SALTON SEA ECOSYSTEM RESTORATION PLAN

Upper Basin Selenium Source Control Report

June 2005

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1.0 INTRODUCTION

Selenium is a naturally occurring semimetallic trace element. It is commonly found in rocks and soils derived from certain types of marine sedimentary rocks in the western United States and is also found in combination with other minerals such as sulfides, silver, copper, lead, and nickel. Selenium can bioaccumulate in aquatic and terrestrial food chains. When present at elevated levels in the diets of animals, selenium can replace sulfur in some important metabolic pathways and cause short- or long-term toxic responses. Early life stages of aquatic and terrestrial animals are especially susceptible to selenium in water or dietary sources. Long-term selenium contamination causes reproductive problems such as embryo mortality and birth defects.

Selenium is important in the Salton Sea ecosystem because it occurs in dissolved and particulate forms in the irrigation water brought in from the Lower Colorado River, and it occurs at elevated levels in Salton Sea sediments. Use of Colorado River water for agricultural and other purposes increases selenium concentration to levels that can be toxic.

This report provides an overview of selenium loading to the mainstem of the Colorado River and control options for reducing this loading. Specifically, this report provides a summary of the extent of selenium loading from the Upper Basin of the Colorado River and identifies control measures that could be implemented in the Upper Basin to reduce selenium loading to the mainstem Colorado River. Five site-specific appraisal-level control measures for reducing selenium loading to the mainstem and cost estimates for implementing these control measures are also provided. A summary of information sources used in this report is provided in Appendix A.

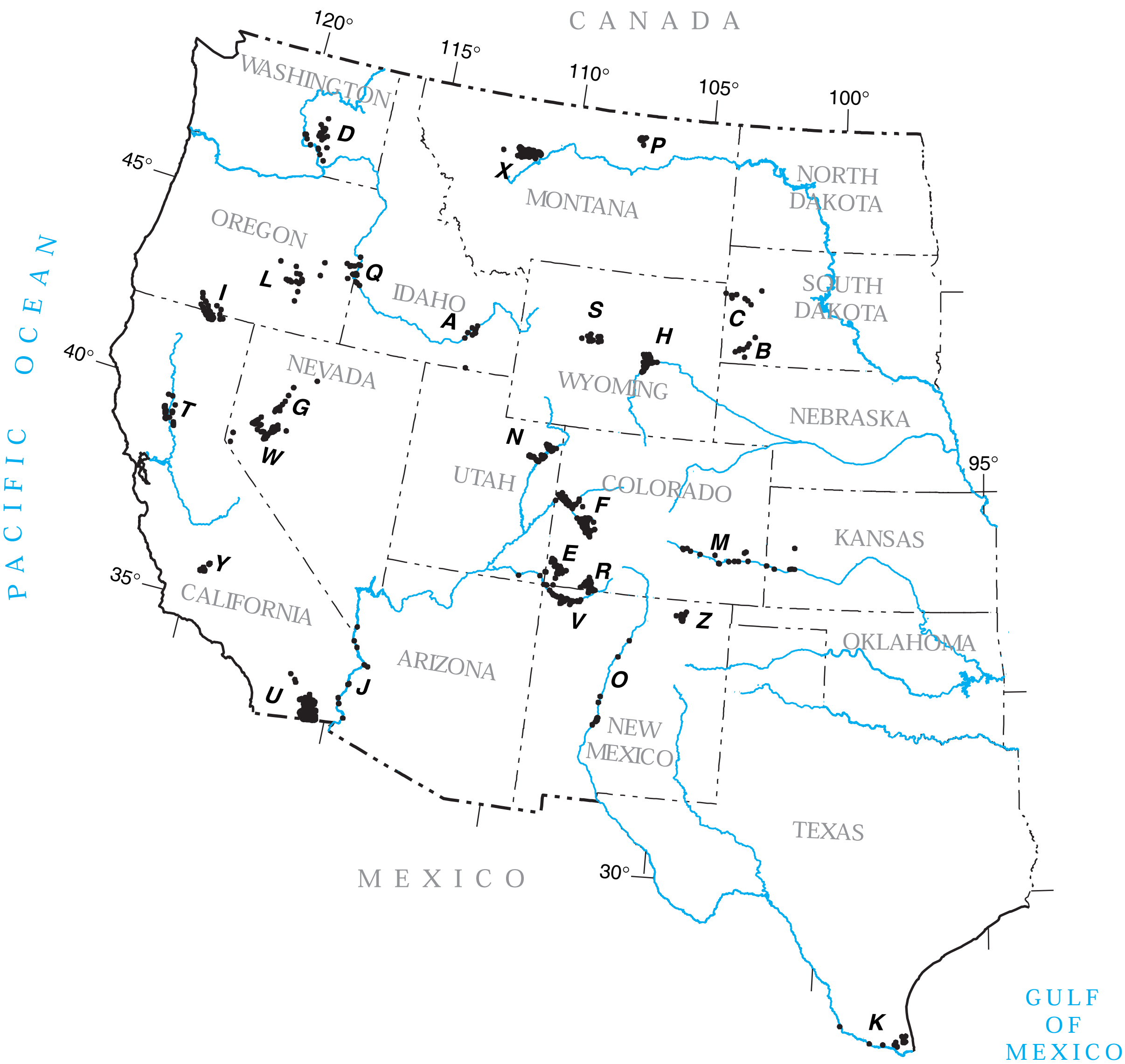
1.1 Background

Water and soils in irrigated areas of the Colorado River drainage can contain high concentrations of selenium because of (1) residual selenium from the soil's parent rock, (2) selenium derived from upstream and transported along local drainages, and (3) selenium brought into the area in surface water imported for irrigation. Application of irrigation water to selenium-rich soils can dissolve and mobilize selenium and create hydraulic gradients that result in the discharge of selenium-contaminated groundwater into irrigation drains and natural waterways. Given a source of selenium, the magnitude of selenium contamination in drainage-affected aquatic ecosystems is strongly related to the aridity of the area and the presence of terminal lakes, like the Salton Sea.

1.1.1 National Irrigation Water Quality Program

Because of selenium toxicity and selenium-induced birth defects found in birds at Kesterson Reservoir and National Wildlife Refuge, the National Irrigation Water Quality Program (NIWQP) was established by the Department of the Interior (DOI). The NIWQP was charged with investigating the extent and magnitude of irrigation-induced water quality problems at DOI irrigation and wildlife areas (U.S. Bureau of Reclamation [Reclamation], 2003a). A comprehensive survey of the approximately 600 Department of Interior irrigation and wildlife areas was conducted, and 26 sites were identified as having a high to medium potential for irrigation-induced contamination problems. The 26 sites are located throughout the western United States as shown in Figure 1-1 and as identified in Table 1-1.

Reconnaissance studies were conducted at these 26 sites. Results of these studies indicated that irrigation-induced drainage problems are prevalent in the western United States (Feltz et al., 1991). Selenium was the trace element commonly found at elevated concentrations in water, bottom sediment and biota, and the element having the greatest potential to cause toxicological effects in most of the study areas.



• *T* Data-collection site for National Irrigation Water Quality Program study area

Source: Seiler et al., 1999.

FIGURE 1-1
STUDY AREAS AND DATA-COLLECTION SITES INCLUDED IN NATIONAL IRRIGATION WATER QUALITY PROGRAM
SALTON SEA ECOSYSTEM RESTORATION PLAN

Table 1-1
Study Areas and Data-Collection Sites included in the National Irrigation Water Quality Program

Area Identifier*	Study Area	Area Identifier*	Study Area
A	American Falls Reservoir, ID	N	Middle Green River Basin, UT
B	Angostura Reclamation Unit, SD	O	Middle Rio Grande, NM
C	Belle Fourche Reclamation Project, SD	P	Milk River Basin, MT
D	Columbia River Basin, WA	Q	Owyhee–Vale Reclamation Project areas, OR-ID
E	Dolores–Ute Mountain area, CO	R	Pine River area, CA
F	Gunnison River Basin–Grand Valley Project, CO	S	Riverton Reclamation Project, WY
G	Humboldt River area, NV	T	Sacramento Refuge Complex, CA
H	Kendrick Reclamation Project, WY	U	Salton Sea area, CA
I	Klamath Basin Refuge Complex, CA-OR	V	San Juan River area, NM
J	Lower Colorado River valley, CA-AZ	W	Stillwater Wildlife Management Area, NV
K	Lower Rio Grande valley, TX	X	Sun River area, MT
L	Malheur National Wildlife Refuge, OR	Y	Tulare Lake Bed area, CA
M	Middle Arkansas River Basin, CO-KS	Z	Vermejo Project area, NM

Source: Seiler et al., 1999.
* Area identifier in Figure 1-1.

Seven of the 26 areas studied were located in the Colorado River watershed, and five were located in the Upper Basin of the Colorado River (see Figure 1-2). The five sites in the Upper Basin are the Middle Green River, Gunnison River and Grand Valley, Pine River, Dolores Project, and the San Juan River. The two sites in the Lower Basin are the Lower Colorado and Gila River Valley, and the Salton Sea.

Based on the investigations, eight sites were identified for detailed investigations, including the following four sites in the Colorado River watershed: Middle Green River, Gunnison River and Grand Valley, San Juan River, and the Salton Sea. At three of the four sites (Middle Green River, Gunnison River and Grand Valley, and Salton Sea), the NIWQP program determined that federal irrigation projects had adverse impacts to fish and wildlife resources, and that remediation efforts should be conducted.

1.1.2 Related Programs

Selenium is a naturally occurring element associated with marine-derived sediments. Therefore, policies and programs to reduce salinity loads also incidentally help to control selenium.

The Colorado River Basin Salinity Control Program was established pursuant to the 1974 Colorado River Basin Salinity Control Act, Public Law 93-320, as amended. The program provides for the construction and operation and maintenance (O&M) of projects in the Colorado River Basin to control salinity concentrations in Colorado River water. A wide range of salinity control actions have been implemented as part of this program, including the following: construction of a desalting plant at Yuma, Arizona; development of a protective well field along the U.S.-Mexico border; development of a salinity control program on Bureau of Land Management lands; implementation of voluntary on-farm salinity control program by U.S. Department of Agriculture; implementation of various other specific projects; and implementation of a program for funding basin-wide salinity control projects.

The Salinity Control Program comprises numerous “units” within which various salinity control projects are implemented. The overall goal of the program is to reduce annual salinity loading to the Colorado River by 1.8 million tons by 2020 (Colorado River Basin Salinity Control Forum, 2002). As of 2001, an annual reduction of 800,000 tons had been achieved.

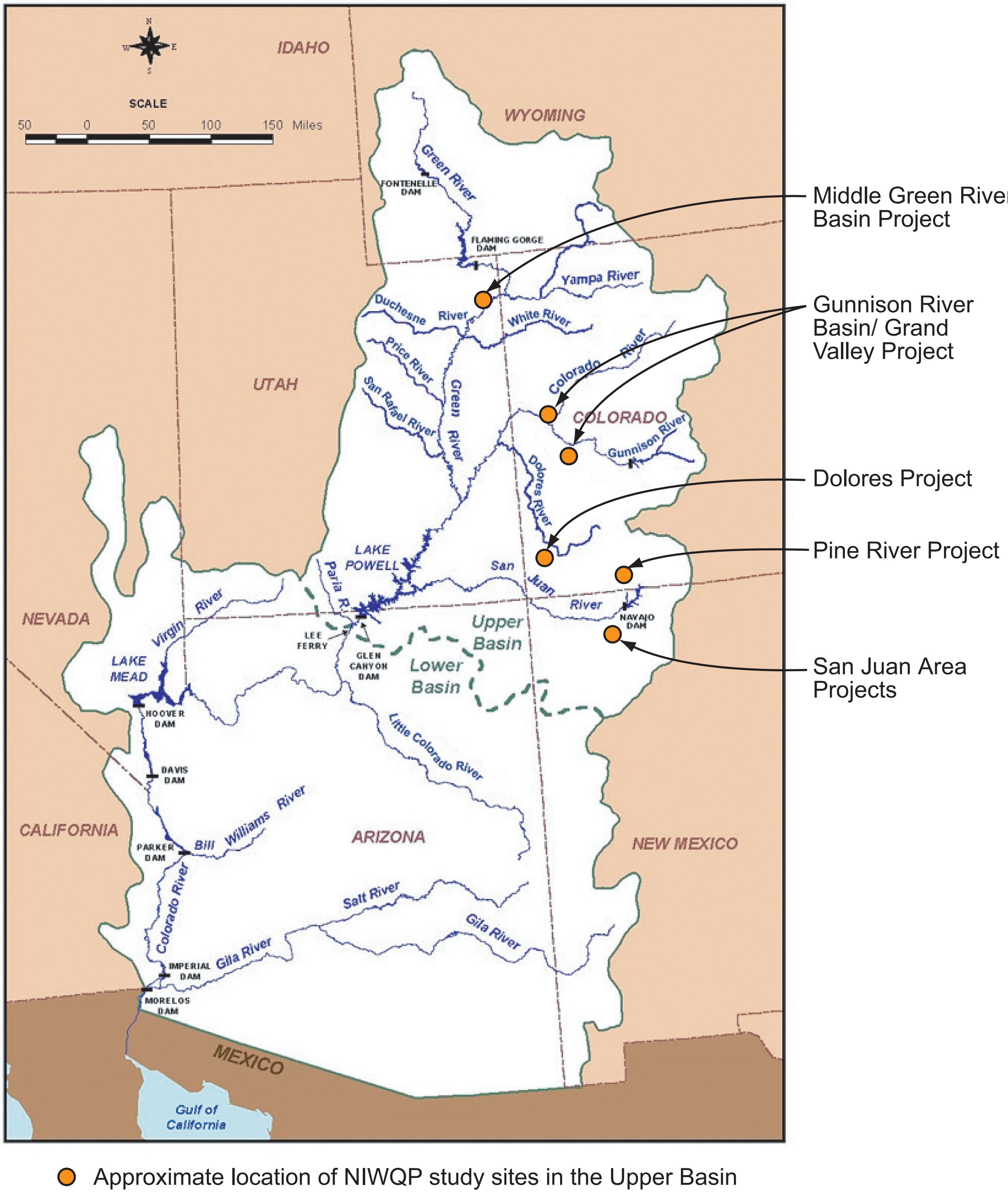


FIGURE 1-2
NATIONAL IRRIGATION WATER QUALITY PROGRAM STUDY SITES IN THE UPPER BASIN
SALTON SEA ECOSYSTEM RESTORATION PLAN

2.0 UPPER BASIN SOURCES

This section provides a summary of the extent of selenium loading from the Upper Basin of the Colorado River, and describes the regional and site-specific distribution, occurrence, and transport of selenium in the Upper Basin.

2.1 Overview

Geologic sources of selenium can be found throughout the Upper Basin in deposits of marine sedimentary rocks and in soils derived from these deposits. These geologic deposits are the principal sources of selenium in the Upper Basin. Infiltration of water through selenium-rich soils can oxidize selenium to a soluble, mobile form that can be transported in drainage and shallow groundwater, and then discharged to aquatic areas such as lakes, streams, and wetlands (Rowland et al., 2003). In arid and semi-arid climates, evaporation and evapotranspiration work to concentrate selenium in soils, shallow groundwater, impounded water, and in terminal water bodies. As shallow groundwater is removed in subsurface agricultural drainage, selenium and salt in that shallow groundwater generally come with it.

Most selenium is mobilized in water draining from soils or wastewater treatment processes containing elevated concentrations of selenium. Water for this mobilization comes from irrigation-related activities, natural rainfall infiltration and runoff, or from point sources (Engberg, 1999). Irrigation-related activities include both on-field activities, such as crop irrigation, and operational or conveyance losses from agricultural-related facilities, such as canals and laterals. Engberg estimated that irrigation-related activities account for 71 percent of the selenium that reaches Lake Powell, even though federal and private irrigation projects represent less than 10 percent of the land area in the Upper Basin. Natural rainfall-runoff processes are estimated to account for 21 percent of the selenium load to Lake Powell, and point sources are estimated to account for the remaining 8 percent of the load. Generally, point sources are not related to irrigation, but rather include wastewater treatment plants and sewage lagoons.

As previously described, the Upper Basin has five primary sources of selenium associated with federal irrigation and wildlife areas (see Figure 1-2). Selenium loading to Lake Powell from these source areas is provided in Table 2-1. Each area is described in detail in Section 2.2. As shown in Table 2-1, three areas, the Gunnison River, Grand Valley, and the Green River Basin, contribute more than 85 percent of the selenium loading to Lake Powell. Because these three areas represent the vast majority of selenium loading to Lake Powell, they are discussed in more detail in Section 2.2.

Table 2-1
Selenium Loading to Lake Powell from the Upper Basin*

Source	River Basin	Selenium Load (lb/day)	Percent
Gunnison River	Colorado	68.1	31.0
Grand Valley	Colorado	66.4	30.3
Green River Basin	Green	54.0	24.6
San Juan River	San Juan	17.2	7.8
Colorado River above Grand Valley	Colorado	7.7	3.5
Dolores River	Colorado	6.2	2.8
Total	**—**	**219.6**	**100**

Source: Engberg, 1999

* Table represents data taken over the period 1985-1994.

The information provided in Table 2-1 is based on an analysis conducted by Engberg (1999) using data collected from 1985 to 1994. However, various changes in the amount of loading to Lake Powell have occurred in the recent past, including decreases in loading from some areas due to source control actions and increases from other areas due to changes in land and water use practices (see Section 2.2 below). The analysis conducted by Engberg is the most recent, comprehensive analysis of Upper Basin selenium source areas and relative contribution to the load from those areas. Because of data limitations and uncertainties described by Engberg's (1999) report, and loading changes since Engberg's analysis was conducted, the load amounts and percentages in Table 2-1 should be viewed as relative magnitudes.

Based on recent studies, Lake Powell functions primarily as a flow-through system for selenium. Engberg's studies showed that 83 percent of the selenium entering the lake is delivered to the Lower Basin, and the remaining 17 percent is sequestered in the lake's sediments or taken up by the lake's biota. However, because of uncertainties in field data, these values should be viewed as relative magnitudes; their accuracy ranges by as much as plus or minus 20 percent (Engberg, 1999). Recent drought conditions on the Colorado River have resulted in lower water levels in Lake Powell and Lake Mead. The effects of these lower reservoir levels on transport of selenium through the system are not well understood at this time.

2.2 Source Areas

2.2.1 Gunnison River

Approximately 31 percent of the selenium loading to Lake Powell comes from the Gunnison River Basin in Colorado (Engberg, 1999). The main water bodies in the lower Gunnison River Basin include the Gunnison River and its two main tributaries, the Uncompahgre River to the southeast and the North Fork Gunnison River to the northeast (see Figure 2-1 and Appendix B). Selenium concentrations and loads in Gunnison and Uncompahgre rivers over the period of 1988 to 2000 are characterized in Butler and Leib (2002). Most of the selenium loading in the basin originates from irrigation of soils formed in or overlying Mancos shale in the Uncompahgre area.

According to Engberg (1999), the Uncompahgre Project in the Gunnison River Basin and the Grand Valley Project (as well as non-federal irrigation projects in the Grand Valley) are the source of more than 94 percent of the selenium found in Colorado River water at the Colorado-Utah state line. Irrigation-induced drainage[1] from the Uncompahgre Project and the Grand Valley might account for as much as 75 percent of the selenium load in the Colorado River near the Colorado-Utah state line (Butler et al., 1996).

North Fork Gunnison River

The annual selenium loads for the North Fork in 1999 and 2000 were 1,400 pounds and 1,300 pounds, respectively (Butler and Leib, 2002), which represents seven to eight percent of the annual selenium loading to the Gunnison River.

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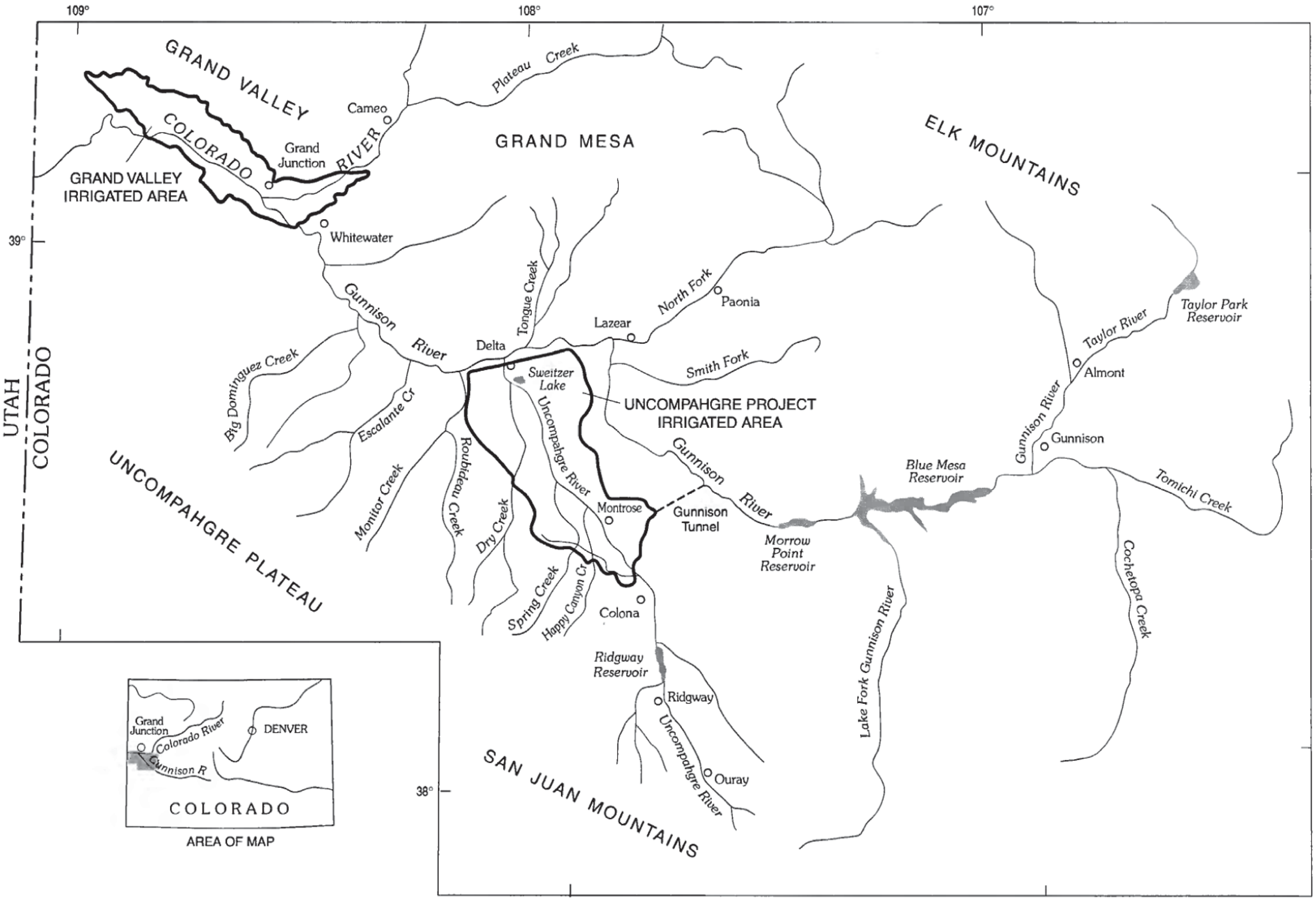
[1] Irrigation-induced drainage comprises surface and subsurface drainage from both on-field activities and operation or conveyance losses. Subsurface drainage includes tile drains and shallow groundwater recharge, which can result in subsequent discharge to a stream or other water body.



Source: Butler et al., 1994.

FIGURE 2-1
GUNNISON RIVER, UNCOMPAHGRE PROJECT AND GRAND VALLEY
SALTON SEA ECOSYSTEM RESTORATION PLAN

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Gunnison River from Smith Fork to Uncompahgre River (excluding North Fork)

Samples taken from tributaries to the Gunnison River between and including the Smith Fork to the Uncompahgre River (excluding the North Fork) generally exceeded 5 micrograms per liter (μg/L) with the exception of the Smith Fork and Tongue Creek (Butler and Leib, 2002). Two tributaries in particular, the Sunflower Drain and Bonafide Ditch, contained the largest measured selenium loads in this reach of the Gunnison River. These two tributaries primarily contain irrigation-induced drainage from areas in the Uncompahgre Valley.

Gunnison River from Uncompahgre River to Whitewater

Nearly all selenium samples taken from the Gunnison River from its confluence with the Uncompahgre River downstream to Whitewater during the 1988 to 2000 water years exceeded the 5 μg/L standard (Butler and Leib, 2002). The highest concentration found in this reach, 150 μg/L, was taken at Alkali Creek (primary source of water to Alkali Creek is irrigation runoff) and a small reservoir located on Mancos shale (Butler and Leib, 2002). Kannah Creek and Whitewater Creek, which are on the north and east sides of the Gunnison River, and Cummings Gulch and lower Roubideau Creek on the south and west sides showed the largest selenium loads of the tributaries of the Gunnison River downstream from the Uncompahgre River.

Uncompahgre River

The Uncompahgre River contributes about 38 percent of the selenium load within the Gunnison River (Butler and Leib, 2002). The tributaries of the Uncompahgre River with the largest selenium loads are Cedar Creek and Loutzenhizer Arroyo. Selenium concentrations at sites in Cedar Creek range from 12 to 28 μg/L. Selenium concentrations in the Loutzenhizer Arroyo basin range from 155 to 347 μg/L in the main arroyo and 125 to 151 μg/L in the west tributary. Butler and Leib (2002) estimated that 12 percent of the selenium load in Loutzenhizer Arroyo is from upstream of the Selig Canal, 38 percent from the reach between the Selig Canal and the west tributary, and 9 percent from the lower reach downstream from the west tributary. The major land use in the basin is irrigated agriculture, and the largest source of selenium loading in the basin is expected to be from canal and lateral leakage, and from deep percolation from agricultural fields. Other sources of selenium loading include residential landscape and golf course irrigation, septic systems, ponds, and natural runoff.

Source Control and Treatment Actions

The following source control and treatment actions have occurred or are on-going in the Gunnison River Basin: the use of polyacrylamide (PAM) to reduce seepage from irrigation ditches; pond and canal lining; phytoremediation (see Section 3.1.3 for a description of phytoremediation); the use of hydrogel to increase water use efficiency; other infrastructure to change water use practices; public outreach; and, agricultural and non-agricultural best management practices (NIWQP, 2004 and Reclamation, 2003b). Many of these actions are research or demonstration projects including pond lining, phytoremediation, and the use of hydrogel. These actions are being undertaken by the NIWQP, the Gunnison Basin Selenium Task Force, and other state and federal partners. Because of the uniqueness of the Gunnison Basin Selenium Task Force and the important results from the Montrose Arroyo Demonstration Project, these are discussed in more detail below.

Gunnison Basin Selenium Task Force – The Gunnison Basin Selenium Task Force was formed in 1998. The Task Force is a "group of private, local, state, and federal interests committed to finding ways to reduce selenium . while maintaining the economic viability and lifestyle of the Lower Gunnison River Basin" (Gunnison Basin Selenium Task Force, 2005b). The Task Force worked jointly with the NIWQP to identify and characterize selenium sources, evaluate source control and treatment options, support demonstration projects, and conduct public outreach (NIWQP, 2004). As part of this collaborative selenium control effort, the following two targets for selenium load reduction in the Gunnison Basin were identified:

- Goal No. 1 – Meet water quality standards. Reduction of about 5,500 pounds per year needed in the Gunnison River at Whitewater, and about 5,800 to 5,900 pounds per year in the Uncompahgre River at Delta.
- Goal No. 2 – Meet the NIWQP objective of 3 parts per million in food organisms. Reduction of approximately 13,000 pounds per year needed in the Gunnison River at Whitewater (for comparison purposes, the total load from the Gunnison Basin is about 20,000 pounds per year).

Plans were under development to meet these two goals; however, as discussed in Section 4.6, NIWQP funding has been severely cut in recent years. To the extent possible, the Task Force has continued its efforts using funding from the U.S. Geological Survey, Reclamation, Section 319 grants, and other stakeholders (NIWQP, 2004). In addition, the Task Force has slightly expanded its focus to include agricultural and non-agricultural land uses.

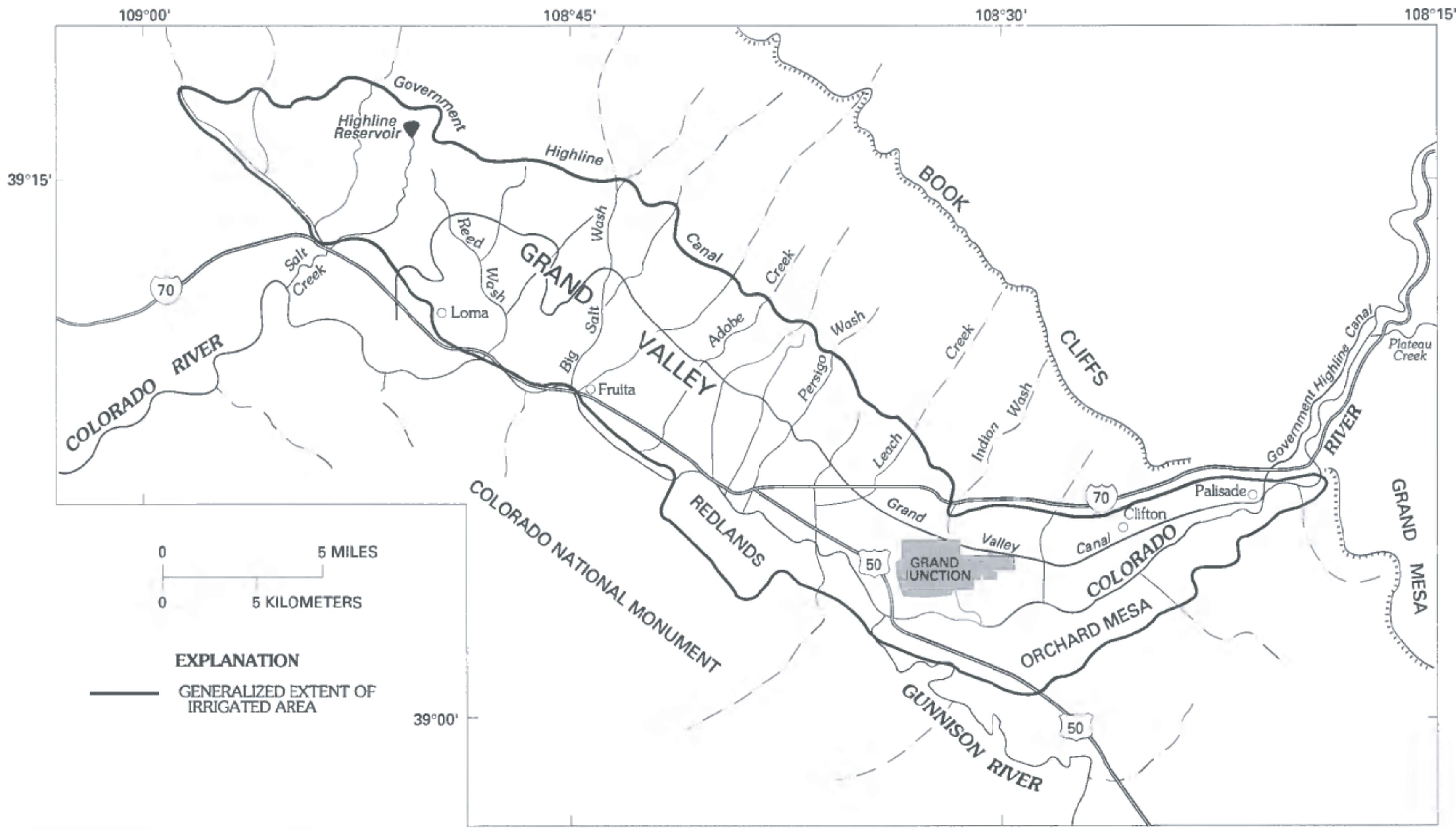
Montrose Arroyo Demonstration Project – In 1998, the NIWQP joined with the Colorado River Basin Salinity Control Program, the Uncompahgre Valley Water Users Association, and the U.S. Geological Survey to replace 8.5 miles of unlined irrigation ditches with 7.5 miles of buried polyvinyl chloride (PVC) pipe. This project reduced selenium loading from the Montrose Arroyo Basin by 27 percent and accounted for approximately 4 percent of the target reduction (5,500 pounds per year) for the Gunnison River Basin (NIWQP, 2004).

2.2.2 Grand Valley

Approximately 30 percent of the selenium loading to Lake Powell comes from the Grand Valley in Colorado (Engberg, 1999). The Grand Valley contains about 70,000 acres of irrigated land, about 38,000 of which are served with federal water (Butler et al., 1996). Of the 38,000 acres receiving federal water, about 30,000 acres are located on soils derived from Mancos shale or on alluvium overlying Mancos shale. The irrigated area is in part bisected by the Colorado River, and numerous small drainages and tributary streams that carry irrigation-induced drainage to the Colorado River (see Figure 2-1 and Figure 2-2).

Recent rural-residential development is becoming an important contributor of selenium loading in the Grand Valley. The population of Mesa County (which includes the Grand Valley area) is expected to more than double from 2000 to 2020 (Mesa County, 2005). With increased rural-residential development, there has been an increase in the construction of private ponds. Seepage from these ponds to the local groundwater can vary based on the local geology; however, in general these ponds have increased weathering of the Mancos shale and Mancos-shale derived soils, and increased the selenium contribution from groundwater sources in both the Uncompahgre and Grand Valley areas. Over time, these rural-residential ponds may become a significant contributor to the selenium loading in the Upper Basin. Reclamation recently completed a collaborative study with the Natural Resources Conservation Service to measure constructed pond seepage and better quantify the groundwater contribution from lined ponds (Reclamation, 2004).

The detailed study done on the area in 1992 and described in Butler et al. (1994) and Butler et al. (1996) shows that selenium loading in the Grand Valley is primarily the result of irrigation-induced drainage from federal and non-federal projects sited in or over Mancos shale. Selenium concentrations in surface water vary within the major tributary basins (Butler et al., 1996). Of 20 surface-water sites sampled in 1991 and 1992, Salt Creek, Reed Wash, Big Salt Wash, and Leach Creek, which drain agricultural areas on the western half of the valley, had the largest mean selenium loads among tributary streams (see Figure 2-2). In general, mean selenium loads from sample sites west of the Gunnison River and north of the Colorado River were higher than sample sites in other parts of the valley.



Source: Butler et al., 1996.

FIGURE 2-2
GRAND VALLEY
SALTON SEA ECOSYSTEM RESTORATION PLAN

Source Control and Treatment Actions

The NIWQP has been involved in treatment efforts in the Grand Valley (NIWQP, 2004). To date, treatment actions have occurred at two sites: the Orchard Mesa Wildlife Area and the Colorado River Wildlife Area, both of which are located along the Colorado River upstream of the Gunnison River confluence. At the Orchard Mesa Wildlife Area, treatment efforts included the excavation of a flushing channel and construction of a drain to divert irrigation-induced drainage into a pipeline that parallels the Colorado River. Treatment at the Colorado River Wildlife Area involved excavation of an inlet channel to provide year-round flushing flows. Plans are being developed for at least an additional four years of maintenance at these sites.

Similar to the Gunnison Basin Selenium Task Force, the Grand Valley Selenium Task Force is a stakeholder group formed in 2002 that is committed to addressing selenium-impaired water bodies in the Grand Valley through source control and treatment efforts. The main driver for these efforts is the State of Colorado’s chronic selenium water quality standard of 4.6 µg/L.

2.2.3 Green River Basin

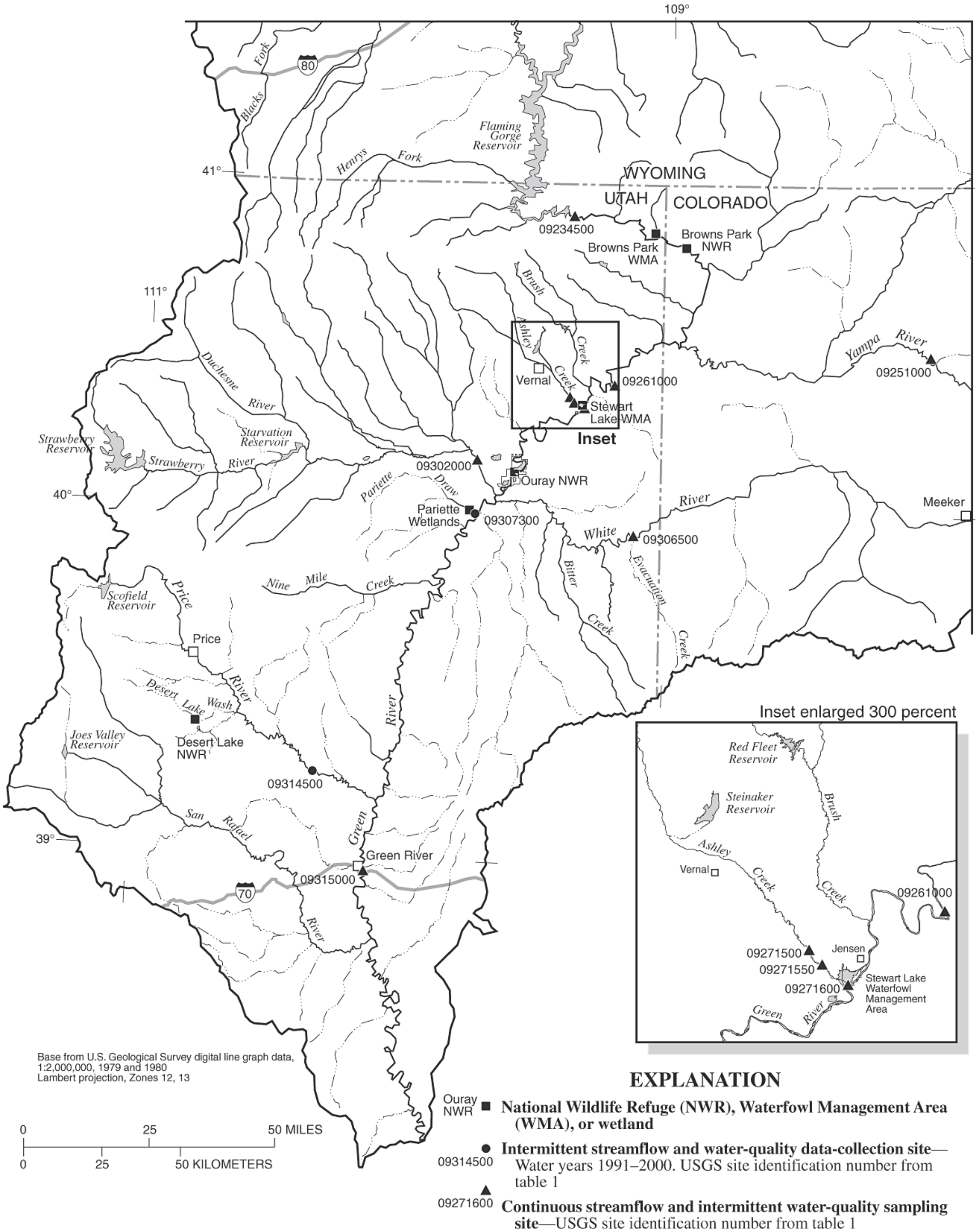
The Green River Basin contains an area of about 12,500 square miles between Flaming Gorge Reservoir and the confluence of the Price and Green rivers (see Figure 2-3). Irrigated areas in the Green River Basin consist of the Vernal and Jensen Irrigation Units of the Central Utah Project along with various private irrigation projects located adjacent to the mainstem and on some of the tributaries. Overall, the Green River contributes approximately 25 percent of the selenium loading to Lake Powell (Engberg, 1999). The three primary contributing areas are the Green River above Ashley Creek; Ashley Creek, a tributary to the Green River; and other tributaries to the Green River. Each area is discussed in more detail below.

Green River above Ashley Creek

The Green River above Ashley Creek accounts for approximately 11 percent of the selenium loading to Lake Powell (Engberg, 1999). The areas of primary concern in this reach are Stewart Lake along with specific reaches and tributaries to the Yampa River. Between 1981 and 1997, drainage from the 4,000-acre Jensen Unit of the Central Utah Project entered Stewart Lake and eventually the Green River (U.S. Geological Survey, 2003). Concentrations of selenium in the Stewart Lake Waterfowl Management Area were found to continually exceed 5 µg/L and were as high as 140 µg/L (Stephens et al., 1992). Stewart Lake retains 75 percent of the selenium load from irrigation runoff, presumably in the bottom sediment and biota (Rowland et al., 2003). Elevated concentrations of selenium have also been found in the Yampa River and its tributaries.

Ashley Creek

Engberg (1999) estimated that Ashley Creek accounts for about 9.8 percent of the selenium loading to Lake Powell. The two primary sources of selenium are drainage from the 14,000-acre Vernal Unit of the Central Utah Project, which enters lower Ashley Creek, and seepage from the City of Vernal, Utah, sewage lagoons. Greater than 85 percent of the selenium in Ashley Creek is thought to have come historically from seepage from sewage lagoons sited adjacent to Ashley Creek (Rowland et al., 2003). The lagoons overlie selenium-rich shale, and water from the lagoons moves vertically into the shale and mobilizes selenium to Ashley Creek and then to the Green River. However, as described under Source Control and Treatment Actions below, recent actions have eliminated these lagoons and reduced the selenium loading from this source area (U.S. Geological Survey, 2003). Therefore, the overall selenium loading from Ashley Creek is likely to be lower than was estimated by Engberg.



Source: Rowland et al., 2002.

FIGURE 2-3
MIDDLE GREEN RIVER
SALTON SEA ECOSYSTEM RESTORATION PLAN

Other Tributaries to the Green River

Other tributaries to the Green River account for about 3.8 percent of the selenium loading to Lake Powell (Engberg, 1999). These other tributaries include the Duchesne River, White River, and Price River, which have been estimated to contribute 4.8 percent, 8.1 percent, and 3.8 percent, respectively, of the selenium load in the Green River.

Source Control and Treatment Actions

Source control and treatment activities have occurred at the Stewart Lake Waterfowl Management Area and Ashley Creek. Remediation activities at the Stewart Lake Waterfowl Management Area began in 1997 under the direction of the NIWQP. On an annual basis, the lake is flooded with water from the Green River and then immediately drained. This flood and drain process flushes the selenium out to the Green River. The goal is to reduce the concentration of selenium in the upper layer of the bottom sediment to 4 micrograms per gram or less (Rowland et al., 2003). As part of the treatment activities, the subsurface drains that contribute high-selenium water to Stewart Lake were also extended to the Green River (U.S. Geological Survey, 2003). However, because the selenium is being transferred from one area (Stewart Lake) to another (the Green River), there is no reduction of selenium load to the Colorado River (i.e., no source control).

Source control activities at Ashley Creek have been ongoing since 1999, when construction of a wastewater treatment facility began adjacent to the Vernal sewage lagoons. The treatment facility became operational in 2001, and the sewage lagoons were decommissioned at that time. Wastewater from the facility is discharged directly to Ashley Creek without contact with the underlying selenium-rich shale; this will help reduce selenium loading to the Green River. Selenium loads in Ashley Creek are expected to decline as seepage from the abandoned sewage lagoons decreases (U.S. Geological Survey, 2003).

2.2.4 San Juan River

The San Juan River runs generally along the Utah-Arizona state line (see Figure 1-2). Upstream San Juan River tributaries transport irrigation return flow containing elevated concentrations of selenium; however, these selenium loads are small in comparison to the overall streamflow of the river. Approximately 8 percent of the selenium loading to Lake Powell comes from the San Juan River (Engberg, 1999).

2.2.5 Colorado River above Grand Valley

The Colorado River above the Grand Valley contributes approximately 3.5 percent of the selenium loading to Lake Powell (Engberg, 1999). The primary source of selenium in this reach of the river is thought to be natural rainfall-runoff processes.

2.2.6 Dolores River

The Dolores River carries part of the drainage from the Dolores Project in southwestern Colorado (see Figure 1-2). The Dolores Project area includes the Mancos River in Colorado and extends into southeastern Utah along the San Juan River to Lake Powell. The project diverts water from McPhee Reservoir, in the Dolores River Basin, for irrigation and municipal supplies in the San Juan River Basin. The Dolores Project and areas downstream from the project were selected for a reconnaissance investigation (Butler et al., 1995) because of possible effects on the water quality of the San Juan River by Mc Elmo Creek. The maximum selenium concentration in a water sample collected in the Dolores Project area (from the Navajo Wash) was 88 μg/L (Butler et al., 1995). These high selenium concentrations are attributed to irrigation-induced drainage from areas overlying selenium-rich shale. Elevated concentrations of selenium were also detected in bottom sediment and biota. Quarterly selenium samples taken at the Dolores River near Cisco, Utah revealed a mean selenium concentration of 1.5 μg/L (Engberg, 1999). This area accounts for approximately 3 percent of the total selenium loading to Lake Powell.

3.0 SOURCE CONTROL MEASURES

This section provides a summary of the available source control measures that could be implemented in the Upper Basin to reduce selenium loading to the mainstem Colorado River. Available source control measures include structural measures, nonstructural measures, and administrative measures.

In general, all of the source control measures described in this section reduce selenium loading by reducing the amount of water exposed to selenium-rich shale and selenium-rich soils, and therefore, reducing the amount of selenium mobilized and discharged to streams and other water bodies. This reduces the amount of selenium mobilized and transported downstream.

Selenium treatment measures were described in the *Final Technologies and Management Techniques to Limit Exposures to Selenium* Report (DWR, 2005). This report focuses on measures that would reduce or eliminate the mobilization of selenium at the source, thereby reducing the need for treatment once mobilization has occurred.

3.1 Structural Measures

Structural source control measures consist of new facilities or improvements to existing facilities. Various structural measures can be used to reduce seepage from canals, irrigation ditches, ponds, and other surface water bodies. These measures include canal lining (whether with concrete or a synthetic liner), lateral piping, pond lining or removal, other soil-binding or particle-flocculation technologies (such as the application of PAM), and other infrastructure that changes water use practices (such as installation of sprinkler systems or replacement of septic tanks with sewage-collection and treatment systems). A few of these measures are described here.

3.1.1 Water Storage and Conveyance Loss Reduction

A variety of structural measures could be implemented to reduce seepage losses from water storage and conveyance features. These measures include canal lining, pond lining, piping of irrigation laterals (lateral piping), application of soil-binding materials (such as PAM), and others. Because canal lining, lateral piping, pond lining, and PAM are being tested or implemented now, these control measures are discussed here. However, it is important to remember that other methods of reducing conveyance and storage seepage losses are possible.

Canal Lining

Lining of irrigation canals is a method to reduce seepage to shallow groundwater, and lining of canals that overlie selenium-rich shale has the potential to reduce selenium loading because of reduced weathering of the shale. In general, lining is likely to be more cost-effective for larger waterways such as main canals, whereas lateral piping is likely to be more cost-effective on smaller waterways. Canal lining has not been used extensively to reduce selenium loading because of the large capital investment. However, the Gunnison Basin Selenium Task Force and the Uncompahgre Valley Water Users Association have identified lining of the Uncompahgre Project East Side canals as a high priority project for selenium control efforts and funding assistance (Gunnison Basin Selenium Task Force, 2004).

Lateral Piping

A demonstration project in Montrose Arroyo in the lower Gunnison Basin provides information about the effectiveness of lateral piping as a selenium control option. The demonstration project replaced 8.5 miles of open-ditch irrigation laterals with 7.5 miles of PVC pipe. Five different sections of laterals were monitored from 1998 to 2000, along with one control site. Selenium loading was reduced in all five sampling sites, but no change occurred at the control site. At Montrose Arroyo the selenium load decreased by about 194 pounds per year, or 28 percent of the pre-project load (Butler, 2001). More than 90 percent of that decrease was in the groundwater load.

Somewhat unique site-specific factors contributed to the substantial selenium reduction observed in this study. The Montrose Arroyo project occurred on very shallow soils over Mancos shale. Similar results may not be achieved in soils with deeper alluvial deposits and deeper water tables (Miller and Radtke, n.d.).

The Uncompahgre Valley Water Users Association is piping 20.5 miles of irrigation laterals in the Uncompahgre Valley. This project is being funded by the Colorado River Basin Salinity Control Program and additional Congressional write-ins to the NIWQP.

Pond Lining

Similar to lateral piping and canal lining, pond lining is intended to reduce the amount of seepage to shallow groundwater. Various lining materials, such as clay or synthetic materials can be used. Constructed ponds in areas known to be underlain by selenium-rich shale and soils would be lined with bentonite clay to reduce seepage (Gunnison Basin Selenium Task Force, 2001).

Polyacrylamide

Polyacrylamide, also known as PAM, may be used to reduce selenium loading by forming a protective topsoil layer in unlined irrigation canals. PAM is a synthetic polymer that binds soil particles and reduces seepage from unlined canals without the capital investment involved with lining or piping.

The Loutzenhizer Arroyo Polyacrylamide Demonstration Project in the Uncompahgre Valley attempted to demonstrate the effectiveness of PAM in reducing canal seepage and selenium loading in the Loutzenhizer Arroyo area (Reclamation, 2003b). Results from the project were inconclusive, but indicate that the application process may play a large role in the effectiveness of PAM (Baker, 2005).

3.1.2 Other Infrastructure to Change Water Use Practices

Changing basic municipal and agricultural water use practices could also lead to a reduction in selenium loading from the Upper Basin. The following list identifies some of the mechanisms that can be used to change water use in an effort to reduce selenium loading:

- On-farm irrigation application improvements, such as installing gated pipe, drip, surge, or sprinkler systems for irrigation.
- On-farm irrigation drainage improvements, such as installing tile drains to capture seepage before it comes in contact with selenium-rich shale or selenium-rich soils.
- Reduction of septic tank leaching from existing and future homes by constructing sewage treatment plants and related facilities, constructing individual sewage disposal systems or installing low-pressure screw pumps to connect homes to nearby municipal sewer lines.
- Reduction of landscape and lawn irrigation by installing sprinklers or drip irrigation systems and water-efficient vegetation.

These measures reduce selenium loading by reducing the amount of water exposed to selenium-rich sediments and soils.

3.1.3 Phytoremediation

Phytoremediation uses plants to take up and metabolize selenium from water and soils. The Gunnison Basin Selenium Task Force and the Shavano Conservation District developed a phytoremediation project to determine the feasibility of using economically valuable crops to remediate selenium in the

Uncompahgre Valley fields (Shavano Conservation District, 2005). Phytoremediation test plots were set up in 2001 at a farm near Montrose, Colorado (Gunnison Basin Selenium Task Force, 2005b). The following four crop species and three hybrid tree species were tested:

- Crop species: kenaf (*Hibiscus cannabinus*), canola (*Brassica napus*), tall fawn fescue (*Festuca arundinacea*), and birdsfeet trefoil (*Lotus corniculatus*)
- Hybrid poplar tree clones: NM-6 (*Populus nigra* X *P. maximowiczii*), OP-367 (*P. deltoides* X *P. nigra*), and 52-225 (*P. trichocarpa* X *P. deltoides*) (Shavano Conservation District, 2005)

Based on a variety of factors including biomass, selenium uptake and growth characteristics, the best-performing crop species were tall fawn fescue and birdsfoot trefoil, and the best-performing poplar tree clone was OP-367 (Shavano Conservation District, 2005). Localized environmental factors may have contributed to lower growth and uptake of selenium in canola, kenaf and some of the tree species. Overall, phytoremediation is a relatively slow process that can be applied on a variety of scales.

For additional information on phytoremediation, see the *Final Technologies and Management Techniques to Limit Exposures to Selenium* report (DWR, 2005).

3.2 Nonstructural Measures

Nonstructural control measures can be implemented without additional infrastructure. Such measures include implementation of Best Management Practices (BMPs) for agricultural and non-agricultural water users, public outreach and education, land preservation and retirement, and effluent trading. Nonstructural measures can be voluntary or required as part of a larger regulatory control mechanism.

3.2.1 Best Management Practices

BMPs can be used to achieve reductions in selenium loading in a variety of ways. In general these practices entail optimized operation of existing or future facilities, perhaps including facilities modification. BMPs can be developed and implemented for agricultural and non-agricultural land uses, as described in more detail below.

Agricultural Best Management Practices

Developing guidelines for agricultural BMPs is important for achieving a basin-wide reduction in selenium loading. Various entities have developed BMPs for agricultural areas in the Upper Basin, such as the Uncompahgre Valley Best Management Practices Decision Committee (1997). Example BMPs developed by the Decision Committee (1997) that have the potential to reduce selenium loading include the following:

- Schedule irrigations according to soil-water depletion and projected crop evapotranspiration. Apply only enough irrigation water to meet the growing crop's needs.
- Monitor soil moisture by the feel-and-appearance method, and/or with the aid of tensiometers, resistance blocks, moisture probes, or other acceptable soil moisture monitoring methods to aid in scheduling irrigation timing and amount.
- Maximize irrigation efficiency and uniformity on surface-irrigated fields. Upgrade the irrigation system and/or equipment as feasible to improve delivery and application efficiency. For example: install surge system irrigation; install gated pipe; decrease set time; level fields; and use tail water recovery systems.
- Minimize deep percolation on sprinkler-irrigated fields by applying the amount of water required to replace water consumed by crop evapotranspiration.

Agricultural BMPs reduce selenium loading by reducing the amount of water exposed to selenium-rich shales and soils. However, currently there is no quantifiable relationship between selenium load reductions and implementation of agricultural BMPs.

Non-Agricultural Best Management Practices

Developing guidelines for non-agricultural BMPs is also important for achieving a basin-wide reduction in selenium loading. Non-agricultural BMPs can be developed for a variety of non-agricultural water uses, such as improved landscape and lawn irrigation efficiencies for large and small areas (golf courses, parks, cemeteries, and urban lawns) through optimizing applied water and monitoring soil moisture, urban water conservation actions (effective for septic users), and conversion of irrigated landscape to xeriscape. Various demonstration projects are underway to determine the effectiveness of BMPs for non-agricultural users (NIWQP, 2003).

3.2.2 Outreach and Education

Maximizing the success of a large-scale effort to reduce selenium sources would most likely require development of a public outreach program. This would facilitate the distribution and availability of needed information for municipal and agricultural interests. Suggested actions that could be achieved by an outreach program include the following: develop an outreach program directed toward target audiences; provide technical and cost information on available structural and nonstructural source control and treatment measures; provide information on cost-sharing sources (if applicable); provide technical assistance to ensure the efficiency of implemented structural and nonstructural source control and treatment measures; and provide monitoring assistance to determine the effectiveness of source control and treatment efforts (Gunnison Basin Selenium Task Force, 2001).

3.2.3 Land Preservation and Land Retirement

Based on analysis conducted as part of the Gunnison Basin Selenium Targeting Project, Mancos-derived soils that have never been irrigated and leached have an average of 34 times more selenium than irrigated and leached soils (Colorado Department of Public Health and Environment, 2003). Preservation of existing land uses on undeveloped land with selenium-rich geologic material has the potential to reduce future selenium loading. Land preservation can include permanent removal of undeveloped lands from future land use changes and easements to regulate future land use changes. The purchase and permanent removal of undeveloped land from future development (agricultural or municipal) would eliminate additional selenium loading from future land use changes. Easements could include limitations on future land uses to uses that minimize or do not contribute to additional selenium loading. Potential uses of undeveloped lands, such as livestock grazing and off-highway vehicle use, should be considered when preserving and managing undeveloped areas because these uses may increase selenium loading.

Land retirement would result in the permanent removal of agricultural production from that land. This would reduce existing selenium loading from the active cultivation of the land, and potentially reduce canal and lateral seepage from associated irrigation facilities. As part of the Colorado River Basin Salinity Control Program, retirement of agricultural land is usually considered as one option for reducing salinity loading to the Colorado River. However, this option is usually not found to be competitive in terms of overall cost effectiveness with water conservation programs (U.S. Department of the Interior, 2003). In addition, retirement of a substantial amount of land currently in agricultural production may make more water available for downstream water users or junior water-right holders and may have adverse impacts to wildlife habitat and in-stream flows. Depending on a variety of factors, this could result in increased selenium loading from application of excess water to lands, or could result in the irrigation of lands that were previously not irrigated.

3.2.4 Trading

The U.S. Environmental Protection Agency (EPA) has funded several pilot projects to test the success of a Water Quality Trading Policy. The Trading Policy which allow pollution reduction required by a Total Maximum Daily Load (TMDL) plan (see Section 3.3 below) to occur in a flexible, tradable permit framework. This economic-incentives-inspired policy would allow the lowest-cost pollution reduction to occur anywhere in the watershed. Effluent trading allows one source to meet its regulatory obligations by using pollutant reductions created by another source that has lower pollution-control costs. For example, construction and operation of a small-scale treatment system for a commercial operation that discharges water directly into a waterway may be more cost-effective than upgrading an entire wastewater treatment plant. Under a trading program, the wastewater treatment plant operator could pay to construct and operate the small-scale treatment system, and use the "credits" to meet their water quality permit requirements for discharges from the wastewater treatment plant.

Trading becomes complicated when there are few alternative regulated sources in a watershed. Trading among point-source and non-point-source dischargers can be difficult to quantify (on the non-point side). It can therefore be challenging to verify success through monitoring. In addition, non-point source dischargers are generally reluctant to participate because of the potential regulatory implications.

The EPA funded a pilot project to develop a trading framework to reduce selenium loading in tributaries to the Colorado River (EPA, 2003). The trading framework is still in the conceptual development phase. However, the project has encountered obstacles related to determining what to trade, how to generate the water quality credits, who would generate and purchase the non-point selenium credits, and how to gain support from federal agencies and agriculture (Breetz et al., 2004).

3.3 Administrative Measures

Administrative measures consist of regulatory measures that can serve as drivers and enforcement mechanisms for structural and nonstructural control measures.

Under Section 303(d) of the Clean Water Act, states, territories, and authorized Indian tribes are to submit lists to the EPA detailing water bodies for which existing pollution controls are insufficient to attain or maintain water quality standards. After submitting the list of "impaired waters," states must develop a plan, called the TMDL plan, to limit excess pollution. Within the TMDL process, states assess water quality problems and contributors to these problems, and establish actions needed to achieve water quality objectives. The focus is on setting TMDLs for specific pollutants throughout the watercourse. TMDL plan implementation can be accomplished through revised National Pollution Discharge Elimination System permit requirements (for point-source contaminants) and through implementation of BMPs that include changes in agricultural practices (EPA, 1999).

Several water bodies within the Colorado River and Salton Sea watersheds are listed as impaired under Section 303(d) of the Clean Water Act, as identified in Table 3-1. The TMDL processes are not uniform among states, so differences in implementation approach may occur. For example, there is no requirement in Colorado to implement changes in non-point source discharges, such as irrigation discharges, that may be identified in a TMDL plan. The current source control and treatment efforts by the Grand Valley and Gunnison Basin Selenium Task Forces are voluntary. Additionally, implementation of a TMDL plan in one area will not necessarily improve downstream water quality. For example, the TMDLs in the Upper Basin are intended to reduce water-borne selenium concentrations in selected water bodies to meet the 4.6 μg/L water quality standard. However, selenium concentrations can be reduced through dilution and flushing flows, which does not reduce overall loading or result in improved water quality in the Lower Basin.

Table 3-1
Selenium Impaired Water Bodies in the Colorado River Watershed

Water Body	Watershed
Upper Basin	
Gunnison River – Uncompahgre River to Colorado River	Gunnison River
Gunnison River Tributaries – Crystal Reservoir to Colorado River and Kannah Creek below the USGS gage	Gunnison River
Gunnison River Tributaries – Leroux Creek and Other North Fork Tributaries*	Gunnison River
Lower Uncompahgre River – U.S. Highway 550 to Gunnison River	Gunnison River
Uncompahgre River Tributaries – South Canal to Gunnison River	Gunnison River
Sweitzer Lake	Gunnison River
Lower Ashley Creek	Green River
Lower Ashley Creek – Winter Storage Pond Draw	Green River
Colorado River – Gunnison River to State Line	Colorado River
Colorado River Tributaries – Roaring Fork to Parachute Creek except for specific segments	Colorado River
Colorado River Tributaries – Government Highline Canal Diversion to Salt Creek (Tributaries on north side of river)	Colorado River
Walker Wildlife Area Ponds	Colorado River
Roan Creek and Tributaries, Clear Creek to Colorado River	Colorado River
Lower Basin	
Alamo River	Salton Sea
Imperial Valley Drains	Salton Sea
Salton Sea	Salton Sea

Sources: California Regional Water Quality Control Board Colorado River Basin Region, 2004; Gunnison Basin Selenium Task Force, 2005a; U.S. Environmental Protection Agency, 2004; and Colorado Water Quality Control Commission, 2003.

* Various tributaries or portions of tributaries to the Uncompahgre River are also listed, including tributaries from South Canal to the Gunnison River.

4.0 POTENTIAL UPPER COLORADO RIVER BASIN CONTROL MEASURES

This section identifies five site-specific appraisal-level control measures for reducing selenium loading to the mainstem and provides cost estimates for implementing these measures. A brief description of some of the agencies implementing source control efforts is also provided.

Selenium-rich shale, including Mancos shale, underlies large areas in the Upper Basin, and therefore, a selenium source control effort should be viewed in the context of the entire Upper Basin watershed. Control measures in one area can easily be offset by increased loading elsewhere. Such increased loading could occur as a result of changes in land use or water management practices. A successful long-term selenium source control program is likely to consist of a variety of control measures implemented throughout the Upper Basin watershed. However, some source areas, such as the Gunnison River Basin and the Grand Valley area, contribute a substantial portion of the overall selenium load to the Upper Colorado River Basin, and source control efforts could be focused in these areas. Although not included as one of the five site-specific source control measures below, a successful source control program would likely include an extensive public outreach program.

Although the NIWQP and its partners have conducted numerous studies in the past two decades on selenium and selenium sources, site-specific and regional unknowns still exist regarding sources and source control measures. Additional studies to characterize selenium sources, including the contribution of different land use types to selenium loading and the effectiveness of control measures, are needed.

4.1 Source Control Measures

Table 4-1 provides a summary of five site-specific appraisal-level source control measures, along with the applicability, effectiveness, cost, and other considerations for each measure. The costs provided in Table 4-1 are from the Gunnison Basin Selenium Task Force's *Revised Draft Evaluation and Screening of Suggested Remediation Measures Lower Gunnison Basin / Uncompahgre Project Area* (2001). These costs should be viewed as rough estimates and are for illustrative purposes only. In addition, these costs are not intended to be used to consider the feasibility of selenium source control efforts in the Upper Basin as compared to selenium treatment in the Salton Sea watershed. Reclamation is currently preparing a report that is anticipated to include more refined cost estimates for selenium treatment and source control measures in the Upper Basin (personal communication, Mike Baker, 2005).

4.1.1 Water Storage and Conveyance Loss Reduction

Source control measures that could be implemented to reduce water storage and conveyance losses include canal lining, lateral piping, and pond lining. Overall, these measures are designed to reduce seepage to the shallow groundwater and reduce weathering of the selenium-rich shale and shale-derived soils. See Section 3.1.1 for additional information on these measures.

Effectiveness

Source control measures that reduce water storage and conveyance losses are effective ways of reducing existing selenium loading. However, the effectiveness of each measure will vary based on a variety of site-specific characteristics, including wetted area, soil type, hydrogeologic conditions, design and construction, and amount of time that the facility is used to store or convey water. As described in Section 3.1.1, the effectiveness of PAM as a seepage reduction tool is also under evaluation.

There are an estimated 183 miles of unlined laterals, 59 miles of unlined main canals, and over 190 acres of unlined ponds on the east side of the Uncompahgre Project area alone (Mancos shale deposits and Mancos-shale derived soils are predominantly located on the east side of the valley). Relative to the other source control measures identified, reducing seepage losses from these existing facilities is likely to result in the greatest reduction in selenium loading.

Table 4-1
Summary of Site-specific Appraisal-level Control Measures

Measure	Applicability	Effectiveness	Cost per Gunnison Basin Selenium Task Force, 2001*	Other Issues
Water Storage and Conveyance Loss Reduction Measures				
Canal Lining	Applicable to larger conveyance structures in all source areas.	Reduces existing loading. Long-term improvement.	Costs can vary, but lining of approximately 50 miles of canals on the east side of the Uncompahgre River was estimated at $70M, or about $1.4M/mile. Costs include standard contingencies and environmental mitigation. Canal O&M cost borne by operating agency. Cost per pound of selenium load reduction is about $1,630.	Habitat mitigation may be needed depending on site-specific features. Generally accepted and desirable improvement practice.
Lateral Piping	Applicable to smaller conveyance structures in all source areas.	Reduces existing loading. Long-term improvement.	Costs can vary, but piping of approximately 150 miles of laterals on the east side of the Uncompahgre River was estimated at $81M, or about $540,000/mile. Costs include standard contingencies and environmental mitigation. Any O&M cost borne by the operating agency or individual landowner. Cost per pound of selenium load reduction is about $930.	Habitat mitigation may be needed depending on site-specific features. Generally accepted and desirable improvement practice.
Pond Lining	Various dispersed small private and public ponds.	Reduces existing loading. Long-term improvement.	Costs estimated at about $9,500/acre including contingencies and administrative costs. Assumes lining with bentonite. Minimal to no O&M costs. Cost per pound of selenium load reduction is about $150.	Reduces existing loading; however does not address future loading from increased rural-residential development. This could be addressed at the land-use planning and permitting level.
PAM	Could be used on irrigation canals, laterals and drainage canals. Requires annual application.	Reduces existing loading. Laboratory tests show a 50-80 percent reduction in seepage.	Costs can vary, but in general, about 4 pounds of PAM are needed per acre; unit cost of PAM is $5 per pound. Labor and sprayer would be additional. Cost per pound of selenium load reduction is about $140.	Use of PAM for this type of application is unproven. Effectiveness may vary based on the application technique and exposure to sunlight. Environmental effects of PAM not well understood. Habitat mitigation may be needed depending on site-specific features.

Table 4-1
Summary of Site-specific Appraisal-level Control Measures

Measure	Applicability	Effectiveness	Cost per Gunnison Basin Selenium Task Force, 2001*	Other Issues
Other Infrastructure to Change Water Use Practices				
On-farm irrigation application improvements (gated pipe, drip, surge, or sprinkler systems)	Applicable to all irrigated areas, but some improvements (i.e., drip irrigation) may require higher value crop types to be economically viable for farmers.	Reduces existing loading.	Drip Irrigation: Installation ~ $1,700 to $2,000/acre plus engineering and overhead costs; O&M conducted by landowner. Cost per pound of selenium load reduction is about $700. In general, gated pipe, surge irrigation, and sprinkler systems would cost less than drip irrigation, and cost per pound of selenium load reduction is likely less than drip irrigation.	Protection of water rights would be needed. Conserved water may be used by downstream or junior water right holders; considerations for this use and potential selenium load increase as a result would be needed.
On-farm irrigation drainage improvements (tile drains)	Applicable, but would require installation of an impermeable layer above the selenium-rich shale formation in most areas.	With an impermeable layer installed, tile drains would reduce the amount of deep percolation from irrigation. Reduces existing loading. See other issues.	Costs vary substantially depending on site characteristics, and therefore, are not provided here. However, large capital investment needed. O&M costs are non-existent or very low. Cost per pound of selenium load reduction is not available.	Disagreement among experts on the effectiveness of tile drains without an impermeable layer to reduce selenium loading. Effectiveness may be highly variable based on site-specific geologic and hydrogeologic conditions. Requires detailed field study for specific sites. Requires detailed knowledge of depth to selenium-rich shale and detailed design for each application.
Sewage treatment plants and related facilities (convert homes on septic systems)	Applicable to rural residential homes. Type of measure will depend on site-specific factors.	Reduces existing loading. Construction of sewage treatment plants can prevent future loading.	Costs can vary substantially. Sewage treatment plant will require a large capital investment and annual O&M cost. Cost per individual sewage disposal system or screw pump is estimated as $5,000, and O&M would be borne by landowner. Cost per pound of selenium load reduction is about $6,000/pound for individual sewage disposal system or screw pump.	Load reduction is typically small unless there are very unique site-specific characteristics. Some counties are already requiring individual sewage disposal systems for specific site conditions.

Table 4-1
Summary of Site-specific Appraisal-level Control Measures

Measure	Applicability	Effectiveness	Cost per Gunnison Basin Selenium Task Force, 2001*	Other Issues
Agricultural Best Management Practices				
Improve irrigation efficiencies (optimize applied water, monitor soil moisture, and level fields)	Applicable to all irrigated areas.	Likely reduces existing loading.	Costs can vary substantially depending on site characteristics, and therefore, are not provided here. However, costs would generally be low and borne by the landowner. See other issues and costs for public outreach and awareness. Cost per pound of selenium load reduction is not quantifiable.	No quantifiable relationship between selenium load reductions and improved irrigation efficiencies. Would require an extensive public outreach and awareness effort.
Non-Agricultural Best Management Practices				
Improve landscape irrigation efficiencies (optimize applied water, monitor soil moisture)	Applicable to all irrigated landscape areas (both public and private).	Likely reduces existing loading.	Costs can vary widely depending on site characteristics, and therefore, are not provided here. However, costs would generally be low and borne by the landowner. See other issues and costs for public outreach and awareness. Cost per pound of selenium load reduction is not quantifiable.	No quantifiable relationship between selenium load reductions and improved irrigation efficiencies. Would require an extensive public outreach and awareness effort.
Convert existing lawns to xeriscape	Applicable to all irrigated landscape areas (both public and private).	Reduces existing loading.	Approximately $5,000 per acre to convert from blue-grass to native grass and shrubs. Includes contingencies, design, and overhead costs. Cost per pound of selenium load reduction is about $1,200.	May be difficult for landowners to accept with the low cost of water in most areas.
Water-efficient appliances and plumbing fixtures (reduce septic tank seepage)	Applicable to rural residential uses on septic systems.	Reduces existing loading. However, small load reduction per application because seepage from septic systems is typically small as compared to other seepage sources.	Cost will vary widely depending on improvements made. However, costs typically low (from a low of $6 for water efficient plumbing fixtures to $600 plus for water efficient appliances). Costs generally borne by homeowner or potentially cost-shared (via rebates) with local agencies. Cost per pound of selenium load reduction is not quantifiable.	Would require an extensive public outreach and awareness effort. May be difficult for homeowners to accept with the low cost of water in most areas.

Table 4-1
Summary of Site-specific Appraisal-level Control Measures

Measure	Applicability	Effectiveness	Cost per Gunnison Basin Selenium Task Force, 2001*	Other Issues
Other				
Land Preservation	Applicable in all areas.	Reduces potential future selenium loading; does not reduce existing loading.	Costs will vary substantially based on location of land, and therefore costs were not estimated for this report. High-priority lands or lands closer to urban areas with the potential for future development are likely to be more costly. Cost per pound of selenium load reduction is not quantifiable.	Requires willing landholders. Acceptance by the local community will likely vary depending on the site. Does not reduce selenium loading from existing land uses.
Public outreach and awareness	Easy to implement. Applicable in all areas.	Unknown. Other similar education and awareness programs have resulted in water conservation of 10-25 percent. Further reductions unlikely.	About $75,000 per year per full-time position. Includes administrative support, facilities (office), supplies and related expenses. Cost per pound of selenium load reduction is not quantifiable.	No quantifiable relationship between reductions and education actions.

Source: Gunnison River Selenium Task Force, 2001.

* Costs based on a variety of assumptions specific to the Uncompahgre Valley as described in the *Evaluation and Screening of Suggested Remediation Measures Lower Gunnison River Basin / Uncompahgre River Area* (Gunnison River Selenium Task Force, 2001). Costs should be viewed as rough estimates and are for comparison purposes only. In addition, these costs are not intended to be used to consider the feasibility of selenium source control efforts in the Upper Basin as compared to selenium treatment in the Salton Sea watershed. All costs based on January 2000 price level. Costs do not include potential Natural Resources Conservation Service Environmental Quality Improvement Program or Colorado River Salinity Control Forum cost-sharing.

The following general costing and effectiveness assumptions were made (Gunnison River Selenium Task Force, 2001):

a. The average annual selenium loads for some of the key drainage areas are as follows: Loutzenhizer Arroyo basin, 4,900 pounds/year; Gunnison River at Whitewater, 20,800 pounds/year; and, Uncompahgre River at Delta, 7,700 pounds/year.
b. Deep percolation volume of 1 to 1.5 acre-feet per acre was assumed for flood-irrigated land.
c. Deep percolation volume from rural-residential units was assumed to be 0.5 acre-feet/acre (0.2 acre-feet per leach filed and average size lawn contribution of 0.3 acre-feet per acre).
d. Water saved by implementation of a measure was assumed to either remain in the stream or be used in some other manner that did not mobilize additional selenium.
e. Measures potentially involving federal funding or permitting by federal agencies were assumed to require mitigation for losses to wetland and wildlife habitat.
f. For structural measures, cost estimates generally include 20 percent contingencies and 22 percent for engineering, design, contract administration, and overhead costs.
g. Cost per pound of selenium load reduction was computed by dividing the Total Annual Cost by the estimated reduction in selenium load in pounds per year. Total Annual Cost was determined to be the sum of the following: 50-year period annualized implementation cost (using the Fiscal Year 1999 federal planning interest rate of 6.875 percent and a capital recovery factor of 0.0713168); and, annual expenditures for facility operation, maintenance, and administration costs.

Other Issues

Canal lining, pond lining, and lateral piping control measures require a substantial initial capital investment. A variety of environmental mitigation measures, including mitigation of habitat losses, may also be needed for these control measures. However, these control measures are generally accepted and desirable improvements by the agricultural community.

The field-effectiveness of PAM on irrigation canals, laterals, and drainage canals has not been proven, and effectiveness may vary based on the application technique and exposure to sunlight (which breaks down the polymer). Additionally, the long-term environmental effects of PAM are not yet well understood.

4.1.2 Other Infrastructure to Change Water Use Practices

Selenium loading could be reduced through changing basic municipal and agricultural water use practices, reducing seepage to the shallow groundwater and leaching of selenium from selenium-rich shale and soil, as described in Section 3.1.2.

Effectiveness

These seepage control and reduction measures are effective ways of reducing existing selenium loading and can be effective ways of preventing new loading sources; however, the effectiveness of each measure varies based on the acceptability of the measure and the ultimate operation and maintenance of the system. For example, the effectiveness of some measures, such as tile drains and sewage treatment plants, are less dependent on O&M because there is either minimal O&M of the system, or the system is operated under well-defined operational criteria. However, the effectiveness of other measures, such as agricultural and residential sprinkler systems, will vary depending on a wide variety of acceptability and ease-of-use factors. In addition, the effectiveness of these measures will vary with site-specific characteristics such as soil type and hydrogeologic conditions.

Other Issues

Some changes to basic municipal and agricultural water use practices, such as installation of tile drains and wastewater treatment facilities, entail a substantial capital investment. O&M costs of some of these facilities are also substantial. The cost of other measures, such as sprinkler systems, is lower and may be borne in part by the water user, but incentives would likely be needed to spur implementation. Additionally, a long-term public outreach effort would be needed to ensure consistently effective operation of these measures over time.

There is disagreement among experts regarding the effectiveness of tile drains to reduce selenium loading. Tile drains may only be effective at reducing selenium loading when there is an impermeable layer to perch the shallow groundwater above the selenium-rich shale. Installation of an artificial impermeable layer can be costly and would require detailed site-specific engineering studies.

4.1.3 Agricultural Best Management Practices

Water storage and conveyance loss reductions and changing basic agricultural water use practices can be incorporated into agricultural BMPs. Farm-level BMPs, such as applying the optimal amount of water, monitoring of soil moisture, and field leveling, can be implemented whether system level changes occur or not. Any and all of these actions can reduce selenium loading by reducing surface recharge to shallow groundwater.

Effectiveness

Agricultural BMPs have the potential to reduce existing selenium loading and prevent loading from new sources, and they are applicable to all irrigated areas. As with other control measures, the effectiveness of a BMP can vary depending on acceptability of the measure by irrigation districts and individual landowners, along with the effectiveness of public outreach efforts in providing information and resources to the agricultural community. In some cases, characterization of subsurface conditions may be insufficient to predict BMP effectiveness with confidence.

Other Issues

Currently, there is no quantifiable relationship between selenium load reductions and implementation of BMPs. Such a relationship would be difficult to determine. Cost-sharing or providing financial incentives to landowners to support implementation of BMPs is complicated because of farm-to-farm variability. As with other control measures, a long-term public outreach effort would be needed to ensure that water users have the best available information and continue to use these measures over time.

In general, implementation of BMPs does not entail substantial capital investment, but can result in some capital equipment purchases and improvements (e.g., monitoring equipment and land leveling), as well as consultant (e.g., irrigation scheduling) and additional labor (e.g., farm management and irrigator) costs. These costs would vary substantially based on the BMP implemented and site-specific conditions. This variation can make cost-sharing opportunities difficult to quantify on a regional scale.

4.1.4 Non-Agricultural Best Management Practices

In the selenium source areas, non-agricultural land uses are currently minor compared with agricultural land uses. Therefore, the non-agricultural portion of selenium loading is anticipated to be lower. However, populations are anticipated to increase in many of the source areas, and therefore, the selenium loading from non-agricultural land uses is likely to increase in the future. Non-agricultural BMPs can be developed for a variety of water uses, such as improved landscape and lawn irrigation efficiencies for large and small areas (golf courses, parks, cemeteries, and urban lawns) through optimizing applied water and monitoring soil moisture, urban water conservation actions (effective for septic users), and conversion of irrigated landscape to xeriscape.

Effectiveness

Non-agricultural BMPs have the potential to reduce existing selenium loading and avoid or minimize new sources. In addition, these measures can be applicable to both private and public facilities. As for agricultural BMPs, effectiveness can vary depending on acceptability of the measure by individual proprietors, along with the effectiveness in delivering needed information and resources to support implementation. Geologic and hydrogeologic conditions will also influence the effectiveness of this measure. However, as previously noted, demonstration projects are underway to determine the effectiveness of non-agricultural BMPs (NIWQP, 2003).

Other Issues

As with implementation of agricultural BMPs, there is no quantifiable relationship between selenium load reductions and implementation of non-agricultural BMPs, and such a relationship would be difficult to determine. Cost-sharing or providing financial incentives to proprietors for implementation of BMPs is complicated because it is difficult to measure results and to ensure ongoing implementation of measures. A long-term public outreach effort would be needed to ensure that water users have sufficient information and continue to use these measures over time.

In general, implementation of BMPs does not require a substantial capital investment, but can result in capital (irrigation equipment, replanting, pumps), consultant (irrigation experts, landscaping contractors), and additional labor costs. In general, most of these costs will be borne by the landowner, or incentives can be provided through a rebate program. However, variations in effectiveness as a result of the BMP implemented and site-specific conditions can make cost-sharing and rebate programs difficult to develop on a regional scale.

4.1.5 Land Preservation

As previously described, Mancos-derived soils that have never been irrigated and leached have an average of 34 times more selenium than irrigated and leached soils (Colorado Department of Public Health and Environment, 2003). Preservation of existing land uses on undeveloped lands with selenium-rich soils has the potential to avoid future selenium loading that might otherwise occur as a result of land-use changes.

Effectiveness

Land preservation would be effective at reducing potential future selenium loading; however, it may be less effective at reducing existing loading. Some selenium loading will continue to occur from undeveloped lands as a result of natural rainfall-runoff processes and other anthropogenic factors (such as livestock grazing and off-highway vehicle use).

Other Issues

Some land uses, such as livestock grazing and off-highway vehicle use, may increase selenium loading from undeveloped lands. Although limitation on future land use changes would reduce the potential for substantial future increases in selenium loading from the undeveloped lands, this control measure would not reduce loading from existing uses. In addition, the cost of land preservation will vary substantially based on the location of the land, and land use restrictions.

4.2 Agencies Implementing Ongoing Control Efforts

This section provides a brief description of some of the agencies implementing source control efforts (see Section 2 for a description of selected site-specific control efforts by source area). It is important to note that selenium source control and treatment efforts in the Upper Basin are being driven by regulatory requirements (303(d) listed water bodies). Fundamentally, the goal of these ongoing efforts is to comply with the regulatory requirements and reduce selenium concentrations in selected water bodies. However, it is important to remember that non-point source dischargers are not required to implement changes that may be identified in a TMDL plan in some states. In these areas, the current source control and treatment efforts that target non-point source dischargers, such as agricultural and rural-residential areas, are voluntary.

Ongoing efforts include both treatment efforts (i.e., diversion of high-selenium water to less sensitive areas, dilution, changes in timing of discharges), and source control efforts (i.e., reducing the amount of selenium mobilized and transported through the system). However, only the source control efforts provide the secondary benefit of reducing selenium loading to the Lower Colorado River Basin and thus to the Salton Sea ecosystem.

4.2.1 Colorado River Salinity Control Forum

Salt, including selenium, is commonly found in marine shale and marine shale-derived soils, and both are mobilized and transported by water. A positive correlation between selenium and total dissolved solids was found in the Grand Valley (Butler et al., 1996). Because salts and selenium share a common geologic source and generally mobilize and transport similarly through the environment, many of the selenium-control measures identified here also are used to control salinity. Therefore, potential opportunities exist to collaborate with the ongoing salinity control efforts in the Upper Basin. The Colorado

River Salinity Control Forum has formed a selenium sub-committee to address selenium and salinity issues, and to identify potential cost-sharing opportunities for the two pollutants (see Section 4.2.3 below).

4.2.2 National Irrigation Water Quality Program

As discussed in Section 2, NIWQP has been involved in characterization studies, alternatives evaluations, and source control and treatment actions in the Upper Colorado River Basin. NIWQP has also served as an information source and assisted in facilitating a coordinated and collaborative approach to water quality improvements and source control efforts among local, regional, state, and federal activities.

NIWQP is funded through Reclamation, however, Reclamation's Fiscal Year 2005 appropriation request did not include funding that can be used for the program (NIWQP, 2004). As described in NIWQP's Status Report for the Gunnison and Grand Valley Study Area (2004), loss of NIWQP funding has resulted in the suspension of important activities in these areas, which may affect the ability of the Grand Valley and Gunnison Basin Selenium Task Forces to meet their goals. Various agencies and stakeholders are working to get NIWQP funding re-instated. Nevertheless, future funding for the program is uncertain.

4.2.3 Gunnison Basin and Grand Valley Selenium Task Forces

The Gunnison Basin and Grand Valley Selenium Task Forces have developed a list of actions needing direct funding assistance to advance the selenium control efforts in the area (Gunnison Basin and Grand Valley Selenium Task Forces, n.d.). These actions are summarized in Table 4-2.

Table 4-2

Actions Needing Funding Assistance to Advance the Efforts of the Gunnison Basin and Grand Valley Selenium Task Forces

Priority*	Action
1	Pipe Uncompahgre Project east side laterals
2	Line Uncompahgre Project east side canals
3	Provide incentives and promote pressurized sprinkler irrigation or drip systems in high loading areas
4	Implement a comprehensive Wise Water Use campaign with special focus on outdoor water use
5	Complete on-going Land Use Study to quantify impacts of growth
6	Line perched ponds on the east side of the Uncompahgre River
7	Investigate and demonstrate additional remediation techniques
8	Monitor load reductions resulting form canal and pong lining
9	Explore additional source control opportunities in other portions of the lower Gunnison River Basin and Grand Valley

Source: Gunnison Basin and Grand Valley Selenium Task Forces, not dated.
* Prioritized in terms of theoretically maximizing selenium reductions.

Additionally, the Gunnison Basin Selenium Task Force (2004) has developed an action plan that identifies seven broad categories of selenium control objectives along with on-going and planned site-specific control actions for each category.

The task forces have identified the following potential funding sources for advancing their efforts and implementing control measures (provided in no particular order): cost sharing with the Colorado River Basin Salinity Control Program; direct funding provided to the Uncompahgre Valley Water Users Association; direct funding provided to the task forces through the various local conservation districts;

re-initiation of the NIWQP; and federal funding initiatives. With regard to the Colorado River Basin Salinity Control Program, the program selects projects based on a cost-effective competitive process. Partial funding of a project that will reduce both selenium and salinity by the task force or others may put the project into the competitive range for cost-sharing with the Salinity Control Program.

As described above and in section 2.0, the Gunnison Basin and Grand Valley Selenium Task Forces are taking a positive, voluntary approach to reducing selenium through identifying and characterizing selenium sources, evaluating source control measures and treatment options, supporting demonstration projects, and conducting public outreach. The efforts of the two Task Forces are generally focused on agricultural and rural-residential water management practices, both of which traditionally result in non-point source discharges which may not be required to implement changes identified in TMDL plans. As previously described, the Gunnison River basin and Grand Valley area contribute over 60 percent of the selenium load to Lake Powell and a substantial portion of this load is likely a result of agricultural and rural-residential water management practices. Overall, the efforts of the Gunnison Basin and Grand Valley Selenium Task Forces are beneficial to the Lower Colorado River Basin and the Salton Sea ecosystem.

4.2.4 Environmental Quality Incentives Program

The Environmental Quality Incentives Program (EQIP), administered by the U.S. Department of Agriculture, Natural Resources Conservation Service, is a voluntary conservation program for farmers and ranchers. EQIP offers financial and technical help to assist eligible participants install or implement structural and management practices on eligible agricultural land. The goal is to promote agricultural production and environmental quality as compatible national goals. EQIP can provide cost-sharing and technical assistance for on-farm selenium reduction efforts, such as on-farm irrigation and drainage improvements.

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Butler, D.L., W.G.Wright, D.A. Hahn, R.P. Krueger, and B.C. Osmundson. Physical, Chemical, and Biological Data for Detailed Study of Irrigation Drainage in the Uncompahgre Project area and in the Grand Valley, West-central Colorado, 1991-92: U.S. Geological Survey Open-File Report 94-110. Denver, Colorado. 1994.

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APPENDIX A

Summary of Available Literature

Table A-1
Summary of Available Literature on Upper Colorado River Basin Selenium Source Loading*

Author	Title	Publication	Summary/Relevant Information
Upper Colorado River Water Quality			
Blanchard, P.J., Poy, R.R., O'Brien, T.F.	*Reconnaissance Investigation of Water Quality, Bottom Sediment and Biota Associated with Irrigation Drainage in the San Juan River Area, San Juan County, Northwestern New Mexico, 1990-91*	U.S. Geological Survey (USGS) Water Resources Investigations Report 93-4065, 1993	Concentrations of selenium larger than established standards and criteria were present in water, bottom sediment, and biota in four areas on three irrigation projects: the middle and north ponds in Gallegos Canyon on the Navajo Indian Irrigation Project (NIIP), the Ojo Amarillo Canyon drainage on the NIIP, a pond receiving irrigation drainage water on the West Hammond Irrigation Project, and a drain on the eastern part of the Hogback Irrigation Project.
California Regional Water Quality Control Board, Colorado River Basin Region	*Watershed Management Initiative Strategic Planning Chapter*	California Regional Water Quality Control Board, Regional Board Staff, updated October 2004	Summarizes the selenium impaired water bodies and timelines for Total Daily Maximum Load (TMDL) implementation for the Salton Sea, Imperial Valley Drains, and Alamo River.
Colorado Water Conservation Board and the Colorado Department of Water Resources	*Colorado's Decision Support System*	Colorado Water Conservation Board and Colorado Department of Water Resources Web site: http://cdss.state.co.us	The Colorado's Decision Support System is a water management system that was developed by the Colorado Water Conservation Board and Colorado Department of Water Resources to assist in making informed decisions regarding historical and future use of water.
Colorado Water Conservation Board and Boyle Engineering Corp.	*Colorado River Decision Support System, Gunnison River Basin Water Resources Planning Model, Final Report*	Colorado Water Conservation Board and Boyle Engineering, December 1999	The Gunnison River Water Resources Planning Model is a monthly water allocation and accounting model that includes 100 percent of the Gunnison Basin's consumptive use and would be capable of making comparative analyses for the assessment of historical and future water management policies.
Colorado Water Conservation Board and Boyle Engineering Corp.	*Colorado River Decision Support System, Upper Colorado River Basin Water Resources Planning Model, Final Report*	Colorado Water Conservation Board and Boyle Engineering, June 2000	The Gunnison River Water Resources Planning Model is a monthly water allocation and accounting model that includes 100 percent of the Upper Colorado River Basin's consumptive use and would be capable of making comparative analyses for the assessment of historical and future water management policies.
Engberg, R.A.	*Selenium Budgets for Lake Powell and the Upper Colorado River Basin*	Journal of American Water Resources Association, 35:771-786, 1999	A selenium budget for Lake Powell estimated that 31 and 30 percent of the selenium loading to Lake Powell is from the Gunnison River Basin and Grand Valley, respectively. Irrigation-related activities are thought to be responsible for mobilizing 71 percent of the selenium that reaches Lake Powell. Most selenium observed in downstream areas of the Colorado River were determined to likely derive mostly from the Colorado River Basin above Lake Powell.

Table A-1
Summary of Available Literature on Upper Colorado River Basin Selenium Source Loading*

Author	Title	Publication	Summary/Relevant Information
Feltz., H.R., Sylvester, M.A., Engberg, R.A.	*Reconnaissance Investigations of the Effects of Irrigation Drainage on Water Quality, Bottom Sediment, and Biota in the Western United States*	USGS Water Resources Investigations Report 91-4034, 1991	In response to concerns expressed by the U.S. Congress and others over contamination at the Kesterson National Wildlife Refuge in California, the Department of the Interior started a program in 1985 to identify the nature and extent of irrigation-induced water quality problems that might exist in other areas of the Western U.S. An evaluation of the results of completed reconnaissance investigations indicates that selenium is the trace element commonly found at elevated concentrations in water, bottom sediment, and biota, and has the greatest potential to cause toxicological effects in most of the study areas. Impaired bird reproduction and deformed embryos were noticed.
Garcia, L.	*Managing Selenium in the Upper Colorado River Basin, 2001*	Colorado State Research Education Extension National Water Quality Program, 2001 Poster available at: http://www.usawaterquality.org/conferences/2003/posters/Garcia.pdf	In support of the Gunnison Basin Selenium Task Force, Colorado State University is cooperating with other state and federal agencies to develop modeling tools for on-going evaluation of management alternatives. The Project Poster is also provided.
Setmire, J.G., Schroeder, R.A., Densmore, J.N., Goodbred, S.O., Audet, D.J., Radke, W.R.	*Detailed Study of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Salton Sea Area, California, 1988-90*	USGS Water Resources Investigations Report 93-4014, 1993	A detailed study of the Salton Sea area by the National Irrigation Water Quality Program (NIWQP), Department of the Interior, was completed in 1990. Overall objectives of the study were to assess the extent, magnitude, and effects of contamination associated with agricultural drainage on migratory and resident birds and their habitats, and to determine the sources and exposure pathways of contaminants.
Setmire, J.G., Wolfe, J.C., Stroud, R.K.	*Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Salton Sea Area, California, 1986-87*	USGS Water Resources Investigations Report 89-4102, 1990	Water, bottom sediment, and biota were sampled during 1986-87 in the Salton Sea area to determine concentrations of trace elements and pesticides as part of the Department of the Interior Irrigation Drainage Program.
Spahr, N.E., Apodaca, L.E., Deacon, J.R., et al.	*Water Quality in the Upper Colorado River Basin, Colorado 1996-98*	USGS Circular 1214	Drainage from extensive irrigated agriculture in the Grand and Uncompahgre valleys of the Colorado Plateau account for as much as 75 percent of the selenium load to the Colorado River.

Table A-1
Summary of Available Literature on Upper Colorado River Basin Selenium Source Loading*

Author	Title	Publication	Summary/Relevant Information
U.S. Department of the Interior	*Quality of Water Colorado River Basin*	Department of the Interior Progress Report No. 21, January 2003	The Gunnison River Basin and Grand Valley area of the Colorado River were the largest source areas of selenium (50-60 percent) found in the mainstem Colorado River. A table of selenium loading in the river is provided. Also provides a summary of studies undertaken by Department of the Interior's NIQWP and the U.S. Bureau of Reclamation and suggests possible future concurrent studies of salinity and selenium.
U.S. Environmental Protection Agency	*Total Maximum Daily Load Program*	EPA Web site, 2005: http://yosemite.epa.gov/R10/water.nsf/TMDLs/TMDL+Program	Describes the process and definition of the TMDL program and provides links to information on impaired water bodies.
U.S. Environmental Protection Agency	*EPA Releases Innovative Approach to Cleaner Water*	EPA Web site: http://www.epa.gov/epahome/headline_011303.htm	Description of EPA's pollution reduction credit program to reduce water quality loading by providing economic incentives to reduce selenium loads to the Lower Colorado River.
U.S. Water News Online	*Polyacrylamide Found to Reduce Soil Erosion in Furrows by up to 99 Percent*	Available at: http://www.uswaternews.com/archives/arcconserv/9polfou7.html, 1999	Technology that reduces seepage of selenium from irrigation ditches. Cost reported at $5 per pound, where a typical project would require one pound per irrigated acre.
Von Guerard, P., U.S. Geological Survey (USGS)	*Selenium Studies and Remediation Planning in the Upper Colorado River Basin*	Presentation, 2005	Presentation given at the 3-16-05 Salton Sea Advisory Committee (SSAC) meeting held at the Metropolitan Water District (MWD) of Southern California. Summarized selenium loading, USGS project activities in Western Colorado and Eastern Utah, modeling efforts, project costs, project results, implications for changing land use, and contact information.
Lower Gunnison and Green River			
Butler, D.L.	*Effects of Piping Irrigation Laterals on Selenium and Salt Loads, Montrose Arroyo Basin, Western Colorado*	USGS Water Resources Investigations Report 01-4204, 2001	A demonstration project in Montrose Arroyo, located in the Uncompahgre River Basin near Montrose, was done during 1998-2000 to determine the effects on selenium and salt loads in Montrose Arroyo from replacing 8.5 miles of open-ditch irrigation laterals with 7.5 miles of pipe.

Table A-1
Summary of Available Literature on Upper Colorado River Basin Selenium Source Loading*

Author	Title	Publication	Summary/Relevant Information
Butler, D.L., Krueger, R.P., Osmundson, B.C., et al.	*Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Gunnison and Uncompahgre River Basins and at Sweitzer Lake, West-Central Colorado, 1988-89*	USGS Water Resources Investigations Report 91-4103, 1991	This report describes the results of a reconnaissance investigation done during 1988-89 of the Uncompahgre Project. Water, bottom sediment, and biota samples were collected in the Gunnison and Uncompahgre river basins, and at Sweitzer Lake to identify potential water quality problems that could be associated with the Uncompahgre Project.
Butler, D.L., Krueger, R.P., Osmundson, B.C., Jensen, E.G.	*Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Dolores Project Area, Southwestern Colorado and Southeastern Utah, 1990-91*	USGS Water Resources Investigations Report 94-4041, 1995	Water, bottom-sediment, and biota samples were collected and analyzed for a reconnaissance investigation during 1990-91 to identify potential water quality problems associated with irrigation drainage in the Dolores Project area in southwestern Colorado and southeastern Utah.
Butler, D.L., Osmundson, B.C., Krueger, R.P.	*Field Screening of Water, Soil, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Dolores Project and the Macos River Basin, Southwestern Colorado, 1994*	USGS Water Resources Investigations Report 97-4008, 1997	A reconnaissance investigation for the NIWQP in 1990 indicated elevated selenium concentrations in some water and biota samples collected in the Dolores Project in southwestern Colorado. High selenium concentrations also were indicated in bird samples collected in the Mancos Project in 1989. In 1994, field screenings were done in parts of the Dolores Project and Mancos River Basin to collect additional selenium data associated with irrigation in those areas.
Butler, D.L., Wright, W.G., Hahn, D.A., Krueger, R.P., Osmundson, B.C.	*Physical, Chemical, and Biological Data for Detailed Study of Irrigation Drainage in the Uncompahgre Project Area and in the Grand Valley, West-Central Colorado, 1991-92*	USGS Open File Report 94-110, 1994	This report lists onsite measurements and concentrations of major constituents, trace elements, and stable isotopes for surface water and groundwater sampling sites in the Uncompahgre Project area and in the Grand Valley.
Butler, D.L., Wright, W.G., et al.	*Detailed Study of Selenium and Other Constituents in Water, Bottom Sediment, Soil, Alfalfa, and Biota Associated with Irrigation Drainage in the Uncompahgre Project Area and in the Grand Valley, West-Central Colorado, 1991-1993*	USGS Water Resources Investigations Report 96-4138, 1996	The focus of this report is on the sources, distribution, movement, and fate of selenium in the hydrologic and biological systems and the effects on biota resulting from a study in 1991-93 of irrigation drainage associated with the Uncompahgre Project area.

Table A-1
Summary of Available Literature on Upper Colorado River Basin Selenium Source Loading*

Author	Title	Publication	Summary/Relevant Information
Butler, D.L., Krueger, R.P., et al.	*Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Pine River Project Area, Southern Ute Indian Reservation, Southwestern Colorado and Northwestern New Mexico, 1988-89*	USGS Water Resources Investigations Report 92-4188, 1993	The Department of the Interior completed 20 reconnaissance investigations in the Western U.S. to determine if irrigation drainage has the potential to affect human health, fish, and wildlife, or if it has adversely affected the suitability of water for other beneficial uses. This report looks at water, bottom sediment, and biota that were sampled and analyzed during 1988-89 to determine if selenium or other potentially harmful constituents were present in the Pine River Project area, southwestern Colorado.
Butler, D.L., Leib, K.J.	*Characterization of Selenium in the Lower Gunnison River Basin, Colorado, 1988-2000*	USGS, Water Resources Investigations Report 02-4151, 2002	Provides more detailed information on selenium loading in the lower Gunnison River Basin. Selenium data were collected for tributaries of the Gunnison River downstream from the North Fork and in the North Fork Basin. The largest selenium load in a tributary stream was in the Uncompahgre River, which accounted for 38 percent of the selenium load in the Gunnison River at Whitewater. Selenium loading was also evaluated for tributaries to the Uncompahgre River.
Butler, D.L., Osmundson, B.C.	*Physical, Chemical, and Biological Data for the Uncompahgre Project Area and the Grand Valley, West-Central Colorado, 1993-98*	USGS Open File Report 99-453, 2000	The data collected for a reconnaissance investigation in 1988-89 and for a detailed study in 1991-92 were published in previously released USGS reports. This report contains all selenium data and other water quality and chemical data for samples collected during water years 1993-97 in the Uncompahgre Project area and in the Grand Valley. Also included in this report are chemical results for samples collected through March 1998 for which analysis had been completed.
Department of the Interior and U.S. Bureau of Reclamation	*Position Statement of the Gunnison Basin Selenium Task Force*	Gunnison Basin Selenium Task Force, Draft 10/08/04	This document contains a summary of the Task Force work, summaries of selenium transport projects, history of selenium problems in the Uncompahgre and Gunnison river basins, what is being done to resolve these problems, and current projects.
Gunnison River Basin Selenium Task Force	*Action Plan; Working Version – revised 9-22-04*	Gunnison River Basin Selenium Task Force, 2004	This document is a matrix of the objectives of the Task Force (that is, pipe laterals and line canals in high selenium loading areas, implement non-agricultural best management practices (BMPs), encourage on-farm efficiency improvements in all high selenium loading areas, etc.), the tasks that are being taken to meet these objectives, the importance of the task item to the overall mission of the task force, responsible parties, and the status/scheduled completion date for each task.

Table A-1
Summary of Available Literature on Upper Colorado River Basin Selenium Source Loading*

Author	Title	Publication	Summary/Relevant Information
Gunnison River-Grand Valley Basin Selenium Task Forces	*CA Contact Letter from Thomas D. Peltier of the Gunnison River and Grand Valley Selenium Task Forces to Celeste Cantu of the CA State Water Resources Control Board, Cal-EPA*	Draft letter dated April 5, 2004	This is a letter requesting California's Colorado River water users to join with the task forces in seeking Congressional support for the NIWQP and related selenium reduction programs in the federal fiscal 2005 budget.
Gunnison River Basin Selenium Task Force Remedial Measures Review Subgroup	*Evaluation and Screening of Suggested Remediation Measures Lower Gunnison Basin / Uncompahgre Project Area*	Revised Draft, 2001	Summary of applicability, benefits, costs, and feasibility of various selenium control options.
NIWQP	*Coordinator's Summary Report on the National Irrigation Water Quality Program*	NIWQP, 2004	Presents a summary on the NIWQP Program including background, statement of problem, possible solution, and NIWQP's objective in the lower Gunnison Basin-Grand Valley study area.
NIWQP	*Status Report – Gunnison-Grand Valley Study Area*	NIWQP, 2004	This document summarizes the status of the NIWQP's selenium remediation activities in the Grand Valley and Gunnison River Basin as of spring 2004. It also describes some of the assumptions, criteria, issues, and lessons learned since planning for remediation began in FY 1995. Report or recent budget constraints have resulted in suspension of several activities.
NIWQP Current Activities	*Gunnison-Grand Valley Project, Colorado – Current Activities*	U.S. Bureau of Reclamation, NIWQP Web site: http://www.usbr.gov/niwqp/info/current/ggv/gunnison.htm	Miscellaneous project information, data tables, maps, etc. of the Gunnison-Grand Valley Basin area.
NIWQP Current Activities	*Middle Green River Basin – Current Activities*	U.S. Bureau of Reclamation, NIWQP Web site: http://www.usbr.gov/niwqp/info/current/middle%20green/middle_green.htm	Miscellaneous project information, data tables, maps, etc. of the Middle Green Basin area.

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Author	Title	Publication	Summary/Relevant Information
NIWQP Current Activities	*Salton Sea – Current Activities*	U.S. Bureau of Reclamation, NIWQP Web site: http://www.usbr.gov/niwqp/info/current/salton%20sea/salton_sea.htm	Miscellaneous project information, data tables, maps, etc. of the Salton Sea area.
Rowland, R.C., Allen, D.V. et al.	*Hydrologic, Sediment, and Biological Data Associated with Irrigation Drainage in the Middle Green River Basin, Utah and Colorado, Water Years 1991-2000*	USGS Open-File Report 02-3434, 2002	Hydrologic, sediment, and biological data were collected in the middle Green River Basin in eastern Utah from 1991 to 2000 in an effort to monitor the effects of irrigation drainage on wetland areas and streams, and aid in the development of selenium remediation efforts at Stewart Lake Waterfowl Management Area (WMA).
Rowland, R.C., Stephens, D.W., Waddell, B., Naftz, D.L.	*Selenium Contamination and Remediation at Stewart Lake Waterfowl Management Area and Ashley Creek, Middle Green River Basin, Utah*	USGS Fact Sheet 031-03, 2003	This fact sheet presents information about selenium in two areas of the middle Green River Basin, Stewart Lake WMA, and Ashley Creek, and summarizes the scope of selenium contamination in each area to discuss the progress toward reducing the concentration of selenium in water, bottom sediments, and biota.
Stephens, D.W. et al.	*Detailed Study of Selenium and Selected Elements in Water, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Middle Green River Basin, Utah, 1988-90*	USGS Water Resources Investigation Report 92-4084, 1992	Identification of areas where selenium was adversely affecting water quality and creating a hazard to wildlife. High selenium concentrations were thought to be coming from sewage lagoon seepage. Selenium concentration in plants, fish, invertebrates, bird tissue, and eggs were found to be heightened.
Stephens, D.W. et al.	*Reconnaissance Investigation of Water Quality, Bottom Sediment, and Biota Associated with Irrigation Drainage in the Middle Green River Basin, Utah, 1986-87*	USGS Water Resources Investigation Report 88-4011, 1988	Selenium, boron, and zinc concentrations in water, bottom sediments, and biological tissue were found to be large enough to cause an increased hazard to wildlife. Selenium concentrations in sediment in discharge drains were 10-85 µg/g. Selenium concentrations in bird tissue and eggs were also measured.

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Author	Title	Publication	Summary/Relevant Information
USFWS	*A Success Story in the Making: Selenium Reduction in the Upper Colorado River, Lower Gunnison Basin*	Colorado Success Stories, USFWS, Region 6 USFWS Web site: http://www.r6.fws.gov/contaminants/success_co.htm	The staff of the Environmental and Contaminants Research Center (EC) Program at Grand Junction, CO field office has worked in partnership with the Department of the Interior NIWQP, other state and federal agencies, local governments, and private landowners to resolve selenium contamination resulting from irrigation drainwater. Within the scope of the NIWQP, the EC Program office in Grand Junction is involved in work with selenium and its impact on fish and wildlife resources in the Uncompahgre, Gunnison and upper Colorado River basins, and most recently assisted NIWQP in installing 8 miles of piped lateral in the Uncompahgre Basin showing a 40 percent reduction in selenium load from this project.
Colorado River Basin Salinity Control Program			
U.S. Bureau of Reclamation, Upper Colorado River Region	*Request for Proposals, Colorado River Basin Salinity Control Program*	RFP, October 2003	Presents an overview of the Salinity Control Program and identifies key agencies involved.
Butler, D.L., von Guerard, P.B.	*Salinity in the Colorado River in the Grand Valley, western Colorado, 1994-95*	USGS Fact Sheet FS-215-96, 1996	Salinity in the Colorado River is dependent on streamflow. General trend is of higher salinity with lower flow. Irrigation return flows increase salinity in the Colorado River.
Miller, J.B., Radtke, R.	*The Colorado River Salinity Control Program as a Potential Selenium TMDL*	Summary Paper	This document presents the selenium loading in the Upper Colorado River Basin from major source areas. It states that it is reasonable to assume that a selenium wasteload allocation for the Colorado River is possible to meet downstream water quality standards by continued implementation of the Colorado River Basin Salinity Control Program.
U.S. Bureau of Reclamation	*The Colorado River Basin Salinity Control Program*	Public Information Brochure	This document provides a summary of the Program and identifies key agencies involved.
U.S. Bureau of Reclamation	*Colorado River Basin Salinity Control Program, Lower Gunnison Basin Unit, Colorado*	Web site general description: http://www.usbr.gov/dataweb/html/lowergun.html	This document provides a summary of the Program in the Lower Gunnison Basin, and efforts undertaken there.

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Summary of Available Literature on Upper Colorado River Basin Selenium Source Loading*

Author	Title	Publication	Summary/Relevant Information
Irrigation and Selenium Research			
Breetz, H. et al.	*Water Quality Trading and Offset Initiative in the U.S.: A Comprehensive Survey*	Dartmouth College, 2004 Available at: http://www.dartmouth.edu/~kfv/waterqualitytradingdatabase.pdf	This document provides an update on proposed EPA sponsored selenium offset trading program. It also describes the status of several programs developed to trade selenium "reduction credits" in an effort to reduce overall selenium loading.
Department of the Interior and U.S. Bureau of Reclamation	*Colorado River System Consumptive Uses and Losses Report 1996-2000*	Reclamation, Managing Water in the West, revised December 2004 Available at: http://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html	This report incorporates annual estimates of consumptive uses and losses of water from the Colorado River system from 1996 through 2000.
Department of the Interior and USGS	*Linking Selenium Sources to Ecosystems: San Francisco Bay-Delta Model*	USGS Fact Sheet 2004-3091, 2004	Provides an overview of the San Francisco Bay-Delta Model, which was created to understand the effects of changing selenium inputs and the associated effects on aquatic food webs.
Engberg, R.A., and M.A. Sylvester	*Concentrations, distribution, and sources of selenium from irrigated lands in western United States*	Journal of Irrigation Drainage Engineering, 119:522-535. 1993.	This article presents the Department of the Interior's NIWQP, and discusses the concentrations, distribution, and sources of selenium from irrigated lands were studied between 1986 and 1990 at 20 reconnaissance project areas in 17 western states under the Program.
Irvine, S., U.S. Bureau of Reclamation	*ABMet® Treatment Technology*	Presentation, 2005	Presentation to the SSAC on 3-16-05 at the MWD of Southern California in Los Angeles. Results of test project for ABMet® selenium treatment technology in Central California. Presented efficiency, benefits, costs, and demonstration project plans. In addition, information about a full scale ABMet® arsenic treatment system in Canada.
Nolan, B.T., Clark, M.L.	*Selenium in Irrigated Agricultural Areas of the Western United States*	Journal of Environmental Quality, vol. 26, May-June. 1997.	A logistic regression model demonstrates the link between selenium contamination and irrigated areas of the Western U.S.
Seiler, R.L., Skorupa, J.P., Peltz, L.A.	*Areas Susceptible to Irrigation-Induced Selenium Contamination of Water and Biota in the Western United States*	USGS Circular 1180, 1999	The Department of the Interior studies contamination induced by irrigation drainage in 26 areas of the Western U.S. during 1986-1995. Irrigation of areas associated with marine sedimentary rocks and deposits of Late Cretaceous or Tertiary age rocks can result in concentrations of selenium in water that exceed criteria for the protection of freshwater aquatic life.

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Author	Title	Publication	Summary/Relevant Information
Seiler, R.L.	*Methods to Identify Areas Susceptible to Irrigation-Induced Selenium Contamination in the Western United States*	USGS Fact Sheet FS-038-97, 1997	Provides information on the identification of methods that are used to identify selenium contamination in the Western U.S.
Miscellaneous			
Amweg, E.L., Stuart D.L., Weston, D.P.	*Comparative Bioavailability of Selenium to Aquatic Organisms after Biological Treatment of Agricultural Drainage Water*	Journal of Aquatic Toxicology, 63: 13-25, 2003.	This reports looks at the bioavailability of selenium in treated water compared to the bioavailability in influent in conjunction with the ecological benefits of a reduction in total selenium loadings from a regional perspective.
Applied Biosciences and U.S. Bureau of Reclamation	*Selenium and Nitrate Removal from Agricultural Drainage at Panoche Drainage District, Firebaugh, California*	November 22, 2004 Pilot-Scale Evaluation of Biotreatment Technology	This report presents the pilot scale studies funding by the U.S. Bureau of Reclamation, to test the removal of selenium and nitrate from the Panoche Water and Drainage District's drainage waters, which currently have drainage effluents containing elevated levels of these contaminants.
Butler, D.L., and, Osmundson, B.C.	*Physical, Chemical, and Biological Data for the Uncompahgre Project Area and the Grand Valley, West-Central Colorado, 1993-98*	USGS Open File Report 99-453, 1999	The report contains all selenium data and other water quality and chemical data for samples collected during water years 1993-97 in the Uncompahgre Project area and in Grand Valley. Also included in this report are chemical results for samples collected through March 1998 that have completed analyses.
Hamilton, S.J., and A.D. Lemly	*Commentary: Water-sediment controversy in setting environmental standards for selenium*	Ecotoxicology and Environmental Safety, 44:227-235, 1999	Many articles have documented adverse effects on biota at concentrations below the current chronic criterion of 5 µg/L. This commentary will present information to support a national water quality criterion for selenium of 2 µg/L, based on a wide array of support from federal, state, university, and international sources.
MSE Technology Applications, Inc.	*Final Report – Selenium Treatment/Removal Alternatives Demonstration Project; Mine Waste Technology Program Activity iii, Project 20*	Prepared for EPA and U.S. Department of Energy, June 2001 Available at: http://www.epa.gov/ORD/NRMRL/pubs/600r01077/600r01077.pdf	The objective of this project was to test and evaluate technologies capable of removing selenium from Garfield Wetlands-Kessler Springs water to below the EPA's maximum contaminant level. The site has a well characterized selenium contamination artesian flow and was selected as the site for demonstrative various selenium treatment technologies.

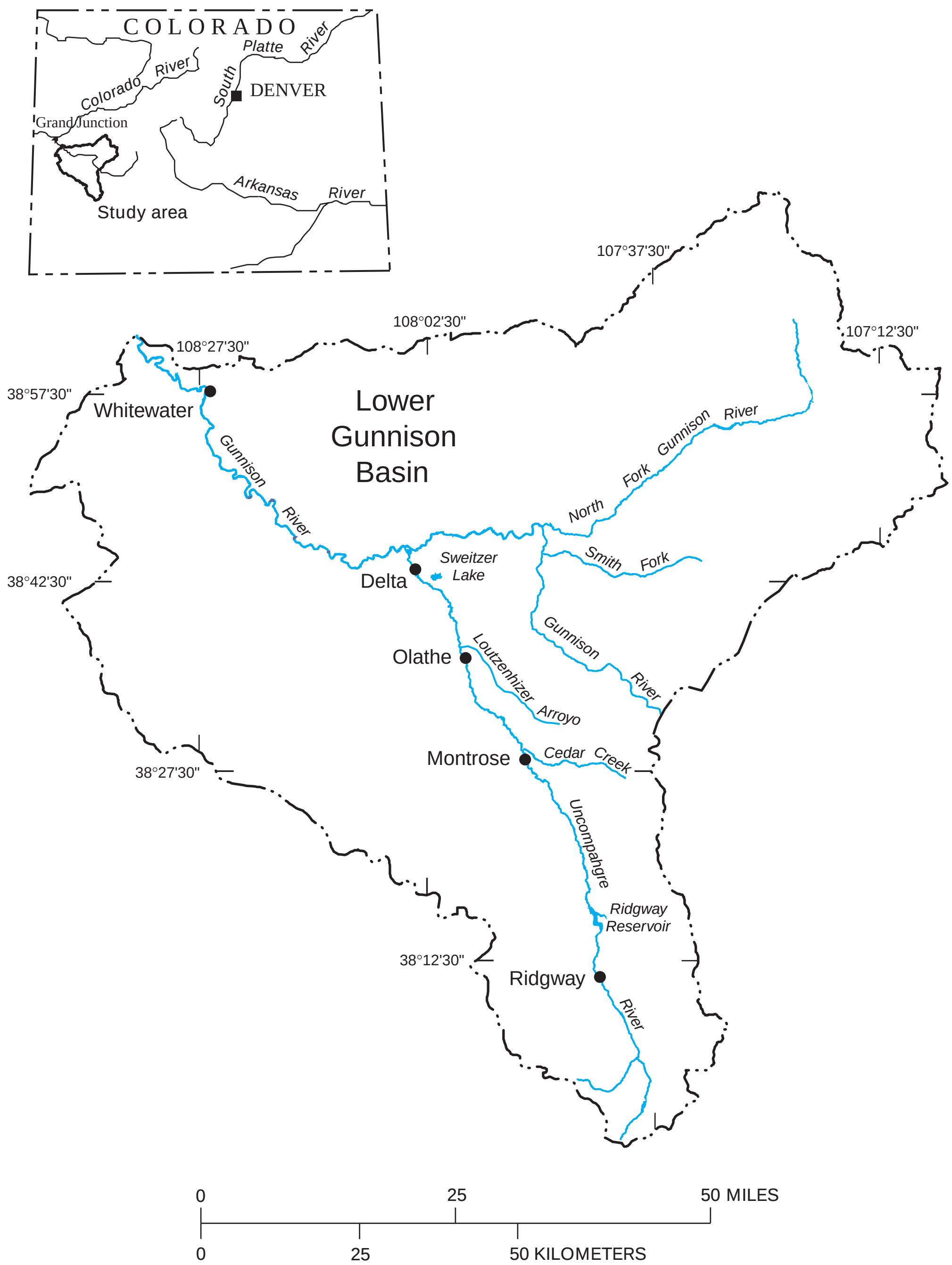
Table A-1
Summary of Available Literature on Upper Colorado River Basin Selenium Source Loading*

Author	Title	Publication	Summary/Relevant Information
Wright, W.G.	*Oxidation and mobilization of selenium by nitrate – A preliminary evaluation*	Effects of Human-Induced Changes on Hydrologic Systems (R.A. Marston, and V.R. Hasfurther, Eds.), page 1070. American Water Resources Association, Jackson Hole, WY. 1994	This article discusses a preliminary evaluation of analytical and thermodynamic data indicating that elevated concentrations of nitrate in ground water could oxidize and mobilize selenium. Ground-water-quality data from irrigated land underlain by Mancos shale of Cretaceous age in western Colorado (investigated as part of the NIWQP) indicate that concentrations of dissolved selenium are positively correlated with dissolved nitrate plus nitrite. Water quality data in the USGS data bases from Colorado and Wyoming indicate that concentrations of dissolved selenium are positively correlated with dissolved nitrate plus nitrite in ground water.

* This table is intended to serve as a starting point for available literature on Upper Colorado River Basin selenium source loading. It is not intended to serve as a comprehensive listing of all literature sources on the subject.

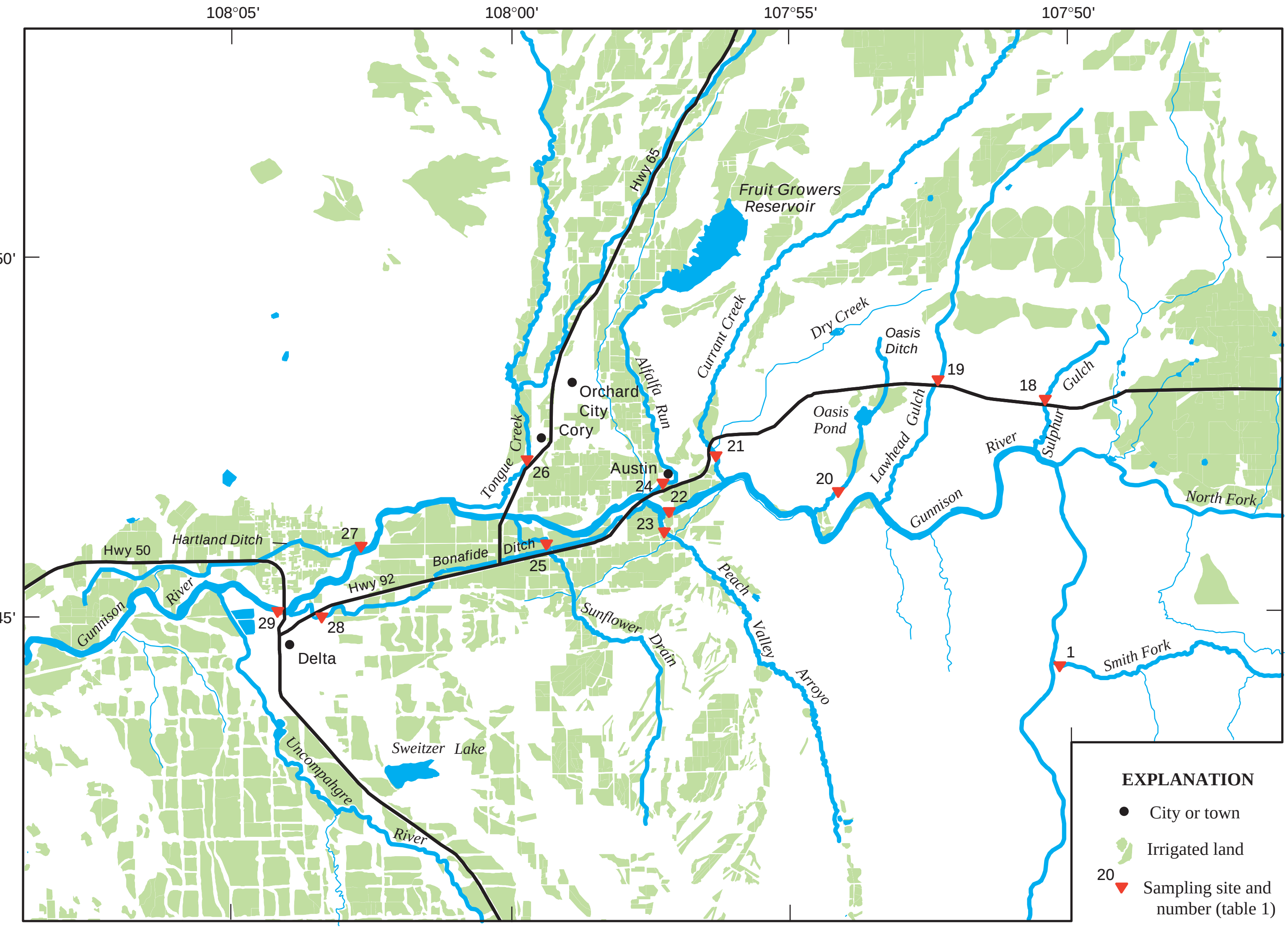
APPENDIX B

Detailed Gunnison River Basin Maps



Source: Butler and Leib, 2002.

FIGURE B-1
LOWER GUNNISON BASIN
SALTON SEA ECOSYSTEM RESTORATION PLAN

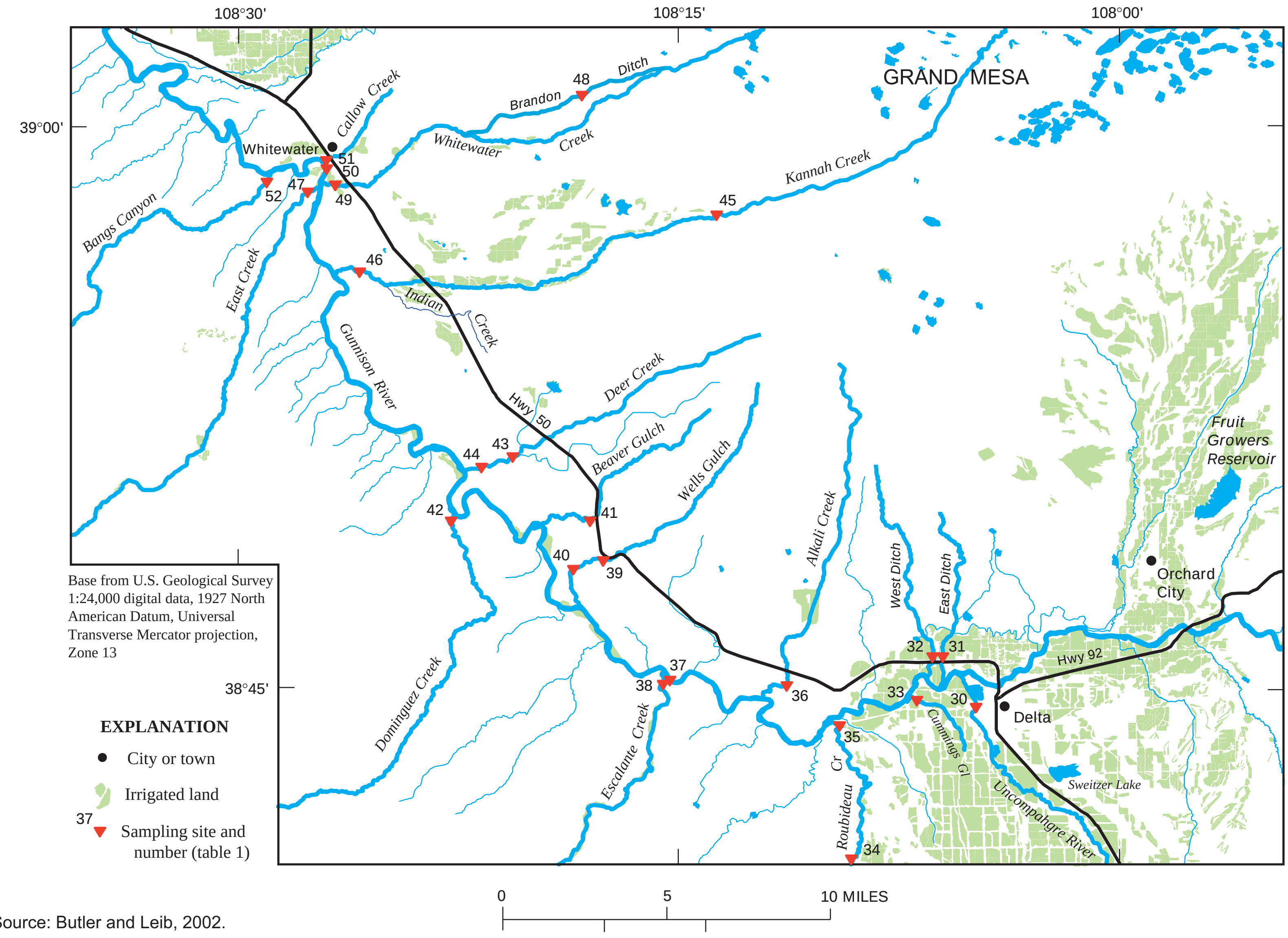


Base from U.S. Geological Survey
1:24,000 digital data, 1927 North American Datum,
Universal Transverse Mercator projection,
Zone 13

0 2 4 MILES
0 2 4 KILOMETERS

Source: Butler and Leib, 2002.

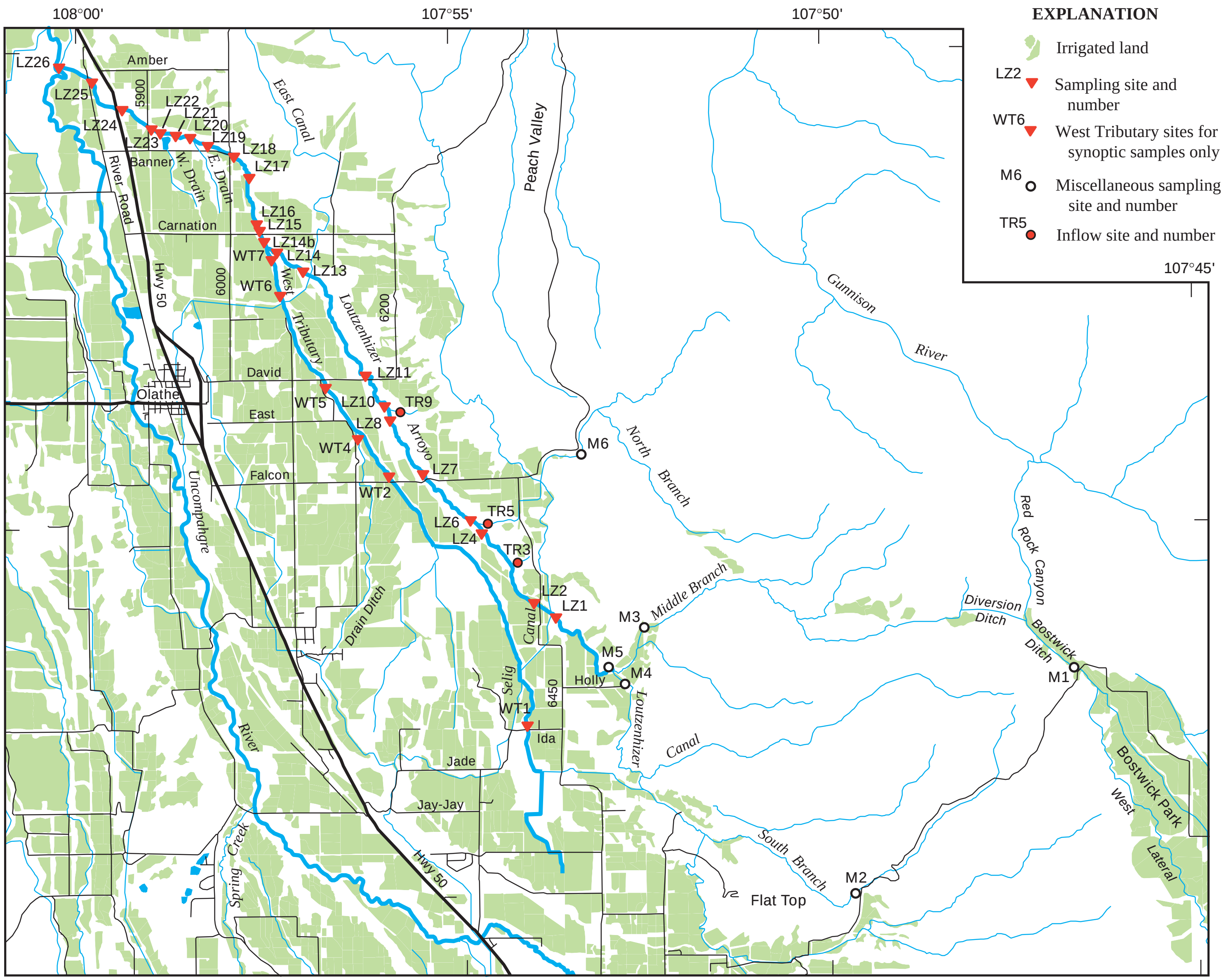
FIGURE B-2
GUNNISON RIVER FROM SMITH FORK TO UNCOMPAHGRE RIVER
SALTON SEA ECOSYSTEM RESTORATION PLAN



Source: Butler and Leib, 2002.

FIGURE B-3
GUNNISON RIVER FROM UNCOMPAHGRE RIVER TO WHITEWATER
SALTON SEA ECOSYSTEM RESTORATION PLAN

E032005010SAC Salton_figure_b_3.ai 05-12-05 tdaus



Base from U.S. Geological Survey
1:24,000 digital data, 1927 North American Datum,
Universal Transverse Mercator projection,
Zone 13

Source: Butler and Leib, 2002.

FIGURE B-4
LOWER UNCOMPAHGRE RIVER INCLUDING LOUTZENHIZER ARROYO
SALTON SEA ECOSYSTEM RESTORATION PLAN