WATER QUALITY DATA ANALYSIS AND INTERPRETATION

CURECANTI NATIONAL RECREATION AREA

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Technical Report NPS/NRWRD/NRTR-95/68

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United States Department of the Interior
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EXECUTIVE SUMMARY

For the past 13 years, Curecanti National Recreation Area (Curecanti NRA) has implemented a water quality monitoring program in the reservoirs (Blue Mesa, Morrow Point, and Crystal) and tributaries that make up approximately 25% of the park. The monitoring program was established to address one of the park's primary resource management objectives: to maintain and enhance water quality at Curecanti NRA. The last seven years of monitoring focused on potential threats to water quality, including: grazing, mining, logging, development, recreation, and dam operations. This report will review the monitoring program, analyze and interpret existing water quality data, and recommend improvements to the monitoring program. The recommendations address aspects of monitoring design, sampling and data management protocols, quality assurance and quality control, and the development of a water quality monitoring plan to formalize monitoring activities.

The water quality in Cimarron and Squaw Creek is quite different from the other tributaries, and exhibits elevated levels of nutrients, bacteria, and dissolved solids. In addition, both creeks carry noticeable sediment loads during runoff and precipitation events; however, no sediment data were included in the data set that was analyzed. Curecanti NRA recognizes the problem with sediment load in both systems and will ensure that turbidity, total suspended solids, and flow measurements are included in any future monitoring at those sites. Also, it appears that the Gunnison River upstream from Blue Mesa Reservoir has a measurable influence on the reservoir, creating a productivity gradient in the reservoir from high to low in a downstream direction. No water quality data were analyzed for Morrow Point and Crystal Reservoirs. Water quality monitoring in these lower reservoirs is strongly recommended to establish baseline conditions and assess potential impacts from tributary inflows and reservoir use.

Based upon a review of the data, it appears there is more spatial than temporal variation in ambient water quality in the reservoirs and tributaries of Curecanti NRA. This conclusion is not surprising, due to the vast area and variety of water sources within the park. Many of these differences may be explained by natural (e.g., geology, topography, landform, vegetation, climate) and anthropogenic factors. Few alarming water quality impacts were detected, probably due in part to dilution effects and the naturally high water quality in the reservoirs and tributaries. The present cyclic monitoring program provides adequate coverage for most water quality issues at Curecanti NRA, and can be easily adapted to changing conditions. If future conditions or situations require more accurate detection of potential acute and chronic water quality impacts, increased or targeted sampling may be required to provide data that can withstand statistical and litigious scrutiny. Collaborative monitoring partnerships with other agencies may offer the best option for addressing complex water quality issues and/or sustaining long-term monitoring in the park.

INTRODUCTION

Curecanti National Recreation Area (Curecanti NRA) encompasses Blue Mesa, Morrow Point, and Crystal Reservoirs of the Colorado River Storage Project's Aspinall Unit. Curecanti NRA is managed by the National Park Service and the Aspinall Unit is managed by the Bureau of Reclamation. Water covers approximately 25% of the park. One of the primary park management concerns is maintenance and/or restoration of the naturally high quality water in reservoirs and tributaries to support fish and wildlife habitat, recreation, and scientific study. The recently completed Water Resources Scoping Report for Curecanti NRA (National Park Service 1995) recommends that a Water Resources Management Plan be developed to address the complex water-related issues facing the park. Although the waters in the reservoirs are of high quality, upstream land-use activities may ultimately impact this condition. Coupled with activities on surrounding lands, the re-operation of the Aspinall Unit may influence the fishery and overall trophic dynamics of this reservoir system. Curecanti NRA feels that the development of a Water Resources Management Plan will provide the park with a framework to address important water issues over the next five to ten years, and be integral to the development of a comprehensive water resources management program for the park. Regarding water quality, the proposed Water Resources Management Plan will focus on:

- Developing a cyclical water quality monitoring program for assessing potential threats to reservoirs and tributaries from grazing, mining, logging, and development. The program will include assessment of impacts from Curecanti NRA's, the concessionaire's, and the Bureau of Reclamation's operations. The program will be based on the analysis of existing water quality data. The program will develop an appropriate means of monitoring the two lower reservoirs (Morrow Point and Crystal) for chemical and biological features. Monitoring will include measurement of biological, chemical, and physical parameters, and be supported by base funding available for the current program.

- Reviewing the appropriateness of an Outstanding National Resource Waters designation for the three reservoirs.

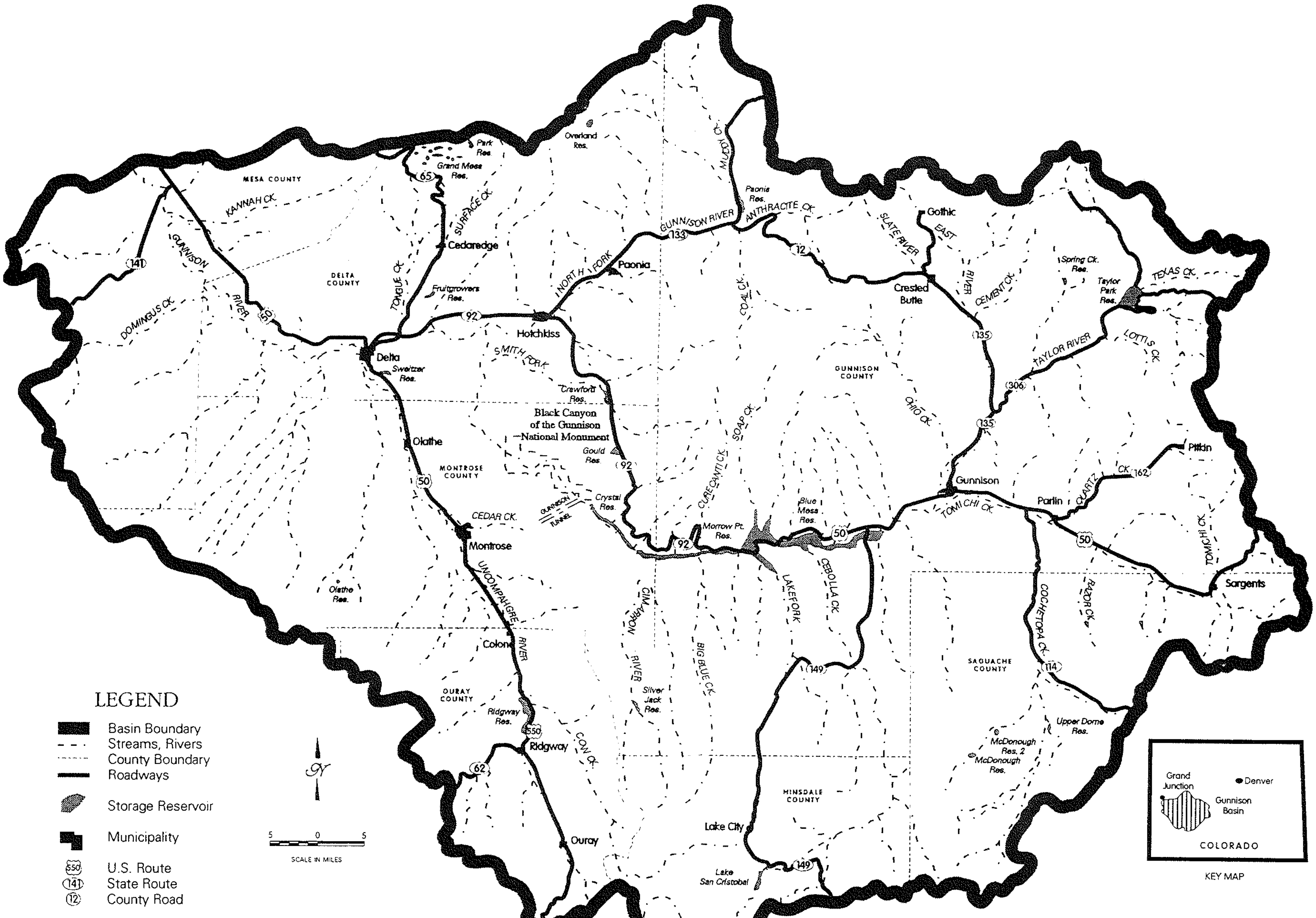
In 1982, Curecanti NRA initiated a water quality monitoring program in Blue Mesa Reservoir to document baseline conditions and assess potential threats to water quality. The park monitoring program was reactivated in 1987 to evaluate water quality in shoreline embayments thought to be affected by tributary inflows and adjacent land use. Monitoring sites on the Gunnison River upstream of Blue Mesa Reservoir were established as well. The monitoring program continued with few changes until 1993. In 1993, a program review was conducted by staff from Curecanti NRA and the Water Resources Division (WRD) which resulted in the establishment of new monitoring sites (described later in this report). However, the group agreed that a thorough analysis of existing water quality data was necessary before recommending major changes to the monitoring program. This report was undertaken to: (1) provide a general review of the park's water quality monitoring program; (2) analyze and interpret existing water quality data; and, (3) help the park develop a threats-based water quality monitoring plan to formalize the current monitoring program. This report identifies sources of water quality data, areas where important information is lacking, and ongoing studies related to water quality. The body of this report presents results from analyses of water quality data, evaluates sampling and data management protocols, and offers recommendations to improve the monitoring program's effectiveness. Water quality data collected by park staff between 1987 and 1993 were used for analyses contained in this report; data analysis methods are described in the Methodology section. Discussion of the ecological significance and management implications associated with observed changes in water quality parameters, including explanations as to why these changes occurred, was beyond the scope of this report. Further analyses comparing park data with information from earlier studies would be required.

BACKGROUND

Study Area Description

Curecanti NRA is located 16 miles west of the town of Gunnison, Colorado and extends some 50 miles to the west (Figure 1). The Gunnison River, which was dammed in 1965 to create the Aspinall Unit, is a tributary of the Colorado River. The reservoirs (Blue Mesa, Morrow Point, and Crystal) store approximately 1,084,146 acre-feet of water. Blue Mesa Reservoir is the largest with approximately 941,000 acre-feet of water and a surface acreage of approximately 9,000 acres. Morrow Point Reservoir has a surface acreage of approximately 800 acres; Crystal Reservoir has a surface acreage of approximately 300 acres (National Park Service 1980). Blue Mesa and Morrow Point Reservoirs serve as power producing systems, and Crystal Reservoir serves as a re-regulation system. A short segment of the Gunnison River lies within park boundaries to the east of Blue Mesa Reservoir. Several large tributaries flow into Blue Mesa Reservoir, including the Lake Fork of the Gunnison River, Cebolla Creek, Soap Creek, and West Elk Creek. Cimarron Creek is the primary tributary inflow into the lower two reservoirs. Other tributaries contribute minor or ephemeral flows to the reservoirs, but provide excellent aquatic and riparian habitat for wildlife and aquatic organisms.

The Gunnison River and the three reservoirs are classified by the Colorado Water Quality Control Commission as Aquatic Life Cold 1, Recreation 1, Water Supply and Agriculture, and designated as Antidegradation Reviewable waters (previously a High Quality 2 designation). The Aquatic Life Cold 1 classification denotes waters which support a wide variety of cold water biota. Recreation 1 waters are suitable for primary human contact including swimming, kayaking, rafting, and water-skiing. The Water Supply and Agriculture classifications denote that the waters are suitable for such purposes. The Antidegradation Reviewable designation recognizes waters which are not outstanding state or national resources, but exhibit high quality. Waters designated as Antidegration Reviewable and classified as Aquatic Cold 1 and Recreation 1 yield to the antidegradation review process, a process which allows degradation of water quality if



Jacqueline V. Nolan, Cartographer
Water Resources Division 1995

Figure 1. Gunnison Basin Watershed.

economic or social development benefits override existing water quality benefits. The following creeks flowing into the three reservoirs are classified as Aquatic Life Cold 1, Recreation 2, Water Supply and Agriculture: North Beaver Creek, South Willow Creek, Steuben Creek, East Elk Creek, Cebolla Creek, Red Creek, Pine Creek, Blue Creek, Stumpy Creek, Cimarron Creek, Crystal Creek, and Corral Gulch. All other tributaries to the reservoirs are classified as Aquatic Life Cold 2, Recreation 2, and Agriculture (State of Colorado 1993).

Previous Water Quality Studies

A relatively large amount of water quality data is available for the Upper Gunnison Basin including Curecanti NRA. Some studies were park-based and others initiated by other agencies or academic institutions. The following discussion documents these studies. Tributaries to Blue Mesa received early scrutiny prior to and just after impoundment (Wiltzius 1965, 1966, 1967, 1971, 1974, 1976). These studies focused on fisheries and water quality measurements including temperature, pH, conductivity, dissolved oxygen, alkalinity, hardness, turbidity, and various ions. Reed (1968) anticipated certain limnological developments in light of reservoir completion on the Gunnison River. He suggested that nutrient leaching and increased availability of major ions after impoundment would create a productive reservoir. The study notes that blue-green algal blooms were encountered in the reservoir soon after river inundation.

Boettcher (1971) evaluated water quality and supply at six planned or existing recreation sites at Curecanti NRA. The Colorado Department of Health (State of Colorado 1975) discussed baseline water quality and potential problem sites within the upper Gunnison River drainage. In the Gunnison River, dissolved solids were low, specific conductance ranged from 167 to 257 micromhos per centimeter (µmhos/cm), and hardness as $CaCO_3$ averaged 140 milligrams per liter (mg/L). Ammonia was detectable, and phosphorus levels were high after return flows of irrigation water in 1975. The largest increases in fecal coliform counts occurred in the river approximately two miles north of Gunnison. The lowest benthic fauna diversity was encountered in channelized sections of the river.

Colburn (1981) studied levels of trace elements in aquatic insects in Gunnison area tributaries including the East River, Slate River, Oh-Be-Joyful Creek, Coal Creek, and the Gunnison River. Aquatic insects concentrated cadmium at two to four orders of magnitude; as with cadmium, manganese in the insects may reflect cumulative effects of past water quality. Richards and Ferchau (1978) and Apley (1981) focused on studies of surface and ground water in the Powderhorn area south of the park. Chemical, physical, and biological data were summarized for Cebolla Creek, a main tributary to Blue Mesa Reservoir. Rumberg et al. (1978) noted that waters in the upper Gunnison Basin including tributaries to Curecanti NRA were generally of high quality. Only fecal coliform, some metals, and ammonia levels exceeded standards at some sites. Effects of the Aspinall Unit impoundments on the physio-chemistry and biology of the downstream environment were discussed by Stanford and Ward (1983). Total dissolved solids and the organic carbon pool increased downstream. Winter water temperatures below the impoundments were elevated, and summer water temperatures were depressed below the last outlet. In addition, Stanford and Ward (1989), Hauer et al. (1989), and Ward and Stanford (1990, 1991) noted faunal discontinuities resulting from damming upper and middle reaches of the Gunnison River.

Metals, inorganics, organic hydrocarbons, and radionuclide data were reported in documents by Aaronson (1982a, 1982b). Only manganese exceeded U.S. Environmental Protection Agency criteria (U.S. Environmental Protection Agency 1976a) in Cimarron Creek. Fish tissue analyses (Kunkle et al. 1983; U.S. Fish and Wildlife Service 1987) for metals were completed in 1983 and 1987. In both studies, metals were not found at levels harmful to humans. The former study suggests follow-up studies which sample the game fish every five years to establish a baseline and interpret changes over time.

A summary of fisheries and benthic studies in the Gunnison River was presented by Nehring and Anderson (1983). Excluding yearly creel surveys and salmonid stocking records, little research was conducted on population structure and dynamics of the fishery at Curecanti NRA prior to 1993. Wiltzius (1971, 1974) focused on post-impoundment investigations of fish populations after initial stocking. Middleton's (1969) research entailed studies on catostomid fishes in Blue Mesa Reservoir and associated tributaries. Wiltzius (1976) prepared a report on the historical influences of irrigation diversions and reservoirs on temperature and fish distribution in the Gunnison River. Wiltzius and Smith (1976) chronicled harvest trends and migration of salmonids in the Aspinall Unit. Weiler (1985) conducted a trend analysis on rainbow trout and kokanee salmon versus catch per angler. McAda and Kaeding (1990) described the effects of dam construction on the fishery of the Gunnison River as it relates to endangered fish species. Johnson (1994) outlined a study in an annual project report that elucidates impacts to the productivity of plankton and quality of the fishery in Blue Mesa Reservoir from reservoir re-operations.

A preliminary report on Blue Mesa Reservoir noted the waters were mesotrophic, and ranked them sixth in overall trophic quality for Colorado's lakes and reservoirs (U.S. Environmental Protection Agency 1976b). Blue Mesa Reservoir's water quality was surveyed as part of a selected lakes and reservoir study; Sapinero Basin was sampled and determined to be oligotrophic (Britton and Wentz 1980). Blackwell and Boland (1979) included Landsat imagery and principal components techniques to determine the trophic status of Blue Mesa Reservoir. Additional multispectral scanner information was obtained in 1983 (Verdin 1984), and correlated to actual water samples. Lack of good relationships between surface and image data sets were attributed to a 24-hour delay between image acquisition and data collection. Water variability patterns were recognized and reported.

Summaries of biological, chemical, and physical data on Blue Mesa Reservoirs and tributaries to Curecanti NRA were presented by Bio-Environs (1985), National Park Service (1986), Hickman (1987), and Cudlip et al. (1987). The National Park Service (1986) study gathered baseline information on benthic fauna at four stream sites (Gunnison River, Cebolla Creek, Lake Fork of the Gunnison River, and Soap Creek), and phytoplankton in Blue Mesa Reservoir. At each of the stream sites, benthic organisms associated with high to medium quality water were found. In 1983, low numbers of phytoplankton and few species were found in Blue Mesa Reservoir. The report noted that there appeared to be no problem with algal blooms, particularly Aphanizomenon flos-aquae; however, 1983 was an anomalous year in that influx of water to the system was extremely high. Chlorophyll and phytoplankton data gathered in 1984 were also presented in the report. Bio-Environs (1985) noted that the three basins in Blue Mesa Reservoir differed in their trophic status: Sapinero was considered oligotrophic, Iola mesotrophic, and Cebolla intermediate between the other two. Hickman (1987) presented a trend analysis of water quality data from 1982 to 1985. He demonstrated that no gross pollution or variation from water quality state standards or Environmental Protection Agency criteria have occurred in Blue Mesa Reservoir. Cudlip et al. (1987) stated that chlorophyll data for Blue Mesa Reservoir did not corroborate the reservoir aging theory that productivity decreases after an initial "boom cycle". The report summarizes biological, physical, and chemical data collected on Blue Mesa Reservoir and notes further research ideas.

At least four major park-based water monitoring efforts (including the present program) have occurred at Curecanti NRA. The first included an early period of sampling pre- and post-impoundment (Wiltzius 1965, 1966). In these studies, sites in the Gunnison River and some tributaries were monitored for basic parameters, alkalinity, some ions, and some metals. In 1982, Roger Andrascik, Resource Management Specialist, and Don Hickman, Park Ranger, initiated a water quality monitoring program in Blue Mesa Reservoir and its tributaries, primarily to document baseline conditions and assess potential threats to water quality. During the 1982 to 1985 sampling period, data were collected from 48 Blue Mesa Reservoir (BML1-BML48) sites, four Crystal Reservoir sites (CL1-CL4), and six sites on Morrow Point Reservoir (MPL1-MPL6). Twenty-one tributaries were sampled. The following parameters were measured at least once at the above sites: air temperature, water temperature, discharge in streams, depth and elevation for reservoir sites, specific conductance, pH, dissolved oxygen, secchi depth in reservoirs, total dissolved solids, total suspended solids, fecal coliform bacteria, fecal streptococci bacteria, total acidity, total alkalinity, calcium, chloride, magnesium, organic nitrogen, total Kjeldahl nitrogen, ammonium, nitrate, sodium, sulfate, potassium, ortho-phosphate, total phosphorus, and hardness (National Park Service, Curecanti NRA, unpublished data).

In 1987, Wayne Valentine, Resource Management Specialist, reactivated the water quality monitoring program in Blue Mesa Reservoir. The 1987 program was designed to monitor potential threats to water quality in shoreline embayments from tributary inflows and adjacent land use. Table 1 notes the sites sampled and the potential threats at those sites (Figure 2). These sites were monitored for air temperature, water temperature, specific conductance, pH, dissolved oxygen, secchi depth at reservoir sites, total dissolved solids, total Kjeldahl nitrogen, total phosphorus, ortho-phosphate, fecal coliform bacteria, and chlorophyll **a** at reservoir sites. The chlorophyll samples were collected in a 5 meter x 0.025 meter PVC pipe. Ammonia and nitrate were measured at the three Cimarron and Squaw Creek sites, and at the Gunnison River at Riverway site. Four beach areas (sites BM14-BM17) were monitored for air/water temperature and

Table 1. Water Quality Monitoring Sites and Associated Threats, 1987-1992.

		Water Quality Issues/Threats										
Site ID	Site Name	Septic	Mining	Oil/ Gas	Road	Recreation	Marinas	Grazing	Upstream	Logging	UST	Development
BM01	Lake Fork Arm		x		x	x		x				
BM02	Lake Fork Marina	x					x					
BM03	Haystack Gulch	x										
BM04	Sunnyside	x										
BM05	Iola	x				x		x				
NW06	Lower North Willow	x				x						
GR07	Gunnison River - Riverway								x			
CM08	Cimarron Ck above Squaw Ck	x									x	
SC09	Squaw Ck above Cimarron Ck	x						x				
CM10	Cimarron Ck below Squaw Ck	x						x				
NW11	Upper North Willow						x	x				
CM12	Cimarron Ck above Benny's	x						x				
BM13	McIntyre Gulch	x			x							x
BM18	Blue Mesa Highlands	x				x						x
BM14	Old Hwy 50 Beach					x						
BM15	Bay of Chickens West					x						
BM16	Bay of Chickens East					x						
BM17	Iola Beach					x						

CURECANTI NATIONAL RECREATION AREA

Water Quality Sampling Sites

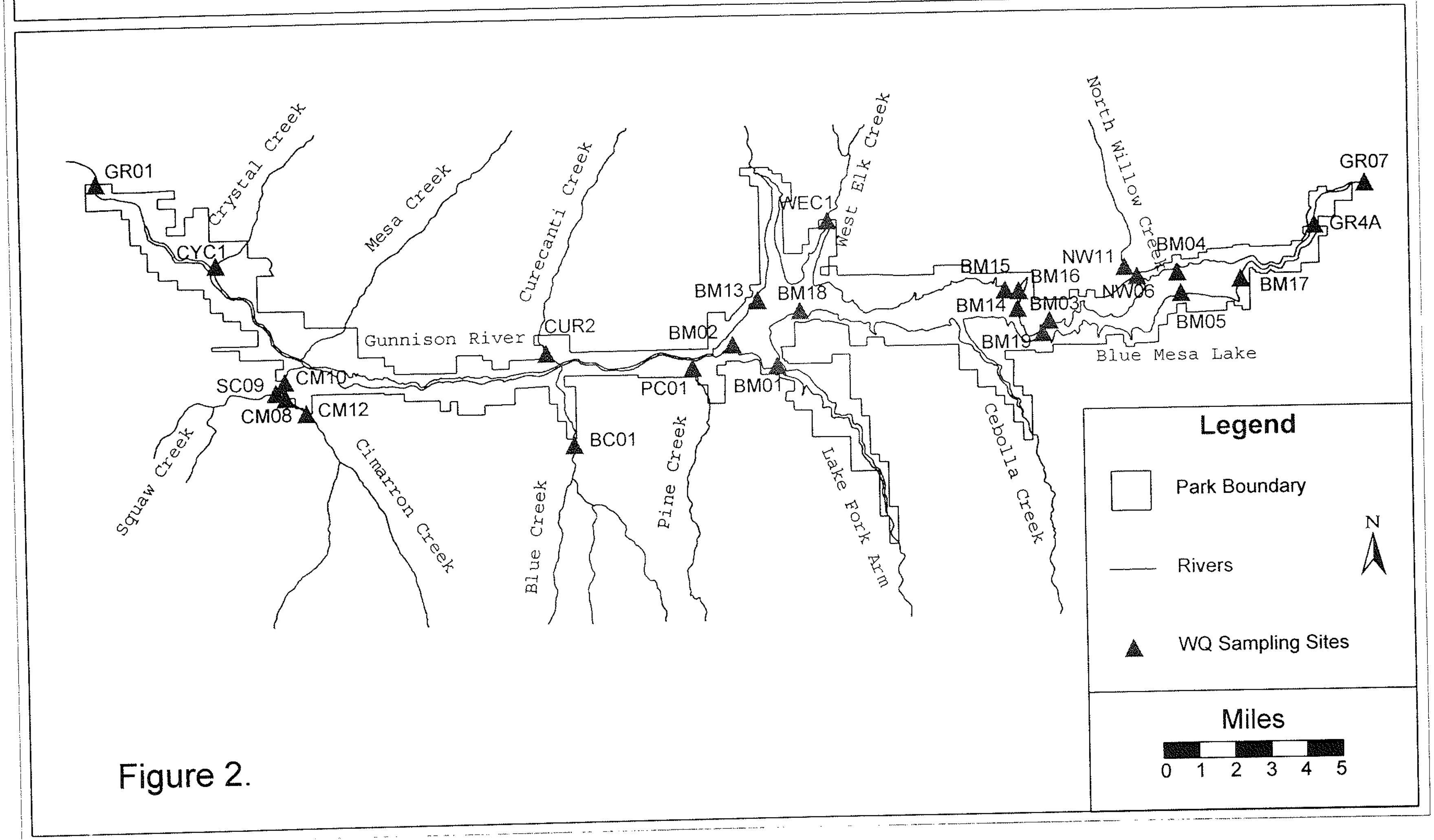


Figure 2.

fecal coliform bacteria only. Fecal streptococci bacteria and chloride were measured a few times at the North Willow, Cimarron and Squaw Creek sites (National Park Service, Curecanti NRA, unpublished data).

Present Water Quality Monitoring Program

Water Quality - In 1992, Curecanti NRA requested technical assistance to review its water quality monitoring program. Related to this request, other program needs were identified and included: 1) relocating current monitoring sites to address changing resource demands and uses; 2) formalizing the threats-based program by developing a monitoring plan; 3) correlating past data with recent data, 4) providing input for the General Management Plan; and, 5) developing a Water Resources Management Plan for the park (Long 1993).

Discussions led by Barry Long (WRD) and Tim Graham (Curecanti NRA) revealed: 1) no sites on Morrow Point or Crystal Reservoirs were being monitored; 2) recent increased urbanization in Crested Butte and Gunnison may cause impacts to water resources; 3) land-use activities such as mining, logging, and grazing in the watershed surrounding the park had not been assessed; 4) impacts from new and existing roads presented potential threats; 5) marinas in Blue Mesa Reservoir, and to a lesser extent in the two lower reservoirs, posed hazards for introduction of oils, fuels and organic solvents from boats; and, 6) uranium mill tailings near the Gunnison River upstream of Curecanti NRA presented a potential threat to park water resources. Presently, contractors for the U.S. Department of Energy are removing the tailings from the site; this work is planned for completion in 1996. The U.S. Department of Energy has established ground water monitoring programs for the removal site and the new disposal site (1994a, 1994b).

In light of the identification of these potential threats to water resources at Curecanti NRA, the park revised the list of monitoring sites. Presently, Curecanti maintains a threats-based water quality monitoring program at six sites in Blue Mesa Reservoir and nine stream sites flowing into all three reservoirs (Table 2, Figure 2). Park staff routinely measure basic parameters, nutrients, and chlorophyll **a**. Following the analysis of the 1987-1993 water quality data, the park will revise its monitoring program.

Limnological Studies - A study currently underway will define the trophic dynamics of Blue Mesa Reservoir. Research carried out by Colorado State University and U.S. Fish and Wildlife Service investigators will define the relationship between fish, their food sources, and reservoir operations (Johnson 1994; National Biological Survey 1994). Additionally, research on entrainment of fish through the dam will provide seminal information on effects of release regimes on a stocked fishery (Jennings, pers. com. 1994).

Biomonitoring - In 1992, Curecanti NRA began a biomonitoring program on all the stream sites of the established water quality monitoring program. The need for a program was identified from a 1992 highway spill in which fertilizer entered Blue Creek

Table 2. Water Quality Monitoring Sites and Associated Threats, 1993 to Present.

		Water Quality Issues/Threats										
Site ID	Site Name	Septic	Mining	Oil/ Gas	Road	Recreation	Marinas	Grazing	Upstream	Logging	UST	Development
BM01	Lake Fork Arm		x		x	x		x				
BM03	Haystack Gulch	x										
BM04	Sunnyside	x										
BM05	Iola	x				x		x				
BM18	Blue Mesa Highlands	x				x						x
BM19	Elk Creek Marina					x	x					
GR07	Gunnison River - Riverway								x			
GR4A	Gunnison River - Cooper Ranch										x	
GR01	Gunnison River - Black Canyon	x				x						
WEC1	West Elk Creek	x										x
PC01	Pine Creek	x				x		x			x	
BC01	Blue Creek				x							
CUR2	Curecanti Creek			x				x				
CM10	Cimarron Ck below Squaw Ck	x			x	x		x			x	x
CYC1	Crystal Creek			x		x		x				
BM14	Old Hwy 50 Beach				x							
BM15	Bay of Chickens West					x						
BM16	Bay of Chickens East					x						
BM17	Iola Beach					x						

(tributary to Morrow Point Reservoir) from a drainage on Highway 50. This accident and an incident at Capitol Reef National Park point to the need for parks to monitor the biological component of aquatic systems in addition to monitoring the chemical and physical aspects. At Capitol Reef National Park the chemical and physical monitoring program did not capture the severity of a rotenone spill (Cudlip et al. 1994). Over 300 fish and thousands of macroinvertebrates were killed as a result of the spill (National Park Service 1991). Curecanti NRA is using the EPA's Rapid Bioassessment Technique (U.S. Environmental Protection Agency 1989) to inventory the streams, compare sites over time, and compare impacted sites such as the Cimarron River with more pristine sites in terms of their macroinvertebrates. Since 1994, six sites have been monitored annually. Relative numbers of genera at stream sites ranged from 10 to 23 in 1994 (Cudlip et al. 1994). Further analysis of data awaits more years of sampling.

Coordination with Other Agencies - The U.S. Geological Survey, through their National Water Quality Assessment (NAWQA) Program, will monitor water quality and quantity at sites above and below Curecanti NRA. Under a Memorandum of Understanding between the National Park Service and the U.S. Geological Survey, two sites on the Gunnison River will be sampled as basic fixed sites during fiscal year 1995, and possibly future years. Water samples will be collected on a monthly basis with two additional extreme flow samples. Bed sediment and tissue samples will also be collected at these sites. Curecanti NRA will assist in sampling at the Riverway site and will have access to the data generated from the study.

Curecanti NRA anticipates participation in the Colorado Division of Wildlife River Watch Network. This program involves middle and high schools, colleges, and other entities in monitoring the waters of Colorado. In 1996, the park expects to incorporate sites on the Lake Fork of the Gunnison River and Cebolla Creek in its monitoring program. Park staff would collect the samples, and Ruland Middle School and the Colorado Division of Wildlife would analyze the samples for pH, dissolved oxygen, alkalinity, hardness, and metals.

Outstanding Waters Designation - As required by the Clean Water Act, the Colorado Department of Health's Water Quality Control Commission holds a review of stream standards and classifications every three years. The next rule making decision will occur in 1997. Curecanti NRA anticipates that the Colorado Water Quality Control Division (CWQCD), which serves as staff to the Commission, may recommend an Outstanding Waters Designation for the three reservoirs (Anderson, CWQCD, pers. com. 1994). The designation would help maintain the excellent water quality that currently exists at Curecanti NRA. However, such a designation prompts the antidegradation review for all projects that involve discharges to these waters. Such a designation would carry with it impacts to park management. If the park needed to construct a sewage system requiring discharge to these waters, the antidegradation review would require performance of an alternatives analysis, or prohibit construction. In addition, adjacent and upstream landowners could be impacted by such a designation. Potentially, future adjustments in reservoir releases may be impacted by this designation as well.

METHODOLOGY

Field Sampling

A total of twenty-six sites were sampled between 1987 and 1993, although not all sites were sampled in any given year. Sixteen sites were sampled in 1987; seventeen sites were sampled from 1988 to 1992; and nineteen sites were sampled in 1993. These sites are located within or just outside of the park boundary and include twelve sites on the Blue Mesa Reservoir (including four beach sites), two sites on the Gunnison River above Blue Mesa Reservoir, eleven tributary sites, and one site below Crystal Dam on the Gunnison River. Samples are taken every three weeks beginning in early May after ice break-up. Beach fecal coliform samples are taken every two weeks beginning before Memorial Day. Seven to eight rounds of sampling are completed for each season depending on the resources available. If time permits, basic parameters including pH, temperature, dissolved oxygen, and specific conductance are measured on the tributaries accessed by trail during the fall, winter, and spring seasons.

Each of the tributaries flows into one of the reservoirs, and therefore is affected by rise and drawdown of the individual reservoirs. Actual sampling sites are adjusted such that samples are taken from a segment of the stream which runs freely and is not influenced by slack water of the reservoir. Crystal Creek runs dry mid-summer and therefore sampling only takes place in the early summer.

The parameters measured include: air temperature (°C), secchi depth (meter, m), water temperature (°C), pH (standard units), dissolved oxygen (mg/L), specific conductance (μmhos/cm or microSiemans/cm, μS/cm), total dissolved solids (mg/L), total chloride (mg/L), total Kjeldahl nitrogen (mg/L), ammonia (mg/L), total nitrate (mg/L), total phosphorus (mg/L), orthophosphate (mg/L), chlorophyll **a** (mg/m^3), fecal coliform bacteria (colony forming units per 100 milliliters, cfu/100 mL), and fecal streptococci bacteria (cfu/100 mL). Total chloride and fecal streptococci bacteria were only measured in 1988. The period of record statistics table in Appendix D indicates which parameters were measured at each site.

Water samples are generally collected by boat. With the exception of West Elk Creek, all tributary sites are accessed by trails. Before 1993, pH was measured with an Orion SA250 pH meter, conductivity was measured with a YSI Model 33 S-C-T meter, and dissolved oxygen was measured with a Hach kit using the Winkler method. Since 1993, temperature, pH, dissolved oxygen, and specific conductance are measured using the Scout II Hydrolab. The sonde unit is placed into the water such that the probes extend approximately 0.5 meter (m) below the water surface. The unit is turned on, left to equilibrate for five minutes and then measurements are taken. Secchi depth (in meters) is measured by lowering the secchi disc into the water on the sunny side of the boat until the disc can no longer be seen. The disc is then raised until it is visible. The line at water level is noted, and the disc brought on board.

Beginning in 1994, the Hydrolab will be used to profile each of the reservoirs and particularly each of the basins within Blue Mesa Reservoir. Historical profiling sites will be used in Blue Mesa Reservoir. Representative sites will be selected within the other reservoirs. The basic parameters will be measured every meter from the surface to depth. These measurements will coincide with water quality sampling efforts.

Nutrient samples are collected approximately 0.5m below the water surface in two 500 mL bottles. These bottles are labelled with the site name and "A" or "B". The "A" bottles have 1 mL of concentrated H_2SO_4 acid added to them before the water sample is collected. Water is first collected in the "B" bottle and then poured into the "A" bottle insuring that no water or its acid preservative spills out of the "A" bottle. The "B" bottle is then refilled and sealed.

Chlorophyll **a** samples are collected with a 5m long PVC pipe. The pipe is plunged perpendicularly into the water up to the 5m mark. A cord is pulled in order to stopper the end of the pipe. The captured water is decanted into a 5-gallon bucket and one liter of this sample is collected.

Fecal coliform bacteria samples are collected at selected sites and at all beach sites. Two whirlpak samples are collected from these sites. The bags are labelled with the appropriate site label.

Macroinvertebrates are also sampled once per year at each of the stream and tributary sites; however, these data are not included in this analysis.

Sample Handling

Nutrient and chlorophyll **a** samples are immediately placed on ice in a cooler. Light exposure for the chlorophyll samples is limited as much as possible. These samples are transported to the Mountain Meadows Research Center in for analysis. Fecal coliform samples are kept on ice in the cooler and taken to the city water laboratory for analysis.

Laboratory Analysis

Nutrient and chlorophyll **a** samples are analyzed using Standard Methods (American Public Health Association 1989) techniques at the Mountain Meadows Research Center in Gunnison, Colorado. The laboratory is approved by the U.S. Environmental Protection Agency and affiliated with Colorado State University. Chlorophyll **a** is analyzed according to the following procedure:

> 1) Each 1 liter sample is filtered using glass fiber filters (GF/C or GF/A). Filters are promptly removed from the filtering apparatus, folded, placed in labelled petri dishes, and frozen until extraction takes place.
>
> 2) To extract the chlorophyll, each individual filter is ground using a glass grinder. Filters are placed into the grinder. Approximately 5 mL of 90%

acetone are added to the tube. The filter is ground until no more material is present. The liquid is decanted into test tubes. The grinding tube is rinsed two times (1-2 mL) and the rinse material is added to the contents of the test tube. All test tubes are placed in a refrigerator overnight for extraction.

3) The spectrophotometer is blanked to a 90% acetone solution. Each test tube sample is measured for volume. The solution is transferred from the graduated cylinder to a spectrophotometer tube. Each sample is analyzed at 630, 647, 664 nanometers. A reading is taken at 750 nanometers and subtracted from each pigment optical density (OD) value as a correction for turbidity. The corrected optical density readings are used in the following equation to calculate the amount of chlorophyll **a** per unit volume, which is expressed in mg/m^3.

$$\text{chla} = 11.85(\text{OD } 664) - 1.54(\text{OD } 647) - 0.08(\text{OD } 630)$$
$$mg/m^3 = \text{chla} * \text{mL of solution in test tube}$$

The Membrane Filter (MF) technique is used to analyze water samples for fecal coliform (American Public Health Association 1989). The results from two replicate samples collected at each site are averaged.

Data Management

All water quality sampling data were entered by park staff into a database file in DBASE III+ software format. A copy of this file was sent to the WRD for analysis. Several changes were made to this file, which was renamed ARCHIVE.DBF, prior to analysis. Site names were added to the file. Air temperature values equal to -1 were assumed to be missing values and were replaced with -9.9. Secchi depth values equal to -1 were replaced with -9.99. pH values equal to -1 or 0 were assumed to be missing data and were replaced -9.99. Fecal coliform values equal to -1 were assumed to be missing data and were replaced with -99. Since DBASE III+ and IV replace blank numeric fields with zeros or -1s it is important to enter a number at the time of data input which cannot possibly be a valid number. This is why numbers composed of -9s are entered into the file. Several data entry errors were corrected through contact with park personnel, who checked the database values against the data sheets. Single character fields were inserted after each parameter field in order to accept STORET codes. Values "< 0.01" were replaced with 0.01 and a K in the comment field following the parameter field. The database was sorted by site identification code and date.

Once the data was standardized and corrected, an analysis file (ANALYSIS.DBF) was created, which is a subset of the ARCHIVE.DBF file. Field names in ANALYSIS.DBF were shortened to eight characters or less so that this file could be imported into other applications. Values "0.01 K" were changed to 0.005 and fecal coliform values of 9999 (too numerous to count) were changed to 3,500. The value 3,500 was selected for fecal coliform plates that could not be counted because it was greater than but close to the highest number of colonies counted (3,163 cfu/100 mL). A higher value was not selected in the interest of reducing high-end bias for statistical purposes. This file was used to generate summary statistics and box-and-whiskers plots. Descriptions of text, graphic, program, and database files which were used in the report are included in Appendix A. Detailed file structures for all database files are contained in Appendix B.

In addition, all data included in the ARCHIVE.DBF file were uploaded into the EPA's national database STORET. Stations in STORET were created for each site and all data labeled with STORET parameter codes (see file structures in Appendix B) were entered into the database. Data from this database are available to all federal and state agencies. Other information related to the STORET database, and data that reside in STORET, can be found in the *Baseline water quality data inventory and analysis report for Curecanti NRA* (National Park Service, in process).

Summary statistics were performed on each parameter in order to determine the following period of record statistics: mean, standard deviation, 10th percentile, 25th percentile, median, 75th percentile, 90th percentile, minimum, and maximum (Appendix D). These statistics were calculated using the Proc Univariate procedure in SAS software, version 6.03. Geometric means were substituted for arithmetic means for fecal coliform bacteria in the tables.

Annual box-and-whiskers plots (Appendix E) were produced by SigmaPlot software, version 1.02a. For the box-and-whiskers plots, the solid horizontal lines within the box represent the median value of the data group. The dashed horizontal lines represent the mean value. The bounds of the box represent the 25th and 75th percentiles of the data values. The whiskers display the range of data values which fall within the 10th and 90th percentiles. Data values outside the 10th and 90th percentiles are plotted as solid dots. In order for a site to generate a box-and-whisker plot, it must have had a minimum of two years of data containing three or more values per annum. In addition, SigmaPlot requires a minimum of three values to compute the 25th and 75th percentiles, five values to compute the 10th percentile, and six values to compute the 90th percentile.

Data from sites in Squaw Creek and the Cimarron River were analyzed using non-parametric statistics (Appendix F). These sites were selected because they appear to contribute the greatest amounts of sediment to the reservoir system. The Wilcoxon signed-ranks statistic was used, which is equivalent to a paired t-test used for data that are normally distributed. The actual two-tailed probabilities were computed from an approximate normal variate constructed from this statistic (Marascuilo and McSweeney 1977 in Systat Version 5.3, 1990).

Data from all sites were compared with Colorado water quality standards (State of Colorado 1993). Water quality standard tables are included in Appendix H for the use designations/classifications that apply to the reservoirs and tributaries in Curecanti NRA.

RESULTS

Summary Statistics

Field Parameters - Water temperatures in Blue Mesa Reservoir ranged from a maximum of 24 °C at Bay of Chickens East (BM16) to a minimum of 2.3 °C at Iola (BM05) (Appendix D). Median water temperatures in Blue Mesa were relatively consistent between sites, but tended to decrease approximately 5 °C (from 20-15 °C) during 1987 to 1993. Water temperatures in the tributaries ranged from a maximum of 25.5 °C at Cimarron Creek above Benny's (CM12) to a minimum of 1.4 °C at Squaw Creek above the confluence with Cimarron Creek (SC09), and exhibited a similar decreasing trend over the same period. Specific conductance values in Blue Mesa Reservoir, excluding the Lake Fork sites, ranged from a maximum of 250 μmhos/cm to a minimum 115 μmhos/cm. The Lake Fork sites had lower conductivities on a few occasions. Median specific conductance values in the reservoir ranged from 188 μmhos/cm at Sunnyside (BM04) to 150 μmhos/cm at Lake Fork Arm (BM01), and tended to increase over time at most sites. Specific conductance values in the tributaries ranged from a maximum of 2,430 μmhos/cm at SC09 to a minimum of 35 μmhos/cm at Blue Creek (BC01) and Curecanti Creek (CUR2), and median values were much higher in Cimarron and Squaw Creek than in the other tributaries. Dissolved oxygen concentrations in Blue Mesa ranged from a maximum of 12.7 mg/L at BM01 to a minimum of 6.3 mg/L at Lake Fork Marina (BM02). Median dissolved oxygen concentrations at all reservoir sites were relatively stable at about 8.0 mg/L with little annual variation. Dissolved oxygen concentrations in the tributaries ranged from a maximum of 16.6 mg/L at SC09 to a minimum of 6.3 mg/L at Lower North Willow (NW06). In general, median dissolved oxygen concentrations were higher and more variable in the tributaries than in the reservoir. The pH values in Blue Mesa Reservoir and the tributaries ranged from a maximum of 9.9 standard units at Cimarron Creek below the confluence with Squaw Creek (CM10) to a minimum of 5.1 standard units at Haystack Gulch (BM03). Median pH values ranged from 8.5-7.1 standard units, and were moderately variable among sites and years. In general, higher pH values were observed in Blue Mesa Reservoir, Cimarron Creek and Squaw Creek than in the other tributaries. Secchi depths in Blue Mesa Reservoir ranged from a maximum of 6.8 m at BM03 to a minimum of 0.5 m at BM04. Median secchi depths were relatively consistent among sites at 3.5 m with little annual variation except for 1988. Median secchi depths ranged from 1-2 m at BM03, BM04 and BM05 during 1988.

Ions - Limited ion data were collected from 1987 to 1993. Total dissolved solids (or total filtrable residue) was the only parameter routinely measured. Chloride was measured one time in NW06 and Upper North Willow (NW11). Total dissolved solids (TDS) values in Blue Mesa Reservoir ranged from a maximum of 217 mg/L at BM03 and BM05 to a minimum of 35 mg/L at McIntyre Gulch (BM13). Median TDS values in the reservoir were relatively stable at about 120 mg/l with little annual variation. TDS values in the tributaries ranged from a maximum of 1,880 mg/L at SC09 to a minimum of 71 mg/L at NW11. Median TDS values were generally higher in Cimarron Creek and Squaw Creek than in North Willow Creek and the Gunnison River.

Nutrients - Ammonia nitrogen values ranged from a maximum of 1.1 mg/L at the Gunnison River at Riverway (GR07) to a minimum of below detection at all sites sampled for ammonia. Median ammonia values were at or below 0.1 mg/L at all sites, except during 1991 and 1992 in Cimarron and Squaw Creek where median values approached 0.4 mg/L. Nitrate nitrogen values ranged from a maximum of 3.9 mg/L at SC09 to a minimum of below detection. Median nitrate values were highly variable but tended to decrease from around 1.0 mg/L to near the detection limit of 0.01 mg/L between 1987 and 1992. Total Kjeldahl nitrogen values in Blue Mesa Reservoir ranged from a maximum of 3.4 mg/L at BM03 to a minimum of below detection. Median Kjeldahl nitrogen values ranged from 0.4 mg/L at BM03 to 0.2 mg/L at BM13. Kjeldahl nitrogen reservoir data exhibited moderate annual variation with the highest median values in 1987 and the lowest in 1990. Total Kjeldahl nitrogen values in the tributaries ranged from a maximum of 5.4 mg/L at CM10 to a minimum of below detection. Median Kjeldahl nitrogen values in the tributaries ranged from 0.8 mg/L at the Gunnison River at Black Canyon (GR01) to 0.3 mg/L at NW11 and exhibited the same annual pattern as the reservoir data. Orthophosphate (soluble reactive phosphorus) values in Blue Mesa ranged from a maximum of 0.3 mg/L at BM01 to a minimum of below detection. Median orthophosphate values at all reservoir sites were near the detection limit of 0.01 mg/L and tended to be higher in years 1987 through 1989 than in 1990 through 1993. Orthophosphate values in the tributaries ranged from a maximum of 0.5 mg/L at NW06 to a minimum of below detection. Median orthophosphate values in the tributaries ranged from 0.12 mg/L at the North Willow Creek sites to 0.02 mg/L at the Gunnison River sites and had the same annual pattern as the reservoir data. Total phosphorus values in Blue Mesa ranged from a maximum of 1.2 mg/L at BM03 to a minimum of below detection. Median phosphorus values ranged from 0.1 mg/L at Blue Mesa Highlands (BM18) to 0.02 mg/L at BM02 and were highest during 1991 to 1993 at most sites. Total phosphorus values in the tributaries ranged from a maximum of 1.8 mg/L at SC09 to a minimum of 0.02 mg/L at GR07, SC09, and Cimarron Creek above confluence with Squaw Creek (CM08). Median phosphorus values were greater than 0.1 mg/L at all tributary sites except GR07 with moderate annual variation. GR07 was the only tributary site to exhibit the same annual pattern as the reservoir sites. Chlorophyll **a** values in Blue Mesa Reservoir ranged from a maximum of 49.1 mg/m^3 at BM04 to a minimum of 0.2 mg/m^3 at BM01 and BM03. Median chlorophyll **a** values ranged from 6.0 mg/m^3 at BM05 to 2.7 mg/m^3 at BM18.

Secchi depth, nutrient, and chlorophyll data collected in Blue Mesa Reservoir between 1987 and 1993 are very similar to data collected during the limnological survey conducted by Bio-Environs (1985). Therefore, no recent changes in trophic status have occurred, and park data appear to support previous findings which state that the Iola Basin is mesotrophic (2-15 mg/m^3 chlorophyll **a**), and the Cebolla and Sapinero Basins are oligotrophic (0-3 mg/m^3 chlorophyll **a**).

Bacteria - Fecal coliform bacteria counts in Blue Mesa Reservoir ranged from a maximum of greater than 3,500 cfu/100 mL at BM16, Bay of Chickens West (BM15), and Iola Beach Site (BM17), to a minimum of zero at all sites. Geometric mean values of fecal coliform bacteria were close to zero at all sites in the reservoir. Fecal coliform bacteria counts in the tributaries ranged from a maximum of greater than 3,500 cfu/100 mL at CM08, CM10, CM12, SC09, NW06, NW11, and Crystal Creek (CYC1) to a minimum of zero at many sites. Geometric mean values for fecal coliform bacteria in Cimarron Creek, Squaw Creek, and Crystal Creek were higher than in the other tributaries, ranging from 122-491 cfu/100 mL.

Comparison of Cimarron Creek and Squaw Creek Data

Of particular interest are data for various water quality parameters at four sampling sites located in the Cimarron area. These sites include Squaw Creek above the confluence with Cimarron Creek (SC09), Cimarron Creek at Benny's (CM12), Cimarron Creek above the confluence with Squaw Creek (CM08), and Cimarron Creek below the confluence with Squaw Creek (CM10). Curecanti NRA recognized in 1987 that water entering from Cimarron Creek to Crystal Reservoir was turbid, particularly during spring runoff (Valentine, pers. com. 1987). This situation was also exacerbated by precipitation events. A sampling regime was designed to define the extent of the problem, and the contribution of sediment from Squaw Creek to Crystal Reservoir. Unfortunately, the parameters selected for analysis (see Methodology Section) do not address the most pressing question regarding sediment yield or production.

Tables in Appendix F reveal the presence of significant differences between sites at the $p=0.05$ level. Several measured parameters at CM08 and CM10 are significantly different from SC09. However, no measured parameters on Cimarron Creek differ significantly between sites above and below the confluence with Squaw Creek. For example, the median specific conductance levels for sites CM08 and CM10 are 470 and 473 µS/cm, respectively. The median for SC09 is 950 µS/cm. Total dissolved solids also reveal that the median for Squaw Creek is higher than the medians for the period of record for the Cimarron Creek sites (CM08 and CM10) immediately adjacent to Squaw Creek inflows. The median total dissolved values for Squaw Creek and Cimarron Creek immediately above and below are 823, 402 and 427 mg/L, respectively. An increase in dissolved solids is apparent in Cimarron Creek below the confluence, but does not significantly differ from the levels above the confluence. One last example includes the values for fecal coliform bacteria measured as number of colony forming units per 100 mL of sample. The geometric mean for Squaw Creek is 226 cfu/100 mL versus 122, 167 and 125 cfu/100 mL for CM08, CM10 and CM12, respectively. Although the Cimarron Creek sites are not significantly different from each other, CM10 and CM12 (a mile above the confluence) are significantly different from SC09 fecal coliform levels for the period of record.

The nutrient data are limited to measurements of total phosphorus, soluble reactive phosphorus, total Kjeldahl nitrogen, ammonia, and nitrate. Very few samples were collected at CM10 for ammonia and nitrate (n=7). The analysis reveals that Cimarron Creek above the confluence with Squaw Creek has a significantly lower concentration of nitrate and ammonia than Squaw Creek. There is no significant difference between sites for soluble reactive phosphorus (or orthophosphate). Levels of total Kjeldahl nitrogen differ significantly between CM10 and SC09, and CM12 and SC09. Nutrient values for the sites exhibited some high values. Summary statistics for each of the nutrients at all sites reveal relatively high maximum total Kjeldahl nitrogen, nitrate, and soluble reactive phosphorus levels.

The statistical analyses indicate that between 1987 and 1992, the water quality of Squaw Creek did not significantly impact the water quality in Cimarron Creek. However, the analyses did not include weighting factors for discharge because no flow data were available.

DISCUSSION AND RECOMMENDATIONS

Significance of Water Quality Indicators

The threats-based water quality monitoring program at Curecanti NRA has focused primarily on measurement of basic field parameters, nutrients, bacteria, and chlorophyll **a**. Monitoring sites include reservoir embayments and tributaries. Routine analyses of water samples for metals, sediments and organics were not included in park-based efforts. Limited data from previous studies exist for these and other constituents, but recent information is lacking. Although monitoring for organics and trace elements (including metals) is expensive and requires special field and laboratory capabilities, periodic scans at specific sites may be advisable in the future. However, the WRD recommends that routine sampling include the same list of parameters with the addition of turbidity, total suspended solids, alkalinity, hardness, and flow (or discharge). Chemical reactions involving nutrients and trace elements are influenced by the alkalinity (or buffering capacity) of the waters. Colorado water quality standards for certain metals are derived by hardness dependent formulas. Flow measurements in tributaries and lake level measurements in reservoirs are important for determining constituent loading and flux values. Also, it may be advisable to analyze water samples for ammonia and nitrate at other sites in addition to those in Cimarron Creek, Squaw Creek, and the Gunnison River.

Water Quality Standards Compliance

The table in Appendix G identifies the Colorado water quality standards that were compared with Curecanti NRA data from 1987 through 1993. The water quality standards evaluation revealed violations of the Colorado pH standard in Blue Mesa Reservoir, Cimarron Creek, Squaw Creek, and the Gunnison River. Of the 601 pH observations used in the standards analysis, 20 observations at nine monitoring sites (BM03, BM04, BM05, BM13, CM08, CM10, CM12, SC09, and GR07) were outside the pH range of 6.5-9.0 standard units. All but two violations were for observations that exceeded 9.0 standard units. The water quality standards evaluation also revealed potential violations of the Colorado standard for fecal coliform bacteria in Blue Mesa Reservoir, Cimarron Creek, Squaw Creek, Crystal Creek, and North Willow Creek. Of the 704 fecal coliform observations used in the standards analysis, 114 observations at 11 monitoring sites exceeded the Colorado standard of 200 cfu/100 mL. However, because the Colorado fecal coliform standard is based on a geometric mean calculation from individual observations, the standard was violated at only two monitoring sites (CYC1 and SC09). If a minimum "five samples within 30-days" criterion is used for computing geometric means, no fecal coliform violations could be reported. Monitoring for compliance with fecal coliform standards would require more frequent sampling.

Water Quality Comparisons and Trends

No specific trend analyses were performed; however, non-parametric tests, summary statistics, and annual box-and-whisker plots were used to compare sites and assess possible water quality trends (Appendix D and E). Based upon these results, it appears that few temporal trends were apparent, and differences among years may be due in part to changes in sampling and analysis techniques and/or quality control procedures. Park data collected between 1987 and 1993 should be compared to earlier data to assess whether trends exist due to natural or anthropogenic sources. Differences among sites were predictable based on the types of water bodies sampled (i.e., reservoir, river, or stream), and the broad spatial coverage of the monitoring program. However, it is obvious that the water quality in Cimarron and Squaw Creek is quite different from the other tributaries. Also, it appears the Gunnison River upstream from Blue Mesa Reservoir has a measurable influence on the water quality in the reservoir. Chlorophyll, nutrient. and secchi depth data from the reservoir sites appear to support the conclusion that a productivity gradient may exist in Blue Mesa Reservoir from high to low in a downstream direction (i.e. the Iola Basin is more productive than the Cebolla Basin, which is in turn more productive than the Sapinero Basin).

Based on the limited analyses of the data for SC09, CM12, CM08, and CM10, Squaw Creek apparently does not influence the water quality of Cimarron Creek. However, weighting measurements by flow may influence the analysis. Squaw Creek flows are small relative to Cimarron Creek, yet, Squaw Creek apparently carries a substantial amount of dissolved material (see specific conductance and total dissolved solids data in Appendix D).

Cimarron Creek and Squaw Creek carry noticeable sediment loads during runoff and precipitation events (Cudlip, pers. observ. 1992). Although the analysis does not reveal significant impacts from Squaw Creek to Cimarron Creek, the park recognizes the problem with sediment load in both systems. Again, continued monitoring should include turbidity, total suspended solids, and flow measurements.

Field Sampling and Laboratory Analysis Protocols

Since Curecanti NRA began monitoring tributaries which flow into Morrow Point and Crystal Reservoirs in 1993, logistics have become an important aspect of the threats-based monitoring program. Decisions on monitoring design, site/parameter selection, equipment, measurement protocols, and sample collection/handling are more difficult over a broader area with limited access points. Transportation of monitoring equipment, boats, and water samples requires good coordination and specialized expertise in some cases. Water samples must be handled properly, preserved if necessary, and transported to the laboratory within specific holding times (American Public Health Association 1989). Duplicate samples should be collected, if possible, to evaluate quality assurance/quality control procedures used by the laboratory.

During the 1993 review, park and WRD staff expressed the concern that sampling discrete shoreline locations adjacent to potential sources of water quality impairment may be insufficient to determine the extent of potential impacts to the reservoirs. In most cases, measurements were made at one location per shoreline embayment. No vertical profile measurements were taken at any site between 1987 and 1993. Grid or tow measurements to assess spatial variability, and vertical profile measurements to assess variability due to depth, are recommended at all sites on a routine or periodic basis in the future. Another issue relates to monitoring sites on a rotating basis to obtain better coverage of park areas on a limited budget. This is a good option for low priority sites or those where conditions have changed; however. each new site should be monitored a minimum of three years before shifting to another site to assure that sufficient data are collected which represent a range of conditions at the site.

The WRD recommends that Curecanti NRA continue to improve field and laboratory procedures. The park should also reserve a section for sampling protocols in a water quality monitoring plan. This information is crucial to future park staff who may be involved in water quality monitoring at the park. Details of special importance include: why certain sites were selected for sampling; where the sites are located; what information was collected; why some sites were discontinued; what instruments were used to collect the information; and how the instruments were calibrated and employed. Standard, nationally recognized procedures could be referenced in the plan. The WRD will soon have available a series of Service-wide inventory and monitoring protocols field manuals for distribution to parks. Also, it may be advantageous to incorporate specific U.S. Geological Survey NAWQA protocols into the threats-based monitoring program.

Data Management Protocols

It is important to standardize the site identification codes and consistently use them from year to year so that all the data are attributed to the correct site. Computer file data should be checked at least once, preferably by someone other than the data entry person. This is an important step in insuring the accuracy of the data set before analyses are performed. When entering data into numeric fields, a substitute number such as -9 or -99 should be input for missing data to prevent blank records from being converted to zeros by DBASE III+. Also, it is helpful to sort or index the files by site identification code and date.

The WRD recommends that Curecanti NRA use the corrected files attached to this report in-place of older files of the same data. New files can be appended to the master file, but must have the same database structure as the master file (Appendix B) and have -9s substituted for missing values before they are appended. Currently, WRD is developing a park-based Water Quality Data Management System software program for use on personal computers designed to assist parks in managing their water quality data in standardized formats. This user-friendly program should be available in 1996.

CONCLUSIONS

Although few definitive conclusions can be drawn from these data, there appears to be more spatial than temporal variation in ambient water quality in the reservoirs and tributaries of Curecanti NRA during the period from 1987 to 1993. Many of these differences may be explained by natural (e.g., geology, topography, landform, vegetation, climate) and anthropogenic factors. Few alarming water quality impacts were detected, probably due in part to dilution effects and the naturally high water quality in the reservoirs and tributaries. However, elevated levels of nutrients, bacteria, and dissolved solids were detected in water samples from certain locations that are in close proximity to adjacent land uses that concern park management. Nutrient inputs from upstream wastewater discharges into the Gunnison River are a potential concern. Sediment transport into Crystal Reservoir from Cimarron and Squaw Creek drainages is a persistent problem. Development along the shore of Blue Mesa Reservoir poses concerns related to a variety of contaminants. Unfortunately, these data do not provide sufficient information to identify sources or quantify inputs of contaminants to the reservoirs. In addition, no monitoring data from Morrow Point and Crystal Reservoirs were included in the data sets that were analyzed. However, these data provide good baseline water quality information for selected sites over time, and the threats-based monitoring program has helped to identify where additional monitoring may be necessary in the future. The park should pursue and maintain partnerships with other agency programs (such as with NAWQA, State of Colorado, and the Bureau of Reclamation) to address complex water quality issues to complement park-based efforts. Examples of areas where agency collaborations could result in benefits to the park include: evaluating potential impacts from development in the upper Gunnison River watershed; evaluating metals and petroleum hydrocarbons at reservoir marinas; and predicting water quality responses to changes in dam operations.

The threats-based water quality monitoring program at Curecanti NRA has been successful because of the commitment of park staff and the program's inherent advantages over many traditional approaches to monitoring. The threats-based program is a cyclical monitoring program designed to: (1) provide adequate baseline information to characterize spatial and temporal water quality conditions; (2) adapt to changing water quality conditions and land-use activities; and, (3) cost less than other monitoring programs because sampling sites can be rotated and specific parameters targeted. In the future, the threats-based water quality monitoring program can easily be expanded or modified to answer specific questions, address new issues, and/or satisfy long-term monitoring goals.

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APPENDICES

Appendix A

Computer Files Transmitted with Data Analysis Report

The **two** computer disks accompanying this report include **four** compressed (ZIP) files containing digital copies of all the tables, figures, and other materials used to produce this report. To decompress these files, you must use the commonly available shareware program PKUNZIP. The command to type at the DOS prompt is:

```
PKUNZIP -E COMPRESS.ZIP FILENAME.EXT
```

where COMPRESS.ZIP is the name of one of the **four** compressed (ZIP) files listed below and FILENAME.EXT is the name of the file you wish to extract. If you want to decompress all of the files in COMPRESS.ZIP, simply omit the FILENAME.EXT. To simply obtain a listing of all the files compressed into a particular ZIP file, type the following:

```
PKUNZIP -V COMPRESS.ZIP |MORE
```

where COMPRESS.ZIP is the name of one of the **four** compressed (ZIP) files. Once you see the file you wish to obtain, substitute this file name for FILENAME.EXT in the first command line to extract and decompress this particular file.

The following compressed (ZIP) files are included on the disks accompanying this report:

(1) <u>CUREDATA.ZIP</u>

This compressed file contains two DBASE III+ files containing all raw data received from Curecanti NRA. Detailed database structures for each of the DBASE III+ files are found in Appendix B. In these files, missing data are represented by -99, -9.9, -9.99, or -9.999. The files compressed into this file include:

(a) ARCHIVE.DBF	-	All raw data for each site for the period from May 1987 to October 1993.
(b) ANALYSIS.DBF	-	This file is a subset of the data contained in ARCHIVE.DBF, and was used to do the statistical analysis in SAS. Field names have been shortened to 8 characters, values below detection have been replaced with ½ the detection limit, and fecal coliform values of 9999 (too numerous to count) have been changed to 3500.

(2) <u>CUREFIG.ZIP</u>

This compressed file contains figures of the park and water quality monitoring sites (Figures 1-2). These files are in Windows Clipboard (CLP) format which can be imported and/or edited in most Windows-based word processors and graphics packages.

(3) CUREBOX.ZIP

This compressed file contains all the box-and-whiskers plots which appear in the report. These files are in Windows Clipboard (CLP) format which can be imported and/or edited in most Windows-based word processors and graphics packages. The names of the files included in this compressed file combine the parameter and site identification codes for the two sites whose plots appear in the file. For example, DOBM3&4.CLP is the file containing the DO box-and-whiskers plots for sites BM03 and BM04.

(4) CUREREPT.ZIP

This compressed file contains all narrative portions of this report in WordPerfect Version 5.1 text files. These files include:

(a) CUREREP.WP - Report text.

(b) APPENDIX.WP - Appendices contained in this report.

(c) STATTABL.WP - Summary statistics table.

Appendix B

Water Quality Database File Structures

The following table provides the DBASE III+ database field structure for all the water quality data contained in ARCHIVE.DBF. These data will allow parks or other interested parties to replicate the statistical analyses and graphics contained in this report; perform more sophisticated analyses; or to establish a baseline park water quality database. Values equalling -99, -9.9, -9.99, or -9.999 in the database represent missing data.

ARCHIVE.DBF

Field Name	Field Type	Width/ # Decimal places	Parameter STORET No.	Field Description
SITE_ID	Character	4		Identification code for sample location
DATE	Date	8		Date sample taken [mm/dd/yy]
TIME	Character	4		Time sample taken [hhmm]
SITE_NAME	Character	25		Name of sample location
AIR_TEMP	Numeric	5/1	00020	Temperature, air: °C
SECCHI	Numeric	5/2	00078	Transparency, Secchi Disc: meters
H2O_TEMP	Numeric	4/1	00010	Temperature, water: °C
PH	Numeric	5/2	00400	pH, field: standard units
D_OXYGEN	Numeric	5/2	00300	Oxygen, dissolved: mg/L
CDUCT_METR	Numeric	6	00094	Specific conductance, field: µmhos/cm
DSLV_SOLID	Numeric	7/2	70300	Residue, total filtrable: mg/L (Total Dissolved Solids)
CHLORIDE	Numeric	5/2	00940	Chloride, total: mg/L
TKN	Numeric	6/3	00625	Nitrogen, Kjeldahl, total: mg/L
NH3	Numeric	6/3	00610	Nitrogen ammonia, total (as N): mg/L

ARCHIVE.DBF				
Field Name	**Field Type**	**Width/ # Decimal places**	**Parameter STORET No.**	**Field Description**
NO3	Numeric	6/3	00620	Nitrate (as N), total: mg/L
TOTAL_P	Numeric	6/3	00665	Phosphorus (as P), total: mg/L
SRP	Numeric	6/3	00660	Phosphate, ortho (as PO_4): mg/L
CHLOROPHYL	Numeric	5/2	32210	Chlorophyll a: mg/m^3
FECAL_COL	Numeric	4	31613	Fecal coliform, MF, M-FC AGAR, 0.45mm filter: cfu/100mL
FECALSTREP	Numeric	3	31673	Fecal Streptococci, MF, AGAR at 35°C: cfu/100mL
COL_RATIO	Numeric	7/3	00111	Ratio of fecal coliform to fecal streptococci

One-character columns follow each water quality parameter. These columns are for STORET remark codes if needed (Appendix C). Each of these columns is labeled with a one-character field name ranging from A to N.

The following table provides the DBASE III+ database field structure for ANALYSIS.DBF, the data file used for SAS analysis. These data will allow parks or other interested parties to replicate the statistical analyses and graphics contained in this report; perform more sophisticated analyses; or to establish a baseline park water quality database. Values equalling -99, -9.9, -9.99, or -9.999 in the database represent missing data.

ANALYSIS.DBF				
Field Name	**Field Type**	**Width/ # Decimal places**	**Parameter STORET No.**	**Field Description**
SITE_ID	Character	4		Identification code for sample location
DATE	Date	8		Date sample taken [mm/dd/yy]
TIME	Character	4		Time sample taken [hhmm]
SITE_NAME	Character	25		Name of sample location
AIR_TEMP	Numeric	5/1	00020	Temperature, air: °C
SECCHI	Numeric	5/2	00078	Transparency, Secchi Disc: meters
H2O_TEMP	Numeric	4/1	00010	Temperature, water: °C
PH	Numeric	5/2	00400	pH, field: standard units
D_OXYGEN	Numeric	5/2	00300	Oxygen, dissolved: mg/L
EC	Numeric	6	00094	Specific conductance, field: µmhos/cm
TDS	Numeric	7/2	70300	Residue, total filtrable: mg/L (Total Dissolved Solids)
CHLORIDE	Numeric	5/2	00940	Chloride, total: mg/L
TKN	Numeric	6/3	00625	Nitrogen, Kjeldahl, total: mg/L
NH3	Numeric	6/3	00610	Nitrogen ammonia, total (as N): mg/L

ANALYSIS.DBF				
Field Name	**Field Type**	**Width/ # Decimal places**	**Parameter STORET No.**	**Field Description**
NO3	Numeric	6/3	00620	Nitrate (as N), total: mg/L
TOTAL_P	Numeric	6/3	00665	Phosphorus (as P), total: mg/L
SRP	Numeric	6/3	00660	Phosphate, ortho (as PO_4): mg/L
CHLRPHYL	Numeric	5/2	32210	Chlorophyll a: mg/m^3
F_COL	Numeric	4	31613	Fecal coliform, MF, M-FC AGAR, 0.45mm filter: cfu/100mL
F_STREP	Numeric	3	31673	Fecal Streptococci, MF, AGAR at 35°C: cfu/100mL
COLRATIO	Numeric	7/3	00111	Ratio of fecal coliform to fecal streptococci

One-character columns follow each water quality parameter. These columns are for STORET remark codes, if needed (Appendix C). Each of these columns is labeled with a one-character field name ranging from A to N.

Appendix C

STORET Remark Codes