A Water Quality Assessment of Four Intermittent Streams in Los Alamos County, New Mexico

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ABSTRACT

In 1996 and 1997, the United States Fish and Wildlife Service investigated the biological, chemical, and physical characteristics of four intermittent streams on the Los Alamos National Laboratory in New Mexico. Width, depth, substrate, temperature, velocity, cover, and other physical parameters were measured. Water, sediment, sediment porewater, and biota were analyzed for various inorganic, organic, or radioactive chemicals. Habitat suitability models and rapid bioassessment protocols were used to identify suitable living space for fish and benthic macroinvertebrates. Toxicity tests of water and sediment porewater and surveys for benthic macroinvertebrates were also conducted. Adult, female, fathead minnow (*Pimephales promelas*) were caged in these streams for two months to measure their survival, growth, and contaminant accumulation. Each measured characteristic was compared to the reference site or to applicable criteria, and these ratios were converted into indices of biological, chemical, and physical quality, which were summed into a Water Quality Index in order to identify any stream impairment.

All stream segments were found to contain cold, flowing water and a community of aquatic life. Los Alamos Canyon contained a perennial stream above the Los Alamos Reservoir with a population of brook trout (*Salvelinus fontinalis*), and was the reference site for all comparisons. Sandia Canyon, Pajarito Canyon, and Valle Canyon stream segments had no fish populations. The Sandia Canyon stream was composed of waste water effluents, although the proportion and contributions of these discharges and storm water runoff were not quantified. Elevated concentrations of aluminum, barium, chromium, molybdenum, explosives, or polychlorinated biphenyls were found either in water, sediment, sediment porewater, caddisflies (*Hesperophylax sp.*), or in the caged-fish. Surface water toxicity to laboratory invertebrates was identified in Valle Canyon, probably from a runoff event, and reproductive toxicity was found in laboratory invertebrates using sediment porewater from Sandia Canyon. However, the causes of toxicity were not conclusive in either event. No surface water toxicity to fathead minnows was found during laboratory testing. In the caged-fish study, factors other than contaminants, particularly flooding, accounted for most of the mortality observed. The benthic macroinvertebrate community was slightly impaired in Pajarito and Valle Canyons, and moderately impaired in Sandia Canyon; where taxa richness was one-fourth of that from the reference site.

Habitat suitability models for brook trout indicated above-average to marginal quality habitat. Lack of flow velocity in riffle habitats resulted in poor quality longnose dace (*Rhinichthys cataractae*) habitat. The Valle Canyon stream segment lacked the flow volume necessary to fully support adult trout, while excess fines in riffles reduced the quality of potential habitat for trout eggs. Diminished stream velocity, cover, prey abundance and diversity, as well as excess nutrients in the Sandia Canyon reduced potential trout habitat. Scouring, erosion, and embedded substrates also reduced the quality of the habitat for benthic macroinvertebrates. The Pajarito Canyon segment had fair trout habitat, though the lower portion had reduced flow and fewer deep pools.

The Water Quality Index suggested a 30 percent impairment of the water quality in Valle Canyon, a 22 percent impairment in Pajarito Canyon, and a 30 percent impairment in Sandia Canyon compared to the reference site. Physical impacts were greater in Pajarito and Valle Canyons, whereas chemical impacts were greatest in Sandia Canyon. However, the Cerro Grande Fire burned a large portion of these canyons watersheds and therefore, water quality impairments are expected to increase as are restoration efforts. Recommendations were provided to focus water quality management objectives on protection of aquatic life in these intermittent streams. The techniques and evaluation procedures used in this study may be applicable to the water quality assessments of other water bodies in New Mexico.

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Attachment A. Chapman, D., and A. Allert. 1998. Los Alamos National Laboratory Use Study Phase II: Toxicity Testing of Surface Waters and Sediment Porewaters at Los Alamos National Laboratory. With Appendices A through C. United States Geological Survey, Biological Resources Division Report, Columbia, Missouri.

Appendix I. Settlement Agreement.

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DISCLAIMER

EXECUTIVE SUMMARY

The Federal Water Pollution Control Act (commonly known as the Clean Water Act) provides a national framework for the protection and restoration of the quality of America's surface waters. It consists of two parts: regulatory provisions that impose progressively more stringent requirements on industries and cities to abate pollution and meet the goal of zero discharge of pollutants; and provisions that authorize federal financial assistance, research, and enforcement. States (or Tribes) with jurisdiction over a particular water body have the primary responsibility to prevent, reduce and eliminate pollution, to determine and formally designate the appropriate use(s) of their waters, and to set water quality standards and criteria that both define the goals of a water body and protect it's beneficial uses. Beneficial uses of the waters in New Mexico to be achieved and protected can include:

- drinking water supplies, domestic use, and human health;
- primary & secondary contact (*e.g.*, swimming, fishing, recreation, ceremony);
- navigation, commerce, and welfare;
- habitat for aquatic life (often listed as coldwater or warmwater fisheries);
- irrigation, other agricultural and aquaculture practices;
- municipal and industrial water supply and storage;
- drinking water for livestock and wildlife; and,
- habitat for wildlife (*e.g.*, wetland plants, amphibians, birds, mammals).

The beneficial uses of a water body include designated uses and existing uses. Designated uses are those uses formally classified and listed by a State (or Tribe) for their surface waters. Existing uses are those that have been attained on or after November 28, 1975, in or on any water body, whether they have been designated or not. Whenever a water body has a designated use that does not include an existing use or the uses identified in section 101(a)(2) of the Clean Water Act, then that use is considered attainable. After discovery of an attainable use, States often revise the designated use of a water body, because, with improved water quality, additional beneficial uses as well as the finite resource of clean water are protected for its citizens.

A Use Attainability Analysis (UAA) is conducted in the event that a designated use is considered inappropriate for a water body. A UAA is a structured scientific evaluation of the conditions affecting the attainment of uses, which often include an investigation into the physical, chemical, biological, and socioeconomic characteristics associated with the surface water body. Some physical factors often investigated include the volume of water, its movement, its temperature, and the texture of the substrate. Some chemical characteristics of a water body often investigated include the dissolved oxygen content, the amount of minerals and nutrients, acidity, alkalinity, dissolved and suspended solids, and sources of pollution. Some of the biological characteristics of a water body often investigated include the organisms known to inhabit or depend upon the surface water, such as aquatic life (*e.g.*, wetland plants, fish, shellfish, aquatic insects, amphibians, and other organisms), livestock drinking, and use by other wildlife (*e.g.*, birds, mammals, amphibians). The socioeconomic characteristics of a water body are often tied to local people and their respective uses of the water, recreational activities, and aesthetic values.

As with other states, New Mexico is in an ongoing process of bringing previously unclassified streams and lakes into the State's water quality management systems, through public participation and the designation of water body uses. In 1995, the New Mexico Water Quality Control Commission (NMWQCC 1995) designated the uses of all waters that were created by point or nonpoint source discharges in a non-classified otherwise ephemeral water of the State for livestock watering and wildlife habitat use only. During this same period, the Department of Energy (USDOE), the University of California Regents (UCR), the New Mexico Environment Department (NMED), the United States Environmental Protection Agency (USEPA), and the NMWQCC were exchanging ideas and opinions about the beneficial uses of the intermittent streams in the canyons on the Los Alamos National Laboratory (LANL or the Laboratory). Rather than conduct a UAA immediately, a Settlement Agreement allowed the USDOE, UCR, and NMED, to hire a third party consultant to gather additional information and conduct a study ". . . for the purposes of identifying the stream uses associated with the watercourses in the canyons into which the parties [USDOE and UCR] discharge waters subject to [National Pollutant Discharge Elimination System] NPDES regulation." The Settlement Agreement also established a four-member selection committee representing the USDOE, the LANL, and the NMED to oversee this study. The USFWS submitted a proposal for the study to evaluate the existing uses of water bodies selected in four canyons that cross the LANL. Eventually, the New Mexico Ecological Services Field Office of the United States Fish and Wildlife Service (USFWS) was selected as the third party consultant to conduct the study (although previously termed the 'LANL Use Study,' this study is now called the 'LANL Water Quality Assessment'). As proposed, the LANL Water Quality Assessment was designed more as a stream survey and assessment of the biological, chemical, and physical characteristics of the selected water bodies, and was not intended as a substitute for a UAA, nor was it designed to determine the waste load allocations necessary to protect downstream waters or provide a socioeconomic analysis often found in a UAA.

Working with the USDOE, NMED, LANL, and others, the USFWS assembled and employed a number of techniques to investigate the biological, chemical, and physical characteristics of four intermittent canyon stream segments on the Laboratory, and a nearby reference site. Physical evaluations of stream segments in these canyons included measurements of stream width, depth, substrate, temperature, flow velocity, cover, channel stability, and other parameters. Water, sediment, sediment porewater, and biota were chemically analyzed for various inorganic, organic, or radioactive chemicals and then compared to applicable water quality standards, or other conditions reported in the literature. These physical and chemical parameters were also used to identify suitable living space for two species of fish and benthic macroinvertebrates using habitat suitability models and rapid bioassessment protocols. In addition, the USFWS contracted the Columbia Environmental Research Center (CERC) of the United States Geological Survey Biological Resources Division to quantify the toxic response of standard test organisms to the canyon stream waters and sediment porewaters in a laboratory setting. Also, the Department of Energy Oversight Bureau of the NMED (Oversight Bureau) previously conducted surveys of benthic macroinvertebrate communities in these four canyon stream segments. Finally, the USFWS caged adult, female, fathead minnow (*Pimephales promelas*) in these streams for two months to measure their survival and growth as well as the bioaccumulation of various contaminants. Each of the measured characteristics were compared to those at the reference site, and to applicable criteria, and then these ratios were converted into indicators of physical, chemical, or biological quality. A Water Quality Index was developed using these indicators to identify the type and amount of water quality impairment compared to the reference site.

All stream segments were found to contain cold, flowing water and a community of aquatic life, plants, and wildlife. Los Alamos Canyon contained a perennial stream segment above the Los Alamos Reservoir with a population of brook trout (*Salvelinus fontinalis*) as well as a diverse community of aquatic macroinvertebrates, and was used as the reference site. Sandia, Pajarito, and Valle Canyon stream segments had aquatic macroinvertebrates, but no existing fish populations, and all but Sandia Canyon had shellfish populations (*i.e.*, the ridged-beak peaclam, *Pisidium compressum*). The Sandia Canyon stream segment was predominantly composed of waste water effluents, although the proportion and contributions of the discharges and storm water runoff were not quantified. Elevated concentrations of contaminants (mostly aluminum, but also barium, chromium, molybdenum, explosives, and polychlorinated biphenyls) were found either in water, sediment, sediment porewater, caddisflies (*Hesperophylax sp.*), or in the caged-fish. Toxicity of the surface water to laboratory invertebrates was identified in Valle Canyon, probably from a runoff event, and reproductive toxicity to laboratory invertebrates was found using sediment porewater from Sandia Canyon. However, the causes of toxicity were not conclusive in either event. No toxicity of surface water was found to fathead minnow during laboratory testing, and in the caged study, factors other than contaminants, particularly flooding, accounted for most the mortality observed. The benthic macroinvertebrate community was considered slightly impaired in Pajarito and Valle Canyons, and moderately impaired in Sandia Canyon where the taxa richness was one-fourth that of the reference site.

Habitat suitability models for brook trout indicated above-average to marginal quality habitat at the time of study. Lack of flow velocity in riffle habitats resulted in poor quality longnose dace (*Rhinichthys cataractae*) habitat. The Valle Canyon stream segment studied lacked the flow volume to fully support adult trout, while excess fines in riffles reduced potential trout egg habitat. Diminished stream velocity, stream side cover, prey abundance, and prey diversity, as well as excess nutrients in the Sandia Canyon segment studied reduced the quality of potential trout habitat. Scouring, erosion, and embedded substrates also reduced the quality of the habitat for aquatic macroinvertebrates in Sandia Canyon. The Pajarito Canyon stream segment had fair trout habitat, though the lower reach had reduced flow and few deep pools. Stream channel stability was fair in Valle, Pajarito, and Los Alamos Canyons but poor in Sandia Canyon.

The final Water Quality Index suggested a 30 percent impairment of the water quality in Valle Canyon, a 22 percent impairment in Pajarito Canyon, and a 30 percent impairment in Sandia Canyon compared to the reference site. Physical impacts were comparatively greater in Pajarito and Valle Canyons, whereas chemical impacts were comparatively greater in Sandia Canyon. Recently however, the Cerro Grande Fire burned a large portion of these canyons' upper watersheds and therefore, water quality impairments are expected to increase, as are restoration efforts.

Recommendations were provided to increase the value of monitoring by using integrative studies and non traditional sampling and to focus water quality management objectives on aquatic life protection in these intermittent streams. The USDOE and the LANL are encouraged to adopt all aquatic life criteria in the evaluation and management of flowing water and sediment resources on the Laboratory, to increase the use of integrative assessments, and continue to seek zero discharge and downstream transport of any persistent, bioaccumulative, or toxic substances. The goals of any water quality management actions should include protecting native species diversity, maintaining healthy macroinvertebrate communities, shellfish, and all other aquatic life species that have adapted to stream conditions unique to the Pajarito Plateau.

INTRODUCTION

Water is necessary for all life. At our houses, we drink, cook, bathe, wash, and garden with water, and in the landscape, we harvest materials (crops, timber, game, livestock, wild plants), energy (power generation transportation, mining, navigation), and recreate (swim, wade, fish, ski, boat) with water moving through the hydrologic cycle. The hydrologic cycle is the circulation of water from the oceans to the atmosphere, to the land, streams, lakes, ponds, ground water, and plants and animals then back again to the oceans (Wesche 1993). The need for clean water, and its beneficial uses and services, are balanced by political organizations and water management agencies, and have been subject to increasingly frequent litigation. During the 1970s, pollution was obviously degrading the quality of freshwater resources available for any one use, and subsequently, Federal, State, and Tribal laws were passed not only to protect surface waters, but to improve the quality of America's lakes, ponds, streams, and other fresh water resources.

Public Law 92-500, the Federal Water Pollution Control Act (commonly referred to as the Clean Water Act) enacted by Congress in 1972, as amended, provides a national framework for water quality protection and restoration. The Clean Water Act recognized that it is the primary responsibility of the States and Tribes, with jurisdiction over a water body, to prevent, reduce and eliminate water pollution, to determine and formally designate the appropriate use(s) of their waters and to set water quality standards and criteria to both define the water quality goals of a water body (or portion thereof) and to protect it beneficial uses. Beneficial uses of the waters in New Mexico to be achieved and protected can include:

- drinking water supplies, domestic use, and human health;
- primary & secondary contact (*e.g.*, swimming, fishing, recreation, ceremony);
- habitat for aquatic life (often listed as coldwater or warmwater fisheries);
- irrigation, other agricultural and aquaculture practices;
- municipal and industrial water supply and storage;
- drinking water for livestock and wildlife;
- navigation, commerce, and welfare; and,
- habitat for wildlife (*e.g.*, wetland plants, amphibians, birds, mammals).

The beneficial uses of a water body include its designated uses and existing uses. Designated uses are those uses formally classified and listed by a State (or Tribe) for their surface waters. Existing uses are those that have been attained on or after November 28, 1975, in or on any water body, whether they have been designated or not. Whenever a water body has a designated use that does not include an existing use or the uses identified in section 101(a)(2) of the Clean Water Act, then that use is considered attainable. After discovery of an attainable use, States often consider revising the designated use, because, with water quality improvements, the water body can support beneficial uses that must be protected under the Clean Water Act.

By 1987, and routinely thereafter, New Mexico, as well as several Tribes, have investigated and elaborated on the beneficial uses of waters in New Mexico to be achieved and protected. The State and Tribes have adopted water quality standards to protect public health and welfare, to enhance or improve various waters' quality, and "serve the purposes of the Act." "Serve the purposes of the Act" (defined in sections 101(a)(2), and 303(c) of the Clean Water Act), is a national stipulation that State or Tribal water quality standards should, wherever attainable, provide water quality sufficient for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water.

By 1987, the State of New Mexico also required protection of downstream water users and their designated uses, as well as established procedures, conditions and requirements to justify removal of the State's designated uses of water. In the event that a designated use: 1) is other than that necessary to serve the purposes of the Act; 2) is somehow considered inappropriate; or, 3) should a State or Tribe and its citizenry wish to adopt subcategories of use where water quality standards are less stringent, the means by which the uses of a particular water body are adjusted and the water quality standards are adjusted is by conducting a Use Attainability Analysis (UAA). A UAA is a structured scientific evaluation of the conditions affecting the attainment of uses, which often include an investigation into the physical, chemical, biological, and socioeconomic characteristics associated with a water body. In general, physical factors are the foundation of the investigation and can include the volume of water, its movement, temperature, and depth, the texture of substrate, and channel characteristics for streams. Chemical characteristics of a water body can include its dissolved oxygen content, the amount of minerals and nutrients, the acidity, alkalinity, dissolved and suspended solids; as well as toxic substances, whether from point sources or nonpoint sources. The biological characteristics of a water body can include a survey of the organisms known to inhabit or depend upon the surface water, such as the local people and their activities, aquatic life (*e.g.*, wetland plants, fish, shellfish, invertebrate communities), livestock, and wildlife uses. Occasionally, a UAA can include an extensive socioeconomic analysis when a designation results in a demonstrated, substantial or widespread economic or social impact often accompanied by extensive citizen participation and public outcry.

As with other states, the State of New Mexico is in an ongoing process of bringing previously unclassified streams and lakes into the State's water quality management systems, through public participation and the designation of water body uses. In 1995, the NMWQCC (1995) designated the uses of all waters that were created by point or nonpoint source discharges in a non-classified otherwise ephemeral water of the State for livestock watering and wildlife habitat use only. During this same period, the Department of Energy (USDOE), the University of California Regents (UCR), the New Mexico Environment Department (NMED), the United States Environmental Protection Agency (USEPA), and the NMWQCC were exchanging ideas and opinions about the beneficial uses of the intermittent streams in the canyons on the Los Alamos National Laboratory (LANL or the Laboratory). Rather than conduct a UAA immediately, a Settlement Agreement (Appendix I) allowed the USDOE, UCR, and NMED, to hire a third party consultant to gather additional information and conduct a study ". . . for the purposes of identifying the stream uses associated with the watercourses in the canyons into which the parties [USDOE and UCR] discharge waters subject to [National Pollutant Discharge Elimination System] NPDES regulation." The Settlement Agreement also established a four member selection committee representing the USDOE, LANL, and NMED to oversee this study. The USFWS submitted a proposal for the LANL Water Quality Assessment (formerly called the LANL Use Study; Appendix II) to evaluate the existing uses of water bodies selected in four canyons that cross the LANL. Eventually, the New Mexico Ecological Services Field Office of the United States Fish and Wildlife Service (USFWS) was selected as the third party consultant to conduct the study (this study is herein called the 'LANL Water Quality Assessment'). As proposed, the LANL Water Quality Assessment was designed more as a stream survey and assessment of the biological, chemical, and physical characteristics of the selected water bodies, and was not intended as a substitute for a UAA, nor was it designed to determine the waste load allocations necessary to protect downstream waters or provide a socioeconomic analysis often found in a UAA.

After review and concurrence by the USDOE, LANL, and NMED, the USFWS proposed to: 1) conduct evaluations of the physical habitat, including stream width, depth, substrate, temperature, current velocity, cover, and other variables that determine suitable habitat for several species of aquatic life; 2) quantify inorganic and organic chemicals in water, sediment, porewater, and biota that could affect fish and wildlife or indirectly affect food production and quality; 3) conduct biological evaluations of species expected regionally and quantify the toxic response of standard test organisms in both laboratory and field settings. All evaluations were to be conducted using comparisons to the reference site, the reference site was selected, *a priori*, as the stream segment in Los Alamos Canyon above the Los Alamos Reservoir. Additionally, biological, chemical, and physical conditions were also compared to applicable standards or criteria, and with other conditions reported in the literature. Taken together, the LANL Water Quality Assessment evaluated the existing and potential uses of these canyon streams based upon their biological, chemical, and physical characteristics and the evaluations identified in Table 1.

In New Mexico, the aquatic life use designation is broken into five fishery subcategories on the basis of representative fish that may be found in cold or warm waters. The various fishery subcategories are: coldwater fishery, high quality coldwater fishery, limited warmwater fishery, marginal coldwater fishery, and warmwater fishery. This subcategorization of the aquatic life use was designed to better protect the classes of coldwater fishery and to designate as superior those coldwater fisheries found in New Mexico's mountains (NMED 2001a). Only the marginal coldwater fishery subcategory requires the actual presence of fish. For the LANL Water Quality Assessment, the USFWS focused on the assessment of fish habitat, because the ability of these shallow and intermittent streams to support fish was questioned by the LANL, and is an important aspect of the fishery use subcategorization. Habitat for fish is a place in which a fish, a fish population, or a fish assemblage can find the biological, chemical, and physical features needed for life, such as suitable water quality, spawning areas, feeding sites, resting sites, and shelter from predators or adverse weather (Orth and White 1993). Physical habitat refers to the stream characteristics of bed materials, water depth, current velocity, bank slope, and cover as well as riparian characteristics that determined the amount of suitable living space for various species and life history stages. Physical habitat varies by life stage. For example, juvenile fish prefer shallow areas with cover, while adult fish tend to select habitats close to foraging locations and escape cover. The biological, chemical, and physical characteristics of a stream play a large role in determining the numbers, sizes, and species of fish that can be sustained or the assemblage of other aquatic life use.

The assessment of the streams' aquatic life potential was conducted in three phases. During Phase I, the physical and chemical characteristics of these streams were compared with New Mexico's water quality standards designed to protect aquatic life, as well as drinking water, and other beneficial uses. Each stream segment's physical habitat relative to two species of fish and the benthic macroinvertebrate community was then characterized. During Phase II, each segment's water and sediment (*i.e.*, sediment porewater) were tested to determine if they posed any acute or chronic toxicity to fish and invertebrates, under laboratory conditions. During Phase III, fish were placed in cages in the stream (*in situ*) to observe their response in the stream environment. A fourth phase of the evaluation was planned, and included the stocking of a native, montane fish assemblage (*e.g.*, Rio Grande trout, longnose dace, Rio Grande chub, and Rio Grande sucker [species names listed in Table 2]), but due to fiscal constraints, was not conducted during the LANL Water Quality Assessment. Such an endeavor would also require public review, but stocking native fish into suitable streams for their recovery remains a valuable conservation opportunity for natural resource management by USDOE, the National Park Service, the Santa Fe National Forest, or others.

Working with others, the USFWS assembled and employed a number of contractors and techniques to evaluate the biological, chemical, and physical characteristics of these four canyon streams. All information made available during this study concerning the existing uses of waters in these four canyons into which the LANL and the USDOE discharge, was collected and evaluated for this LANL Water Quality Assessment. This report summarized the objectives, methods, results, and findings of the LANL Water Quality Assessment. The biological evaluations were greatly assisted by toxicity testing, advice, and other services provided by the CERC. Also significant were the contributions of the New Mexico State University Fish and Wildlife Cooperative Research Unit and the LANL's Ecology Group, which has conducted numerous biological surveys in conjunction with USDOE projects that provided for an extensive database on the biodiversity of the LANL and surrounding areas. Both the LANL and the NMED have investigated and continue to survey the aquatic invertebrates in these streams (Bennett 1994; Cross 1994a, 1995a, 1997; Ford-Schmid 1996), including the stream segments selected for the LANL Water Quality Assessment (Ford-Schmid 1999). In the case of Sandia Canyon, benthic macroinvertebrate surveys were conducted annually from 1990 to 1997 (Bennett 1994; Cross 1994a, 1995a; Ford-Schmid 1999), often elaborating on the water quality impairment by acids or chlorine. Since the benthic macroinvertebrate community was recently surveyed, additional benthic macroinvertebrate surveys were considered unnecessary to meet the objectives of the study. Because the benthic macroinvertebrate community surveys conducted by Ford-Schmid (1999) were contemporaneous (except Pajarito Canyon surveyed in 1994) with the LANL Water Quality Assessment and overlapped the study locations, these results were used in our evaluation.

Guidance on water body survey and assessment techniques was also found in the Technical Support Manual, Volume I: Waterbody Surveys and Assessments for Conducting Use Attainability Analyses (USEPA 1983) and in the Water Quality Standards Handbook: Second Edition (USEPA 1995a). The combination of the techniques reported here may be applicable to the evaluation of other similar water bodies in New Mexico. Water body surveys and assessments should be designed with sufficient detail to answer the following questions:

1. What aquatic life uses or other beneficial uses are currently being achieved in or on the water body?

2. What are the causes of any impairment of water quality for a beneficial use?

3. What aquatic or other beneficial uses can be attained based on the biological, chemical, and physical characteristics of the water body?

OBJECTIVES

The objectives of this assessment were to:

1. determine the existing uses of the intermittent stream reaches in Sandia, Pajarito and Valle Canyons that cross the LANL;

2. determine if fish could be supported or propagated, or both, in the intermittent stream reaches selected by the Selection Committee;

3. identify any limiting, biological, chemical, and physical conditions that impair the water quality for aquatic life use, or a healthy fishery; and,

4. provide an informative report about the water quality of the selected intermittent streams of this area and the techniques used to evaluate them. After review by the Selection Committee, all information and data generated will be made available to the public, other researchers, monitoring organizations, and government agencies so as to allow an understanding of how the data were collected and analyzed.

ENVIRONMENTAL SETTING

General Setting

The study area is located within Los Alamos County on the Pajarito Plateau, the east slope of the Jemez Mountains in north-central New Mexico (Figure 1). The Jemez Mountains rise as a large volcanic landmass at the southern end of the Rocky Mountains approximately 80 kilometers (km) by air north of Albuquerque and 32 km northwest of Santa Fe. The Jemez Mountains are a remnant of a massive volcano that became active approximately 16 million years ago. Volcanic eruptions approximately 8.5 and 1.5 million years ago deposited thick lava flows, surge ash, and fall ash, which together, with sedimentary deposits, formed the soils and distinct plateaus around the Jemez Mountains (Kelly 1978; Nyhan *et al.* 1978; Self *et al.* 1996). The prominent physiographic features (Figure 2) that remained after the volcanism ended are the calderas (e.g, the Valle Grande and the Valle Toledo), dome mountains within the calderas (*e.g.*, Redondo Peak, Cerro de Abrigo), and the semicircular, mountainous rim of the collapsed volcano (*e.g*, the Sierra de los Valles are the easternmost portion of this rim that has nine peaks including Cerro Grande, Pajarito Mountain, and Tschicoma Peak) (Foxx *et al.* 1998). One material deposited, called the "Bandelier Tuff," which is mostly pumice and rhyolite ash, was laid down 1.4 to 1.1 million years ago on the western flanks (*i.e.*, the Jemez Plateau) and eastern flanks (*i.e.*, the Pajarito Plateau) of this volcanic mountain (Kudo 1974; Nyhan *et al.* 1978).

The Pajarito Plateau is a geologic feature that is about 32 to 40 km in length and 8 to 16 km wide (Figure 3). The Pajarito Plateau consists of a series of east- to southeast-trending mesas, separated by approximately 14 deeply incised canyons cut by subsequent erosion, runoff, and base flow. Some of the major canyons of the plateau include Santa Clara, Guaje, Pueblo, Los Alamos, Pajarito, Water, Frijoles, Ancho, and Capulin. The Pajarito Plateau slopes eastward from an elevation of about 2,286 meters (m) below the Sierra de los Valles (that range from 2,895 m to 3,526 m) towards White Rock Canyon that contains the Rio Grande (Figure 4). The White Rock Canyon rim is at an elevation of about 1,889 m with steep slopes formed by the down-cutting of the Rio Grande that is at an elevation of about 1,647 m. All of the surface water that drains from the Plateau, as well as ground water discharge, is into the Rio Grande (Purtymun 1995).

Environmental History

A brief summary of historical natural resource use identifies some of the human interactions with the ecosystems of the Jemez Mountains. Evidence of dry farming corn, beans, and squash was found as early as 4,000 years ago and continued through 1000 A.D. (Stuart 1986), and is still conducted by the LANL and the Pueblo people (Fresquez *et al.* 1997). During the Upland Period (~1100 A.D.), many people moved into the forest and woodlands, and evidence of larger scale farming began on the Pajarito Plateau (Foxx and Tierney 1984). A great drought around 1290 A.D., and other factors, led to large population declines, abandonment of the uplands, and the relocation of many villages to the confluences of major rivers and streams (Scurlock 1998). Many Pueblos in the region today, still reside near springs, arroyos, rivers and streams, and their people often consider the upland ruins sacred and certain natural resources to be ancestral. Several of the Pueblos of northern New Mexico have maintained a close relationship with wildlife, particularly migratory birds (Scurlock 1998). Archaeologist Edgar L. Hewett, who gave the name "Pajarito" to this plateau, was said to be inspired by the name of a pueblo ruin, "Tshirege," which means place of the bird people (Julyan 1996). Game hunting has been well documented, but historically, the ancestral people were not known to subsist upon or consume fish, amphibians, reptiles, or mollusks (Scurlock 1998). Nonetheless, fish bones were excavated from ruins at the Bandelier National Monument indicating some consumption, albeit not subsistence (Hubbard 1976). Bivalve shells have also been found (Steen 1977). Cultural traditions today include: using the Pajarito Plateau's natural resources for food, agriculture, trade, medicines, construction, crafts, arts, and ceremonies.

From the mid 1500s to the mid 1900s, the environmental history of the Jemez Mountains largely reflects the exploration and colonization by the Spanish, Europeans, and Anglo-Americans. The activities of farming, livestock raising, silviculture, mining, hunting, and trade in fur, settlement, and conflict with Puebloan people increased during this period. Several wildlife species (*e.g.*, grizzly bear, beaver, bighorn sheep, elk, mink, river otter, and gray wolf), were depleted from this environment, though later some were reintroduced or recovered naturally (Bailey 1971; Findley *et al.* 1975; New Mexico Department of Game and Fish [NMDGF] 1998). Portions of the Pajarito Plateau were then alternatively used for farming, grazing, mining, silviculture, recreation, and homesteading by various groups (USERDA no date; Foxx *et al.* 1998; Scurlock 1998). Steen (1977) reported a water control system, with a ditch and diversion dam, on Pajarito Creek (Site LA 12701), but these irrigation facilities were not clearly identifiable to their cultural provenance.

Land ownership on the Pajarito Plateau includes the Department of the Interior National Park Service Bandelier National Monument, the USDOE, the Department of Agriculture Santa Fe National Forest, the Counties of Los Alamos, Santa Fe, and Sandoval, the Pueblos of Santa Clara, San Ildefonso, Cochiti, and Jemez, and private lands including the towns of Los Alamos and White Rock. By the mid to late 1900s, large portions of the Pajarito Plateau and Jemez Mountains were acquired by the Federal Government for the Forest Service, the Bandelier National Monument, and portions were later used for the Manhattan Project to develop the atomic bomb that subsequently became the Los Alamos National Laboratory.

The Los Alamos National Laboratory

The LANL currently covers more than 111 km^2 of mesas and canyons on the Pajarito Plateau in northern New Mexico (Figure 1). Owned by the USDOE (1 of 28 USDOE-owned laboratories in the United States), the LANL has been managed by the University of California since 1943, when it was part of the Manhattan Engineering Division's Project Y designed to create the atomic weapons used during World War II. Today, the LANL is a multi-disciplinary and multi-program scientific research center whose central mission is to design, develop, and test nuclear weaponry and reduce the nuclear danger through evaluation and stockpile stewardship. The LANL also includes programs in energy, nuclear safeguards, biomedical science, education, electronics, aeronautics, physics, chemistry, metallurgy, earth sciences, environmental cleanup, mathematics and computational science, materials science, and other basic sciences (UCR 2000). Approximately one-third of the staff are physicists, one-fourth are engineers, one-sixth are chemists and materials scientists, and the remainder work in mathematics and computational science, biological science, geoscience, and other disciplines (UCR 2000). The LANL's mission recently became integrated with the newly-formed National Nuclear Safety Administration of the USDOE. Also recently, the Cerro Grande Fire burned a large portion of the forest ecosystems on and up slope of the LANL; the appearance of the landscape has changed dramatically, and the habitats discussed herein may be altered and impacted by these watershed conditions. The LANL is currently evaluating the flood and erosion risks associated with the affected areas and implementing strategies to address the potential increased storm water runoff expected (USDOE 2001).

Climatological Setting

Weather dictates the ranges of precipitation, temperature, humidity, wind, and evaporation experienced on the Pajarito Plateau. The climate of the area is governed by latitude, elevation, and proximity to the Sierra de los Valles that locally modifies airflow and precipitation patterns. Bowen (1990, 1992) evaluated a composite record from 1961 to 1990 using weather stations at an elevation of approximately 2,250 m above sea level to describe the climate of Pajarito Plateau. The Pajarito Plateau has a temperate mountain climate with four distinct seasons. Spring tends to be windy and dry. Summer tends to be warm and dry in June, followed by a two-month rainy season. July is the warmest month with an average daily high of 27.2 degrees Celsius (C) and an average daily low of 12.8 C. The extreme daily high temperature on record is 35 C. In autumn, there is a return to drier, cooler, and calmer weather. January is the coldest month with temperature ranges from 4.4 to -8.3 C. The extreme daily low temperature on record is -27.8 C.

The average annual precipitation on the Pajarito Plateau is 47.6 centimeters (cm), but varies considerably from year to year and by elevation. The lowest recorded annual precipitation for the stations on Pajarito Plateau is 17.3 cm and the highest is 77.1 cm. The source of precipitation to the Jemez Mountains comes from the winds across the Pacific Ocean and Gulf of Mexico. The elevation of the Jemez Mountains causes cooler temperatures thus condensing water out of the rising air, resulting in higher humidity and precipitation in the mountains and semi-arid lands at lower elevations. The annual precipitation levels show this effect of the changing elevations as there is an east-to-west gradient in precipitation across the Pajarito Plateau. Lower elevations near the Rio Grande received about 35 cm average annual precipitation and the higher elevations receive 60 cm or more (Bowen 1990). The peak rainfall months are July and August. Lightning is very frequent. Most winter precipitation falls as snow with an average of 150 cm, but it can vary widely. The highest recorded snowfall for one season is 389 cm and the extreme single storm snowfall on record is 122 cm.

Hydrologic Setting

Intermittent flowing streams have helped to form the entrenched canyons on the Pajarito Plateau since its deposition 1.1 million years ago. Intermittent and ephemeral streams play a vital role in the hydrological cycle, transporting the rain collected across the Pajarito Plateau to the Rio Grande. According to Purtymun (1995):

> Los Alamos surface water occurs primarily as intermittent streams. Springs on the flanks of the Sierra de los Valles supply base flow into upper reaches of some of the canyons (Guaje, Los Alamos, Pajarito, Canyon de Valle, and Water Canyon), but the amount is insufficient to maintain surface flow across the Pajarito Plateau before it is depleted by evaporation, transpiration, and infiltration. Runoff from heavy thunderstorms or heavy snowmelt reaches the Rio Grande several times a year in some drainages. Effluents from sanitary sewage, industrial waste treatment plants, and cooling-tower blowdown are released into some canyons at rates sufficient to maintain surface flow for short distances on the Pajarito Plateau.

Purtymun (1995), and the USDOE (1999) identified several portions of these intermittent streams as perennial. Dale (1998) identified portions of Sandia Canyon, Pajarito Canyon, Valle Canyon, and Los Alamos Canyon above the reservoir as having perennial flow. Since 1943, the primary use of Sandia Canyon has been disposal of liquid waste from industrial and sanitary systems, and the resultant downstream wetlands had nearly reached their full areal extent by 1974 (LANL 1999a). The Sandia Canyon benthic macroinvertebrate community has been investigated annually from 1990 to 1997 (Bennett 1994; Cross 1994a, 1995a; Ford-Schmid 1999; this study). These intermittent streams, invertebrate communities, and other aquatic wildlife have been investigated annually for years or have also been reported as perennial by many researchers (Brooks

1989; Bennett 1994; Cross 1994a, 1995a, 1995b; Foxx and Blea-Edeskuty 1995; Cross and Davila 1996; Cross 1997; and Ford-Schmid 1996, 1999).

However, definitions of what constitutes perennial are varied. The NMWQCC (1995) defines "perennial stream: as a stream or reach of a stream that flows continuously throughout the year in all years; its upper surface, generally, is lower than the water table of the region adjoining the stream." The location of the regional water tables near these streams was not determined for this study, although springs were observed above the stream bed. Also, the stream segments were visited from July 1996 to November 1997 and found free-flowing (though ice-covered during winter). Potentially surface water flow may be altered by recharge of the alluvial aquifer, recharge due to the establishment (or cessation) of discharged waste water effluents, or variability of rainfall, but any consequent change in flow might take decades to fully manifest itself as the mechanism of ground water recharge and discharge along these canyons is not well known (Frenzel 1995). However, Blake *et al.* (1995) suggested, based on tritium data and stable isotope analyses, that an area of recharge at an average elevation of 2,530±100m was the most likely source of the waters found in Los Alamos Creek and Pajarito Creek.

Geologic Setting

Geologic characteristics influence the nature and extent of groundwater storage, the type of material available for erosion and transport, and to some extent the chemical quality of the surface and ground water (Grant 1997). The natural geochemistry of the surrounding soils, alluvial ground waters, and surface waters at the LANL are largely determined by the local geology, which is primarily made up of the Bandelier Tuff (rhyolite ash flow and falls, pumice and breccia, some welded), and alluvium derived from the Tschicoma Formation (latite, quartz latite, and pyroxene andesite flows; some tuffs) (Kelly 1978; Self *et al.* 1996). The stream segments studied in Sandia, Valle, and Pajarito Canyons were dominated by soil subtypes derived from the Bandelier Tuff, whereas soils in the upper portion of Los Alamos Canyon were derived primarily from the more stable and less erodible Tschicoma Formation (Nyhan *et al.* 1978; Gray 1996). The generalized soil types in Los Alamos Canyon are primarily sandy loams, as in the other canyons studied. Sandy loams have a moderately high precipitation runoff potential, and a low water transmission rate (Gray 1996). Nyhan *et al.* (1978) found that Sandia Canyon also contained Carjo loams and rock out-croppings. Pajarito and Valle Canyons were more heterogenous. Pajarito was dominated by Carjo loams on the north-facing slopes and a combination of Tocal very fine sandy loams, fine loamy Typic Eutroboralfs, and clayey skeletal Typic Eutroboralfs elsewhere. Nyhan *et al.* (1978) did not identify Carjo loams in Valle Canyon, and reported mostly Tocal very fine sandy loams and Typic Eutroboralfs.

Given the volcanic origins, soils on the Pajarito Plateau have surprisingly variable physical and chemical characteristics (*e.g.*, percent calcium carbonate, clay mineralogy, iron oxides, and trace element chemistry), thus, generalized statements regarding 'background" soil and water mineral and trace element concentrations or mobility may require caution in their interpretation. Because soils with higher clay content may also have higher concentrations of aluminum and iron, and perhaps barium (Ferenbaugh *et al.* 1990; Longmire *et al.* 1996), canyons with higher clay content soils could correspondingly have higher background concentrations of these minerals in water, sediment, and porewater. While all canyons contain some percentage of clay soils, Pajarito Canyon contained a distinctly clayey soil (Nyhan *et al.* 1978). Soil clay fractions were primarily composed of montmorillonite and illite, which were the weathered products of the Bandelier Tuff (Gray 1996, citing others). Clay soils can also restrict the movements of certain heavy metals and have a higher cation exchange capacity, so they may influence the dissolution, mobility, and toxicity of metals (Ebinger *et al.* 1994; Longmire *et al.* 1996). Graf (1995) reported that soil and sediment transport of sorbed metals and radionuclides are a primary mechanism for contaminant distribution within the watersheds of the Pajarito Plateau. High absorption affinities of fine-grained sediments for metals and radionuclides enhanced their transport to the Rio Grande downstream (Graf 1995).

Ecoregional Setting

Knowledge and classification of the ecological communities of the Jemez Mountains can form a basis for natural resource conservation and management. Ecological classifications have been recognized as important tools to identify the unique interactions among plant and animal species as well as systematically characterizing the current pattern and condition of the landscape. Ecoregional classifications recognize the limiting effects of the moisture regime and temperature minima as well as the evolutionary origin on the structure and composition of terrestrial plant and animal communities in the West. Several biogeographers (Bailey 1976; Brown and Kerr 1979; Omernik 1987; Grossman *et al.* 1998; Brown *et al.* 1998) have developed hierarchical classification systems for the biotic communities of North America that include those of the Jemez Mountains and the Pajarito Plateau. Omernik (1986, 1987) identified the Jemez Mountains as part of the Southern Rockies Ecoregion. These ecological classifications were used to facilitate the LANL Water Quality Assessment in the biotic inventory of expected plants and animals, in the delineation of habitat, in the interpretation of biological values, and in the selection of a reference site.

Using interpretation of high altitude aerial photography, the National Wetland Inventory mapped the wetlands of the Pajarito Plateau using the Cowardin *et al.* (1979) wetland classification system. In this montane region, wetlands and riparian areas are located in a wide range of sites from cliff faces to flat canyon valley floors (Windell *et al.* 1986; USFWS 1990; USDOE 1999). Perennial, temporarily flooded, seasonally flooded, or artificially flooded palustrine wetlands in forested and scrub/shrub habitats, as well as perennial, intermittent, and temporarily flooded, riverine streambed, wetlands and riparian areas were identified and mapped on the LANL by the USFWS (1990).

Jacobi *et al.* (1995) and Cowley *et al.* (1997) classified the intermittent and perennial streams of New Mexico that included those of the Jemez Mountains into Aquatic Ecoregions. Based on a statistical analysis of 25 chemical, physical, and climate variables, Jacobi *et al.* (1995) and Cowley *et al.* (1997) identified streams above 2,135 m on the Jemez Mountains as being part of Aquatic Ecoregion 1 and those waters on the Jemez Mountains from 2,135 m to 1,675 m as part of Aquatic Ecoregion 2. Jacobi *et al.* (1995) characterized Aquatic Ecoregion 1 by elevation (>2,135 m), low water hardness, low alkalinity and other chemical constituents, low fish species diversity, and a rich benthic invertebrate fauna. This classification, however, does not take into account geologic and zoogeographic histories of native fish in watersheds (Hatch *et al.* 1998) or previous historical disturbances such as logging, fire, agricultural activities, long-term isolation from other streams, or other factors that could account for any lack of fish fauna observed in a water body.

Floral Communities

A considerable database of plant species of the Jemez Mountains including the Pajarito Plateau has been acquired over the past 40 years and reported by Foxx *et al.* (1998). Foxx and Tierney (1984) described 6 major plant communities that included 16 different types of plant habitats (Figure 4). The six major communities were:

1. the subalpine meadows atop the Sierra de los Valles and Valle Caldera;
2. the spruce-fir (*Picea*, *Pseudotsuga*, and *Abies spp.*) or conifer forest, of the upper mountains at elevations from 2,900 m to 3,050 m;
3. the mixed conifer forest of the mountainsides, high mesa slopes, and upper canyons at elevations from 2,440 m to 2,740 m;
4. the ponderosa pine (*Ponderosa pinus*) forest of the mesa tops and mid-canyons at elevations from 1,980 m to 2,440 m;
5. the woodlands (*Juniperus* and *Pinus spp.*) of the lower mesas and canyons at elevations from 1,950 to 2,290 m; and,
6. the woodland savannah and grasslands of the lower elevation mesas and canyons at elevations from 1,650 m to 1,950 m.

The elevations of these six plant communities reported by Foxx and Tierney (1984), were estimated, as local changes in temperature, soil moisture, altitude, aspect, slope, geology, and differences in the amount of solar radiation result in many transitional overlaps of these soils and plants. Dick-Peddie (1993, citing others) recognized this canyon effect on New Mexico plant communities when he wrote of the tendency of the higher elevation plant communities to move further down canyons than expected and of the lower plant communities to move further up the mesa and ridges than expected in connection with available soil moisture. Foxx and Tierney (1984) did not report riparian and wetland vegetation as a major community.

In total, Foxx *et al.* (1998), reported over 1,060 plant species on the LANL and surrounding areas and classified each species according to a variety of taxonomic, geographic, economic, ethnographic and biotic attributes. Fifteen percent (160/1061) of the total plant species listed almost always occur in wetlands (obligate, 7 percent) or usually occur in wetlands (facultative, 8 percent). Some of the vegetation in this region has an obligate relationship with fungus. Jarmie and Rogers (1996) reported 228 species of fungi on the Pajarito Plateau. Some of these fungi are harvested for food, most assist in the transformation of nitrogen compounds, and some are poisonous.

Faunal Communities

By virtue of its location on a mountain in a semi-arid climate, the Pajarito Plateau offers diverse land forms, a decisive change in elevation and temperature, and clean water from melted snow, runoff, springs, and seeps, that have all produced a diverse plant and animal community. The interfingering of deep, steep-sided canyons with narrow mesas that descend the Jemez Mountains and Pajarito Plateau with an inversion of the normal altitudinal distribution of vegetative communities along the canyon floors has also resulted in many transitional overlaps of plant and animal communities and increased biological diversity. Beardsley (1994) reported that areas with abundant sunshine and water, such as the Jemez Mountains, favor an abundance of plant species, and with strongly varying temperatures between summer and winter, there were more abundant animal species compared with areas of low seasonality.

The extraordinary biodiveristy found on the Jemez Mountains including the Pajarito Plateau was illustrated by the presence of over 1,060 species of vascular plants (Foxx *et al.* 1998), 67 species of mammals, 208 species of birds (Travis 1992), 23 species of reptiles, 9 species of amphibians, over 1,200 species of arthropods, over 230 taxa of aquatic macroinvertebrates (Cross 1996b), and 9 species of fish (Calamusso and Rinne 1999; Sublette *et al.* 1990). Of the 310 vertebrate species of the Jemez Mountains (listed in Table 2), 7 percent are fully aquatic including 9 montane species of fish (with 14 other species found in the Rio Grande). An additional 13 percent of the vertebrate species are semi-aquatic, such as amphibians, ducks, herons, and the American dipper, that are found in suitable habitat (lakes, ponds, streams, wetlands) on the Jemez Mountains. For instance, waterfowl visited the standing bodies of water on the Pajarito Plateau as well as foraged along the Rio Grande and other wetlands in tributary canyons (Brooks 1989; Travis 1992; Foxx and Blea-Edeskuty 1995). Twenty-eight percent of the species are entirely terrestrial, but an additional 34 percent of the terrestrial species are also found in association with wetlands and riparian vegetation resulting in the majority (63 percent) of the vertebrates species found on the Jemez Mountains depending in some way on wetland or riparian habitat to complete their life cycles. A list of common and scientific names of wildlife discussed in this report is provided in Table 2.

STUDY AREA AND SITE SELECTION

Description of the Canyons

Four watersheds contain the stream segments studied, including Los Alamos, Sandia, Pajarito, and Valle Canyons (the term Valle Canyon is used in place of Cañon de Valle, and since Valle Canyon is not an entire watershed, the term drainage is used where appropriate). These canyons were evaluated as watersheds (Table 3), and their various geomorphic dimensions were obtained from LANL reports (LANL 1999b; USDOE 1999) or United States Geologic Survey topographic maps (Figure 5).

Los Alamos Canyon

Los Alamos Canyon, the largest drainage basin (28.4 km^2), ranged in elevation from 3,182 m at the top of Pajarito Mountain to 1,725 m at its confluence with Guaje Canyon. Los Alamos Canyon had the greatest proportion of spruce-fir forest and least amount of grassland compared with other canyons studied (Table 3). The top elevation of the stream segment studied was 2,371 m and the predominant vegetation type was a mixed conifer forest (Figure 6). Biological resources for portions of Los Alamos Canyon were reported by Ferenbaugh *et al.* (1990); Bennett (1993); Foxx *et al.* (1995); Cross and Davila (1996); Gray (1996); Hinojosa (1997); Ford-Schmid (1999); and Hansen *et al.* (1999).

Los Alamos Canyon on lands owned by the Santa Fe National Forest is a popular recreational area. Camping, picnic areas, and an ice-skating rink are located near Los Alamos Reservoir, and the reservoir itself was used for fishing, swimming, and ice sports in the winter. Purtymun (1979) and Purtymun *et al.* (1983, 1984, 1985, 1986a, 1986b, 1987, 1991, and 1993) have documented the uses of water from this reservoir for irrigation, municipal, and industrial purposes, and these uses consumed an average of about 7,570 m^3 per year.

The LANL Technical Areas within the Los Alamos watershed included: TA-2, TA-3, TA-21, TA-41, TA-43, TA-62, TA-72, TA-73, and TA-74, that are all below the stream segment studied. Activities conducted at these technical areas are potential sources of contamination including a nuclear reactor housed at TA-2, and weapons development at TA-41 (LANL 1995b). There is also mesa top contamination that may eventually reach the canyon through erosive processes. The most probable contaminants of the middle and lower canyon are radiological and chemical including uranium, plutonium, tritium, strontium, cesium, chromium, mercury, acids, and solvents (LANL 1995b).

The NPDES discharges to Los Alamos Canyon have numbered as many 12, but have now been reduced to 5. Discharges are from research laboratories and cooling towers. The USDOE (1999) reported the total volume of wastewater discharged to Los Alamos

Canyon was 74,573 m^3 per year. None of these discharges or potential sources of contaminants are located in or above the stream segment studied.

Sandia Canyon

Sandia Canyon had the smallest watershed (14.2 km^2) and ranged in elevation from ~2,286 m to 1,664 m at its confluence with the Rio Grande. The canyon vegetation was dominated by piñon and/or juniper woodland, although the stream segment studied was in a mixed ponderosa pine forest (Figure 6). The top elevation of the stream segment studied was 2,192 m. Although access is restricted on USDOE lands, Sandia Canyon received some employee recreation as well as public trespass visitation. Biological resources for portions of Sandia Canyon were reported by Dunham (1993); Cross (1993); Bennett (1994); Cross (1994b); Cross (1994c); Cross and Davila (1996); Hinojosa (1997); Ford-Schmid (1999), Bennett *et al.*(1999), and Bennett *et al.*(2001).

The LANL Technical Areas within the Sandia Canyon watershed included: TA-3, TA-5, TA-53, TA-60, and TA-61. Activities conducted at these technical areas that are potential sources of contamination included research laboratories, a sewage treatment plant, cooling towers, and salvage yard, a county landfill on the north slope, a former Atomic Energy Commission facility, several firing ranges, and the proton accelerator and support facility (LANL 1999b). There is also mesa top contamination that may eventually reach the canyon through erosive processes. The contaminants most likely in the upper canyon, above the stream segment studied, are polychlorinated biphenyls (PCBs), metals, and other organic chemicals (LANL 1999b). In the remainder of the canyon soils and sediments, contaminants included tritium, uranium, plutonium, lead, mercury, cadmium, hydrocarbons, and other metals or organic chemicals (LANL 1999b).

The NPDES discharges associated with Sandia Canyon have numbered as many as 10, but now number 7. Discharges are from the power plant, sewage treatment, and cooling towers. The USDOE reported the total volume of wastewater discharged to Sandia Canyon was 408,446 m^3 per year (USDOE 1999; Bennett *et al.*2001).

Pajarito Canyon

Pajarito Canyon ranged in elevation ranged from 3,182 m at the top of Pajarito Mountain to 1,658 m at its confluence the Rio Grande. The canyon vegetation was dominated by ponderosa pine and spruce-fir forest (Figure 7). The vegetation near the stream segment studied was also spruce/fir mixed with ponderosa pine and contained a steep-sided narrow canyon with a 2-m waterfall. Pajarito Canyon was also substantially developed (15.3 percent) compared with other canyons studied, largely owing to the town of White Rock, New Mexico, downstream (Table 3, Figure 7). The top elevation of the stream segment studied was 2,249 m. Although access is restricted in the upper watershed, some daytime, employee recreation occurred, and downstream, Pajarito Canyon received unrestricted recreation near the town of White Rock. Biological resources for portions of Pajarito Canyon were reported by Banar (1993); Raymer (1993); Salisbury (1994); Keller and Risberg (1995); Benson *et al.* (1995); Cross *et al.* (1996); Ford-Schmid (1996); and Hinojosa (1997).

There are numerous LANL Technical Areas within the Pajarito Canyon watershed. Activities conducted at these technical areas that are potential sources of contamination included the research and testing of explosives, firing and detonation sites, material disposal areas, and Material Disposal Area M in particular (LANL 1999b). There is also mesa top and building contamination that may eventually reach the canyon through erosive processes. The most probable contaminants of the upper canyon, above the segment studied, are heavy metals such as lead, iron, mercury, and cadmium. These, along with explosives, radionuclides including depleted uranium, asbestos, and other heavy metals would likely be found in the remainder of the canyon soils and sediments downstream of the segment studied (LANL 1999b).

The NPDES discharges associated with Pajarito Canyon have previously included 17 outfalls, but now there are none. Previous discharges were associated with explosive testing, other material laboratories and shops, and an X-ray building. Activities associated with explosives manufacture and testing as well as runoff from the material disposal areas could contribute contaminants to the segment studied. The USDOE reported the total volume of wastewater discharged to Pajarito Canyon was 34,826 m^3 per year (USDOE 1999).

<u>Water Canyon Watershed and the Valle Canyon Drainage</u>

The Valle Canyon drainage ranged in elevation from 3,182 m at the top of Pajarito Mountain to 2,073 m at its confluence with the parent watershed, Water Canyon. Water Canyon vegetation was mostly forest and woodlands (87 percent, Table 3), although it also had the greatest amount of grasslands (Figure 7), which was attributed to the succession and effects of the La Mesa Fire of 1977. The vegetation near the stream segment studied was ponderosa pine. There are five springs in the Valle drainage and stream baseflow reported by Cross (1997) was 6.5×10^{-4} m^3/second. The top elevation of the stream segment studied was 2,237 m. Although access is strictly restricted for most of watershed, there was some daytime, employee recreation. The lowermost portion of Water Canyon received unrestricted public recreation. Biological resources for portions of Water Canyon were reported by Banar (1993); Cross (1995b); Haarmann (1995); USDOE (1996); Cross (1997); Hinojosa (1997); and Ford-Schmid (1999).

The LANL Technical Areas within the Valle Canyon drainage included: TA-8, TA-9, TA-14, TA-15, and TA-16. Activities conducted at these technical areas are potential sources of contamination that included the research and testing of explosives, firing and detonation sites, material disposal areas, and Material Disposal Area P in particular

(LANL 1999b). Septic system discharges, NPDES outfall discharges from the high explosives machine shop Building 260, wastes from a silver recovery shop, and the wastes from treatment plant are previously discharged directly into the canyon corridor above the stream segment studied. There is also mesa top and building contamination that may eventually reach the canyon through erosive processes. The most probable contaminants of the upper canyon, above the stream segment studied, are heavy metals such as lead, mercury, silver, and barium, explosives, and possibly PCBs (LANL 1999b), although Cross (1997) identified many more heavy metals as potential contaminants. These, along with uranium, and other heavy metals would likely be found in the remainder of the canyon soils and sediments downstream of the stream segment studied (LANL 1999b).

Before 1996, NPDES discharges associated with Valle Canyon included eight outfalls, but some of these have been removed or consolidated and now 5 discharges occur to Water Canyon or its tributaries (Haarmann 1995; USDOE 1996; USDOE 2001). Activities associated with explosives manufacture and testing, NPDES discharges, as well as runoff from the material disposal areas could have contributed contaminants to the segment studied (LANL 1998c). The USDOE (1999) reported the total volume of wastewater discharged to Valle Canyon was 63,784 m^3 per year.

Site Selection, Location, and Description of the Stream Segments Studied

Sites within four canyon drainages that were studied were not randomly selected, but instead, were identified by the Selection Committee and mutually agreed upon by all parties (Figure 5). These sites are classified as "segments of streams within canyon drainages" and further divided into "stream reaches" using the hierarchical stream system proposed by Frissell *et al.* (1986). These stream segments were selected for study by the Selection Committee based on preliminary information provided by the LANL, the Oversight Bureau, as well as other factors (presence of NPDES discharges, logistics, national security, safety, *etc.*). The stream segments in the four canyons identified by the Selection Committee to be included in the LANL Water Quality Assessment are:

- in Los Alamos Canyon (both above and below the Los Alamos Reservoir),
- in Sandia Canyon,
- in Pajarito Canyon, and
- in Valle Canyon (a tributary drainage to Water Canyon).

In each stream selected, a representative, 300-m stream segment was chosen based on similarity in habitat appearance to the general habitat features observed within approximately 600 m of the upstream boundary of perennial water flow identified by others. All LANL Water Quality Assessment activities took place in connection with this 300-m segment, including water, sediment, and biological sample collection, monitoring, observations, habitat analyses, and toxicity testing.

A large pool in each stream segment was selected for installation of a water quality monitoring device in 1996. The same pool was used for a preliminary, caged-fish study, and later in 1997, this pool also became the upstream location of the first of nine selected for the *in situ*, caged-fish bioassays. Two 100-m reaches were evaluated at the distal ends of the 300-m stream segment. The beginning of these 100-m reaches was selected at random upstream of the third set of *in situ* cages, and downstream of the seventh set of *in situ* cages (Figures 8, 9, 10, and 11). These 100-m reaches were divided into 10 transects for detailed habitat measurements (*e.g.*, flow, substrate characteristics).

Each cage, monitoring location, and habitat transect evaluation for each stream segment was documented using a global positioning system (GPS; Precision Lightweight Global Position System Receiver [PLGR Model HNV-560c, Rockwell International, Cedar Rapids, Iowa]), and this location is provided in Table 4. However, the GPS locations for the habitat evaluation transects in the lower portion of the Pajarito Canyon stream segment were unavailable at the time of study. The general location of the stream segments selected for study included:

- *Site 1: Los Alamos Canyon (reference site)* (Figure 8). This stream segment is located approximately 330 m upstream of Los Alamos Reservoir, on the Santa Fe National Forest, in Section 12, Township 19 North, Range 5 East of the New Mexico Principal Meridian. This Los Alamos Canyon stream segment was chosen as the reference site because it was considered relatively free of LANL contamination and wastewater discharges; it was in proximity to the other study sites; it was perennial; and has an existing trout fishery.

- *Site 2: Los Alamos Canyon, below the reservoir* (Figure 5). This stream segment is located about 330 m below the Los Alamos Reservoir in Section 18, Township 19 North, Range 6 East of the New Mexico Principal Meridian. During 1997, surface water flows were found to infiltrate the alluvial canyon bottom immediately below the dam's spillway, and then re-emerge approximately 60 m downstream and continue to State Road 501. The stream channel in this area is intermittent, as diversion of surface water from the Los Alamos Reservoir is used for irrigation in the town of Los Alamos. Only one stream reach in this segment was selected for habitat evaluation. To differentiate between the stream segment above the reservoir, this site was indicated as "Los Alamos Canyon, below the reservoir," in this report.

- *Site 3: Sandia Canyon* (Figure 9). This stream segment is located approximately 700 m downstream of the waste water Outfall 01A-001, on USDOE land, in Section 16, Township 19 North, Range 6 East of the New Mexico Principal Meridian. This stream segment receives several waste water discharges as well as runoff from the extensive paved areas in the upper watershed at TA-3, which comprise the majority of its flow. There is also a 2 hectare (ha) wetland that has formed near the top of the drainage, above the stream segment evaluated in this study.

- *Site 4: Pajarito Canyon* (Figure 10). This stream segment is on USDOE land, in Section 20, Township 19 North, Range 6 East of the New Mexico Principal Meridian. This stream segment is located approximately 300 m downstream of several springs (Charlie's Spring, Homestead Spring, and Starmer's Spring) that supply baseflow to the stream (Dale 1998).

- *Site 5: Valle Canyon* (Figure 11). This stream segment is on USDOE land, in Section 29, Township 19 North, Range 6 East of the New Mexico Principal Meridian. This stream segment is located approximately 800 m downstream of several springs (S.W.S.C. Spring, and Burning Ground Spring) that supply baseflow to the stream (Dale 1998), although recharge from the area's unique geology (faults, permeable ash layers) has been suggested (R. Ryti, Neptune Inc., pers. comm.).

MATERIALS AND METHODS

BIOLOGICAL DATA COLLECTION AND ANALYSES

Fish Surveys

The presence of fish in the study streams was determined by surveying a length of approximately one-third of the perennial stream segment using backpack electrofishing equipment (Model 12 POW Electrofisher, Smith-Root, Inc., equipped with a 24 volt battery). Electrofishing procedures applied at the sites generally followed those for wadable streams reported by Meador *et al.* (1993), with exceptions as noted below. Representative reaches were sampled in a single pass, working upstream in Los Alamos Canyon, and downstream in the other canyons surveyed.

The current density (from the backpack electrofishing equipment) was about 0.1 milliamperes per square cm. Electrofishing equipment was operated with a variable voltage (from 500 to 1,000 millivolts). This adjustment allows the system's applied power to be increased or decreased given fish response and effectiveness of capture (Kolz and Reynolds 1989). During this survey, the waveform varied from 40 to 60 hertz, input amperage ranged from 12 to 18 amps, and output amperage ranged from 0.1 to 2 amps. In canyons where no fish were found within 300 m, increased power was applied to ensure fish response would be observable. When fish were observed and captured, the electrical power applied was stopped to reduce the probability of injury to the fish.

The backpack electrofishing equipment records the time power was applied, or "shocking seconds." Shocking seconds ranged from 550 to 900, except Sandia Canyon, where over 1,500 shocking seconds were applied. To determine fish presence, the stream reach in Sandia Canyon was electrofished on November 20, 1996, in Valle Canyon and Pajarito Canyon on November 22, 1996, and in Los Alamos Canyon on January 3, 1997, October 10, 1997, and December 17, 1998. Presence and total numbers of fish and fish species collected were recorded. In October 1997, in Los Alamos Canyon, captured fish were weighed and measured, examined for general condition, then returned downstream. Capture locations were then marked with flagging stakes for a subsequent, additional habitat assessment. Habitat quality parameters were then measured at locations where the fish were found in order to calibrate the fish habitat models.

Caged-Fish Bioassays

Fish are excellent indicators of water quality since: 1) they remain in contact with their aquatic habitat and avoidance of exposure is difficult, 2) they are highly sensitive to pollution and their responses integrate multiple stressors, and 3) they can serve as a direct measure of the bioavailability of contaminants from the many different environmental compartments in aquatic systems (Cleveland *et al.* 1999). While monitoring chemicals in water and sediment are a valuable means of judging the quality of the canyon stream environments, it is not practical to monitor all stressors that may be relevant to the sustainability of a fishery. Also, routine analytical methods may not be sufficiently sensitive to reliably measure low and potentially significant concentrations of pollutants in the environment (Price 1979). The combination of stressors that are encountered in these canyon streams may be modified by site specific factors or produce effects different from those indicated in fish in a laboratory. To overcome these disadvantages or depend on the use of natural fish populations (or lack of fish populations), caged-fish were placed in the streams in order to evaluate their response to various site specific stressors.

Cage Construction, Placement, Fish Measurement, and Chemical Analyses

Cages were constructed of 2-cm, polyvinyl chloride (PVC) pipe and nylon netting (Memphis Net and Twine Co., Inc., Memphis, Tennessee). The PVC pipes were glued into a rectangular box with dimensions of 61 cm long by 38 cm wide by 38 cm deep. Nylon netting with a 0.30-cm mesh of the same box dimensions, and with a reclosable top, was secured to the piping using plastic fasteners. Numerous 0.3-cm holes were drilled into the piping to reduce buoyancy. Following construction, cages were placed in a tap-water filled pool for three days, then in the streams for several days prior to the initiation of testing, in order to leach any potentially toxic compounds present in the PVC piping or glue.

Nine sets of cages (18 total) were placed along the 300-m stream segment studied for the caged-fish bioassays. One set of nine cages was used to evaluate the *in situ* toxicity of canyon stream water (Toxicity Cages), and the other set was used to evaluate the bioaccumulation of contaminants (Bioaccumulation Cages). Each cage was weighted with a rock from the stream (~20 to 36 cm in diameter), and secured with rope to nearby trees, boulders, or stakes. The rock placed on the cage's bottom not only secured the cage to the stream bottom, but reduced stress to the fish. Cages were marked with USFWS identification tags, then each cage was supplied with 10 fathead minnow (*Pimephales promelas*). Cage sets (consisting of 1 Toxicity Cage and 1 Bioaccumulation Cage) were positioned approximately every 30 m in the 300-m stream segment. While attempts were made to place cages in a variety of habitat types, most cages were placed in pools and glides. Cage locations were documented using GPS. (Table 4, Figures 8, 9, 10, and 11).

Fathead minnows were reared in well-water for approximately seven months at the CERC, prior to shipment to the site and use in the caged-fish bioassays. Fathead minnow were selected because they are native to this region (Sublette *et al.* 1990; Platania 1993), their life-cycle is well-documented, their gender is easily distinguishable, and toxicity test methods for this species have been standardized so they are practical for caged-fish bioassays. To prevent establishment of a fishery from escaped fish, only female fish were used. Lack of male fish would also tend to reduce territorial behavior and stress, as well as reduce gender variation in contaminant body burdens. Two weeks prior to the start of the caged-fish bioassays, the fish were acclimated to a pH of 8.0 and a hardness of 100 mg/L at the Columbia Facility to simulate the water chemistry of streams at the LANL. The day before tests were to start, fish were shipped overnight to the USFWS in water-filled, plastic bags with an oxygen head space in styrofoam and cardboard coolers. Fish were then randomly separated into water and oxygen filled plastic bags in groups of 20 to 40 for ease of transport and release into the in-stream cages. Prior to release, fish were acclimated to ambient water temperatures by placing the bags in the stream and individual fish were weighed and measured. Total fish length and weight was measured in a plastic tray, on a portable electronic scale (Ohaus® Model LS-2000 Standard).

To determine the potential performance of a caged-fish study in these canyon streams, a pilot caged-fish bioassay (pilot study) was initiated on June 17, 1997, using 2 cages per stream at the beginning of the 300-m stream segment of study. Five female fish were placed in each cage, and another five fish were measured, sacrificed and composited at the start of this bioassay to establish baseline whole body concentrations of contaminants. On July 25, 1997, and July 28, 1997, these pilot study fish were removed, measured, sacrificed, composited, placed in glass jars, and frozen for PCB congener analysis.

On July 29, 1997, 90 fish were measured and sacrificed at the start of the full-scale, caged-fish bioassays to establish baseline tissue concentrations of elemental contaminants. Twenty fish were then weighed and measured and 10 each were placed in the Toxicity and the Bioaccumulation cages. Each stream then, would contain 9 sets of cages with 10 fish in each cage, for a total of 90 fish. Toxicity cages were checked for fish mortality daily for the first 96-hours of exposure, then weekly or biweekly for the remaining ~2 months. Bioaccumulation cages were checked periodically, and fish were removed for length and weight measurement and chemical residue analysis after 1 month (on August 25, 1997) and again after 2 months exposure (on September 29, 1997, from Valle Canyon, on September 30, 1997, from Los Alamos and Sandia Canyons, and on October 1, 1997, from Pajarito Canyon). At the end of the study, all remaining fish and cages were removed.

Scans of 17 elements and PCBs were performed on pre-exposure fish and on the samples of fish collected from the pilot and caged-fish studies. A list of the chemicals and elements analyzed, the symbols used in this report, the analytical methods used, and the sample types collected by the USFWS are provided in Table 5, and are also detailed in Attachment A (Chapman and Allert 1998). Generally, fish and invertebrate tissues were analyzed by the Midwest Research Institute (MRI), Kansas City, Missouri. The MRI determined the concentrations of 15 elements by the 40 CFR 136 method of inductively coupled plasma atomic emission spectrometry (ICP/AES); mercury was determined by cold vapor atomic absorption spectrometry; and selenium was determined by hydride-generation atomic spectroscopy. The CERC analyzed fish for PCBs using high performance gel permeation chromatography followed by capillary gas chromatography and electron capture detection.

Benthic Macroinvertebrate Collection, Community Surveys, and Analyses

The benthic invertebrate community of a stream may contain a variety of biota, including bacteria, protists, rotifers, bryozoans, worms, crustaceans, aquatic insect larvae, clams, crayfish, and other forms of invertebrates. Aquatic invertebrates are found in or on a multitude of microhabitats including plants, woody debris, rocks, interstitial spaces of hard substrates, and sand and muck. Invertebrate habitats exist in all vertical strata including the water column, the bottom surface, and deep below a stream bed in the hyporheic zone (Hynes 1970; The Federal Interagency Stream Restoration Working Group 1998). However, because the larger invertebrates can contribute significantly to a stream's total invertebrate biomass, as well as standard methods of their study are available, the benthic macroinvertebrate community was the focus of this study. Benthic invertebrates are also important as prey for fish, and can directly and indirectly influence the overall suitability and sustainability of a fishery. Furthermore, the health of a benthic macroinvertebrate community can be an indicator of physical or chemical stressors present in the stream that are not discernable from short-term toxicity testing or chemical analyses. For instance, organic wastes tend to decrease the species diversity, while increasing the total numbers of remaining taxa, whereas toxic substances tend to reduce both numbers and kinds of organisms (USEPA 1983).

Caddisfly (Order Trichoptera) larvae are known for the portable cases they construct using their silk to fasten together rock fragments into a tubular shape (Merritt and Cummins1996). Caddisflies were easily observable in the stream segments studied, and one family (Limnephilidae) was collected by hand for chemical analyses. On August 11 through August 13, 1997, samples of over 50 individual *Hesperophylax sp.* were hand-collected from each stream, kept on ice, and later processed. Processing consisted of removing the cases from half of the samples collected for each stream segment and rinsing the bare larvae free of debris with deionized water, prior to freezing in plastic bags. The other caddisfly larvae were similarly rinsed and frozen with cases left on. This was done to observe the differences in caddisfly larvae as they could be eaten, whole, by fish or birds and in caddisfly larvae without the geologic influence of their cases in order to compare contaminant concentrations.

Benthic macroinvertebrate community surveys were conducted by the NMED's Oversight Bureau (Ford-Schmid 1996, 1999). Methods of the surveys were reported by Ford-Schmid (1996), and included three replicate, modified Hess circular samples collected from rubble substrate. Samples were sorted, and invertebrates were keyed to the lowest taxonomic level using appropriate keys. Surveys of the invertebrate communities were conducted in the same four canyons examined during the LANL Water Quality Assessment, although at different times, and these sites were in or directly adjacent to the100-m habitat evaluation reaches studied. The sites and dates reported by Ford-Schmid (1996, 1999) associated with the LANL Water Quality Assessment stream segments are:

- Site LA 13.0, February 25, 1997, in the Los Alamos Canyon segment studied.
- Site SA 7.64, March 20, 1996, in the Sandia Canyon segment studied.
- Site PA 9.0, July 22, 1994, in the Pajarito Canyon segment studied.
- Site VA 2.6, May 12, 1997, in the Valle Canyon segment studied.

Taxonomic data were then entered into computer programs that calculated various metrics, which encompass a range of invertebrate sensitivity indices and ratios with reference site conditions (here, Site LA 13.0 in Los Alamos Canyon) including: standing crop density, taxa richness, dominant taxon, the dominant species tolerant quotients, and other community metrics. Calculation of community metrics, definitions, scoring, and interpretation were made according to Garn and Jacobi (1996). Invertebrate taxa are listed in Appendix III and compared with a list of invertebrate taxa of Pajarito Plateau reported by Cross (1997), and identified as to temperature preference, if available, using Idaho DEQ (1996).

Fish and Invertebrate Tissue Quality Evaluation Methods

Identification of contaminants of concern in whole body fish and invertebrates collected for the LANL Water Quality Assessment was accomplished on a stream segment basis. The evaluation methods included a comparison of the concentrations of chemicals in tissues on biota from Sandia, Valle, and Pajarito Canyons to the reference site biota as well as to various concentrations (Tissue Quality Criteria) reported in the literature that affect wildlife or livestock (NRC 1980; Sample *et al.* 1996; USDOI 1998). For invertebrates, the mean concentration of each stream segment was also compared to concentrations reported in invertebrates collected from other parts of New Mexico (Lynch *et al.* 1988; Failing 1993; Simpson and Lusk 1999). For whole body fish, mean concentrations reported in the caged fathead minnow were also compared to concentrations in fish collected nationwide (Schmitt *et al.* 1999), to threshold concentrations in fish consumed by people (USEPA 1997a), and in fish (fillets) collected regionally (Fresquez *et al.* 1999). Emphasis was placed on the bioaccumulation of contaminants that are known to pose serious health risks to wildlife or people in the caged fathead minnow or caddisflies.

CHEMICAL DATA COLLECTION AND ANALYSES

Water Column Monitoring

Two types of water column chemistry data were collected: 1) continuous, hourly, *in situ* measurements of temperature, dissolved oxygen (DO), conductivity, and hydrogen ion activity (pH) were collected at one location (in a pool) in Los Alamos, Sandia, Pajarito and Valle Canyons, using a Hydrolab® water quality monitoring device (Datasonde); and 2) measurements of temperature, DO, conductivity, pH, and other water quality parameters were collected concurrent with other sampling events (*e.g.*, toxicity tests, habitat assessments).

On December 13, 1996, the USFWS deployed a calibrated Hydrolab® Datasonde water quality monitoring device at the beginning of each stream segment. Each Hydrolab® Datasonde was secured in a pool within protective and vented plastic pipes. The Hydrolab® Datasonde probes measure these parameters using sensors designed to meet the criteria and specifications in section 2550 (temperature), section 2520-B (specific conductance), section 4500-O (dissolved oxygen), and section 4500-H+ (pH) in Standard Methods for the Examination of Water and Wastewater, 19th Edition (American Public Health Association and others 1995). The pH, DO, and conductivity probes were calibrated and maintained according to the manufacturer's instructions (Hydrolab Corporation 1986, 1988). Ten monitoring devices were used and exchanged at each site at approximately two week intervals. Readings were taken after a 5-minute equilibration (warmup) period, and the raw and post-calibrated data were transferred to spreadsheets for tabulation, display, and summary statistics. Datasonde monitoring ceased in Pajarito Canyon on September 25, 1997, and in Sandia, Valle, and Los Alamos Canyons on November 17, 1997.

Existing Water and Sediment Data

According to the Settlement Agreement, the USDOE, the LANL, and the NMED agreed to accept only water quality data generated using USEPA methods for this study where applicable. On July 10, 1998, the LANL provided sediment and water quality data to the NMED for review. On July 23, 1998, the NMED forwarded the LANL sediment and water quality data to the USFWS for consideration in the LANL Water Quality Assessment. The LANL provided chemical and flow monitoring data measured for various outfalls under the NPDES permit between 1994 and 1997 for the four canyons to the NMED for review and consideration prior to submission to the USFWS. Discharges were categorized according to watershed, any exceeedences of permit limits were noted, and data were then compared to water quality standards for wildlife habitat, coldwater fishery, and other use designations (NMWQCC 1995). The LANL provided hundreds of chemical measurements of sediment in the Los Alamos, Sandia, Pajarito, and Water watersheds.

Surface Water Collection and Analyses

In the summer of 1996, the CERC collected surface water for toxicity testing and chemical analyses. The CERC's methods are described in detail by Chapman and Allert (1998; Attachment A), and therefore, will only be summarized here. Individual surface water samples were prepared by compositing 120 milliliters (mL) samples collected every 20 minutes over a 24-hr period using an automated sampler. Samples were collected on August 13, August 14, August 16, and August 20, 1996. The pH, conductivity, DO, total ammonia as nitrogen, alkalinity, hardness, and turbidity, and other water chemistry (*e.g.*, nitrate as nitrogen, sulfate, phosphorus, and chloride) of these water samples were also measured, compared graphically, and descriptive statistics were calculated and presented. The *in situ* measurements of pH, conductivity, DO, and temperature of the stream water were measured and recorded daily, compared graphically, and descriptive statistics were calculated and presented. Additionally, filtered surface water samples were analyzed for a suite of 62 elements by semi-quantitative inductively coupled plasma-mass spectrometry (ICP-MS). However, ICP-MS is not an approved method under 40 CFR 136, and therefore while these data, while presented in Attachment A, were not included in the evaluation.

In 1997, the USFWS collected grab water samples from two locations in each 300-m stream segment; near the Hydrolab® Datasonde, at the upper end of the stream reach, and at the downstream end. Water was collected with a gloved hand using an acid-cleaned, low density polyethylene cubitainer from the center of stream flow at each sampling location. Water samples for analyses were collected from downstream to upstream at each location five times (July 28, July 31, August 11-13, August 25, and September 29 - October 1, 1997). Water samples were also simultaneously collected three times on July 28, August 11-12, and September 29 - October 1 for explosives analyses using 1-L amber glass bottles. In all cases, care was taken to avoid disturbing bottom sediments.

Within 4 hours of collection, approximately half of each water sample for some of the elemental and nutrient analyses was filtered through a disposable, 0.45-µm, in-line filter (Geotech High Capacity Groundwater Filtering Capsules, Model GD 045700, Geotech Environmental Equipment, Inc., Denver, CO). Sub-samples were preserved and analyzed as described in Table 6. Samples for the analysis of explosives were not filtered. Filtered samples were preserved and all were shipped under chain-of-custody to the CERC for determination of elements and explosives. The remaining unfiltered and filtered samples were retained in a USFWS laboratory at 4 °C pending nutrient analyses and other water quality parameters (Table 6). Sample collection procedures and laboratory analyses of all constituents regulated by the State of New Mexico (Title 20 New Mexico Annotated Code [NMAC] Part 6.1) were conducted in accordance with USEPA-approved methods for the 1997 water samples.

Chloride (Method 8207), nitrate-nitrogen (Method 8171), ammonia-nitrogen (Method 8038), orthophosphate (Method 8048), total phosphorus (Method 8190) and sulfate (Method 8051) were analyzed at a USFWS laboratory using colorimetric analyses (Hach® Model DR/2010 Spectrophotometer) and digital titration (Hach Company 1997a, 1997b). The pH and temperature of water was measured using a Hach® One Combination pH Electrode (Model 48600), and Hach® One Meter (Model 43800). Alkalinity was measured by titration with H_2SO_4 to a pH 5.0 endpoint (Method 8203);

hardness, as calcium carbonate, was measured by EDTA titration (Method 8213); turbidity was determined using a portable Turbidimeter (Model 2100P) by nephelometry (Method 8195; Hach Company 1997c); and total suspended solids (TSS) were determined by photometry (Method 8006).

Surface Water Toxicity Testing

The surface water toxicity testing methods are described in detail by Chapman and Allert (1998; Attachment A), and are only summarized here. Toxicity tests on surface water were performed in the CERC's mobile laboratory using the crustacean, *Ceriodaphnia dubia*, as well as larval, fathead minnow. Because of the logistical difficulties in sample collection and testing methods associated with these mountainous sites, the start of the toxicity test did not occur on the same day the water was collected. Therefore, each day's water sample 24-hour composite was held overnight (after water chemistry measurements) before use in toxicity testing on the following day.

The *C. dubia* were reared at the CERC for more than three months prior to the tests. Culture techniques were those described by the USEPA (1994a). The *C. dubia* toxicity test was conducted according to USEPA (1994a), using daily static renewals. The *C. dubia* were shipped overnight to the LANL a month prior to the test and were maintained at the LANL until the test. Fathead minnows were hatched at the CERC, and larvae were shipped overnight to the LANL one day prior to the tests. Fathead minnow larvae were reared in well-water (280 mg/L hardness, pH ~7.8) and then gradually acclimated to soft water prior to their arrival at the LANL for testing.

Toxicity tests were performed in 100 percent site water, and a dilution series of 50, 25, and 12.5 percent of the composited surface water mixed with a soft water diluent prepared according to American Society for Testing and Materials methods (ASTM 1989). The soft water diluent was similar to the basic water chemistry (*e.g.* pH, alkalinity, hardness) typical of the soft waters found on the LANL. A 100 percent diluent control treatment was performed with each test. A positive control dilution series (*i.e.*, the reference toxicant) consisting of three concentrations of sodium chloride was also tested concurrently with each toxicity test. Lastly, a procedural control using well-water was also performed concurrent with each test. One neonate *C. dubia*, less than 12 hours old, was exposed to 20 mL of the composite water sample or the appropriate dilution in 30-mL glass beaker for seven days with 10 replicates of each dilution or control. Endpoints, recorded daily, were lethality (absence of movement) and reproduction (number of neonates produced). Temperature in the test beakers was maintained at 20 ± 1^{N}C by means of a temperature controlled water bath.

A mortality event in the surface water toxicity test of the undiluted sample from Valle Canyon with *C. dubia* occurred on day three, that affected the survivorship and reproductive success. A second toxicity test was started on August 15, 1996, to see if the mortality event would reoccur. This additional test was similar in methods to those described, except no dilutions of the site waters were tested, and test duration was only 120 hours.

The larval fathead minnow tests were 96-hour static renewals conducted according to USEPA (1993) and ASTM (1989) protocols for acute toxicity testing. The test was started on August 14, 1996, and fish were less than 72 hours post-hatch at the start of the test. Test containers were 1 liter (L) beakers containing 0.75 L of composite sample or appropriate dilution, with 10 fish per container. Four replicates of the 100 percent concentration of each canyon stream segment and two replicates of each dilution concentration were tested. Fish were fed brine shrimp (*Artemia* sp.) nauplii (24 hours old) twice daily. The endpoints, recorded daily during water renewal, were lethality (*i.e.*, the animal does not move with gentle prodding) and moribundity (*i.e.*, the animal does not retain equilibrium or does not swim normally until prodded). Water quality (*e.g.*, temperature, DO, pH, conductivity) were measured daily in fathead minnow test chambers and adequate oxygen levels were maintained in test chambers by continuous, gentle aeration. Temperature in the chambers was maintained at 20 ± 1 °C by controlling ambient temperature in the mobile lab.

Water Quality Evaluation Methods

Identification of contaminants of concern in surface waters collected for the LANL Water Quality Assessment was accomplished on a stream segment basis (*i.e.*, the two collection sites on the stream were averaged). The process began with examination of the existing water quality data for compatibility with approved collection, storage, and analytical methods. The major evaluation method included a comparison of the concentrations of chemicals in the water column to the various water quality criteria for the beneficial uses of surface waters in New Mexico existing at the time of the LANL Water Quality Assessment (NMWQCC 1995). A database evaluation system was developed for the LANL Water Quality Assessment by Deitner and Caldwell (2000) to aid in the comparison of water quality measurements against one or more water quality standards or criteria. Water quality standards and criteria from the NMWQCC (1995) as well as the USEPA (1998a) were used. The database system has the capability of computing the functional relationships of hardness and other factors as they affect the water quality criteria. When the contamination of field blanks or laboratory blanks was indicated and it was above or approached the water quality criterion, then the exceedance of that water quality criterion was either discounted by the amount found in the field blank or was discarded. The USFWS went beyond this regulatory approach by utilizing toxicity testing to evaluate the presence of a biological response that may have not been identified during the screen of the water quality data. Additional emphasis was placed on the caged-fish bioassays, bioaccumulation in organisms, and health of the macroinvertebrate community as a measure of water quality.

Sediment and Porewater Collection and Analyses

In 1996 and 1997, the CERC collected sediment and porewater (*i.e.*, the interstitial water found between sediment particles) for chemical analyses and an evaluation of toxicity. Detailed methods and location of collection sites are reported by Chapman and Allert (1998; Attachment A). At least 3 L of porewater was collected from each site, except Los Alamos Canyon, below the reservoir. Sediments were too coarse to extract porewater at this site.

In 1996, the CERC collected sediment by compositing grab samples that were analyzed for a suite of 62 elements, and other chemical and physical parameters (*e.g.*, total organic carbon content, texture, and acid volatile sulfides). Sediment porewater was sampled by the CERC using a method based on Winger and Lasier (1995). Fused-glass aquarium air stones attached to Teflon® tubes were inserted into depositional areas of the stream bed. Negative pressure was applied by means of a syringe, and porewater was drawn from the sediment using the glass air stone as a filter. Porewater was extracted from depositional areas along the length of the 300-m stream segment studied by the USFWS. Porewater was then injected into an acid-washed, polyethylene sample bottle. The sample was then kept on ice or refrigerated until use. Several extractors were used at each site in order to obtain a sufficient total volume of porewater. Air stones were removed and relocated to a new depositional area within the same site after drawing approximately 100 mL of porewater to avoid drawing overlying water through the sediment into the sample. The 100-mL subsamples of porewater from each site were filtered (0.45 μm) and acidified with 1 percent, ultrapure nitric acid and for element analysis. The remainder of the sample was shipped for toxicity testing.

In 1997, sediment was collected by the CERC from depositional areas along the same stream segment sampled in 1996. A specially designed plastic (polyvinyl chloride) scoop was used to collect sediment while introducing a minimum of surface water into the sample. The sediment was placed in a polyethylene bucket and homogenized, and then immediately used for on-site, porewater extraction. Porewater was extracted by means of pressure filtration, using an apparatus similar to that described in Carr and Chapman (1995), but modified for portability. Pressure was provided by a manual pump. During porewater extraction, the CERC also collected sediment samples for elemental analysis as well as for acid volatile sulfides and simultaneously extractable metals. A third sample was saved for grain size analysis and total organic carbon analysis.

In 1997, sediments were also collected by the USFWS, on two dates from Los Alamos, Sandia, Valle, and Pajarito Canyons, as two composite samples per stream segment. Two composite samples were collected during July 30-31, 1997, and during September 29 - October 1, 1997. One composite sediment sample was prepared from sediments collected at three upstream locations, approximately 30 m apart, starting at the beginning of the 300-m stream segment. The second composite sample was from sediments collected at three downstream locations, approximately 30 m apart, starting at the opposite, lower end of the 300-m stream segment. Samples were collected from the top ~10 cm in depositional areas using an acid-cleaned, high density polyethylene scoop. Aside from removal of large organic matter from the samples (*e.g.*, sticks, leaves), sediments were not processed further. Scoops of sediment were evenly distributed between sample containers until each container was full. Sediments were analyzed for texture, total organic carbon, elemental, PCBs, and explosives. Containers, preservation, and analyses are presented in Tables 5 and 6.

Grain size for all sediment samples collected and analyzed for texture in 1996 and 1997 were determined by the Bouyoucous Hydrometer Method. Total organic carbon of sediment was determined in 1997 using a Coulometrics® Carbon Analyzer, Model 5020. Porewater and sediment collected in 1996, and sediment collected in 1997, were analyzed by the CERC for 62 elements using a semiquantitative ICP-MS. Mercury and selenium in sediment were analyzed by the CERC by hydride-generation atomic absorption spectroscopy. Sediment and porewater samples collected in 1997, by the USFWS, and also by the CERC, were analyzed by the MRI. The MRI analyzed 15 elements by ICP/AES, mercury by cold vapor atomic absorption spectrometry, and selenium by hydride-generation atomic spectroscopy. In 1997, sediment samples were also analyzed for PCBs and explosives. Further explanation of the methods of analysis, quality assurance and quality control, and the list of explosives and PCB congeners analyzed were reported by Chapman and Allert (1998; Attachment A).

Porewater Toxicity Testing

Porewater toxicity tests were performed with *C. dubia*. Methods used were equivalent to those used to test surface water, except that porewater was collected as a single pooled sample from each site as opposed to daily collections of surface water. The pooled sample was shipped to the CERC for toxicity testing, and was centrifuged to remove fine particles not removed by filtration. Maximum holding time between collection of porewater from the LANL, and the start of toxicity tests was 4 days in 1996, and 10 days in 1997. In 1997, the sample from Site 1 (Los Alamos Canyon) was inadvertently contaminated prior to the test. This sample was then collected again and retested four weeks later, using a separate but equivalent set of procedural controls as reported by Chapman and Allert (1998).

Sediment Quality Evaluation Methods

Sediment quality evaluation techniques have been well developed for dredging-related projects (*e.g.*, USEPA/USACE 1998). Although the majority of evaluation protocols are designed for assessing dredged materials for ocean dumping, the procedures have broader application and were applied to the LANL Water Quality Assessment of sediment quality. Identification of contaminants of concern in sediment collected from the LANL was accomplished on a stream segment basis (*i.e.*, several collection sites on the stream were averaged). The mean concentration of contaminants in the sediments were compared to background concentrations for canyon sediments on the LANL reported by Ryti *et al.* (1998), the LANL's Screening Action Levels (SALs; LANL 1998a), and to the mean sediment concentrations found in the reference site (Los Alamos Canyon). Also, Sediment Concentrations of Concern were developed using toxic thresholds reported in the literature (*e.g.*, Anonymous 1977; Long and Morgan 1991; Persaud *et al.* 1993; Ingersoll *et al.* 1996) and averaging them to produce a consensus-based toxicological threshold as described by MacDonald *et al.* (2000a). Thus, the Sediment Concentrations of Concern is a conservative threshold where biological effects would be possible, but below which adverse population effects would not be expected (Table 7). Similarly, Sediment Quality Criteria were developed using concentrations where toxicity was considered probable as reported in the literature (Long and Morgan 1991; Persaud *et al.* 1993; Ingersoll *et al.* 1996) and averaging them to produce a consensus-based toxicological threshold as described by MacDonald *et al.* (2000a). Sediment Quality Criteria (SQC) would be the concentration at which biological effects would be likely (Table 8). Any exceedance indicated a contaminant of potential toxicological concern. Finally, a weight-of-evidence approach was used to determine which contaminants were elevated in LANL sediments, by identifying those mean contaminant concentrations that exceeded at least 2 out of the 4 background comparisons (*i.e.*, to Ryti *et al.* [1998], the LANL SALs, the reference site concentrations, or the SQC). Ratios of the mean sediment concentrations of contaminants in the canyons had to be at least 10 times the background concentrations reported by Ryti *et al.* (1998) and the mean reference sediment concentrations to be considered elevated. Also, porewater toxicity tests were evaluated for the presence of a biological response that may have not been identified during this screen of sediment contaminant concentrations.

Quality Assurance and Analytical Quality Control

Sample containers for the collection of water, sediment, invertebrates, and fish, were purchased and came with a quality assurance certificate (with the exception of the plastic bags used for invertebrates). A list of sample types collected by the USFWS, the containers used, the analyses performed, and the reporting limits are presented in Table 5 and Table 6. Abiotic samples (water, sediment, and porewater) collected by the CERC were similarly quality assured and are documented by Chapman and Allert (1998; Attachment A).

The USFWS has contracts with several laboratories to provide routine chemical analyses for contaminants in animal tissues and environmental samples (USFWS 1997). These laboratories that conducted the chemical analyses of water, porewater, sediment, and biological tissues for the LANL Water Quality Assessment were responsible for establishing the precision and accuracy of their analytical procedures. Quality control procedures included the analysis of blank, replicate, split, and spiked samples as well as analyses of standard reference materials. Data from such procedures were evaluated and documented by the laboratory chemists, the CERC, and the Patuxent Analytical Control Facility prior to submittal to the USFWS and are provided in Attachment A. Quality assurance procedures included, standard operating procedures, method standardization, proper collection, preservation, and storage of samples, using appropriate methods and equipment, and collection of additional field blanks and duplicate samples, as noted in the data tables and Attachment A. While there are a few specific concerns regarding the quality of some water samples and analytes, the overall data quality was certified as acceptable by the MRI Laboratory Director. Concentrations of the contaminants in surface waters were not considered to exceed a water quality criterion or standard if the corresponding field or laboratory blank had unacceptable concentrations of these same contaminants.

Data Treatment and Statistics

Some environmental data were received in an electronic format. Other data were initially recorded by hand on printed data forms or notebooks in the field, then transferred to electronic format as spreadsheets. Printed data sheets and electronic spreadsheets were then compared to verify accuracy of transfer. Some of the environmental contaminant data were reported in either dry weight (DW) or wet weight (WW) concentrations and were so indicated. To convert dry weight concentrations into wet weight concentrations, the following equation was used:

$$WW = (DW) * [1 - (\text{sample moisture (percent)}/100)] \qquad \text{Equation (1)}$$

For statistical purposes and simplicity, all results that were below the analytical laboratory's instrument detection limit, were replaced with a value one-half the instrument's detection limit prior to further statistical treatment as per USEPA (1998b). Some data were natural log transformed to normalize the data distribution prior to parametric statistical tests (Bailey 1981) such as the one-way analysis of variance or students' t-test. Nonparametric statistical tests were also employed and are so indicated in the text. Several descriptive statistics and analyses (*e.g.*, regression, principal component analyses) were conducted on concentrations of selected contaminants in biota. Unless otherwise specified, statistical significance refers to the level of $p < 0.05$. The software program STATISTICA (StatSoft Inc. 1994) was used for statistical summaries and testing of data.

PHYSICAL DATA COLLECTION AND HABITAT EVALUATIONS

Stream Channel Measurements

Cover and habitat types (*e.g.*, pool, riffle, glide) were determined by the same biologist to avoid biases in estimation (Roper and Scarnecchia 1995). Other habitat measurements (*e.g.*, depth, width, rate of flow, bank stability, landscape characterizations) were determined under close supervision of the primary fishery biologist. Several measured parameters were reach-based measurements, in that they were measured once over the entire stream reach evaluated. Examples of "reach-based" parameters included gradient, meander length, and percent pools (see below). Most parameters, however, were measured at each transect, and in some cases at several intervals across a transect (*e.g.*, flow and depth). Photographs were taken of the streams and measurement activities and are available for review.

Stream Reach Selection and Transect Setup

Two 100-m reaches were evaluated at the distal ends of the 300-m stream segment selected in each canyon. The beginning was determined by pacing at random (using two serial numbers from United States currency) the number of steps upstream of the third set of *in situ* cages, or downstream of the seventh set of *in situ* cages (Figures 8, 9, 10, and 11). To determine appropriate transect placement, a flexible tape was extended along the stream center-point for 100-m. The length of each major stream habitat type (riffle, glide, or pool) was then identified using the methods of Meehan (1991; Table 9), measured and summed. Percentages of riffles, glides, and pools, and pool class (an index of pool quality, based on pool habitat class described Hickman and Raleigh [1982] and Hamilton and Bergersen [1984]; in Table 10), which included measurements of maximum pool depth and percent combined in-stream and bank cover were determined, then calculated by dividing the total length of each habitat type by the total reach length (100-m). These 100-m reaches were divided into 10 transects for detailed habitat measurements (*e.g.*, flow, substrate characteristics, *etc.*). Transects were preliminarily located at 10-m intervals, but the final transect locations were determined by adjusting them slightly up or downstream to include representative percentages of each major habitat type in the stream reach (*i.e.*, if 70 percent of stream was riffle habitat, then 7 out of 10 transects were adjusted to include riffles). The transect level line was stretched perpendicular to stream flow, extending across the stream to the bank-full width (defined below). Transect measurements were then taken independently- one set for bank-full dimensions and another for wetted width dimensions. Habitat transects on each stream reach were located using GPS (Table 4).

Bank-full Width

The term bank-full in stream systems is associated with the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain (Rosgen 1996). Bank-full width typically corresponds to the width where the stream bank gradient levels out or there is evidence of previous flow regimes (*e.g.*, scarification or discoloration of exposed rocks and bank soils, change in bank structure, change in bank vegetation, bank erosion). Bank-full width was relatively well defined in these stream reaches, possibly due to frequent storm events and snowmelt, but the bank-full channel profile was defined according to sustained water levels rather than over-bank flood events.

Flow and Discharge

Stream discharge is the volume of water flowing past a cross section in a channel per unit time (Orth and White 1993). Stream flow was measured using a portable flow meter (Model 2000, Marsh-McBirney, Inc., Maryland) and a top-setting wading rod (Model 1276-E, Scientific Instruments, Inc., Wisconsin). Flow was measured at each transect in 5-10 increments (depending on stream width) at approximately 0.6 depth (Platts *et al.* 1983). Total stream discharge (Q) was then calculated as Q = cross sectional area*flow. Variables measured and calculated are presented in Table 11. Detailed flow measurements for each stream were only collected during the summer in 1997.

Bank Stability

Bank stability is determined primarily by rooted vegetation cover, rock and rubble content, and soil type. Description and classification of bank condition and potential for future erosion (Tables 12 and 13) was determined using Platts *et al.* (1983). Bank stability (erosion potential) and bank vegetation cover were determined by visual estimation. Wetted-channel bank stability was also evaluated based on vegetation cover and indications of erosion. Additional methods of evaluating channel stability were described in the Stream Geomorphology and Habitat Stability Section below.

Cover

Cover and cover types that could provide shelter for an adult-sized fish, were rated using estimates provided by Platts *et al.* (1993; Table 14). Cover included: 1) instream structures such as boulders, rocks, logs, and vegetation; 2) bank cover in the form of overhanging or undercut channel; and, 3) overhead cover consisting of overhanging trees and shrubbery. Cover was estimated visually by considering all cover types falling within a 1-m width on either side of the habitat transect line. Percent in-stream cover was visually estimated as submerged and exposed rocks, aquatic vegetation, and submerged and overhead logs or branches capable of providing shelter for an adult-sized fish. Percent bank cover was visually estimated as overhanging bank structure, including overhead and aquatic vegetation, capable of providing shelter for at least an adult trout or an adult minnow. Percent pool cover was determined the same as cover, but applied to a length of stream containing a pool.

Substrate Characteristics

Substrate is important to fish spawning, escape cover for fry, invertebrate colonization, and overall streambed stability. Therefore, measures of substrate characteristics were incorporated into fish habitat suitability models, invertebrate habitat models, and geomorphological classifications. Under normal circumstances, descriptions of substrate will be similar from year to year for cobbles and boulders, which are less likely to move during high flow regimes. Smaller substrates, however, will move and size distributions may change in response to high flow regimes.

Using a "pebble count" method described by Lane (1947) and Platts *et al.* (1993), substrate size distribution was determined (20 pebbles were measured per transect; 10 in the wetted width and 10 additional in the bankfull width). Measurements were made at the same intervals where depths were determined. A piece of bottom substrate (*i.e.,* a pebble) was randomly selected, examined and categorized. The degree of pebble embeddedness, was determined by visual estimation or, in murky water, by touch. The pebble was then removed, and categorized to size (Table 15) and substrate type (*e.g.*, rock versus organic detritus).

Embeddedness is essentially a measure of the coverage of larger substrate material by fine sediments and was determined using the rating scale developed by Platts *et al.* (1983; Table 16). High embeddedness can lead to reduced invertebrate habitat availability and stability and reduced oxygen concentrations in fish spawning habitat (*i.e.*, redds). Subsequently, substrate data were linked to general habitat type (glide, pool, or riffle) to create new habitat-specific substrate characteristic variables. For instance, the brook trout Habitat Suitability Index model (see below) required calculation of percentages of different substrate sizes, average substrate sizes, and percent of fine silts in riffle habitats.

Detailed Site and Landscape Characterizations

A number of additional observations of the surrounding landscape were determined in the field and when possible, confirmed using topographic maps, electronic databases, or other visual observations. Information recorded included:

- color photographs and locations determined by GPS of stream transects and cages,
- approximate location of tributaries, their confluences, springs, and NPDES outfalls,
- topography, elevation, soil types and local geology,
- instream, upstream, or nearby structures, channel modification (clearing, rip-rapping, widening, deepening, realigning, lining),
- evidence of fire, logging, grazing, or agriculture,
- major habitat types or land use (*e.g.*, wetlands, grassland, forest, developed areas),
- dominant vegetation classified broadly according to major tree species or families, deciduous tree species or families, and understory vegetation,
- adjacent riparian vegetation (visually estimated using a four category classification developed by Platts *et al.* [1983]) of 0-25 percent, 26-50 percent, 51-75 percent, or 76-100 percent),

- recent precipitation (amount, date, and time), air temperature (°C) was observed and when available, confirmed using the LANL's meteorological data,
- number of days and extent of stream flow was determined through observations, data, and reports by the LANL, the USDOE, or the Oversight Bureau.

Habitat Evaluation Methods

Evaluation of general fish and invertebrate habitat suitability was quantitatively assessed at the study sites using the USFWS's Habitat Suitability Index (HSI) models for fish species typically found in the montane streams of New Mexico, and the Rapid Bioassessment Protocol (RBP) developed by the USEPA (Plafkin *et al.* 1989; Barbour *et al.* 1999, in draft form). Physical habitat and suitability relationships were measured and determined from extensive field observations, measurements of physical characteristics, a review of published literature, and consultation with biologists familiar with a particular species. All measurements necessary for calculation of the HSI models were based on the assumptions used to generate the HSI indices.

The physical habitat data were also qualitatively interpreted to address site-specific habitat limitations not quantified by the HSI or RBP models, such as the effects of stressors such as floods or drought have on long-term fish survivability. Important or limiting variables for the reach were weighed more heavily when calculating the final HSI score. This provided a more site-specific assessment of the potential long term fish habitat capability. Because predictions of habitat suitability for a particular species assume that only that particular species is present, habitat selection affected by interspecies competition is not accounted for in the HSI models, and therefore predictions cannot be made regarding the potential species diversity, distribution, or total fish biomass. The HSI models also do not indicate standing crop or production of fish, the effects from short-term perturbations, or account for interactions among different fish species. Finally, it is important to note that this study's analysis is essentially a snapshot in time, like all fluvial habitat studies, and the conclusions only indicated if the habitat was suitable, and if fish use could have existed during the time that this study was conducted.

Habitat Suitability Index Models

Numerous examples of habitat quality evaluations can be found in the literature, but few present a means to quantitatively relate these habitat characteristics to the habitat requirements of a species of fish. Because "best professional judgement" statements correlating physical conditions to habitat suitability for a particular fish species are subjective, the LANL Water Quality Assessment combined qualitative and quantitative approaches to the habitat data interpretations. The quantitative approaches employed were based primarily on the USFWS HSI models for fish (Raleigh 1982; Edwards *et al.* 1983), and the USEPA RBP (Plafkin *et al.* 1989) for habitat suitability for benthic macroinvertebrates. Habitat data were also qualitatively interpreted in light of literature findings to substantiate, and in some cases, address habitat and fish population relationships that were beyond the scope of the quantitative models, such as flood or drought effects on fish survivability over the long term. This approach provided a more site-specific assessment of fishery habitat potential and overall health of the aquatic habitat present at the LANL. Variables included in a HSI model must satisfy the following criteria: 1) the variable is related to the capacity of the habitat to support the species; 2) there is at least a basic understanding of the relationship of the variable to habitat; and, 3) the variable is practical to measure within the constraint of the model application (USFWS 1981).

The HSI models provide quantitative indicators of habitat suitability for individual species and a consistent means of comparing habitat conditions. The numerical HSI value for a particular species is derived from an evaluation of the ability of key habitat components to supply the life requisites of the species evaluated. Habitat characteristics were determined from extensive field observations and measurements, through a review of the published literature, and consultations with biologists familiar with a particular species.

Fish habitat suitability was quantitatively assessed at the study sites using the USFWS HSI models for fish species typically found in smaller streams in this region of New Mexico. Based on preliminary reviews of fish species of the Jemez Mountains that are present in montane streams similar to those on the LANL, two species, the brook trout (*Salvelinus fontinalis*) and the longnose dace (*Rhinichthys cataractae*) were selected for further study using the HSI approach (Raleigh 1982; Edwards *et al.* 1983). Several HSI models were available for other species found elsewhere in New Mexico, but were dismissed if they were not species expected in montane streams or there were key habitat parameters that would preclude them, such as water flow and depth. Such species considered but eliminated were: sucker species, such as the non-native longnose sucker (*Catostomus catostomus*), which prefers much deeper water and with higher flows than would be found on the LANL; and chub species, such as the non-native creek chub (*Semotilus atromaculatus*), which prefer much deeper pools, much wider streams, and warmer water temperatures. Native montane species, such as the Rio Grande chub (*Gila pandora*), would have been desirable to evaluate, but there was no HSI model available. Other fish species were not selected based on their preference for warmer waters, such as species of cyprinids. Although brook trout are not native to New Mexico (they were introduced prior to 1900), they occur in the Jemez Mountains (NMDGF 1998), and are a good representative of trouts that have been studied extensively, and had a developed HSI model (Raleigh 1982).

All measurements necessary for calculation of the HSIs were based on the assumptions used to generate the HSI suitability graphs. Habitat assessment techniques developed by

Armour *et al.* (1983); Hamilton and Bergersen (1984); and Meador *et al.* (1993) were relied upon for methods of measurement of variables not included in the HSI models, and to supplement or clarify HSI assumptions. Some parameters were measured using two different techniques as a quality assurance measure. For instance, elevation was determined from USGS topographical maps and cross-checked with field GPS. In a few instances, when exact measurements were not available (*e.g.*, in the brook trout HSI model the average annual base-flow regime) values were estimated based on surrogate variables, historical data, and best professional judgement. The potential effects of measurement bias and natural variability on the overall calculated HSI score was also estimated.

Habitat suitability scores for each HSI parameter were integrated into a comprehensive index for each life-stage using the following equations.

$$Adult = \left[ThalwegDepth * \%InstreamCover * (\%Pools * PoolClass)^{1/2} \right]^{1/3} \quad \text{Equation (2)}$$

$$Juvenile = \frac{\%InstreamCover * \%Pools * PoolClass}{3} \quad \text{Equation (3)}$$

$$Fry = \left[\%Pools \left(\%SubstratSize * \%RiffleFines \right)^{1/2} \right]^{1/2} \quad \text{Equation (4)}$$

$$Other = \left[\left[\frac{(Substrate * \%RiffleFines)^{1/2} + \%Veg}{2} \right] * (Temp * DO * pH * BaseFlow * StreamVeg)^{1/5} \right]^{1/2} \quad \text{Equation (5)}$$

$$HSI = (LifeStage * Other)^{1/2} \quad \text{Equation (6)}$$

The final HSI score is calculated by multiplying together each individual life-stage score with the additional index "Other," which is a set of life-requisite parameters common to all life-stages. High HSI scores indicated near optimal habitat conditions for those factors included in the model. Intermediate scores indicated average habitat conditions, and low scores indicated poor or unsuitable habitat. A HSI score of zero does not necessarily mean that the species would not be present, although the probability of that species occupying that habitat would be low.

The presence of a fish species in an evaluated stream is one way to verify the output of the generalized species HSI model. If habitat scores determined for locations where fish are present are relatively high, say above a score of 0.5, this suggests that the model is applicable to this area, and furthermore, other streams in the area with similar scores would be expected to contain similarly suitable fish habitat. Brook trout were identified throughout the reaches examined in upper Los Alamos Canyon (see Results and Discussion below). Therefore, brook trout would be expected in stream habitat with characteristics (*i.e.*, HSI scores) similar to Los Alamos Canyon reference site. Because longnose dace were not present in any of the streams evaluated, no calibration or validation of the HSI model was possible. Therefore, we assumed that longnose dace in this region preferred the same types of habitat of longnose dace from other locations in the United States from which the HSI indices were derived. Parameters assessed for the brook trout and longnose dace models are outlined in Figure 12 and Figure 13, respectively.

Invertebrate Habitat Assessment

The RBP was employed to evaluate the suitability of invertebrate habitat to provide a further assessment of the ecological integrity of the streams studied (Plafkin *et al.* 1989; and Barbour *et al.* 1999, in draft form). The various habitat parameters were weighted to emphasize the most biologically significant parameters. The ratings for individual parameter measurements were totaled and compared to the Los Alamos Canyon stream segment as a reference site. Higher scores indicated increased habitat quality. A score that is fully supporting of aquatic organisms would be>75 percent of the reference. A partially supporting habitat would score >60 percent, and non-supporting habitat would score <58 percent of the reference. The RBP habitat parameters were grouped according to "microscale" habitat, which were those habitat features that have the greatest influence on benthic macroinvertebrate community structure, and "macroscale" habitat, such as channel geomorphology (Table 17). Microscale habitat parameters had a scoring range of 0-20, whereas macroscale parameters scored from 0-15, with the exception of certain tertiary parameters that scored from 0-10. The maximum possible score is 200 and scores were computed for each stream segment studied.

Habitat Quality Index

The Habitat Quality Index (HQI) was developed by Binns (1978), for streams in Wyoming, and because it involves low flow streams, it was considered to be useful in the evaluation of the LANL streams. The primary factors evaluated in this model of fish habitat suitability were low flow regime, variable annual flow regime, and warm summer water temperature. Secondary factors included in the model included water velocity, total cover, stream wetted width, food abundance and diversity, nitrate concentrations, and stream bank stability. Binns (1978) derived a multiple regression expression to relate these parameters to an index of habitat quality. In the Wyoming streams studied, the HQI score was highly correlated to trout biomass. Although the quantitative relationship between the HQI score and fish biomass determined by Binns (1978) would likely be different for Wyoming streams than for New Mexico streams, the HQI scoring process was used to compare the reference stream segment in Los Alamos Canyon (that had a existing population of brook trout) to the other stream segments under study with an unknown fishery potential (*e.g.*, Sandia, Valle, and Pajarito Canyons).

Stream Geomorphology and Habitat Stability

Stream channel geomorphological classification followed the hierarchical system developed by Rosgen (1994, 1996), which is based on the premise that dynamically-stable stream channels have a morphology that provides for the appropriate distribution of flow energy, and thus maintain a morphologically stable stream channel (Figure 14). Habitat characteristics important for dissipating flow energy included channel sinuosity, bed substrate type, and vegetative stability of the stream banks and surrounding riparian zones (Rosgen 1996). This geomorphological assessment was included to evaluate if the habitat conditions measured at the time of this study would remain relatively constant over time, as well as provide baseline information in the event that stream channels are modified in the future.

The Rosgen (1996) geomorphological classification did not assess the quality of the habitat or the ability of the habitat to support a particular species or beneficial use. However, many of the parameters used to determine geomorphologic stability are also used in the HSI models, or are found in literature discussing fish-habitat associations, and provided some insight into watershed scale influences on the stream segments studied. By relating the geomorphological characteristics of the stream segment studied on the LANL to those geomorphological characteristics observed in other stable, unaltered montane streams of the same type, conclusions were drawn regarding the stability of the LANL stream channels.

The Rosgen (1996; Figure 15) classification levels, Level I and Level II, were used to classify stream channel stability. Entrenchment, slope, and sinuosity are considered Level I characteristics, while bankfull depth and bed substrate type are considered Level II characteristics. These Level I and II characteristics helped define the current stability of a stream and help point appropriate management actions to improve a stream's stability, and thus, its habitat stability. Habitat stability was based on a Level II geomorphological survey developed by Rosgen (1996). Additional Level III parameters (Figure 16) were evaluated and used to generate a "Pfankuch Rating." By comparing the Pfankuch Rating to the stream channel classification, a habitat stability score of "GOOD," "FAIR," or "POOR" was determined. A GOOD score suggested that the stream channel is stable compared to other unaltered streams of the same type. Therefore, channel geomorphology, and thus general aquatic habitat characteristics, would likely also remain in equilibrium from year to year. A POOR score suggested the channel has changed over time, perhaps following a severe flood.

Developing A Water Quality Index

Karr and Dudley (1981) defined biological integrity as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitats of a region." This definition and the underlying ecological theory provided the basis for the development of biological criteria in the United States as well as the direct incorporation of biological integrity as a goal into the Clean Water Act. Biological integrity can be represented by indices which integrate the interaction of the environment with specific populations and communities. Subsequently, numerous researchers have demonstrated that the use of an index of biological integrity as an effective tool to assess the cumulative response of the aquatic community to the total environment. These and other multimetric indices have been recommended to strengthen data interpretation and reduce error in judgement based on isolated indices and measures. Therefore, the LANL Water Quality Assessment similarly combined the ecological attributes of each stream (the biological, chemical, and physical characteristics measured) into a Water Quality Index (WQI) for an overall assessment of the condition of each stream as recommended by Karr and Chu (1997).

The biological, chemical, and physical characteristics measured in each stream segment were compared (as a ratio) to those of the reference site and to applicable criteria in order to develop separate metric indices of biological, chemical, and physical quality. Each metric was then given a rating score on an ordinal scale (*i.e.*, 5, 3, 1) to normalize the various metrics on a common scale (Table 18). These indices of biological, chemical, and physical quality scores were then summed on a site-specific basis so that sites could be compared with each other based on the ranking of data relative to the reference site. The extent to which the indices of biological, chemical, and physical quality deviated from the reference site was considered indicative of the degree of aquatic life impairment at a specific canyon stream segment studied (Table 18). The strength of the WQI is the ability to provide a direct measure of the health of these streams, as well as to detect and quantify chemical and physical impacts. The links between the biological integrity and health of a stream, and the chemical or physical agents or impacts is not definitive, but is useful in identifying the relative sources of the impairment.

RESULTS AND DISCUSSION

RESULTS OF THE BIOLOGICAL INVENTORIES

Aquatic Life and Wildlife Observed and Expected Regionally

Qualitative observations during this study, including actual sightings, and signs such as tracks, nesting areas, and scat, indicated use of these streams by a variety of organisms, including various bird species (raptors, migratory birds), amphibians (salamanders, frogs [observed in Sandia Canyon only]), and mammals (elk, squirrels, racoon). A list of common and scientific names of wildlife discussed in this report is provided in Table 2. Invertebrate surveys in the four canyons examined concurrently in these stream segments identified over 117 different taxa (Cross 1996a; Ford-Schmid 1999). Studies by the LANL have also identified elk, mule deer, coyote, red fox, porcupine, mountain lion, and bobcat in the LANL area. Twenty-nine small mammal, 200 bird (112 breeding in area), 8 reptile, 13 snail, and 25 terrestrial arthropod species have also been identified on the LANL, many of which use the canyon environments at some time for food, water, reproduction, and shelter. Many of these species are permanent residents within the LANL environment. For example, Biggs *et al.* (1997a) found that radio collared elk captured on the LANL grounds remained at the LANL year-round. Cross (1995b), in an examination of invertebrate colonization associated with NPDES outfalls, incidentally observed extensive use of several of these outfalls by elk (browsing, bedding, presumably drinking), some use by coyote, and occasional observations of snails, clams, and amphibians. Of the 310 vertebrate species of the Jemez Mountains, 7 percent are fully aquatic, 13 percent are semi-aquatic, and the majority (63 percent) depend on wetlands or riparian habitat to complete their life cycles (Table 2).

Adaptations to the semi arid conditions on the Pajarito Plateau by wildlife vary and are generally functional or behavioral. Some aquatic invertebrates reported by Cross (1997) have dessication-resistant eggs, or can survive periods of dormancy and dessication. Amphibians take advantage of temporary waters (Foxx *et al.* 1999) or have fast-growing larval stages, burrow, or estivate during hot days. Most animals likely find ways to minimize water loss (e.g, through microclimate selection as indicated by 63 percent of the vertebrate species being associated with cool and moist riparian habitats) or find water to drink. Birds and other animals of arid ecosystems and woodlands have been documented drinking and bathing from temporary waters, springs, and other wetlands (Smyth and Coulombe 1971; Williams and Koenig 1980; Gubanich and Panik 1987; Brooks 1989). Many of the bird species that were documented drinking water were reported on the LANL (Travis 1992; Hinojosa 1997). Over 60 species of vertebrate wildlife were documented by Brooks (1989), Foxx and Blea-Edeskuty (1995), and Haarmann (1995) as using artificial water bodies formed by waste discharges by the LANL for food, shelter, and drinking. Animals have been found to make repeated, and long-duration visits (*e.g.* raccoons remained near a lagoon for over 20 hours) to artificial water bodies on the LANL, even when areas were partially fenced, or when only contaminated water was available (Brooks 1989; Hansen *et al.* 1999).

To illustrate the dependency by animals on LANL water bodies, two vertebrate groups and an avian species were selected for further discussion; amphibians, montane fish, and the American dipper, which could be considered a sentinel species for the health of these canyon streams. Amphibians of the Pajarito Plateau represent a guild of aquatic life important to ecosystem function and the biological diversity of the Jemez Mountains. Whether perennial, interrupted, intermittent, or ephemeral in nature, clean water in streams, ponds, reservoirs, or wetlands are critical for a large number of amphibians. Amphibians uniquely link aquatic and terrestrial environments. Even if temporary waters may seem insignificant, these surface waters are primary breeding sites and nursery habitats for spadefoot toad, green toad, red-spotted toad, woodhouse toad, canyon treefrog, leopard frog, and juvenile tiger salamander on the Pajarito Plateau. Hammerson (1999) reported that the red-spotted toad and canyon treefrog only breed in pools along intermittent streams, in ponds formed from rain fall, snow melt, or in springs. Many species, such as toads, frogs, salamanders, reptiles, and even migratory birds, have altered their lifestyles and behavior to take advantage of temporary pools for resting, breeding, and feeding (Mares 1999). The immature stages of many amphibians and invertebrates are entirely aquatic; for example, tiger salamanders develop gills and remain in water bodies as long as two years. Ponds, streams, and wetlands of even a temporary nature are important resources to the wildlife of this semi-arid region.

According to Calamusso and Rinne (1999), there are at least three native fish of the Jemez Mountains: the Rio Grande cutthroat trout, the Rio Grande sucker, and the Rio Grande chub. The Rio Grande cutthroat trout is a sport fish, the state fish of New Mexico, and one of the most striking and colorful of the trouts (NMDGF 1998). The Pajarito Plateau is in the known historic range of the native Rio Grande cutthroat trout. The trout likely occurred in "all waters capable of supporting trout in the Rio Grande drainage," including small, isolated, headwater streams in the Rio Grande basin (Sublette *et al.* 1990; Stumpff and Cooper 1996). Most cutthroat trout streams identified by Cowley (1993) are those above the 150-day, frost-free isoline, which included the upper portions of streams on the Pajarito Plateau.

Whether cutthroat trout inhabited any of the intermittent streams of the Pajarito Plateau is unknown, as there are few fossil records. The current occurrence of the ridged-beak peaclam in Frijoles, Pajarito, Water, and Los Alamos Canyons (Cross 1996b) suggests some historic connection to a larger body of water in the past, although passive dispersal of the pea clam is also possible. Goff *et al.* (1996) reported that the Rio Grande was once dammed by the Tshirege Member during the late Pleistocene Epoch, forming a 72 km lake that was 54 m above the rim of White Rock Canyon and at times reached as far upstream as Española, New Mexico. However, clearly these canyons are dynamic geomorphic systems and it would be difficult to ascertain the historic fish distribution without additional fossil records.

Currently, cutthroat trout populations and their distribution have been severely reduced (Stumpff and Cooper 1996). Some cutthroat trout streams have had as few as 50 adult trout in them (NMDGF 1973), and cutthroat trout populations have recently been decimated by the effects of fire, flood, drought, and habitat degradation (Propst *et al.* 1992; Stumpff and Cooper 1996). As trout streams have diminished, so has the range of the cutthroat trout in New Mexico; although steps are being taken to conserve the fish (Cowley 1993). The Rio Grande cutthroat trout prefers waters that are clean, clear, and cold, and have sufficient cover, pools, and food to support their needs (Sublette *et al.* 1990). There is an active program to reintroduce the trout to streams in its historic range that provide suitable habitat, are isolated, and contain no other trout (Cowley 1993).

Birds common to forests and woodlands compose the basic breeding avifauna of the LANL (Travis 1992). However, one bird species is particularly well-adapted to the intermittent streams found on the LANL. The American dipper, or water ouzel, is a robin-sized bird that can swim and dive using its wings and feet, and even walk under water (Kingerly 1996). Dippers are not easily confused with any other bird species and are identified by their color, size, and distinctive traits such as incessant dipping, a blinking white eyelid, and behavior near streams (Kingerly 1996). During this study, dippers were observed using the stream segments studied in Los Alamos, Sandia, and Pajarito Canyons. Similar to trout, dippers are inseparable from fast-flowing, clear montane streams, with cascades, riffles, waterfalls, and are dependent on the streams' invertebrates for food (Kingerly 1996). Because of this dependency, a dipper's health is susceptible to dietary contamination from metals, radionuclides, and organic chemicals that contaminate montane streams (Kingerly 1996, Strom 2000). For example, Strom (2000) found that sediments contaminated with lead from upstream mining activities was correlated with concentrations of lead in the dipper's tissues, such that the lead had adversely altered the dipper's physiology. The dipper is an example of an avian species that feeds high in the food web and the adults have high site fidelity (they typically do not migrate from a watershed). Thus, the dipper reflects the water quality and the health of a canyon stream environment. Measures of their productivity and any adverse effects posed by contamination should be considered as part of the evaluation of the risks to aquatic wildlife of the LANL.

Fish Surveys

While many aquatic organisms inhabit and use the LANL waters, electrofishing surveys did not locate fish in the Sandia, Pajarito, or Valle Canyon stream segments studied. In Los Alamos Canyon, brook trout were found throughout the segment studied, and occasionally rainbow trout were found in the lower reach nearest the Los Alamos Reservoir. Fish in Los Alamos Canyon were observed routinely and identified in

October 1997, and found under ice, during low-flow conditions in December 1998. Although rainbow trout have been routinely stocked in the Los Alamos Reservoir by the NMDGF (Sloane 1998), this species probably does not permanently reside in this stream segment. Brook trout prefer smaller, cooler waters than rainbow trout (NMDGF 1998) and rainbow trout tend to compete with and exclude brook trout from their territory (Raleigh 1982; Clark and Rose 1997). Even brook trout spawned in a lake will move into and overwinter in small (<2 m) tributary streams, suggesting stream residence provides some fitness advantage for this species (Curry *et al.* 1997). Rainbow trout were found only in the lowermost portions of the stream segment closest to the Los Alamos Reservoir, whereas brook trout were found throughout the stream segment sampled. As brook trout are no longer being stocked in this stream, reproductive-capable individuals were found, and the habitat was suitable, it is likely that Los Alamos Canyon supports a sustainable coldwater fishery of brook trout.

Mean sizes of brook trout sampled in Los Alamos Canyon were (Figure 17 and Figure 18) 95 and 124 mm (ranged from 71-195 mm) in October 1997, versus 119 and 123 mm (ranged from 84-207 mm) during December 1998. Sublette *et al.* (1990) reported that the minimum size of brook trout at sexual maturity was about 95 mm for males, and 100 mm for females, so fish in Los Alamos Canyon were capable of reproducing. In 1997, the mean weight of fish captured in the lower portion of the reach was significantly greater (t-test, $p=0.03$) than of fish in the upper portion of the reach. There was no significant difference in the winter 1998 sampling. No consistent trends in weight or length were noted between 1997 and 1998.

Fish captured while electrofishing in Los Alamos Canyon in October 1997 were clearly associated with areas of higher than average bank cover compared to that found during the habitat measurements taken in August 1997, and seemed to prefer pool habitats, particularly in the colder months (Figures 19 and 20). Average bank cover does not vary with moderate fluctuations in stream flows, so comparisons between the cover measured in August with those measured in October were considered valid. Evaluation of cover in December 1998 was complicated because most stream reaches electroshocked had at least some ice cover, and winter weather reduced the extent of bank vegetation as cover. Percent of pools, however, may vary with discharge. Fish captured in December 1998 did seem to be highly associated with pool habitat. During the cold, low-flow, winter months, it is likely that water depth is an important factor for fish survival, rather than cover, so a preference for pools would not be unexpected. Overall, in both October 1997 and December 1998, it appeared that fish were selecting relatively deeper waters, such as pools.

Caged-Fish Bioassays

A series of intense rainstorms occurred during the caged-fish bioassays (Figure 21). Acute mortality (96-hour exposure) was observed in Los Alamos Canyon (20 percent) and Sandia Canyon (38 percent; Figure 22). However, the high flow regime due to localized rainstorms was most likely responsible for this observed mortality. Fish were crushed by the in-cage rock or were crushed in between the cage pipe-frame and the netting. Some fish also likely escaped when the netting was ripped or separated from the pipe-frame, and occasionally, fish remaining in cages were killed when the cages themselves remained in dry areas after a flood. When mortality was accounted for by crushing or escape, no significant acute mortality was observed in the canyons studied (Figure 22). The 90 percent to 100 percent survival in one third of the cages in each stream segment also suggested that mortality was not likely due to acutely toxic substances in water. While in cages, fish were not allowed to seek refugia from high flows that they would in the wild. Therefore, the mortality experienced by the fish during high flows was considered an artifact of their caged condition, and not necessarily what would have happened to wild fish exposed to high flows.

Chronic mortality (two months exposure) was observed in Sandia Canyon and Pajarito Canyon (Figure 23). Again, high flows due to localized rainstorms were likely responsible for the observed mortality. Cages frequently had large amounts of sediment deposited in them, were thrown from the stream, were ripped, or broken. Also, the USFWS received a report of vandalism that occurred to cages in Sandia Canyon, where fish were removed and allegedly sold as bait. Because the cages were checked infrequently during the two month chronic bioassays, it was more difficult to determine a cause of death. For instance, dead fish buried in sediment at the bottom of the cage may have been trapped in the sediment during high flows, or may have died from other causes and then were buried by sediment. Therefore, the corrected percent survival only accounted for fish that were obviously killed by crushing or when the cages were thrown from the stream, when fish were missing due to ripped netting, or vandalism (Figure 23). No significant chronic mortality was observed in any of the canyon stream segments studied in 1997, when mortality due to crushing, vandalism, or escape was accounted for. In summary, although exposed to harsh conditions, at least 15 percent of the caged-fish survived long-term exposure to these stream segments. In Valle Canyon and Los Alamos Canyon, mean survival was as high as 70 percent, with 100 percent survival in some cages.

Due to the high variability associated with fish length and weight measurements, no statistically significant weight gains over time or differences in average fish weight among canyon stream segments or cages were identified. General trends, however, indicated that fish gained weight in Los Alamos, Sandia, and Pajarito Canyons (Figure 24). Fish in Valle Canyon appeared to lose weight during the first month, and then gained weight in the second month (Figure 25). Valle Canyon fish only experienced about 10 percent flood-associated mortality on average. While physiological stress associated with contaminant exposure can result in weight loss and reduced weight gain in fish, other factors, such as food availability and water temperature could also confound results. Nonetheless, the observed weight loss in Valle Canyon fish occurred in 8 out of 9 cages, suggesting that there may be an adverse physiological response to conditions in Valle Canyon that should be investigated further.

Benthic Macroinvertebrate Surveys

Ford-Schmid (1999) reported the results of the benthic macroinvertebrate community surveys in the 4 canyon stream segments studied (Appendix III). Taxonomic composition, biological condition, indices of diversity, and other assessments of the benthic macroinvertebrate community in these four canyon stream segments are presented in Table 19. Standing crop density was high at all sites and the number of taxa ranged from 10 in Sandia Canyon (Site 7.64) to 41 at the reference site (LA 13.0) in Los Alamos Canyon. This was within the range of anticipated taxa for turbulent streams in New Mexico (Cole *et al.* 1996).

One hundred and seventeen taxa were collected from these 4 canyon streams including 33 Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) taxa (*i.e.*, EPT taxa), and 29 Chironomid taxa. The EPT taxa thrive in coldwater with reliable oxygen and a mix of cobble and gravel substrate (Cole *et al.* 1996). In these 4 canyon streams, Ford-Schmid (1999) found over 50 percent of the total number of unique taxa (~230) reported by Cross (1997) found in streams on the Pajarito Plateau. Eight of the species found by Ford Schmid (1999), were identified by the Idaho DEQ (1996) as preferring coldwater, and these were found only in Los Alamos and Pajarito Canyons. A similar analysis of the invertebrate taxa reported by Cross (1996b; 1997) found 14 species preferring coldwater, and these were found mostly in Frijoles Canyon (10), and Guaje Canyon (8), but also in Los Alamos (4), Pajarito Canyon (2), Sandia Canyon (2) and Chaquehui Canyon. The majority of the invertebrate taxa preferring coldwater were caddisflies of the Families Limnephilidae and Philopotamidae of the Order Trichoptera. Interestingly, no heptageniids (a family of mayflies) were found in any canyon stream segment except Los Alamos Canyon.

Heptageniid mayflies were considered by Clements (1994) and Clements *et al.* (1999) to be sensitive to heavy metals in coldwater streams of the Southern Rocky Mountains. Nelson and Roline (1993) suggested that the absence of heptageniid mayflies can be used as a biological criterion to indicate the presence of heavy metal contamination. In this study, heptageniid mayflies were absent from canyons where the presence of excess Al, Fe, Ba, Cr, or Mo was found in sediments or in water from Sandia, Valle, and Pajarito Canyons (below). However, heptageniids were found in Los Alamos Canyon that also had elevated aluminum in water.

Garn and Jacobi (1996) suggested that low invertebrate density may be indicative of pollution or habitat degradation in their studies. Plafkin *et al.* (1989) also suggested that low invertebrate taxa richness was indicative of poor water quality. In this study, Ford-

Schmid (1999) found low invertebrate density and low taxa richness in Sandia Canyon. Combined invertebrate community scoring metrics indicated that the overall biological condition of the benthic macroinvertebrate community was slightly impaired in Valle Canyon and Pajarito Canyon, and moderately impaired in Sandia Canyon compared with the reference site (Table 19). However, the impairment of the benthic macroinvertebrate community at Sandia Canyon could be due to a number of factors, such as the elevated nitrates and salts found in the water, the eroded stream channel and sedimentation, or the reproductive toxicity demonstrated in the sediment porewater. All of these factors could have impaired the benthic macroinvertebrate community, and these conditions were not found at the other sites.

RESULTS OF THE ENVIRONMENTAL SAMPLING AND TOXICITY TESTS

Existing Water and Sediment Data

Extensive surface water quality monitoring data collected by the LANL (*e.g.* USDOE 1996; USDOE 1999) and the NMED (Ford-Schmid 1996; Dale 1998) were collected for other purposes (*e.g.*, compliance with Resource Conservation and Recovery Act regulations, research), and as such, did not satisfy the collection, storage, and analytical requirements of USEPA-approved methods for surface water. Few of the thousands of water quality monitoring data collected by the LANL or the NMED could be included and therefore, unfortunately, were not evaluated during this LANL Water Quality Assessment. The NMED reviewed all water quality data submitted for the LANL Water Quality Assessment and found only the LANL data for a biological oxygen demand and several constituents in unfiltered water could be incorporated into this LANL Water Quality Assessment. Since mostly dissolved constituents in water have applicable water quality standards, and total suspended solids data were not available to convert total measurements into dissolved concentrations, these data were not incorporated into the LANL Water Quality Assessment. Water quality data collected in 1997 by the USFWS, met the collection, storage, and analytical requirements of the USEPA-approved methods, and were evaluated against the water quality standards (NMWQCC 1995) applicable at the time of the study.

A summary of the LANL (1998b) element concentrations in sediment mostly collected at the property line were provided for use in the LANL Water Quality Assessment (Table 20). The maximum concentration reported in the canyon watershed was compared with the Sediment Quality Criteria where biological effects would be considered likely. Generally, the maximum concentrations of arsenic and selenium were elevated in Los Alamos Canyon, and silver was elevated in Los Alamos and Sandia Canyon. Mercury concentrations were above the Sediment Quality Criterion in each canyon, but the maximum concentration reported in Los Alamos Canyon was one thousand times higher than the concentrations expected to protect aquatic life from adverse effects, suggesting mercury contamination in the canyon.

Water Column Monitoring

The Hydrolab® Datasonde water quality monitoring devices made over 7,000 measurements of temperature in degrees Celsius (°C), DO in parts per million (mg/L), conductivity in millisiemens per cm (mS/cm) at 25 °C, and hydrogen ion concentrations (pH) in standard units. Occasionally an entire unit or a probe would fail to record data, due to low battery power, insufficient memory, or when removed from the stream by flood (mostly in late December 1996, mid February 1997, and April 1997). Additionally, the devices could not measure conductivity above 2 mS/cm and temperature below freezing (0 °C), although temperatures below freezing in montane streams would be expected (Hynes 1970).

The daily, quarterly (every four hours), temperature, DO, conductivity, and pH data are presented in Figures 26 through 41. The average temperature (and range) in Los Alamos Canyon was 6.6 °C (<0 to 16.7 °C); 9.4 °C (<0 to 23.0 °C) in Sandia Canyon; 8.1 °C (<0 to 22.6 °C) in Valle Canyon; and 6.9 °C (<0 to 17.8 °C) in Pajarito Canyon. The average DO (and range) in Los Alamos Canyon was 9.6 mg/L (5.2 to 13.3 mg/L); 8.6 mg/L (4.3 to 17.6 mg/L) in Sandia Canyon; 8.4 mg/L (5.4 to 15.4 mg/L) in Valle Canyon; and 9.3 mg/L (5.7 to 13.0 mg/L) in Pajarito Canyon. The average conductivity (and range) in Los Alamos Canyon was 0.09 mS/cm (0.01 to 0.14 mS/cm); 0.77 mS/cm (0.12 to >2 mS/cm) in Sandia Canyon; 0.21 mS/cm (0.07 to 0.27 mS/cm) in Valle Canyon; and 0.13 mS/cm (0.04 to 0.35 mS/cm) in Pajarito Canyon. The average pH (and range) in Los Alamos Canyon was 7.56 (6.98 to 7.86); 7.89 (7.11 to 8.70) in Sandia Canyon; 7.56 (6.89 to 9.27) in Valle Canyon; and 7.66 (6.79 to 7.99) in Pajarito Canyon.

The NMWQCC (1995) identified the standards applicable to a high quality coldwater fishery for DO, temperature, pH and conductivity as:

> Dissolved oxygen shall not be less than 6.0 mg/l, temperature shall not exceed 20 C (68 F), pH shall be within the range of 6.6 to 8.8, and conductivity (at 25 C) shall not exceed a limit varying between 0.3 mS/cm and 1.5 mS/cm depending on the natural background in particular stream reaches (the intent of this standard is to prevent excessive increases in dissolved solids which would result in changes in stream community structure).

The NMWQCC (1995) identified the standards applicable to a coldwater fishery for DO, temperature, and pH as:

> Dissolved oxygen shall not be less than 6.0 mg/l, temperature shall not exceed 20 C (68 F), and pH shall be within the range of 6.6 to 8.8.

The NMWQCC (1995) identified the standards applicable to a marginal coldwater fishery for DO, temperature, and pH as:

> Dissolved oxygen shall not be less than 6 mg/l, on a case by case basis maximum temperatures may exceed 25 C, and the pH may range from 6.6 to 9.0.

The NMWQCC (1995) identified the standards applicable to a warmwater fishery for DO, temperature, and pH as:

> Dissolved oxygen shall not be less than 5 mg/l, temperature shall not exceed 32.2 C (90 F), and pH shall be within the range of 6.5 to 9.0.

All measurements of temperature, DO, pH, and conductivity in these canyon stream segments were compared with these standards. Yearly average stream temperatures were low (<9 °C) in Los Alamos, Pajarito, and Valle Canyons. Average temperature in Sandia Canyon was elevated compared to the other canyons mostly due to the majority of flow being comprised of effluent discharges, and parking lot runoff from the upper watershed. Temperatures were elevated in Valle Canyon compared with other canyons most likely due to its shallow depth. Stream segments studied in Sandia and Valle Canyons exceeded the high temperature criteria for both a high quality coldwater fishery and coldwater fishery in summer 1997. Temperatures in no canyon stream segment rose above 24 °C, which was the short-term maxima temperatures necessary for survival of juvenile and adult brook trout (and other trout and salmon) during summer (Brungs and Jones 1977). Lee and Rinne (1980) found that cutthroat trout as well as introduced species of trout in the southwest United States could survive in waters up to 27 °C. Temperatures in the stream segments of Sandia and Valle Canyons did not exceed the standards for a marginal coldwater fishery at any time.

Average annual DO concentrations (>8 mg/L) and pH (<8) were similar among stream segments studied. Minimum DO concentrations ranged from 4.3 mg/L in Sandia Canyon to 5.7 mg/L in Pajarito Canyon. All of the stream segments occasionally fell below the minimum DO standards for both the high quality coldwater fishery and the coldwater fishery. The Los Alamos Canyon stream segment dropped to 5.6 mg/L for 3 hours on August 22, 1997, and for 2 hours on August 23, 1997. The Pajarito Canyon stream segment dropped below 6.0 mg/L for 1 hour in June 1997. The Valle Canyon stream segment dropped below 6.0 mg/L once in May, June, and August 1997, and six times in July 1997. The Sandia Canyon stream segment dropped below 6.0 mg/L repeatedly from May through September 1997, with these <6.0 mg/L DO concentrations lasting for days at a time. Additionally, for 3 days in June and 3 days in July, measured DO concentrations dropped below 5 mg/L for several hours each day. The DO followed a diurnal pattern in all streams being greatest in late afternoon and lowest in the early morning, as well as less diurnal fluctuation in the winter months compared with summer months were lower. These fluctuations suggested these streams were photosynthetically active and productive (Cole 1983).

Only the Valle Canyon stream segment had a pH above 9.0, the maximum range for all categories of a fishery. After nine months of monitoring, the pH increased greatly from mid to late afternoon during the week of October 13 to October 19, 1997, and after that, the pH fell and remained near its average pH (7.6). At the time of the measurement, a material disposal area (MDA-P) was being excavated to remove the hazardous and solid waste. It was undeterminable whether the elevated pH was associated with runoff events or with diurnal fluctuations possibly associated by plant productivity.

Conductivity was generally low (<0.3 mS/cm) in all stream segments except Sandia Canyon, which had significantly higher conductivity (at times greater than 2 mS/cm) due to effluent discharges. Elevated chlorides, carbonates, and cations likely contributed to the high conductivity (Hynes 1970). Only the stream segment in Sandia Canyon had conductivity greater than the high quality coldwater fishery conductivity standards.

Analytical Results

Many elements were initially analyzed (in 1996) using a semi-quantitative method (ICP\MS), and some elements had an insufficient rate of detection to conduct statistical analyses or a determination of trends. The analyses of those elements that were not evaluated further are: Ag, Au, Ca, Ce, Co, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Ho, In, K, La, Li, Lu, Na, Nb, Nd, Os, Pb, Pd, Pr, Pt, Rb, Re, Ru, Sb, Sc, Sm, Sn, Ta, Tb, Te, Th, Ti, Tl, Tm, U, W, Y, Yb, and Zr (see Table 5 for chemical symbols and names). The analytical results for moisture content, Al, As, Ba, B, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Se, stable Sr, V, and Zn found in water, porewater, sediment, and tissues are presented in Figures 42 through 60 and raw data are presented in Appendix IV.

Water Chemistry

The water chemistry of the Los Alamos, Pajarito, and Valle Canyon stream segments is typical of montane streams. Generally, they are dilute, soft waters (hardness <60 mg/L $CaCO_3$, alkalinity <200 mg/L $CaCO_3$, Cl^- <20 mg/L) with low nutrients (*e.g.*, nitrate as nitrogen <0.2 mg/L, and orthophosphate <0.5 mg/L) and salts (Table 21). Waters in Sandia Canyon were atypical for this region, however. Its water had much higher concentrations of salts, nutrients, and other constituents (Figures 61 through 64). This was because the source water was composed primarily of effluent from LANL operations (USDOE 2001). Similar trends and values were reported for these canyon stream segments by Chapman and Allert (1998; Attachment A), by Dale (1998), and by LANL (1996a).

Nutrients in Sandia Canyon were elevated and as much as 10 times the concentrations found in Los Alamos, Pajarito, and Valle Canyons (Figure 61). However, nitrate concentrations in Sandia Canyon were not found in this study to exceed 10 mg/L (a water quality standard designed to protect domestic water and human health). However, Heikoop *et al.* (2001) found nitrate concentrations as high as 30 mg/L in Sandia Canyon. Phosphate concentrations were elevated (>5 mg/L) in Sandia Canyon, which could accelerate algal growth, increase biological oxygen demand, and affect the aquatic community trophic dynamics and community structure. Using annual average temperature and pH, Sandia Canyon (and the other sites studied) did not contain ammonia concentrations greater than the water quality standards for a coldwater fishery (NMWQCC 1995). Also, no dominance of nuisance species in response to excess nutrients was observed in the stream segments studied.

Pajarito Canyon stream waters were observed to be a milky white color and the measured turbidity was also quite elevated (Figure 64). Freeman and Everhart (1971) reported a white iridescent cast to water of pH 8 containing 5.2 mg/L aluminum. The white suspension may have been aluminum colloids of natural origin (see below). The water quality standards (NMWQCC 1995) identify that "turbidity attributable to other than natural causes shall not reduce light transmission to the point that the normal growth, function, or reproduction of aquatic life is impaired or that will cause substantial visible contrast with the natural appearance of the water." The NMWQCC (1995) also reported a numeric standard for turbidity of 10 nephelometric turbidity units (NTU) in streams that are designated coldwater fisheries. All canyon stream segments exceeded the 10 NTU turbidity standard at least once during the study. Except in Pajarito Canyon, the elevated turbidity was associated with an increase of total suspended solids, which were found to increase after precipitation events in the watershed.

Descriptive statistics of elements dissolved in water are presented with water quality standards in Table 22, and the range of concentrations are also presented in Figures 43 through 60. Several field-collected water blanks from the 1997 sampling contained some chromium (9.2, 3.4, and 5.6 μg/L) and nickel contamination (15.1 and 7.6 μg/L). The MRI Laboratory blanks also had detectable aluminum (50.8 μg/L), cadmium (2.8 and1.8 μg/L), chromium (7.0 μg/L), and vanadium (5.6 μg/L), which suggested that contamination of field blank water samples may have been at the laboratory, rather than from the field. The excess cadmium found in the surface water samples was greater than the water standards for a coldwater fishery. Because this cadmium was attributable to contamination of the blanks, cadmium was not viewed as exceeding the coldwater fishery standards. In Table 22, copper in water from Sandia Canyon appears to exceed the copper standard protective of a fishery. However, the copper standard was presented using a default hardness value (50 mg/L as $CaCO_3$), whereas during the individual water quality standard comparison, the individual hardness value for Sandia Canyon (averaging

~80 mg/L as $CaCO_3$) was used instead and copper was not found exceeding the water quality standard. Only aluminum and barium were found in the surface waters sampled during the LANL Water Quality Assessment to be above New Mexico water quality standards (NMWQCC 1995). Review of USEPA criteria (1998a, 1998c, 1999) identified explosives, iron, and molybdenum to be additional pollutants of concern.

Aluminum in Water

Hem (1985) reported that in most natural waters, aluminum is rarely above a few tenths of a milligram per liter, and where concentrations are greatest, the pH is often low. In the LANL Water Quality Assessment, aluminum was detected (89.5 to 14,893 micrograms per liter [μg/L]) in all water samples exceeding the chronic (85μg/L) and often acute (750μg/L) water quality standards for coldwater fishery (Figure 43). Geochemical equilibrium modeling using $MINEQL^+$ (Schecher and McAvoy 1991), and the highest measured concentrations of aluminum and iron (3.9 mg Al/L and 1.6 mg Fe/L, see below) found in Pajarito Canyon, predicted the primary precipitate to be diaspore (AlOOH), an aluminum complex, followed by lesser concentrations of the iron solid hematite (FeO_3), and a minor fraction of calcium phosphate ($Ca_5OH(PO_4)_3$). Elevated aluminum concentrations at the average pH (~7.7) found in Pajarito Canyon would likely result in the formation of a diaspore solid, which could remain in suspension and have caused the water's milky white appearance. Alternatively, amorphous aluminum complexes (such as $Al(OH)_3$ or gibbsite [Hem 1985]) may have formed from dissolution of the parent material (Bandelier Tuff) in the spring waters. Because gibbsite forms of aluminum are not at equilibrium, it would not be predicted using equilibrium models such as $MINEQL^+$ (Sposito *et al.* 1996). Gibbsite crystals have considerable stability and small size (<0.10 micrometers in diameter; Hem 1985), and they could have passed through the 0.45 micrometer filter media as a colloid in the water column sampled. Formation of an aluminum precipitate likely contributed to the elevated aluminum in water and turbidity measured in the Pajarito Canyon stream segment. The occurrence of elevated concentrations of aluminum in water samples from the Jemez River is not unusual (NMWQCC 1998). Concentrations of Al in Pajarito Canyon as high as 12 mg/L have been reported in filtered water samples by others (Dale 1998; LANL 1998a). An index of erosion was not correlated with elevated aluminum concentrations in Pajarito Canyon.

Aluminum toxicity to aquatic life vary widely due to aluminum's complex chemistry in waters of different pH (Freeman and Everhart 1971). The bioavailability and toxicity of aluminum are related to the pH of waters; at pH 5.5 to pH 6.5, fish and invertebrates are stressed and eventually asphyxiated (Sparling *et al.* 1997). Poléo (1998) found that acidic conditions favored the polymerization of aluminum at the gill surface that increased mucus secretion, and both polymers and mucus clogged the gills that lead to acute hypoxia. At no time did the pH of waters drop below 6.5 during the time of study.

However, low pH conditions have only been reported to occur during sulfuric and nitric acid spills to Sandia Canyon in1990 and 1994 (Bennett 1994; Cross 1995a).

Since previous research has focused primarily on aquatic systems with low pH, there was an information gap regarding the chemical and biological effects of elevated aluminum to aquatic life in high pH waters. The USFWS funded a study to address the effects of aluminum to the health of the native fish, *Hybognathus amarus* and *P. promelas,* by exposing the larvae of these fishes to dilutions of test water simulating the chemical characteristics of the Rio Grande and various concentrations of aluminum (Buhl 2001). There was a low solubility of the aluminum at pH 8.0-8.2 in the simulated Rio Grande water. In the acute assays, the fishes were not sensitive to dissolved aluminum concentrations as high as 1.3 mg/L (Buhl 2001). Other research was obtained for aluminum toxicity at high pH. Buhl (2001; citing Call *et al.* 1984) reported that total aluminum concentrations of 2.9 to 49.8 mg Al/L killed less than 10 percent of juvenile *P. promelas* in soft lake waters adjusted to a pH of 7.6 and 8.0. The USEPA (1988) reported a 96-h LC50 of 35 mg Al/L for juvenile *P. promelas* in water of 220 mg/L hardness. However, Freeman and Everhart (1971) reported that trout exposed to waters of pH 8, at 12 °C, containing 5.2 mg Al/L, were sluggish, fed poorly, had a darkened color, and experienced equilibrium problems or gill hyperplasia. Fifty percent of the test population of trout died after 45 days of flow-through exposure in a laboratory. However, trout in Rio de Frijoles and Santa Clara Creek have persisted in Pajarito Plateau waters that contain elevated aluminum concentrations greater than the coldwater fishery standard, but the amount of any gill damage has not been reported.

In this study, the elevated aluminum in Pajarito Canyon waters did not appear to present acute or chronic hazards to fathead minnow, crustaceans, or the benthic macroinvertebrates studied. Aluminum concentrations in Pajarito Canyon averaged over 3 mg/L, and yet caged-fathead minnow survived these exposures for 2 months. Ford-Schmid (1999) found only a slightly impaired benthic macroinvertebrate community in Pajarito Canyon. Chapman and Allert (1998) found no surface water or porewater toxicity to fathead minnow and *C. dubia* exposed to undiluted Pajarito Canyon waters in a laboratory setting. However, these species are generally less sensitive than trout (USEPA 1988). Prolonged exposures to waters containing elevated aluminum (in the form of gibbsite crystals or aluminum precipitates such as diaspore) in high pH water may affect trout gill filament function and would need further research. Water quality standards developed for streams on the Pajarito Plateau may need to consider prolonged exposure to aluminum particles in the development of a site-specific standard for aluminum in coldwater fisheries of the Jemez Mountains.

Barium in Water

Barium is a divalent, alkaline earth metal, and when pure, it is soft and silvery-white. Barium is most often found in nature as barite ($BaSO_4$) and witherite ($BaCO_3$), both of which are highly insoluble salts (Grolier Inc., 1997). The NPDES outfall at Building 260 as well as Material Disposal Area "P" in TA-16 have discharged explosives and barium nitrate sand along with other materials above the stream segment studied,(LANL 1995a). Barium compounds that easily dissolve in water may cause health effects in people (ATSDR 1992). To protect human health, the USEPA (1996a) allows no more than 2 mg Ba/L in drinking water sources and the NMWQCC (1995) groundwater standard is 1 mg Ba/L. Only stream water from Valle Canyon (range: 2.2 to 5.0 mg Ba/L) exceeded these water quality criteria (Figure 45).

There are no water quality standards for barium developed either by the USEPA (1998a) or New Mexico (NMWQCC 1995) for the protection of aquatic life. Toxicity information collected from the AQUIRE toxic effects database (USEPA 1998c) indicated that concentrations of >8 mg Ba/L are associated with adverse reproductive effects in *Daphnia magna*, a fresh water crustacean. In general, barium in the water column was not acutely toxic at concentrations <8 mg/L. The lowest barium concentration causing an adverse effect reported in the AQUIRE database, was 2.6 mg Ba/L, above which fish were observed to be "stressed." Thus, the elevated barium found in water in Valle Canyon, would not be acutely toxic to aquatic life but could contribute to stress in fish and cause weight loss or other sublethal effects. Barium was above the maximum contaminant level for acceptable drinking water and above the water quality standard for groundwater.

Molybdenum in Water

Elevated molybdenum concentrations were detected (range: 0.03 to 0.3 mg Mo/L) in water collected from the Sandia Canyon stream segment (Figure 56). There are no water quality standards for molybdenum developed either by the USEPA (1998a) or New Mexico (NMWQCC 1995) for the protection of aquatic life, or drinking water (USEPA 1996a). Additional toxicity information was obtained from the ECOTOX database (USEPA 1998d) indicating that concentrations of >0.6 mg Mo/L were associated with some adverse effects in aquatic life, and adverse reproductive effects in *Daphnia magna* were associated with molybdenum concentrations >2.1 mg/L. Molybdenum compounds are currently used for corrosion inhibition during cooling tower operations of the Steam Plant at Technical Area 3 and was the most likely source of molybdenum found in both Sandia Canyon water and sediment. While molybdenum dissolved in water from Sandia Canyon was elevated, the excess concentrations in the surface water did not appear to present any acute or chronic toxicity to aquatic (Chapman and Allert 1998). However, molybdenum is known to accumulate in plants such that their molybdenum content increases by five times that in the medium in which they grow (Kovalsky *et al.* 1961).

Therefore, bioaccumulation of molybdenum in plant species above concentrations considered to pose a dietary risk to wildlife or livestock should be evaluated if affected plant materials are used as food.

Explosives in Water

The explosive compound, RDX, is an environmentally persistent explosive compound unique to military operations, and is moderately mobile in the environment (Talmage *et al.* 1999). Although only moderately water-soluble (38.4 mg/L at 20 °C), it also has a low absorption coefficient for soils and sediments, so it tends to migrate into groundwater. RDX is resistant to aerobic microbial degradation, and only slightly biodegradable via anaerobic bacterial action, so RDX that is buried in soil tends to have a long environmental half-life. Studies on ingestion by mammals indicated that RDX is rapidly excreted and does not bioaccumulate (Talmage *et al.* 1999).

Like RDX, HMX is an environmentally persistent explosive compound that is moderately to highly mobile in the environment. In many ways its environmental fate and transport is similar to RDX, although HMX tends to be slightly less toxic and less susceptible to microbial degradation (Talmage *et al.* 1999). Talmage *et al.* (1999) estimated that HMX in the Holston River in Louisiana would persist in surface waters for a distance of over 20 km downstream of the sources.

With the notable exception of Valle Canyon, explosive compounds were not found above the reporting limits in canyon streams during the LANL Water Quality Assessment. The compounds, HMX, RDX, 4,2,6-DNT, and 2,4,6-DNT were detected twice during water sampling in each reach of the Valle Canyon stream segment and these compounds were detected at high concentrations in sediment. Concentrations of all four compounds were notably higher in the second sampling, indicating source contributions may vary over time. Nonetheless, all water samples contained explosive compounds that exceeded the chronic water quality benchmarks (Table 23) recommended for the protection of aquatic life. Explosives found in water also exceeded the human health-based drinking water guidelines. Moreover, because these compounds are resistant to degradation, and readily translocated to groundwater, downstream water resources, including water supply wells, the Rio Grande, and drinking waters may be at risk. No information was provided regarding the presence or lack of detection of explosives in downstream locations.

Radiological Constituents in Water and Porewater from the Stream Segments Studied

The radiological constituents of water and porewater samples were collected in 1996 and the data were received by the USFWS in January 2000. These data are presented as an addendum to Attachment A. Uranium 234 was most frequently detected and was greatest in Pajarito Canyon. However, no radiological constituents (gross alpha, radium) were found to exceed the few applicable water quality standards (NMWQCC 1995).

Surprisingly few empirical studies are available that quantify the effects of radionuclides in water and sediment to aquatic life and wildlife of the Pajarito Plateau and Rio Grande. Therefore, working with the Laboratory, the USFWS contracted a study by the New Mexico State University Fish and Wildlife Cooperative Research Unit on the effects of depleted uranium (DU) on the survival and health of *C. daphnia* and *Hyalella azteca* (Kuhne 2000). Depleted Uranium released to the environment is found in the soil of test fields as three uranium oxides. The low solubility of the alloyed heavy metals and the uranium oxides have led researchers to consider DU found in the soil as more of a terrestrial hazard than an aquatic one. However, research has indicated DU present in soil is not stationary and has the potential to move into intermittent stream systems. Since previous research has focused primarily on terrestrial systems, there was an information gap regarding the chemical and biological effects of DU to aquatic life. The USFWS, therefore, funded a study to address the effects of DU-contaminated soil on the health of the invertebrates *C. dubia* and the amphipod, *Hyallela azteca*, by exposing these organisms to dilutions of test water overlying and aged with DU soil and a reference soil (relatively contaminant free). In both the acute and chronic *C. dubia* assays, significant differences in survival versus the control and reference groups were observed at the estimated LC50 of 14,600 μg DU/L. Significant differences in reproduction versus the reference group was observed at 3,600 μg DU/L. Significant differences in survival of *Hyallela azteca* versus the reference group was observed at 3,600 μg DU/L and for growth at 1,800 μg DU/L. Information generated from this study enable researchers to determine the potential impact of concentrations of DU on aquatic systems in the LANL Water Quality Assessment. Concentrations of DU in water and porewater samples collected for the LANL Water Quality Assessment (Attachment A) were below the thresholds of concern identified by Kuhne (2000).

Surface Water Toxicity

Chapman and Allert (1998; Attachment A) discussed the results of the surface water toxicity tests using the fathead minnow and the crustacean, *C. dubia*. No significant toxicity was observed in the larval fathead minnow toxicity tests. *C. dubia* survival (and therefore reproduction) was completely eliminated in the undiluted Valle Canyon water sample tested in 1996. This sharp decrease in survival rate corresponded to the transfer of the day-3 water samples that were collected following a rain event. Immediately following the day-3 mortalities, a new test was started using water collected on day-4 from Valle Canyon. No further mortality was observed in this additional test, indicating that the cause of the mortality was transitory. Reproductive toxicity was not evaluated in this second test.

Although no mortality or reproductive impairment was observed in the undiluted water samples from Los Alamos, Sandia, or Pajarito Canyons, dilution of those samples with ASTM soft water resulted in some mortality and reproductive impairment in the Sandia and Pajarito Canyon waters at the 12.5 percent dilution. No adverse effects were associated with the soft-water diluent tested itself (*i.e.*, the ASTM Control), and no observable changes in basic water chemistry (pH, alkalinity, hardness) were measured. Inverse concentration-response patterns can result from toxicity in the receiving water or the limitation of necessary components (*e.g.*, ionic imbalance) in the receiving water or synthetic dilution water (USEPA 2000). The reason for this inverse concentration-response pattern at the extreme dilution (referred to as "reverse toxicity" by Chapman and Allert, 1998), or its ecological and toxicological significance, was unresolved. However, as the 100-percent concentration represented the actual condition of the ambient stream, these results were the ones that were used for the interpretation of toxicity.

Sediment Quality Discussion

Sediment interacts strongly with other water quality components. Sediments are the unconsolidated materials at the bottom of a water body, consisting of mineral particles, organic material, and water. The mineral share is most familiar as clay, silt, sand and gravel, but sediment also contains some trace elements and organic materials. Organic materials in sediments are largely derived from the activities of living organisms, but can also be composed of synthetic chemicals. Water is also a large component of sediment, occupying as much as sixty percent of the volume by filling in the spaces between the particles (*i.e.*, "porewater"). Sediments are an important component of water bodies in New Mexico because they support a wide variety of aquatic life, such as worms, clams, crustaceans, and insects. Benthic organisms are key links in the aquatic food web leading from nutrients and other constituents in water and sediment to fish, wildlife, and people (USEPA 1993).

Contaminated sediments are those that "contain chemical substances at concentrations that pose a known or suspected environmental or human health threat" (NRC 1997). Sediments can serve as a "reservoir" from which fish, shellfish, and benthic organisms can accumulate contaminants into their tissues. Contaminants are introduced to sediments through many routes including storm runoff, spills, municipal and industrial discharges, and atmospheric deposition (NRC 1997). Common contaminants in sediments are heavy metals, polycyclic aromatic hydrocarbons and PCBs. Once these pollutants are in water, they tend to accumulate in sediments and then increase in concentration in the animals at higher trophic levels, where they can pose health risks to wildlife that consume the contaminated aquatic life (USEPA 1993).

The physical and chemical characteristics of sediment samples are provided in Appendix IV and are graphically presented in Figures 43 through 60. Mean concentrations in sediments collected for the LANL Water Quality Assessment were compared to concentrations reported by Ryti *et al.* (1998) as background concentrations in canyon sediments (Table 24). The mean concentration of chromium in Sandia Canyon (114 mg/kg DW) was 10 times the background concentration for canyon sediments on the LANL (10.5 mg/kg DW) reported by Ryti *et al.* (1998). Mean concentrations in sediments collected on stream segments from the Laboratory were compared to those found in the Los Alamos Canyon reference site sediment. The mean concentration of silver was elevated in Sandia, Pajarito, and Valle Canyon sediment relative-to-reference site sediments. Barium, PCBs, HMX, and RDX were elevated in Valle Canyon sediments and Cr and PCBs were found elevated in Sandia Canyon sediments relative-to-reference site sediments (Table 24).

Mean sediment concentrations in all canyons were also compared with the SQC (*i.e.*, the consensus sediment quality criteria, see methods and Table 8). Since the SQC is a threshold concentration, mean concentrations were considered elevated when the ratio of the mean to the SQC was greater than unity. Mercury was elevated above the SQC in all canyons, largely because the detection limit (~0.1 mg/kg DW) was greater than the SQC (0.002 mg/kg DW).

Mean canyon sediment concentrations were compared to the LANL's Screening Action Levels (SALs) that were only designed to protect human health in an industrial setting (LANL 1998a). Using these SALs, only Mn in Valle Canyon sediments was considered elevated. The human health SALs were then compared to the aquatic life SQC, and were found to be less protective, as toxicity to aquatic life has been found and reported in sediment with much lower concentrations of contaminants than at concentrations at the level of the SALs. Without protection for aquatic life or wildlife, sediment evaluation using SAL will be less protective of the environment particularly for highly toxic and persistent chemicals such as explosives, mercury, and PCBs. Sediment SALs that protect aquatic life and wildlife would be one part of the restoration and maintenance of the biological, chemical, and physical integrity of these intermittent streams. The LANL Water Quality Assessment approach identified Ba and explosives as contaminants of concern in Valle Canyon, and Cr as a contaminant of concern in Sandia Canyon and these are discussed below.

<u>Barium and Explosives in Valle Canyon Sediment</u>

The Environmental Surveillance Group reported elevated barium in LANL surface water and foodstuffs (LANL 1998a), but barium was not reported as elevated in either sediments or soils because it did not exceed the SALs. However, Warren *et al.* (1997) reported a maximum soil concentration of 2,040 mg Ba/kg DW in the LANL's Technical Area 16 (TA-16). Material Disposal Area "P" at TA-16 was operated as a landfill until 1984 and received explosives and barium nitrate sand along with other materials (LANL 1995a). Within the entire TA-16 region wind-borne contamination of barium, lead, and uranium was likely widespread as indicated by the enrichment of these elements in area soils as reported by Warren *et al.* (1997). Ryti *et al.* (1998) reported the background barium concentration of 127 mg/kg DW for canyon sediments. Buchman (1998) reported a background for barium in freshwater sediments was 700 mg/kg. Elevated barium in the Valle Canyon sediment encountered during the LANL Water Quality Assessment would likely have originated from the Building 260 Outfall and the Material Disposal Area "P," either as runoff, or wind-borne from TA-16.

Barium was found to be elevated in Valle Canyon sediment as the mean (± standard deviation) concentration (1022 ± 654 mg/kg DW) was significantly greater ($p=0.0002$) than that found in the reference site sediment (Los Alamos Canyon: 35 ± 19 mg/kg DW). Barium in sediment has been reported to be toxic to benthic organisms at 40 mg/kg DW (Anonymous 1977). Buchman (1998) also reported that 48 mg/kg DW was the apparent effects threshold for amphipods. These thresholds would be exceeded by the background barium concentration reported by Ryti *et al.* (1998). However, porewater toxicity to invertebrates was not found in Valle Canyon by Chapman and Allert (1998), though the benthic macroinvertebrate community was identified as slightly impaired. Additional studies of barium exposure to aquatic life may be necessary in order to evaluate chronic toxicity.

Concentrations of nitroaromatic munition compounds (explosives) including TNT, 2,4,6, DNT, RDX, and HMX were detected in Valle Canyon sediment. Concentrations of explosives in sediment were greater from upstream sampling locations closest to the Material Disposal Area P than from sampling locations further downstream. No explosives were detected in the other canyon sediments collected. The explosive, HMX, is used in nuclear devices to implode fissionable material and is found in other military munitions (McLellan *et al.* 1988). The maximum concentration of HMX in sediment (1,130 nanograms per gram [ng/g] DW) from Valle Canyon was over 400 times greater than organic carbon-normalized (using 0.5 percent) sediment quality benchmark (2.3 ng/g DW) reported by Talmage *et al.* (1999) considered safe for benthic organisms. Similarly, the maximum concentrations of TNT (127 ng/g DW) in Valle Canyon sediment was 15 times greater than the organic carbon-normalized (using 0.5 percent) sediment quality benchmark for TNT (8 ng/g DW) reported by Talmage *et al.* (1999). Insufficient information was available to determine sediment quality benchmarks for the protection of benthic organisms from RDX. The explosives HMX and TNT detected in Valle Canyon sediment would be considered by Talmage *et al.* (1999) to be potentially toxic to benthic organisms. However, porewater toxicity was not found in Valle Canyon by Chapman and Allert (1998), and the benthic macroinvertebrate community was identified as only slightly impaired. Additional studies of munition exposures to aquatic life may be necessary to in order to better evaluate chronic toxicity.

Chromium in Sandia Canyon Sediment

Chromium is a metallic element listed by the USEPA as a priority pollutant and is one of the most persistent and prevalent toxic chemicals found at Superfund sites (USEPA 1994b). Under laboratory conditions, chromium is mutagenic, carcinogenic, and teratogenic to a wide variety of organisms (Eisler 1986a). Chromate, that has a hexavalent oxidation state, is toxic at high levels, and is often used for corrosion inhibition in water-cooling systems (Eisler 1986a; ATSDR 1993). Chromium toxicity to aquatic organisms can be influenced by the oxidation state, water hardness, pH, temperature, and salinity. The oxidation state of chromium in sediment was not measured in the LANL Water Quality Assessment. Divalent chromium was reported to be converted to less toxic trivalent chromium by the Sandia Canyon wetlands (J. Gerwin, Northern New Mexico Citizens Advisory Board, April 29, 2000, written communication).

Chromium compounds were used for corrosion inhibition during operations of the Steam Plant at Technical Area 3 (LANL 1999a). These point source discharges of effluent and blow-down water from the steam plant and cooling towers, then, were likely a major source of chromium that contaminated the Sandia Canyon sediment (Figure 49). Sandia Canyon sediments contained significantly higher concentrations ($p = 0.001$) of total chromium (114 ± 66.9 mg/kg DW) than found in sediment from other canyons including the reference site (3.7 ± 2.0 mg/kg DW). The chromium properties of the sediment are significantly altered in Sandia Canyon. The maximum chromium concentration in Sandia Canyon sediment detected by this study (198.9 mg/kg DW) was nearly 20 times the background concentration of 10.5 mg/kg DW for canyon sediments reported by Ryti *et al.* (1998) and exceeded the SQC consensus toxicity threshold concentration (176 mg/kg DW) for the protection of aquatic life. The maximum sediment concentration recently reported by LANL (1999a) was 2,080 mg/kg. Average and maximum chromium concentrations in Sandia Canyon sediment were also greater than the Probable Effects Concentration (111 mg/kg/ DW) reported by MacDonald *et al.* (2000a) to protect benthic aquatic life. Laboratory tests of porewater indicated reproductive toxicity to invertebrates exposed to porewater (Chapman and Allert 1998). However, Chapman and Allert (1998) did not attribute the reproductive toxicity found in Sandia Canyon porewater to Cr or other metal contamination. The lack of cooling tower effluent limitations that are protective of aquatic life may have allowed the contamination of Sandia Canyon sediment. According to the NMWQCC (1995), surface waters of the State shall be free of water contaminants from other than natural causes that will settle and damage or impair the normal growth, function or reproduction of aquatic life or significantly alter the physical or chemical properties of the bottom.

Sediment Texture

Using the United States Department of Agriculture standard soil texture triangle, all sediment grain sizes ranged from sand, loamy sand to sandy loam. Average grain size of sediment samples collected in each stream segment were not significantly different and would be classified as loamy sand (Table 25). Sediment organic content was low, ranging from 0.1 percent in the lower Pajarito Canyon stream segment to 2.4 percent in the upper Los Alamos Canyon stream segment. These extreme values contributed to a significant difference in the organic content measured in the stream segments (Table 25).

Sediment Porewater Toxicity

Porewater toxicity tests conducted by the CERC in 1996 were considered by Chapman and Allert (1998) to be unsuccessful due to the occurrence of male *C. dubia* in the tests (Attachment A). Tests were repeated again in1997 and significantly reduced reproduction and some decrease in survival were found in porewater from Sandia Canyon (Chapman and Allert 1998; Attachment A). While the 1996 data were considered invalid by Chapman and Allert (1998), the two tests nonetheless demonstrate a pattern of toxicity, suggesting that the adverse effects on *C. dubia* reproduction were consistent in both years.

Porewater temperature, DO, pH, and ammonia were all within acceptable limits for most aquatic organisms, and probably did not directly contribute to mortality. Nutrients, sulfates, chlorides, hardness, and alkalinity were elevated in porewaters as compared to surface waters, but were not at concentrations expected to adversely impact aquatic organisms. Concentrations of Cr, Mo, and Sr in Sandia Canyon sediments and porewaters were elevated, and the low total organic carbon and acid volatile sulfide concentrations reported by Chapman and Allert (1998) indicated that sediment metals may be highly bioavailable. Concentrations of total PCBs in Sandia Canyon sediments were detected at concentrations as high as 154 µg/kg, DW, a concentration that falls within the range where toxic effects to sediment biota have been observed (Eisler 1986b; Hoffman *et al.* 1996; ATSDR 1996). , are Potential sources of PCBs to the Sandia wetlands and to the stream segment studied could be from activities at Solid Waste Management Unit #3-0056(c) where PCB-containing electric transformers were drained, rinsed, and stored, as well as from historic PCB-contaminated sludge and waste water discharges. Nonetheless, as pointed out by Chapman and Allert (1998), Sandia Canyon receives a chemically complex effluent, so a Toxicity Reduction Evaluation (TRE) or similar study would be required to definitively identify the source of the toxicity.

During the LANL Water Quality Assessment, the USFWS and CERC were contracted to conduct the toxicity testing as part of the scope of work agreed to under Interagency Agreement Number DE-A132-96AL76575. If a consistent pattern of toxicity was detected, as was the case in Sandia Canyon sediment porewater (although the macroinvertebrate community was also identified as impaired), then the next step of evaluation would likely be to conduct a TRE. A TRE is a methodical, stepwise investigation of the cause(s) of, and appropriate control(s) for, any condition that has demonstrated acute or chronic toxicity. Investigators should seek technical review and comment from their regulatory authority when developing TRE plans that outline investigative and problem resolution techniques, including reasonable time lines and milestones, in order to avoid delays and maximize consideration of relevant factors that may affect toxicity. When multiple toxicants are present in a sample, as is the case in the Sandia Canyon, identifying and resolving the toxicants serially may be necessary due to masking or confounding influences. The LANL Water Quality Assessment did not distinguish which contaminant or combination of contaminants was responsible for the observed reproductive effects and this is not important for regulatory purposes. The result is the same, aquatic life use is impaired in Sandia Canyon. Fiscal limitations of the LANL Water Quality Assessment prevented the USFWS from conducting the TRE.

Tissue Quality Discussion

The net accumulation of a substance by an organism as a result of uptake from all environmental sources is termed bioaccumulation (USEPA 1995b). Determining the extent of bioaccumulation in organisms is widely used as a method to monitor and assess contaminant distribution and bioavailability geographically and over time (Crawford and Luoma 1992). Phillips (1980), identified three benefits from using organisms in chemical monitoring programs. First, concentrations of contaminants are often greater in tissue than in water and therefore, the probability of detecting trace amounts of contaminants in the environment is increased. Second, resident organisms provide a time-integrated assessment of a contaminant in question. Third, the direct bioavailability of contaminants that accumulate can be measured. When tissue quality is used together with water and sediment analyses, they provide complementary lines of evidence in understanding contaminant fate, transport, and effects (Crawford and Luoma 1992).

Certain mammals, birds, amphibians, and fishes rely on aquatic invertebrates for food. Bioaccumulation of contaminants in the food web may affect population abundance and survival of wildlife that is not resident in a water body, yet dependent upon it for sustenance (Hoffman *et al.* 1996). The significance of the concentrations of chemical contaminants in aquatic invertebrates is not always clear, as elevated concentrations are found in apparently healthy individuals. However, studies of chemicals in tissues can provide additional information about ecological relations such as the composition of food webs in contaminated habitats. Questions concerning the pathways of exposure among species and trophic groups are critical in the assessment of exposure. To date, few studies have reported the background concentrations of contaminants in aquatic biota of the Pajarito Plateau (*e.g.*, Nimmo *et al.* 1994; Carter 1997). Therefore, the concentrations in caddisfly nymphs and caged-fish collected for the LANL Water Quality Assessment were compared to the reference site, to values reported in the literature as regionally ambient or elevated, and to levels considered elevated and that may pose a dietary concern to fish and wildlife (Table 26).

Elemental Contaminants in Aquatic Macroinvertebrates

The bioaccumulation of metals in benthic macroinvertebrates can provide a useful measure of the extent and magnitude of contamination that temporally integrates exposure via the water column and sediment. Because invertebrates represent an important source of food for fish, their bioaccumulation of metals, may also serve as a significant exposure route to fish. The chemical concentrations of elements in caddisflies, both with and without their cases are provided in Table 26 and are graphically presented in Figures 43 through 60. Organic chemicals (*e.g.*, explosives and PCBs) were not analyzed in invertebrate tissues. Mean inorganic concentrations reported in these invertebrates collected for the LANL Water Quality Assessment were compared to concentrations reported by other researchers in New Mexico (Lynch *et al.* 1988; Failing 1993; Simpson and Lusk 1999). However, note that most of these researchers investigated agricultural or mining pollution. Concentrations of Mo, Mn, and Cr in aquatic invertebrates collected for the LANL Water Quality Assessment were regionally elevated and Cr was above levels of concern for fish or wildlife that would potentially consume these invertebrates.

Migratory birds, bats, fish, amphibians, and other wildlife often consume large quantities of aquatic invertebrates as food, and therefore are candidates for bioaccumulation of these contaminants from polluted streams and polluted food supplies. Although Los Alamos Canyon (13.1 mg/kg DW) and Pajarito Canyon (13.7 mg/kg DW) also contained invertebrates with elevated Cr, the highest mean Cr concentrations in caddisfly nymphs (without cases) were from Sandia Canyon (21.8 mg/kg DW), all of which were within the dietary concentration known to adversely affect wildlife. Growth and survival of second generation black ducks (*Anas rubripes*) were reduced when fed diets containing 10 mg/kg DW of the trivalent form of Cr (Eisler 1986a). Therefore, depending on the form of Cr and the extent of contamination of the benthic macroinvertebrates, aquatic wildlife that rely on Los Alamos, Pajarito, and Sandia Canyon invertebrates for food may be at a risk of reduced growth and reduced survival.

Manganese (861 mg/kg DW) and Mo (43.5 mg/kg DW) concentrations in invertebrates were significantly elevated in Sandia Canyon compared with concentrations in invertebrates collected from the other canyons. Manganese concentrations in Sandia Canyon were also elevated in water, sediment, and caged-fish (Figure 54). The toxicological significance of elevated Mn is not readily established, but were generally below levels of concern reported by the NRC (1980). Molybdenum concentrations in Sandia Canyon were also elevated in water, porewater, and sediment, but not fish. Concentrations of Mo in aquatic invertebrates were above dietary levels of chronic concern for wildlife, and concentrations at these levels in the diets of domestic animals could impair their bone development. Concentrations of Mn and Mo were not likely acutely toxic, although species tolerances vary widely (NRC 1980).

Contaminant Accumulation in Caged-Fish

The chemical concentrations of elements in caged-fish (female fathead minnow) are provided in Table 27 and are graphically presented in Figures 43 through 60. Explosives were not analyzed in the caged-fish tissues, but PCBs were analyzed in caged-fish after one month of exposure. No detectable As, Be, or Pb concentrations were found in fish above the reporting limit. Fish significantly accumulated Al and Mn from baseline conditions in all canyons. In addition, caged-fish accumulated Fe, Mg, Se, and V in Los Alamos Canyon; Cu, Fe, Hg, Se, and V in Sandia Canyon; Cd and Cu in Pajarito Canyon; and, Ba, Cu, Fe, and Ni in Valle Canyon compared to baseline conditions. Mean concentrations reported in fathead minnow were compared to concentrations found in fish collected nationwide (Schmitt *et al.* 1999) and in fish fillets collected regionally (Table 27). Fish had previously acquired concentrations of Cd and Zn from the CERC facility prior to shipment and subsequent exposure, and these concentrations of Cd and Zn were greater than those found in fish sampled nationwide. None of the other comparable contaminant (*i.e.*, Cu, Hg, Se) concentrations in fathead minnows were greater than the 85th percentile concentration in fish sampled nationwide. With the exception of Ba, and Cr, fathead minnows contained concentrations similar to those reported as background in fish fillets collected from the Rio Grande above the LANL (Table 27). However, the metals in these fish had bioaccumulated their body burdens in only 2 months. Additional exposure time might increase or decrease the steady-state concentrations. Only concentrations of PCBs in fathead minnows were above the dietary levels of concern for predatory wildlife.

PCB Accumulation in Caged-Fish

PCBs do not occur naturally in the environment. PCBs have been used as hydraulic lubricants, insulators, heat transfer fluids, dielectric fluid for transformers and capacitors, pesticide extenders, dust-reducing agents, flame retardants, sealants, and organic diluents (Hutzinger 1979). PCBs are a complex mixture of 209 isomers and congeners with 1 to 10 chlorines attached to the biphenyl structure in various arrangements. Aroclors are commercial PCB preparations that were produced up until 1977 by the Monsanto Chemical Company that contained various amounts of chlorine by weight.

The commonly reported analytical methods used by the LANL for PCB detection and quantification (*e.g.*, LANL 1995c, 1996a; Gonzales *et al.* 1999) in environmental samples relies on matching a pattern of peaks to series of Aroclor standards. Due to differences in degradation, partitioning, and metabolism, the PCB pattern in environmental samples can be very different from these Aroclor standards, making identification and quantification of PCBs difficult and making ecological risk and human health assessments questionable (USEPA 1997c; Valoppi *et al.* 1999). The importance of PCB congener-specific information has become more evident as the toxicities of individual congeners are defined (Gerstenberger *et al.* 1997). The analysis of whole organisms was considered by Erickson (1993) to be the most accurate measure of PCBs present in the aquatic environment.

The Environmental Surveillance Program has reported no detection of PCBs in Sandia Canyon sediments collected at the edge of the LANL boundary for nearly two decades (LANL 1979, 1986, 1993, 1994, 1995c, 1996a, 1996b, 1997, and 1998a), though it was evident from this study and others that PCBs do occur in the environment on the LANL. Sandia Canyon sediment, in the stream section studied below the wetland, had elevated PCB congeners (up to 154 µg/kg DW as the sum of PCB congeners; Attachment A, Appendix A), compared with other canyon stream sediments (Figure 65). Concentrations of PCBs in Sandia Canyon sediment were greater than the threshold for effects to benthic fauna (40 µg/kg DW), but were below the probable adverse effects threshold to benthic aquatic life (400 µg/kg DW) reported by (MacDonald *et al.* 2000b). Recently, Bennett *et al.* (2001) reported that PCB concentrations in the Sandia Canyon wetlands was as high as 2,000 µg/kg WW. MacDonald *et al.* (2000b) reported that sediment concentrations over 1,700µg/kg DW had a 82.5 percent probability of toxic effects to the community of benthic fauna, and their average survival would be less than 70 percent. Screening action levels for sediment quality that do not explicitly include the protection of benthic aquatic life have a high probability of impairing the water quality necessary to protect aquatic life as well as degrading the biological integrity of a stream or wetland.

PCBs accumulate from sediment and water to animals in the food web because they are highly lipid-soluble and persistent in the environment. PCBs have been shown to adversely affect reproduction in fish, wildlife, experimental animals, and are toxic to people (Eisler 1986b; Hoffman *et al.* 1996; ATSDR 1996). Other common adverse effects in wildlife include thymic atrophy, enzyme induction, nervous systems dysfunction, behavioral abnormalities, liver injury, estrogenic activity, endocrine disruption, immunosuppression, crossed bills, hepatotoxicity, and tumor promotion (Eisler 1986b; Eisler and Belisle 1996; Hoffman *et al.*1996; Niimi 1996). PCB congener-specific biological responses have been demonstrated through enzyme induction, estrogenic effects, hormone alterations, reproductive failure and numerous other adverse effects at extraordinarily low concentrations (*e.g.*, <1 part per quintillion in water and <50 µg/kg as falcon diet; Hoffman *et al.* 1996).

Although total PCBs (*i.e.*, the sum of the PCB congeners) are those that are discussed in this study, congener-specific data are reported in Attachment A. The concentrations of PCBs bioaccumulated in a composite of 5 fish from Sandia Canyon in 1 month were elevated (1.5 g/g WW [or 1.2 g/g WW with baseline removed]). Fish had previously acquired concentrations of PCBs prior to site exposure (baseline = 0.3 g/g WW), but concentrations continued to accumulate in Sandia Canyon, and after 1 month. This concentration was greater than the geometric mean of PCBs in fish sampled nationwide (~0.3 g/g WW as Aroclor 1254; Schmitt *et al.* 1999). To protect wildlife and aquatic predators, Eisler (1986b) recommended that whole body fish concentrations be less than 0.3 g/g WW, however these concentrations may not be acutely toxic to the fish themselves (Niimi 1996).

The quality of a water body can also be reflected by the relative safety for consumption of fish by people and wildlife. The concentrations of PCBs in the caged-fish could pose a risk to wildlife or people that could regularly eat them - this does not imply that consumable fish occur on portions of Sandia, Pajarito, and Valle Canyons. Rather, should wild biota taken from Sandia Canyon contain PCB concentrations equivalent to those found in the caged-fish, then there would be concern for human health and wildlife that would consume site-biota regularly. For example, the USEPA (1997a) recommends that adults do not eat even a small amount of fish tissue (<114 grams per month) containing > 0.7 µg/g WW of the PCB Aroclor 1254 (Figure 65). The USEPA (1997a) recommends that children eat even less fish containing > 0.2 µg/g WW of the PCB Aroclor 1254. It is also possible that the maximum tissue concentrations of PCBs in the caged-fish had not likely reached steady-state during the month-long exposure time (USEPA 1998e) and their body burdens could increase in a year.

Similar health risks could be posed to piscivorus wildlife or other predators that would have fed on these caged-fish or other aquatic biota with an equivalent PCB concentration from Sandia Canyon (*e.g.*, invertebrates, amphibians, riparian mammals). Embryo toxicity and reproductive impairment appear to be the most sensitive health risks for avian species exposed to PCBs (Hoffman *et al.* 1996). The primary exposure to the developing embryo results from the maternal transfer of bioaccumulated PCBs to the egg. Consequently, PCB concentrations in the egg may be the most useful measurement for estimating potential reproductive effects in species of concern. No information was collected during this study on the concentrations of PCBs in eggs from birds associated with Sandia Canyon stream and wetlands. However, using the fish-to-egg biomagnification factors provided by Hoffman *et al.* (1996), the PCBs measured in the caged fish from Sandia Canyon could result in total PCB concentrations 32 times greater (~38 g/g WW total PCBs) in avian eggs. Field studies measuring exposure and effects in avian eggs indicates that concentrations ranging from 1 to 8 g/g WW in terns, eagles, and falcons begin to result in embryo mortality, impaired reproductive success, edema, deformities, and mortality. Fair and Meyers (2000) reported that western bluebirds (*Sialia mexicana*) that resided and fed in Sandia Canyon had a thinner eggshell thickness index and eggs that were smaller than at other locations on the LANL. Of the species studied, bluebirds were reported by Hoffman *et al.* (1996) to be one of the least sensitive species, suggesting additional avian population effects, particularly to insectivorous bird populations, could occur in the Sandia Canyon Watershed and perhaps downstream, if PCBs are exported to the Rio Grande.

Because PCBs are difficult to detect in water and sediments (*i.e.*, no routine scans of sediment and water at the edge of the LANL boundary have found PCBs), biological samples, which accumulate PCBs, should be concurrently collected and analyzed for PCB congeners, in order to increase the probability of detecting PCB contamination, to identify the presence of those PCB congeners that are toxicologically relevant, and to provide complementary lines of evidence in understanding PCB fate, transport, and effects to biota in Sandia Canyon as well as to the receptors in the ecosystems downstream. Although initial clean up of PCBs in the Sandia Canyon watershed has been initiated in the headwaters (USDOE 2001), the PCB contamination identified in this study was further downstream, below the Sandia wetlands. PCB contamination, therefore, will likely continue to bioaccumulate in existing aquatic life and be consumed by wildlife. Also, PCBs could move downstream during storm events to the Rio Grande where it may bioaccumulate in fish and potentially affect their consumers. Although the sources of PCBS were not identified, the NMED (2001b) recently reported that concentrations of PCB congeners in Cochiti Reservoir fish tissue would exceed the USEPA-recommended screening value for the protection of human health from long-term consumption of PCB-tainted fish.

RESULTS OF THE HABITAT EVALUATIONS

Basin-wide factors, such as physiographic province, ecoregion, and climate were generally similar among the stream segments examined in this study, and therefore microhabitat features, such as substrate or available cover, were considered to be the primary influence on overall fish carrying capacity of a particular stream. Features such as discharge, flows, water depth, bottom substrate and embeddedness, riparian and in-stream cover are often the primary parameters that define suitable habitat for the majority of fishes. Additional parameters such as channel width, percentage of pools and riffles, bank stability, and general channel dimensions have also been reported as important (Idaho DEQ 1996).

Physical Habitat

The following excerpt from Beschta and Platts (1986) provided a good overview of the importance of some of the morphological features of small streams needed to maintain a stable stream and healthy fishery:

> Unit stream power, defined here as the loss of potential energy per unit mass of water, can be reduced by adding stream obstructions, increasing channel sinuosity, or increasing flow resistance with large roughness elements such as woody debris systems, logs, boulders, or bedrock. Notable morphological features of small streams are pools, riffles, bed material, and channel dimensions. Pools, which vary in size, shape, and causative factors, are important rearing habitat for fish. Riffles represent storage locations for bed material and are generally used for spawning. The particle size and distributions of bed material influence channel characteristics, bedload transport, food supplies for fish, spawning conditions, and rearing habitat. Riparian vegetation helps stabilize channel structure and contributes in various ways to fish productivity.

According to Karr and Dudley (1978), there are four major components of a stream system that determine the productivity of the fishery: 1) flow regime; 2) physical habitat (*e.g.*, channel form, substrate, riparian vegetation); 3) water quality (*e.g.*, temperature, pH, pollution); and, 4) energy inputs from the surrounding watershed (*e.g.*, nutrient and organic matter influx). Deficiencies in one or more of these habitat characteristics limit a fishery. For example, water depths and variations in discharge (flood levels versus summer low-flow) would have likely influenced any distribution of fish within each canyon stream studied. A study by Meador and Matthews (1991) found that even with drastic seasonal fluctuations in discharge, abundance of fish species remained relatively constant over time, but the fish varied their spatial habitat associations in response to water volume. A critical feature to the stability of fish populations in streams with varied discharge, as is found in the southwest, is the availability of pools that hold perennial water sources. Pools represent critical refugia that allow fish to survive in a stream that may, for a period of time, have extremely poor overall habitat conditions.

Precipitation and Flow Regimes

Precipitation during 1997 (64.8 cm) was above average (47.5 cm), due to several high intensity rainstorms in August, and from above-average snow accumulation during the previous winter (Figure 66). However, because the sandy soils in the canyons were fairly permeable and have low water holding capacities, stream flow increases were "flashy" as flows increased rapidly, then decreased to pre-storm levels within a day. Discharge data collected by the Oversight Bureau (Dale 1998) also indicated that while flows were higher in 1997 than 1996, they were fairly typical when compared to the high flow regime measured in 1994 and 1995.

The amount of useable habitat in a stream system is partly a function of the flow regime, so the quantity and quality of a fishery can vary according to seasonal flow fluctuations. Since stream flow measurements were only collected once in this study, useable habitat estimates would be valid only for the 1997 flow regime. However, because the actual mean seasonal flows were similar to historical values and, these streams were small and only moderately entrenched (with the exception of the upper reach of Sandia Canyon), habitat availability would likely not change markedly with moderately increased or decreased discharge. Therefore, fish habitat determined in 1997 could be considered a good representation of typical habitat conditions. Furthermore, if flows were higher than usual in 1997, useable habitat would not necessarily be greater at higher flows. While higher flow rates increase total cross sectional areas, high velocity regions are often unuseable by fish, and thus useable habitat can actually be lower during high flow regimes.

Mean flow velocities in all canyons ranged from less than 0.1 m/s to 0.3 m/s (Figure 67). Flows over riffles were similar to mean flows, except in Los Alamos Canyon, below the reservoir. This reach contained numerous narrow, shallow, riffles. Mean pool flows were all positive, but there were still zero flow regions in most pools measured, which provide resting and hiding areas for fish, and potential accumulation points for organic matter. For this study, mean discharge, calculated from flow velocity, depth, and width measurements, was greatest in Los Alamos Canyon (~2 cubic feet per second [CFS]), followed by Sandia Canyon and Pajarito Canyon (~0.5 CFS), and was lowest in Valle Canyon (~0.1 CFS) (Figure 68). Using 5 years of discharge data reported by Shaull *et al.* (1996a, 1996b, 1998, 1999, 2000), the mean annual discharge in Los Alamos Canyon at Gaging Station E025 was 2.2 CFS, and in Pajarito Canyon at Gaging Station E240 was 1.5 CFS. Recently, discharge monitoring stations closer to the LANL Water Quality Assessment sites have been added.

Instream Habitat

In 1997, the wetted width of all streams but Valle Canyon was 1 - 2 m (Figure 69). Valle Canyon was consistently narrower, ~0.6 m. Mean thalweg depths ranged from 0.05 to 0.12 m, with maximum depths in pools of 0.12 to 0.24 m (Figure 70). In addition to stream discharge and flow, water depth, and bed substrate (described below), other major microhabitat features that influence fish distribution and biomass were the percent glides, riffles, and pools (Figure 71), types and percentages of cover (Figure 72), and bank vegetation coverage (Figure 73). Although the basic channel geomorphology was similar among sites, the quality of the habitat varied in each stream. Variations were at least partially due to differences in water flows and surrounding topography. As discharge increases, the percentage of glides will probably increases due to the innundation of gravelly riffle areas. Additional pools may form in some areas with increases in discharge, but lack of drop structures and dams would prevent any large percentage increase in pool habitats.

For all the canyons, habitat was dominated by either glides or riffles. Riffles are a primary area for generating food, especially insects (Waters 1969) as well as an area for spawning fish. Mean percent pools ranged from a high of ~30 percent in the lower reach of Sandia Canyon, to <5 percent in the upper reach of Valle Canyon. Beschta and Platts (1986) suggested that pools were the major stream habitat feature selected by most fish. Elser (1968) noted that deep, slow-moving pools with large amounts of overhanging cover support the highest and most stable fish populations. Finally, Platts (1974) stated that,

> . . . high-quality pools supported the highest fish biomass. In the South Fork Salmon River drainage of Idaho, pool quality was an important factor accounting for variation in total fish numbers. High-quality pools alone, however, do not make the fishery. Pools of all shapes, sizes, and quality are needed. Young-of-the-year fish need shallow, low quality pools the other fish will not use.

All three canyons in the LANL could provide at least some low-flow/zero-flow habitats necessary for early lifestage fish and as refugia from spates. Likewise, pools could also provide refugia during low flows/drought and hard winter freezes, allowing fish to survive limited periods when overall habitat was sub-optimal. For instance, all canyons except Valle Canyon contain several large pools that could support fish even if flows in riffle and glide habitat temporarily stopped or had winter ice cover. Although Valle Canyon does contain a few, small pools, the pool habitat provided was poor when compared to the other canyons.

Cover

Another important habitat feature for most stream fishes is availability of cover. Fish cover may be in the form of instream objects, such as rocks, logs, and vegetation or bank undercuts and vegetation. At least 10 percent of every stream reach examined contained suitable fish cover, and cover was typically greater than 25 percent. At most sites, bank cover dominated, primarily from overhanging vegetation, although Sandia Canyon had a significant undercut bank component. Bank vegetation type varied among the sites, sometimes dominated by trees (*e.g.*, Sandia Canyon), and in others by shrubs (*e.g.*, Los Alamos Canyon) or grasses (*e.g.*, Pajarito and Valle Canyons).

Detailed vegetation surveys were not conducted for this study. However, general observations of the dominant species and vegetation cover were recorded for each stream segment studied. At the time of study, the stream segments examined were mostly within heavily vegetated areas. Overstory vegetative cover was, on average, greater than 75 percent conifers (*i.e.* spruces, firs, and ponderosa pine) with an additional 20 percent coverage by deciduous trees (Figure 74). Likewise, understory vegetation coverage was also extensive, largely dominated by small conifers in Los Alamos, Sandia, and Pajarito Canyons. Mixed deciduous vegetation dominated Los Alamos Canyon, below the reservoir, and oaks (*Quercus spp.*) dominated the understory in Valle Canyon (Figure 75). Sandia Canyon also frequently contained numerous water birch (*Betula* *occidentalis*). Consequently, shade likely reduced instream plant growth, and thus reduced *in situ* or autochthonous organic matter production. These systems are therefore likely heterotrophic, with most of the energy input (organic matter) coming from the surrounding watershed. Bacteria, fungi, and invertebrates decompose and feed on pine needles, leaf matter, and other organic debris, and predators, in turn, feed on these organisms. The decomposer community forms the food base for the fish that inhabit or could inhabit these streams, as well as downstream.

Substrate

The topography and land use of an area largely determines the rate at which substrate is moved. Within streams, substrates are likely transported in a "leapfrog" pattern, where particles move various distances over the streambed transported on the rising of flow and depositing on receding flow, or as suspended solids during turbulent flow (Wesche 1993). The stream segments studied on the LANL were lined with sand, gravel, pebbles, cobbles, and boulders derived from erosion and deposition from the surrounding mesa tops, canyon walls, and from upstream sources.

Substrate characteristics were measured in detail for this study and included percent of various sediment size classes, distribution in various habitat types (Figure 76; corresponding to different flow regimes), and embeddedness of larger substrates by fine materials. The mean substrate sizes in each canyon were relatively similar, with the exception of Sandia Canyon (Figure 77). Most canyons were dominated by sandy and gravely substrates with some cobbles and larger boulders. Although Sandia Canyon also contained these same fine-grained substrates, especially in the upper stream reach studied, many of the lower transects were dominated by bedrock. Following storm events, sediments were likely scoured from the surface of one bedrock area and deposited downstream. Unstable sediment could make invertebrate colonization and fish spawning difficult. However, in stream segments other than Sandia Canyon, embeddedness was low, and at least 25 percent of the substrate material was gravel or larger, resulting in good habitat for invertebrate colonization and fish spawning (see the results of the habitat model below, for details on habitat suitability).

Habitat Suitability Index Model Results

Preferred Trout Habitat and the Brook Trout HSI

The HSI scores for adult brook trout (Table 28) ranged from 0.05 (Valle Canyon) to 0.75 (Los Alamos and Sandia Canyons) and ranged from 0.30 to 0.85 for juvenile brook trout (Figure 78). Average stream depth (only for the adult fish), percent pools, and pool class were the limiting habitat features identified for adult and juvenile trout in Pajarito Canyon (Figure 79), Valle Canyon, and Los Alamos Canyon, below the reservoir. Individual suitability scores for adult brook trout in Pajarito Canyon were close to optimal for most other habitat features. The HSI scores for brook trout fry (Figure 78) were consistently high in all canyons (>0.7), but scores for eggs (Figure 78) were consistently lower (~0.5) due to a lack of preferred gravel sizes and embeddedness.

Brook trout tend to inhabit higher elevation, colder streams than other fish, such as rainbow and brown trout and dace (Gard and Flittner 1974), and will occupy the shallowest of waters. Water depth and flows, amount of pool area, and cover were considered the most important habitat features for brook trout (Raleigh 1982). However, brook trout are highly adaptable to a variety of aquatic environments and exhibit marked differences in growth rate throughout their range (they have a propensity to stunt in small stream habitats) (Raleigh 1982; NMDGF 1998). Raleigh (1982) reported that brook trout inhabiting narrow and cold streams tended to be small and short-lived (3-4 years), whereas brook trout in larger rivers and lakes tend to be larger and live longer (8-10 years). Brook trout may spend their entire lives in a restricted stream segment, moving only to avoid extreme temperatures or other fish (Raleigh 1982).

Brook trout preferred water depths greater than ~8 cm (Raleigh 1982). Wesche (1974) studied two small streams in Wyoming and found that while most of the trout preferred depths from 15-46 cm, about 10 percent of the brook trout surveyed occupied shallower depths. Several studies of cutthroat trout have also noted that standing stocks tended to be greater in pools and glides than in riffles (Glova 1987; Ireland 1993; Herger *et al.* 1996), although smaller trout seem to remain near instream cover in the form of large cobbles in riffle areas (Beschta and Platts 1986; Rinne and Minckley 1991). Brook trout will also inhabit ponds and pools (Winkle *et al.* 1990; NMDGF 1998). Enhancement of pool area, depth, and cover is a common management practice to enhance trout habitat (NMDGF 1998).

During winter, when fish may face extremely low temperatures (and become lethargic), some fish will seek deep crevices in the streambed for protection from the current, from the effects of ice, as well as from other predators (Orth and White 1993). Ponds and large pools may provide warmer, more optimal temperatures for growth, as well as overwintering habitat. Winter stream conditions can limit brook trout populations. Excessively low water temperatures are probably not a limiting factor for brook trout in the Southwest, considering that brook trout are commonly found in far colder streams in Alaska. Chisholm *et al.* (1987) noted that in Wyoming's high elevation streams, absence of extensive surface ice is important in determining suitable trout habitat. Fish also preferred pools with some cover, and tended to move downstream to deeper waters with lower flows (<0.15 m/s), presumably more so if adequate pool habitat is not available.

The optimal temperature for brook trout growth and feeding reported in the literature varies from 13-19 °C, but they typically do poorly in temperatures exceeding 20 °C for extended periods of time (Baldwin 1956; Sublette *et al.* 1990). Warm water temperatures, however, may be limiting, especially when ambient air temperatures remain elevated for long periods. An evaluation of thirteen fish species, including both cold and warmwater species, noted that temperatures selected or avoided by fish declined as the acclimation temperature got colder from summer to winter. For brook trout, at an acclimation temperature of 24 °C (near the upper lethal limit for brook trout), fish avoided temperatures above 25 °C and below 18 °C, whereas at an acclimation temperature of 12 °C, fish avoided temperatures above 16 °C and below 9 °C. For a given acclimation temperature, brook trout will remain in waters with temperatures ranged no more than 7 to 9 °C (Cherry *et al.* 1975). Upper limit temperature tolerances may also be higher for brook trout introduced to the southwestern United States. A study by Lee and Rinne (1980) found that brook trout were as well adapted to elevated water temperatures as native Gila trout (*Salmo gilae*) or Arizona trout (*S. apache*), and could even tolerate temperatures as high as 28.7 ± 0.7 °C with fluctuations of 22 to 28 °C. Acclimation of trout to higher water temperatures increased their temperature tolerance downstream of natural sources (Woodward *et al.* 2000). Therefore, slowly rising temperatures may acclimate fish, allowing them to inhabit waters with higher temperatures than would typically be selected by coldwater fish.

Many trout in New Mexico spawn shortly after snowmelt, and the young hatch and grow rapidly in early summer prior to the onset of summer rains (Rinne and Minckley 1991). Brook trout, however, typically spawn in the fall, the eggs overwinter, and they do not hatch until the following spring. While brook trout prefer spawning habitat to include groundwater upwellings, "pea to walnut" sized gravel, and nearby cover, they will spawn in sub-optimal habitats (Moyle and Baltz 1985). If access to stream spawning gravels is denied, brook trout can spawn in sub-optimal substrate as long as there are some groundwater upwellings (NMDGF 1998). Spawning success was poorest as substrate embeddedness increased (more fines) and intergravel oxygen levels dropped (Raleigh 1982). Emerging fry occupied similar habitats to adults in low-flow areas, as well as preferred some groundwater upwellings (Raleigh 1982).

<u>Preferred Dace Habitat and the Dace HSI</u>

The HSI scores for dace (Table 29) were all quite low (~0.2) indicating that dace habitat is only marginal (Figure 80). The primary limiting factors for dace habitat suitability was the lack of velocity of flow in riffle habitats (Figure 81). Dace generally prefer riffle habitats with higher velocity flows than were present in the stream segments studied.

The longnose dace (*Rhinichthys cataractae*) is among the most widespread minnow species in North America. They are native to middle and upper elevations of the Rio Grande, Pecos River, and Canadian River drainages (Sublette *et al.* 1990). They are small fish (typically 6.3 to 8.8 cm), and tend to inhabit cool to cold, swift-flowing, headwater streams, with depths generally less than 30 cm, over gravel/boulder substrates. Dace may also inhabit lakes and slower waters, especially when competing species are absent, but flowing water (>45 cm/sec) is part of their preferred habitat. Preferred water temperatures were 15 to 21 °C, but they have been collected from streams with water temperatures as high as 22.7 °C. They are mature at age 2, and generally live for 4 years (Edwards *et al.* 1983; NMDGF 1998).

Eggs are demersal, adhesive, transparent, and are laid in natural depressions; hatching in 7 to 10 days at 16 °C (McPhail and Lindsey 1970). Young are initially pelagic, inhabiting slow, shallow, protected regions, but will move to swifter water within a few weeks (Gee and Northcote 1963). Reproduction is bimodal in *R. osculus* (speckled dace) in the Chiricahua Mountains, Arizona, with peaks in early spring and late summer. Spawning timing can be affected by water flows (flooding) and food availability. John (1963) reported that late summer floods induced spawning by dace.

Habitat Quality Discussion

Typically, habitat evaluations are used to assess how healthy or productive a particular fish community is, or assess the impacts of a natural or anthropogenic alteration of that habitat. In the LANL Water Quality Assessment, an unusual and hypothetical question was asked, "Could the stream segments examined in this study support a fishery?" The questions were not, "What kinds of fish would inhabit such streams?" Or, "How much suitable habitat would be required to sustain a coldwater fish population?" But rather, the questions related to a relatively generic statement regarding the potential for a fishery (as the term is used by the NMWQCC [1995]) to occur in the water bodies at the LANL. For instance, the NMWQCC (1995) defined a coldwater fishery as:

> "A stream reach, lake or impoundment where the water temperature and other characteristics were suitable for support or propagation or both of coldwater fishes, such as but not limited to, longnose dace, roundtail chub, Rio Grande chub, Rio Grande Sucker, brown, Gila, cutthroat (including the native Rio Grande cutthroat), brook or rainbow trout, or speckled dace."

Additionally, the NMWQCC (1995) identified a high-quality coldwater fishery as:

> "A perennial stream reach in a minimally disturbed condition which has considerable aesthetic value and is a superior coldwater fishery habitat. A stream reach to be so categorized must have water quality, stream bed characteristics, and other attributes of habitat sufficient to protect and maintain a propagating coldwater fishery (*i.e.*, a population of reproducing salmonid)."

A sustainable fish population is not explicitly required when defining a fishery, and therefore, was not specifically addressed by the LANL Water Quality Assessment. Determining the propagation capability of a fish population in stream segments on the

LANL was beyond the scope of this study and would have required several years of data to quantify relationships between instream flow and available habitat (see Bovee 1982, 1986). Therefore, no attempt was made to predict weighted useable area, or other indicators of the expected size of a fish population.

The HSI model for brook trout was developed including data from many western streams, but likely did not consider some of the unique habitat features of the semi-arid Southwest. Thus the HSI score of 0.8 for Los Alamos Canyon (rather than the maximum score 1.0) may have indicated: (1) that brook trout habitat in Los Alamos Canyon may not be optimum, even though reasonable numbers of brook trout were present, or (2) that the HSI model was not perfectly suited to predict optimum brook trout habitat in this area. Therefore, the HSI scores for the other canyon streams on the LANL were not adjusted by the amount derived by assigning a maximum HSI score of 1.0 to Los Alamos Canyon.

Ultimately, the habitat suitability of these stream reaches for fish could only be conclusively established by introduction of fish into those streams, followed by annual monitoring of survival, growth, and reproductive success. Fish populations in a particular area adapt to their habitats, so generalized models such as the HSI can only approximate the general habitat characteristics associated with a particular species. Fish in specific geographic areas adapt to localized habitat conditions, and thus could occupy habitats that a generalized HSI would predict is unacceptable.

Habitat in Los Alamos Canyon supported an apparently self-sustaining population of brook trout. The presence of the Los Alamos Reservoir may give these brook trout important refugia for sustaining the population that the other streams do not have. However, the year-round presence of brook trout observed and surveyed throughout the stream segment as well as the absence of rainbow trout in this same segment suggested that these two species have segregated into different habitats. Rainbow trout (*Oncorhynchus mykiss*) compete with, and frequently excluded, brook trout from water bodies accessible to both species. Rainbow trout encroachment has markedly reduced the brook trout's native range in the United States (NMDGF 1998). The larger rainbow trout stocked into Los Alamos Reservoir were likely too large to move very far upstream in Los Alamos Canyon, thereby leaving that habitat available for the smaller brook trout. Consequently, brook trout were likely excluded from the reservoir, and given their small size, they would be vulnerable as prey. These brook trout, survived in the Los Alamos Canyon stream segment studied, and it had similar habitat to those in the stream segments studied in the other canyons.

While there are many different approaches to evaluating fishery habitat, most had a core set of measurements in common, such as water temperature, current velocity, discharge, water depth, percent pools/glides/riffles, type and quality of pools present, cover type, bank (channel) stability, bed substrate, and food availability (*e.g.*, Binns 1978; Idaho

DEQ 1996). More detailed metrics were added in the LANL Water Quality Assessment to evaluate habitat requirements for particular fish species, and to further investigate the health, diversity, and ecological integrity of a stream. In general, though, if water was deep enough, had a reasonable flow, provided a diversity of hiding, resting, foraging, and spawning locations, and had a channel that was reasonably stable, it was considered likely that a fish population would be present or potentially supported there.

Most habitat models were developed for use in limited areas, such as individual States or Ecoregions. While numerous habitat variables were typically examined, most models were generally tailored to include only those variables that were considered limiting in a particular region. For example, an alternative HSI model was designed for the high-altitude streams found in the Southern Blue Ridge Province (SBRP) in the Southeast United States by Schmitt *et al.* (1993). Schmitt *et al.* (1993) chose not to include variables such as stream flow or depth because the variables of elevation, gradient, and pH correlated better with fish biomass. This particular simplification worked for the Southeast, because there is a consistent and predictable relationship between elevation and gradient with water depth and discharge. That same predictable relationship does not hold for many streams in the Southwest, so HSI scores generated using the simplified model may be inaccurate. For example, using the SBRP HSI, scores were generated at ~0.8 for every stream segment studied on the LANL, even though the results of the Raleigh (1982) HSI model, and observations made by the USFWS biologists, suggested that it was unlikely that fish habitats were equivalent in all four canyons. Therefore, the SBRP HSI model was considered inappropriate for this assessment or for use in other montane streams of New Mexico.

Calibration and Validation of HSI Models

There is potential for variation in HSI scores due to measurement variability and the influence of changes in each parameter on the overall HSI scoring. The potential effects of measurement bias and natural parameter variability on the overall calculated HSI score was estimated. Measurement variability in actual habitat parameter measurements was based on the variability in a particular habitat parameter measurement that would result in a 0.1 unit change (10 percent) in the corresponding Suitability Index (SI) score. For example, temperature measured in the 10-16 °C range would all yield an SI score of 1.0, but for measured temperatures less than or greater than this range, a change in temperature of ~1°C would result in a 0.1 change in the SI score. Precision of temperature measurement was typically ±0.1°C, so measurement bias was unlikely to significantly affect the overall HSI scoring. Natural temperature fluctuations, however, may vary by several degrees over the course of a day, which, if temperatures were near the outside limits of the 1.0 SI score (10-16 °C), could change the SI score by 20 percent (0.2 units). As a validation of the HSI approach, Table 30 presented the optimal, worse-case, and range of HSI model parameter scores with the habitat associations reported by the New Mexico Department of Game and Fish (NMDGF 1998) and the Habitat Quality Index (Binns 1978).

Other Habitat Considerations

The steep, >250-m drop from the Pajarito Plateau into White Rock Canyon containing the Rio Grande (Figure 4), as well as the occurrence of ephemeral segments in most of these canyons, likely prevents the natural migration of fish from the Rio Grande. Such barriers are not an unusual situation in the western United States. The absence of fish or depauperate fish fauna in many western streams is often explained by geographic isolation due to cliffs, waterfalls, or mountain ranges (Smith 1981). Existing fish populations in many isolated southwestern streams were the result of fish migrating into these streams when sea levels were significantly higher, when temporary formation of lakes were caused by obstructions (*e.g.*, lava flows) across rivers, or by dispersal over drainage divides (Rinne and Minckley 1991). In some areas of the United States, fish introductions by people would be more important than ecoregional delineations in determining fish distributions (Maret *et al.* 1997). It would be reasonable to postulate that some fish populations may have persisted in the intermittent streams on the Pajarito Plateau for a time after geological isolation. However, extreme droughts or floods as well as groundwater pumping and subsequent alteration of surface water flows, grazing impacts, pollution, and over harvest may have eliminated any such isolated fish populations. Without a sustained connection to larger, fish-bearing waters, such as the Rio Grande, and lacking any augmentation by people, fish would probably not be able to naturally re-colonize these streams.

Flooding is also an important factor structuring aquatic communities in streams. Streams that are hydraulically complex (*i.e.* those that have greater hydraulic resistance and storage, pool volume, channel variability, and woody debris) with lower intensity floods will lose fewer fish, but community resilience is also dependent on the timing of spawning in relation to the timing of flood events (Pearsons *et al.* 1992). For example, Pearsons *et al.* (1992) found spring-spawning fish, such as rainbow trout, would be adversely affected by a spring flood than would fall-spawning fish, such as brook trout.

Overall, physically harsh and unpredictable environments, subject to disturbances from floods or drought, are likely to have lower fish species diversity and reduced populations. Nonetheless, a fishery can be remarkably persistent despite floods causing physically harsh and unpredictable habitat conditions (*e.g.*, John 1964; Rinne 1975; Ross *et al.* 1985; Pearsons *et al.* 1992). Habitat use by fish affected by physically harsh conditions may be less structured than in more benign systems (Rinne 1975; Ross *et al.* 1985). In a study of fish in streams of the Chiricahua Mountains in Arizona, flash-floods and drought significantly affected population dynamics and presumably reduced species diversity, but did not entirely eliminate the fishery (John 1964). Fish community persistence was greater in benign environments, than in harsh environments, although habitat use was less structured in harsh systems (Ross *et al.* 1985). Ross *et al.* (1985) pointed out four factors that affect fish community persistence: 1) high intrinsic rate of reproduction resulting in rapid repopulation by survivors of the environmental perturbation; 2) rapid return to areas dewatered during drought; 3) highly developed, refuge-seeking behavior during drought; and, 4) increased physiological tolerance to environmental change. Ross *et al.* (1985) reported that in lower elevation warmwater fisheries, fish communities were persistent, but less stable in a stream suffering from reduced or eliminated water flows and elevated water temperatures.

Younger fish are most vulnerable to flood mortality, while older and larger fish generally were displaced downstream, but not killed (John 1964; Rinne 1975). Rinne (1975) reported that fish in the streams of the Chiricahua Mountains, including speckled dace (*R. osculus*), *Agosia* spp., and *Campostoma ornatum*, spawned in early spring or late summer, and depending on conditions, they might spawn twice. The most damaging scenario to fish populations would be if fish spawned in the spring and experienced flood mortalities, and then were faced with another flash flood (John 1964; Rinne 1975). As the LANL stream segments are isolated, with natural immigration being unlikely, repeated flash floods could reduce and perhaps eliminate any isolated fish populations. However, habitat, while not ideal at all locations, did not preclude the use of these streams by a small population of fish (*i.e.*, HSI Scores were greater than zero).

In the semi-arid streams of the Southwest, drought may also adversely affect a fish population due to the combination of reduced habitat, food shortages, higher water temperatures, and reduced water quality conditions (John 1964). Crowding of fish into small, permanent pools can exacerbate these effects. Thus, potential fish populations would be expected to decrease during drought. However, if permanent pools were present, and allow even a small population of fish to persist, they could recolonize the stream during more optimal conditions. In such situations, stronger individuals would survive, and thus a more tolerant fish sub-population could develop more rapidly than in a less stressful environment.

Habitat Quality Index

In Wyoming, trout habitat and trout production is associated with a wide variety of streams. Binns (1978) used regression of trout biomass and 22 attributes characterizing trout habitat in streams to arrive at a Habitat Quality Index (HQI). Using the multiple regression equation described in Binns (1978), HQI scores were calculated for the stream reaches studied on the LANL. These HQI scores are a potential predictor of trout biomass (per Binns 1978) and the highest HQIs were from the Los Alamos Canyon (Figure 82). Scores for the other canyon stream reaches were roughly **a** to ¼ of those calculated for Los Alamos Canyon, suggesting a more limited biomass in these stream reaches. While the HQI methodology was generated from Wyoming streams, the HQI scores add to the weight-of-evidence that the LANL canyon streams have the potential to contain at least some fish biomass (although the predicted standing crop density would be as low as **a** to ¼ of the trout density that was found in the Los Alamos Canyon stream segment studied).

Invertebrate Habitat Assessment

For all stream segments but those in Sandia Canyon, the RBP habitat scores ranged from ~160 to 180 (Figure 83), indicating highly suitable habitat for invertebrate colonization. The lower suitability score associated with Sandia Canyon (~130) was driven by poor substrate characteristics, such as average size, embeddedness, and stability, as well as a high erosion potential. This did not mean that there would be no invertebrates present, but rather, that the community structure would likely be dominated by more stress-tolerant taxa. Results of benthic macroinvertebrate community assessments (Ford-Schmid 1999) indicated that the benthic macroinvertebrate community was moderately impacted, likely by pollution and degraded habitat conditions, as well as it contained more stress tolerant taxa (Cross 1995a).

Stream Geomorphology and Habitat Stability

According to the Rosgen (1996) classification scheme, Los Alamos Canyon was a "B" stream type, with moderate entrenchment, sinuosity, and width to depth ratio. The relatively steep slope of this channel type and predominance of gravel substrate resulted in a final classification of "B4A." The B4 type channel is relatively stable and does not normally supply high sediment loads. Valle Canyon was also a "B" type stream, but because of its more moderate slope it classified as a "B4" channel. Upper Pajarito Canyon also classified as a "B4" channel, while the lower reach of the segment studied was rated as a "B3" due to the predominance of a cobble substrate. Sandia Canyon classified as a "B2C" and "B2" channel, for the upper and lower reaches of the segment studied, respectively, due to the boulder and bedrock substrate common in this channel. Normally stable versions of these channel types would contribute minor quantities of sediments downstream, but the highly erodible banks in some sections of Sandia Canyon combined with the scoured bedrock bottom likely resulted in higher sediment transport during high flow events (that were found commonly in the segment studied). Los Alamos, Valle, and Pajarito Canyon stream segments ranked as fairly stable, whereas the Sandia Canyon stream segment ranked as unstable, especially the upper portion of the segment, near the upstream wetland. Therefore, this suggested that the stream habitat in Sandia Canyon was unstable and more prone to disturbances than the other streams studied. This evaluation of the stream channel stability was also used to allow predictions of the stability of the measured habitats over time.

RESULTS OF THE WATER QUALITY INDEX DEVELOPMENT

The values assigned, and the summary indices of biological, chemical, and physical quality are provided in Table 31, Table 32, and Table 33, respectively. The Index of Biological Quality for Valle, Pajarito, Sandia, and Los Alamos Canyons was 42, 48, 38, and 60. This suggests that the integrity of the aquatic community is 70 percent in Valle Canyon, 80 percent in Pajarito Canyon, and 63 percent in Sandia Canyon as compared to that in Los Alamos Canyon. Using the decision matrix in Table 18, aquatic life use was supported in Pajarito Canyon, but only partially supported in Valle and Sandia Canyons. The Index of Chemical Quality for Valle, Pajarito, Sandia, and Los Alamos Canyons was 33, 37, 31, and 41. This suggests that the chemical integrity of the water, sediment, and biota was 80 percent in Valle Canyon, 90 percent in Pajarito Canyon, and 76 percent in Sandia Canyon as compared to that in Los Alamos Canyon. Chemicals of concern identified were PCBs, Cr, Al, Fe, and explosives. The Index of Physical Quality for Valle, Pajarito, Sandia, and Los Alamos Canyons was 22, 24, 28, and 38. This suggests that the physical integrity of habitat for fish and benthic macroinvertebrates was 58 percent in Valle Canyon, 63 percent in Pajarito Canyon, and 74 percent in Sandia Canyon as compared to that in Los Alamos Canyon. Physical impairments in Valle Canyon and Pajarito Canyon were lack of adult or trout egg habitat. The unstable stream channel, sedimentation, and the embeddedness of the substrate reduced macroinvertebrate habitat, and the reduction of prey reduced the potential habitat for trout in Sandia Canyon.

When each of these biological, chemical, and physical quality indices are summed into a final Water Quality Index, Valle, Pajarito, Sandia, and Los Alamos Canyons' total scores are: 97, 109, 97, and 139, respectively. The final Water Quality Index of Valle and Sandia Canyon was 70 percent and Pajarito Canyon was 78 percent of the Los Alamos Canyon reference stream. When the chemical and physical quality scores are subtracted from the reference site, the amount of impact relative to the biological integrity can be gauged (Figure 84). Physical impacts were found at 37 percent, chemical impacts were found at 8 percent, and the resultant biological integrity of the Pajarito Canyon stream segment was 80 percent of that of the reference site. At the Valle Canyon stream reach, physical impacts were 42 percent, chemical impacts were 17 percent, and the resultant biological integrity was 70 percent of that of the reference site. At the Sandia Canyon stream reach, physical impacts were 26 percent, chemical impacts were 33 percent, and the resultant biological integrity was 63 percent of that of the reference site, suggesting that chemical impacts had a greater effect on the biological response and community than did physical impacts.

CONCLUSIONS

Currently, the designated uses of the intermittent streams that cross the LANL are livestock watering and wildlife habitat (NMWQCC 1995) and these designated uses do not include aquatic life (*i.e.*, fisheries) use. These intermittent streams have likely harbored aquatic life for millennia, though the benthic macroinvertebrate community has apparently only been formally studied since 1990 (Bennett 1994; Cross 1994a, 1995a, 1995b, 1996b, 1997; Cross and Davila 1996; Ford-Schmid 1996, 1999, and this study). Therefore, aquatic life is an existing use of these intermittent streams that should be protected. The protection of aquatic life is a basic mandate of the Clean Water Act.

The objective of the Clean Water Act (section 101(a)) is to "restore and maintain the chemical, physical, and biological integrity of our Nation's waters." In order to achieve this objective, it was declared that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and for recreation in and on the water be achieved. The USEPA (1995b) has suggested that the term "aquatic life" more accurately reflects the protection of the aquatic community that was intended in section 101 (a) of the Clean Water Act. If the designated uses of the intermittent streams that cross the LANL do not include protection of aquatic life, then the NMED may need to perform and submit to the USEPA the results of a Use Attainability Analysis.

Additionally, under New Mexico's Antidegradation Policy, no activity is allowable which would partially or completely eliminate an existing use whether or not that use has been designated in the State's water quality standards. Therefore, permits issued that might allow activities to commence without expressly protecting the aquatic life in these intermittent streams may need additional consideration. The USDOE, the USEPA and the State of New Mexico should determine if there is a need to conduct an antidegradation policy analysis or other review in order to identify if existing aquatic life uses of these intermittent streams are adequately protected by any planned or permitted activities.

Recreational Uses (Primary and Secondary Contact)

The aesthetic qualities of these canyon streams was an existing use; as evidenced by the recreation of LANL employees and citizens that was observed during the LANL Water Quality Assessment. Children were found to play in and around the Sandia Canyon stream. Some of the pools in this stream were of sufficient size for wading or bathing. In Los Alamos Canyon, extensive recreation was observed in the form of swimming, fishing, and ice skating in and on the Los Alamos Reservoir. Fishing upstream in Los Alamos Canyon is allowed on the Santa Fe National Forest. However, the USFWS did not evaluate the fecal coliform content of these waters, and no other information on fecal coliform content was provided. As fecal coliform content is an important criterion for the designation of recreational uses, the criteria for identification of use attainability was not met by the LANL Water Quality Assessment. Nonetheless, as primary contact in Los Alamos Reservoir was observed to occur, as was secondary contact in the intermittent stream segments, these uses should be considered existing.

Domestic Water Supply
No domestic water supply use was observed occurring in associated with these stream segments. Also, several constituents in water (that have domestic water supply water quality standards) were either not analyzed (*i.e.*, cyanide) or were analyzed using non-USEPA-approved methods (*e.g.*, tritium, total mercury, dissolved silver, and dissolved uranium). Therefore, statements as to the quality of these canyon stream waters for drinking water and domestic water supply was necessarily limited. However, using non-USEPA-approved methods, these constituents were reported by others (Dale 1998; LANL 1998a; Blake *et al.* 1995; this study) as being below domestic water supply standards. From the data available for the LANL Water Quality Assessment, only barium in Valle Canyon exceeded the domestic water quality standards for the State of New Mexico (NMWQCC 1995). With proper treatment, stream waters from Los Alamos, Sandia, and Pajarito Canyons could be made usable for a domestic water supply in the future and as these are source waters, this use should be considered and protected for downstream users.

Wildlife Habitat
Total mercury and total selenium, which are the applicable numeric standards for waters designated as wildlife habitat, were not analyzed by the USFWS at detection limits below the water quality standards or using USEPA-approved methods. However, no excess mercury or selenium accumulation was noted in the sediment or biota collected during the LANL Water Quality Assessment, suggesting that in the stream segments studied, selenium and mercury had not reached concentrations problematic for wildlife consumption. Concentrations of bioaccumulative contaminants of concern are best detected in biota due to the higher probability of detection (Phillips 1980). Dissolved mercury and selenium concentrations were also below the detection limits, but the water quality standards are based on total concentrations. All canyons offered stream habitat and water for wildlife to drink and bathe as well as offered food, ecosystem services, and shelter. The Sandia Canyon stream segment was found to contain PCBs at levels that led to bioaccumulation in caged-fish, which if accumulated in native biota, could present health risks to predatory wildlife that would consistently eat the aquatic life found there as food.

The majority of vertebrate wildlife species found in this region were found in association with the wetlands and riparian vegetation near the intermittent streams or tributaries. Of the 310 vertebrate species of the Jemez Mountains (Table 2), 7 percent were fully aquatic including 9 montane species of fish (with 14 other species found in the Rio Grande downstream). An additional 13 percent of these species were semi-aquatic, such as the amphibians, ducks, herons, and the American dipper, which were found in suitable habitat (lakes, ponds, streams, wetlands) on the Pajarito Plateau. For instance, waterfowl visited the standing bodies of water on the Pajarito Plateau as well as foraged along the Rio Grande and at other wetlands in tributary canyons. Birds and other animals of arid ecosystems and woodlands have been documented drinking frequently and bathing from temporary waters, springs, and other wetlands and many of these species were found using the LANL. Over 60 species of vertebrate wildlife were documented using artificial water bodies formed by waste water discharges for food, shelter, and drinking. Animals were found to make repeated, and long-duration visits to artificial water bodies on the LANL, even when access was partially restricted, or where the water was contaminated. For example, Hansen *et al.* (1999) reported that racoons entered a lagoon that was partially fenced and remained foraging there over 20 hours had accumulated tritium. Invertebrate surveys in the 4 stream segments examined identified 117 different benthic macroinvertebrate taxa which spend the majority of their life span intimately associated with these intermittent streams. Studies by the LANL, as well as qualitative observations made during this study, including actual sightings, and signs such as tracks, nesting areas, and scat, indicated use of these stream segments as habitat for a variety of wildlife species, including various birds, mammals, reptiles, and amphibians.

Livestock Watering

Tritium, total mercury and dissolved cobalt that are applicable to the livestock drinking water quality standards were not analyzed by the USFWS using USEPA-approved methods. However, dissolved mercury was not detected using USEPA-approved methods with detection limits below the livestock standard. Dissolved cobalt and tritium was analyzed by non-USEPA approved methods, so these constituents were not further addressed. Aluminum concentrations in Pajarito Canyon were greater than the livestock drinking water quality aluminum standard in one instance, and it is believed that the aluminum is of natural origin.

Livestock watering was an existing use in Los Alamos Canyon. Cattle grazing was reported in lower Los Alamos Canyon by Foxx (1992) and Ferenbaugh *et al.* (1990). Historic sheep and goat grazing (prior to 1975) was reported to occur on the Pajarito Plateau by the Homesteaders (C. Montaño, written communication) as well as by Native American peoples. Although the area has steep slopes that pose a risk to some domestic animals, quality forage and water in the canyon streams were available to support at least some individuals. Livestock watering, therefore, appears to be an attainable use in these canyons, and the NMWQCC (1995) designated this use in 1995. However, water quality for livestock drinking water might be unacceptable in Pajarito Canyon due to elevated aluminum.

Irrigation Use

The use of the Pajarito Plateau for agricultural crops was a historic use of the area (Nyhan *et al.* 1978), including diversion of waters and ditch conveyance for flood irrigation (Steen 1977). Irrigation of high elevation crops of grasses, legumes, and orchards is not unusual, as such irrigated pastures can be provided as forage for livestock (Young *et al.* 1994). Los Alamos Canyon water has been used for turf-irrigation in the Town of Los Alamos on a yearly basis. Experimental vegetable crops are also grown in Los Alamos Canyon for research purposes (Fresquez *et al.* 1999). Irrigation was an existing use of waters in Los Alamos Canyon, and may be an attainable use in the other canyons studied. However, this study did not evaluate these waters for fecal coliform content, which is a water quality parameter to be considered in the designation of irrigation use. Except for aluminum in a reach of Pajarito Canyon, no water constituent measured exceeded the water quality standards to protect irrigation use, and this aluminum was believed to be of natural origin.

Coldwater Fishery Use and Coldwater Aquatic Life

The NMED (2001a) stated that,

> ". . . definitions [of fisheries in New Mexico], except for that of marginal coldwater fishery, apply to waters where fish may or may not be present– the designation is based on water quality considerations and 'stream bed characteristics' or 'other characteristics.' The definition of 'marginal coldwater fishery requires that the water body be 'known to support a coldwater fish population during at least some portion of the year.' This is the one classified aquatic life use that actually requires the presence of fish species."

Use of coldwater streams or lakes by aquatic life could therefore be considered covered by the coldwater fishery use designation by New Mexico. According to the NMED (2001a), many people think that the coldwater fishery use designation applies only to waters that support fish, that is, "those poikilothermitic aquatic vertebrate organisms of the Superclass Pisces, characteristically having fins, gills, and a streamlined body." According to the USEPA (1995b), even if sport or commercial fish are not present in a water body, it does not mean that it may not be supporting an aquatic life protection function. An existing aquatic community composed entirely of invertebrates and plants, such as may be found in a pristine alpine tributary stream, should still be protected whether or not such a stream supports a fishery (USEPA 1995b). Therefore, a fishery is more than just a fish in water; it is the biological, chemical, and physical characteristics of a water body, including the invertebrate community and all the other aquatic life forms that provide food as well as other ecosystem functions and services.

Based on location, measurement of air and water temperatures, and the presence of coldwater indicator species of aquatic life, these intermittent streams were considered coldwater in nature. Based on the presence of an apparently propagating brook trout population in Los Alamos Canyon, above the reservoir, the presence of shellfish, and other forms of aquatic life, a coldwater fishery was considered an existing use. As Sandia Canyon contained potential trout habitat, and aquatic life was supported, a coldwater fishery was considered an existing use. Since Los Alamos Canyon, below the reservoir, and the stream segment studied in Pajarito Canyon contained potential trout habitat, and aquatic life was supported, a coldwater fishery was considered an existing use. Valle Canyon contained potential trout habitat (although marginal in quality), however, with established shellfish populations and other aquatic life, a coldwater fishery was considered an existing use. Since all these intermittent streams contained aquatic life, a coldwater fishery was considered an existing use and should be considered for State designation.

However, water temperature extremes and other physical characteristics did not support a high quality coldwater fishery in any canyon stream segment studied. Therefore, high quality coldwater fishery use was not considered an existing use. Turbidity and aluminum in the Pajarito Canyon segment were above the water quality criteria for a coldwater fishery. However, these parameters did not appear to contribute to any toxicity in the caged-fish reared in this water for over two months, or during toxicity testing, or preclude the colonization of the stream by benthic macroinvertebrates. Should it be determined that the elevated aluminum and turbidity are due to natural background conditions, then site-specific water quality standards for aluminum and turbidity may need to be developed for these intermittent streams and likely, all streams of the Jemez Mountains.

Pollution by barium and explosives, lack of sufficient pool habitat and flow, and silting of spawning substrate in Valle Canyon make it likely that it would only support a very limited trout population. Also, extremes in climate or predator harvest would likely limit the long-term viability of trout without periodic stocking and habitat restoration. Total chlorine residuals and cyanide (amenable to chlorination) were not determined in the stream segments studied, but naturally elevated concentrations of these parameters would not be expected. While water depth was a limiting habitat factor for brook trout in these streams, these conditions could be improved by creating larger pools or channels of greater depth, by using techniques proposed by Rosgen (1996), Hunter (1991), or the Federal Interagency Stream Restoration Working Group (1998).

RECOMMENDATIONS

A critical goal of any water quality management program is the protection of aquatic life. It is the basic mandate of the Clean Water Act to restore and maintain the chemical, physical, and biological integrity of our Nation's waters. Aquatic life in the form of wetland plants, aquatic invertebrates, fish, insects, shellfish, amphibians, and other biota that have adapted to the intermittent streams and other waters of the Pajarito Plateau and should be explicitly protected. Actions that could be taken by the Laboratory (and others) to protect aquatic life include:

- meet water quality standards applicable to a designated use of coldwater fishery;
- identify aquatic life use in all water quality programs, plans, permits, and reports;
- use aquatic life criteria developed by the USEPA (1998a) in the evaluation of water quality trends, conditions, and impacts;
- establish sediment screening criteria based on toxicological thresholds for aquatic life;
- employ standardized biological tests to identify the effects of waste waters or streams that contain chemicals or mixtures which either do not yet have protective criteria established or that produce their toxic effects at very low concentrations that are beyond the capability of laboratory instruments to detect;
- use narrative biological criteria and regional reference conditions to preserve, protect, and restore water resources to their most natural condition attainable;
- manage for native species diversity, including benthic macroinvertebrate communities and other aquatic life using multiple standardized measures of the physical, chemical, and biological characteristics of other similar regional water bodies;
- continue to identify pollutant sources, remove them or reduce impacts, and restore the stream channel;
- seek zero discharge of any persistent, bioaccumulative, or toxic substances found within a watershed that pose a threat to aquatic life, wildlife, or other uses; and,
- quantitatively model the total maximum daily load of any persistent, bioaccumulative, or toxic substances that threaten the function of these canyons to convey clean water and sediment downstream.

Successfully managing the health and integrity of the aquatic habitats on the Laboratory and reducing the impacts of the Cerro Grande Fire will require a sound scientific understanding of these canyon ecosystems. The connection between land cover, watershed condition, and channel dynamics will need to be better understood in these steep, coarse-bedded streams. Short-term restoration of the impacted canyon habitats will likely be limited by the fire-related inputs of sediments, salts, ash, contaminated sediments, organic inputs, and erosive processes. For a time, such processes will likely affect the energy flow dynamics and limit the numbers and diversity of aquatic life. To protect aquatic life during restoration the interactions of the entire set of landscape components will need to be incorporated: uplands and wetlands, aquatic habitats, riparian corridors, and stream beds. Detailed habitat surveys such as those of this study could be further developed in order to measure, analyze, and map the biological, chemical, and physical characteristics of these canyon streams and monitor their recovery. An approach that integrates biosurvey data, which reflects the integrity of the water resource directly, along with water chemistry, physical habitat, bioassays, and other monitoring and source information, would be central to accurately defining the health of these streams. Restoration goals should also include the production of clean water and sediment for use by resident aquatic life, wildlife, people, and the ecosystems downstream.

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