scientifically based and scientifically defensible; (2) research activities address important arid West regulatory issues; (3) EPA, as the key regulatory agency, is kept closely involved in the project's decision-making process; and (4) the project demonstrates fiscal responsibility.

With these key outcomes in mind, the WQRP operates under the guidance of an EPA Project Officer, who works closely with the WQRP Office, established as a separate entity within the Pima County Wastewater Management Department offices in Tucson, Arizona. In addition, the project receives oversight and critical review from the following:

- *Quality Assurance Consultant (QAC)* – The QAC works independently of project researchers to review research project quality assurance plans, review project data, and recommend approaches to solve research problems.

- *Regulatory Working Group (RWG)* – The RWG assists with the identification of important regulatory issues that require research and helps ensure that research findings consider regulatory implications. A maximum of 15 members representing state and federal regulatory agencies, Indian tribes, municipalities, industry, environmental organizations, consulting firms and universities serve on the RWG. Many members of the RWG have served since the group was formed in 1997, providing consistent leadership to the WQRP (see inset for current and past members).

- *Scientific Advisory Group (SAG)* – The SAG assists with the development of research projects selected for funding, reviews research proposals and reviews project reports to help ensure the conclusions and recommendations from funded studies are supported by project results. The SAG is currently composed of five members and two alternates who

have research experience and training in environmental toxicology, biology, and ecology, as well as a variety of other water quality disciplines. Many of the SAG members have been project participants since their selection in 1997 (see inset for list of current and past SAG members).

WQRP Regulatory Working Group

Participants (Current)

- Kathleen M. Chavez, Chair, Pima County Wastewater Management, Tucson, Arizona
- Edward C. Anton, California State Water Resources Control Board, Sacramento, California
- Rodney W. Cruze, Riverside Regional Water Quality Control, Riverside, California
- Paul D. Frohardt, Colorado Water Quality Control Commission, Denver, Colorado
- Michael Gritzuk, City of Phoenix, Water Services, Phoenix, Arizona
- Catherine Kuhlman, U.S. EPA, Region 9, San Francisco, California
- Andrew Laurenzi, The Nature Conservancy, Tucson, Arizona
- Susan MacMullin, U.S. Fish & Wildlife Service, Albuquerque, New Mexico
- Patrick J. Maley, Winnemucca, Nevada
- S. Lynn Mays, Malcom Pirnie, Inc., Houston, Texas
- James F. Pendergast, U.S. EPA, Office of Science and Technology, Washington, D.C.
- Sam Rector, Arizona Department of Environmental Quality, Phoenix, Arizona
- Eric Rich, Navajo Environmental Protection Agency, Tuba City, Arizona
- Daniel Santantonio, City of Las Cruces, Utilities Division, Las Cruces, New Mexico
- Neil Stessman, Volunteer, National Audubon Society, National Wildlife Federation, Billings, Montana

Participants (Past)

- Patrick Antonio, Navajo Environmental Protection Agency, Window Rock, Arizona
- Daniel P. Beard, National Audubon Society, Washington, D.C.
- Jaqualyn Forrest, Heal the Bay, Santa Monica, California
- Barbara Tellman, University of Arizona, College of Agriculture, Tucson, Arizona

1.1.4 WQRP Funded-Research

To date, the WQRP has funded three projects; additional research activities currently are being planned. The first report completed by the WQRP, *Pre-Research Survey of Municipal NPDES Dischargers in the Arid and Semi-Arid West*, resulted from an RWG recommendation that the project survey as many arid West dischargers as possible to obtain information necessary to properly characterize arid West discharges and associated water quality concerns. A key finding of the resulting report was that there was a general lack of data that effectively described effluent-dependent water habitats (WQRP 2000).

Recognizing that having an understanding of the attributes of effluent-dependent water habitats was critical to a discussion of the applicability of federal water quality criteria and standards to arid West waters, the RWG recommended that the WQRP commission a study to properly characterize effluent created habitats. This study, which became known as the Habitat

WQRP Scientific Working Group

Participants (Current)

- Paul Adamus, Ph.D., Corvallis, Oregon – Terrestrial ecology, wetland-riparian systems, ornithology and aquatic invertebrates
- Gary A. Chapman, Ph.D., Paladin Water Quality Consulting, Corvallis, Oregon – Water quality criteria development, aquatic and sediment toxicology
- Karmen E. King, Colorado Mountain College, Leadville, Colorado – Aquatic toxicology, fisheries biology and aquatic chemistry
- Robert W. McFarlane, Ph.D., McFarlane & Associates, Environmental Consultants, Houston, Texas – Aquatic and terrestrial ecology, threatened and endangered species, environmental impact assessments, habitat evaluation and wetlands
- Benjamin R. Parkhurst, Ph.D., HAF, Inc., Laramie, Wyoming – Ecological risk assessment, aquatic toxicology, fisheries biology and aquatic ecology

Alternates include:

- Robert H. Gray, Ph.D., Richland, Washington – Aquatic toxicology, environmental assessments, fisheries, herpetology and water quality
- Carlton Sims White, Ph.D., University of New Mexico, Department of Biology, Albuquerque, New Mexico – Nutrient cycling, ecosystems

Participants (Past)

- Ray Alden, Ph.D., University of Nevada at Las Vegas, Las Vegas, Nevada
- William H. Clements, Ph.D., Colorado State University, Fort Collins, Colorado
- Emily Stanley, Ph.D., University of Wisconsin, Madison, Wisconsin

Characterization Study, is the subject of this report, and the findings from this effort are providing the foundation for future research funded by the WQRP.

The third WQRP-funded study is the Extant Criteria Evaluation Study. This project, which will be completed in summer 2002, is focused on an analysis of the applicability of existing federal water quality criteria to arid West waters. Using four types of criteria as models (e.g., selenium representing chemicals where bioaccumulation or dietary intake are important for determining toxicity), this study will evaluate federal criteria in the context of the physical, chemical, and biological characteristics of arid West waters.

1.2 WHAT CONSTITUTES THE ARID WEST?

It is important to understand what the arid West encompasses from both a geographical and regulatory standpoint. Accordingly, this section provides a description of the arid West, first geographically, using ecoregions from the sites selected for the Habitat Characterization Study, and then from a regulatory viewpoint. Understanding how a region is structured from a regulatory perspective is important, especially since one of the key outcomes identified for WQRP-funded research is the need to address relevant arid West regulatory issues.

1.2.1 Geographical Diversity

The arid West is defined as the arid and semi-arid portions of the western United States that extend from south-central Texas west to southeastern California and north along the east side of the Sierra Nevada and Cascade Ranges to the Canadian Border in eastern Washington. The eastern boundary of this region extends from central North Dakota south through central South Dakota, Nebraska, western Kansas and Oklahoma to south-central Texas. The arid and semi-arid areas of this region, which incorporates portions of 17 western states, is characterized generally by annual precipitation of less than 15 inches, with numerous localities receiving less than 12 inches of precipitation annually (Ricklefs 1990).

While much of the region can be classified as arid or semi-arid based on annual precipitation, the northern portions are characterized by strong seasonality with warm summers and cold winters. By contrast, southeastern California, southern Arizona, New Mexico, and Texas are characterized by comparatively mild winters and warm to hot summers.

The "Arid West" Defined

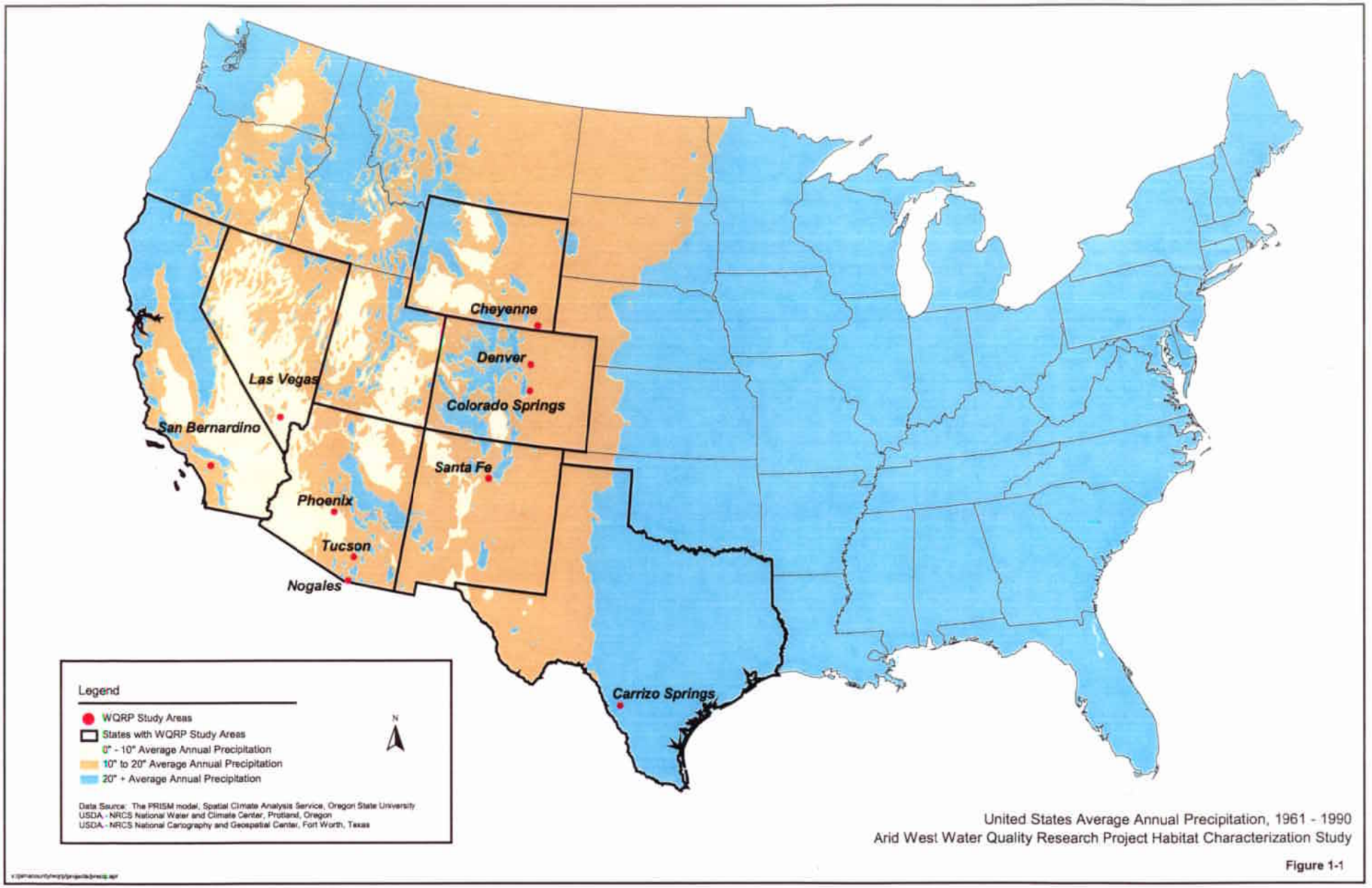
What constitutes the arid West has been a major policy question of the American nation since at least the 1870s. In 1878, John Wesley Powell, second director of the U.S. Geological Survey, released his *Report of the Arid Lands West of the 100th Meridian*. The report used the first federal rainfall map of the country to demonstrate the extremely precipitous drop in mean annual rainfall from east to west across the United States.

Powell used the 20-inch-per-year precipitation contour, or *isohyet*, to define the western land too dry to farm without imported surface or groundwater. Geographers, geologists, climatologists and biologists have all used a variety of definitions for the term *arid*, *semi-arid*, and *humid*. One definition, used by geographers, defines arid as less than 10 inches of mean annual rainfall and semi-arid as between 10 and 20 inches (**Figures 1-1 and 1-2**). Other definitions combine rainfall with potential evapotranspiration to define a soil moisture deficit. Agronomists and soil scientists talk about *mesic*, or moist, vegetation and soils, and *xeric*, or water-deficient environments.

The WQRP has adopted a geographic definition of the arid West (see text). This approach was selected because the project is attempting to fully encompass the many ways that the combination of low rainfall and evapotranspiration coupled with the potential discharge of treated effluent can result in the creation of unique aquatic and terrestrial ecosystems. However, as the WQRP continues to collect data, perhaps we will need other, more specific definitions to better describe the "arid West."

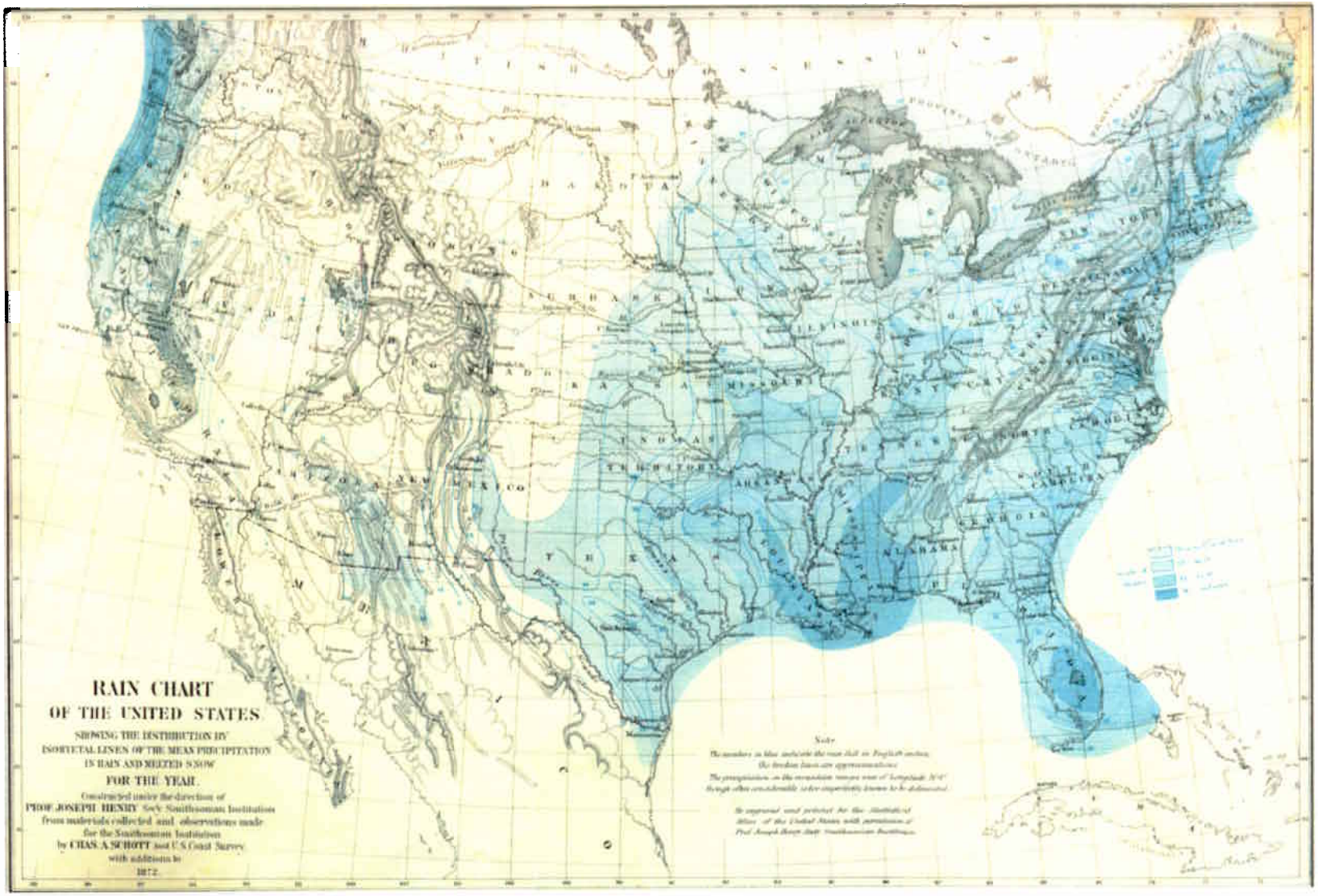
Terrestrial vegetation within the arid West is most frequently composed of plant communities of low stature, dominated by a variety of species of small trees, shrubs, grasses, and forbs. Forested landscapes within the region are generally restricted to higher elevation sites where precipitation is greater and summer temperatures more moderate, or where water is more readily available. At lower elevations, often the most complex vegetation communities are located along watercourses.

Classification of landscapes into ecoregions has been a useful tool for describing ecologically similar areas (Omernik 1987; Omernik and Bailey 1997). The primary function of classifying landscapes by ecoregion is to provide a geographic framework for organizing ecosystem resource information. Ecoregions are regions of relative homogeneity in terms of ecological systems or in relationships between organisms and their environment. Ecoregions represent



United States Average Annual Precipitation, 1961 - 1990
Arid West Water Quality Research Project Habitat Characterization Study

Figure 1-1



Rain Chart of the United States
Figure 1-2

patterns displayed by ecosystems and their components and have been defined by examining factors that either cause regional variations in ecosystems or integrate causal factors. Integrative factors include land use, land surface form, potential natural vegetation, and soils.

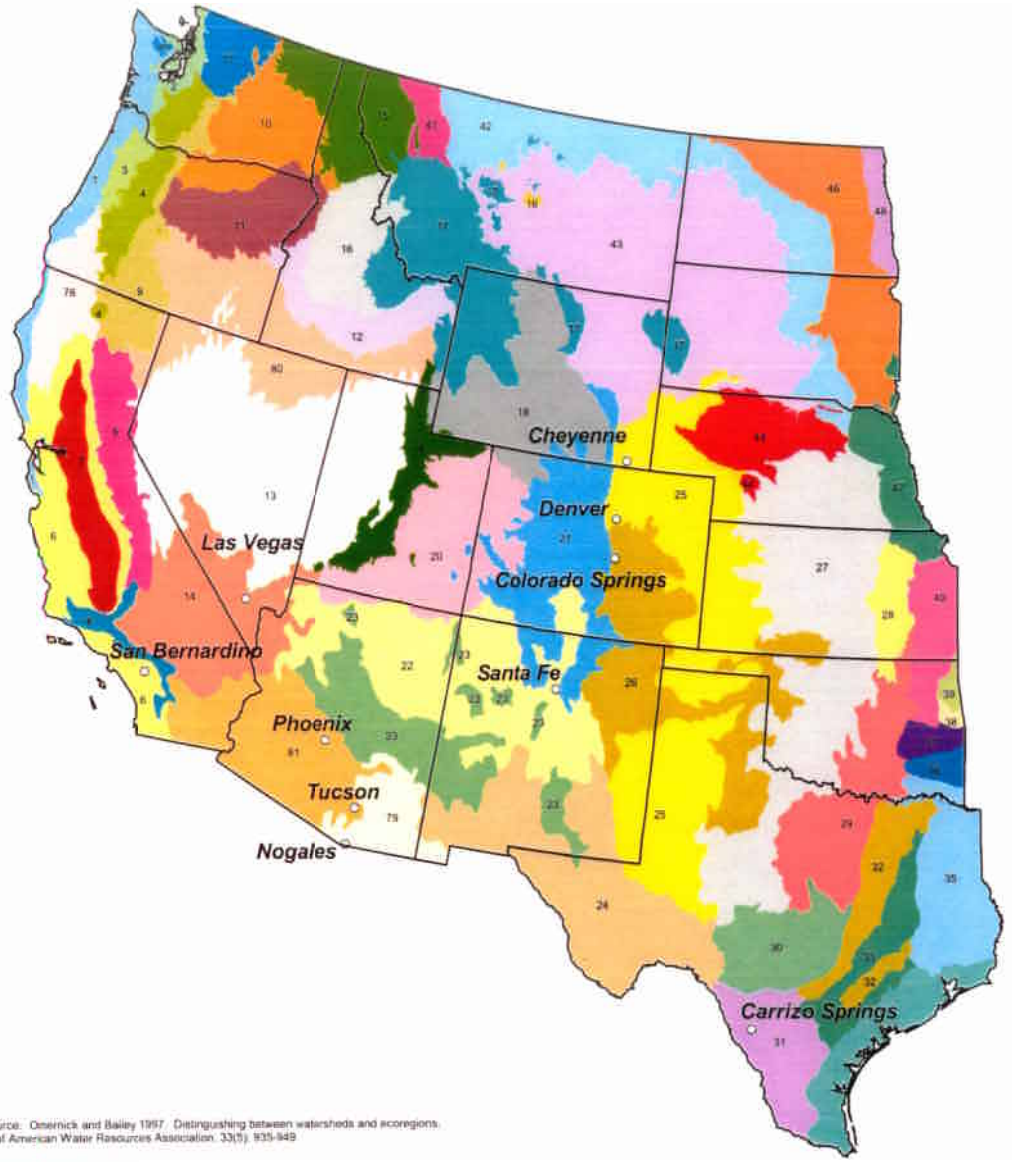
Ecoregions relevant to the effluent-dependent waters included as case studies in this report include the following (**Figure 1-3**):

- *Arizona/New Mexico Plateau*. This ecoregion includes portions of northern Arizona and New Mexico and a small portion of southern Colorado. It represents a large transitional region between semi-arid grasslands and low-relief tablelands of the Southwestern Tablelands ecoregion in the east, the drier shrub lands and woodland-covered higher relief tablelands of the Colorado Plateau in the north, and the lower, hotter, less vegetated Mojave Basin and Range in the west and Chihuahuan Deserts in the south. Higher, more forest-covered, mountainous ecoregions border the region on the northeast and southwest. Local relief in the region varies from a few meters on plains and mesa tops to well over 984 feet along tableland and side slopes. The vegetation is grama/galleta steppe, Great Basin sagebrush, and saltbush/greasewood. Land use is subhumid grassland and semi-arid grazing land along with grazed desert shrubland.

- *Northwestern Great Plains*. This ecoregion includes portions of Montana, North Dakota, South Dakota, and Wyoming and encompasses plains with low to high hills, tablelands with moderate relief, and open low to high hills. It is a semi-arid rolling plain of shale and sandstone punctuated by occasional buttes. Potential natural vegetation includes wheatgrass/needlegrass, grama/needlegrass/wheatgrass, and wheatgrass/grama/buffalo grass. Native grasslands, largely replaced on level ground by spring wheat and alfalfa, persist in rangeland areas on broken topography. Agriculture is restricted by the erratic precipitation and limited opportunities for irrigation. Land uses include subhumid grassland and semi-arid grazing land.

- *Southern and Central California Chaparral and Oak Woodlands*. The primary distinguishing characteristic of this ecoregion is its Mediterranean climate of hot, dry summers and cool, moist winters, and associated vegetative cover comprising mainly chaparral and oak woodlands; grasslands occur in some lower elevations and patches of pine are found at higher elevations. Most of the region consists of open low mountains or foothills, but these are areas of irregular plains in the south and near the border of the adjacent Central California Valley Ecoregion. Much of this region is grazed by domestic livestock; very little land has been cultivated.

- *Sonoran Basin and Range*. This ecoregion includes portions of southern California and Nevada and southwestern Arizona. This ecoregion encompasses lowland desert scattered with mountains of relatively low elevation. Potential natural vegetation includes creosote bush, cresosote bush/bursage, and paloverde/cactus shrub associations. This region contains large tracts of federally owned land; land use includes both grazed and ungrazed desert shrubland.



Legend

- Habitat Characterization Study Areas
- States with Habitat Characterization Study Areas

Ecoregions

- Coast Range
- Puget Lowland
- Willamette Valley
- Cascades
- Sierra Nevada
- Southern and Central California Chaparral and Oak Woodlands
- Central California Valley
- Southern California Mountains
- Eastern Cascades Slopes and Foothills
- Columbia Plateau
- Blue Mountains
- Snake River Basin
- Central Basin and Range
- Mojave Basin and Range
- Northern Rockies
- Idaho Batholith
- Montana Valley and Foothill Prairies
- Middle Rockies
- Wyoming Basin
- Wasatch and Uinta Mountains
- Colorado Plateaus
- Southern Rockies
- Arizona/New Mexico Plateau
- Arizona/New Mexico Mountains
- Chihuahuan Deserts
- Western High Plains
- Southwestern Tablelands
- Central Great Plains
- Flint Hills
- Central Oklahoma/Texas Plains
- Edwards Plateau
- Southern Texas Plains
- Texas Blackland Prairies
- East Central Texas Plains
- Western Gulf Coastal Plain
- South Central Plains
- Ouachita Mountains
- Arkansas Valley
- Boston Mountains
- Ozark Highlands
- Central Irregular Plains
- Canadian Rockies
- Northwestern Glaciated Plains
- Northwestern Great Plains
- Nebraska Sand Hills
- Northern Glaciated Plains
- Western Corn Belt Plains
- Lake Agassiz Plain
- North Cascades
- Madrean Archipelago
- Northern Basin and Range
- Sonoran Basin and Range

Data Source: Omernick and Bailey 1997. Distinguishing between watersheds and ecoregions. Journal of American Water Resources Association. 33(5): 935-949

Omernik's Level III Ecoregions for the Continental United States
Arid West Water Quality Research Project Habitat Characterization Study

Figure 1-3

- *Madrean Archipelago.* Also known as the Sky Islands in the United States, this is a region of basins and ranges with medium to high local relief, typically 3,280 to 4,921 feet. Native vegetation in the region is mostly grama-tobosa shrubsteppe in the basins and oak-juniper woodlands on the ranges, except at higher elevations where ponderosa pine is predominant. The region has ecological significance as both a barrier and a bridge between two major cordilleras of North America, the Rocky Mountains and the Sierra Madre Occidental.

- *Southern Texas Plains.* This ecoregion is located in southern Texas. This rolling to moderately dissected plain was once covered with grassland and savanna vegetation including mesquite/acacia savanna (bluestem, bristlegrass) and mesquite/live oak savanna (bluestem). Having been subject to long continued grazing, thorny bush is now the predominant vegetation type. This "brush community," as it is called locally, has its greatest extent in Mexico and contains a greater and more distinct diversity of animal life than that found elsewhere in Texas. This ecoregion is characterized by smooth to irregular plains. Open woodland grazing and subhumid grassland and semi-arid grazing are typical land uses for this area.

- *Southwestern Tablelands.* This ecoregion includes portions of Colorado, New Mexico, Texas, Oklahoma, and Kansas. Unlike most adjacent Great Plains ecological regions, little of Southwestern Tablelands is in cropland. Much of this elevated tableland is in subhumid grassland and semi-arid grazing land and some cropland with grazing land. This ecoregion is characterized as tablelands with moderate to considerable relief. The potential natural vegetation in this region is grama-buffalo grass with some mesquite-buffalo grass in the southeast and shinnery (midgrass prairie with open low and shrubs, including sandsage/bluestem and bluestem/grama prairies) along the Canadian River.

- *Western High Plains.* This ecoregion includes portions of eastern New Mexico and western Texas, the panhandle of Oklahoma, eastern Kansas and Nebraska, Colorado, and southeastern Wyoming. Much of the Western High Plains comprises smooth to slightly irregular plains that are often cultivated or grazed. Grama/buffalo grass is the potential natural vegetation in this region as compared to mostly wheatgrass/needlegrass to the north, Trans-Pecos shrub savanna to the south, and taller grasses to the east. The northern boundary of this ecoregion is the approximate northern limit of winter wheat and sorghum and the southern limit of spring wheat.

1.2.2 Regulatory Diversity

The arid West is as regulatory diverse as it is geographically diverse. Consider the following stakeholders encompassed by this region:

- All or portions of five EPA regional offices (Regions 6, 7, 8, 9 and 10)

- Seventeen state governments often with more than one agency with regulatory jurisdiction over the state, including jurisdiction over water quality, water quantity and state fishery and wildlife issues

- Numerous tribal governments (28 tribal governments in Arizona alone)

- Other federal agencies with interests in western water resource management, including the U.S. Fish and Wildlife Service, Army Corps of Engineers, Bureau of Reclamation, United States Forest Service and Bureau of Land Management

- United States-Mexico border agencies that implement cooperative agreements to address cross-border environmental concerns

Given the diversity of the regulatory entities with potential interest in environmental issues in the arid West, especially water quality issues, it is not surprising that there can be many different and possibly conflicting viewpoints over how water resources should be regulated or managed. By having a combined regulatory and scientific emphasis to research funded by the WQRP, it is hoped that the gap between regulatory and scientific issues can be bridged effectively.

Creation of Effluent-Dependent Reaches in the Santa Cruz River Watershed, Arizona (compiled from Tellman et al. 1997)

The headwaters of the Santa Cruz River are located in the San Rafael Valley in southern Arizona. Initially, the river flows south into Mexico and eventually turns north, flowing back into Arizona. Ultimately, the Santa Cruz River, with a watershed area of 8,200 square miles, is tributary to the Gila River, reaching the Gila River on the Gila River Indian Community, southwest of the Phoenix metropolitan area.

Historically, the Santa Cruz River was perennial from its headwaters through Mexico and north to the town of Tubac, Arizona, approximately 40 miles north of the U.S./Mexico border. Except for two short reaches of perennial water near San Xavier, south of Tucson, and what is now central Tucson, the Santa Cruz River from Tubac northward to its confluence with the Gila River was typically ephemeral.

Today, primarily because of extensive groundwater pumping in the region, many of the formally perennial reaches downstream of the San Rafael Valley would currently be dry. However, two reaches of the river have relatively constant flow as a result of the discharge of effluent in the Nogales and Tucson, Arizona areas. The first effluent-dependent reach extends from Nogales 35 miles to north of Tubac, Arizona. The second reach begins in the western part of Tucson and continues downstream. In both reaches, extensive riparian ecosystems have developed in response to the constant discharge of effluent.

1.3 ARID WEST RIVERINE ECOSYSTEMS

Within the arid West there exists a southerly trend of diminished perennial stream flow. In the southwestern United States there are few perennial rivers, and, where they exist, they are often highly regulated systems providing water supply for urban and agricultural uses and flood control protection for urban centers. The majority of waterways in the region, south of 40° latitude, are ephemeral (flowing only after precipitation) or intermittent (spatially, i.e., short permanently flowing reaches in an otherwise dry channel, or temporally, e.g., flowing during a particular season). For example, based on digitized hydrographic maps (scale 1:100,000), the State of Arizona (non-tribal lands) contains 107,500 miles of stream of which only about 4,970 miles are considered perennial, the remainder being ephemeral or intermittent, either naturally or as a result of

human intervention. Portions of the perennial waters are perennial only because of the discharge of effluent into an otherwise dry riverbed (ACERP 1995).

Of note and of considerable significance with respect to arid West riverine systems, the riparian communities that occur along perennial and some ephemeral streams represent part of the most important wildlife habitat in the region. In some situations, these riparian ecosystems are maintained by effluent discharge from municipalities and have become established along watercourses that could not possibly support such vegetation in the absence of effluent discharge; in other words, these ecosystems are effluent-dependent.

1.3.1 Creation of Effluent-Dependent Waters

Effluent-dependent stream ecosystems are created by the discharge of treated wastewater into either naturally ephemeral or intermittent stream channels or streams channels that are ephemeral or intermittent as a result of hydrologic modifications in the watershed. The use of water for agriculture, power, and mining coupled with the rapid urbanization of the arid West has resulted in the need to dam existing rivers to provide a reliable surface water supply, caused the depletion of groundwater, and led to the importation of even greater quantities of water over large distances and elevations.

The majority of effluent-dependent waters addressed by this study have resulted from the creation of stream ecosystems in hydrologically modified watersheds. Exceptions include Las Vegas Wash and the Santa Cruz River at Tucson, where in-stream flows historically have been intermittent or ephemeral. In cases where hydrologic modification has occurred, some of these modifications have been significant. For example, the Salt River historically was a major perennial tributary to the Gila River. However, with the construction of upstream reservoirs and the Granite Reef Diversion Dam, by the 1930s the Salt River had been converted to a dry riverbed (see inset and Tellman et al. 1997 for additional examples).

As urban centers have grown, the need to dispose of treated wastewater has grown as well. Various options exist to dispose of wastewater, including discharge to river channels, and in this regard the West is no different than any other part of the United States. However, because so many surface waters in the West are ephemeral or intermittent, the discharge of treated wastewater to such water bodies creates a new aquatic ecosystem that either replaces predevelopment baseflow or creates a new perennial water where only ephemeral flows may have previously existed. In addition, the discharge of effluent has created opportunity for either the creation of a new riparian community or the reestablishment of a prior existing riparian community along the stream channel. It is in this regard that the arid West is fundamentally different from non-arid regions.

Superimposed on the created effluent-dependent stream ecosystem are the climatic characteristics of the arid West. Precipitation, being lower in annual volume and often delivered by intense, monsoonal summer storms, limits western surface and groundwater resources. Stream flow, in particular ephemeral-channel flow, can be non-existent for years; when the rain comes, stream flow is often catastrophically dynamic (Baker 1977). The reason for this dynamic type of stream flow is only partially related to climate. In fact, the runoff patterns in the arid West may

be more related to soil and vegetative factors (Osterkamp and Friedman in press), rainfall/runoff curve relations (Hawkins and Khojeini 2000), or other surficial factors. Whatever the cause, the fact remains that stream flow hydrographs of arid West storms generally have steeper limbs (more "flashy") than storms in non-arid areas, signifying the potential for more dynamic flooding.

Impressed upon these flow conditions is the persistent high pressure, low humidity, continental air masses, which produce high evaporation rates as compared to the eastern United States. The combination of high potential evaporation, steep rainfall-runoff curves, and low annual rainfall conspire to create a soil moisture deficit (Dunne and Leopold 1978), a condition in which the moisture level of the soil declines faster than the ability of precipitation to replace it. Soil moisture deficit does occur in non-arid regions, but its occurrence usually indicates extreme conditions (drought). Most cropped plants require imported water to survive in the West because they are non-native; native plants have adapted well to arid conditions.

1.3.2 Effluent-Dependent Waters in the Arid West

Effluent-dependent waters are a common phenomenon of the arid West. A 1998 survey of permitted wastewater discharges in the West identified 4,515 NPDES permits within the 17 western states that have arid and semi-arid lands. Of these permits, 1,001 were major municipal dischargers (discharge > 1 million gallons per day [mgd]), and of the 1,001 major dischargers, 251 were specifically located in areas considered arid or semi-arid. Within these 251 permitted discharges, there were 71 permit holders that resulted in 78 wastewater discharge sites, creating effluent-dependent waters in what would otherwise be ephemeral or intermittent watercourses (WQRP 2000). Additional information obtained since 1998 (e.g., establishment of new discharges, or updated survey information) suggests that currently the number of effluent-dependent waters is somewhat greater than 78 (WQRP, personal communication).

Table 1-1
Distribution by State and Discharge Volume of Discharges Creating Effluent-Dependent Waters (WQRP 2000)

State	1-25 MGD	25-49 MGD	50-200 MGD	> 200 *MGD*
Arizona	12	0	4	0
California	11	2	0	0
Colorado	2	0	1	0
Kansas	2	0	0	0
Montana	2	0	0	0
North Dakota	0	1	1	0
Nebraska	1	0	0	0
New Mexico	10	0	0	0
Nevada	1	0	2	1
South Dakota	2	0	0	0
Texas	12	0	0	0
Utah	5	1	0	0
Washington	1	0	0	0
Wyoming	4	0	0	0
Totals	65	4	8	1

The majority of wastewater treatment facilities in the arid West that discharge to ephemeral, intermittent, or effluent-dependent water courses are located in eastern California, Arizona, New Mexico, and west Texas (Table 1-1). These four states are collectively home to 65 percent of the discharge sites. The largest dischargers by volume are located in Arizona, Colorado, and Nevada.

1.4 HABITAT CHARACTERIZATION STUDY

The Habitat Characterization Study was commissioned by the WQRP to characterize the habitats of 10 arid West effluent-dependent waters. As indicated above, effluent-dependent waters are defined as surface waters where treated effluent from wastewater treatment plants is being discharged into a normally dry streambed or a stream that otherwise, in the absence of effluent, would have minimal flow during only part of the year. For this study, the term "habitat" is broadly interpreted to include all physical attributes (e.g., flow, gradient and substrate) and chemical attributes (e.g., effluent and ambient water quality) of the effluent-dependent water ecosystem that influence the biological response in both the aquatic and terrestrial components of the ecosystem.

The 10 study areas selected for the Habitat Characterization Study represent case studies of the physical, chemical, and biological characteristics of these created waters. In conducting this study, no effort was made to test any particular hypothesis, but instead the focus of the effort was on assembling data for the purpose of objectively characterizing the effluent-dependent water ecosystem. Accordingly, this project included the following tasks:

- *Identify, Compile, and Evaluate Historical Data*—Gather physical, chemical and biological data from the 10 study areas to document the physical, chemical and biological characteristics of these sites and, to the extent possible, evaluate how these effluent-dependent waters have changed since the discharge of effluent was initiated.

- *Site Reconnaissance*—Visit each of the 10 study areas to document existing conditions, physically and biologically. This effort included documenting, to the extent practicable, potential stressors to the created ecosystem.

- *Habitat Characterization*—Characterize the aquatic and terrestrial habitats of the 10 study areas using the historical and site reconnaissance data. Identify commonalities as well as differences among all 10 sites.

- *Data Integration and Analysis*—Discuss the results within the existing stream ecosystem literature, regulatory framework and the western water economy. Of particular interest from a scientific perspective was to what degree arid West effluent-dependent waters differ physically, chemically, and biologically from natural perennial streams. If differences exist, then it was important to evaluate these differences within the context of regulatory programs applicable to effluent-dependent waters and the economics associated with wastewater treatment in the West.

1.5 REPORT ROAD MAP

The Habitat Characterization Study was conceived as a specific investigative effort within the larger and broader WQRP. After extensive review and discussion with dischargers, regulators, and other stakeholders, the scope of the investigation was finalized and a request for proposals to conduct the study was announced by the Pima County Wastewater Management Department. The work was divided into individual tasks, each of which generated a variety of interim reports,

data files, technical presentations, outreach materials, and other records. It was felt by the project managers that these scientific products still had retained their value, even when updated or summarized by subsequent products. However, the sheer volume of data and analysis collected produced a cumbersome paper report and much of the valuable data was difficult to extract.

The decision was reached in late 2001 to issue the final report as an electronic document, and this is that report. Although a number of paper copies have been made, the primary document consists of a CD containing the summary final report and a collection of appendices, which together make up the Habitat Characterization Study Final Report. Most likely, this text has been downloaded to your computer from such a CD and the report authors and project managers encourage you to rely upon this paperless form. The Habitat Characterization Study Final Report contains the following sections:

- **Chapter 2** summarizes project methods and provides a brief description of each of the 10 study areas;
- **Chapter 3** characterizes the effluent-dependent water ecosystem in the context of established stream ecology literature and summarizes the key findings from the site characterizations;
- **Chapter 4** considers the project findings in the context of water as a commodity in the West;
- **Chapter 5** discusses results in the context of the existing water quality regulatory framework and provides recommendations on potential alternative approaches for regulating these unique habitats;
- **Chapter 6** summarizes regulatory and policy discussions either ongoing or planned that may have bearing on the regulation of water quality in effluent-dependent waters;
- **Chapter 7** provides a summary of the findings of the Habitat Characterization Study; and
- **Chapter 8** provides recommendations stemming from the project findings.

In addition to the above chapters from the final report, this report is supported by the following appendices that more fully detail the information summarized herein. Many of these appendices represent tasks or products completed earlier in the project:

- **Appendix A** – Introduction to Appendices
- **Appendix B** – Methods
- **Appendix C** – Study Area Descriptions
- **Appendix D** – Data Analysis
- **Appendix E** – Stream Ecosystem Model

- **Appendix F** – Project Preference List
- **Appendix G** – Flooding Effects
- **Appendix H** – Ionic Strength Effects
- **Appendix I** – Toxicity Database
- **Appendix J** – Regulatory Touchstone
- **Appendix K** – Water Quality Standards
- **Appendix L** – NPDES Permits Summary
- **Appendix M** – Historic Aquatic Species
- **Appendix N** – Aquatic Biology Results
- **Appendix O** – Historic Terrestrial Species
- **Appendix P** – Historic Aerial Photos
- **Appendix Q** – Terrestrial Habitat Characterization
- **Appendix R** – Historic Chemical Data