Cheyenne River Sediment Recon Report
Cheyenne River
South Dakota and Wyoming

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LIST OF ACRONYMS AND ABBREVIATIONS

AF	acre-feet
ARSD	Administrative Rules of South Dakota
ARU	Angostura Reclamation Unit
ATP	adenosine triphosphate
BP	before present
cm	centimeters
CRP	Conservative Reserve Program
CRST	Cheyenne River Sioux Tribe
CWA	Clean Water Act
e2M	engineering-environmental Management, Inc.
Hg	Mercury
kg	kilogram
MCL	maximum contaminant level
mm	millimeter
µg/g	micrograms per gram (parts per million)
µg/g dw	micrograms per gram (parts per million) dry weight
µg/L	micrograms per liter (equivalent to parts per billion, in a liquid)
mg/L	milligrams per liter (equivalent to parts per million, in a liquid)
ng/g	nanograms per gram (parts per billion)
ng/L	nanograms per liter (equivalent to parts per trillion, in a liquid)
NAD	nicotinamide adenine dinucleotide
NCBP	National Contaminant Biomonitoring Program
NIWQP	National Irrigation Water Quality Program
NRHP	National Register of Historic Places
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
P.L.	Public Law
S.	Senate
SAR	Sodium Absorption Ratio
SDDENR	South Dakota Department of Environment and Natural Resources
Se	Selenium
SMCL	secondary maximum contaminant level
SHPO	State Historic Preservation Officer
TCP	Traditional Cultural Property
TDS	total dissolved solids
THPO	Tribal Historic Preservation Officer
TMDL	Total Maximum Daily Loads
TSS	total suspended solids
USACE	U.S. Army Corps of Engineers
USBOR	U.S. Bureau of Reclamation
USDOE	U.S. Department of Energy
USEPA	U.S. Environmental Protection Agency

USFDA	U.S. Food and Drug Administration
USFWS	U.S. Fish and Wildlife Service
USGS	U. S. Geological Survey
WRDA	Water Resources Development Act

Executive Summary

The Cheyenne River and its tributaries carry runoff and sediment from the Black Hills and the grasslands surrounding them, as well as a portion of the Badlands. In general, human activities throughout this area and in particular, mining activities associated with the Black Hills, have raised a concern about the potential for adverse affects related to sediment transported down the Cheyenne River and into Lake Oahe. The Water Resources Development Act of 2000 (WRDA) directed that within 10 years the Secretary of the Army shall (1) complete a study of sediment contamination in the Cheyenne River and (2) take appropriate remedial action to eliminate any public health and environmental risk posed by the contaminated sediment. The Omaha District, Corps of Engineers, contracted with engineering-environmental Management, Inc (e2m) to compile a comprehensive database of existing literature on the Cheyenne River relative to potential contamination. Review of the available information identified key issues, as summarized in the following paragraphs.

A primary geological formation in the Cheyenne River basin is Pierre Shale, which has a significant impact on the mineralogical and chemical nature of the river's sediment. It tends to yield high amounts of selenium, along with other heavy metals such as mercury. Review of the literature showed that there has been minimal comprehensive studies of the background constituents, either mineral or elemental, of the sediment in the Cheyenne River.

The Homestake Mining Company near Lead, SD, was the dominant mine in the Black Hills since its incorporation in 1877. Wastewater from the milling operations flowed into Whitewood Creek, which is in the Belle Fourche River basin. The Belle Fourche joins the Cheyenne River above Plainview, SD. Recovery of gold from ore was facilitated by amalgamation with mercury. In 1901, that process was supplemented with cyanide extraction. During the 1960's, the estimated discharge of mercury into Whitewood Creek ranged between 9 and 18 kilograms per day (kg/day). Cyanide treatment began to be used exclusively in the early 1970s. The estimated daily discharge included 140 kg of cyanide, and 8600 kg of arsenic.

Homestake Mine, including an 18-mile stretch of Whitewood Creek, was designated a Superfund site in 1983. Remedial action was completed in 1994. There is evidence that arsenic concentrations in the Cheyenne River are elevated as a result of mining practices in the Black Hills. The higher readings of arsenic tend to be in the deeper sediments. This is especially evident where the pool effects of Lake Oahe have caused sediment deposition. Total mercury concentrations have not been shown to exceed natural background levels, but methylmercury concentrations appear elevated. The Belle Fourche River does show mercury concentrations higher than normal background levels. The Belle Fourche thus could continue to add mercury to the Cheyenne, albeit in small quantities. Sediment samples indicate that selenium concentrations are nearly high enough to negatively affect wildlife. However, this appears to be caused by natural conditions. Data on environmental sampling (water quality, sediment and fish tissue) showed that all other constituents were not a major concern. This includes such constituents as cadmium, copper, cyanide, lead, uranium and zinc.

The arsenic contamination apparently isn't problematic at the present time, since human activities on the river generally don't interact with the deeper sediment, where the higher concentrations of arsenic reside. This is also true for wildlife interaction with the riverbed.

While elemental mercury readings generally are below health thresholds, there have been some higher readings of methylmercury in the water and fish tissue. This is a result of a ready supply of elemental mercury (whether naturally occurring, or from human activities), along with other conditions favoring methylation (i.e, adequate concentrations of dissolved sulfate and organic material, lack of dissolved oxygen, high pH and high dissolved solids). Advisories have been issued (1973, 2001) on the Cheyenne for consumption of fish, due to the potential for excessive mercury. The existing literature on mercury provides much less data than needed to address the issue of possible sediment contamination, especially in light of mercury's toxicity and potential for bioaccumulation.

In order to carry through with the 1999 WRDA directive, the Corps of Engineers will need to gather more data (either from new, unpublished reports from other agencies, or through additional sampling and analysis). This will concentrate on mercury, but may also include arsenic. The goal is to reach a firm conclusion on whether the Cheyenne River sediment is contaminated, and what remedial measures would be appropriate.

1.0 Project Background

The headwaters of the Cheyenne River are located in the Thunder Basin National Grassland in the Powder River Basin of northeastern Wyoming. The river flows generally east around the southern margin of the Black Hills of southwestern South Dakota. The Cheyenne then flows northeast past the Badlands of South Dakota and on to its convergence with the Missouri River at Lake Oahe, in central South Dakota (Figure 1-1). The Cheyenne River and its tributaries carry runoff and sediment from the Black Hills and the grasslands surrounding them, as well as a portion of the Badlands. In general, human activities throughout this area and in particular, mining activities associated with the Black Hills, have raised a concern about the potential for adverse affects related to sediment transported down the Cheyenne River and into Lake Oahe. It is also noteworthy that a number of the formations crossed by the Cheyenne River and its tributaries contain elevated levels of various natural elements, some of which have the potential to cause adverse health affects.

Concern has been raised about the mineral and chemical make up of the sediment in and of the Cheyenne River. The concerns center on how the sediment, and contaminants it might contain, may affect the health of people who obtain their water from the river, fish, recreate or otherwise come into contact with sediment from the Cheyenne River and of the fish and wildlife that equally come into contact with sediment from the Cheyenne River.

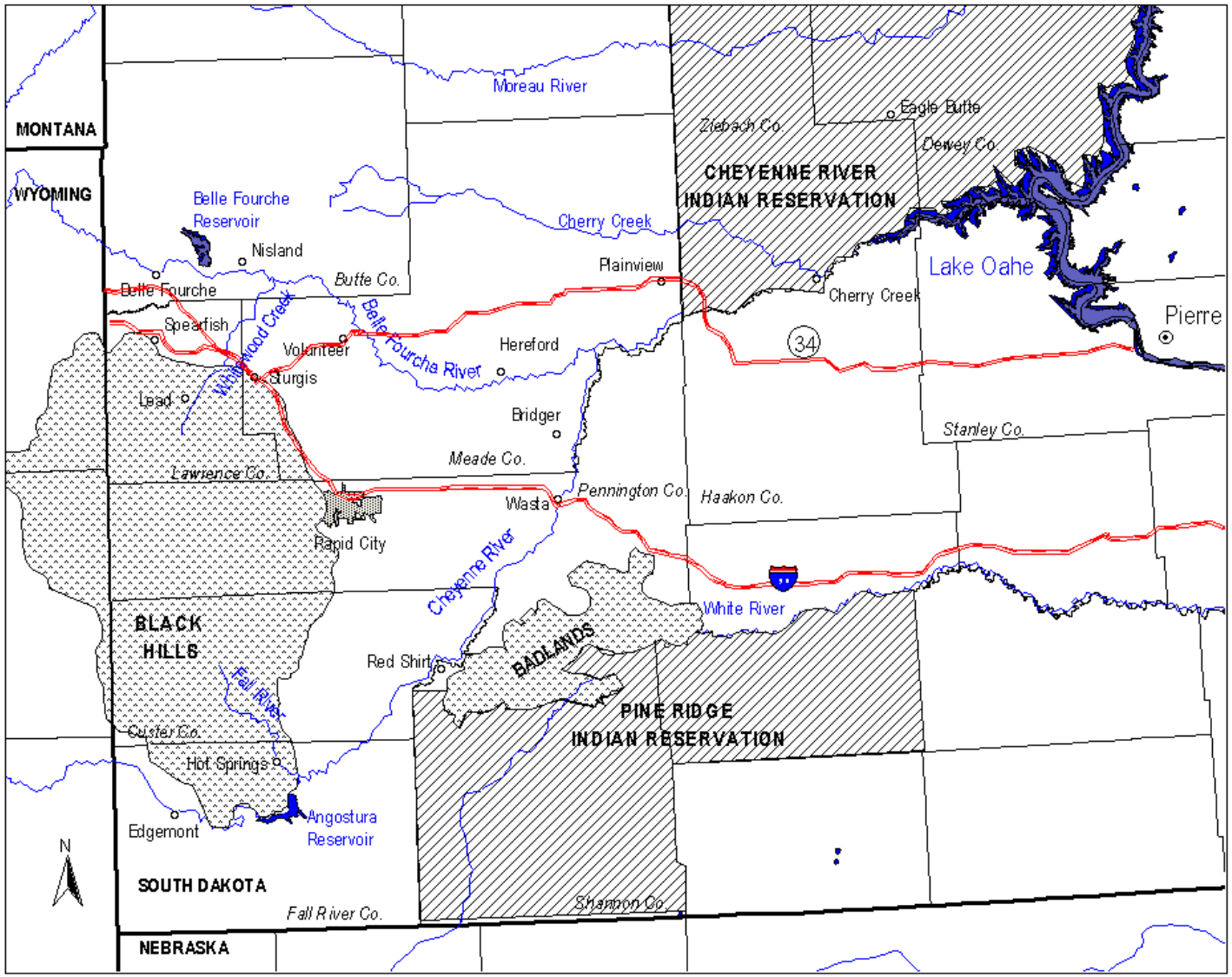


Figure 1-1. General location map

2.0 Legislative Background

Title VI of the Water Resources Development Act (WRDA) of 1999, Public Law (P.L.) 106-53 (S.507), Cheyenne River Sioux Tribe, Lower Brule Sioux Tribe and State of South Dakota Terrestrial Wildlife Habitat Restoration, approved on August 17, 1999, Sections 601 thru 609, provides for (1) transfer to the South Dakota Department of Game, Fish and Parks (SDGFP) the lands and recreation areas (a) located above the top of the exclusive flood pool of the Oahe, Big Bend, Fort Randall, and Gavins Point projects of the Pick-Sloan Missouri River Basin Program (b) which were acquired by the Secretary for the implementation of the Pick-Sloan Missouri River Basin Program (c) located outside the external boundaries of a reservation of an Indian tribe and (d) located within the State of South Dakota; (2) transfer to the Secretary of the Interior for the use of the Indian Tribes in perpetuity, the lands and recreation areas (a) located above the top of the exclusive flood pool of the Oahe and Big Bend projects of the Pick-Sloan Missouri River Basin Program (b) which were acquired by the Secretary for the implementation of the Pick-Sloan Missouri River Basin Program and (c) located within the external boundaries of the Cheyenne River Sioux Tribe and the Lower Brule Sioux Tribe; (3) establishment of a $165.4 million trust fund in the Treasury of the United States ($108 million for the State of South Dakota and $57.4 million for the Cheyenne River Sioux Tribe and the Lower Brule Sioux Tribe), of which the interest, after the fund has been fully capitalized, shall be transferred to the above parties to fund the annual scheduled work for terrestrial wildlife habitation restoration work, cultural resources preservation, and management of transferred lands and recreation areas, and other purposes.

Various technical amendments to WRDA of 1999, P.L. 106-53 (S.507) were provided in WRDA of 2000, P.L. 106-541 (S.2796), Title V – Miscellaneous Provisions, Sections 540, which was approved on December 11, 2000. One of the major provisions was that not later than 10 years after the date of enactment of this subsection, the Secretary of the Army shall (1) complete a study of sediment contamination in the Cheyenne River and (2) take appropriate remedial action to eliminate any public health and environmental risk posed by the contaminated sediment.

3.0 Cheyenne River Sedimentation Recon Study

On 20 September 2001, the U.S. Army Corps of Engineers (USACE) contracted with engineering environmental Management, Inc. (e2M) under contract number DACA45-00-D-0010, Delivery Order 16 to compile a bibliography, with abstracts, of all relevant published studies or other sources of significant data; e.g., letters, memoranda, newspaper and magazine articles, interviews, maps, aerial photographs, databases, etc., concerning possible sediment contamination affecting the main channel of the Cheyenne River from the headwaters to its convergence with the Missouri River at Lake Oahe. On 28 June 2002, the bibliography was delivered to the USACE under the heading "Final Bibliography Report, Literature Search, Cheyenne River Sedimentation Recon Study, South Dakota and Wyoming, 28 June 2002" and consisted of an access database, which included 296 entries. The documents were classified according to their primary topic. The fourteen topic classifications are listed below, with the number of entries for each topic.

> Water Quality (82); Bedrock Mineralogy (58); Sediment Contamination (46);
> Fish (38); Mine Tailings (17); Contamination (15); Wildlife (10);
> Sedimentation (9); Water Resources (6); Sediment Mineralogy (4);
> Vegetation (4); Benthic Macroinvertebrates (3);
> Threatened and Endangered Species (2); Human Health (2)

The Access database will be the focal point for this report and shall determine whether there is enough information to formulate a conclusion as to the possibility of contamination of the Cheyenne River sediment or if more data shall be needed.

References in this report are identified by their database numbers (1 through 296) or as supplemental (S1, S2, etc…) references and are listed at the end of the document.

4.0 Literature Search and Analysis

4.1 Bedrock Mineralogy and Constituent Elements

4.1.1 Introduction

A significant problem exists in evaluating possible contamination in sediment of the Cheyenne River because most, if not all, of the possible contaminants are also natural constituents of the rocks, minerals, and soils of the basin. The processes of weathering, erosion, and transport working on this material, produces the sediment that is carried by the Cheyenne River. To evaluate possible sediment contamination in the Cheyenne River, it becomes important to understand something about the bedrocks of the basin, and the soils weathered from those bedrocks.

The Cheyenne River originates in east-central Wyoming in areas of Eocene and Paleocene-age rock exposures. The Belle Fourche River, a tributary to the Cheyenne River, also originates in the same geological formations. Both rivers stay within the outcrop belts of Late Cretaceous-age shales and chalks as they flow around the Black Hills uplift. The Cretaceous-age shales can be a source of sulfate and several heavy metals. The rivers continue flowing eastward across flat lying outcrops of Cretaceous-age Pierre Shale that contains high concentrations of iron, manganese, and limestone concretions. The Pierre Shale also is characterized by an abundance of low permeability bentonite clay. As a result, the Cheyenne River can experience high levels of turbidity during periods of intense or extended rainfall.

Bedrock mineralogy, and therefore the elemental constituents which make up minerals, varies with bedrock type. The major bedrock types in the Cheyenne River basin include the Precambrian igneous-metamorphic core of the Black Hills, surrounded and overlain by sedimentary layers of progressively younger rocks from the Paleozoic Cambrian Period through the Mesozoic Era to the Cenozoic Tertiary Period. A generalized geologic map of the Cheyenne River Basin, including South Dakota and the northeastern part of Wyoming, is shown on Figure 4-1.

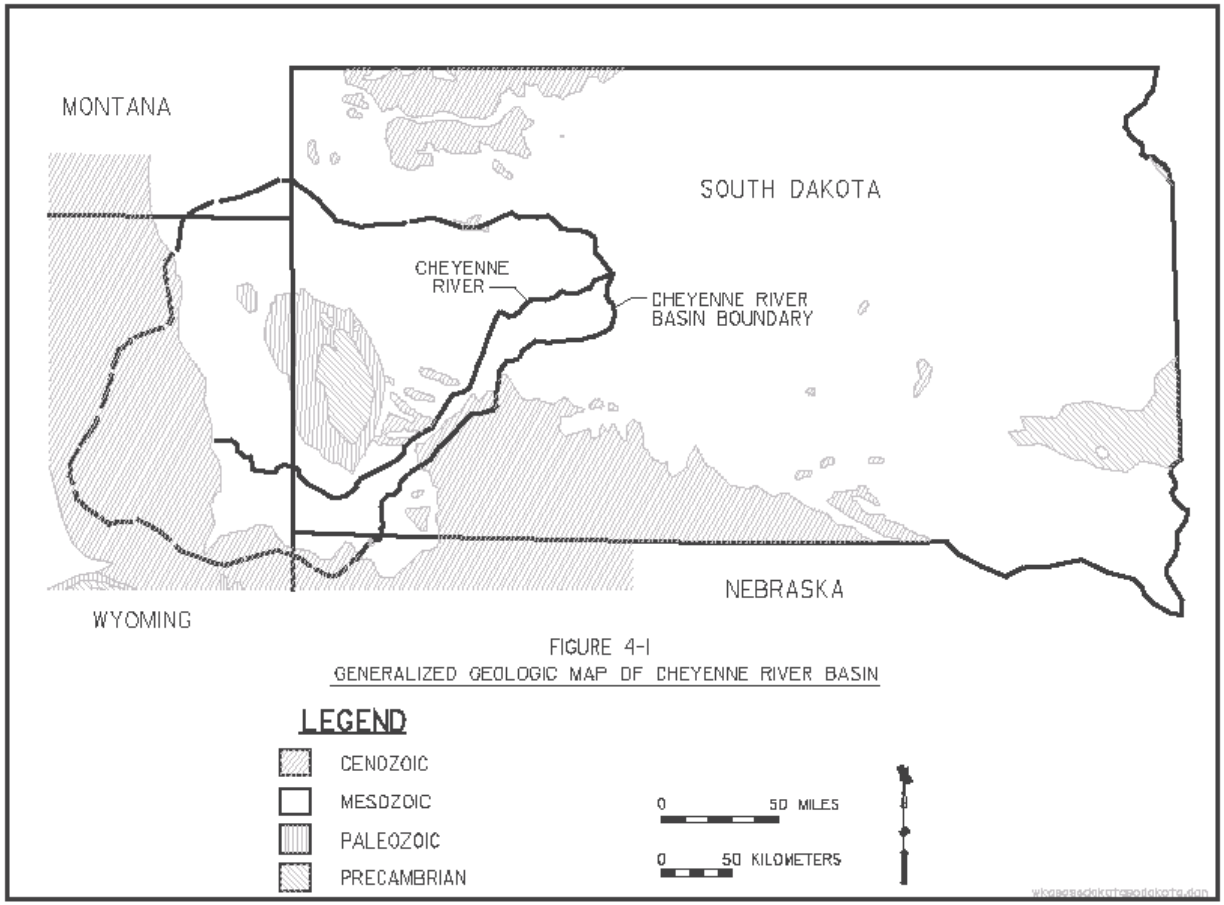


FIGURE 4-1
GENERALIZED GEOLOGIC MAP OF CHEYENNE RIVER BASIN

4.1.2 Precambrian Core of the Black Hills

The Precambrian core of the Black Hills is largely composed of metamorphosed sedimentary rocks with lesser amounts of metabasalt, metagabbros, granites, and pegmatites. Metamorphic grade generally decreases with distance from the Harney Peak Granite, and to the north (Ref. S32). Together, igneous and metamorphic rocks make up approximately 92.1 % of the volume of the crust of the earth (Ref. S12). As such, a typical mineral and elemental make up of the rocks in the core of the Black Hills may be approximated by using the crustal abundance of common minerals and elements. Typical crustal abundances for the common minerals by weight percentages and elements as ppm are given in Tables 4-1 and 4-2, respectively.

Table 4-1
Abundance of Common Minerals in the Crust of the Earth

Mineral	Weight Percent
Plagioclase	39
K-feldspar	12
Quartz	12
Pyroxenes	11
Micas	5
Amphiboles	5
Clay Minerals & Chlorites	4.6
Olivines	3
Calcite & aragonite	1.5
Dolomite	0.5
Magnetite	1.5
Others (e.g., garnets, kyanite, and apatite)	4.9
	Total 100.0

While mineral and chemical analysis of individual rock types within the igneous-metamorphic core of the Black Hills may vary greatly from these averages, they do provide a reasonable starting point to interpret mineral and chemical analysis of sediment arriving at the Cheyenne River from this portion of the basin. It is also important to note that the Cheyenne River does not cut directly through the Black Hills, but passes to the south and east. This allows sediment from the various rock types in the Black Hills core to be mechanically and chemically weathered and homogenized along tributary streams prior to entering the Cheyenne River proper. The minimum distance traveled by sediment from the igneous-metamorphic core of the Black Hills down tributary streams to the Cheyenne River is over 20 miles. During this transport, these sediments are in turn commingled with the sediments derived from the surrounding Paleozoic, Mesozoic and Cenozoic sedimentary rocks as they travel first to and then down the Cheyenne River.

Table 4-2
Abundance of Elements in the Crust of the Earth, in ppm (µg/g)

Element	Crustal Average		Element	Crustal Average
H	1,400		Rh	0.005
Li	20		Pd	0.01
Be	2.8		Ag	0.07
B	10		Cd	0.2
C	200		In	0.1
N	20		Sn	2
O	466,000		Sb	0.2
F	625		Te	0.01
Na	28,300		I	0.5
Mg	20,900		Cs	3
Al	81,300		Ba	425
Si	277,200		La	30
P	1,050		Ce	60
S	260		Pr	8.2
Cl	130		Nd	28
K	25,900		Sm	6
Ca	36,300		Eu	1.2
Sc	22		Gd	5.4
Ti	4,400		Tb	0.9
V	135		Dy	3
Cr	100		Ho	1.2
Mn	950		Er	2.8
Fe	50,000		Tm	0.5
Co	25		Yb	3.4
Ni	75		Lu	0.5
Cu	55		Hf	3
Zn	70		Ta	2
Ga	15		W	1.5
Ge	1.5		Re	0.001
As	1.8		Os	0.005
Se	0.05		Ir	0.001
Br	2.5		Pt	0.01
Rb	90		Au	0.004
Sr	375		Hg	0.08
Y	33		Tl	0.5
Zr	165		Pb	13
Nb	20		Bi	0.2
Mo	1.5		Th	7.2
Ru	0.01		U	1.8

4.1.3 Sedimentary Rocks of the Cheyenne River Basin

Surrounding the igneous-metamorphic core of the Black Hills is a layer of Paleozoic sedimentary rocks. During the Paleozoic, the Black Hills area was near the eastern shoreline of a great seaway in the Rocky Mountain area. Except for the Minnelusa Formation that thickens to the south, Paleozoic sedimentary units are thinnest in the area of the Black Hills and thicken to the north (Ref. S46). The Paleozoic sedimentary rocks surrounding the core of the Black Hills, from nearest to farthest included:

- The Lower Ordovician and Upper Cambrian Deadwood Formation, a brown to light-gray glauconitic sandstone, shale and limestone, from 4 to 700 feet thick (Ref. S11).

- The Middle Ordovician Winnipeg Formation, a gray and light-green shale and siltstone, from 0 to 110 feet thick.

- The Upper Ordovician Whitewood Dolomite, a gray to tan dolomite, from 0 to 150 feet thick.

- The Lower Mississippian and Upper Devonian Englewood Formation, a pink to light-gray dolomitic limestone, from 35 to 60 feet thick.

- The Lower Mississippian Pahasapa (Madison) Limestone, a gray to light tan, cavernous dolomitic limestone that forms conspicuous cliffs, from 300 to 600 feet thick.

- The Lower Permian and Pennsylvanian Minnelusa Formation, a light-brown to red and gray sandstone, solution breccia/anhydrite, limestone and shale (with slight uranium anomalies in basal part), from 400 to more than 1,500 feet thick.

- The Lower Permian Opeche Shale, a red silty shale, from 25 to 150 feet thick.

- The Lower Permian Minnekahta Limestone, gray to purplish-gray, slabby limestone, from 35 to 50 feet thick.

Surrounding and overlying these Paleozoic sedimentary rocks is a layer of Mesozoic sedimentary rocks. The Mesozoic sedimentary rocks, surrounding the outcrop of Paleozoic rocks encircling the core of the Black Hills, from nearest to farthest included:

- The Triassic and Permian Spearfish Formation, a red shale and siltstone, and white gypsum and minor limestone, characterized geochemically by high concentrations of strontium and lithium (presumably in the gypsum beds) and anomalous concentrations of uranium and radioactive potassium, from 325 to 900 feet thick.

- The Middle Jurassic Gypsum Spring Formation, a massive white gypsum and minor claystone, from 0 to 125 feet thick.

- The Upper and Middle Jurassic Sundance Formation, a reddish-gray to light-gray siltstone, sandstone, white limestone, and glauconitic sandstone and shale, from 250 to 475 feet thick.

- The Upper Jurassic Unkpapa Sandstone, a variegated, iron-stained sandstone, from 0 to 275 feet thick.

- The Upper Jurassic Morrison Formation, a light-gray siliceous claystone and shale, from 0 to 150 feet thick.

- The Lower Cretaceous Inyan Kara Group distinguished from surrounding units by high concentrations of uranium and low levels of radioactive potassium. The Inyan Kara Group is subdivided into two formations. The Lakota Formation is a brown, yellow, and reddish–brown claystone and sandstone locally interbedded with limestone and lignite lenses, from 35 to 700 feet thick. The Fall River Sandstone is a brown to ocher sandstone and minor siltstone, from 100 to 200 feet thick.

- In the Black Hills area and generally to the west into Wyoming, the Lower Cretaceous Scull Creek, Newcastle Sandstone, Mowery Shale, and Upper Cretaceous Belle Fourche Shale form the Graneros Group. East toward the Missouri River and South toward Colorado and Nebraska, the lower Cretaceous Scull Creek Shale continues but the Newcastle Sandstone and Mowry Shale transitions into the Lower Cretaceous Dakota Sandstone. Above that, the Upper Cretaceous Belle Fourche Shale transitions into the Upper Cretaceous Graneros Shale.

- The Lower Cretaceous Scull Creek Shale, a black shale, characterized by anomalous concentrations of lead, manganese, uranium and thorium, from 150 to 270 feet thick.

- The Lower Cretaceous Newcastle Sandstone, a gray to light-brown sandstone and siltstone containing beds of bentonite and lignite, from 0 to 100 feet thick.

- The Lower Cretaceous Mowry Shale, a black siliceous shale containing thin bentonite layers, characterized by anomalous concentrations of lead, manganese, uranium and thorium, from 125 to 230 feet thick.

- The Lower Cretaceous Dakota Sandstone, a white, tan, or light gray sandstone, very fine to coarse grained, loose to tightly cemented; interbedded with dark colored shale.

- The Upper Cretaceous Belle Fourche Shale, a dark gray to black bentonitic shale containing minor limestone lenses and large concretions, characterized by anomalous concentrations of thorium, rubidium, hafnium, lanthanum, and lithium in bentonite layers and niobium, manganese, and chromium in black shale, also small uranium anomalies, from 150 to 850 feet thick.

- The Upper Cretaceous Graneros Shale, a medium to dark gray non-calcareous shale, with calcareous concretions and pyrite and marcasite crystals common. Locally the

Graneros Shale may contain thin lenses and beds of sandstone, and may be sandy or silty at the base.

- The Upper Cretaceous Greenhorn Limestone, a light-gray limestone and limy sandstone, from 225 to 400 feet thick.

- The Upper Cretaceous Carlisle Shale, a dark gray to black sandy shale containing large concretions, characterized by anomalous concentrations of rubidium, and lithium in bentonite beds, and lead, vanadium, and antimony in black shale, from 345 to 620 feet thick.

- The Upper Cretaceous Niobrara Formation, a light-gray to yellowish gray marl and shale, soils developed on the Niobrara may have high concentrations of selenium, from 80 to 300 feet thick.

- Beyond the outcrop of the Niobrara, the overlying Upper Cretaceous Pierre crops out to form the upper most bedrock layer over a significant portion of the Cheyenne River basin to the north, south and east of the Black Hills. In addition, the Cheyenne River valley is cut into the Pierre Shale for much of its length. As such, the Pierre Shale has a significant impact on the mineral and chemical composition of the sediments in the Cheyenne River, particularly the fine grained silt and clay sediments.

- The Upper Cretaceous Pierre Shale is a dark-gray to black shale containing minor limestone lenses and large concretions, characterized by anomalous concentrations of rubidium, niobium, and lanthanum in bentonite beds; zinc, selenium, cadmium, bismuth, vanadium, and antimony in black shale; manganese, nickel, chromium, and zinc in concretion-rich horizons; radioactive potassium in much of the unit; and uranium in the basal part of the unit, from 1,200 to 2,700 feet thick.

- Significant mostly in the western and northern portions of the basin are the Upper Cretaceous Fox Hills Sandstone and Lance Formation.

- The Upper Cretaceous Fox Hills Sandstone is a light-gray sandstone and shale, from 125 to 200 feet thick.

- The Upper Cretaceous Lance (Hell Creek) Formation is a medium-gray shale interbedded with channel sandstone and minor lignite lenses, from 2,000 to 3,400 feet thick.

Cenozoic rocks appear to have a generally minor impact on the sediments of the Cheyenne River as they either crop out only in the extreme upper portion of the basin, in Wyoming, or in limited areas. Cenozoic rocks within the Cheyenne River Basin include:

- A number of mostly small Tertiary (Eocene and Paleocene) intrusive igneous bodies occur along the northern portion of the Black Hills and extend to the northwest, to Devil's Tower.

- The Tertiary (Paleocene) Fort Union Formation occurs in the far western portion of the basin and is divided into three members. The Ludlow (Tullock) Member, somber gray clays and sandstones with thin beds of lignite, from 0 to 350 feet thick. The Cannonball (Lebo) Member, green marine shales and yellow sandstones often as concretions, from 0 to 225 feet thick. And the Tongue River Member, light-colored clays and sands with coal beds to the north and west (Powder River Basin, Wyoming), from 0 to 425 feet thick.

- The Tertiary (Eocene) Wasatch Formation also occurs in the far western portion of the basin and is a buff arkosic sandstone with lenticular conglomerate bodies, drab siltstone, carbonaceous shale, and many coal beds, from 0 to 3,000 feet thick in the Powder River Basin to the west (Ref. S25).

- The Tertiary (Oligocene) White River Group consists of the basal Chadron Formation and the overlying Brule Formation, from 0 to 300 feet thick. The Chadron Formation is composed of dark-gray bentonite and light-gray tuffaceous claystone, siltstone, sandstone, and arkose interbedded with thin lenticular beds of limestone. The Brule Formation is composed of massive, modular pinkish-gray calcareous claystone, tuffaceous siltstone, and channel sandstone.

4.1.4 Analysis of Sedimentary Bedrocks

From the above descriptions it is apparent that the bedrock, exclusive of the igneous metamorphic core of the Black Hills is predominately sandstones, shales (including clays), and carbonates (limestone and dolomites). One can again compare the elemental abundances in these principal types of sedimentary rocks, which comprise 90 percent or more of the exposed bedrock in the basin, to get a sense of their impact on the sediments of the Cheyenne River. Table 4-3 gives the elemental abundances for these three principal sedimentary rock types in ppm.

A comparison of crustal occurrence of the principal sedimentary rock types show that sandstones and carbonates occur in about equal volumes, with shales being slightly greater than the sandstones and carbonates combined. This is probably a reasonable assumption for the exposed sedimentary bedrock within the Cheyenne River Basin. Not surprisingly, there is some variance between the abundances in Table 4-3 and those in Table 4-2, the crustal abundances used as a proxy for the igneous metamorphic rocks as a group. This is due to how nature redistributes the elements from the weathering of rock into soils, then sediments, and finally into sedimentary rocks. Sandstones are primarily composed of quartz grains (silicon dioxide), which explains the high levels of silicon. The sand grains may be cemented together with carbonates, iron oxides or sometimes clay minerals. Other elements occur as “contaminants” in the cement or as minor grains, as in the case of some resistant minerals such as zircon, garnet, beryl, etc. Carbonates are mostly calcite or dolomite (calcium and magnesium with carbon and oxygen), with other elements being incorporated as “contaminants” such as grains of sand, silt or clays or occasionally as substitutions of some other metals for either calcium or magnesium in the crystalline structure. Shales are primarily aluminum silicates with the capacity to

substitute a wide variety of metals in their crystalline structure. This helps explain the high levels of the common and trace metals, as well as silicon and aluminum. Shales, particularly black shales, contain organic matter that also adsorbs and holds trace metals, along with the clays. The chemistry of shales and how they interact with the environment is particularly important given the likely impact that shale bedrock in general and the Pierre Shale in particular, have on the Cheyenne River and the sediments it carries.

Table 4-3
Abundance of Elements in Sedimentary Rocks, in ppm (µg/g)

Element	Shales	Sandstones	Carbonates	Element	Shales	Sandstones	Carbonates
Li	66	15	5	Mo	2.6	0.2	0.4
Be	3	0.X	0.X	Ag	0.07	0.0X	0.0X
B	100	35	20	Cd	0.3	0.0X	0.09
F	740	270	330	In	0.1	0.0X	0.0X
Na	9,600	3,300	400	Sn	6.0	0.X	0.X
Mg	15,000	7,000	47,000	Sb	1.5	0.0X	0.2
Al	80,000	25,000	4,200	I	2.2	1.7	1.2
Si	273,000	368,000	24,000	Cs	5	0.X	0.X
P	700	170	400	Ba	580	X0	10
S	2,400	240	1,200	La	24	16	6.3
Cl	180	10	150	Ce	50	30	10
K	26,600	10,700	2,700	Pr	6.1	4.0	1.5
Ca	22,100	39,100	302,300	Nd	24	15	6.2
Sc	13	1	1	Sm	5.8	3.7	1.4
Ti	4,600	1,500	400	Eu	1.1	0.8	0.3
V	130	20	20	Gd	5.2	3.2	1.4
Cr	90	35	11	Tb	0.9	0.6	0.2
Mn	850	X0	1,100	Dy	4.3	2.6	1.1
Fe	47,200	9,800	3,800	Ho	1.2	1.0	0.3
Co	19	0.3	0.1	Er	2.7	1.6	0.7
Ni	68	2	20	Tm	0.5	0.3	0.1
Cu	45	X	4	Yb	2.2	1.2	0.7
Zn	95	16	20	Lu	0.6	0.4	0.2
Ga	19	12	4	Hf	2.8	3.9	0.3
Ge	1.6	0.8	0.2	Ta	0.8	0.0X	0.0X
As	13	1	1	W	1.8	1.6	0.6
Se	0.6	0.05	0.08	Hg	0.4	0.3	0.2
Br	4	1	6.2	Tl	1.0	0.5	0.2
Rb	140	60	3	Bi	0.4	0.17	0.2
Sr	300	20	610	Pb	20	7	9
Y	26	15	6.4	Th	12	1.7	1.7
Zr	160	220	19	U	3.7	0.45	2.2
Nb	11	0.0X	0.3				

X - an unquantifiable number at the order of magnitude shown or less.

4.1.5 Analysis of the Pierre Shale

As discussed above, the Pierre Shale likely has a significant impact on the mineralogical and chemical nature of the sediment in the Cheyenne River. An extensive study of the chemical and mineralogical composition of the Pierre Shale was published by the USGS in 1980 (Ref. S36). Table 4-4 presents a summation of analysis from the Pierre Shale, and equivalent units, which can be used to understand impacts of the Pierre Shale on sediments in the Cheyenne River. The major sources of sediments were the Elkhorn Mountains Volcanics and similar volcanic piles to the west, which contributed two-thirds to three-quarters of the material in the Pierre Shale and its equivalents. For that reason, the Pierre contains twice as much selenium (Se) as other marine shales. One would also expect to see elevated levels of other heavy metals associated with volcanics in the Pierre Shale, such as mercury. However, mercury analysis was not reported in this study. The impact of the Pierre Shale would be most apparent in the fine grained sediments of the Cheyenne River, such as clays, silts, and sediments high in either or both. The effects of the Pierre on sediments of the Cheyenne River would likely increase with increasing distance downstream.

4.1.6 Soils of the Western United States

Table 4-5 presents data for soils west of the 96th meridian from a USGS study of soils of the United States (Ref. S37). (The 96th meridian runs through Minnesota, roughly 22 miles east of the South Dakota line.) A comparison of the data in Tables 4-4 and 4-5 show similar results between analysis of the Pierre Shale and soils in the western U.S. The Pierre Shale contains above average concentrations of many of the trace metals, when compared to either the geometric or arithmetic means for western soils. However, with only a few minor exceptions, the analysis from the Pierre Shale falls within the range of western soils analysis.

Table 4-4
Composition of the Pierre Shale and Equivalent Rocks, in ppm (or percent)

Element or Mineral	Marine Shale and Siltstone	Organic Rich Marine Shale	Marine Marls	Bentonites
Oxides	**Percent**	**Percent**	**Percent**	**Percent**
SiO_2	61	53	39	55
Al_2O_3	14	13	11	18
$Fe_{(x)}O_{(y)}$	9.5	12.8	8.8	8.9
MgO	2.4	1.1	1.8	3.0
CaO	1.9	0.92	17.4	1.8
Na_3O	1.1	0.65	0.63	1.5
K_2O	2.5	2.7	2.2	0.45
H_2O	7.6	8.5	5.4	13.1
TiO_2	0.58	0.61	0.45	0.39
P_2O_5	0.14	0.15	0.22	0.10
S and S^{-3}	0.76	6.5	1.75	0.63
SO_3	0.47	3.2	0.49	1.0
F	0.072	0.079	0.073	0.094
Cl	0.019	0.05	0.02	N.D.
C, organic	0.93	5.9	1.3	0.5
C, mineral	0.45	0.19	3.83	0.10
Trace Elements	**ppm**	**ppm**	**ppm**	**ppm**
Zr	190	180	140	260
Y	27	19	20	32
Yb	2.8	3.0	2.0	2.7
La	34	19	22	57
Sn	1.5	1.4	0.7	2.1
Sc	17	17	17	9.1
B	110	141	71	61
Ga	17	14	12	19
Pb	21	20	20	31
Ba	640	600	440	700
Sr	150	96	540	190
Mn	750	150	2,700	250
Co	13	13	15	6.7
Ni	40	58	46	25
Zn	120	140	120	76
Cd	0.88	2.2	2.2	1.5
Cr	80	108	78	9.1
V	180	490	180	67
Cu	38	90	39	11
Mo	6.3	86	5.9	2.9
Se	4.7	60	11	0.7
As	18	113	18	5.3
U	5.9	13	5.0	5.7
EU	18	27	12	9
Minerals	**Percent**	**Percent**	**Percent**	**Percent**
Total Clay	62	58	51	88
Quartz	23	20	13	3.4
Cristobalite	1.6	0	0	0
K-feldspar	1.4	2.8	0.7	<0.1
Plagioclase	4.3	1.0	1.3	2.9
Calcite	0.7	0	28	1.0
Dolomite	2.9	0.4	1.9	0.0
Organic matter	1.3	8.2	1.8	<0.1
Pyrite	0.5	3.9	1.6	0.2

Table 4-5
Abundance of Elements in Soils of the Western United States, in ppm (or percent)

Element	Geometric Mean	Standard Deviation	Observed Range	Arithmetic Mean
Al, percent	5.8	2.00	0.5 - 10	7.4
As	5.5	1.98	<0.10 - 97	7.0
B	23	1.99	<20 - 300	29
Ba	580	1.72	70 - 5,000	670
Be	0.68	2.30	<1 - 15	0.97
Br	0.52	2.74	<0.5 - 11	0.86
C, percent	1.7	2.37	0.16 - 10	2.5
Ca, percent	1.8	3.05	0.06 - 32	3.3
Ce	65	1.71	<150 - 300	75
Co	7.1	1.97	<3 - 50	9.0
Cr	41	2.19	3 - 2,000	56
Cu	21	2.07	2 - 300	27
F	280	2.52	<10 - 1,900	440
Fe, percent	2.1	1.95	0.1 - >10	2.6
Ga	16	1.68	<5 - 70	19
Ge	1.2	1.32	0.58 - 2.5	1.2
Hg	0.046	2.33	<0.01 - 4.6	0.065
I	0.79	2.55	<0.5 - .6	1.2
K, percent	1.8	0.71	0.19 - 6.3	None
La	30	1.89	<30 - 200	37
Li	22	1.58	5 - 130	25
Mg, percent	0.74	2.21	0.03 - >10	1.0
Mn	380	1.98	30 - 5,000	480
Mo	0.85	2.17	<3 - 7	1.1
Na, percent	0.97	1.95	0.05 - 10	1.2
Nb	8.7	1.82	<10 - 100	10
Nd	36	1.76	<70 - 300	43
Ni	15	2.10	<5 - 700	19
P	320	2.33	40 - 4,500	460
Pb	17	1.80	<10 - 700	20
Rb	69	1.50	<20 - 210	74
S, percent	0.13	2.37	<0.08 - 4.8	0.19
Sb	0.47	2.15	<1 - 2.6	0.62
Sc	8.2	1.74	<5 - 50	9.6
Se	0.23	2.43	<0.1 - 4.3	0.34
Si, percent	30	5.70	15 - 44	None
Sn	0.90	2.11	<0.1 - 7.4	1.2
Sr	200	2.16	10 - 3,000	270
Ti, percent	0.22	1.78	0.05 - 2.0	0.26
Th	9.1	1.49	2.4 - 31	9.8
U	2.5	1.45	0.68 - 7.9	2.7
V	70	1.95	7 - 500	88
Y	22	1.66	<10 - 150	25
Yb	2.6	1.63	<1 - 20	3.0
Zn	55	1.79	10 - 2,100	65
Zr	160	1.77	<20 - 1,500	190

4.1.7 Conclusions

A significant problem exists in evaluating possible contamination in sediment of the Cheyenne River because most, if not all, of the possible contaminants are also natural constituents of the rocks, minerals, and soils of the basin. The primary database references contain little useful information for evaluating possible bedrock sources for potential sediment contaminants. Outside references were used to supplement information from the primary database references, in preparing this section of the report. However much of the information is difficult to compare and evaluate, as different lists of elements were analyzed and varying detection levels were reported in the documents reviewed. Of particular concern is the lack of uniform data on the concentration and distribution of heavy metals (such as mercury) and other toxic elements (such as selenium) in the various sedimentary bedrock units, particularly the Cretaceous shales and marls (Pierre Shale, Niobrara Formation, etc.). Additional research, focused on a limited list of potential contaminants of concern, involving a more thorough literature search and possibly including sampling of specific bedrock units, should be considered.

4.2 Background Sediment Constituents

4.2.1 Introduction

Many sediment studies that have been conducted along the Cheyenne River by the USGS and others, focused primarily on questions about possible environmental contamination related to mining. In addition, data has been collected for USBOR and the USDOE to monitor for possible environmental effects of irrigation projects or to prospect for potential sources of uranium in and around the Black Hills. These studies tend to focus on a limited number of chemical constituents or have goals unrelated to the specific condition of the Cheyenne River or the sediment it carries. Mineralogical data on sediments rarely were collected, and do not appear to have been collected from uncontaminated sediment samples. Lack of mineralogical data is not a significant problem as most analysis for contamination involves organic or inorganic elemental analysis of samples. Mineralogical analysis can, in some circumstances, provide information about the source of an elemental constituent in sediment and how it migrates through the environment.

4.2.2 Sediment Along the Cheyenne River above the Belle Fourche River

The USGS has been conducting studies of the Angostura Reclamation Unit, near Hot Springs, South Dakota, for the USBOR. Sediment analysis for a limited number of inorganic chemicals, mostly using the 62μm or less fraction of the samples, were published and are included here as Table 4-6 (Ref. 180). These analyses can be used to help approximate background levels for these constituents in uncontaminated sediment in the Cheyenne River, upstream of its confluence with the Belle Fourche River. Locations of various sampling locations are shown in Figure 4-2.

Table 4-6
Summary of Inorganic Chemicals from Sediment Samples Collected in the Angostura Unit, Hot Springs, South Dakota

Element	Number of Samples	Samples Below Detection Level	Range (µg/g)	Geometric Mean (µg/g)
Arsenic	29	0	5.6 – 21.7	9.0
Boron	25	3	<0.4 – 27	1.34
Cadmium	29	19	<2.0 – 2.0	0.91
Chromium	29	0	2 - 86	21
Copper	29	0	3 - 28	13
Lead	29	0	12 – 67	20
Mercury	29	19	<0.02 – 0.06	0.03
Molybdenum	29	18	<2 - 7.5	1.73
Nickel	29	0	4 - 39	16
Selenium	29	0	0.2 – 14	0.95
Vanadium	29	0	11 – 200	43
Zinc	29	0	21 – 317	62

Sediment samples were analyzed for uranium and reported separately as some may have been contaminated by tailings from ore milling at Edgemont, S.D. for uranium, vanadium, and molybdenum. An unknown number of samples collected in 1988 had reported concentrations of 1.9 to 5.3 mg/kg. In 1997, sediment samples from eight sites contained 2.5 to 17.8 mg/kg of uranium

Samples have been periodically collected along the Cheyenne River by the USGS, though published background data by the USGS from the Cheyenne River proper appear to be limited. A suspended sediment sample taken at Wasta, South Dakota, above the confluence with the Belle Fourche River provides some additional background data. That sample as reported in a USGS Open File Report (Ref. 25) published in 1989 provides the analysis shown in Table 4-7.

In 1998, the Office of Emergency and Remedial Response of the USEPA for background collected a sediment sample at Wasta, S.D. Antimony, cadmium, lead, mercury, nickel, selenium, silver, and thallium were reported as not detected (no detection levels were given). The Wasta sample was reported as a silty sand with the analysis shown in Table 4-7.

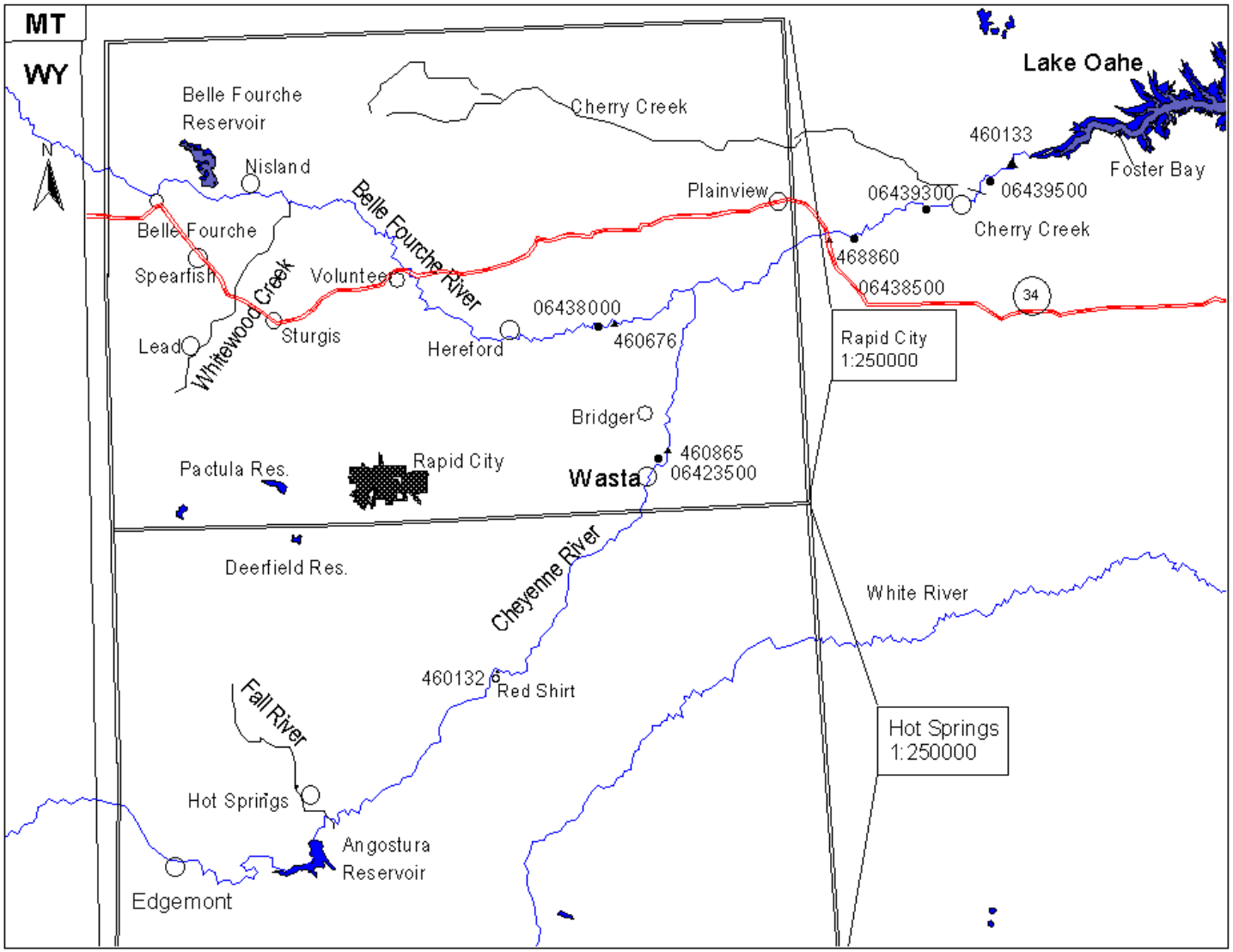


Figure 4-2. Location map for sampling locations (• = USGS station; ▲ = SDDENR station)

Table 4-7
Two Sediment Samples Collected on the Cheyenne River, near Wasta, South Dakota

Element	USGS Sample (μg/g)	1998 USEPA Sample (μg/g)
TOC	<0.1	4,200 (0.42%)
Aluminum	67,000 (6.7%)	3,900 (0.39%)
Antimony	0.8	
Arsenic	6.2	5
Barium		340
Cadmium	<0.5	
Calcium		40,000 (4.0%)
Chromium	47	3
Cobalt	11	2
Copper	16	6
Iron	27,000 (2.7%)	8,800 (0.88%)
Lead	17	
Magnesium		1,600 (0.16%)
Manganese	600 (0.06%)	520 (0.052%)
Mercury	0.06	
Nickel	14	
Potassium		1,900 (0.19%)
Selenium	0.6	
Sodium		900 (0.09%)
Titanium	2,900 (0.29%)	
Vanadium		11
Zinc	88	23

Two samples were taken by the USEPA in 1972 (Ref. 118) about 50 meters downstream of the I-90 bridge on the Cheyenne River (at Wasta) for background. The results from the limited analysis conducted were: arsenic – 5.9 & 3.6 μg/g, copper – 14.7 & 2.7 μg/g, mercury - less than 0.01 μg/g, (both), and zinc – 47.1 & 10.8 μg/g. Additional samples were collected on an uncontaminated tributary of the Cheyenne River, Elk Creek, at the bridge on the road between Wasta and Elm Springs (one sample) and on the Belle Fourche River above Whitewood Creek at Nisland (two samples) and about 4 miles west of Nisland (one sample). Combining those analyses with the Cheyenne River samples, the USEPA reported the following sediment background levels for the Cheyenne River Basin: arsenic – 4 to 17 ppm (μg/g), copper – 3 to 25 ppm (μg/g), mercury – 0.1ppm (μg/g), and zinc – 10 to 100 ppm (μg/g). Selenium was analyzed for but not reported in the document reviewed.

4.2.3 Sediment Along the Belle Fourche River above Whitewood Creek

Additional data were collected along the Belle Fourche River, a major tributary of the Cheyenne River, above the confluence with Whitewood Creek. Another USGS report from

1989 (Ref. 18) included a summary of analysis from 13-background sediment samples from the Belle Fourche River. That summary is reproduced here as Table 4-8.

The USGS reported the analysis of a background sediment sample, taken in 1998 from the Belle Fourche River between Nisland and the confluence with Whitewood Creek, of 23 ng/g (0.023 μg/g) total mercury (Ref. 225). Additional background sample data are provided as graphs, without exact numerical values, for five additional sites and a total of nine samples, all with values at approximately that same level. Seven more samples from five additional sites upstream of Homestake mine on Whitewood Creek are graphed showing levels up to 0.02 μg/g and described as possibly representing streams draining the 'igneous-metamorphic core of' the Black Hills where mercury might originate from natural weathering and also from numerous small mining operations.

Table 4-8
Summary of Thirteen Chemical Constituents in Uncontaminated Sediment Samples From the Flood Plain Along the Belle Fourche River Upstream of Whitewood Creek

Element	Arithmetic Mean (μg/g)	Standard Deviation (μg/g)	Minimum Concentration (μg/g)	Maximum Concentration (μg/g)
Calcium	19,400	10,400	8,330	40,900
Magnesium	2,680	740	1,440	3,970
Sodium	926	520	258	2,110
Potassium	515	393	174	1,490
Arsenic	9.2	5.2	4	20
Cadmium	0.12[1]	0.15	<0.05[2]	0.52
Chromium	4.0[1]	2.5	<0.5[2]	9.5
Copper	10.7	3.3	5.5	16
Cyanide	<0.5[1]	0	<0.5[2]	<0.5
Iron	23,700	20,900	11,200	86,600
Lead	13.4	4.3	5.7	23
Manganese	550	480	298	2,090
Mercury	<0.1	0	<0.1[2]	<0.1
Nickel	13.5	5.5	79	27
Selenium	1.0[1]	0.1	<1.0[2]	1.5
Silver	1.6[1]	1.4	<0.5[2]	5.5
Zinc	55	20	31	108

1 May not be significant, some values less than detection.
2 Less than detection limit.

4.2.4 Regional Studies

Probably the most comprehensive study of sediment in the Cheyenne River Basin that can be used to approximate background, was part of a study for the National Uranium Resource Evaluation Program, Department of Energy, by Union Carbide Corp. Several hundred samples were collected in the 1° by 2 ° Hot Springs and Rapid City Quadrangles (Figure 4-2). The Hot

Springs Quadrangle encompasses the Southern Black Hills and surrounding area while the Rapid City Quadrangle covers the Northern Black Hills and surrounding areas. A report was published for each quadrangle studied (Ref. S45 and S46).

Samples came from the Cheyenne River, the Belle Fourche River and many of their tributaries, so the data represent a truly broad regional picture of the Black Hills and surrounding area. Although some of the samples were likely impacted by contamination, the number of samples in each data set (each quadrangle) minimizes that impact. Also, as the contaminants differed in each quadrangle, it is possible to compare and contrast data from each quadrangle to evaluate the likely impact of including samples elevated by anthropogenic contamination. The data are presented with individual sample analysis as well as summary data, so it may be possible to remove suspect samples from the original data sets, however sample locations are difficult to evaluate as they are given only by latitude and longitude in the report. Table 4-9 presents a summary of the sedimentary data from the Hot Springs Quadrangle and Table 4-10 presents the summary data from the Rapid City Quadrangle.

Table 4-9
Summary for Stream Sediment Data of the Hot Springs Quadrangle, in ppm (or percent)

Element	Measurable Values	Below Detection	Detection Limit	Minimum value	Maximum Value	Mean	Standard Deviation
U-FL	355	2	<0.25	<0.25	16.30	3.30	1.851
U-NT	357			0.90	19.50	3.79	1.995
Th	352	5	<2	<2	19	8	2.7
Ag	0	357	<2	<2	<2	<2	
Al (%)	357			0.97%	5.84%	4.39%	1.045%
As	356	1	<0.1	<0.1	293.2	8.4	20.77
B	295	62	<10	<10	75	25	11.9
Ba	357			176	4,854	748	528.1
Be	354	3	<1	<1	17	2	1.4
Ca (%)	357			0.13%	16.34%	2.04%	2.095%
Ce	350	7	<10	<10	136	43	14.9
Co	356	1	<4	<4	47	15	5.9
Cr	357			1	89	42	15.1
Cu	357			3	122	23	11.9
Fe (%)	357			0.05%	6.82%	2.55%	0.937%
K (%)	357			0.54%	2.74%	1.54%	0.317%
Li	357			7	195	31	14.0
Mg (%)	357			0.09%	2.79%	0.85%	0.371%
Mn	357			74	9,264	593	587.3
Mo	105	252	<4	<4	30	6	4.3
Na (%)	356	1	<0.05%	<0.05%	2.50%	0.52%	0.279%
Nb	352	5	<4	<4	33	14	5.1
Ni	357			3	77	21	10.5
P	357			11	1,841	559	199.6
Sc	357			1	14	7	2.3
Se	355	2	<0.1	<0.1	7.8	1.0	0.79
Sr	357			29	1,038	188	107.6
Ti	357			18	4,795	2,306	558.6
V	356	1	<2	<2	479	88	52.1
Y	357			4	25	14	3.3
Zn	357			13	298	84	39.2
Zr	357			2	126	75	14.8

Table 4-10
Summary for Stream Sediment Data of the Rapid City Quadrangle, in ppm (or percent)

Element	Measurable Values	Below Detection	Detection Limit	Minimum value	Maximum Value	Mean	Standard Deviation
U-FL	471			1.09	12.40	2.88	1.208
U-NT	475			1.20	16.40	3.57	1.428
Th	463	8	<2	<2	16	7	2.6
Ag	3	468	<2	<2	4	3	1.0
Al (%)	471			0.17%	9.30%	5.17%	1.397%
As	471			0.6	935.2	11.1	51.15
B	454	17	<10	<10	203	50	31.9
Ba	471			34	12,550	892	825.2
Be	465	6	<1	<1	6	1	0.6
Ca (%)	470	1	<0.05%	<0.05%	22.68%	2.10%	2.544%
Ce	470	1	<10	<10	112	46	12.4
Co	447	24	<4	<4	48	9	5.6
Cr	471			1	107	45	16.8
Cu	470	1	<2	<2	401	21	20.5
Fe (%)	471			0.11%	29.32%	2.86%	1.876%
K (%)	471			0.22%	2.83%	1.37%	0.386%
Li	471			2	104	32	15.7
Mg (%)	470	1	<0.05%	<0.05%	5.26%	0.92%	0.460%
Mn	471			16	5,811	569	553.0
Mo	91	380	<4	<4	24	5	2.9
Na (%)	469	2	<0.05%	<0.05%	2.47%	0.59%	0.341%
Nb	359	112	<4	<4	11	4	1.3
Ni	471			2	122	26	14.0
P	471			71	3,179	872	278.8
Sc	470	1	<1	<1	15	7	2.6
Se	422	49	<0.1	<0.1	4.5	0.8	0.75
Sr	471			5	849	170	90.6
Ti	471			96	7,718	2,272	775.8
V	471			6	332	98	53.8
Y	471			1	71	15	5.0
Zn	471			4	511	109	61.2
Zr	471			3	123	71	15.7

4.2.5 Conclusions

It becomes apparent from the discussion above that there does not appear to have been a comprehensive study of the background constituents, either mineral or elemental, of the sediment of the Cheyenne River. While much data exists, it is widely scattered and usually was collected to answer limited questions about specific contaminants or locations, or was intended for purposes only incidentally related to the Cheyenne River. Good mercury data in particular appear to be limited.

4.3 Mining and Tailings Discharge

4.3.1 History

The first mine and mill at Lead, South Dakota, was constructed in 1876 and incorporated as Homestake Mining Company in 1877. Seventeen other major mines operated near the Homestake mine, but Homestake mine has been the dominant mine in the Black Hills and the subject of most studies (Ref. 182). Early milling operations, which included the use of stamp mills, began in 1878. By 1880, more than 60 stamp mills with more than 1,000 stamps were in operation at Lead, SD. These stamps consisted of little more than large cast-iron or steel blocks dropped on anvils. Wastewater and tailings material from the stamp mills were discharged directly into Whitewood Creek.

Prior to 1900, much of the ore consisted of near surface, red-colored oxide or hydroxide minerals associated with paleoplacer deposits and residual oxidation products of pyrite, pyrrhotite and arsenopyrite. Gold was recovered from the ore by gravity or amalgamation with mercury. Mercury amalgamation was supplemented with cyanide extraction beginning in 1901.

After 1900, mining focused on the black and green reduced ores below the zone of oxidation. The mills in Lead, SD processed approximately 5,000 tons of ore per day. The sand and coarser fractions of the tailings were put back in the underground works as fill to support ground structures; this constituted about one-half of the total tailings volume. The silt and finer fractions, “slimes”, were transported from Lead to a slime plant in Deadwood, three miles away, for further cyanidation treatment and then discharged into Whitewood Creek (Ref. 168). In 1917, a number of small, independent milling operations ceased and Homestake Milling became the only contributor of tailings into Whitewood Creek. (Ref. 168).

Most of the materials discharged to Whitewood Creek were fine-grained concentrates of sulfide minerals and host rock material. In 1959, the mill-processed ore contained 44 percent slimes with particles finer than 0.075 millimeters (mm) with 85 percent finer than 0.045 mm (Ref. 18). The sulfides associated with the Homestake district are arsenopyrite, pyrite, chalcopyrite, galena, and sphalerite and comprised 7 to 8 % of the tailings. These sulfides are present in sufficient amounts to be considered important sources of trace-element contaminants including arsenic, cadmium, copper, mercury, nickel, selenium, and zinc (Ref. 182). Samples collected from the flood plains indicate that, although most of the sulfide minerals have been weathered

to secondary oxides and hydroxides, the arsenic concentration is as much as one percent (Ref. 18).

Mercury amalgamation continued to be used in the processing of the ore until the early 1970s when cyanide treatment began to be used exclusively. During the 1960s, between 20 and 40 pounds (9 and 18 kg) of mercury were estimated to be discharged daily into Whitewood Creek, along with the tailings.

Estimates of daily tailings and contaminants discharged into Whitewood Creek during mining and milling operations are listed in Table 4-11.

Table 4-11
Estimated Daily Tailings Discharge Data for Whitewood Creek

Material Discharged	Estimated Daily Load
Tailings Material	2,700 metric tons
Processing water	34 million liters
Cyanide	140 kilograms (kg)
Zinc	108 kg
Copper	30 kg
Arsenic	8.6 metric tons

Various estimates for the total volumes over the 120-plus years of operation range from 75 million tons (68 million metric tons) to 1 billion tons (0.9 billion metric tons) with only 18-20 percent remaining in an 18-mile segment of Whitewood Creek and the rest washed into the Belle Fourche and Cheyenne Rivers (Ref. 168).

Estimates for the volume of mercury used and lost to the wastestream vary from an eighth of an ounce to almost half an ounce per ton of ore crushed with almost 50 percent of this volume lost to the entire wastestream (Ref. 24). From 1878 until 1970, Homestake Mining Company discharged metallic mercury, as effluent from the mercury amalgamation process of gold recovery, into the Cheyenne River watershed. Approximately 12-40 pounds of metallic mercury was discharged per day until 1970, and approximately 2.5 pounds of mercury leached from stock-piled ore daily since 1970 (Ref. 18).

4.3.2 Tailings Distribution and Composition

Arsenic and the trace elements copper, antimony, and mercury occur in large concentrations in bottom sediments downstream from the City of Lead, SD. Although the concentrations of trace elements in bottom sediments vary, the pattern of concentration change downstream is similar. Concentrations of other trace elements known to be associated with the mill tailings do not have such distinct patterns of change downstream. Iron and manganese are present in substantial concentrations in uncontaminated sediments, and the contrast between contaminated and uncontaminated sediments is small.

Substantial concentrations of arsenic and mercury occur in bottom sediments for more than 150 river kilometers downstream from the original tailings discharge point. Because there currently is no significant point discharge of these elements to Whitewood Creek, the large concentrations present in the bottom sediments from the City of Lead, SD are the result of input from the large deposits of arsenic and mercury bearing sediments present along these reaches. The duel mechanisms of this input are the addition of solid-phase components by bank collapse and the adsorption of dissolved-phase components present in groundwater inflow. Evidence for bank collapse is apparent as indicated by visible erosion of the arsenic and mercury bearing sediment deposits that occurs during periods of high discharge. In addition, well-crystallized arsenopyrite has been identified in Cheyenne River suspended sediment and in bottom sediments of the Cheyenne River Arm of Lake Oahe (Ref. 96).

Results of a stratified, random, sediment-sampling program in 1985, indicated that most of the near-surface sediment on the flood plains along Whitewood Creek and the Belle Fourche River are contaminated by arsenic. Along Whitewood Creek, the average arsenic concentration was 1,400 ppm. Along the Belle Fourche River, the arsenic concentrations decrease from about 1,300 ppm near the confluence of the Whitewood Creek, to about 400 ppm near the mouth. There were lower arsenic concentrations on the Cheyenne River flood plain where samples averaged about 70 ppm (Ref. 18).

In 1981, at the request of the governor of South Dakota, Homestake Mine and an 18-mile stretch was nominated for inclusion on the National Priorities List, and was placed on the List in 1983. In 1990, a Record of Decision was issued. The selected remedial action for the Whitewood Creek site included: removal and/or covering of contaminated residential sites; disposal of the arsenic-contaminated soil; revegetation of remediated areas; institutional controls; additional surface-water monitoring; and investigation of the 100-year floodplain. USEPA invoked Applicable or Relevant and Appropriate Requirement waivers based on the technical impracticability of remediating contaminated ground and surface waters. Construction was complete in 1994 and the site was deleted from the National Priorities List in 1996. USEPA completed the first Five-Year Review Report in 2002, finding only minor additional remediation is required.

4.4 Surface Water Quality

Toxic substances are known to associate strongly with fine-grained particulate matter. Consequently, it is not surprising that toxicants tend to accumulate in the bottom sediments of rivers, lakes, and wetlands. These toxicants can be released from bottom sediments into overlying surface waters through diffusion and resuspension. Surface water quality conditions in the Cheyenne River were evaluated to determine if any surface water pollution concerns exist that could be attributed to sediment contamination.

4.4.1 Adoption of Water Quality Standards Pursuant to the Clean Water Act

Water quality standards serve as the foundation for the water-quality based approach to pollution control and are a fundamental component of watershed management. Water quality standards are State or Tribal law or regulation that: 1) define the water quality goals of a water

body, or segment thereof, by designating the use or uses to be made of the water; 2) criteria necessary to protect the uses; and 3) protect water quality through antidegradation provisions. States and Tribes adopt water quality standards to protect public health or welfare, enhance the quality of water, and serve the purposes of the Clean Water Act (CWA). "Serve the purposes of the CWA" (as defined in Sections 101(a), 101(a)(2), and 303(c) of the CWA) means that water quality standards should: 1) include provisions for restoring and maintaining chemical, physical, and biological integrity of State waters, 2) provide, wherever attainable, water quality for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water ("fishable/swimmable"), and 3) consider the use and value of State waters for public water supplies, propagation of fish and wildlife, recreation, agricultural and industrial purposes, and navigation (40 CFR 131.2).

4.4.2 Water Quality Standards Promulgated by Tribes

Tribal participation in the water quality standards program requires completion of two principal tasks. One task is for the Tribe to submit an application to the USEPA Regional Administrator to administer the program. USEPA reviews the Tribe's application and decides whether the Tribe meets the applicable requirements. The second task is the development of water quality standards. A number of Tribes have elected to compile several years of water quality monitoring data prior to initiating development of water quality standards. Funding, guidance, training, and technical assistance are available from USEPA.

To date, no tribes in South Dakota have adopted tribal water quality standards.

4.4.3 Water Quality Standards Promulgated by the State of South Dakota For The Cheyenne River

4.4.3.1 Delineated Stream Segments and Designated Beneficial Uses

Four segments are delineated along the Cheyenne River from Lake Oahe to the South Dakota-Wyoming state-line in South Dakota's water quality standards (Ref. S1). The delineated segments on the Cheyenne River include: 1) from Lake Oahe to the confluence with the Belle Fourche River, 2) from the confluence of the Belle Fourche River to the confluence of the Fall River, 3) from the confluence of the Fall River to Angostura Reservoir, and 4) from Angostura Reservoir to the Wyoming border. The Cheyenne River in Wyoming is basically the headwaters area, where sediment contamination would least be expected. The designated beneficial uses assigned to each of these segments are listed in Table 4-12.

Table 4-12
Beneficial Uses Assigned to Delineated Segments Along the Cheyenne River in So. Dakota

Cheyenne River Segment	Warmwater permanent fish life propagation	Warmwater semipermanent fish life propagation	Immersion recreation	Limited contact recreation	Wildlife propagation and stock watering	Irrigation
Lake Oahe to Belle Fourche River	X		X	X	X	X
Belle Fourche River to Fall River		X	X	X	X	X
Fall River to Angostura Reservoir	X		X	X	X	X
Angostura Reservoir to Wyoming border		X		X	X	X

4.4.3.2 Surface Water Quality Criteria

Water quality standards criteria for selected constituents applicable to the Cheyenne River in South Dakota are summarized in Table 4-13.

Table 4-13
Summary of Numeric Surface Water Quality Standards for Selected Constituents Applicable to the Cheyenne River in South Dakota

Parameters (mg/l except where noted)	**Warmwater permanent fish life propagation**	**Warmwater semipermanent fish life propagation**	**Immersion recreation**	**Limited contact recreation**	**Wildlife propagation and stock watering**	**Irrigation**
Alkalinity ($CaCO_3$)					750[1]/1,313[2]	
Chlorine, total residual	0.019 acute 0.011 chronic	0.019 acute 0.011 chronic				
Coliform, fecal (per 100ml) May 1 – Sept. 30			200 (mean) 400 (max.)	1,000 (mean) 2,000 (max.)		
Conductivity (umhos/cm)					4,000[1]/7,000[2]	2,500[1]/4,375[2]
Hydrogen Sulfide, undisassociated	0.002	0.002				
Nitrogen, unionized ammonia as N	0.04[1]/1.75X the criterion	0.04[1]/1.75X the criterion				
Nitrogen, nitrates as N					50[1]/88[2]	
Oxygen, dissolved	≥ 5.0	≥ 5.0				
pH (S.U.)	6.5 – 9.0	6.5 – 9.0				
Sodium Adsorption Ratio						10
Solids, suspended	90[1]/158[2]	90[1]/158[2]				
Solids, total dissolved					2,500[1]/4,375[2]	
Temperature (°F)	80	90				
Total Petroleum Hydrocarbons					≤ 10	
Oil and Grease					≤ 10	

[1] 30-day average
[2] Daily maximum

South Dakota surface water quality standards for metals are based on the federal USEPA criteria documents and USEPA recommendations. Consistent with USEPA guidance, the water quality standards for most of the metals are based on the measured hardness of the water. As the hardness increases, the toxicity of the metal in the water generally decreases. This is true except for mercury, arsenic, selenium, and hexavalent chromium. For these four metals, there is one criterion that is applicable at all times regardless of the hardness of the water. Water quality standards criteria for selected toxics applicable to the Cheyenne River in South Dakota are summarized in Table 4-14.

Table 4-14
Summary of Numeric Surface Water Quality Standards for Selected Contaminants Applicable to the Cheyenne River in South Dakota

Contaminant	Human Health Value (ug/l)	Aquatic Life Value (ug/l)
Antimony	4,300	-----
Arsenic*	0.14	Acute: 360 / Chronic: 190
Cadmium*	-----	Acute: $(1.136672 - [(\ln \text{hardness})(0.041838)])e^{(0.1.128[\ln \text{hardness}]-3.828)}$ Chronic: $(1.101672 - [(\ln \text{hardness})(0.041838)])e^{(0.7852[\ln \text{hardness}]-3.490)}$
Chromium (III)*	-----	Acute: $(0.316)e^{(0.819[\ln \text{hardness}]+3.688)}$ Chronic: $(0.86)e^{(0.819[\ln \text{hardness}]+1.561)}$
Chromium (VI)*	-----	Acute: 15 / Chronic 10
Copper*	-----	Acute: $(0.96)e^{(0.9422[\ln \text{hardness}]-1.464)}$ Chronic: $(0.96)e^{(0.8545[\ln \text{hardness}]-1.465)}$
Cyanide	220,000	Acute: 22 / Chronic: 5.2
Lead*	-----	Acute: $(1.46203 - [(\ln \text{hardness})(0.145712)])e^{(1.273[\ln \text{hardness}]-1.464)}$ Chronic: $(1.46203 - [(\ln \text{hardness})(0.145712)])e^{(1.273[\ln \text{hardness}]-4.705)}$
Mercury**	0.15	Acute: 2.1 / Chronic: 0.012
Nickel*	4,600	Acute: $(0.998)e^{(0.846[\ln \text{hardness}]+3.3612)}$ Chronic: $(0.997)e^{(0.846[\ln \text{hardness}]+1.1645)}$
Selenium*	-----	Acute: 20 / Chronic: 5
Silver*	-----	Acute: $(0.85)e^{(1.72[\ln \text{hardness}]-6.52)}$ Chronic: -----
Thallium	6.3	-----
Zinc*	-----	Acute: $(0.978e^{(0.8473[\ln \text{hardness}]+0.8604)}$ Chronic: $(0.986)e^{(0.8473[\ln \text{hardness}]+0.7614)}$

* Aquatic life values refer to the dissolved amount of each substance. (Dissolved metals are those metals in an unacidified sample that pass through a 0.45-um membrane filter.)
** The aquatic life values for mercury refer to the following: acute – dissolved, chronic – total.

4.4.4 Affected Environment

4.4.4.1 South Dakota's 2000 305(b) Water Quality Assessment

Under Section 305(b) of the Federal Clean Water Act, States are required to assess water quality within their jurisdiction on a periodic basis and submit a "305(b) report" to the USEPA. The USEPA compiles all the state 305(b) reports and submits a report to Congress describing water quality conditions in the nation. The following text is excerpted from State of South Dakota's 2000 305(b) report regarding surface water quality conditions in the Cheyenne River (Ref. 255).

Cheyenne River water quality continues to be generally poor. The monitored two lower river segments did not support their designated fishable uses due to high total suspended solids

(TSS) similar to past reporting periods. Also similar to the last two assessments was impairment of the swimmable use owing to excessive fecal coliform levels. No TSS violations were noted for the upper Cheyenne River during 1996-1997. Below average rainfall in the upper drainage during the 1994 water year may have been largely responsible for the decrease in TSS. Total dissolved solids (TDS) remained high during both periods (25% and 43% exceedance) for the upper river segment and were responsible for ratings of partial and non-support respectively. This assessment of the Upper Cheyenne River was again not supporting for TDS. It is probable the elevated concentrations of TDS are mainly of natural geologic origin being derived from runoff leaching the extensive shale formations in the upper Cheyenne River drainage. Changes in the other measured parameters were minor between the previous and present reporting cycle.

Large silt loads carried by this normally shallow prairie stream impact Lake Oahe during seasonal periods of high flow. Monitoring records indicate that 11.6 million tons of sediment per year flow from the Cheyenne River into lower Lake Oahe. Severe soil erosion in the Badlands and along much of the river's lower course is the source of the suspended solids problem in the lower reaches. A major transporter of eroded soil in the former is the Sage Creek tributary of the Cheyenne River, which drains a large portion of the northern Badlands.

The lower Cheyenne drainage, in general, contains a high percentage of erodible cropland and rangeland in west-central South Dakota that may contribute additional large amounts of eroded sediment carried by numerous small tributaries during periods of heavy rainfall that occurred with increasing frequency from 1991-95 and 1997. Many small stockwater dams in the lower watershed had been reported to be rapidly filling with sediments during the mid 1990s as a result of this increased precipitation even though large acreages of rangeland and cropland were enrolled in the Conservation Reserve Program (CRP) in this region of the state.

High fecal coliform counts were commonly recorded at all river sites nearly every reporting period. Likely sources of bacteria are livestock wastes and partially treated wastewater carried by overland runoff during periods of high precipitation in this basin. Irrigation return flows, cropland, and rangeland also contribute to water quality problems, the latter two sources particularly in the lower half of the river course. The river frequently carries relatively high concentrations of nitrate (>1.0 mg/l) at the lowermost site near Bridger, South Dakota. Possibly, one source is irrigation return flows entering the tributary Belle Fourche River.

A past problem was the presence of excessive levels of mercury in fish and sediments in the Cheyenne River arm of Lake Oahe. Previous studies in the 1970s and 1984 revealed mercury levels in game fish that exceeded recommended USFDA levels for consumption. The mercury appeared to originate from gold mining operations in the northern Black Hills region and entered the Cheyenne via the tributary Belle Fourche River. Mining operations had used mercury in their gold recovery process but mercury was discontinued in 1970. As a result, mercury concentrations seemed to have declined in fish and habitat of the Belle Fourche River, Cheyenne River, and the Cheyenne River arm (Foster Bay) of Lake Oahe between 1970-71 and 1984-88 (Ruelle et. al, 1993 and Sowards et. al., 1991) Recent (1998) tests carried out on fish flesh samples collected (by USEPA) from the lower Cheyenne River and Foster Bay by the U.S. Department of Health and Human Services, Atlanta Georgia, supported those results. Mercury

(methylmercury) in fish flesh of several species was found to have declined to nominal concentrations.

Angostura, Deerfield and Pactola Reservoirs are high quality waterbodies vulnerable to nutrient enrichment and sedimentation from natural soil erosion, recreational activities, and various silvicultural activities. Eutrophication and sedimentation of Angostura Reservoir may be hastened by the frequent inflow of poor quality water from the upper Cheyenne River.

4.4.4.2 South Dakota's 2002 303(d) Waterbody List

Section 303(d) of the Federal Clean Water Act requires states to identify waters that do not or are not expected to meet applicable water quality standards with technology-based controls alone. The Act also specifies that states must establish a priority ranking for these waters, taking into account the pollution severity and designated uses of the waters. States must submit to USEPA the "waters identified and loads established" for review and approval. Once identification and priority ranking of waters are completed, states are to develop Total Maximum Daily Loads (TMDLs) at a level necessary to achieve the applicable state water quality standards. The most current approved 303(d) list for South Dakota is the 2002 list (Ref. S40). The portions of the Cheyenne River that are identified on the 2002 303(d) list are listed in Table 4-15.

Table 4-15
South Dakota's 2002 Section 303(d) Waterbody List

Location	Parameters of Concern	Priority*
Beaver Creek to Angostura Reservoir	Conductivity Dissolved Solids Suspended Solids	3
Angostura Reservoir to mouth of Cheyenne River	Suspended Solids Fecal Coliform	3
* 1 = High, 2 = Medium, 3 = Low Priority		

4.4.4.3 Summary of Available Surface Water Quality Data

4.4.4.3.1 USGS Stations

Summaries of surface water quality data collected at four USGS monitoring stations along the lower Cheyenne River and one USGS station on the lower reaches of the Belle Fourche River are provided in Tables 4-16 through 4-20. Figure 4-2 shows the locations of the USGS water quality monitoring stations.

Table 4-16
Site: Cheyenne River near Eagle Butte, South Dakota
Station Number: USGS 06439500
Site Location: Haakon County, South Dakota; Latitude 44°41'44", Longitude 101°13'08"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Conductivity (umhos/cm)	1972-1981	100	272	1,710	2,055	2,500	3,700
pH (S.U.)	1972-1981	98	6.9	7.9	8.1	8.2	9.2
Alkalinity (mg/l)	1972-1980	91	74	114	140	180	304
Nitrate-Nitrite as N (mg/l)	1972-1981	97	<0.10	0.30	0.69	1.50	3.20
Phosphorus, Total (mg/l)	1972-1981	96	<0.01	0.07	0.16	0.42	15.00
Cyanide, Total (mg/l)	1972-1973	7	0.00	0.00	0.00	0.01	0.02
Hardness (mg/l)	1972-1981	102	150	550	745	948	1,500
Calcium, Dissolved (mg/l)	1972-1981	101	25	130	180	230	350
Magnesium, Dissolved (mg/l)	1972-1981	101	8	55	77	94	140
Sodium, Dissolved (mg/l)	1972-1981	101	67	150	200	250	460
Sodium Adsorption Ratio	1972-1981	102	1	2	3	5	7
Potassium, Dissolved (mg/l)	1972-1981	101	4	10	13	15	21
Chloride, Dissolved (mg/l)	1972-1981	101	7	29	50	76	160
Sulfate, Dissolved (mg/l)	1972-1981	101	280	790	990	1,200	1,700
Arsenic, Dissolved (ug/l)	1972-1973	8	8	11	17	30	59
Boron, Dissolved (ug/l)	1972-1981	97	100	240	310	340	540
Cadmium, Dissolved (ug/l)	1972-1973	8	<2	<2	<2	<2	<2
Chromium, Dissolved (ug/l)	1972-1973	8	<20	<20	<20	<20	20
Cobalt, Dissolved (ug/l)	1972-1973	8	<2	<2	<2	<2	10
Copper, Dissolved (ug/l)	1972-1973	8	<20	<20	<20	<20	<20
Iron, Dissolved (ug/l)	1972-1973	7	30	40	90	105	310
Lead, Dissolved (ug/l)	1972-1973	8	<2	<2	<2	2.5	6
Manganese, Dissolved (ug/l)	1972-1973	8	<10	<10	<10	25	190
Molybdenum, Dissolved (ug/l)	1972-1973	8	1	4	5	7	8
Nickel, Dissolved (ug/l)	1972-1973	8	<2	7	10	13	30
Silver, Dissolved (ug/l)	1972-1973	7	n.d.	n.d.	n.d.	n.d.	n.d.
Strontium, Dissolved (ug/l)	1972-1973	8	820	1,700	2,100	2,525	3,100
Vanadium, Dissolved (ug/l)	1972-1973	8	0	0.1	0.5	1.6	3.1
Zinc, Dissolved (ug/l)	1972-1973	6	20	20	20	20	20
Aluminum, Dissolved (ug/l)	1972-1973	6	10	23	30	68	610
Selenium, Dissolved (ug/l)	1972-1973	8	1	4	5	5	10
Mercury, Total Recoverable (ug/l)	1972-1973	8	<0.5	<0.5	<0.5	0.6	1.0

n.d. = Not detected

Table 4-17
Site: Cheyenne River at Cherry Creek, South Dakota
Station Number: USGS 06439300
Site Location: Ziebach County, South Dakota; Latitude 44°35'59", Longitude 101°29'51"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Turbidity (NTU)	1978-1994	93	1	11	64	170	12,000
Conductivity (umhos/cm)	1972-1994	276	610	1,825	2,160	2,455	3,900
Dissolved Oxygen (mg/l)	1972-1994	190	5.7	8.2	9.1	11.5	21.8
pH (S.U.)	1972-1994	230	7.2	8.0	8.2	8.3	10.2
Alkalinity (mg/l)	1972-1994	118	79	118	140	192	331
Ammonia, Total as N (mg/l)	1972-1992	88	<0.01	0.03	0.07	0.15	0.90
Nitrate-Nitrite as N (mg/l)	1973-1992	119	<0.1	0.2	0.6	1.6	4.8
Phosphorus, Total (mg/l)	1972-1994	177	<0.01	0.05	0.17	0.44	18.0
Cyanide, Total (mg/l)	1974-1987	17	<0.01	<0.01	<0.01	<0.01	0.01
Hardness (mg/l)*	1972-1994	198	46	645	840	988	2,600
Suspended Sediment, Total (mg/l)	1972-1994	176	9	173	393	3,333	53,900
Calcium, Dissolved (mg/l)	1972-1994	198	18	160	200	230	390
Magnesium, Dissolved (mg/l)	1972-1994	198	0.3	61	82	97	150
Sodium, Dissolved (mg/l)	1972-1994	198	48	152	200	240	1,200
Sodium Adsorption Ratio	1972-1994	198	2	3	3	4	13
Potassium, Dissolved (mg/l)	1972-1994	198	0.7	10	12	14	23
Chloride, Dissolved (mg/l)	1972-1994	199	3	30	54	80	240
Sulfate, Dissolved (mg/l)	1972-1994	199	140	825	1,000	1,200	1,900
Arsenic, Dissolved (ug/l)	1974-1994	106	<1	3	4	7	26
Cadmium, Dissolved (ug/l)	1974-1991	100	<1	<1	<1	<1	6
Chromium, Dissolved (ug/l)	1976-1994	53	<1.0	<1.0	1	3	20
Chromium, Total (ug/l)	1975-1985	39	<10	<10	14	35	240
Copper, Dissolved (ug/l)	1974-1994	95	<1	2	3	5	60
Iron, Dissolved (ug/l)	1972-1994	95	<10	10	20	30	1,600
Lead, Dissolved (ug/l)	1974-1994	55	<1	<1	1	4	320
Manganese, Dissolved (ug/l)	1974-1994	126	<10	<10	20	40	460
Molybdenum, Dissolved (ug/l)	1984-1994	35	<1	4	5	6	13
Nickel, Dissolved (ug/l)	1979-1994	60	<1	2	3	4	7
Silver, Dissolved (ug/l)	1977-1994	66	<1	<1	<1	<1	1
Strontium, Dissolved (ug/l)	1983-1994	48	120	2,200	2,550	2,900	4,000
Vanadium, Dissolved (ug/l)	1983-1994	31	<1.0	1.4	2.4	3.4	12.0
Zinc, Dissolved (ug/l)	1975-1994	101	<10	<10	10	14	62
Aluminum, Dissolved (ug/l)	1983-1993	54	<10	<10	<10	18	840
Selenium, Dissolved (ug/l)	1974-1994	93	<1	2	3	4	15
Mercury, Total Recoverable (ug/l)	1977-1994	89	<0.1	<0.1	<0.1	0.1	3.3

* Hardness was not part of the station record, but was calculated from the measured calcium and magnesium values as follows:
Hardness, mg equivalent $CaCO_3$/L = 2.497 [Ca, mg/l] + 4.118 [Mg, mg/l].

Table 4-18
Site: Cheyenne River near Plainview, South Dakota
Station Number: USGS 06438500
Site Location: Ziebach County, South Dakota; Latitude 44°31'54", Longitude 101°55'47"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Conductivity (umhos/cm)	1974-2001	308	610	1,628	1,950	2,250	4,000
pH (S.U.)	1974-1989	162	7.2	7.8	8.1	8.3	9.0
Alkalinity (mg/l)	1974-1989	105	6	130	172	200	298
Dissolved Solids, Total (mg/l)	1974-1989	173	286	1,240	1,560	1,740	3,150
Suspended Solids, Total (mg/l)	1974-1989	166	5	38	125	562	29,090
Ammonia, Dissolved as N (mg/l)	1974-1981	41	<0.02	0.04	0.10	0.37	0.74
Cyanide, Total (mg/l)	1983-1984	12	<0.01	<0.01	<0.01	<0.01	<0.01
Calcium, Dissolved (mg/l)	1983-1984	13	140	190	208	219	294
Magnesium, Dissolved (mg/l)	1983-1984	13	56	82	86	92	122
Sodium, Dissolved (mg/l)	1983-1984	13	99	161	191	221	267
Potassium, Dissolved (mg/l)	1983-1984	12	7	9	11	13	17
Chloride, Dissolved (mg/l)	1983-1984	13	26	37	52	71	89
Sulfate, Dissolved (mg/l)	1983-1984	13	450	724	996	1,150	1,500
Arsenic, Dissolved (ug/l)	1983-1984	12	<10	<10	<10	<10	<10
Cadmium, Dissolved (ug/l)	1983-1984	13	<10	<10	<10	<10	<10
Chromium, Dissolved (ug/l)	1983-1984	12	<10	<10	<10	<10	<10
Copper, Dissolved (ug/l)	1983-1984	13	<50	<50	<50	<50	<50
Iron, Dissolved (ug/l)	1983-1984	13	<50	<50	<50	<50	<50
Lead, Dissolved (ug/l)	1983-1984	13	<50	<50	<50	<50	<50
Manganese, Dissolved (ug/l)	1983-1984	13	<10	<10	13	30	150
Nickel, Dissolved (ug/l)	1983-1984	13	<40	<40	<40	<40	<40
Silver, Dissolved (ug/l)	1983-1984	13	<10	<10	<10	<10	<10
Zinc, Dissolved (ug/l)	1983-1984	12	<10	<10	<10	<10	20
Selenium, Dissolved (ug/l)	1983-1984	10	<2	<2	4	5	19
Mercury, Total Recoverable (ug/l)	1983-1984	12	<0.20	<0.20	<0.20	<0.20	0.33

Table 4-19
Site: Cheyenne River near Wasta, South Dakota
Station Number: USGS 06423500
Site Location: Pennington County, South Dakota; Latitude 44°04'52", Longitude 102°24'03"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Conductivity (umhos/cm)	1978-2001	238	300	1,490	1,845	2,140	3,500
Dissolved Oxygen (mg/l)	1983-1987	12	6.0	8.8	10.6	11.1	13.6
pH (S.U.)	1983-1987	16	7.9	8.2	8.4	8.5	8.8
Cyanide, Total (mg/l)	1983-1984	11	<0.01	<0.01	<0.01	<0.01	<0.01
Calcium, Dissolved (mg/l)	1983-1984	11	114	169	194	207	232
Magnesium, Dissolved (mg/l)	1983-1984	11	36	50	66	70	79
Sodium, Dissolved (mg/l)	1983-1984	12	109	131	157	199	262
Potassium, Dissolved (mg/l)	1983-1984	11	7	10	12	13	17
Chloride, Dissolved (mg/l)	1983-1984	12	30	69	87	97	114
Sulfate, Dissolved (mg/l)	1983-1984	12	302	675	778	835	1,070
Arsenic, Dissolved (ug/l)	1983-1984	11	<10	<10	<10	<10	<10
Cadmium, Dissolved (ug/l)	1983-1984	12	<10	<10	<10	<10	<10
Chromium, Dissolved (ug/l)	1983-1984	12	<10	<10	<10	<10	<10
Copper, Dissolved (ug/l)	1983-1984	12	<50	<50	<50	<50	<50
Iron, Dissolved (ug/l)	1983-1984	11	<50	<50	<50	<50	<50
Lead, Dissolved (ug/l)	1983-1984	12	<50	<50	<50	<50	<50
Manganese, Dissolved (ug/l)	1983-1984	12	<10	<10	<10	15	30
Nickel, Dissolved (ug/l)	1983-1984	12	<40	<40	<40	<40	<40
Silver, Dissolved (ug/l)	1983-1984	12	<10	<10	<10	<10	<10
Zinc, Dissolved (ug/l)	1983-1984	12	<10	<10	<10	<10	20
Selenium, Dissolved (ug/l)	1983-1984	9	<2	<2	<2	3	15
Mercury, Total Recoverable (ug/l)	1983-1984	10	<0.20	<0.20	<0.20	<0.20	0.7

Table 4-20
Site: Belle Fourche River near Elm Springs, South Dakota
Station Number: USGS 06438000
Site Location: Meade County, South Dakota; Latitude 44°22'11", Longitude 102°33'56"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Turbidity (NTU)	1978-1994	105	0.5	3.5	13	66	4800
Conductivity (umhos/cm)	1970-2001	359	390	1,690	1,950	2,525	6,500
Dissolved Oxygen (mg/l)	1970-1994	208	6.1	8.4	9.5	11.2	16.0
pH (S.U.)	1970-1994	242	6.8	7.9	8.2	8.3	10.2
Alkalinity (mg/l)	1970-1994	138	66	130	151	222	596
Ammonia, Total as N (mg/l)	1970-1992	95	<0.01	0.05	0.09	0.17	0.88
Nitrate-Nitrite as N (mg/l)	1970-1992	102	<0.1	0.6	1.4	2.9	10.0
Phosphorus, Total (mg/l)	1970-1994	200	<0.01	0.02	0.05	0.25	12.6
Cyanide, Total (mg/l)	1983-1988	28	<0.01	<0.01	<0.01	<0.01	0.06
Hardness (mg/l)	1970-1983	124	190	740	860	1,400	2,400
Dissolved Solids, Total (mg/l)	1970-1994	205	405	1,390	1,700	2,380	5,520
Calcium, Dissolved (mg/l)	1970-1994	214	50	170	200	250	510
Magnesium, Dissolved (mg/l)	1970-1994	214	4.7	73	95	140	270
Sodium, Dissolved (mg/l)	1970-1994	201	29	116	160	230	640
Sodium Adsorption Ratio	1970-1989	110	0.6	2	2	3	6
Potassium, Dissolved (mg/l)	1970-1994	199	1	9	10	13	34
Chloride, Dissolved (mg/l)	1970-1994	213	4	15	23	35	160
Sulfate, Dissolved (mg/l)	1970-1994	219	230	795	1,000	1,400	2,900
Arsenic, Dissolved (ug/l)	1970-1991	95	<2	5	8	12.5	140
Barium, Dissolved (ug/l)	1970-1994	46	0	34	45	100	200
Boron, Dissolved (ug/l)	1970-1987	12	80	200	240	385	710
Cadmium, Dissolved (ug/l)	1970-1991	89	<1	<1	<1	<1	7
Chromium, Dissolved (ug/l)	1970-1991	60	<1	<1	<1	2	20
Chromium, Total (ug/l)	1970-1984	48	<10	<10	<10	33	470
Copper, Dissolved (ug/l)	1970-1991	86	<2	<2	3	5	130
Iron, Dissolved (ug/l)	1970-1994	76	<10	<10	20	33	220
Lead, Dissolved (ug/l)	1970-1991	80	<5	<5	<5	<5	87
Manganese, Dissolved (ug/l)	1970-1994	111	1	10	30	90	1,900
Molybdenum, Dissolved (ug/l)	1970-1994	32	<1	2	4	7	18
Nickel, Dissolved (ug/l)	1970-1994	65	<1	3	4	5	20
Silver, Dissolved (ug/l)	1970-1994	71	<1	<1	<1	<1	1
Strontium, Dissolved (ug/l)	1970-1994	47	920	2,050	2,400	2,950	6,600
Vanadium, Dissolved (ug/l)	1970-1994	53	<6	<6	<6	<6	<6
Zinc, Dissolved (ug/l)	1970-1991	95	<10	<10	<10	20	84
Aluminum, Dissolved (ug/l)	1970-1994	46	<10	<10	<10	<10	179
Selenium, Dissolved (ug/l)	1970-1994	96	<2	3	4	6	22
Mercury, Total Recoverable (ug/l)	1970-1984	38	<0.2	<0.2	<0.2	0.5	9.3

4.4.4.3.2 South Dakota Department of Environment and Natural Resources

The SDDENR maintains a surface water-quality monitoring network that includes several monitoring locations on the Cheyenne and Belle Fourche Rivers. A summary of surface water quality data collected by the SDDENR at four monitoring stations along the mid and lower Cheyenne River and one station on the lower reaches of the Belle Fourche River are provided in Tables 4-21 through 4-25. Figure 4-2 shows the locations of the SDDENR water quality monitoring stations.

Table 4-21
Site: Cheyenne River northeast of Cherry Creek, South Dakota
Station Number: SDDENR 460133
Site Location: Haakon County, South Dakota; Latitude 44°41'52", Longitude 101°13'10"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Alkalinity (mg/l)	1999-2002	38	121	157	190	222	433
Calcium, Total (mg/l)	1999-2001	11	145	160	180	192	438
Dissolved Oxygen (mg/l)	1999-2002	36	6.7	9.1	10.9	13.1	22.3
Hardness (mg/l)	1999-2002	38	640	750	821	920	1,460
Magnesium, Total (mg/l)	1999-2001	11	66	72	79	89	100
Ammonia, Total (mg/l)	1999-2002	35	0.00	0.00	0.00	0.03	0.33
Kjeldahl Nitrogen, Total (mg/l)	1999-2002	38	0.00	0.26	0.48	0.71	1.75
Nitrate-Nitrite as N (mg/l)	1999-2002	38	0.0	0.2	0.4	1.3	2.1
pH (S.U.)	1999-2002	36	7.2	8.2	8.3	8.4	8.9
Phosphorus, Total (mg/l)	1999-2002	38	0.02	0.05	0.14	0.40	9.58
Sodium, Total (mg/l)	1999-2001	11	144	168	219	232	248
Conductivity (umhos/cm)	1999-2002	38	1,200	1,815	2,025	2,238	2,900
Fecal Coliform Bacteria (org/100ml)	1999-2001	11	0	25	60	215	1,000
Suspended Solids, Total (mg/l)	1999-2002	38	2	28	104	259	21,000

Table 4-22
Site: Cheyenne River near Plainview, South Dakota
Station Number: SDDENR 468860
Site Location: Haakon County, South Dakota; Latitude 44°31'53", Longitude 101°55'52"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Alkalinity (mg/l)	1968-2002	265	0	124	153	207	2,879
Calcium, Total (mg/l)	1974-2001	76	41	151	181	200	1,600
Chloride, Total (mg/l)	1968-1977	46	10	30	39	71	104
Dissolved Oxygen (mg/l)	1972-2002	280	2.0	9.0	10.7	12.8	22.2
Dissolved Solids, Total (mg/l)	1968-1998	547	282	1,286	1,674	2,055	9,248
Hardness (mg/l)	1968-2002	272	33	623	789	917	5,072
Iron, Dissolved (ug/l)	1968-1977	44	0.02	0.02	0.04	0.18	26.00
Magnesium, Total (mg/l)	1974-2001	76	6	60	77	83	262
Manganese, Dissolved (ug/l)	1968-1977	44	<1	30	100	280	4,800
Ammonia, Total as N (mg/l)	1978-2002	226	0.00	0.02	0.04	0.09	0.82
Kjeldahl Nitrogen, Total as N (mg/l)	1974-2002	44	0.0	0.0	0.3	0.5	1.0
Nitrate-Nitrite as N (mg/l)	1968-2002	211	0.0	0.4	0.8	1.4	4.6
pH (S.U.)	1968-2002	436	5.7	8.0	8.2	8.3	10.8
Phosphorus, Total (mg/l)	1983-2002	190	0.01	0.10	0.23	0.54	15.10
Potassium, Dissolved (mg/l)	1968-1977	44	7.6	11.2	12.8	14.3	19.7
Sodium, Dissolved (mg/l)	1968-1983	52	74	138	172	199	249
Conductivity (umhos/cm)	1968-2002	289	598	1,664	1,995	2,310	3,286
Sulfate, Dissolved (mg/l)	1968-1977	44	118	726	939	1,058	1,299
Fecal Coliform Bacteria (org/100ml)	1968-2001	264	3	10	46	370	92,000
Suspended Solids, Total (mg/l)	1968-2002	314	1	49	188	1,170	53,180

Table 4-23
Site: Cheyenne River near Wasta, South Dakota
Station Number: SDDENR 460865
Site Location: Pennington County, South Dakota; Latitude 44°04'52", Longitude 102°24'03"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Alkalinity (mg/l)	1967-2001	240	0	126	168	196	3,300
Calcium, Total (mg/l)	1973-2001	122	10	133	179	208	850
Chloride, Total (mg/l)	1967-1977	50	11	51	90	104	149
Dissolved Oxygen (mg/l)	1967-2001	312	6.7	9.1	10.8	12.2	16.5
Dissolved Solids, Total (mg/l)	1967-1998	286	0	1,183	1,516	1,720	15,600
Hardness (mg/l)	1967-2001	272	37	526	709	824	3,152
Iron, Total (mg/l)	1968-1977	43	<0.1	0.6	1.7	7.7	4,800.0
Magnesium, Total (mg/l)	1973-2001	122	3	42	60	72	250
Manganese, Total (ug/l)	1967-1977	40	0	30	60	215	3,200
Ammonia, Total as N (mg/l)	1977-2001	243	0.00	0.03	0.03	0.10	1.06
Kjeldahl Nitrogen, Total as N (mg/l)	1974-2001	41	0.0	0.6	0.6	1.2	3.6
Nitrate-Nitrite as N (mg/l)	1988-2001	43	0.0	0.3	0.6	1.1	2.0
pH (S.U.)	1967-2001	473	6.8	7.9	8.1	8.3	9.0
Phosphorus, Total (mg/l)	1983-2001	193	0.00	0.15	0.33	0.80	22.50
Potassium, Total (mg/l)	1973-1977	31	5.8	11.6	13.0	15.0	21.4
Sodium, Total (mg/l)	1973-2001	119	9	131	175	216	516
Conductivity (umhos/cm)	1968-2001	275	530	1,545	1,900	2,225	4,000
Sulfate, Dissolved (mg/l)	1968-1993	40	189	649	828	930	1,240
Fecal Coliform Bacteria (org/100ml)	1967-2001	279	0	10	50	340	210,000
Suspended Solids, Total (mg/l)	1967-2001	322	5	45	176	848	35,400

Table 4-24
Site: Cheyenne River east of Red Shirt, South Dakota
Station Number: SDDENR 460132
Site Location: Custer County, South Dakota; Latitude 43°40'19", Longitude 101°53'36"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Alkalinity (mg/l)	1999-2001	11	168	175	188	205	220
Calcium, Total (mg/l)	1999-2001	16	113	197	219	240	279
Dissolved Oxygen (mg/l)	1999-2001	33	7.5	8.9	10.4	12.0	13.5
Hardness (mg/l)	1999-2001	13	443	775	853	898	1,020
Magnesium, Total (mg/l)	1999-2001	16	39	70	75	83	94
Ammonia, Total (mg/l)	1999-2001	34	0	0	0	0	0
Kjeldahl Nitrogen, Total (mg/l)	1999-2001	34	0.0	0.0	0.6	0.6	1.8
Nitrate-Nitrite as N (mg/l)	1999-2001	34	0.1	0.5	0.9	1.3	1.9
pH (S.U.)	1999-2001	29	7.6	8.1	8.2	8.2	8.6
Phosphorus, Total (mg/l)	1999-2001	34	0.00	0.04	0.07	0.17	1.14
Sodium, Total (mg/l)	1999-2001	12	186	228	237	250	272
Conductivity (umhos/cm)	1999-2001	11	2,290	2,400	2,440	2,485	2,600
Fecal Coliform Bacteria (org/100ml)	1999-2001	15	6	33	86	170	1,600
Suspended Solids, Total (mg/l)	1999-2001	34	9	27	53	93	1,000

Table 4-25
Site: Belle Fourche River north of Elm Springs, South Dakota
Station Number: SDDENR 460676
Site Location: Meade County, South Dakota; Latitude 44°22'10", Longitude 102°33'58"

Parameter	Period of Data	Number of Obs.	Minimum	25th Percentile	Median	75th Percentile	Maximum
Alkalinity (mg/l)	1976-2001	25	66	138	152	186	422
Calcium, Total (mg/l)	1976-2001	43	71	168	200	237	435
Chloride, Total (mg/l)	1976-1977	13	14	17	23	37	57
Dissolved Oxygen (mg/l)	1976-2001	95	7.2	8.8	10.0	11.4	14.1
Dissolved Solids, Total (mg/l)	1976-1988	65	628	1,493	2,010	2,759	5,030
Hardness (mg/l)	1976-2001	59	295	702	811	1,114	2,075
Magnesium, Total (mg/l)	1976-2001	43	32	74	85	118	240
Manganese, Total (ug/l)	1976-1977	10	60	185	460	1,005	1,370
Ammonia, Total as N (mg/l)	1977-2001	82	0.00	0.00	0.03	0.15	2.50
Kjeldahl Nitrogen, Total as N (mg/l)	1999-2001	33	0.0	0.6	0.6	0.9	3.5
Nitrate-Nitrite as N (mg/l)	1999-2001	33	0.0	0.4	0.7	1.1	6.2
pH (S.U.)	1976-2001	153	7.1	7.8	8.1	8.2	8.6
Phosphorus, Total (mg/l)	1999-2001	33	0.00	0.03	0.06	0.16	2.36
Potassium, Total (mg/l)	1976-1977	10	6.3	12.7	14.5	16.4	20.8
Sodium, Total (mg/l)	1976-2001	42	68	113	153	199	377
Conductivity (umhos/cm)	1976-2001	76	830	1,670	2,195	2,860	4,920
Sulfate, Dissolved (mg/l)	1976-1977	10	330	863	1,048	1,623	2,325
Fecal Coliform Bacteria (org/100ml)	1976-2001	77	0	7	43	140	52,400
Suspended Solids, Total (mg/l)	1976-2001	98	0	11	41	167	8,080

4.4.4.4 Surface Water Quality Conditions Reported in the Literature

The USGS, in cooperation with the Cheyenne River Sioux Tribe, completed a comprehensive assessment of surface water quality conditions and trends in the lower Cheyenne River (Ref. 208). The report assessed 23 years worth of monitoring data (i.e., 1972-94) collected on the Cheyenne River at Cherry Creek (USGS station 06439300). The following is excerpted from the abstract of the USGS report.

Water-quality data are compared to standards for domestic water supply and drinking water, even though they are not assigned as beneficial uses of surface water for the Cheyenne River. Comparisons also are made to standards and criteria that have been developed to support the beneficial uses assigned for the river. No primary drinking-water standards (maximum contaminant levels – MCLs) for the constituents considered were exceeded. However, the primary standard for total phosphorus entering a reservoir was frequently equaled or exceeded. Secondary standards (secondary maximum contaminant levels – SMCLs) for drinking-water supplies for dissolved sulfate were frequently exceeded. Various exceedances of secondary standards for dissolved solids, fecal coliform bacteria, pH, and manganese were also noted. The standard for irrigation for specific conductance was frequently exceeded. Standards for wildlife propagation and stock watering generally were met. Standards for warm-water permanent and marginal fish propagation were frequently exceeded for suspended sediment. Ammonia standards were frequently equaled or exceeded. The standard for chronic toxicity of selenium for aquatic life for fisheries was frequently equaled or exceeded. Selected water-quality constituents collected at each station were analyzed for trend using the Seasonal Kendall and Tobit test methods. Whenever possible, the results of the Seasonal Kendall test on flow-adjusted concentrations were used to define trends. The trend test that

provided the most statistically significant p-value was selected. Trends with p-values less than or equal to 0.05 were considered to be statistically significant. Trend analysis for water-quality data collected from the Cheyenne River at Cherry Creek showed that of the 14 constituents considered, five had trends that were determined to be statistically significant, five were not statistically significant, and four showed no trend. Of the five statistically significant trends, three were increasing, and two were decreasing. Increasing trends included dissolved sulfates, dissolved chloride, and dissolved solids. The two statistically significant decreasing trends included dissolved arsenic and dissolved manganese. Previous investigations have shown that elevated concentrations of dissolved arsenic in the Cheyenne River are linked to mining practices in the Black Hills. The statistically significant decreasing trend in dissolved arsenic probably results from changes made in the methods used for the disposal of mine tailings.

At the request of the Cheyenne River Sioux Tribe, the USGS conducted a water and bed-sediment survey to better understand the occurrence of mercury in water and sediment in the Cheyenne River Basin. Water and bed-sediment samples were collected at 18 sites in the Cheyenne River Basin in two sampling rounds during July and August 1998. The following is excerpted from the preliminary report based on this study by S.K. Sando (Ref. 225).

Typically, mercury occurs in very low concentrations in surface waters, in either inorganic or organic forms. Inorganic mercury is not particularly toxic, but under certain conditions, it can be converted to organic mercury (methylmercury, a very potent neurotoxin) by bacterially mediated methylation, and then assimilated by aquatic organisms and biomagnified through the food chain. The conditions that are necessary for methylation of mercury include adequate concentrations of dissolved sulfate and organic material, and lack of dissolved oxygen. These conditions do not have to be prevalent throughout a given aquatic environment, but must exist at least in isolated microzones for mercury methylation to occur.

Many of the sites in the Cheyenne River Basin had concentrations of unfiltered total mercury that exceeded 10 ng/L, a concentration that might be considered the upper end of the range of typical stream concentrations at locations where the dominant sources of mercury are naturally occurring or result from atmospheric deposition. Several of the sites with unfiltered total mercury that exceeded 10 ng/L are not strongly influenced by intensive mining activities. Discharges from numerous smaller mining operations might contribute mercury at some of the sites, or mercury could be derived in part from Cretaceous shales that are prevalent in the Belle Fourche and Cheyenne River Basins. The Cretaceous shales are highly erodible and enriched in pyrite and several heavy metals (including mercury). Generally sites influenced by intensive mining activities tended to have larger unfiltered total mercury concentrations.

Nearly all of the mercury present in stream water in the Cheyenne River Basin occurs in suspended particulate form. Therefore, concentrations of unfiltered total mercury are very dependent upon flow conditions. High flows resuspend particles from the bed sediment and markedly increase concentrations of unfiltered total mercury.

Relatively large concentrations of unfiltered total mercury and methylmercury occur in both water and bed sediment throughout the Cheyenne River Basin, even at sites uninfluenced by

mining activities. The data suggest the lower Belle Fourche River might be an area of substantial methylmercury generation and fluxes to the lower Cheyenne River Basin, although additional data are needed to support this observation. Conditions suitable for methylation of mercury are prevalent throughout the Cheyenne River Basin although localized sites of intense methylation also are apparent. These observations, coupled with the data that indicate that inorganic mercury also is relatively common in the Cheyenne River Basin, might warrant some concern.

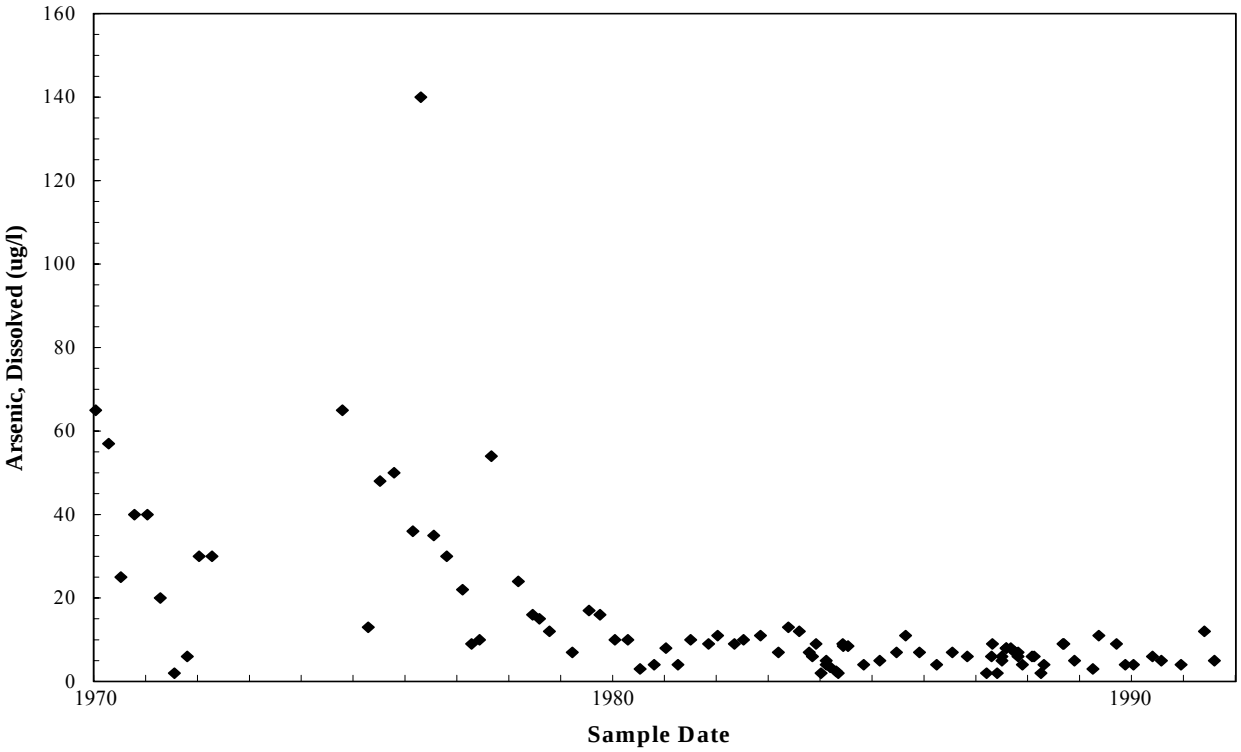
4.4.4.5 Fish Tissue Contamination as an Indicator of Surface Water Quality

Bioavailable chemicals can bioaccumulate in the tissues of aquatic organisms. Fish are capable of accumulating many toxic substances in excess of 1,000 times the concentrations found in surface waters. Subsequently, fish tissue analyses may provide information concerning the presence of contaminants in a water body that may not be detected through either water or sediment samples. Because of this, fish tissue monitoring is an excellent indicator of potential contamination problems in surface waters. Refer to Section 4.8, Fisheries and Benthic Macroinvertebrates, for a discussion of fish tissue contamination within the project area.

4.4.4.6 Water Quality Trends

Water quality trends in the lower Cheyenne River for selected parameters are described by USGS (Ref. 208) -- see above discussion in this Section under "Surface Water Quality Conditions Reported in the Literature." Concentrations of dissolved sulfate, dissolved chloride, and dissolved solids have significantly increased, while concentrations of dissolved arsenic and dissolved manganese have significantly decreased over the past 30 years (Ref. 208). As mentioned, mining operations in the Black Hills are known to have contributed significant levels of contaminants to the Cheyenne River via the Belle Fourche River in the past. However, recent water quality management controls placed on the mining operations appear to have reduced the contaminant loads entering the Cheyenne River. This trend in reduced contaminant loading can be seen in a time series plot of dissolved arsenic levels monitored at the lower Belle Fourche River station (Figure 4-3).

Figure 4-3.
Dissolved arsenic concentrations measured in the Belle Fourche River near Elm Springs (USGS station 06438000) from the period 1970 through 1991.



4.4.5 Environmental Consequences

4.4.5.1 Attainment of Applicable Surface Water Quality Standards

The water quality data collected at the USGS and SDDENR stations were compared to the criteria defined in South Dakota's water quality standards as summarized in Tables 4-26 through 4-29.

Table 4-26
Summary of South Dakota Water Quality Standards that were Compared to the Available Surface Water Quality Data

Parameters	Warmwater permanent fish life propagation	Warmwater semipermanent fish life propagation	Wildlife propagation and stock watering	Irrigation	Human Health Value	Aquatic Life Value
Alkalinity (mg/l as $CaCO_3$)			750[1]/1,313[2]			
Conductivity (umhos)			4,000[1]/7,000[2]	2,500[1]/4,375[2]		
Nitrogen, Nitrates as N (mg/l)			50[1]/88[2]			
Oxygen, Dissolved (mg/l)	$\geq$ 5.0	$\geq$ 5.0				
pH (S.U.)	6.5 – 9.0	6.5 – 9.0				
Sodium Adsorption Ratio				10		
Solids, Suspended (mg/l)	90[1]/158[2]	90[1]/158[2]				
Solids, Total Dissolved(mg/l)			2,500[1]/4,375[2]			
Arsenic, Dissolved (ug/l)					0.14	Acute: 360 Chronic: 190
Cadmium, Dissolved (ug/l)						Acute: 33* Chronic: 4.6*
Chromium (III), Dissolved (ug/l)						Acute: 2,860* Chronic: 930*
Copper, Dissolved (ug/l)						Acute: 114* Chronic: 63*
Cyanide, Dissolved (ug/l)					220,000	Acute: 22 Chronic: 5.2
Lead, Dissolved (ug/l)						Acute: 526* Chronic: 21*
Mercury, Dissolved (ug/l)					0.15	Acute: 2.1
Mercury, Total (ug/l)						Chronic 0.012
Nickel, Dissolved (ug/l)					4,600	Acute: 7,783* Chronic: 864*
Selenium, Dissolved (ug/l)						Acute: 20 Chronic: 5
Silver, Dissolved (ug/l)						Acute: 110*
Zinc, Dissolved (ug/l)						Acute: 631* Chronic: 576*

[1] 30-day average
[2] Daily maximum
* Based on a hardness of 750 mg/l as $CaCO_3$

Table 4-27
Comparison of Surface Water Quality Data Collected at USGS Stations on the Cheyenne River to Identified South Dakota Surface Water Quality Standards Criteria

Parameters	Station 06439500	Station 06439300	Station 06438500	Station 06423500
Alkalinity (mg/l as $CaCO_3$)	MS	MS	MS	---
Conductivity (umhos)	MS	MS	MS	MS
Nitrogen, Nitrates as N (mg/l)	MS	MS	---	---
Oxygen, Dissolved (mg/l)	---	MS	---	MS
pH (S.U.)	MS	Some higher values exceed 9.0	MS	MS
Sodium Adsorption Ratio	MS	Some higher values exceed 10	---	---
Solids, Suspended (mg/l)	---	Criteria often exceeded	Criteria often exceeded	---
Solids, Total Dissolved(mg/l)	---	---	MS	---
Arsenic, Dissolved (ug/l)	Human Health Value exceeded	Human Health Value exceeded	---	---
Cadmium, Dissolved (ug/l)	MS	MS	MS	MS
Chromium (III), Dissolved (ug/l)	MS	MS	MS	MS
Copper, Dissolved (ug/l)	MS	MS	MS	MS
Cyanide, Dissolved (ug/l)	---	MS	MS	MS
Lead, Dissolved (ug/l)	MS	Occasional value may exceed chronic Aquatic Life criteria	---	---
Mercury, Dissolved (ug/l)	---	---	---	---
Mercury, Total (ug/l)	---	Chronic Aquatic Life criteria may be occasionally exceeded	---	---
Nickel, Dissolved (ug/l)	MS	MS	MS	MS
Selenium, Dissolved (ug/l)	Chronic Aquatic Life criteria exceeded	Occasional value may exceed chronic Aquatic Life criteria	Occasional value may exceed chronic Aquatic Life criteria	Occasional value may exceed chronic Aquatic Life criteria
Silver, Dissolved (ug/l)	MS	MS	MS	MS
Zinc, Dissolved (ug/l)	MS	MS	MS	MS

Note: MS = Meets Standards.
Note: Refer to Figure 4-2 location map for sampling locations for sample locations.

Table 4-28
Comparison of Surface Water Quality Data Collected at SDDENR Stations on the Cheyenne River to Identified South Dakota Surface Water Quality Standards Criteria

Parameters	Station 460133	Station 468860	Station 460865	Station 460132
Alkalinity (mg/l as $CaCO_3$)	MS	MS	MS	MS
Conductivity (umhos)	MS	MS	MS	MS
Nitrogen, Nitrates as N (mg/l)	MS	MS	MS	MS
Oxygen, Dissolved (mg/l)	MS	MS	MS	MS
pH (S.U.)	MS	Some higher values exceed 9.0	MS	MS
Sodium Adsorption Ratio	---	---	---	---
Solids, Suspended (mg/l)	Criteria often exceeded	Criteria often exceeded	Criteria often exceeded	Some higher values exceed criteria
Solids, Total Dissolved(mg/l)	---	Some higher values exceed criteria	Some higher values exceed criteria	---

Note: MS = Meets Standards.
Note: Refer to Figure 4-2 location map for sampling locations for sample locations.

State surface water quality standards for suspended solids are regularly exceeded in the Cheyenne River, and standards for dissolved solids are also exceeded though at a lesser frequency. These observations are in line with the State of South Dakota's latest 305(b) water quality assessment. However, other concerns that may exist include elevated levels of arsenic, selenium, and mercury. The State of South Dakota has set a very low criterion for arsenic in regards to human health protection based on the risk of exposure through the ingestion of contaminated aquatic organisms. This low value appears to be exceeded on a regular basis. The chronic selenium criterion for the protection of aquatic life also appears to be exceeded on a frequent basis. It is noted that the detection/reporting limit for mercury applicable to much of the past monitoring that occurred is above the current criteria defined by the state and makes assessing mercury contamination problematic. Quantifiable levels of mercury, above the defined criteria, were measured on occasion in surface waters and the possibility exists that mercury could present a surface water quality concern.

Table 4-29
Comparison of Belle Fourche River Surface Water Quality Data to Identified South Dakota Standards Criteria

Parameters	USGS Station 06439500	SDDENR Station 06439300
Alkalinity (mg/l as $CaCO_3$)	MS	MS
Conductivity (umhos)	Occasional value may exceed Irrigation criteria	Occasional value may exceed Irrigation criteria
Nitrogen, Nitrates as N (mg/l)	MS	MS
Oxygen, Dissolved (mg/l)	MS	MS
pH (S.U.)	Some higher values exceed 9.0	MS
Sodium Adsorption Ratio	MS	---
Solids, Suspended (mg/l)	---	Criteria exceeded
Solids, Total Dissolved(mg/l)	Occasional value may exceed criteria	Occasional value may exceed criteria
Arsenic, Dissolved (ug/l)	Human Health Value exceeded	---
Cadmium, Dissolved (ug/l)	MS	---
Chromium (III), Dissolved (ug/l)	MS	---
Copper, Dissolved (ug/l)	Occasional value may exceed criteria	---
Cyanide, Dissolved (ug/l)	MS	---
Lead, Dissolved (ug/l)	MS	---
Mercury, Dissolved (ug/l)	---	---
Mercury, Total (ug/l)	Chronic Aquatic Life criteria may be exceeded	---
Nickel, Dissolved (ug/l)	MS	---
Selenium, Dissolved (ug/l)	Chronic Aquatic Life criteria exceeded	---
Silver, Dissolved (ug/l)	MS	---
Zinc, Dissolved (ug/l)	MS	---

Note: MS = Meets Standards.
Note: Refer to Figure 4-2 location map for sampling locations for sample locations.

4.4.6 Conclusions

Water quality in the Cheyenne River Basin is affected by many natural and anthropogenic factors such as geology, effluent discharges, agricultural practices and irrigation return flows, and mining practices. The two major factors that appear to have or have had the greatest impact on the water quality of the Cheyenne River are natural factors associated with the geology of the basin and mining practices.

4.5 Potential Sediment Contamination

4.5.1 Introduction

The literature on "sediment contamination" identified over fifty possible contaminants, but concentrated on 14 such constituents, as shown below.

Arsenic	Manganese
Cadmium	Mercury, methyl
Chromium	Mercury, total
Copper	Selenium
Cyanide	Sodium
Iron	Sulfate
Lead	Zinc

Four of these 14 constituents received special attention: total mercury, methylmercury, arsenic (in its various forms) and selenium. The ten constituents other than arsenic, selenium and mercury (methyl and total) were determined to be below the level at which they would be considered a contaminant, or where they would be at a harmful concentration. This evaluation therefore concentrated on arsenic, selenium and mercury.

To corroborate the decision to focus on only a handful of constituents, we refer back to the water quality section, and to the standards listed in Tables 4-13 and 4-14. The station covering the most constituents is that of the USGS at Cherry Creek (Table 4-17). Water quality standards are not in place for nineteen of those constituents, as listed in Table 4-30.

Table 4-30
Constituents Lacking Water Quality Standards
(Cheyenne River, USGS, at Cherry Creek)

Aluminum	Hardness	Potassium
Ammonium	Iron	Sodium, dissolved
Calcium	Magnesium	Strontium
Chloride	Manganese	Sulfate
Chromium, total	Molybdenum	Turbidity
Copper	Phosphorus	Vanadium
Cyanide		

For constituents having established standards, the 75th percentile was chosen as the set of values to compare to the standards. That statistical level shows the high side of data samples, without including maxima (which often are outliers from the main group of data). The criterion with the lowest concentration was chosen as the comparative value for each parameter, to assess the worst-case water quality problem. Table 4-31 lists seven constituents for which the Cherry Creek station on the Cheyenne was the only station yielding meaningful data.

Table 4-31
Comparison of 1999 Cheyenne River Samples
(USGS at Cherry Creek) to Water Quality Standards
(in µg/L, for aquatic life value, chronic)

Parameter	75th Percentile	Standard
Cadmium	<1	4.6
Chromium, dissolved	3	930
Lead	4	21
Nickel	4	864
Selenium	4	5
Silver	<1	110
Zinc	14	576

Data for several constituents were available from most of the sampling stations, and these are listed in Table 4-32.

Table 4-32
Comparison of Recent Cheyenne River Samples
(multiple stations) to Water Quality Standards

Constituent	75th Percentile	Standard
Alkalinity	180 - 222	750 mg/L, for wildlife propagation and stock watering
Conductivity	2140 – 2500	2500 µmhos, for wildlife propagation, stock watering
Nitrogen, nitrates as N	1.1 - 1.6	50 mg/L, for wildlife propagation, stock watering
Oxygen, dissolved	8.9 – 13.1	≥ 5.0 mg/L, for warmwater fish life propagation
pH	8.2 – 8.5	6.5 – 9.0, for warmwater fish life propagation

The sample data for constituents in tables 4-31 and 4-32are all below the specified standards. However, sampling produced values for sodium adsorption ratio (SAR) that are higher than the standard of 10 (for irrigation). The Cherry Creek (Cheyenne River) station yielded an SAR 75th percentile value of 14. For this evaluation on potential contamination, we proceeded without looking further at SAR, since the scientific literature did not bring up a concern about SAR.

The above discussion leads to the conclusion that it is reasonable to focus on arsenic, mercury (total and methyl) and selenium, and to exclude all other constituents from our evaluation. Although the selenium water quality data did not exceed the standard, as shown in Table 4-31, it must be closely analyzed due to its pronounced presence in sediment and fish.

4.5.2 Selenium

4.5.2.1 Available Data

Many references examined the selenium levels. The most information came from Ref. 118 (1972 data), which presented readings from wells along the Belle Fourche and Cheyenne Rivers. The Cheyenne readings did not exceed the recommended limit of 0.01 mg/L. The Belle Fourche wells ranged from 0.002 to 0.022 mg/L.

4.5.2.2 Evaluation

Reference 118 noted that the, "occurrence of selenium appears to correlate with the more recent shales of the Plains area rather than the igneous and metamorphic rocks of the Black Hills uplift. This is discussed in Section 4.1, Bedrock Mineralogy and Constituent Elements. The evidence is strong that high levels of selenium are a natural phenomenon of the Cheyenne River basin, and that concentrations do not deviate significantly with those natural levels.

4.5.2.3 Conclusions

Existing data show no significant increase in selenium in the Cheyenne River above background levels. The area's geology produces relatively high concentrations of selenium in the river system, independent of human activities. Based on available information, our conclusion is that the Cheyenne River is not contaminated with selenium.

4.5.3 Arsenic

4.5.3.1 Available Data

Over a third of the nearly 300 references in the database deal with arsenic. Sampling and quantifying arsenic are not straightforward, since it exists in several forms in the water and soil and has been analyzed and reported in various ways depending on the objectives of the studies. Some studies used X-ray diffraction or optical methods for mineralogical data; other studies used a variety of extraction fluids and processes to distinguish between trivalent, pentavalent, and strongly bound (e.g. sulfidic) forms of arsenic. Other sediment studies sieved samples to investigate the arsenic concentrations in various particle size ranges. The arsenic analyses of the surface water samples are no less problematic, as some studies report "total" analysis while others report "dissolved", using a 0.45 micron filter and others with unspecified filter sizes. For simplicity in this evaluation, we used total arsenic. The significance of the different forms of arsenic is discussed in Section 4.8.2.3. The literature sources presented arsenic sample data for wells, surface water, oxidized floodplain, stream bottom sediment and interstitial water. Reference 118 showed that well water sampled in 1972 along the Cheyenne River was under the recommended limit for wells, 0.05 mg/L. Some well samples along the Belle Fourche exceeded that limit, but the average readings were less than 0.05. Arsenic in the surface water of the Cheyenne River technically is problematic, since virtually all readings are greater than the human health standard of 0.14 µg/g (Table 4-14). However, that widespread exceedance is an indication that the high concentrations are a natural phenomenon, with no major sources of anthropogenic contamination. The sediment itself, however, is clearly above natural concentrations. Reference 199 noted that the sampling (around 1990) showed that the

Cheyenne had sediment concentrations of about 30 mg/kg, while the natural concentration was in the range of 5 to 10 mg/kg. That document was one of many that showed that the Belle Fourche concentrations (250 mg/kg) were clearly higher than those on the Cheyenne, and that the arsenic levels in the Cheyenne go up below the Belle Fourche confluence. This strongly indicates that the high amount of arsenic in the lower Cheyenne River is due to the historical mining activity in the Belle Fourche drainage (i.e., Whitewood Creek).

Another study in 1984 and 1985, where sediment samples were collected in the Cheyenne River Basin and the Belle Fourche River, indicated the following. Samples collected (95) from sediment deposits along both the Belle Fourche River and Whitewood Creek had a mean arsenic concentration of 1,920 µg/g and a maximum concentration of 11,000 µg/g. Random sampling of flood plain sediments indicated that anomalous concentrations of arsenic occur throughout the Cheyenne River basin. The largest concentrations measured in 42 randomly collected flood-plain sediment samples from Whitewood Creek averaged 1,400 µg/g. Concentrations measured in sediments from the Belle Fourche River flood plain decrease gradually in a downstream direction from about 1,300 ppm just downstream from the mouth of Whitewood Creek to about 400 ppm at the mouth of the Cheyenne River. Arsenic concentrations of the Cheyenne River flood plain sediments averaged about 70 µg/g from 312 randomly collected sediment samples. It should be noted that these are "flood plain" sediments, which typically contain between 150 and 500 percent larger concentrations of arsenic than do active-channel sediments (Refs. 18, 95, 96, 97, 98).

In relation to active-channel sediments, suspended-sediment samples collected from the Cheyenne River at Cherry Creek had arsenic concentrations that ranged from 12 to 36 µg/g. Additional suspended-sediment samples collected from the Cheyenne River at Wasta contained between 8.5 and 10 µg/g arsenic (Refs. 85, 96, 97, 98). Another study extracted from these same references indicated similar concentrations of arsenic from samples collected of sediments of the Cheyenne River arm of Lake Oahe. This study also indicated that samples collected at much greater depths had the greatest concentrations of arsenic in the sediment. A sample collected from 70 – 72 cm had an arsenic concentration of 140 µg/g as opposed to 9-23 µg/g in the upper 4 centimeters (cm). The phenomenon of arsenic concentrations remaining high under additional sediment is shown in Figure 4-4. It shows how recent (1985, 1989) shallow deposits are not too far off from the background concentration. As the sediment is probed below the first few centimeters, the arsenic concentration increases significantly. Although the 1972 data set comprises only three points, they corroborate the 1985 and 1989 data. That is, they show that sediment being deposited is much cleaner (in terms of arsenic) than when the gold mine was discharging large amounts of pollutants into the Belle Fourche River (disposal methods improved in the mid-1970s).

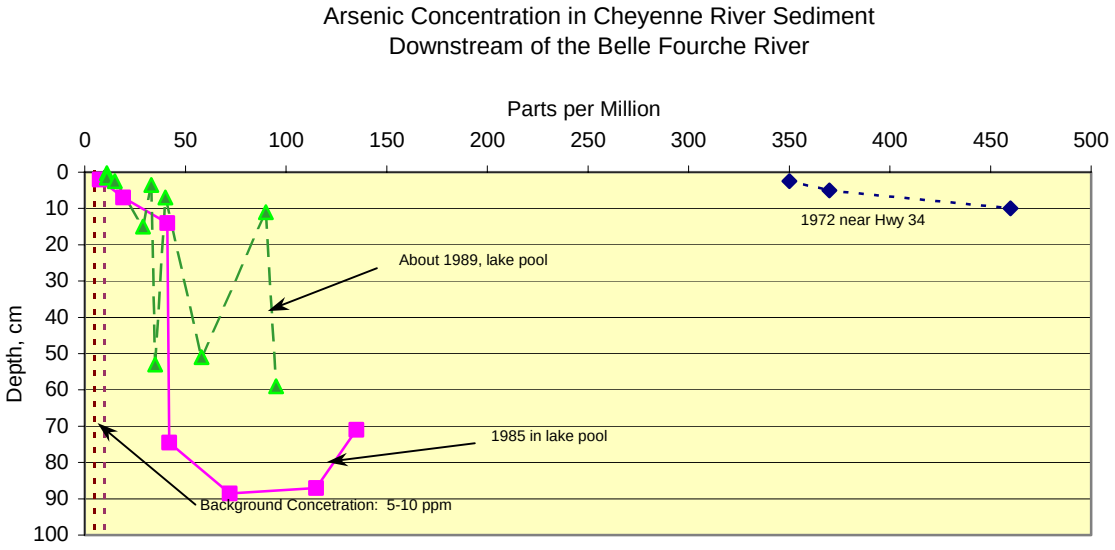


Fig. 4-4

Figure 4-5 shows the distribution of sediment along the river from when Oahe Dam began impounding water in 1958. The 1976 and 1989 profiles are taken from surveys. The 1985 line is an interpolation between the 1976 and 1989 profiles. The projected 2002 sediment depth is taken from Ref. 23, which estimated the amount of deposition in the Cheyenne River Arm for 100 years of reservoir operation. The description of the sampling in Ref. 97 (as shown in Fig. 4-4) indicates that samples for that study probably were taken between river miles 20 and 30. These data are also plotted in Fig. 4-5 showing their vertical location relative to the approximate change in mine disposal methods (1976) and to the present river bed elevation (2002, projected). Reference 200 doesn't specify where in the Cheyenne River Arm its 1989 samples were taken, so for simplicity we plotted them at the same location as the 1985 values.

Core sample data for the Cheyenne River embayment of Lake Oahe that were plotted in Figure 4-4 are as follows: 0-2 cm depth = 11 µg/g arsenic, 2-3 cm = 15 µg/g arsenic, 3-4 cm = 33 µg/g arsenic, 6-8 cm = 40 µg/g arsenic, 10-12 cm = 90 µg/g arsenic, 14-16 cm = 29 µg/g arsenic, 50-52 cm = 58 µg/g arsenic, 52-54 cm = 35 µg/g arsenic, and 58-60 cm = 95 µg/g arsenic. The arsenic in the sediments was oxidized during transport and then reduced in the sediment column where it was preserved as coatings on grains; hence, the higher arsenic concentrations at depth.

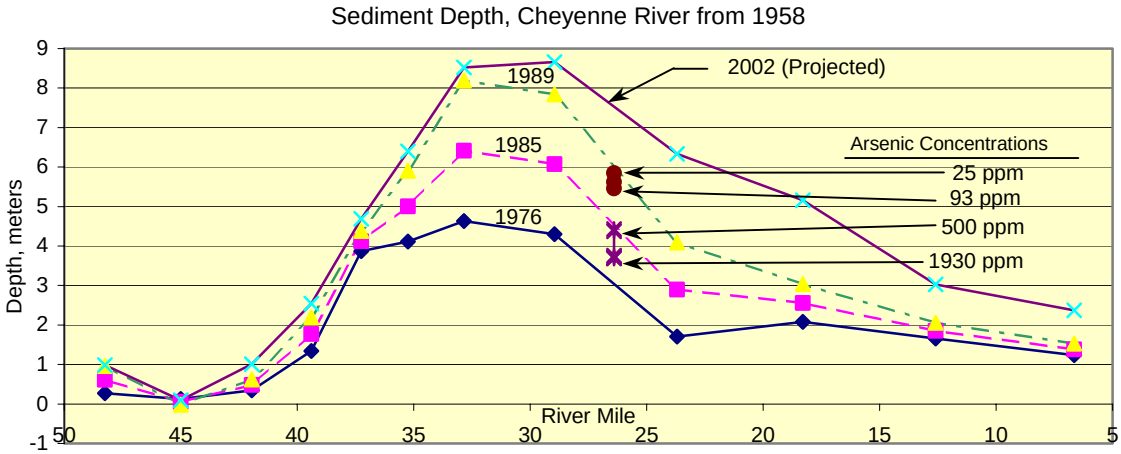


Fig. 4-5

The projections in Ref. 23 show that annual sediment deposition in the Cheyenne River Arm ranges from 4 to 12 centimeters in lower reach (below about river mile 18) between years 1976 and 2002. The high deposition reach (mile 18 to 35) ranges from 9 to 18 cm per year. The next five miles upstream has a rate of 3 to 10 cm/yr. Between miles 40 and 50, the deposition rate is less than 4 cm/yr, and is close to zero as the effects of the reservoir pool diminish.

The projections of sediment deposition in Ref. 23 were published in 1999. As a comparison, Ref. 97, which was published in 1989, estimated sediment rates of 5 cm/yr in the lower arm, 6-10 cm/yr in the middle arm, and 12-23 cm/yr in the upper arm.

4.5.3.2 Evaluation

Data on total arsenic (without a rigorous breakdown of its different forms) indicate that the concentration of arsenic in the river sediment diminishes over time, as cleaner sediment mixes with earlier deposits. This is true only for shallow sediments that can be scoured and transported. In deeper sediment, arsenic concentrations that resulted from high historical levels of this constituent tend to remain at high concentrations. This situation does not appear significant where the river's sedimentation regime is near equilibrium. Where the river is under the influence of the lake pool, however, deposition is a significant, ongoing process. Although the new sediment does not have problematic amounts of arsenic, the deeper sediment continues to harbor high concentrations. Any process or event that could tap into or erode into those deeper sediments could allow this contamination to impact the people's use of the river, as well as affecting fish and wildlife.

4.5.3.3 Conclusions

Available data indicate that arsenic concentrations in Cheyenne River sediment are not a significant problem, unless activities would reach into deeper sediments. In general, the free-flowing river would not have much high-concentration deep sediment, since the aggradation/degradation regime is probably in equilibrium over that long term. That is, the

sediment that deposits during certain flow events probably will ultimately be picked up and carried away in the future. However, some areas may be in a depositional mode, similar to the reach affected by the Lake Oahe pool. Caution would be prudent in those areas, depending on the type of activities and projects that could be impacted by high arsenic concentrations. It would be reasonable to formulate a list of activities and potential projects relative to their locations, and determine whether any of those areas are in a depositional regime. Sampling for arsenic in those areas could define the risks involved in conducting those activities there.

4.5.4 Mercury

4.5.4.1 Available Data

Mercury is the chemical most often addressed in the literature on potential contaminants in the Cheyenne River. About half of the 296 documents discussed mercury (elemental) or methylmercury. In fact, methylmercury may have the greater importance, and is discussed in detail elsewhere in this document.

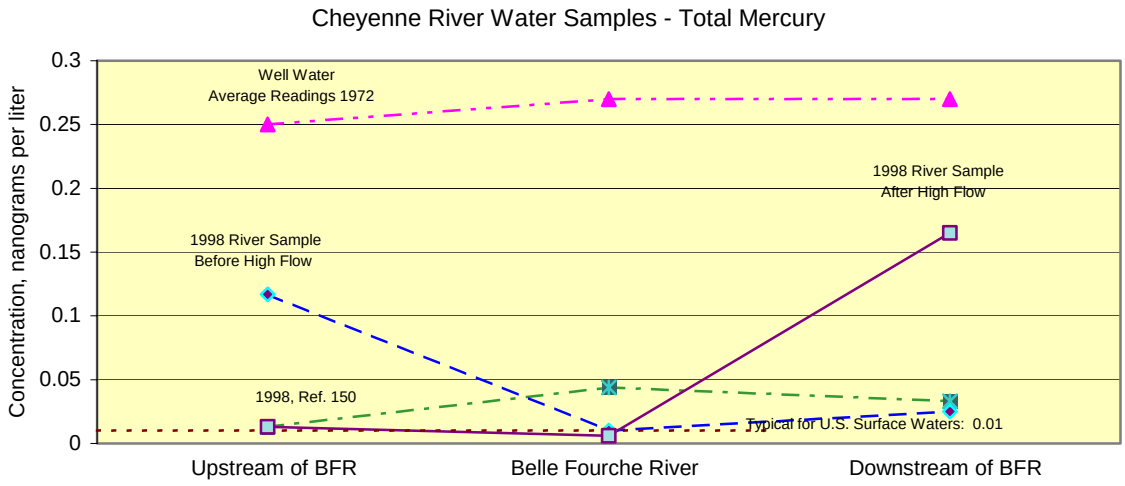


Fig. 4-6

Mercury was an intrinsic part of the mining process, and like arsenic, it was much more evident in the Belle Fourche River than the Cheyenne River (upstream of the Belle Fourche). Figure 4-6 gives some indication of this relationship, with well water readings taken along both rivers in 1972. The concentration of mercury rose in the Cheyenne River starting at the Belle Fourche confluence. In fact, the readings on the downstream reach of the Cheyenne matched the well water readings along the Belle Fourche. That relationship is clearer on some 1998 data plotted in the same figure. Reference 150 shows the mercury level in the Cheyenne River rising downstream of the Belle Fourche, but not reaching the mercury concentration in the Belle Fourche itself. The 1998 concentrations generally were close to the typical value for United States surface waters, 0.01 nanograms per liter. However, the concentration changes dramatically relative to whether the samples are taken before or after a significant high flow event. The 1998 data show that before a particular high flow, the mercury concentration in the water was actually much higher in the upper Cheyenne River than the Belle Fourche River. After the high flow, the Cheyenne above the Belle Fourche registered around 0.01 ng/L, as did

the Belle Fourche. The Cheyenne River downstream of the Belle Fourche then rose to more than 0.15 ng/L.

Total mercury in the sediment itself has continued to drop over the years. In 1972, the Cheyenne River above the Belle Fourche had concentrations in the range of the background concentration (0.1 parts per million). The Belle Fourche had five times that amount, and the lower Cheyenne was around 0.3 ppm. By 1985, the Belle Fourche River's level of mercury remained elevated (at 0.15 ppm), but the Cheyenne was under the 0.1 ppm threshold. Testing in 1998 showed that even the Belle Fourche was under the threshold (showing a concentration of 0.05 ppm), and the Cheyenne was less than 0.02 ppm. These data are plotted in Figure 4-7.

4.5.4.2 Evaluation

Mercury levels evidently are responding to flushing flows in the same way as arsenic. That is, the mercury is picked up by high flows, effectively reducing its concentration in the sediment. That process appears to be shifting higher levels of mercury from the Belle Fourche to the Cheyenne. Over the long-term, the concentrations appear to be safely within the background range. However, the period shortly after a high flow event could exhibit some significant short-term elevations of mercury concentrations downstream of the Belle Fourche.

4.5.4.3 Conclusions

The Cheyenne River appears to have restored itself to its condition preceding the Belle Fourche mining era, in terms of average concentrations of mercury in the riverbed. However, the mercury continues to load into the river water as high flows rework the sediment. This could be significant, especially where some water uses might cause frequent exposure to the elevated concentrations of mercury in the water. Just as for arsenic, it may be advisable to outline what activities or facilities could cause frequent contact with the river, and to do additional sampling for mercury accordingly.

4.5.5 Methylmercury

4.5.5.1 Available Data

Methylmercury in the Cheyenne River has not been studied to the extent of elemental mercury. However, the available information indicates that its concentration in the Cheyenne and Belle Fourche Rivers is clearly above normal values, according to 1998 values plotted in Figure 4-8. The most notable situation in these methylmercury plots is the higher values in the Belle Fourche River. Although one set of data (Ref. 150) shows the Cheyenne River concentration to be lower below the Belle Fourche compared to the upper Cheyenne, the other datasets have higher values in the Cheyenne after it picks up the Belle Fourche flows.

4.5.5.2 Evaluation

The methylmercury concentration in the water seems to behave differently than total mercury in response to a high flow event. While Figure 4-6 apparently shows that high flows tend to

reduce the mercury concentrations if the inflow is cleaner water (upstream Cheyenne) and increase mercury concentrations as waters with more mercury enter the system, methylmercury concentrations rise in all reaches after the high flow (Fig. 4-8). A study conducted by USGS, in obtaining a better understanding of mercury in water and sediment in the Cheyenne and Moreau River Basins in South Dakota, suggested that the lower Belle Fourche River might be an area of substantial methylmercury generation (the conditions at the Lower Belle Fourche River appear to be favorable for methylation) and fluxes to the lower Cheyenne River Basin (Ref. 225). Some of the other constituents in the methylation process are conductivity, total dissolved solids, nonfilterable solids, and pH.

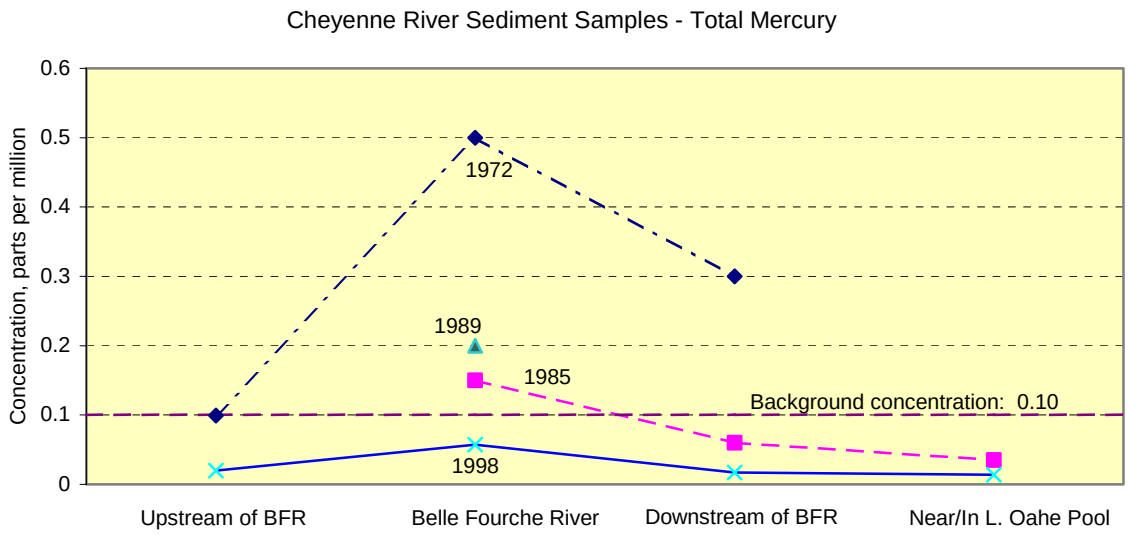


Fig. 4-7

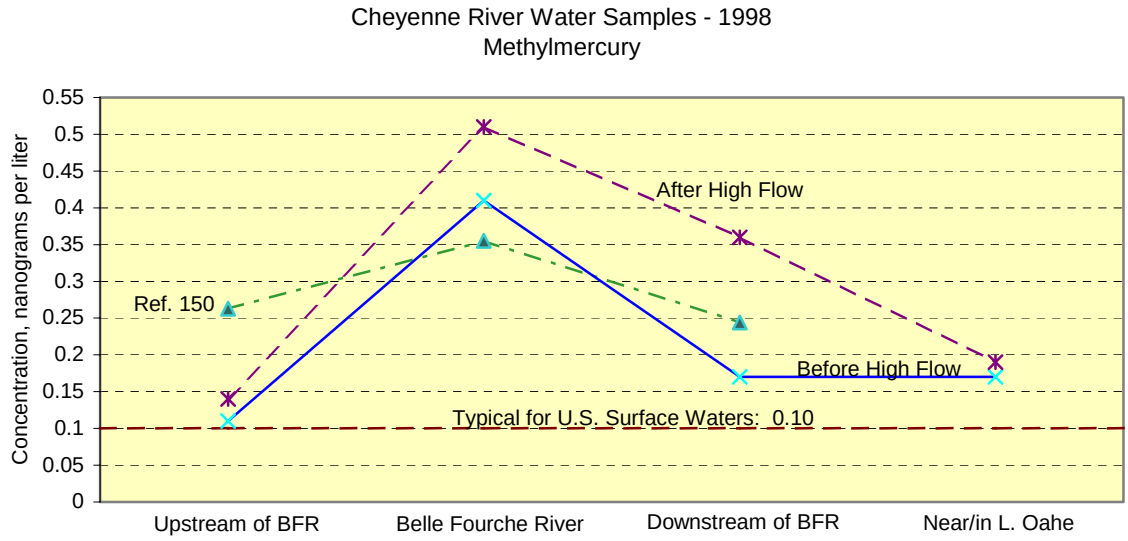


Fig. 4-8

4.5.5.3 Conclusions

Figure 4-8 shows that there are elevated levels of methylmercury in the Cheyenne River, however, there has not been enough studies to substantiate that finding. It is assumed that the

source of the elevated levels near the convergence of the Belle Fourche River to the Cheyenne River was from past mining upstream of the Belle Fourche River from this point.

The above discussion on methylmercury drew heavily on the information presented in a 1987 report (Ref. 109), and basically agrees with the conclusions contained therein. That 1987 evaluation stated that, "Total mercury in sediments was not correlated with concentrations of mercury in fish; instead, mercury uptake by fish was correlated with variables that either facilitate mercury uptake or promote methylation." That report included the statement that, "More research on methylation of mercury is clearly needed." We concur with that assessment, in light of the many variables in the methylation process, and because of the potential harm that high concentrations of methylmercury can cause.

4.5.6 Upstream Considerations

The evaluation of arsenic, selenium and mercury in the preceding paragraphs on sediment were focused on the Cheyenne River from the reach immediately upstream of the Belle Fourche River, down into Lake Oahe. This is due to much information indicating that potential contamination is most likely below the Belle Fourche River, probably due to the effects of mining operations in the Belle Fourche basin. The mandate for this study, however, covers the entire Cheyenne River. Therefore, literature also was reviewed for the reach above Wasta, particularly in the area of Angostura Reservoir. Concentrations of potential contaminants at Angostura could be similar to what has been observed at Lake Oahe.

The USBOR evaluated water quality and sediment in 1999 (Ref. 9) in relation to the Angostura Reclamation Unit (ARU). The USBOR noted that available sediment samples except for uranium samples, "do not indicate any serious contamination with trace elements or uranium. Elevated concentrations of molybdenum, selenium, arsenic and zinc were observed at a minimum of one site, but only molybdenum was elevated at more than one site when compared to a baseline for Western soils. Comparison to criteria for the protection of aquatic life indicates that the sediments are not contaminated to potentially harmful concentrations." In regard to uranium, the USBOR stated that after a uranium mill in Edgemont ceased operation in 1972, and was subsequently cleaned up, "there is no longer any significant contamination to Angostura Reservoir from the site."

The USGS prepared a report in 2001, wherein they compiled and analyzed 1988 and 1994 sample data from the ARU (Ref. 93). That study included interesting information on fish tissue, as well as water quality and sediment. Some of the fish sample information is presented in Figures 4-~~9~~ and 4-10.

The 1994 data compiled in Ref. 93 show that arsenic concentration in sediments was about the same above and below Angostura Reservoir (12 µg/g), and Ref. 9 shows that there wasn't a clear increase in arsenic concentrations in the reservoir (5.1, 7.2, 16.4 µg/g). Nevertheless, the concentrations could be problematic, since the irrigation level of concern is 8.2 µg/g, and the background is 5 to 10 µg/g.

The USGS 2001 report (Ref. 93) on the ARU drew the following conclusions.

► "Bottom-sediment arsenic concentrations in the area are commonly within the National Irrigation Water Quality Program (NIWQP) level of concern, at sites both upstream and downstream from irrigation operations."

► "Bottom-sediment arsenic and selenium concentration in the ARU area apparently can reach levels that might be of concern; however, there is insufficient information to determine whether the irrigation operations of ARU contribute to elevated concentrations."

► "Elevated selenium concentrations at sites upstream from irrigation operations indicate that naturally occurring selenium concentrations are relatively high in the ARU area, and irrigation operations of the ARU probably do not contribute substantially to selenium concentrations in the Cheyenne River."

► " . . . selenium concentrations in fish might be problematic. Selenium concentrations in fish samples routinely are within the NIWQP level of concern, and also commonly exceed the dietary guideline for protection of avian consumers."

4.6 Fisheries and Benthic Macroinvertebrates

Sediment can be ingested by benthic macroinvertebrates, and can also become resuspended in water. Anything within the sediment or sediment particles, including contaminants, can be ingested with the sediment. Aquatic organisms ranging from algae to fish can be exposed to, and ingest, these suspended sediments. Various species of fish eat algae, benthic invertebrates, and other fish that may have ingested these sediments, and so may also be exposed to these sediments through diet. Sampling tissues of predator species, such as fish, and analyzing them for concentrations of substances that could be potential contaminants, indicates whether these animals may have been exposed to high levels of these substances in the aquatic ecosystem.

4.6.1 Affected Environment

4.6.1.1 Historical

In the 1960s, as part of fisheries management, an inventory of populations (fish, insects and benthic macroinvertebrates) was conducted for the Belle Fourche and Cheyenne River Basins. In 1996 and 1997, a similar study was conducted between Angostura Dam and Lake Oahe along the main stem of the Cheyenne River at nine reaches. Thirty species, representing ten families were collected. The fish community was composed mostly of Cyprinidae (minnows), Ictaluridae (bullhead, catfish,), and Catostomidae (suckers) families with 85% of the total catch made up of flathead chub (28%), plains minnow (24%), western silvery minnow (20%), sand shiner (7%) and channel catfish (6%). The channel catfish is the most abundant sport fish in the Cheyenne River mainstem. Among the species captured were five species considered rare in South Dakota (sturgeon chub, plains topminnow, flathead chub, plains minnow, and western silvery minnow) (Refs. 173, 254).

Twelve different families in six orders were collected among all three invertebrate sampling locations taken in this survey. Rapid bioassessment metrics calculated for composite samples taken from the Belle Fourche River and the Cheyenne River above and below the confluence do not differ to any great degree or indicate any severe signs of stress (Refs. 173, 254). Since it had been nearly 40 years since an inventory had been conducted (1960s to late 1990s), this

1990s study was considered to provide baseline data for future assessment of the fish community and watershed health. No conclusions were made in either study to indicate the health of the watersheds (Ref. 173).

Levels of mercury in fish tissue were detected during 1974, 1980, and 1984 ranging from 0.04 µg/g (equivalent to parts per million, ppm) to 1.52 µg/g. The highest levels of mercury [1.52 µg/g (1974)] were found in northern pike. Correspondence in 1974, from the South Dakota Department of Environmental Protection to USEPA Region VIII, indicated the need to continue the ban on commercial fishing with warning signs remaining in place for the Cheyenne River Arm due to the level found during the 1974 study (Refs. 111, 115, 121, 122). The original warning signs may have been due to samples of fish tissue collected between 1972 and 1976 where concentrations of 0.05 – 1.20 ppm were detected (Ref. 114). Additional correspondence indicated two tissue samples were collected specifically from the Cheyenne River with results of 0.08 mg/g (or, 80 ppm). The initial advisory posting for the Cheyenne River Arm of Lake Oahe by the State of South Dakota was based on a safe consumption level recommended by the USFDA of 0.5 ppm. In 1984, 10 fish each of four fish species in Foster Bay were sampled for mercury (Ref. 37). Mercury concentrations in fillets, in µg/g wet weight, ranged from 0.09-0.32 for northern pike; 0.12-0.38 for walleye; 0.11-0.34 for carp; and <0.05-0.35 for channel catfish. For whole fish, all fish had mercury samples below 0.35 µg/g wet weight except one northern pike at 2.20 µg/g wet weight, one walleye at 1.70 µg/g wet weight, one carp at 1.20 µg/g wet weight, and one channel catfish at 1.80 µg/g wet weight. Ten percent of the fish sampled had whole body concentrations that greatly exceeded the safe consumption level of 0.5 µg/g wet weight, indicating that the potential for mercury poisoning, although reduced from that existing in the mid-1970s, still existed.

Tissue samples in walleye were collected from the Grand, Moreau, and Cheyenne Rivers during April 1994 – 1996. The scope was to determine if contaminants, specifically selenium and mercury, were causing low natural reproduction in lower Lake Oahe. The study concluded that no significant differences in selenium and mercury concentrations in walleye tissues among sample sites were determined that would explain differential walleye egg hatchability among the three spawning sites (Ref. 76).

Arsenic was sampled in 10 fish each of four fish species in Foster Bay in 1984 (Ref. 37). Arsenic concentrations in whole fish, in µg/g wet weight, ranged from <0.05-0.21 for northern pike; 0.25-1.50 for walleye; 0.07-0.25 for carp; and 0.04-0.06 for channel catfish. Only one walleye had a whole-body arsenic concentration >0.41 µg/g wet weight.

4.6.1.2 Current

A Phase I and II study (Refs. 12, 56) focused on the collection and analysis of fish from the Cheyenne and Belle Fourche Rivers and associated areas of Lake Oahe. Data collection was carried out in two phases that were designed to evaluate potential human health risks, although the actual risk evaluation was not part of the study. Additionally, a biomonitoring approach was used to evaluate the potential for metal contaminant sources in the Cheyenne River drainage; the sampling design was configured around the bioaccumulation characteristics of mercury.

Phase I fish collection was conducted in Foster Bay (Cheyenne River discharge to Lake Oahe), Cheyenne River downstream from Bridger, Cheyenne River downstream from Cherry Creek, and the Moreau River near the Lake Oahe confluence. The Moreau River was considered a reference (background) area. Fish species captured included northern pike, walleye, channel catfish, and white bass.

Of interest during this study (Phase I), the diet of the fish species was recorded. In particular, the stomach of channel catfish contained food items such as yellow perch, invertebrates, and organic debris. Channel catfish were collected from the Cheyenne River at Cherry Creek and the town of Bridger. Aluminum, arsenic, chromium, lead, copper, selenium and zinc were detected. Other metals that were detected, are common in muscle tissue and not considered elevated, were calcium, iron, magnesium, manganese, potassium, and sodium.

For mercury, both dry and wet weight concentrations were calculated. The highest concentration of mercury was detected in a white bass collected from Foster Bay at a concentration of 3.7 µg/g mercury, dry weight (dw) (0.83 µg/g mercury, wet weight). All concentrations were less than 1 µg/g mercury, wet weight. Of interest, for the channel catfish, whose diet encompasses invertebrates, mercury concentrations were 0.32 – 1.2 µg/g (dw) in Cherry Creek and Bridger, respectively, and 0.4 – 1.4 µg/g dw in Foster Bay; this may be indicative of potential concentrations of mercury in the diet (to include invertebrates). Sampling was also conducted in the Moreau River; considered to be a reference area. The concentrations of mercury from fish from the Cheyenne River Basin were not significantly elevated when compared to this reference area.

General conclusions made regarding the Phase I study included: 1) total mercury concentrations were <1µg/g wet weight in all fish fillets; 2) no significant differences in total length or weight between fish collected from Foster Bay and Moreau River sites; 3) channel catfish total wet weight mercury concentrations were significantly higher from the Moreau River than from Foster Bay; 5) there was a strong and highly significant positive correlation between total mercury and methylmercury; 6) there was a significant positive correlation between both total mercury and methylmercury and fish length (except in northern pike); 7) there was a significant correlation between methylmercury and fish weight in all fish species (except northern pike); 8) there was a significant correlation between total mercury and fish weight in walleye and white bass; and 9) methylmercury was significantly correlated with fish age in walleye and white bass and total mercury was correlated with fish age in white bass only. Phase II sampling was conducted in the Belle Fourche River (near Volunteer and Hereford) and the Cheyenne River (near Wasta, Bridger, and Cherry Creek). Fish species captured were channel catfish, western silvery minnow, plains minnow, flathead chub, and carp.

During Phase II, surface sediment and surface water samples were also taken and water quality parameters (temperature, dissolved oxygen, conductivity, and oxidation/reduction potential) were measured. Sediment samples collected for aluminum, arsenic, chromium, cobalt, copper, magnesium, manganese, nickel, vanadium, and zinc in the Belle Fourche River (Volunteer and Hereford) and in the Cheyenne River (Bridger and Cherry Creek) were at decreased

concentrations with respect to the upstream location of the Cheyenne River (Wasta). Fish tissue samples for Bridger and Cherry Creek had mercury concentrations in catfish of 0.20 – 0.47 μg/g dry weight (dw) and 0.22 – 0.43 μg/g dw, respectively. For the forage fish, mercury concentrations were not detected (0.167 – 0.181 μg/g dw) in Cherry Creek and Bridger for the minnow; Hereford concentrations for the minnow ranged from not detected (.146 μg/g dw) to 0.20 μg/g dw. For carp, Cherry Creek total mercury concentrations were 0.39 μg/g dw and not detected (.216 μg/g dw) for the two samples collected, respectively. Bridger, Hereford, and Volunteer concentrations were 0.27, 0.28 and 0.35 μg/g, respective for mercury in carp. All results reported on a dry weight basis. For the chubs, Cherry Creek total mercury results ranged from non detect to 0.24 μg/g dw, and for Bridger non detect to 0.25 μg/g (not detected values are not available).

Water samples collected from all downstream locations (Volunteer, Hereford, Bridger, Cherry Creek) were not detected for total metals [antimony (50 μg/l), cadmium (5 μg/l), selenium (5 μg/l), silver (10 μg/l), thallium (5 μg/l), beryllium (5 μg/l), cobalt 10 μg/l), mercury (0.2 μg/l) and nickel (20 μg/l). The remaining metals analyzed were detected at the highest concentrations at the upgradient location (Wasta). However, in the sediment, the concentrations of most metals were lower (all but sodium and calcium) at Wasta. Further, the mercury concentrations in fish tissue samples for the Wasta location were not detected 0.151 – 0.175 μg/g dw). The fish species analyzed at this location were the minnow and carp.

General conclusions made regarding the Phase II study included: 1) total mercury concentrations were < 1 μg/g wet weight in all fish species; 2) total mercury and methylmercury concentrations were highest in catfish fillets in comparison to the remaining carcass or whole body samples; 3) total mercury and methylmercury in catfish fillets were directly correlated with fish size, either length or weight; 4) total mercury and methylmercury in catfish fillets were not correlated with fish age; 5) methylmercury concentrations exceeded total mercury concentrations in each catfish fillet; 6) the highest concentrations of total mercury were detected nearest the potential mercury source in all minnow species; 7) whole body total mercury concentrations were not positively correlated with increasing fish size for flathead chub; 8) mercury was detected in one water sample (0.4 μg//L near Wasta) and in no sediment samples; 9) metal concentrations were associated with particulates, as results were lower in filtered water samples; and 10) as the size of a catfish increases, mercury concentrations in the fillet increase.

Phase III (Ref. 11) was conducted near Cherry Creek in the Cheyenne River Arm of Lake Oahe to collect channel catfish of larger size than were generally collected in the earlier two phases. The concentrations of mercury detected ranged from 0.25 to 1.11 μg/g; wet weight.

In two separate reports, it was discovered that mercury concentrations exceeded the USFDA guideline of 0.5 ppm, in the flesh of walleye and channel catfish sampled along the Cheyenne River in 1970 and 1971, before closure of the Homestake mine (Ref. 52), and of four other fish species sampled in 1994 (Ref. 93). Those samples are included in the data presented in Figure 4-9. However, that figure averaged the data, and therefore the sample values exceeding the 0.5 ppm guideline are not shown. Nonetheless, the higher values upstream of the Cheyenne River Arm of Lake Oahe are a strong indication.

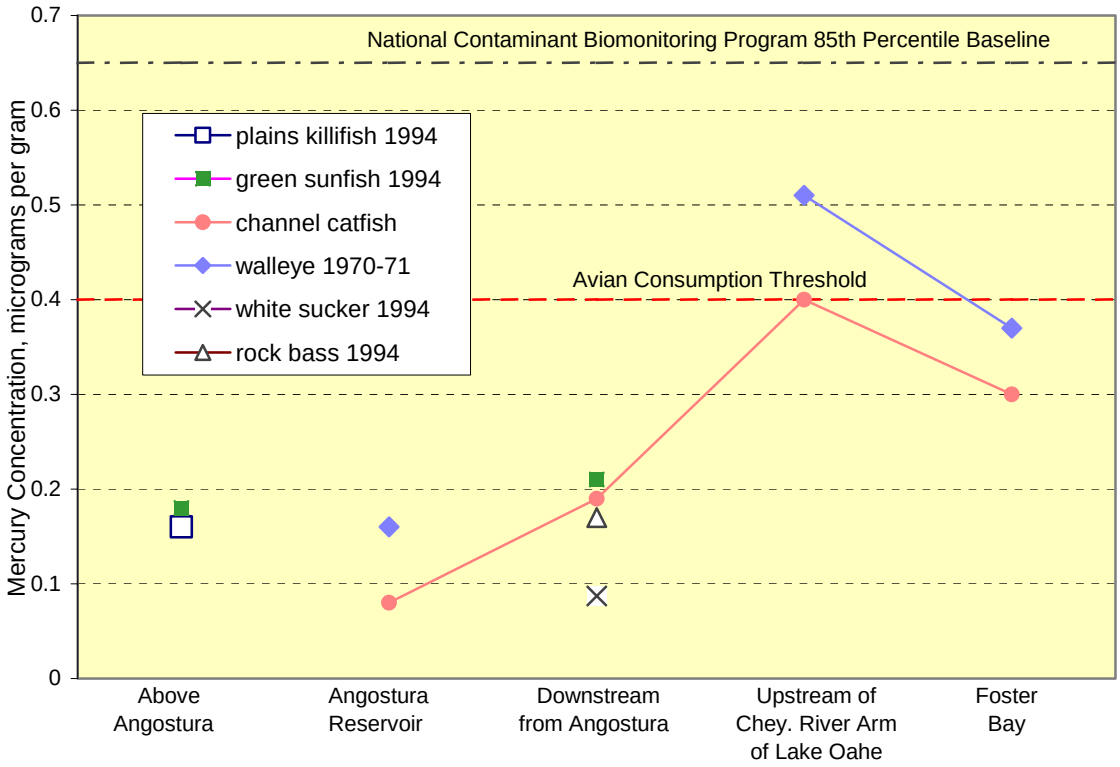


Figure 4-9. Mercury in fish flesh, Cheyenne River (1970-71 and 1994).

According to Figure 4-9, it appears that there was no discernible mercury problem in the Angostura Reservoir in 1971. However, there is evidence that high amounts of mercury was being loaded into the Cheyenne during mining operations in the Belle Fourche drainage. Figure 4-10 expands the data coverage of Figure 4-9, using channel catfish and sauger. The mercury concentrations in the fish upstream of the Belle Fourche River (Wasta area) were well within the "safe" category for human consumption. Once the Belle Fourche entered the Cheyenne, the mercury in sauger rose to problem levels, and remained high in the upper area of Lake Oahe. Mercury levels in Foster Bay sauger were significantly less than in the upper Cheyenne arm. Similarly, while the samples were taken before the mining stopped on Whitewood Creek, the data indicate that the Cheyenne River above the Belle Fourche River did not have symptoms of excessive mercury.

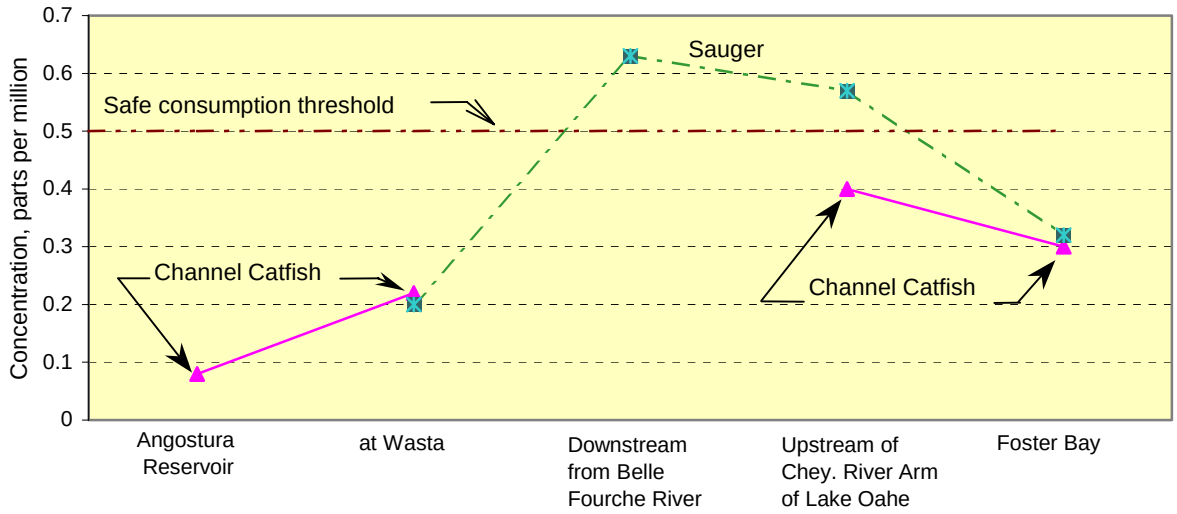


Figure 4-10. Mercury Concentration in Fish Flesh, Cheyenne River (1970-71).

Information on arsenic in sediment and fish in the Cheyenne above the Belle Fourche was examined, to show whether Angostura Reservoir is storing arsenic as sediment settles out of the river. The high amounts of arsenic in the riverine system are reflected in the 1994 fish flesh samples (Ref. 93). The sampling site above Angostura Reservoir (at Edgemont) produced concentrations of 1.25 µg/g in green sunfish, and 0.93 µg/g in plains killifish. The National Contaminant Biomonitoring Program 85th percentile baseline for arsenic is 0.81 µg/g. The 17 fish samples taken downstream of the dam showed arsenic concentrations of no more than 0.4 µg/g.

In 1996, total arsenic in six fish species (brown trout, longnose dace, mountain sucker, white sucker, green sunfish, and sand shiner) in lower Whitewood Creek ranged from <0.7 to 9.7 µg/g wet weight (Ref. 100). In 1997, fillets from channel catfish sampled from the Belle Fourche River had arsenic concentrations ranging from <0.30 to 0.85 µg/g (Ref. 174).

Selenium in sampled fish also looks like a potential problem. Fish samples ranged from 3.06 µg/g at Edgemont, to an average of 7.29 µg/g (for 17 samples, across 4 species) downstream of Angostura Reservoir. Reference 90 provided the NCBP 85th percentile baseline value of selenium concentrations in fish tissue: 2.8 µg/g. Several biologists suggest that an appropriate "effect level" would be 10.0 µg/g.

4.6.2 Summary of Considerations for Risk Assessment

A summary of considerations for risk assessment based on research data involving mercury, methylmercury, and arsenic are provided below, with details provided in Appendix A. Much of the experimental data from laboratory and field research that is available for assessing the potential toxic impacts of mercury, methylmercury, or arsenic originated in areas outside the

Cheyenne River basin. These research results may be applicable to the same or similar animal species occurring in the Cheyenne River main stem.

Mercury and Methylmercury

Benthic macroinvertebrates can ingest sediment containing mercury and methylmercury. Many of these benthic macroinvertebrates convert inorganic mercury to methylmercury and release the methylmercury into the water, making it bioavailable to other aquatic species (Ref. S52). Algae and other organic species bioconcentrate the waterborne mercury or methylmercury so that the mercury or methylmercury in their tissues is many times its concentration in the water (Ref. S24). Aquatic species can also be exposed to mercury and methylmercury through diet. Because mercury and methylmercury are eliminated very slowly, requiring 1 to 3 years for 50 percent removal in some fish (Ref. S26), the mercury and methylmercury ingested in food can bioaccumulate in tissues, making possible higher tissue concentrations of mercury and methylmercury as the aquatic animal increases in age and size. Mercury and methylmercury have the potential to biomagnify, or result in increased tissue concentrations for predators that are at higher levels in the "food chain". Humans, as well as many birds, mammals, and fish, eat fish, mollusks, crustaceans, and/or benthic macroinvertebrates (Ref. S44) that may have bioaccumulated mercury or methylmercury. Large, older fish with tissue concentrations of mercury >0.5 ppm were found in the Cheyenne River in 1998 (Refs. 11, 64) and could present a health hazard to humans if locally caught fish constitute a relatively high proportion of the diet. All fish and some invertebrates convert nearly all ingested inorganic mercury into methylmercury (Refs. S5, S33). Because methylmercury is more toxic than inorganic mercury, this increases the concern regarding bioconcentration. Mercury and methylmercury can also impact fish reproduction. Fish eggs and hatchlings appear especially prone to death or deformities when exposed to mercury (even when not methylated) in the water (Ref. S4). Female fish that were exposed to aqueous mercury or methylmercury "maternal transferred" it to developing eggs in their ovaries (Refs. S4, S26). Male fish exposed to methylmercury were found to have impaired sperm (Ref. S60) or impaired spawning activity (Ref. S26).

Arsenic

Aquatic animals bioaccumulate arsenic, but the accumulation rates do not appear to biomagnify; they do not increase by orders of magnitude up the food chain (Ref. S8). One reason is that arsenic is eliminated much more rapidly than mercury or methylmercury by animals high in the food chain. Half of ingested arsenic is eliminated by mammals and birds through the kidneys within 3 days (Refs. S17, S55), and half the arsenic exposed to fish in water or diet is eliminated through the bile within 7 days (Refs. S38, S39, S43, S56). Another factor is that some benthic macroinvertebrates that ingest soil or sediment containing arsenic may have relatively high arsenic bioconcentration and bioaccumulation rates (Refs. S15, S28), although they are lower in the food chain. This may occur because they store arsenic in their tissues in an organic form that is relatively low in toxicity and eliminate the stored arsenic very slowly (Refs. S15, S22). Arsenic in carbon compounds (organic arsenic) may be less toxic than inorganic arsenic at the same oxidation state (III or V) (Refs. S10, S43). When only organic forms or only inorganic forms of arsenic are compared, however, As(V), the form in arsenate, is much less toxic than As (III), the form in arsenite (Ref. S43).

4.6.3 Conclusions

Levels of mercury in fish tissue were so high in 1973 that commercial fishing was banned on the Cheyenne River Arm (Ref. 111), and the South Dakota State Department of Health posted an advisory against consumption of more than 1.5 pounds of fish per week taken from the Cheyenne River Arm (Ref. 14). Recent studies (Refs. 11, 222) found large, older fish with tissue mercury concentrations exceeding 0.5 ppm, the USFDA-recommended safe consumption level, in the Cheyenne River main stem. The Cheyenne River Sioux Tribe instituted an advisory in January 2001 for high-risk individuals to limit consumption of fish greater than four pounds taken from the Cheyenne River (Ref. 64). Monitoring of mercury concentrations in fish is important in providing current data for authorities and individuals to make decisions regarding whether to eat fish and aquatic invertebrates taken from the Cheyenne River.

4.7 Threatened and Endangered Species

Species that are listed as threatened or endangered have low populations and are in danger of becoming extinct. Species occurring in the Cheyenne River main stem area that are listed or proposed for listing as threatened or endangered by the US Fish and Wildlife Service were identified (Refs. S50, S59). A number of these species could come into contact with Cheyenne River sediment. Due to their scarcity, these species were not sampled for tissue concentrations of potential sediment contaminants in field studies included in the literature review. However, there were no reports of dieoffs of individuals belonging to these species from the 1970's to the present. The potential for each of the threatened or endangered animal species to be adversely affected by Cheyenne River sediment was evaluated, and this evaluation is provided as Appendix B.

4.8 Wildlife

Terrestrial wildlife could be adversely impacted by sediment that could contain mercury, methylmercury, or arsenic by eating vegetation growing in sediment deposited by the Cheyenne River or by eating animals that could have bioaccumulated mercury, methylmercury, or arsenic from potentially contaminated sediments.

4.8.1 Available data

From March to June of 1989, a wildlife evaluation was conducted along a portion of Whitewood Creek (Ref. 103). Big game in the area consisted of white-tailed deer, mule deer, and pronghorn (antelope). Upland game birds common to the area were wild turkey, gray partridge, and ring-necked pheasant. Big and upland game were concentrated on the lower portion of Whitewood Creek, near the Belle Fourche River confluence, because of irrigated agricultural fields of corn and alfalfa. Ten raptor species were observed in the area; these included two bald eagles and a nesting pair of golden eagles. The American kestrel, red-tailed hawk, and great horned owl were the most common raptor species. A total of 80 bird species were observed site-wide, the most abundant being the western meadowlark on grassland habitat. Other common species included the red-winged blackbird, mourning dove, mallard, American robin, eastern kingbird, and grasshopper sparrow. A rookery used by great blue

herons was present at the mouth of Whitewood Creek on the Belle Fourche River. Small mammal populations were low to moderate; the deer mouse was the only species captured. Larger mammals present included the fox squirrel, cottontail rabbit, white-tailed jackrabbit, porcupine, black-tailed prairie dog and muskrat. Both the coyote and red fox were also present. Reptile and amphibian species observed included the plains garter snake, chorus frog, northern leopard frog, and painted turtle.

In 1980 double-crested cormorant and cliff swallow specimens were collected from the Cheyenne and Moreau River drainages within the Cheyenne River Sioux Tribal lands (Ref. 19). The livers were analyzed for heavy metal contamination, e.g., mercury, selenium, cadmium, and arsenic concentrations. Specimens that were used for the study controls from the Moreau River were nine double-crested cormorants and nine cliff swallows. Specimens from the Cheyenne River study group were eleven double-crested cormorants and fourteen cliff swallows. For selenium, cadmium and mercury levels, the double-crested cormorants from the Cheyenne River contained significantly higher levels than did the Moreau River study group. These results are similar to results obtained during several previous investigations within the same river systems. Heavy metal concentrations found in cliff swallows were not significantly different between rivers. Arsenic was not detected above 0.3 mg/kg in any of the collected birds.

A sampling of the results of liver analyses tested for mercury, arsenic, and selenium taken from the great blue heron, cormorant, spotted sandpiper, killdeer, and cliff swallow on the Cheyenne River was reported in 1984 (Ref. 151). A total of 54 samples were tested. For samples collected on Foster Bay of Lake Oahe, the results were: 1) great blue heron (0.69-2.0 ppm Hg, 2.5-8.4 ppm Se), 2) cormorant (0.38-36.0 ppm Hg, 1.3-21.0 ppm Se), and 3) spotted sandpiper (0.21-5.1 ppm Hg). For samples collected at the Highway 34 bridge crossing of the Cheyenne River, the results were: 1) spotted sandpiper (0.037-0.36 ppm Hg), 2) killdeer (0.023-0.24 ppm Hg), and 3) cliff swallow (no data).

Another study was conducted in 1997 to determine whether birds nesting on Whitewood Creek are exposed to metal contaminants (Ref. 127). Tree swallows were used as indicators of local contamination because they readily use nest boxes, feed on emergent aquatic insects near their nest box, and tissue residues reflect sediment contamination and the transfer of those chemicals into the biota. A low percentage of nest boxes (2%) were occupied by tree swallows on Whitewood Creek, even though the habitat appeared suitable. Lower occupancy by tree swallows may relate to an impoverished insect fauna on Whitewood Creek due to arsenic toxicity or to habitat structural changes (Ref. 127).

Based on arsenic concentrations in tissues and diet of house wren chicks, they are being exposed locally to arsenic. Because arsenic was not detected in sibling eggs, the data suggest that arsenic concentrations in chick livers and carcasses originated in the diet (supported by laboratory studies suggesting a half-life of arsenic of <3.0 days in birds). For Whitewood Creek, arsenic concentrations in house wren livers ranged from 1.75-5.63 µg/g, house wren carcasses ranged from 5.9-25.2 µg/g, and from house wren diet, 103 µg/g dry weight. Mud from barn and cliff swallow nests contained 810 and 202 µg/g dry weight of arsenic.

4.8.2 Considerations for Risk Assessment

The mercury and arsenic concentrations in the wildlife sampled demonstrate the effects of increases in the exposure concentration and/or duration to tissue concentrations, and the bioaccumulation that tends to occur in species that are higher up the food chain.

4.8.2.1 Potential Effects of Mercury, Methylmercury, and Arsenic Exposure on Birds

Hesse et al. (Ref. S18) found that mercury contamination in birds collected in the Cheyenne River basin apparently varied with exposure to mercury in the diet. For non-fish-eating birds, Japanese quail (an upland species) had very low tissue concentrations, and tissue concentrations in shorebirds generally became greater as the size of the bird increased and the water in which feeding occurred became deeper (Ref. 80). Fish-eating birds (Ref. 81) had mercury concentrations that reflected the high tissue concentrations of methylmercury that bioaccumulated in fish. Long-lived birds such as white pelicans and great blue herons had mercury tissue concentrations above 8 and 16 ppm respectively, whereas least terns had mercury concentrations in liver and kidney of 1.4 and 2.6 ppm respectively. In comparison, the mercury concentrations in the fish they ate were usually > 0.5 ppm in 1972 (Refs. 1, 2), but rarely exceeded 1 to 2 ppm.

Raptors in the Cheyenne River area include the bald eagle, golden eagle, osprey, hawks, owls, and an occasional peregrine falcon near the mouth of the Cheyenne River Arm (Ref. S58). Although the golden eagle has winter roosts in the North Cheyenne Area of the Oahe project (Ref. S58), it preys on small mammals, snakes, and birds rather than fish; therefore, it would not be expected to be impacted by potential mercury contamination of Cheyenne River sediments. Similarly, owls prey mainly on small land-based mammals and so would not likely be impacted. Hawks prey mainly on small mammals and birds, but may prey especially on waterfowl during migration, and the peregrine falcon preys mainly on ducks and shorebirds. Because migratory waterfowl would not remain long in the Cheyenne River area, they would not ingest enough organisms with potentially high mercury concentrations to bioaccumulate a toxic amount of mercury. Therefore, hawks and peregrine falcons would not be expected to be significantly impacted by potential mercury contamination in sediment. Survival or reproduction of local populations of the threatened bald eagle and state-listed osprey could potentially be adversely impacted by mercury contamination of sediments due to the high proportion of fish in their diets. If this occurs, however, the continued existence of the species would not be expected to be jeopardized because the Cheyenne River represents only a small portion of their ranges. Local populations of other long-lived, fish-eating birds such as the white pelican and great blue heron could possibly be impacted by potential mercury or methylmercury contamination in sediments that became bioavailable and bioaccumulated in fish; in these cases also, because the Cheyenne River constitutes only a small portion of their ranges, adverse impacts on local populations of these two species would not be expected to adversely affect statewide avian diversity in South Dakota and Wyoming. The high mercury concentrations in livers of double-crested cormorants, which sometimes exceeded lethal concentrations several times over (Ref. 81), can be explained by the fact that the Cheyenne

River Arm is also an area of high selenium exposure. Double-crested cormorants and some other marine birds (double-crested cormorants winter on the Gulf of Mexico) and marine mammals possess enzymes that form crystals of mercury selenide in a 1 Hg:1 Se ratio, rendering large (and equal) concentrations of mercury and selenium inactive, and potential toxicity is limited to the amount by which either mercury or selenium exceeds the other (Ref. S31).

Migrating ducks and geese would not be expected to spend enough time at the Cheyenne River Arm to be adversely impacted by mercury or methylmercury contamination in sediments that became bioavailable and bioaccumulated in organisms that constituted the diet of these waterfowl. Adverse impacts, especially on the young, would be more likely for a resident nesting population of waterfowl than for a migrating flock, but the extent of the impact would still depend largely on dietary composition, specific foraging locations, and specific nesting locations relative to the mercury contamination.

Other birds frequenting the Cheyenne River area that eat fish, mussels, or other wetland organisms that could bioconcentrate mercury include the interior least tern, piping plover, American bittern, gulls, herons, sandpipers, other terns, and belted kingfishers (Ref. S58). Because of their diet, the survival or reproduction of local populations of these birds could possibly be adversely impacted by potential mercury or methylmercury contamination in sediments that became bioavailable and bioaccumulated in fish or mussels; if this should occur for any of these species, the continued existence of the least tern and piping plover would not be expected to be jeopardized, and the statewide diversity of avian species in South Dakota and Wyoming would not be expected to be adversely affected, because the Cheyenne River constitutes only a small portion of the breeding ranges of all these birds.

Because half of all arsenic ingested is excreted within 3 days in birds, and the storage form of arsenic appears to be greatly reduced in toxicity, the impact of arsenic contamination on adult birds would not be expected to be as great as the impact of potential arsenic contamination would be on the offspring, which could be exposed to elevated concentrations of arsenic during brain and nerve development. In an experiment, Camardese et al. (Ref. S7) administered sodium arsenate in the diet of mallard ducklings at arsenic concentrations from 30 to 300 ppm. The arsenic accumulated in the brain and liver and was found to reduce growth, reduce brain ATP (the energy currency of cells), and increase resting time. These concentrations that affected duckling development were environmentally relevant, as arsenic has been found at elevated concentrations of up to 430 ppm dry weight in plants utilized by waterfowl (Ref. S7).

4.8.2.2 Potential Effects of Mercury, Methylmercury and Arsenic Exposure on Mammals

This section discusses only mercury and methylmercury because environmentally relevant arsenic concentrations would not be expected to impact mammals, since half the arsenic mammals ingest is excreted within 3 days. Water-oriented mammals living within the Cheyenne River Arm of Lake Oahe include beavers, raccoons, muskrats, and mink. The river otter, a state-listed species (Ref. S58) for which fish is a major part of the diet, has been sighted in the upper Cheyenne River above Angostura Reservoir and downstream from Oahe Dam, but

has not been seen in the Cheyenne River Arm, and so would not be expected to be impacted by any potential mercury or methylmercury contamination of sediments in the lower Cheyenne River. Beavers would not be expected to be impacted by high concentrations of mercury or methylmercury in sediments because they are herbivores that eat dryland vegetation. Potential mercury and methylmercury contamination of sediments that results in high mercury or methylmercury tissue concentrations of fish and shellfish could possibly adversely impact survival and/or reproduction of raccoons, muskrats, and mink because their diets contain animals that could bioaccumulate mercury and methylmercury. Raccoons and muskrats eat fish and mussels. Raccoons also eat crayfish, crabs, other arthropods, frogs, nuts, seeds, and berries; the percentage of the diet comprised of aquatic animals is unknown. The American mink eats fish, frogs, snakes, small mammals, birds, and insects. If potential mercury or methylmercury contamination should adversely impact survival and/or reproduction of raccoons, muskrats, and/or mink, only local populations of these species would likely be affected. If this situation occurs for any of these three mammals, the statewide diversity of mammalian species in South Dakota and Wyoming would not be expected to be adversely affected because the Cheyenne River constitutes only a small portion of their ranges.

4.8.2.3 Potential Effects of Mercury, Methylmercury, or Arsenic Exposure on Reptiles and Amphibians

The dominant aquatic-oriented amphibians at Lake Oahe are the northern leopard frog, chorus frog, and tiger salamander (Ref. S58). Frogs are carnivorous, but are mainly insectivores; fish may comprise only 1 percent of their diet (Ref. S54). Therefore, frogs would not be expected to be significantly impacted by potential mercury or arsenic contamination of Cheyenne River sediments. Salamanders are meat-eaters or scavengers, and insects are an important food item; they may also eat crustaceans, fish, earthworms, amphibians, and reptiles (Ref. S54). The proportion of their diet that consists of fish and crustaceans is unknown. Although the likelihood that the tiger salamander could be adversely impacted by high mercury or arsenic concentrations in sediments that became bioavailable in the water can not be estimated, any adverse impact on survival or reproduction would likely affect only the local population. Any adverse impacts to these local amphibian populations would not be expected to adversely affect the statewide diversity of amphibian species in South Dakota and Wyoming because the Cheyenne River constitutes only a small portion of their ranges.

The state-listed false map turtle is omnivorous, but fish and mollusks can comprise up to a quarter of its diet. Therefore, it could possibly be adversely impacted by potential contamination of arsenic, mercury, or methylmercury in sediments through dietary exposure to aquatic organisms that bioaccumulated methylmercury or arsenic. However, there have been no reported sightings of the false map turtle in the Cheyenne River Arm of Lake Oahe (Ref. S58). Common aquatic-oriented reptiles at Lake Oahe are the western painted turtle, snapping turtle, and red-sided garter snake (Ref. S58). The western painted turtle is omnivorous (Ref. S57), and fish comprise only a small part of its diet. Therefore, it would not be likely to be impacted by potentially high concentrations of mercury, methylmercury, or arsenic through dietary sources. The snapping turtle may live up to nearly 60 years; it is omnivorous, and fish could comprise about one-third of its diet (Ref. S54). Red-sided garter snakes prefer living near water and eat mainly fish, tadpoles, frogs, and salamanders (Ref. S57). The fish species

eaten include dace, shiners, minnows, mudminnows, and small trout (Ref. S51), but the percentage of fish in the diet is unknown. Because their diet includes a high proportion of organisms that could bioaccumulate mercury, methylmercury, or arsenic, survival and/or reproduction of local populations of snapping turtles or red-sided garter snakes could possibly be adversely impacted if potential mercury, methylmercury, or arsenic contamination in sediments became bioavailable. If this should occur, however, it would not be expected to impact the statewide diversity of reptile species in South Dakota and Wyoming because the Cheyenne River constitutes only a small portion of their ranges.

8.4.3 Conclusions

Phytoplankton bioconcentrate the mercury and arsenic in water, and benthic organisms bioconcentrate the mercury and arsenic in sediments. Phytoplankton and benthos are in turn eaten by other organisms, including small crustaceans and fish, and the fish and invertebrates are eaten by other fish, amphibians, reptiles, birds, and mammals, including human beings. At each step in this food chain, or food web, the metal contained in the prey has the potential to bioaccumulate over time in the tissues of the predator. Evaluating the bioconcentration and bioaccumulation factors, and obtaining data to accomplish this, are essential in order to accurately assess the risk to humans and wildlife of potential mercury and arsenic contamination in Cheyenne River sediments.

Methylmercury can be transferred from adult female fish to their eggs. This maternal transfer has been found for other vertebrate species and other metals, such as copper and cadmium, for selenium, and for lipid-soluble compounds such as polychlorinated biphenyls (PCB's). High concentrations of these substances in adult females can be transferred to developing eggs in ovaries of fish, reptiles, amphibians, and birds, and across the placenta of mammals. The risks to these future generations need to be taken into consideration also.

USACE does not have adequate data at this time to determine if sediments in the Cheyenne River main stem may be contaminated. However, if sediments are contaminated to the extent that there could be adverse impacts on survival or reproduction of mammals, birds, reptiles, amphibians, fish, or invertebrates, it is likely that only local populations would be affected, and that the continued existence of these species would not be expected to be jeopardized. Biodiversity in the States of South Dakota and Wyoming as a whole would not be affected. Biodiversity on the Cheyenne River Sioux Tribal Reservation, however, could be adversely impacted, but the degree of impact is unknown at this time.

4.9 Cultural Resources

From the Paleoindian period (ca. 11,500-6500 BP) to the present, numerous tribes have occupied the lands adjacent to the Cheyenne River. Historically, known tribes include the Arikara, Mandan, Sioux, Cheyenne, and Kiowa.

The Treaty of 1868 placed the Lakhota Sioux on the Great Sioux Reservation that encompassed all of western South Dakota, North Dakota, eastern Wyoming, and parts of Nebraska and Montana. In 1889, however, after several tribal leaders had been murdered and the people

neared starvation, they agreed to divide their land and accepted six separate reservations in North and South Dakota, one of them being the Cheyenne River Sioux Reservation, encompassing some 2,806,914 acres. The tribe comprises bands of Mnikoju, Siha Sapa, Oo'henumpa, and Itazipco, who are members of the Algonquian linguistic family and speak the Lakhota dialect of the Siouan language. The reservation has 19 communities, 13 of which are Indian. Tribal headquarters are located in Eagle Butte, the largest town on the reservation.

The Surplus Lands Act of 1908 and 1910 authorized the Secretary of the Interior to open 1.6 million acres of the Cheyenne River Sioux Reservation for homesteading and settlement by non-Indians. The construction of the Oahe Reservoir, which commenced in 1948, removed 104,420 acres of trust land from the reservation. As a result of the Water Resources Development Act of 1999, 32,879 acres were transferred in 2001 to the Department of Interior, to be held in trust for the Tribe.

The Cheyenne River also forms a small part of the Pine Ridge Reservation boundary, home to the Oglala Sioux Tribe, who also are members of the Algonquian linguistic family and speak the Lakhota dialect of the Siouan language. The seven bands of the Oglala (Tetonwan) include, as of the late 1800s: Payabya, Tapisleca, Kiyuksa, Wajaja, Itesica, Oyuhpe, Wagluhe.

The Pine Ridge Reservation encompasses 2.8 million acres and has a tribal enrollment estimated at 28,000. The Reservation is divided into eight districts: Eagle Nest, Pass Creek, Wakpamni, LaCreek, Pine Ridge, White Clay, Medicine Root, Porcupine, and Wounded Knee. Tribal headquarters are located in the town of Pine Ridge.

The present and former Omaha District take lands along the Cheyenne River arm of Lake Oahe have been previously surveyed for cultural resources, primarily by the Archaeology Laboratory of the Center for Western Studies, Augustana College (Refs. S27 and S48). Sixty-nine sites have been identified, four of which have been determined to be ineligible for listing on the National Register of Historic Places (NRHP). The remaining sixty-five sites have not been evaluated for eligibility. In addition, a Traditional Cultural Property (TCP) survey was conducted on portions of the area by the Cheyenne River Sioux (Ref. S23). Sixteen TCPs have been located to date, a number of which may be eligible for listing on the NRHP, but also need to be considered under Executive Order 13007 regarding access to Sacred Sites.

Site types within the study area include earthlodge villages, bison kills, camp sites, artifact scatters, and historic foundations, as well as the aforementioned TCPs. The frequency of site occurrence along the surveyed portions of the Cheyenne River, in conjunction with the incidence of sites along other similarly-sized rivers in the Missouri River basin, imply that other such sites may be expected to occur long the unsurveyed portions of the river.

Table 4-33
Historic Properties Recorded on the Cheyenne River Arm of Lake Oahe
by National Register Status

USGS 7.5 Minute Quadrangle	Sites Listed on National Register	Sites Eligible for National Register	Sites Not Eligible for National Register	Unevaluated Sites	Traditional Cultural Properties
Alleman Station	0	0	0	11	-
Carlin Flat	0	0	0	0	-
Crockett Mountains	0	0	0	5	-
No Heart Creek SW	0	0	1	5	1
Rousseau Creek SW	0	0	1	5	5
Rousseau Creek	0	0	0	18	3
Sansarc NE	0	0	1	19	7

Note - Locational data for archeological sites are restricted from public disclosure under Section 304 (a) of the National Historic Preservation Act, as amended in 1992 and Section 9(a) of the Archeological Resources Protection Act.

Table 4-34
Historic Properties by Site Number

Alleman Station	Carlin Flat	Crockett Mountains	No Heart Creek SW	Rousseau Creek SW	Rousseau Creek	Sansarc NE
39ST284		39DW79	39ST1	39DW76	39DW81A	39DW64
39ZB16		39DW80	39ST10	39DW85	39DW82	39DW65
39ZB17		39ST267	39ST48	39ST265	39DW83	39DW66
39ZB18		39ST270	39ST254	39ST266	39DW84	39DW67
39ZB19		39ST271	39ST274	39ST268	39DW86	39DW68
39ZB20			39ST275	39ST269	39DW87	39DW69
39ZB21					39DW88	39DW70
39ZB22					39ST256	39DW71
39ZB23					39ST257	39DW72
39ZB24					39ST258	39DW73
39ZB25					39ST259	39DW74
					39ST260	39DW75
					39ST261	39DW77
					39ST262	39DW78
					39ST263	39ST278
					39ST264	39DW279
					39ST276	39DW280
					39ST277	39DW280
						39DW281
						39DW282
						39DW283

Note - Locational data for archeological sites are restricted from public disclosure under Section 304 (a) of the National Historic Preservation Act, as amended in 1992 and Section 9(a) of the Archeological Resources Protection Act.

4.9.1 Conclusions

Any invasive sediment testing or remediation activities, which may take place along the Cheyenne River as a result of Title VI, will have to take into account potential effects to Historic Properties or TCPs as required under Section 106 of the National Historic Preservation Act. Activities such as the leveling of staging areas, access or construction roads, or dredging, should be coordinated with District Cultural Resources staff.

Undertaking areas outside of the present and former Omaha District take lands will need to be surveyed for cultural resources, if not previously surveyed. Any site, which may be affected by such activities, will have to be evaluated for its eligibility to be listed on the NRHP. If any such sites are found to be eligible, the district will consult with the appropriate Tribal Historic Preservation Officer (THPO)/State Historic Preservation Officer (SHPO), tribes, and other interested parties, as to the appropriate action to be taken, either avoidance or mitigation.

5.0 Summary

The USACE is evaluating the Cheyenne River for potential sediment contamination, as required under the Water Resources Development Act of 1999. The USACE has established a database of existing literature on the Cheyenne River's environmental conditions. This report draws from that literature, along with documents that will be added to the database. The goal of this evaluation is to eliminate any health risks associated with sediment contamination in the Cheyenne River.

The geology of the Cheyenne River basin has facilitated loading of undesirable constituents into the riverine system. For example, normal leaching of selenium out of rock formations has produced a fairly high concentration of that element in the river. Mining activities not only accelerated the availability of problematic elements, but also introduced additional contaminants into the system (e.g., cyanide, mercury). River impoundments such as Angostura and Lake Oahe can cause additional retention of potential contaminants , by reducing the flow through of some chemicals transported by the river.

This report looked at the wide array of potential contaminants, and focused on those with indications of high concentrations, especially those which have a high risk. Besides direct measurement of the constituents in the sediment, concentrations in the water and in fish tissue provide significant information on the effect caused by chemicals in the sediment. Bioaccumulation of trace elements in fish has further effects as the fish are consumed by wildlife and humans.

The river is an integral component of the native Americans' environment. The CRST's primary water facility draws directly from the Cheyenne River arm of Lake Oahe. Tribal members also make considerable use of the river for fishing and recreation.

The studies comprising the database reveal concerns about potential contaminants . For example, uranium was mined on the upper Cheyenne, and cyanide was used to remove gold from ore. Improved disposal methods in the mining operation significantly reduced the loading of problematic constituents into the system, and some contaminants (such as uranium and cyanide) didn't persist in the river at dangerous concentrations. Consequently, the review eventually focused on three constituents: arsenic, selenium, and mercury (total and methyl).

The information presented in this report shows that three constituents; arsenic, selenium and mercury are potentially contaminating the sediment in the Cheyenne River. Sediment sampling directly shows the concentrations, while water quality and fish tissue are indicators of how the sediment is affecting the aquatic ecosystem.

5.1 Arsenic

Available data show that arsenic concentrations can be relatively high in the river's sediment, particularly sediments deposited during the first half of the 20th Century. Background levels

are roughly in the range of 5-17 ppm, and there have been many samples well above that range. However, the high concentrations generally are in deeper sediment, particularly in Lake Oahe. Figure 4-4 clearly shows how concentrations decrease proportionally to the depth of the sample. Evidence shows that this was a function of mining in the Belle Fourche River basin. For example, a 1972 sample above the Belle Fourche contained only 4.8 ppm, while readings taken at 10-cm depths in 1985 were up to 460 ppm downstream of the Belle Fourche. In 1989, readings were less than 90 ppm at depths greater than 10 cm, 15 ppm at 2.5 cm, and 11 ppm at depths less than 2 cm.

Figure 4-3 illustrates the arsenic levels in surface water quality before and after the Homestake mine remediation (1972). After 1980, readings were in the general range of 2 to 8 µg/L. The 75th percentile at Cherry Creek is 7 µg/L. The obvious problem with these numbers is that the standard for human health value for surface water quality is only 0.14 µg/L (Table 4-14). Arsenic concentrations in the Cheyenne River generally are well above that standard, regardless of which reach is sampled. In other words, arsenic evidently is at high concentrations from natural forces, and thus likely isn't solely the result of contamination from human activities.

The fact that arsenic readings exceed the standard for human health for surface water quality shouldn't necessarily be construed as an actual health concern. As noted in Section 4.4.5.1, the State of South Dakota has set a very low criterion for arsenic pertaining to human health protection, based on the risk of exposure through the ingestion of contaminated aquatic organisms. It is through bioaccumulation of elements such as arsenic that the low aqueous concentrations could be magnified to a demonstrable health risk. From another perspective, arsenic readings are in fact well below the standards for aquatic life value, where the criteria are 190 µg/L (chronic) and 360 µg/L (acute). The aquatic life value is another standard to assess water quality.

Concentrations in fish tissue are another indication of whether arsenic poses a significant risk to the river's environment. As noted in Section 4.8.1.2, two samples were recorded above the National Contaminant Biomonitoring Program (NCBP) 85th percentile measure of 0.81 µg/g: 0.93 and 1.25 µg/g. This again could be the result of natural levels of arsenic in the river.

Although this region has high naturally occurring levels of arsenic, the sampling data discussed above show that some of the Cheyenne River's sediment have elevated levels of arsenic. This is especially true in the Cheyenne River Arm of Lake Oahe. However, those same data show that the high concentrations of arsenic in the sediment tend to be only in older sediment (i.e., sediment deposition that occurred before the mid-1980s. More recent deposits evidently have significantly less arsenic, and thus may actually encapsulate the deeper sediment that would hold more arsenic. A critical issue is that the high concentrations in deeper sediment are essentially not mobile as long as they remain buried. So, they would have negligible effects on water quality or fish contamination. Any efforts to physically remove the buried contaminated sediment would allow the arsenic to be released back into solution, which would allow the contamination to spread. Thus, physical remediation efforts would not be recommended.

5.2 Selenium

There is not much available information on selenium concentrations in the Cheyenne River's sediment. Several reports merely note that selenium levels are consistent with what the region's geology would naturally produce. Water quality analysis showed that concentrations tend to be below the standard 5 µg/L (Table 4-14). Furthermore, selenium loading is not a direct result of mining, as may be the case of arsenic and mercury. However, irrigation practices do increase the amount of selenium in soil. The main irrigation project on the Cheyenne River is the Angostura Unit. Downstream from Angostura, 17 fish samples averaged 7.29 µg/g dw (Ref. 93). ck units – typically fillet samples are not in water units, compared to the NCBP 85th percentile level of 2.8 µg/g. Upstream of Angostura (at Edgemont), the reading was 3.06 µg/g. Although this reading could indicate that the Angostura Unit may have led to an increase of selenium in fish, the high reading (3.06) found upstream of Angostura Reservoir could also indicate that the NCBP 85th percentile may not be the best criterion to discriminate between contamination and (high) background levels. Reference 93 pointed out that some researchers consider 10.0 µg/g to be the "effect level." Relying on that standard, selenium in fish downstream of Angostura Reservoir apparently would be exposed to greater concentrations than would fish above the reservoir, but that higher concentration would not be a problem.

Although there is no clear evidence that selenium is a significant problem on the Cheyenne River, the environmental consequences from excessive selenium can be quite serious. For example, bird deformities and mortality on the Kesterson Wildlife Refuge (California) from selenium accumulation were significant. While irrigation in the Cheyenne River valley is unlike the closed basin at Kesterson, scientists need to be aware of the potential for impacts to wildlife from selenium here. This position follows from one of the conclusions of Reference 93, which was stated above in Section 4.5.6. That is, " . . . selenium concentrations in fish might be problematic. Selenium concentrations in fish samples routinely are within the NIWQP level of concern, and also commonly exceed the dietary guideline for protection of avian consumers." Our conclusion thus would be that there is not definitive evidence that the Cheyenne River sediment is contaminated with selenium, although it would be prudent to continue sampling efforts (sediment and fish tissue, as well as water quality) to minimize the risk to wildlife.

5.3 Mercury

Knowledge of mercury concentrations in the Cheyenne River environment has been fragmented by improvements in sampling techniques, as well as by the fact that toxicity of elemental mercury is much different from that of methylmercury. Section 4 explored the concentrations in water, sediment and fish tissue, for both elemental mercury and methylmercury. We use the aqueous and fish tissue samples as indicators of potential sediment contamination. First of all, Figure 4-7 showed that total mercury in the river sediment does not appear to be a problem. Concentrations of total mercury in the river itself may have been high in the past (before the mine tailings were better managed in the Belle Fourche drainage), but those levels now are in a range closer to what is expected in a "normal" stream (according to Figure 4-6). Methylmercury, on the other hand, has exhibited high levels (Figure 4-8). Fish

sample data displayed in Figures 4-9 and 4-10 show that sauger and walleye in the Cheyenne Arm of Lake Oahe had mercury concentrations greater than safe limits.

The present data seem to show that although the Cheyenne River sediment is not contaminated compared to regional background levels, there is strong evidence that the river system transports high amounts of mercury. Methylmercury in the water can rise to high levels when other conditions are present (i.e., high levels of suspended solids and pH). Furthermore, there is ample mercury in the river to result in high concentrations in fish. So, the issue of sediment contamination should be expanded for mercury, to assess how low or moderate concentrations in the sediment may be contributing to potentially high levels in the river and its animal life.

6.0 Conclusions

6.1 Definitive Data on Arsenic.

This report highlighted several sets of sampling data that show high concentrations of arsenic in Cheyenne River sediment. The scattered data (across many sub-reaches, and over many decades) make it difficult to draw detailed conclusions on how the problem varies along the river. Nonetheless, there is enough data to draw the conclusion that some sediment deposits in the Cheyenne River have elevated levels of arsenic. The two primary clues for this determination are concentration versus depth samples, and time-dependent samples on the Belle Fourche River.

Finding significantly higher concentrations of arsenic in deeper sediment is an indication that an earlier source of arsenic loading has been minimized. That would fit with the concept that poor management of mining wastes introduced large amounts of arsenic to the river, and that such mining wastes no longer end up in the river. Surface water data on the Belle Fourche matches this scenario, where dissolved levels of arsenic settled into a narrow range after the 1970s, when more responsible mining practices were implemented.

Mapping of arsenic concentrations in sediment in the Cheyenne River below the Belle Fourche would be an excellent scientific endeavor. However, all indications are that the elevated levels of arsenic is now only in deeper sediments, away from where negative effects would occur to humans or wildlife. Any effort to treat or remove the sediment could easily cause significant disturbance to the environment. In addition, it could actually disperse the arsenic. Therefore, the preferred course of action is to leave the arsenic-laden sediment in place.

6.2 Shortcomings in the Existing Data.

As noted in Section 6.1, the existing research covered a very large geographic area. In addition, much of the research efforts were focused on specific projects (e.g., Homestake Mine impacts on Whitewood Creek, Angostura Irrigation unit). So, their applicability to the Cheyenne River is greatly limited.

Older research documents often lose relevance as conditions change. Furthermore, sampling methods sometimes improve to the point that older data isn't comparable to new data. For the Cheyenne River information, this is especially true for mercury. In fact, some older samples may actually have been tainted through a standard preservation technique. Thus, the available literature can't answer all the significant questions on potential contamination in the Cheyenne River. Most of the constituents reviewed as potential contaminants were far enough below selected thresholds to be adequately screened using available data. In fact, the data was conclusive enough to draw firm conclusions on "borderline" constituents like selenium. Arsenic was found to be a contaminant in some of the Cheyenne's sediment, but all other constituents except possibly mercury were ruled out as contaminants.

6.3 Mercury.

The above paragraph alluded to a significant change in sampling technique for mercury. Also, the detection limit for mercury now is lower than it was when older samples were analyzed. This situation discounts much of the value of older data, leaving decision makers with a very sparse array of evidence. Furthermore, the importance of methylmercury concentrations was not recognized until recently. So, although toxicity of methylmercury is a critical issue on the Cheyenne River, there presently is scant documentation. Evidence for a firm conclusion on mercury possibly contaminating the Cheyenne River sediment is meager. Additional sampling will be needed, working systematically, with input from the tribes and agencies.

6.4 Focusing Future Study.

Since the Congressional directive did not limit the sediment contamination study to any particular river reaches, the effort must cover hundreds of miles of the Cheyenne River. A logical assumption is that certain reaches would have higher concentrations of arsenic or possibly mercury than other reaches, and that investigative resources should be directed accordingly. Since the available data give only weak indications on such geographical disparity in the streambed chemistry, a special mapping study should precede development of any detailed sampling plan. This probably should include a sediment transport model, so that theoretical "hot" areas can be tracked downstream, and through time.

6.5 Risk-based Analysis.

If additional analysis determines that arsenic and possibly mercury actually are contaminating the Cheyenne River's sediment, the USACE is responsible for determining how to eliminate the risk to human health and the environment. This would involve evaluating the extent of risk associated with different levels of contamination. That, in turn, would be the basis for considering remedial measures. For example, for any constituents that would be at higher concentrations in deeper sediment, it may be best to leave that sediment in place, allowing the shallower sediment to isolate it from the flowing river. That would avoid the environmental disturbance from any removal effort, and would minimize contaminant dispersal.

6.6 Future Studies.

The USACE analysis for this report utilized a large pool of studies that have been produced by a wide range of researchers. Those studies were to broad ranged and did not form a single conclusion on what is the current makeup of the sediment in the Cheyenne River, therefore it is suggested that these studies be tied together with current, focused data which will be obtained in a future study in accordance with the specific mandate for determining Cheyenne River contamination and remediation. Several entities are already involved in parallel examinations, and the USACE needs to draw on this wealth of expertise. Therefore, the USACE will work with the tribes and agencies, to develop a work plan to fill in the critical data gaps.

Database References

Ref. No.	Title, Author(s), Date
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2	Mercury in fish, sediments and water in Lake Oahe, South Dakota, Journal WPCF, Volume 45, No. 10, Carl M. Walter, Fred C. June and Harold G. Brown, October 1, 1973.
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S 60 Friedmann AS, Watzin MC, Johnsen TB, Leiter JC. 1996. Low levels of dietary methylmercury inhibit growth and gonadal development in juvenile walleye (*Stizostedion vitreum*). *Aquatic Toxicology* 35:265-278.

Appendix A

Fisheries and Benthic Macroinvertebrates Risk Assessment

A Fisheries and Benthic Macroinvertebrates – Risk Assessment

A.1 Methylation of Mercury

Methylmercury is more toxic than inorganic mercury, and conditions under which inorganic mercury is methylated are prevalent in the Cheyenne River. However, the methylating conditions in the river may have little impact on the percentage of mercury in fish tissue that is methylated. Seven fish species sampled from Canadian lakes differed in diet (fish-eating predators northern pike, walleye, sauger, and yellow perch; whitefish and cisco, which are bottom feeders and zooplankton eaters; and bottom-feeding suckers) but were all found to contain intestinal bacteria that converted inorganic mercury into methylmercury (Ref. S33). The intestinal bacteria were concentrated in areas of intestinal mucus, where the unbound methylmercury produced is easily transported across the intestinal wall. These intestinal bacteria may account for the findings of Bloom (Ref. S5) that mercury content for the muscle tissue of all fish he sampled from bays in Puget Sound, Washington, appeared to be 95-99 percent methylmercury.

The existence of conditions in the Cheyenne River favorable to mercury methylation may be more important for aquatic invertebrates, as bacterial methylation of mercury may vary greatly in these species. Bloom (Ref. S5) found methylmercury constituted about 6 percent of the total mercury in copepods (zooplankton) and mussels, 50 percent in clams, 3-100 percent in two shrimp species, and over 90 percent in scallops and two crab species sampled from bays in Puget Sound, Washington.

A.2 Bioaccumulation of Mercury and Methylmercury

Aquatic organisms can bioaccumulate mercury and methylmercury through exposure in water or food. In a laboratory experiment, Lock (Ref. S24) found that concentrations of methylmercury in the green alga *Chlamydomonas reinhardtii* (which produces its food through photosynthesis) reached 320 ppm (dry weight) 5 hours after the algae were placed in water that contained 20 ppm methylmercury. For the water flea *Daphnia pulex* and rainbow trout, Lock (Ref. S24) found that uptake of methylmercury from water reached a plateau, but methylmercury from food continued to accumulate in tissues at a linear rate. Concentrations of methylmercury in tissues were linearly related to concentrations of methylmercury in food and in water. The plateau appeared to indicate a decrease in uptake of methylmercury, perhaps resulting from gill surface mucus secretion, rather than a balance between uptake and elimination. Indeed, McKim et al. (Ref. S26) found in a 144-week experiment that brook trout eliminated methylmercury very slowly, needing an estimated 1-3 years in clean water to remove 50 percent of the methylmercury. During life stages when fish are growing at a faster rate than the body is accumulating methylmercury, tissue concentrations will decrease. As the fish matures and growth rates decline, however, continued bioaccumulation of methylmercury results in increased tissue concentrations with age (or its equivalents, length and weight).

Fish embryo (egg) and larval (hatchling) stages appear especially sensitive to mercury, even when not methylated. When Birge et al. (Ref. S4) experimented by placing catfish eggs in

water with 0.19 and 0.3 ppb inorganic mercury, only 67 and 48 percent of the eggs, respectively, hatched; of those hatching, only 68 percent and 30 percent, respectively, survived 4 days after hatching. Total body mercury was 14 and 60 ppb (78 and 200 times the water concentration of mercury, respectively, or a bioconcentration factor of 78 and 200), 4 days after hatching (Ref. S4). Another experiment (Ref. S4) showed that effects of mercury on embryos and larvae appear to be due to mercury exposure not only of fertilized eggs in the water, but also of unfertilized oocytes developing into eggs in the ovary. Adult rainbow trout maintained in water with mercury concentrations of 0.21 ppb for 5 months suffered only 4-7 percent mortality. However, survival of their larval offspring 4 days after hatching was significantly lower than the 90 percent survival of control larvae regardless of whether the eggs were placed in clean water (26 percent survival) or in water with 0.12 ppb inorganic mercury (4 percent survival). In a third experiment, Birge et al. (Ref. S4) showed that egg and larval survival could also be affected by mercury in spawning beds. After they placed trout eggs on mercury-dosed bottom soil containing 0.18 ppm mercury, 85 percent of the eggs hatched and 70 percent of the hatchlings lived 10 days, compared to 95 and 94 percent respectively for controls with background 0.05 ppm mercury.

Impacts of mercury exposure of adult fish on reproduction can be due to impairment of sperm or of spawning activity in the male, as well as to deleterious effects on oocytes developing into eggs in the female. McKim et al. (Ref. S26) found by experimentation that methylmercury accumulated through water exposure was transferred from adult brook trout to their eggs, and that spawning activity was decreased or eliminated at the two highest concentrations of mercury in the water. An experiment by Friedmann et al. (Ref. S60) showed that exposure of juvenile male walleye to dietary methylmercury that resulted in methylmercury concentrations in muscle of 2.37 ppm wet weight significantly reduced growth and development of testes; this tissue concentration was similar to that found in Northern pike in 1984 (Ref. 124). Another experiment (Ref. S20) demonstrated that the concentration of methylmercury in muscle of female walleye collected from mercury-contaminated and uncontaminated lakes in the United States and Canada exceeded, but was directly related to, the methylmercury concentration in their eggs.

Bioaccumulation of mercury also occurs in aquatic macroinvertebrates. In an experiment, Tessier et al. (Ref. S44) found that total mercury in soft tissues of the freshwater snail *Viviparus georgianus* and the freshwater clam *Elliptio complanata* varied systematically with mercury concentration in the water, length of exposure, and size of the individuals, as has been generally reported for fish tissue. Jernelov (Ref. S52) showed experimentally that benthic macroinvertebrates exposed to sediment in which inorganic mercury was buried could cause fish tissue levels of methylmercury to increase even if the fish did not eat the macroinvertebrates. In Jernelov's study, mussels and oligochaete worms ingested and methylated inorganic mercury buried within the upper 9 cm of the sediment within 15 days and released the methylmercury into the water, making it bioavailable to fish at the gills.

Mercury and methylmercury have the potential to bioaccumulate in increased amounts as they go up the "food chain". Humans, as well as many birds, mammals, and fish, eat fish, mollusks, and crustaceans. Methylmercury and total mercury content of fish muscle (fillets) has been correlated with fish age and size because the fish bioaccumulate mercury in their tissues.

Mercury concentrations in the tissue of sediment dwellers (benthic organisms), which may be eaten by fish and some birds, would be expected to reflect the concentration of mercury in the sediment. Surface layers of sediment contain lower concentrations of mercury now than in the past, so benthic organisms on or near the sediment surface (which are more vulnerable to predation) may be taking up less mercury, although bioaccumulation could occur over time. Recent studies (for example, Refs. 64 and 11, with fish collected in 1998 or later) demonstrate that many larger, older fish that have tissue concentrations of mercury >0.5 ppm remain in the Cheyenne River and could present a health hazard to humans if locally caught fish constitutes a relatively high proportion of the diet.

A.3 Toxicity of Arsenic

Many sulfhydryl-containing proteins and enzyme systems are altered when arsenic binds to the sulfhydryl (sulfur-hydrogen) groups, affecting the ability of the proteins to function properly. Arsenic impairs aerobic respiration (energy production) in mitochondria by inhibiting adenosine triphosphate (ATP)-driven energy-linked reduction of NAD+, unreduced nicotinamide adenine dinucleotide (Ref. S19). Chronic exposure may lead to damage of the peripheral and central nervous system as well as the liver, the seat of detoxification processes (Ref. S17).

Toxicity differs for different arsenic "species", which differ in the way arsenic (As) bonds with other atoms. Arsenic (V), the arsenic species in arsenate, is much less toxic than As (III), the arsenic species found in arsenite, because As (V) does not appear to react with sulfhydryl groups (Ref. S43). Arsenic (V) in water is stable at normal or alkaline pH and when the water is well oxygenated, but it is reduced to As (III) at acidic pH or under anaerobic or low-oxygen conditions (Ref. S17). In mammals, arsenic concentrates in the body covering (skin, hair/fur, nails/claws, sweat). Based on tests with mice, mammals absorb nearly all the arsenic they ingest, and As (V) must be converted to As (III) by glutathione prior to methylation. The major methylated product is dimethylarsenic, which forms rapidly and is excreted rapidly. Half of the arsenic ingested by mammals is excreted, mainly in urine, within 3 days if nonmethylated, and at a lower rate if methylated (Ref. S17). Half of the arsenic ingested by mallard ducks was also eliminated within 3 days in an experiment conducted by Pendleton et al. (Ref. S55). Fish appear to excrete inorganic arsenic mainly through the bile. This was shown by experiments with inorganic arsenic that was absorbed by green sunfish from water through the gills (Ref. S38), or ingested by brown trout and rapidly converted to organic arsenic in the gastrointestinal tract (Ref. S56). This may be true for organic (carbon- and hydrogen-containing) species of arsenic as well, because rainbow trout exposed in experiments to water concentrations of approximately 1 ppm of any one of four arsenic compounds (two inorganic and two organic) all had arsenic tissue concentrations below 3 ppm, similar to controls, after 28 days (Ref. S43).

Arsenic in carbon compounds (organic arsenic) may be less toxic to animals than inorganic arsenic at the same oxidation state (III or V). Cockell and Hilton (Ref. S10) conducted an experiment in which three As (V) compounds were spiked in food of juvenile rainbow trout, and found that relatively low dietary concentrations of the inorganic species disodium arsenate resulted in much higher carcass arsenic concentrations and greater reductions in growth than occurred with high dietary concentrations of two organic species, dimethylarsenic acid or

arsanilic acid. Cockell and Hilton (Ref. S10) reported that their carcass arsenic concentration results for rainbow trout agreed with the results for mammals obtained by the National Research Council of Canada (Ref. S30). In another experiment, Spehar et al. (Ref. S43) found amphipods (*Gammarus pseudolimnacus*) were more sensitive to water concentrations of about 1 ppm of inorganic As (III) than water concentrations of about 1 ppm of inorganic As (V), organic As (III), or organic As (V) compounds. The reason for the difference in toxicity of organic and inorganic arsenic remains unknown; however, an experiment by Schlenk et al. (Ref. S35) showed that exposure of hatchery-raised channel catfish to monosodium methyl arsonate, but not the inorganic species sodium arsenite or sodium arsenate, significantly increased the production of metallothionein (a sulfhydryl-containing protein that protects against free oxygen radicals produced by arsenic) in liver cells.

A.4 Bioaccumulation of Arsenic

Aquatic animals are known to accumulate arsenic, but the accumulation rates do not appear to biomagnify; they do not increase by orders of magnitude up the food chain. Chapman (Ref. S8) found up to 70 ppm arsenic in Portuguese oysters, up to 119 ppm arsenic in mussels, up to 110 ppm arsenic in lobsters, and a maximum of 10 ppm in plaice (a marine flat fish) after he experimentally exposed them to 0.14-1.0 ppm arsenic as arsenite in water. After Spehar et al. (Ref. S43) exposed several aquatic animals to approximately 1 ppm of four different arsenic species in water, arsenic tissue concentrations varied greatly: less than 5 ppm for amphipods and rainbow trout, about 9-17 ppm and about 20-80 ppm for two snail species, and about 30-45 ppm for stoneflies. For green sunfish exposed experimentally to sodium arsenate in water, Sorensen (Ref. S39) found the concentration of arsenic in tissues increased not only with arsenate concentration in water and duration of exposure, but also with increases in water temperature; maximum arsenic tissue concentrations were up to 5 times the water concentrations at 10°C (50°F) and 8 times the water concentrations at 20°C (68°F) after 5 weeks of exposure. Fish appear to eliminate arsenic much more rapidly than they do methylmercury; at 10°C, 50 percent of the arsenic in green sunfish tissues was eliminated in approximately 1 week (Ref. S39).

Benthic macroinvertebrates living in sediment may bioaccumulate arsenic from that sediment, as is the case for earthworms (which can exist under aerobic or anaerobic conditions) exposed to arsenic in soil. Meharg et al. (Ref. S28) found experimentally that the earthworm *Lumbricus terrestris* bioaccumulates arsenic up to 120 ppm dry weight within 23 days of exposure to soil with a concentration of 40 ppm arsenic as disodium arsenate (a bioconcentration of up to 3). In an experiment, Fischer and Koszorus (Ref. S15) found the manureworm *Eisenia fetida* bioaccumulated arsenic up to 900 ppm dry weight when placed in soil with arsenate concentrations of 10-50 ppm for 8 weeks (a bioconcentration factor of 10-18) but did not eliminate any arsenic after being placed in uncontaminated soil for 8 weeks. Results of an experiment by Morgan et al. (Ref. S29) showed that arsenic was sequestered in earthworm tissues, although arsenic speciation was not determined. Because of the very high bioaccumulations in living earthworms, Meharg et al. (Ref. S28) suggested that earthworms may sequester arsenic within their tissues in the form of arsenic species that are less toxic than inorganic arsenate. An experiment by Langdon et al. (Ref. S22) with two earthworm species suggested that arsenate from soil was metabolized into the organic arsenic species

arsenobetaine at relatively low whole-body arsenic concentrations and, as whole-body arsenic concentrations increased, an increasing amount of arsenic was inactivated by conversion to As (III) and subsequent complexation to sulfur groups in proteins (possibly metallothionein). The use of arsenate and the range of soil arsenic concentrations of 10 to 50 ppm in these experiments were environmentally relevant, as arsenic concentrations as high as 30 ppm were found in Cheyenne River sediments in 1990 (Ref. 199), and arsenate was the predominant species in surficial, oxidized sediments that were rapidly accumulating in the Cheyenne River area of Lake Oahe in 1989 (Ref. 229).

Appendix B

Threatened and Endangered Species

B Threatened and endangered species

B.1 Available Data

The US Fish and Wildlife Service (USFWS) provides current lists of threatened and endangered species and species that are candidates for or proposed for listing, and their occurrence by county. Table 4-33, Occurrence of Threatened, Endangered, and Candidate Species, is based on USFWS data current March 14, 2003 for South Dakota (Ref. S59) and April 11, 2003 for Wyoming (Ref. S50) for counties associated with the Cheyenne River main stem.

Table B-1

Occurrence of Threatened, Endangered, and Candidate Species

CERTAINTY OF OCCURRENCE IN COUNTIES ALONG CHEYENNE RIVER MAIN STEM

		SOUTH DAKOTA									WYOMING		
SPECIES	STATUS	Custer	Dewey	Fall River	Haakon	Meade	Pennington	Shannon	Stanley	Ziebach	Converse	Niobrara	Weston
Black-footed ferret *Mustela nigripes*	Endangered; Experimental Population	Possible	Possible	Possible	Possible	X	Possible	Known	Possible	X	Possible if prairie dog towns large	Possible if prairie dog towns large	Possible if prairie dog towns large
Whooping crane *Grus americana*	Endangered	X	Known	X	Known	Known	Known	Known	Known	Known	X	X	X
Least tern (interior pop.) *Sterna antillarum*	Endangered	X	Known	X	Known	Known	Known	X	Known	Known	X	X	X
Piping plover *Charadrius melodus*	Threatened; Critical habitat	X	Known	X	Known	X	X	X	Known	Known	X	X	X
Bald eagle *Haliaeetus leucocephalus*	Threatened	Known	Known	Known	Known	Known (Nesting	Known	Known	Known	Known	Known	Known	X
Pallid sturgeon *Scaphirhincus albus*	Endangered	X	Known	X	X	X	X	X	Known	X	X	X	X
Topeka shiner *Notropis topeka*	Endangered	X	Historical	X	X	X	X	X	X	X	X	X	X
American burying beetle *Nicrophorus americanus*	Endangered	X	X	X	Possible	X	X	X	X	X	X	X	X
Mountain plover *Charadrius montanus*	Proposed Threatened	X	X	Historical (Breeder)	X	X	X	X	X	X	Known	Known	Known
Black-tailed prairie dog *Cynomys ludovicianus*	Candidate for Listing	Known	Known	Known	Known	Known	Known	Known	Known	Known	Known	Known	Known

X = Not known to exist currently or historically in the county.

B.2 Black-footed Ferret

Black-footed ferrets could potentially occur in almost all counties along the Cheyenne River main stem in South Dakota and Wyoming and are known to occur in Shannon County, SD. Black-footed ferrets are associated with large black-tailed prairie dog colonies. Black-tailed prairie dogs are herbivores and so would not be expected to be affected by potential mercury or arsenic in Cheyenne River sediments. Therefore, no adverse effects on the black-footed ferret, which preys on them, would be anticipated.

B.3 Whooping Crane

The whooping crane is known to migrate through the counties along the Cheyenne River main stem that are not in or bordering Wyoming. The whooping crane migrates north from late April to mid June and south in late September to mid October. Wetlands with cattails, bulrushes, and sedges are preferred habitat, and the whooping cranes can also be found in upland areas, especially during migration. Food consists of crayfish, frogs, and other small aquatic life, as well as plants. Although the aquatic species eaten by the cranes may have bioaccumulated mercury or arsenic, the cranes would likely not be exposed to enough potential mercury or arsenic within the few days they are migrating through the area to result in effects that are lethal or teratogenic (producing deformities in offspring).

B.4 Interior Least Tern

The interior population of the least tern is a summer migrant in six South Dakota counties that are located in the Cheyenne River main stem area. Habitat consists of sparsely vegetated sandbar islands on which the birds nest and raise their young. Food consists primarily of small fish 6-9 cm long, and foraging areas include wetlands and the river. Terns hover over shallow water and then dive to capture fish. Terns are colonial nesters, nesting with other terns and with piping plovers. Two or three eggs are laid in a bowl-shaped depression in the sand; eggs require about 24 days to hatch, and fledging occurs about 21 days after hatching. Nesting areas could occur in any sandy or sandy-gravelly substrate along the Cheyenne River main stem. Although fish muscle or fillet mercury concentrations would be expected to be higher in older, larger fish, it would be expected that the piping plover would bioaccumulate mercury (methylmercury) and arsenic ingested from many small fish. Therefore, potential mercury and arsenic contamination of sediments in the Cheyenne River main stem may adversely affect survival or reproduction of local populations of the interior least tern but would not be expected to jeopardize the continued existence of the species.

B.5 Piping Plover

Piping plovers utilize midstream sandbar islands, reservoir shorelines, and alkalai wetlands for summer breeding and nesting. Piping plovers often nest in or near least tern colonies because they utilize similar habitats. The nesting season lasts from late April until August. A clutch of four eggs is laid in a shallow depression, and incubation lasts 25 to 31 days. Chicks can walk and feed within hours of hatching and fledge within 21 days of hatching. Piping plovers feed

on insects or small crustaceans on the island surface, especially along the shoreline. Crustaceans can bioaccumulate mercury and arsenic, so it would be expected that the piping plover would bioaccumulate mercury, methylmercury, and arsenic ingested from many small crustaceans. Therefore, potential mercury and arsenic contamination of sediments in the Cheyenne River main stem may adversely affect survival or reproduction of local populations of the piping plover but would not be expected to jeopardize the continued existence of the species.

B.6 Bald Eagle

Bald eagles are known to occur in all counties that the main stem of the Cheyenne River either passes through or borders. Bald eagles have successfully nested in Meade County, SD, and a few bald eagles consistently winter along the Belle Fourche River. Bald eagles were documented along Whitewood Creek within one mile of its confluence with the Belle Fourche River in a March 1989 survey (Ref. 103). Bald eagles are raptors, at the top of the food chain. They eat small mammals, waterfowl, and fish. Local populations of bald eagles could be adversely affected if the fish have bioaccumulated mercury or arsenic. However, because the Cheyenne River represents a very small part of the bald eagle's nesting range, potential mercury and arsenic contamination of sediments in the Cheyenne River main stem would not be expected to jeopardize the continued existence of the species.

B.7 Pallid Sturgeon

The pallid sturgeon is known to occur in Dewey and Stanley counties, which border Lake Oahe and the Cheyenne River Arm. The pallid sturgeon is adapted to large, turbid, warm-water rivers. Spawning is believed to occur in May or June over gravel or other hard surface. The diet consists of aquatic insects, mollusks, and small fish that are foraged from the river bottom and from tributaries. Reservoir habitat is not the natural habitat for the pallid sturgeon, and in rivers pallid sturgeon are most often caught over a sandy substrate, 3.5 to 10 feet deep. Although the Cheyenne River Arm sediments are not sandy-gravelly, telemetry studies conducted on Lake Sharpe pallid sturgeon from 1989 to 1991 indicated that large (>5 kg) pallid sturgeon were most often found over mud substrates, while small (<5 kg) pallid sturgeon were most often found over gravel substrates (Ref. S13). It is possible that pallid sturgeon in Lake Oahe could forage the Cheyenne River Arm bottom for small fish and any mollusks that are not buried by the rapidly accumulating sediment in the lower Cheyenne River Arm. If the pallid sturgeon does forage for aquatic fauna along the bottom, it might ingest fish (such as gizzard shad, which eat benthic organisms that could potentially bioaccumulate mercury and arsenic) or macroinvertebrates, which also could potentially bioaccumulate mercury and arsenic from Cheyenne River sediments. There is a small likelihood that pallid sturgeon inhabit the Cheyenne River Arm, and if they do, there could be adverse effects on the local population of pallid sturgeon from potentially high mercury and arsenic concentrations in the sediment of the Cheyenne river Arm through dietary exposure. Because the Cheyenne River Arm would represent a very small percentage of the existing pallid sturgeon habitat, however, potential contamination of Cheyenne River sediments with high concentrations of mercury and arsenic would not be expected to jeopardize the continued existence of the species.

B.8 Topeka Shiner

The Topeka shiner was historically found in Dewey County, SD but is no longer found there. The Topeka shiner is characteristic of small, headwater, prairie streams with good water quality and cool temperatures. Topeka shiners most often occur in pool and run areas of streams and are seldom found in riffles (choppy water). The Topeka shiner is an insectivore. Because the headwaters of the main stem of the Cheyenne River are not contaminated with mercury or arsenic, and because no Topeka shiners are known to occur in the Cheyenne River main stem, potential mercury or arsenic contamination of sediments in the Cheyenne River main stem is unlikely to adversely affect the Topeka shiner.

B.9 American Burying Beetle

American burying beetle habitats include pastures and other agricultural land with humus or loose topsoil suitable for burying carrion. The burying beetle buries small dead animals in the soil and lays its eggs in the carcass. The emerging larvae will then have a constant food supply and will not have to compete with fly larvae, since the carcass is buried. The American burying beetle could possibly occur in Haakon County, SD. The general lack of deep humus and friable soils along the river, however, make it unlikely the American burying beetle would be present within the Cheyenne River main stem area.

B.10 Mountain Plover

The mountain plover previously bred in Fall River County, South Dakota, but no longer is found there. The mountain plover breeds commonly in Wyoming. It arrives on its breeding grounds (level, short grass prairie pastures, fallow farmlands, cultivated fields, and prairie dog towns) from late March to late April and typically lays three eggs in a shallow depression. Nests are loosely congregated, suggesting some colonialization. Chicks begin to fledge in June, and fall migration to California occurs in August. Mountain plovers are insectivores, and their diet consists mainly of beetles, grasshoppers, crickets, and ants. These insects would be found in and near the upland breeding grounds and so are not likely to be exposed to high levels of mercury or arsenic that could be bioaccumulated. Therefore, the mountain plover would be unlikely to be adversely impacted by potentially high mercury or arsenic concentrations in Cheyenne River main stem sediments.

B.11 Black-tailed Prairie Dog

The black-tailed prairie dog is a Candidate species for listing and is known to occur in all counties along the Cheyenne River main stem in South Dakota and Wyoming. Prairie dogs are herbivores that graze on upland grasses, forbs, and shrubs and should not be affected by high concentrations of mercury or arsenic in Cheyenne River sediments. They could possibly be subject to alkali disease (selenium toxicity) if the soil is high in selenium, which would be taken up by the plants eaten by the prairie dogs. Black-tailed prairie dogs are herbivores and so would not be expected to have high concentrations of mercury or arsenic; therefore, no adverse effects on the black-tailed prairie dog would be anticipated.

B.12 Conclusions

Mercury and arsenic contamination of sediments in the Cheyenne River main stem would not be likely to adversely impact six of the Threatened, Endangered, Proposed, or Candidate species found in or near the main stem of the Cheyenne River because their diets include little or no aquatic organisms. For the bald eagle, interior least tern, piping plover, and pallid sturgeon, potential mercury and arsenic contamination in sediments and water of the Cheyenne River main stem could potentially adversely affect survival or reproduction of local populations because they eat aquatic organisms that could have bioaccumulated mercury, methylmercury, and/or arsenic. If local populations of these four species were adversely affected, however, the continued existence of these species in South Dakota and Wyoming would not be expected to be jeopardized.