SERGENT, HAUSKINS & BECKWITH

GEOMORPHIC HAZARD EVALUATION

Riverton Uranium Mill Tailings Site

Uranium Mill Tailings Remedial Action Project

September 24, 1984

Prepared by:

Mary L. Gillam

Reviewed by:

Ralph E. Weeks, P.G.

Consulting Geotechnical Engineers

PHOENIX • ALBUQUERQUE • SANTA FE • SALT LAKE CITY • EL PASO • TUCSON

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ADVANCED SYSTEMS DIVISION, ALBUQUERQUE OPERATIONS

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JACOBS WESTON TEAM

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1.0 EXECUTIVE SUMMARY

The U.S. Department of Energy requires that potential geomorphic hazards be addressed at sites proposed for stabilization of uranium mill tailings during the next 200 to 1,000 years. The Riverton Site is located on the valley floor between the Wind and the Little Wind Rivers about 2.4 miles upstream from their junction, 5 feet above the level of the Wind River (1 mile to the north), and 20 feet above the level of the Little Wind River (about 0.5 mile to the southeast). The site lies on a small remnant of the oldest valley-floor alluvial unit, which appears from weak soil development to be on the order of 2,000 years old.

Geomorphic hazards critical to the site are related to encroachment and erosion by the two meandering rivers. These hazards include 1) channel migration toward the site; 2) channel aggradation, which would promote migration; 3) reactivation of cut-off channels near the site; and 4) catastrophic flooding.

During late Holocene time, the Wind River has shifted north and west away from the site, while maintaining an essentially constant elevation. It now appears stabilized at the north side of the valley, but aggradation could trigger a rapid shift toward the site. At the same time, the Little Wind River has incised due to a shift in the junction with the Wind River. The active meander belt will continue widening slowly toward the site.

The hazard from aggradation is greatest for the Wind River because the elevation difference between the site and the channel is very small. Near Highway 789, recent aggradation has diverted part of the flow into an abandoned channel, creating a distinctive island. At the nearby gaging station, an increase in gage readings at constant discharge indicates progressive aggradation as rapid as 5 feet per 100 years, probably resulting from water diversion for irrigation.

Aggradation is also occurring at the inlet to Boysen Reservoir. Rough calculations based on sedimentation rates suggest that related aggradation is unlikely to affect the site in less than 200 years, but is likely to affect it in less than 1,000 years.

Several abandoned cut-off channels from the Wind River to the Little Wind River pass near the site. Owing to the elevation difference between the rivers, any one of these channels would be a preferred route for the Wind River. The most likely and potentially most damaging route is the one along the south edge of the valley, which adjoins the southwest corner of the site.

Although the valley-floor alluvium was deposited under normal flow conditions, moderate floods could have occurred during late Holocene time. Some of the cut-off channels may have been activated by floods. Preliminary calculations suggest that the proposed PMF is not consistent with the Holocene stratigraphy of the valley floor, but more moderate floods could also reach the site or promote channel hazardous changes.

Based on the rates and risks associated with these geomorphic processes, the overall hazard of river encroachment on the site appears moderate to high during the next 200 years and high from 200 to 1,000 years.

2.0 INTRODUCTION

The U.S. Department of Energy (1984) requires that potential geomorphic hazards be evaluated at proposed sites for long-term stabilization of uranium tailings. The geomorphic hazards for the present uranium tailings site near Riverton, Wyoming (Figure 2.1) are discussed in this report.

A geomorphic hazard is any landform change, either natural or artificially induced, that can affect a facility during its intended lifetime (Schumm and Chorley, 1983). For stabilization of uranium tailings, the U.S. Environmental Protection Agency has established a design-life objective of 1,000 years to be met wherever reasonably achievable and a minimum design-life of 200 years (U.S. Department of Energy, 1984).

The Riverton site is about 2 miles southwest of the town of Riverton in Section 9, T1S, R4E (Figure 2.2). The site lies on the alluvial valley floor of the Wind and Little Wind Rivers. Therefore, the principal geomorphic hazards are associated with changes in the location and behavior of these rivers, leading to possible erosion or

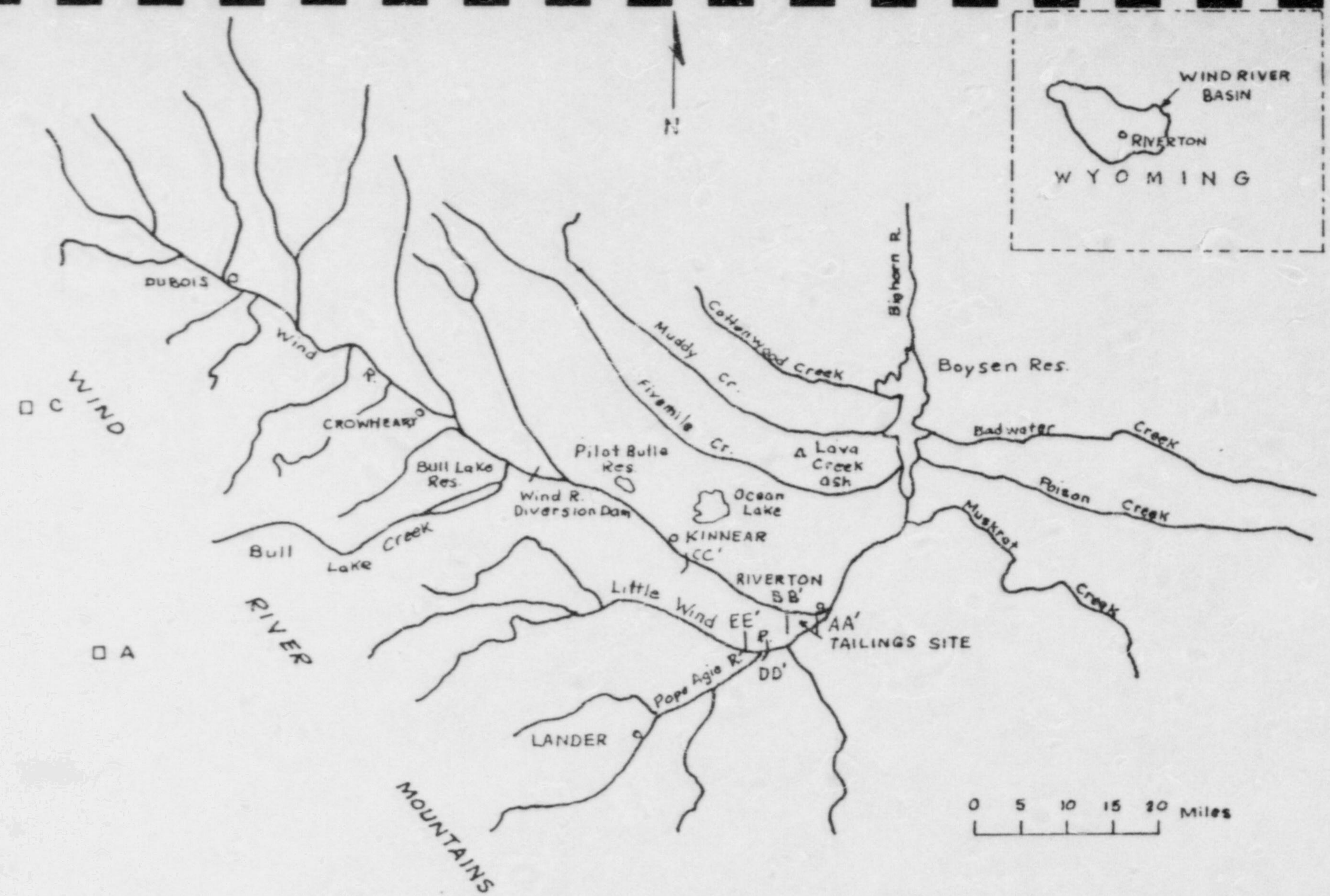

Figure 2.1 Regional location map. A & C denote approximate locations of tree ring data series shown in Figure 4.1. AA'-EE' indicate locations of stratigraphic cross sections shown in Figure 5.6.

Figure 2.2 Aerial photograph of site. From Ford Bacon and Davis Utah Inc., 1981, Figure 2.1.

deposition at or near the site. In this report, the future behavior of the rivers is predicted from their behavior during the recent geologic past, including latest Pleistocene and Holocene time. The effect of man's previous activities is considered, although obviously future human impacts cannot be included.

Future geomorphic processes are difficult to predict because of the complexity of natural systems. Where uncertainty exists, it is best to take a conservative approach (Schumm and Chorley, 1983).

The Riverton site was first studied by Ford, Bacon and Davis Utah Inc. (1981). Of the additional studies now in progress, those most pertinent to this geomorphic hazard evaluation include calculation of the Probable Maximum Flood (PMF) and preliminary design of the containment. This report supplements earlier, less detailed reports on geomorphic hazards at the site (Sergent, Hauskins and Beckwith, 1984a, 1984b).

3.0 INVESTIGATIVE APPROACH

This study was performed in two phases. The initial phase included these steps:

1. Acquisition and review of published literature on the site area and the surrounding region (bedrock and Quaternary geology, soils, geomorphology, sedimentation, surface-water hydrology).

2. Discussions with several Quaternary geologists, geomorphologists, and archaeologists about the status of on-going research in this region.

3. Examination of available aerial photography for the immediate site area (dated 1939, 1948, 1949, and 1976) and the original survey plats for a much larger area (from the late nineteenth and early twentieth centuries).

4. Map compilation of changes in the position of the channels of the Wind and Little Wind Rivers within a radius of several miles of the site.

5. Systematic elimination of posssible geomorphic hazards that do not appear to pose a problem to the

in-place stabilization of the Riverton tailings. Subsequent identification of the potential hazards which will grossly impact the feasibility and/or design of the in-place stabilization approach.

The field phase included the following steps:

1. A reconnaissance evaluation of existing Quaternary geologic mapping for the area north of the Wind River (Morris and others, 1959), including an assessment of the applicability of this mapping to the tailings stability problem.

2. A reconnaissance investigation of geomorphic conditions along the Wind River from a point about 10 miles upstream from the site to Boysen Reservoir, and along the Little Wind River from its confluence with the Wind River to a point about 5 miles upstream.

3. Detailed examination of 1979 aerial photographs (scale 1 inch to 660 feet) at the U.S. Agricultural Stabilization and Conservation Service in Riverton. A map was prepared showing photogeologic units in the valley bottom for a radius of several miles around the site.

4. Examination of surficial deposits and geomorphic processes at the site. The accuracy of the photogeologic map for the site and surrounding area was checked to the extent that time allowed.

5. Preparation of eight technical descriptions of surface soils, using modified Soil Conservation Service methods, as a basis for estimating the absolute ages of the deposits at and near the site.

6. Acquisition and review of locally-available, unpublished information (soils, floods, discharge rating curves, land use, historic photographs, reservoir sedimentation).

One geologist later attended a field trip to examine Quaternary terraces and soils in the Bighorn Basin, which lies directly north of the Wind River Basin. The participants in this trip, organized by the Friends of the Pleistocene, included several experts on the Quaternary history and archaeology of Wyoming.

4.0 REGIONAL SETTING

4.1 LOCATION

The Riverton site is 2.3 miles southwest of the center of Riverton (Figures 2.1 and 2.2) in Fremont County, Wyoming. The tailings cover an area of roughly 72 acres in Sections 4 and 9 of T1S, R1E. Although the site lies within the boundaries of the Wind River Indian Reservation, it is owned by Western Nuclear, Inc.

About 900,000 tons of tailings (702,000 cubic yards) form a rectangular pile that stands above the natural ground surface. The tailings consist of fine to coarse sand and slimes and are covered with 1.5 feet of pit-run sand and gravel. Weeds provide about 20 percent cover on the unirrigated surface (Ford, Bacon and Davis Utah Inc., 1981).

4.2 CLIMATE

4.2.1 Historic Climate

Climatological records beginning in 1923 are available for the airport northwest of town. The region is semiarid to arid. From 1931 to 1960, annual precipitation averaged 8.79 inches but ranged from 4.85 to 14.74 inches (McGreevy and others, 1969). The largest recorded annual precipitation, 18.43 inches, occurred in 1923. About 45 percent of the precipitation falls in April, May, and June, and about 22 percent in September and October. The mean annual temperature for the period from 1931 to 1960 was 43.5° F (McGreevy and others, 1969). Monthly temperatures vary from a January average of 15.3° F to a July average of 70.2° F. (Young, 1974).

Although wind directions are highly variable, a slight preference is apparent for the local east-west trend of the Wind River valley. Wind speeds average about 12 miles per hour (14 to 15 mph in winter, 9 to 10 mph in summer) with occassional storms bringing periods of high winds with gusts of more than 75 mph. The native vegetation is typical of cold semi-arid basin climates and is mostly grasses, forbs and shrubs (Young, 1974).

4.2.2 Paleoclimate

Maximum climatic changes during the next 1000 years are likely to be much smaller than the glacial-interglacial climatic contrast (Schumm and Chorley, 1983). A variety of physical evidence and several numerical models indicate that in the continental mid-latitudes the last glaciation was generally cooler and drier than the present interglaciation (Barry, 1983).

During the last glaciation, July temperatures in the central Rocky Mountains may have been 18 to 27° F colder (Pierce, in Porter and others, 1983), and January temperatures may have been 9° F colder (Reheis, 1984). Mears (1981) estimated a decrease in mean annual temperature of 18 to 23° F for the intermontane basins of Wyoming, based on the preservation of permafrost features (ice-wedge and sand-wedge polygons) in surficial deposits. During this study, similar, poorly preserved features were observed in a gravel pit approximately 4 miles west of the site, at an elevation of about 5260 feet (SE 1/4 SW 1/4 Sec 2, T1S, R3E). One numerical model (Gates, 1976) suggests a decrease of 30 percent in precipitable moisture for northwest Wyoming. Although precipitation probably decreased, soil moisture and runoff apparently increased because of reduced evapotranspiration (Reheis, 1984).

During the present interglaciation, the greatest warmth and wetness probably occurred during a long interval centered around 9000 years ago (Kutzbach and Guetter, 1984). Throughout the Holocene, mean annual temperatures may have departed ± 3.6° F and mean annual precipitation may have departed at least ± 10 to 20 percent from modern values (Knox, 1982). Tree-ring data series from the Wind River Mountains (Figure 4.1) indicate considerable short-term variations in available moisture during the last several hundred years (Stockton and Jacoby, 1976).

4.3 GEOLOGY OF THE WIND RIVER BASIN

4.3.1 Pre-Quaternary Geology

The physiographic Wind River drainage basin corresponds to a downfolded structural basin that is

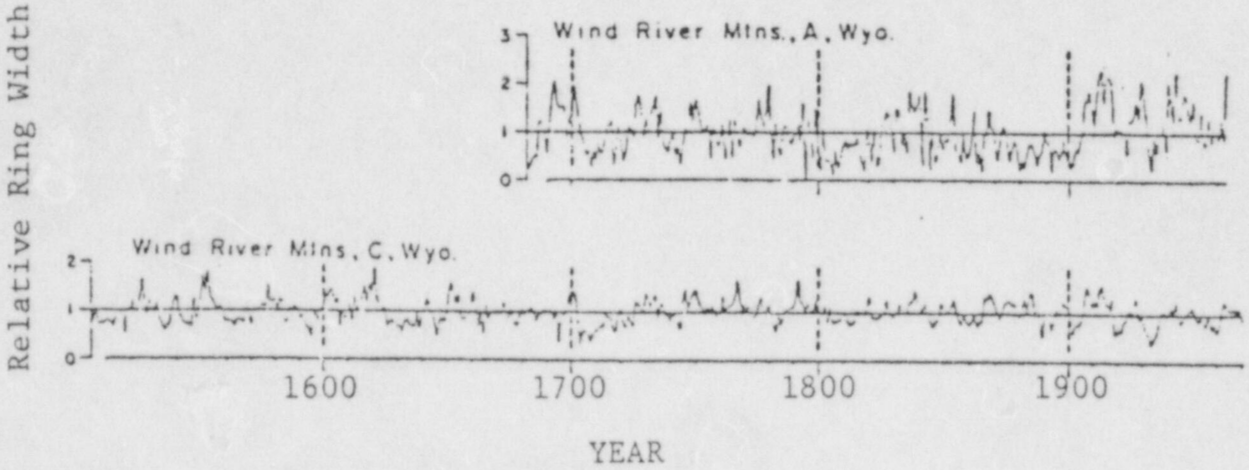

Figure 4.1 Tree-ring data series for two sites in the Wind River Mountains. Locations shown in Figure 2.1. From Stockton and Jacoby (1976).

bordered by uplifted and upfaulted mountain ranges. Igneous and metamorphic rocks of Precambrian age form the cores of these ranges and underlie the sedimentary rocks that accumulated within the basin from Late Cretaceous to Eocene time. The maximum thickness of these sediments is more than 40,000 feet (McGreevy and others, 1969; Love and others, 1979a,b).

The central part of the basin and the Riverton area are underlain by the Wind River Formation of Eocene age. This formation is composed of fine- to coarse-grained sandstone, siltstone, and shale with smaller amounts of bentonite, tuff, and limestone. In the Riverton area, these beds are nearly horizontal and extend to a probable depth of at least 2,000 feet and a maximum depth of 5,000 feet (Ford, Bacon and Davis Utah Inc., 1981).

Erosion has dominated the development of the basin since late Tertiary time, although temporary periods of landscape stability are indicated by remnants of late-Tertiary erosion surfaces in the Wind River Mountains (Blackwelder, 1915; Richmond, 1976). The course of the Wind River was superimposed from the constructional surface of the Wind River Formation (Morris and others, 1959). The upper part of the river may once have been tributary to the Sweetwater River, located to the southeast. However, the river's abrupt northward turn near Riverton suggests that it may have been captured by a tributary of the ancestral Bighorn River (Colby and others, 1956).

4.3.2 Quaternary Geology

During Quaternary time, erosion of the Wind River basin continued. Periodic growth of valley glaciers in the mountains (Mears, 1974; Richmond, 1976; Porter and others, 1983) was accompanied by simultaneous development of alluvial terraces at lower elevations.

With respect to geomorphic hazards at the Riverton site, the most important study on terraces within the basin is that of Morris and others (1959). These authors mapped 13 terrace levels (Qt1 to Qt13) north of the Wind River in the area between the Wind River

Diversion Dam, Boysen Reservoir, and Cottonwood Creek. The terraces lie as much as 825 feet above the modern drainage system. Although Scott (1965) questions the terrace correlations of Morris and others (1959), their work provides an adequate framework for this study, which focuses primarily on unmapped Holocene deposits.

An outcrop of the Lava Creek B volcanic ash bed occurs on terrace Qt8 (Scott, 1965; Izett and Wilcox, 1982). Samples of this ash from other localities have been dated as approximately 620,000 years old. Remnants of Qt8 along the north side of the Wind River have an average height of 340 feet above the modern channel, giving a long-term channel incision rate of 0.55 feet per 1,000 years. However, the presence of the terraces indicates that short-term incision rates differed from this average by an indeterminable amount.

Ten terraces, ranging up to 1,140 feet above the modern drainage, border the Wind River near Bull Lake (Richmond and Murphy, 1965; Murphy and Richmond, 1965; Richmond, 1976). Other studies have addressed terraces along Fivemile Creek (Hadley, 1960) and in a large area that includes several sites within the Wind River Basin (Leopold and Miller, 1954).

Terraces along the Wind River are underlain by roughly 2 to 25 feet of rounded channel gravel and 1 to 2 feet of overbank sand. Locally, these deposits are covered by as much as 25 feet of fan alluvium (Morris and others, 1959). Eolian activity apparently has been minor.

5.0 SURFICIAL GEOLOGY AND GEOMORPHOLOGY OF THE SITE AREA

The site is on the valley floor between the Wind and Little Wind Rivers (Figure 2.2), about 2.4 miles upstream from their junction, 5 feet above the low-flow level of the Wind River (0.9 to 1.0 mile to the north) and 20 feet above the low-flow channel of the Little Wind River (0.4 to 0.6 mile to the southeast). The elevation of the site is about 4950 feet above mean sea level. Except for the incised channels of the two rivers, natural relief on the valley floor is usually less than 2 feet. More than a mile west of the site, the ridge between the two rivers displays a series of unmapped Pleistocene terraces. Remnants of younger Pleistocene terraces locally border the base of this ridge and the north and south edges of the alluvial valley floor.

5.1 LATE PLEISTOCENE TERRACES

The youngest and lowest of the Pleistocene terraces is about 5 feet above the level of the site and 10 to 15 feet above the Wind River (Figures 5.1, 5.2 and 5.3). It correlates with terrace Qt1, mapped by Morris and others (1959) north of the river. An older and higher Pleistocene terrace, correlated with Qt2 of Morris and others, also occurs near the site. This terrace is roughly 35 to 45 feet above the Wind River. North of the river, two terraces with slightly different elevations were mapped by Morris and others as Qt2. On Figure 5.1, these are shown as Qt2a and Qt2b.

The age of terrace Qt1 is important because it provides an upper, limiting age for the younger alluvial deposits in the valley bottom. This age may be estimated from terrace correlations to glacial moraines in the Wind River Mountains, from soil development on the terraces, and from weathering of the terrace gravels.

The Pinedale deglaciation began more than 14,000 years ago and ended more than 9,000 years ago. However, minor readvances occurred in some areas during overall retreat (Porter and others, 1983). Younger and smaller moraines of the Temple Lake glacial stade (Moss, 1951) are older than 6,500 years (Burke and Birkeland, 1983). The correlation of terrace Qt1 to these moraines is uncertain from published descriptions, but Qt1 probably correlates either with a late Pinedale readvance or with the Temple Lake stade.

Four soil profiles were described at existing exposures on terrace Qt1 (Figures 5.1 and 5.4; Tables 5.1 to 5.5). These soils display thin, weak argillic B horizons and thick carbonate accumulations with Stage I morphology, although the appearance of the carbonate varies with the texture and thickness of the upper soil horizons. About 5 to 10 percent of the granitic and

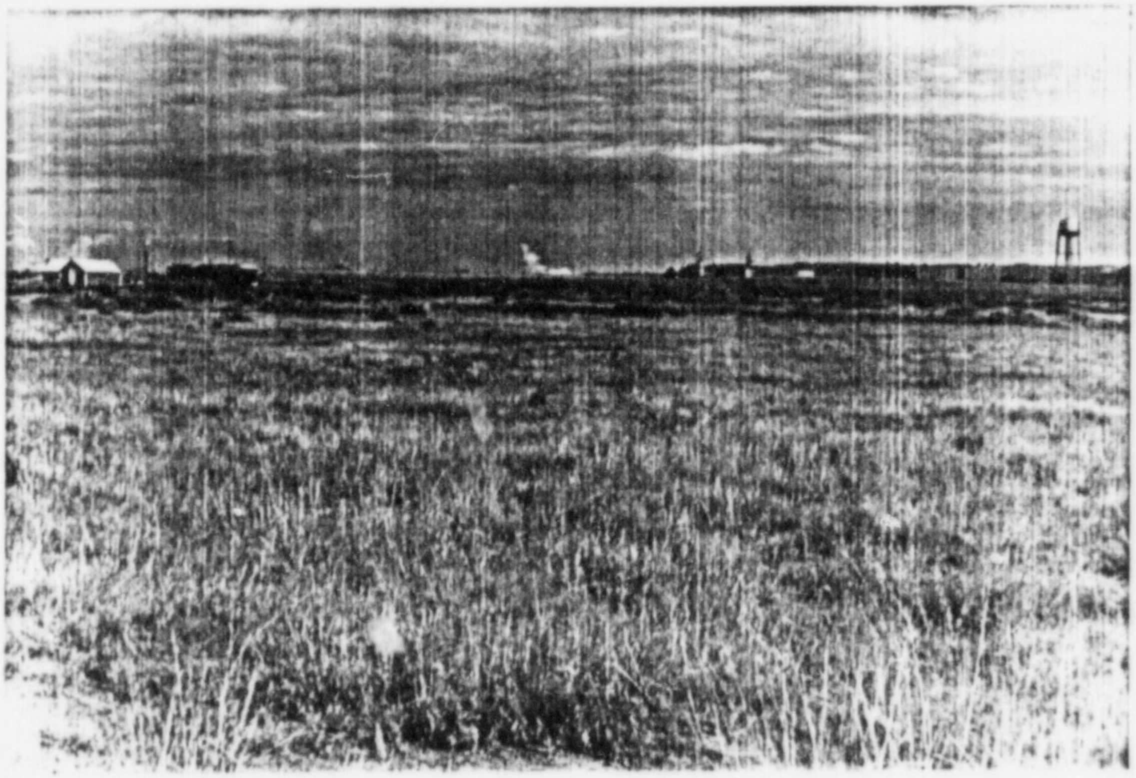

Figure 5.2 Alluvial deposits near tailings pile. A, view north across alluvial deposit Qal4 toward south side of tailings pile. B, view southeast along topographic scarp between terrace Qt1 and cut-off zone west of tailings pile.

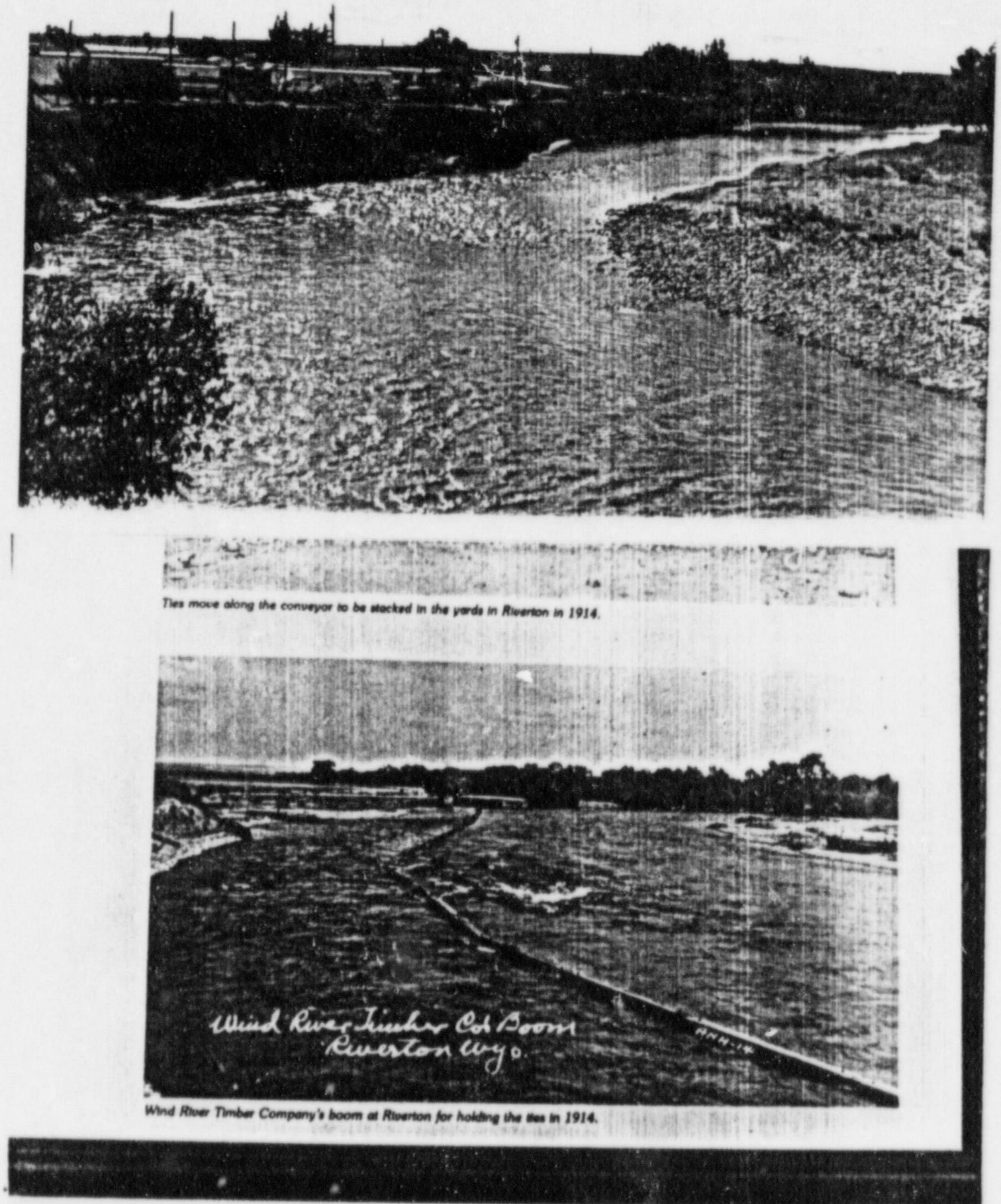

Figure 5.3 Wind River in 1984 and 1.14. A, meandering channel of the Wind River at Riverton in 1984; left bank exposes gravel of terrace Qt1 above Wind River Formation. B, greater width of the Wind River in this area in 1914, before water diversions for irrigation began (exact location and season unknown); from a book by the Riverton Senior Citizens Center and the Early Riverton Group (1981).

Figure 5.4 Four soil profiles in alluvium of terrace Qt1 (very late Pleistocene in age) in Riverton area (Photographs shown on following pages and locations on Figure 5.1). Scale graduated in 0.1-meter intervals with zero at natural ground surface (buried by spoil at some sites). Red tags correspond to horizon boundaries in descriptions.

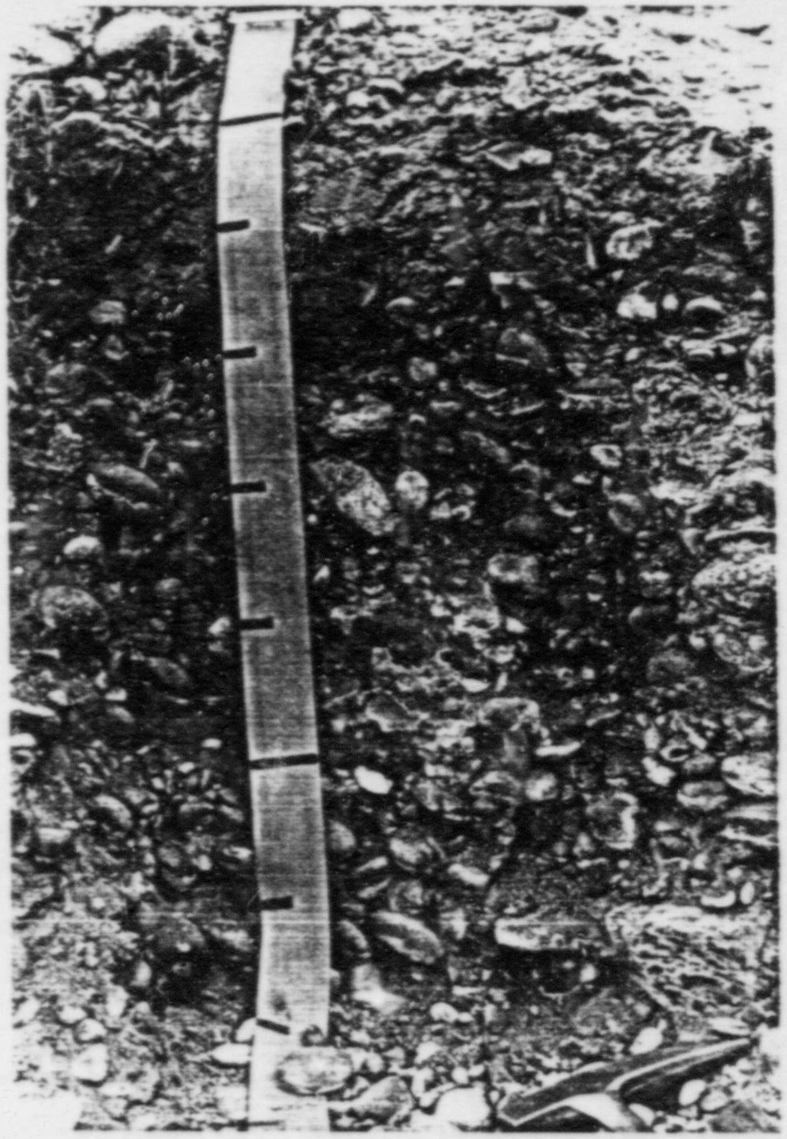

Figure 5.4A Soil Profile 5

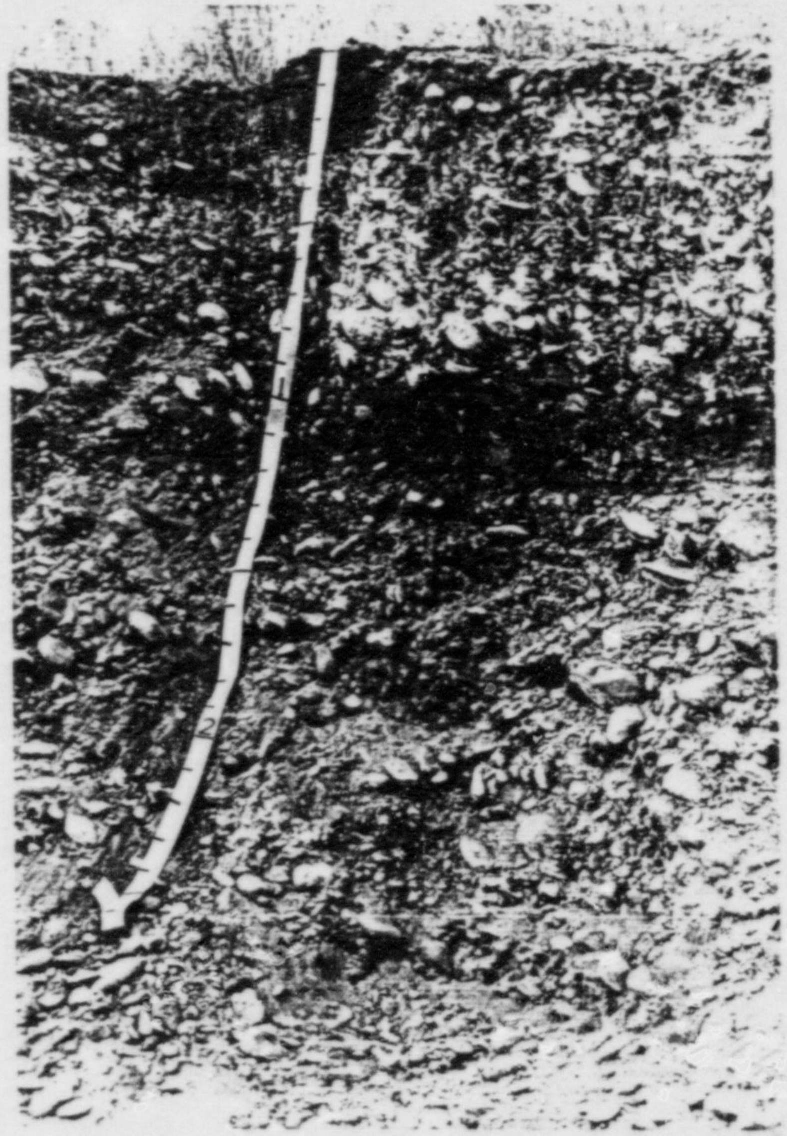

Figure 5.4B Soil Profile 6

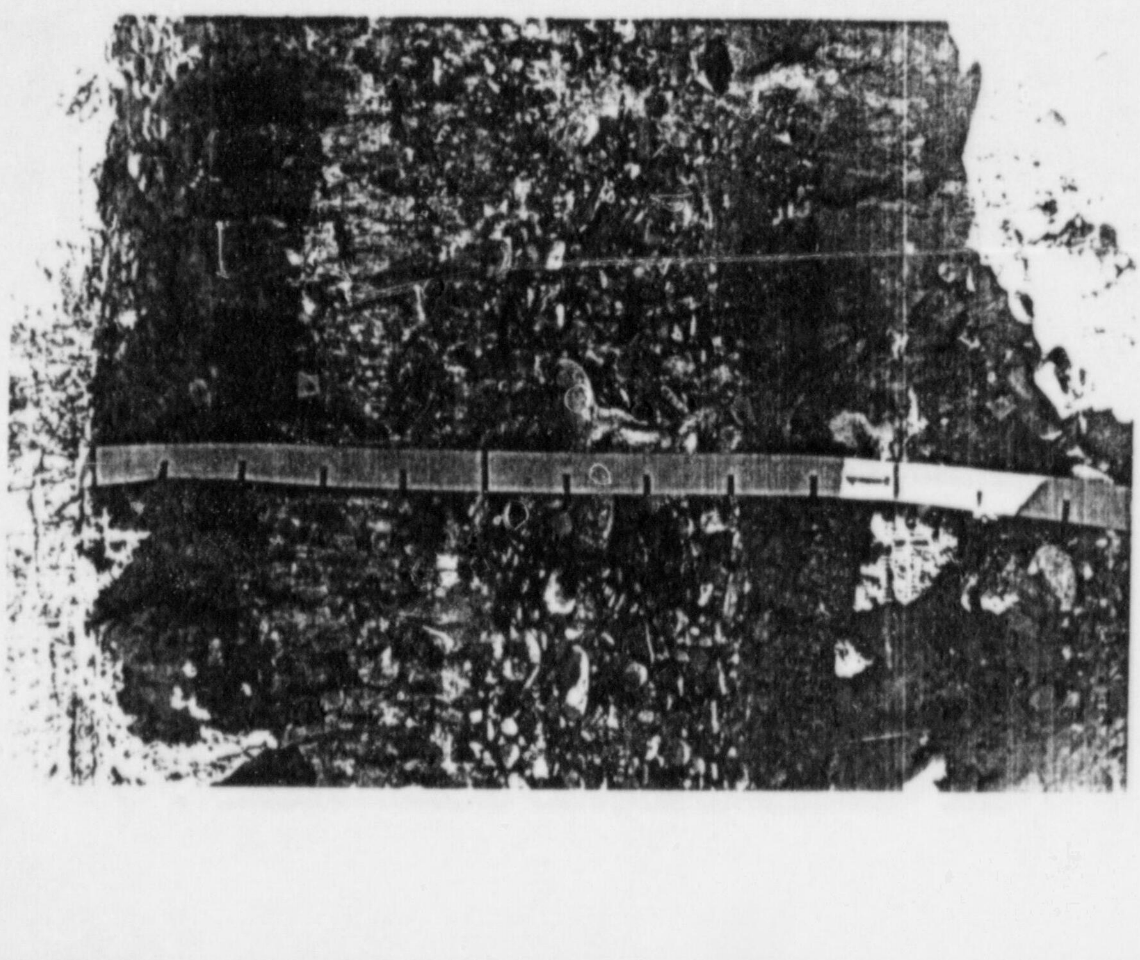

Figure 5.4C Soil Profile 7

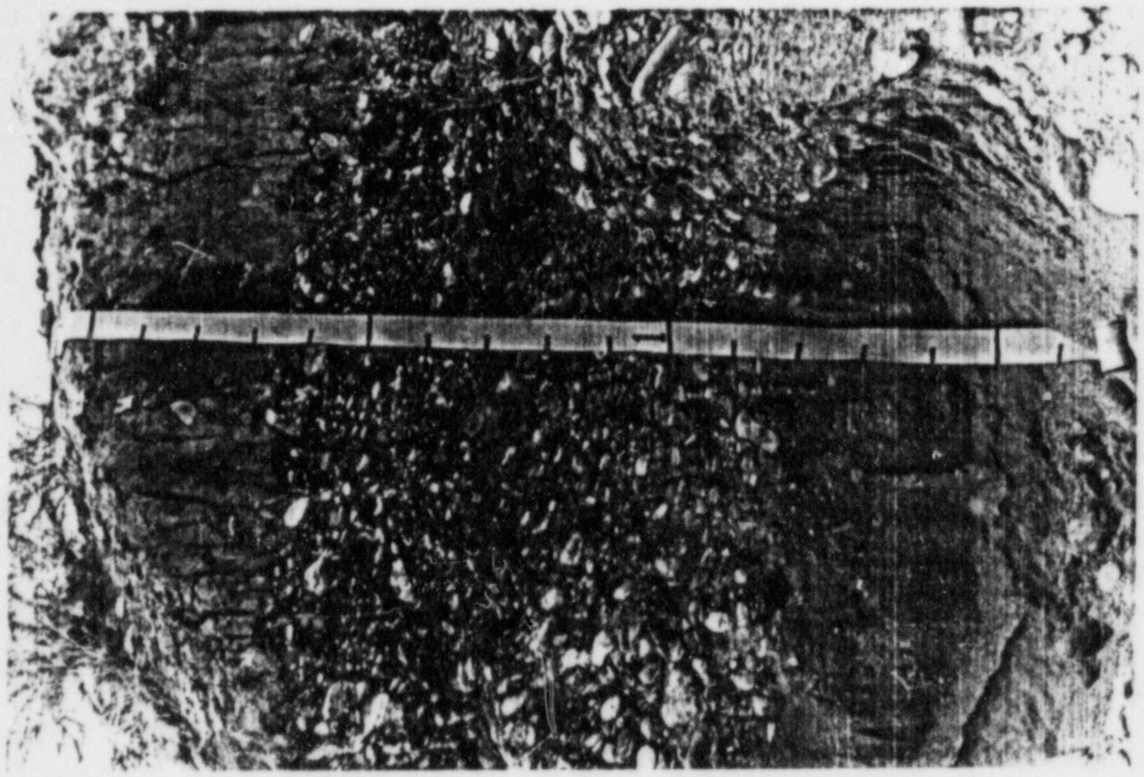

Figure 5.4D Soil Profile 8

TABLE 5.1 TERMINOLOGY FOR SOIL DESCRIPTIONS

HORIZON NOMENCLATURE (SPECIAL TERMS)

j	juvenile	g	gleyed	n	unoxidized
ox	oxidized	s	altered color & structure		
t	increased clay content				

COLOR

Munsell hue, value, and chroma

d	dry	m	moist

DRY CONSISTENCE / MOIST CONSISTENCE

DRY CONSISTENCE		MOIST CONSISTENCE	
lo	loose	lo	loose
so	soft	vfr	very friable
sh	slightly hard	fr	friable
h	hard	fi	firm
vh	very hard	vfi	very firm
eh	extremely hard	efi	extremely firm

WET CONSISTENCE

Stickiness		Plasticity	
so	nonsticky	po	nonplastic
ss	slightly sticky	ps	slightly plastic
s	sticky	p	plastic
vs	very sticky	vp	very plastic

TABLE 5.1 TERMINOLOGY FOR SOIL DESCRIPTIONS (cont'd.)

TEXTURE

Modifiers (Sand)		Size Classes	
vf	very fine	S	sand (sandy)
f	fine	Si	silt (silty)
m	medium	C	clay (clayey)
co	coarse	L	loam (loamy)
vco	very coarse		

STRUCTURE

Grade		Size		Type	
mass	massive	vf	very fine	gr	granular
sg	single grain	f	fine	pl	platey
1	weak	m	medium	pr	prismatic
2	moderate	co	coarse	abk	angular, blocky
3	strong	vco	very coarse	sbk	subangular, blocky

CLAY FILMS

Frequency		Thickness		Morphology	
1	few	n	thin	pf	coating ped faces
2	common	mk	moderately thick	br	bridging grains
3	many	k	thick	po	lining pores
4	continuous	vk	very thick*	co	coating grains
				g	coating gravel*

TABLE 5.1 TERMINOLOGY FOR SOIL DESCRIPTIONS (cont'd.)

CARBONATE STAGE

Stage	Morphology in Gravel	Morphology in Fine Earth
I-	discontinuous coats on bottoms or 1-2% nodules 1-2 mm dia.	few filaments, or 1-2% nodules
I	continuous coats on bottoms	common to abundant filaments
I+	continuous coats on bottoms and tops, or discontinuous coats on bottoms with minor carbonate in matrix	webby carbonate
II-	continuous coats on bottoms, with or without coats on tops; disseminated, filamentous, and/or <10% nodular carbonate in matrix	<10% nodules
II	similar to above, with 10-50% of matrix whitened	10-50% whitened
II+	similar to above, with 50-90% of matrix whitened	50-90% whitened
III-	similar to above with 90-100% whitened	90-100% whitened
III	similar to above, with 100% whitened	100% whitened

EFFERVESCENCE

ve	very slight
e	slight
es	strong
ev	violent

TABLE 5.1 TERMINOLOGY FOR SOIL DESCRIPTIONS (cont'd.)

HORIZON BOUNDARIES

	Distinctness		Topography
va	very abrupt	s	smooth
a	abrupt	w	wavy
c	clear	i	irregular
g	gradual		
d	diffuse		

Notes: *Denotes non-standard term.

Horizon nomenclature after Soil Survey Staff (1951, 1975) and Birkeland (1974).

Carbonate stage terminology adapted from Gile and others (1966), Bachman and Machette (1977), and Shroba (1977).

For definitions of other terms, see Soil Survey Staff (1951, 1975).

TABLE 5.2 DESCRIPTION OF SOIL PROFILE 5

LOCATION: NE¼ NE¼ SW¼ NE¼ Sec. 8,T.1S., R.4E. (about 2900 ft. west and 200 ft. south of southwest corner of tailings) in former gravel pit (now dump) west of road

DEPOSIT: River gravel and sand, correlated with terrace Qtl (Morris and others, 1959), probably latest Pleistocene

SURFACE CONDITIONS: Original surface flat; soil buried by about 19 cm of spoil

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Consistence Wet	Texture <2mm	Percent ≥2mm	Structure	Clay Films	Carbonate Morphology	Effervescence	Boundary
sand (river bar)	0-5	A	10YR 6/3d 10YR 4.5/3m	so	ss,ps	vfSL	5	1 f pl	--	--	e	c,w
	5-15	B2t	10YR 6/3d 10YR 4.5/3m	sh	ss,ps	vfSL+	5	1 co pr to 2 m-co sbk	3 n g, 2 vn pf	Stage I-; discontinuous thin coats on gravel bottoms; few flecks in matrix	e	c,s
sandy gravel; 5-10% of granitic rocks grusified (river channel)	15-25	IIB3ca	10YR 5/3d 7.5YR 4/3m	sh	ss,ps	mSL	60	2 f sbk	1 n co	Stage I; continuous laminar carbonate ≤0.5mm thick on gravel bottoms	es	c,w
	25-47	IIC1oxca	10YR 6/2.5d 10YR 4.5/2m	lo	so,po	mS	70	sg	--	Stage II; continuous laminar and sandy carbonate ≤1mm thick on gravel bottoms; 5% slightly hard carbonate nodules in matrix	es	c,w
	47-64+	IIC2nca	10YR 6/2d 10YR 4.5/2m	lo	so,po	mS	70	sg	--	Stage I; continuous laminar and weakly cemented, sandy carbonate ≤1mm thick on gravel bottoms	es	--

TABLE 5.3 DESCRIPTION OF SOIL PROFILE 6

LOCATION: SW¼ NE¼ NW¼ SW¼ Sec. 9, T.1S., R.4E. (about 300 ft. west and 1750 ft. south of southwest corner of tailings, in gravel pit north of Highway 789, opposite from Arapahoe Cemetery

DEPOSIT: River gravel and sand, correlated with terrace Q+1 (Morris and others, 1959), probably latest Pleistocene

SURFACE CONDITIONS: Flat; on edge of alfalfa field (surface horizons plowed?)

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effervescence	Boundary
sand (river bar)	0-5	A	10YR 5/2.5d 10YR 3.5/2.5m	so	so,ps	L-	15	1 vf pl to 1 vf gr	--	--	--	c,s
	5-19	B2tca	10YR 5/3d 10YR 4/3m	so-sh	so,ps	L-	15	1 co pl to 2 m sbk	3 n co	Stage I; continuous, weakly cemented coats ≤0.5mm thick on gravel bottoms	e	c,w
sandy gravel; 10-cm sandier layer within upper IIC2ca may mark top of a separate depositional unit; layer at 183-211cm is unusually porous, with small voids between pebbles; 5-10% of granitic rocks grusified (river channel)	19-29	IIB3ca	10YR 4.5/3d 10YR 4/3m	lo-so	so,po	mLS	70	1 f sbk	2 n gt	Stage I; continuous, weakly cemented coats ≤0.5mm thick on gravel bottoms	es	g,w
	29-91	IIC1nca	10YR 6/2.5d 10YR 4.5/2d	lo	so,po	mS	70	sg	--	Stage I+; continuous, powdery to weakly cemented coats ≤1mm thick on gravel bottoms and locally on tops; 1% of matrix whitened	es	g,w
	91-183	IIC2nca	10YR 6.5/1.5d 10YR 4.5/1.5m	lo	so,po	mS	70	sg	--	Stage I; continuous, moderately cemented coats ≤1mm thick on gravel bottoms	es	c,w
	183-211	IIC3oxca	7.5YR 5/3d 7.5YR 4/3m	lo	so,po	mS	80	sg	1 n gt	Stage I; continuous powdery coats ≤1mm thick gravel bottoms	es	c,w
	211-235+	IIC4nca	10YR 6/2d 10YR 4.5/2d	lo	so,po	mS	60	sg	--	Stage I-; sparry carbonate coats, patchy to absent on gravel bottoms	es	--

TABLE 5.4 DESCRIPTION OF SOIL PROFILE 7

LOCATION: NW¼ NW¼ NE¼ NW¼ Sec. 36, T.1N., R.4E. (about 3 mi. northeast of tailings); on south side of linear terrace remnant, about 60 ft. west of cut through remnant

DEPOSIT: Primarily river gravel and sand of terrace Qtl (Morris and others, 1959), probably latest Pleistocene

SURFACE CONDITIONS: Flat; this site apparently undisturbed, although surrounding area is disturbed; sparse sagebrush, grasses and weeds; profile composited from two sites about 20 ft. apart

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Consistence Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effervescence	Boundary
sand (alluvial fan)	0-8	A	10YR 5/3d 10YR 4/2m	so	so,po	fSL-	5	1 m sbk	--	--	e	a,s
sand (river bar)	8-14	Cn	10YR 5/3d 10YR 4/3m	so	so,po	fLS	5	1 vco pr to 2 m-co sbk	--	--	--	a,s
	14-27	B21tb	10YR 5/3.5d 7.5YR 4/3m	h	s,ps	mSCL	1	3 m pr to 3 co abk	2 n pf	Stage I-; continuous powdery coats ≤0.5mm thick on gravel bottoms and tops	--	c,w-i
	27-48	B22tcab	10YR 6.5/3d 10YR 4/3m	h	s,p	CL	5	3 m pr to 3 co abk	2 n pf	Stage II; continuous weakly cemented coats 1mm thick on gravel bottoms; common coats & many filaments on ped faces; minor disseminated carbonate in matrix	es	c,w
sandy, gravel; 5-10% of grantic rocks grusified (river channel)	48-57	IIB3cab	10YR 5.5/3d 10YR 4.5/3m	so	so,po	vcoSL+	50	1 m sbk	--	Stage II; continuous powdery coats 1mm thick on gravel bottoms;common filaments & 5% soft masses, 2-4cm in diameter, in matrix	es	g,w
	57-80	IICloxcab	10YR 6/3d 10YR 4.5/2m	lo	so,po	vco S	70	sg	--	Stage II-; continuous powdery coats 1mm thick on gravel bottoms; 5% soft, vertically elongated masses, 2-4cm in diameter, in matrix	es	c,s

TABLE 5.4 DESCRIPTION OF SOIL PROFILE 7 (cont'd.)

LOCATION: NW¼ NW¼ NE¼ NW¼ Sec. 36, T.1N., R.4E. (about 3 mi. northeast of tailings); on south side of linear terrace remnant, about 60 ft. west of cut through remnant

DEPOSIT: Primarily river gravel and sand of terace Q+1 (Morris and others, 1959), probably latest Pleistocene

SURFACE CONDITIONS: Flat; this site apparently undisturbed, although surrounding area is disturbed; sparse sagebrush, grasses and weeds; profile composited from two sites about 20 ft. apart

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effer-vescence	Boun-dary
stratified fine to very coarse sand in layers 6-12cm thick; contains a few very fine pebbles; cross-bedded (river bar)	80-109	IIIC2ncab	10YR 6/2d 10YR 4.5/2m	lo	so,po	f-vcoS	1	sg	--	Stage I; 1% soft, vertically elongated masses in matrix, extending downward from horizon above	e	c,w
	109-136	IVC3ncab	10YR 6.5/2d 10YR 5.5/2m	lo	so,po	vcoS	60	sg	--	Stage II-; continuous, powdery to moderately cemented coats ≤0.5mm thick on gravel bottoms; 3% isolated soft masses, 2-3cm in diameter, in matrix	es	d,w
sandy gravel, similar to third unit	136-172	IVC4ncab	10YR 6.5/2d 10YR 5.5/2m	lo	so,po	vcoS	60	sg	--	Stage I; continuous, thin, moderately cemented coats on gravel bottoms	es	g,w
	172-187+	IVC5ncab	10YR 6.5/2d 10YR 5.5/2m	vfr	so,po	vcoS	60	sg	--	Stage I-; discontinuous thin coats on gravel bottoms	es	--

TABLE 5.5 DESCRIPTION OF SOIL PROFILE 8

LOCATION: NW¼ NW¼ NE¼ NW¼ Sec. 36, T.1N., R.4E. (about 3 mi. northeast of tailings); in east side of cut through linear terrace remnant, in area of former large gravel pits

DEPOSIT: River gravel and sand of terrace Qtl (Morris and others, 1959), probably latest Pleistocene

SURFACE CONDITIONS: Original surface flat; soil buried to varying depth by spoil

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Consistence Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effer- vescence	Boun- dary
sand (river bar)	0-8	A	10YR 5.5/2.5d 10YR 4/2.5m	so	ss,ps	mSL	2	1 m sbk to 1 f gr	--	--	--	c,s
	8-20	B21t	10YR 5/3d 10YR 4/3m	sh	ss,p	L+	2	3 m pr	3 n co	--	--	c,s
	20-36	B22tca	10YR 5.5/3d 10YR 5/3m	sh	ss,p	L+	2	3 m pr	3 n co	Stage I-; minor disseminated carbonate in matrix	es	c,w
sandy gravel with thin sandier bed at top; 5% of granitic rocks grusified (river channel)	36-50	IIB3ca	10YR 6/2d 10YR 4/2m	lo-so	so,po	coLS	60	sg	--	Stage I; continuous, weakly cemented coats 1mm thick on gravel bottoms; minor disseminated carbonate in matrix	es	g,s
	50-64	IIC1nca	10YR 6.5/2d 10YR 4.5/2m	lo-so	so,po	vcoS	60	sg	--	Stage I+; continuous, weakly cemented coats 1mm thick on gravel bottoms; 1% weakly cemented nodules or vertically elongated masses and minor disseminated carbonate in matrix	es	c,s

TABLE 5.5 DESCRIPTION OF SOIL PROFILE 8 (cont'd.)

LOCATION: NW¼ NW¼ NE¼ NW¼ Sec. 36, T.1N., R.4E. (about 3 mi. northeast of tailings); in east side of cut through linear terrace remnant, in area of former large gravel pits

DEPOSIT: River gravel and sand of terrace Q+1 (Morris and others, 1959), probably latest Pleistocene

SURFACE CONDITIONS: Original surface flat; soil buried to varying depth by spoil

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Consistence Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effervescence	Boundary
	64-109	IIIC2nca	10YR 6.5/2d 10YR 4.5/2m	lo	so,po	vcoS	50	sg	--	Stage I; continuous coats ≤1mm thick on gravel bottoms, powdery near horizon top & laminated or sparry near base	es	c,s
sand, fining upward, few very small pebbles, cross-bedded (river) bar)	109-152	IVC3n	10YR 6.5/2d 10YR 4.5/2m	lo	so,po	mS (top), vcoS (base)	1	sg	--	--	es	c,w
sandy gravel, similar to second unit	152-165+	IVC4nca	10YR 6.5/2d 10YR 4.5/2m	lo	so,po	vcoS	50	sg	--	Stage I-; discontinuous, thin, sparry coats & iron oxide stains on gravel bottoms	es	--

gneissic rocks in the gravel are grusified (Figure 5.5). In comparison with other locations (Shroba and Birkeland, 1983; Reheis, 1984), this degree of soil development and weathering suggests a very late Pleistocene or early Holocene age. After the Bighorn Basin field trip, several of the participants briefly viewed this soil and confirmed this age interpretation.

A fossil rodent skull from soil profile 6, located in a small gravel pit about 2,000 feet southwest of the site, was submitted for radiocarbon dating. Although the skull appeared to have been deposited with the surrounding gravel, the date of 265 ± 330 years before 1950 (GX-10518) indicates that the skull is much younger.

5.2 LATE HOLOCENE ALLUVIUM

Most of the surficial deposits on the valley floor at elevations lower than terrace Qt1 are fluvial deposits of the Wind and Little Wind Rivers. The remaining deposits include fan alluvium and slopewash near the valley margins.

The origin of the fluvial deposits is evident from prominent meander scars (Figure 2.2) and the character of the materials. The deposits consist mostly of sandy gravel that is imbricated and locally cross-bedded. A thin layer of fine-grained deposits covers the gravel and fills some abandoned channels. This layer is composed mostly of fine sand that commonly is unstratified but locally may be stratified, cross-bedded, or pebbly. The unstratified sand previously was interpreted as eolian (Sergent, Hauskins and Beckwith, 1984a), but here is considered a low-energy fluvial deposit because fossil aquatic snails were found in one exposure. Ford, Bacon and Davis Utah Inc. (1981) reports about 15 to 25 feet of alluvium below the site. Other sections (Figure 5.6) show roughly 5 to 15 feet of alluvium in the surrounding area.

On aerial photographs, the fluvial deposits of the valley floor were divided into four units (Qal1 to Qal4 on Figure 5.1) based on the apparent freshness and cross-cutting relationships of channel scars, vegetation type and density, surface relief, and color or

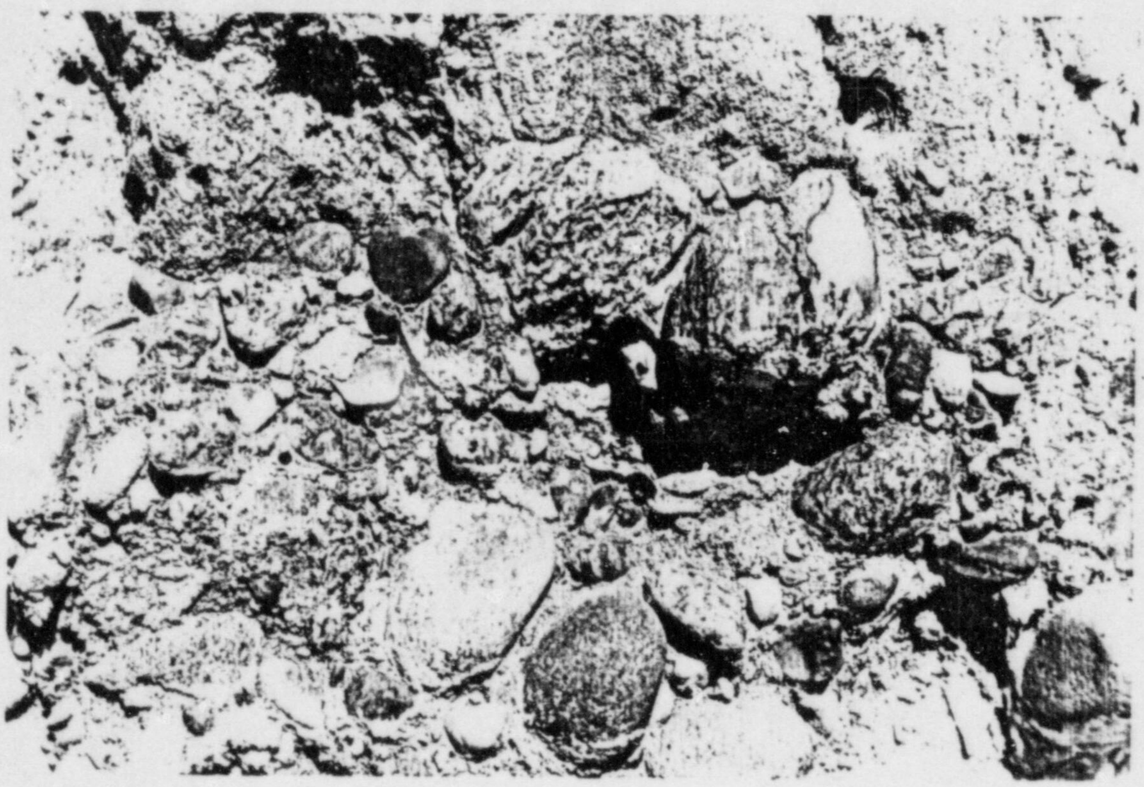

Figure 5.5 Weathering of granite and gneissic rocks in alluvium of Qt1.

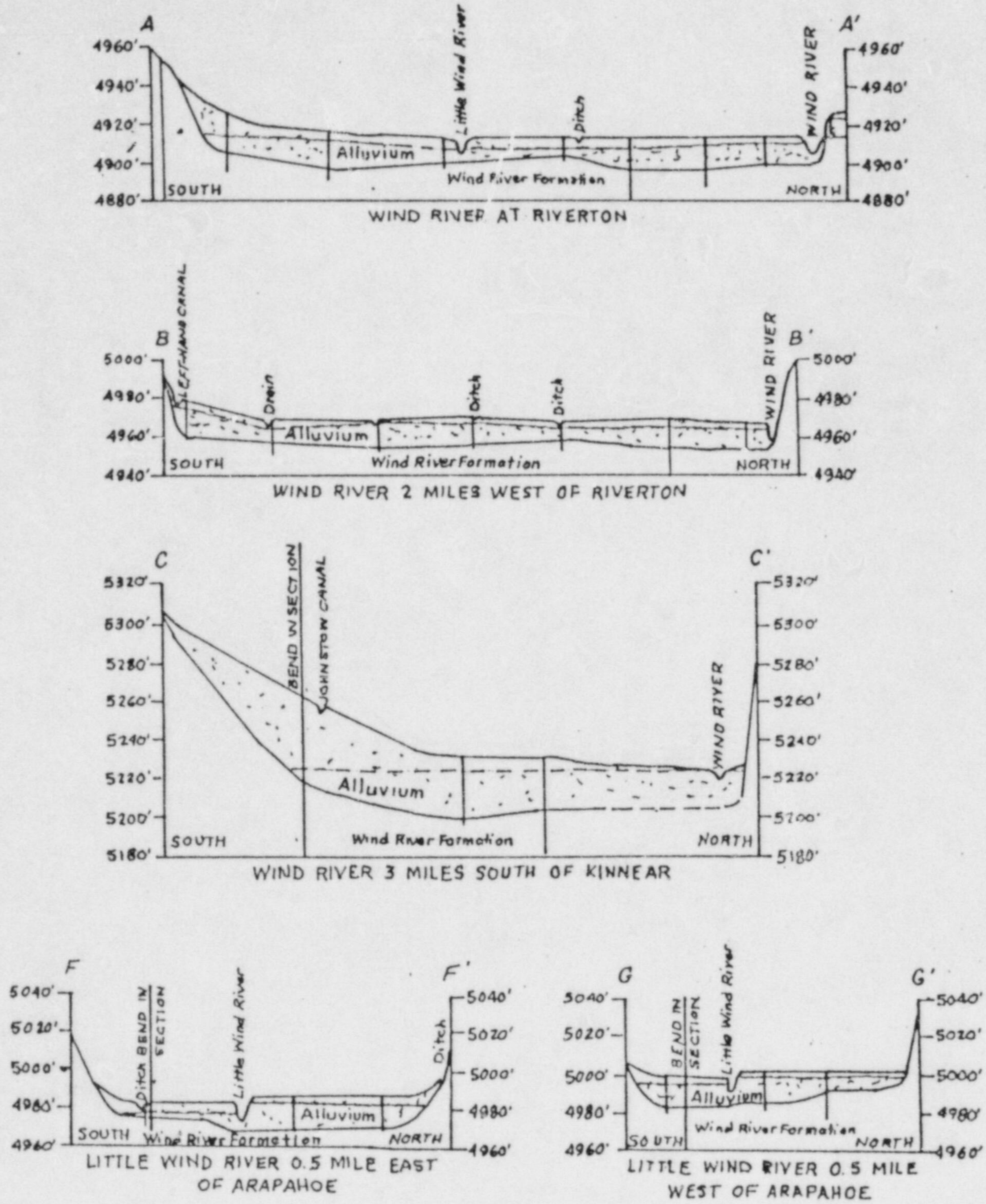

Figure 5.6 Cross sections showing thickness of late Holocene alluvial deposits along the Wind and Little Wind Rivers. Vertical scale 1 inch to 20 feet. Horizontal scale 1 inch to 2,000 feet. Vertical exaggeration 25 times. Locations shown on Figure 2.1. From McGreevy and others, 1969, Plate 3. Lower alluvium is composed of sand, gravel, cobbles, and boulders. Upper alluvium includes sandy to silty floodplain, slopewash, and alluvial fan deposits.

tone. However, these criteria reflect not only the age of the deposits, but also land use and groundwater levels. Therefore, the boundaries may not everywhere represent geologic contacts. Nevertheless, the resulting photogeologic map provides a general indication of the geologic history of the valley floor. The relative age of the units is apparent from cross-cutting relationships and relative proximity to the rivers.

The site rests on unit Qal4, which is characterized by grassy vegetation, a very flat surface, and relatively faint meander scars (Figures 5.1, 5.2, and 2.2). The larger remnants of this unit near the site have an area of about 2 square miles. Unit Qal4 probably was deposited mostly by the Wind River, at a time when the channels of both rivers were at the level of the uppermost deposits. The narrow width and southeast trend of the groundwater contaminant plume suggests that the alluvium contains paleochannels that flowed from the wind to the Little Wind River (White and others, 1984). Since deposition of Qal4, the Little Wind River has incised its channel and several temporary channels have cut across this unit from the Wind River to the Little Wind River. As a result, the remnant beneath the site is bordered on the west, south, and east sides by scarps that increase in height toward the Little Wind River. The present distribution of this unit suggests that it formerly was more extensive, and that it was partly eroded during deposition of Qal3 and incision by the Little Wind River.

The age of the deposits on the valley floor is important because it provides a relative indication of the rate at which the rivers migrate laterally. The deposits comprising unit Qal4 vary slightly in age, as indicated by the distinct meander scars. To assess their average age, four soils were described at existing exposures near the southwest corner of the site (Figures 5.1 and 5.7; Tables 5.6 to 5.9). Although one soil has a very weak cambic B horizon, the other soils lack B horizons and all display very weak carbonate development. In comparison with other Holocene soils (Burke and Birkeland, 1983; Reider, 1980, 1983, 1984), these soils appear to be late Holocene in age, perhaps around 2,000 years old. This age interpretation is

Figure 5.7 Four soil profiles on alluvial deposit Qal4 (late Holocene in age) near southwest corner of tailings site. (Photographs shown on following pages and locations in Figure 5.1). Scale graduated in 0.1-meter intervals with zero at natural ground surface (buried by spoil at some sites). Red tags correspond to horizon boundaries in descriptions.

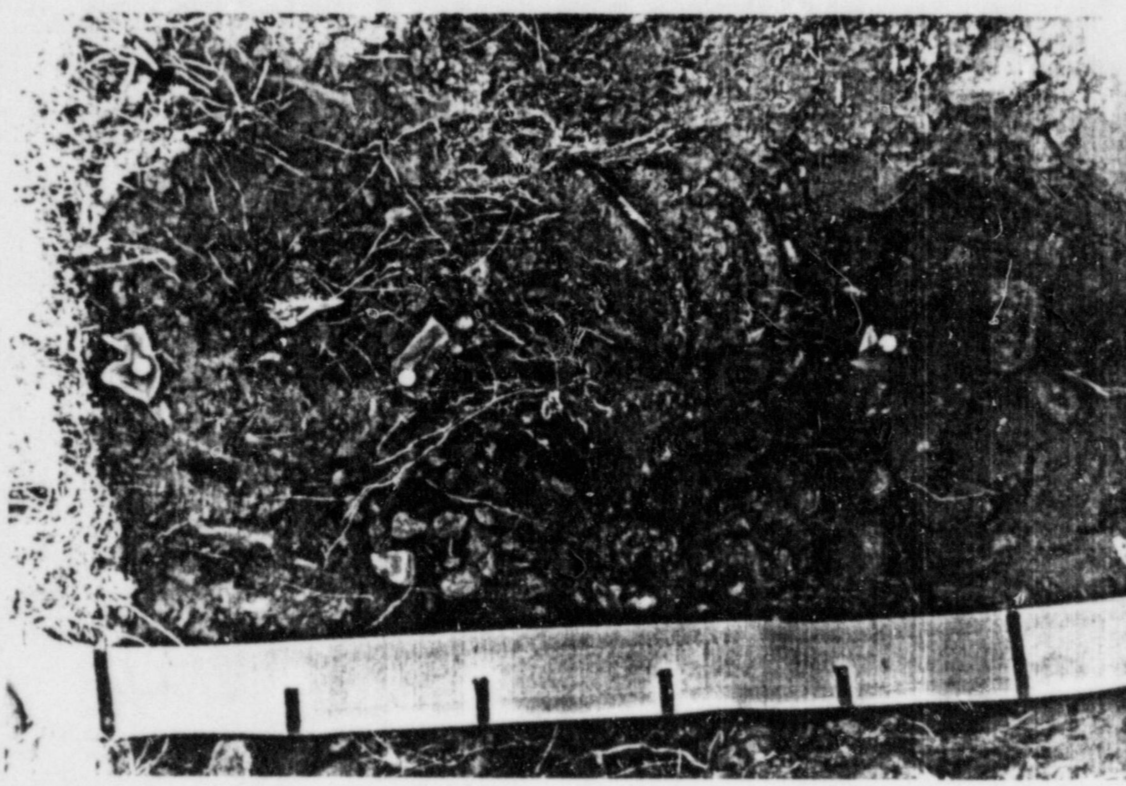

Figure 5.7A Soil Profile 1

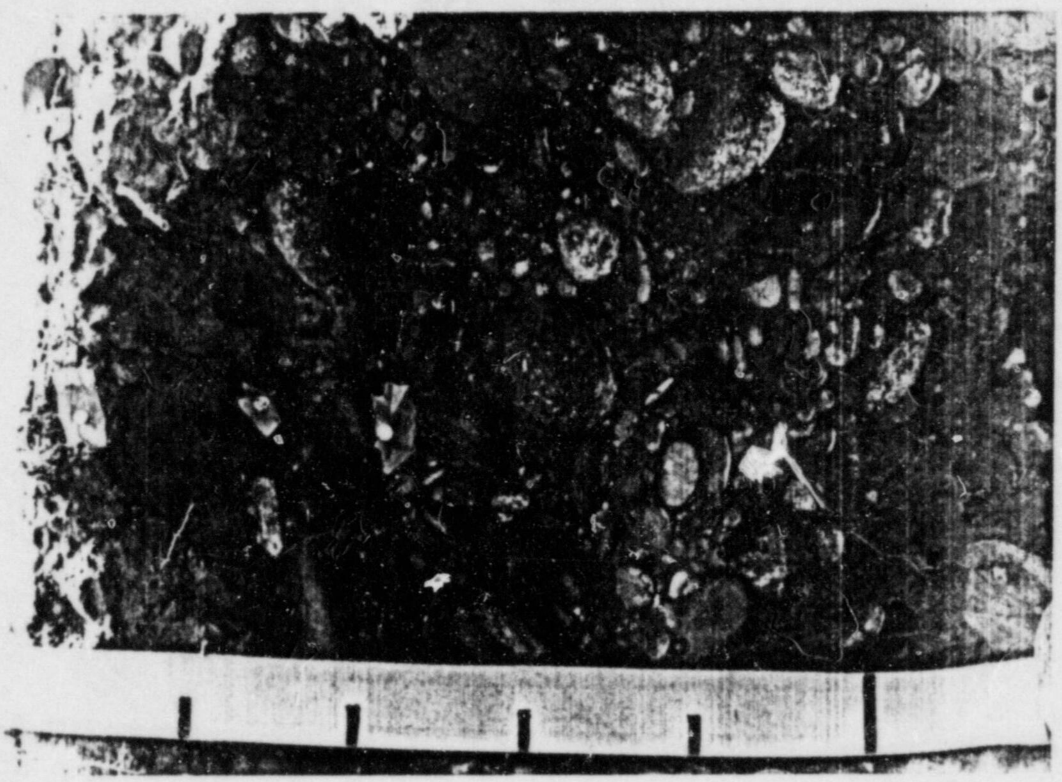

Figure 5.7B Soil Profile 2

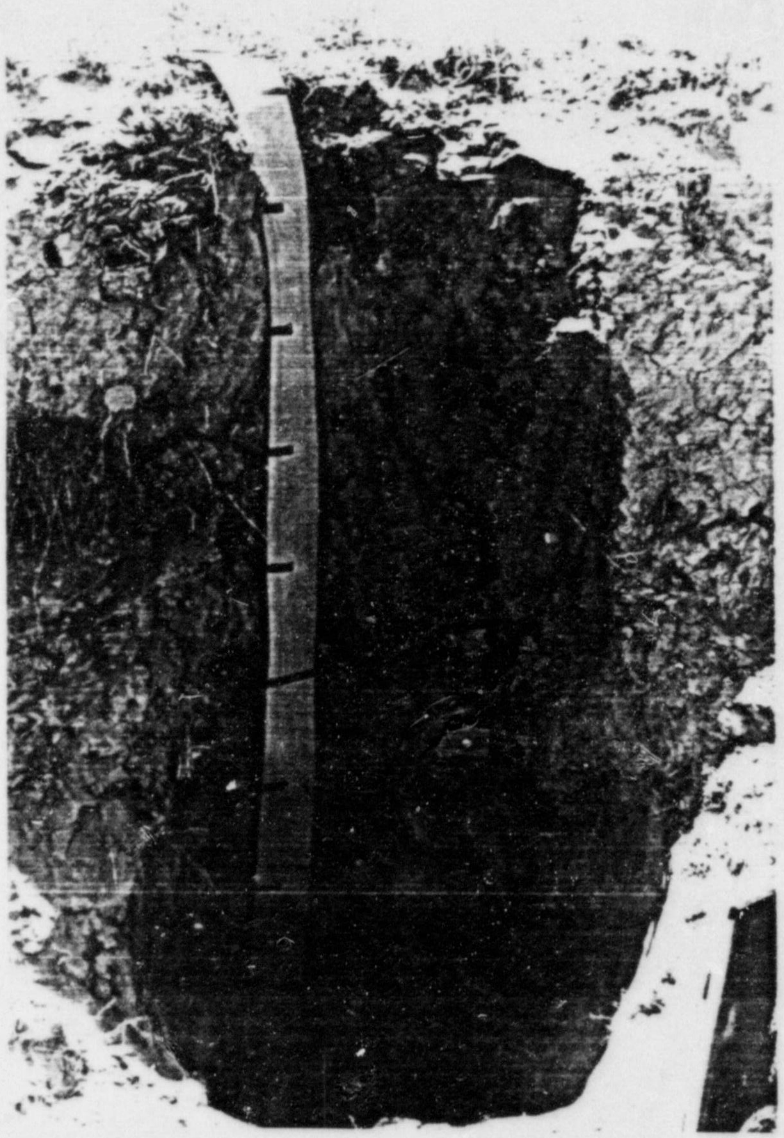

Figure 5.7C Soil Profile 3

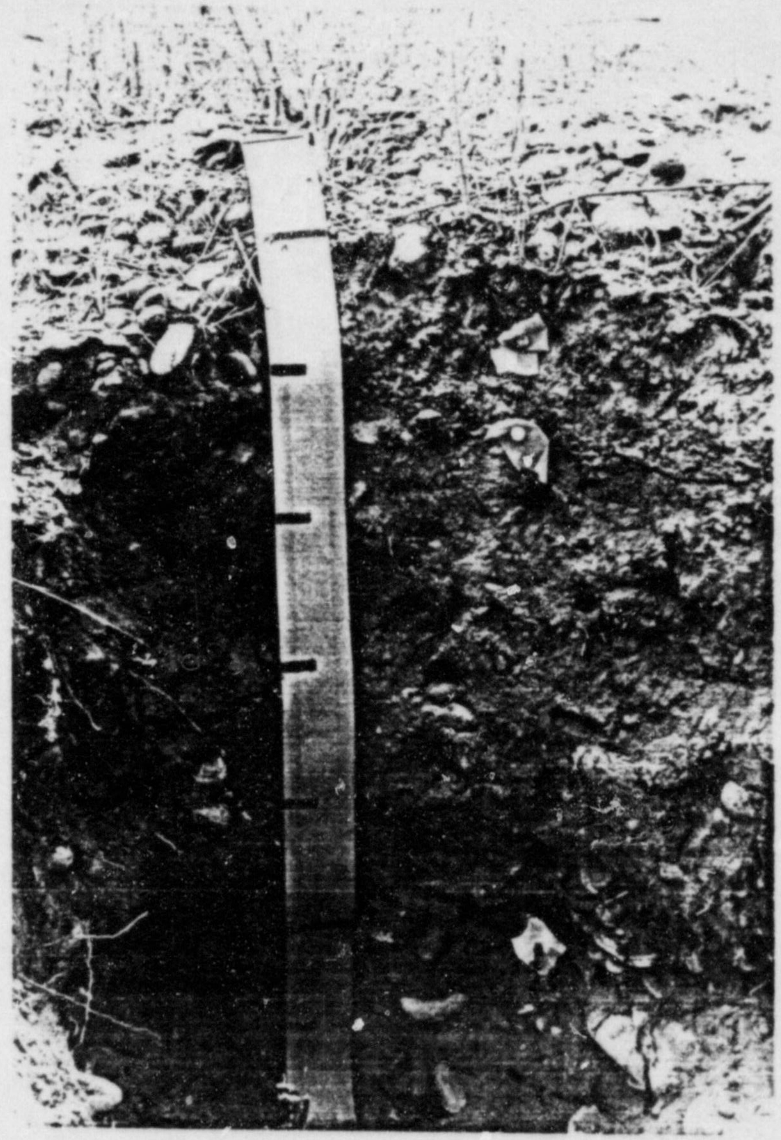

Figure 5.7D Soil Profile 4

TABLE 5.6 DESCRIPTION OF SOIL PROFILE 1

LOCATION: SW¼ NE¼ NW¼ NW¼ Sec. 9, T.1S., R.4E. (about 760 ft. north and 360 ft. west of southwest corner of tailings), in NE corner of small excavated pond

DEPOSIT: River gravel and sand of low terrace, probably late Holocene

SURFACE CONDITIONS: Flat; grasses and Russian thistle

Parent Material	Depth (cm)	Horizon	Color Dry (d) Moist (m)	Consistence Dry or Moist	Consistence Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effervescence	Boundary
sand (river bar)	0-3	A1	10YR 5/2.5d 10YR 3/3m	so	so,po	fiSL	3	1 f sbk	--	--	e	a,s
sandy gravel; moderately sorted, well rounded 2-10cm in diameter; unweathered (river channel)	3-16	C1n/Bs	10YR 6/3d 10YR 3.5/3m	so	ss,ps	fiSL-	60	1-2 m-co sbk	--	Stage 0; few faint filaments on gravel; rare flecks 0.5mm dia. in matrix	e	c,s
	16-42	C2ca	10YR 6.5/2d 10YR 3/3m	so	so,po	mLS	60	1 f-m sbk	--	Stage I; continuous thin coats on gravel bottoms; disseminated carbonate in matrix	es	c,w
	42-57+	C3ca	10YR 6/3d 10YR 4/2m	lo	so,po	mS	60	sg	--	Stage I-; discontinuous to continuous, thin to very thin coats on gravel bottoms	es	--

TABLE 5.7 DESCRIPTION OF SOIL PROFILE 2

LOCATION: NE¼ NW¼ SE¼ NW¼ Sec. 9, T.1S., R.4E. (about 560 ft. east and 160 ft. south of southwest corner of tailings), in east wall of gravel pit

DEPOSIT: River gravel and sand of low terrace, probably late Holocene

SURFACE CONDITIONS: Flat bottom of natural swale about 1 ft. deep; patchy vegetation (pea family, grasses, Russian thistle) suggests possible deflation or minor erosion of upper A horizon

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Consistence Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effer-vescence	Boun-dary
sand (river bar)	0-3	A	10YR 5/2.5d 10YR 3/2m	lo-so	so,po	mLS	0	1 m sbk	--	--	--	c,s
	3-14	B1	10YR 5/3d 10YR 3/3m	so	so,po	mLS	0	1 vco pr to 1 m sbk	--	--	--	s,g
sandy gravel, unweathered (river channel)	14-21	IIB2s	10YR 4/3d 10YR 3/3m	lo	so,po	mLS	60	sg	--	--	ve	c,w
	21-46	IIC1ca	10YR 5.5/3d 10YR 3/3m	lo	so,po	m-coS	60	sg	--	Stage I-; discontinuous thin coats on gravel bottoms	ve	g,w
	46-64+	IIC2ca	10YR 5.5/3d 10YR 3/3m	lo	so,po	m-coS	60	sg	--	Stage I-; discontinuous thin coats on gravel bottoms	e	--

TABLE 5.8 DESCRIPTION OF SOIL PROFILE 3

LOCATION: NW¼ NE¼ SE¼ NW¼ Sec. 9,T.1S.,R.9E. (about 760 ft. east and 20 ft. south of southwest corner of tailings), in ditch bank next to fence

DEPOSIT: River gravel and sand of low terrace, probably late Holocene

SURFACE CONDITIONS: Flat bottom of natural swale (abandoned river channel) about 1 ft. deep and 30 ft. wide; grasses, weeds, few sagebrush

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Consistence Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effervescence	Boundary
gravelly sand; gravel unweathered (river bar or low-energy channel)	0-6	A	10YR 5/2.5d 10YR 3/2m	so	so,po	mSL	5	1 m sbk	--	--	--	c,w
	6-39	Coxca	10YR 5/3d 10YR 4/2.5m	lo	so,po	f-mLS	10	sg	--	Stage 0; few filaments on gravel; rare, discontinuous thin coats on gravel bottoms; few flecks in matrix	--	g,w
	39-58+	Cnca	10YR 6/2.5d 10YR 4.5/2.5m	lo	so,po	mS	10	sg	--	Stage I; continuous, thin to very thin coats on gravel bottoms	--	--

TABLE 5.9 DESCRIPTION OF SOIL PROFILE 4

LOCATION: NE¼ NE¼ SE¼ NW¼ Sec. 9, T.1S.,R.4E. (about 1040 ft. east and 20 ft. south of southwest corner of tailings), in ditch bank next to fence

DEPOSIT: River sand of low terrace, probably late Holocene

SURFACE CONDITIONS: West slope (about 1°) of minor ridge about 2 ft. high, possibly former point bar; grasses

Parent Material	Depth (cm)	Horizon	Color Dry (d), Moist (m)	Consistence Dry or Moist	Consistence Wet	Texture <2mm	Percent >2mm	Structure	Clay Films	Carbonate Morphology	Effervescence	Boundary
stratified sand (river bar or low-energy channel)	0-8	A	10YR 6/2.5d 10YR 4/2m	so	so,po	fSL	0	2 m-co sbk	--	Stage 0; minor disseminated carbonate in matrix	e	c,w
	8-48	C1nsa	10YR 6.2d 10YR 4.5/2.5m	so	so,po	vfSL	1	1 vco pr to sg	--	Stage I; continuous thin coats on gravel gravel bottoms	e	c,s
	48-57	C2n	10YR 6/2d 10YR 4/2.5m	fr	ss,p	SiCL	0	1 c sbk	--	Stage 0; minor disseminated carbonate in matrix	e	a,s
	57-79	C3n	10YR 6/2d 10YR 4.5/2.5m	vfr	so,po	mLS	0	sg	--	Stage 0; minor disseminated carbonate in matrix	e	a,s
	79-103	C4nsa	10YR 6/2d 10YR 4.5/2m	vfr	so,po	SiL or vfSL	0	mass	--	Stage 0; minor disseminated carbonate in matrix	e	c,s
	103-111+	C5n	10YR 6/2d 10YR 4/2.5m	vfr	so,po	vfLS	0	sg	--	Stage 0; minor disseminated carbonate in matrix	e	--

broadly consistent with the work of Leopold and Miller (1954) and Hadley (1960), who describe terraces a few feet above Fivemile and Muddy Creeks as late Holocene.

No archaeological work has been done on Holocene deposits near the site, but several radiocarbon dates have previously been obtained from sites mostly near Boysen Reservoir. The oldest dates at each of these sites range from 1,100 to 3,500 years (Mary Hopkins, Wyoming State Historic Preservation Office, personal communication, 1984; the actual locations are confidential and have not been released to UMTRAP). An archaeologist (John Albanese, personal communication, 1984) states that the oldest preserved Holocene terrace at many Wyoming sites is at least 1,600 years old.

Unit Qal3 is characterized by very fresh-appearing meander scars, maximum local relief of one to two feet, and grass or scrub vegetation. Cross-cutting channel scars, discontinuous low scarps, and minor vegetation contrasts were used locally to divide this unit into four sub-units (Qal3 to Qal3d). In general, the younger sub-units are closer to the Wind River. Sub-unit Qalc corresponds to the zone of cut-off channels west of the site. The cut-off channel east of the site, also included in Qal3, is truncated at the north end by a younger part of Qal3. These parts of the unit could not be precisely correlated with the sub-units identified to the west, but this cut-off channel appears older than the one comprising Qal3c. A few deposits along the Little Wind River were also included in unit Qal3. The age unit Qal3 is unknown. However, the freshness of the meander scars suggests that it may be much younger than unit Qal4.

Units Qal2 and Qal1 form a narrow belt along the channels of the Wind and Little Wind Rivers. Unit Qal2 is distinguished from the adjacent units by dense riparian vegetation. A channel containing sediments of this unit cuts across unit Qal3 from the Wind to the Little Wind River just above their junction. Plats from the late nineteenth and early twentieth centuries show active channels within parts of the area mapped as Qal2, indicating that some of the deposits are less than 100 years old. The entire unit is probably less than a few hundred years old. Unit Qal1, was differentiated from unit Qal2 only along the Wind River north of the site and includes unvegetated, active bars.

5.3 RIVER CHANNEL MORPHOLOGY

The Wind River has a mixed-load channel typical of rivers in which the bedload forms a significant part of the total load. It has an irregular, single-phase meandering pattern that locally is semi-confined by the valley sides. Meander length and amplitude, sinuosity, gradient and degree of anabranching vary over distances on the order of one to two miles (Figure 5.1; Table 5.10). The average gradient increases from about 7 feet per mile near Boysen Reservoir to 15 feet per mile near the site. Average sinuosity typically ranges from 1.1 (sinuous) to 1.3 (meandering), although it is locally higher. Common bars and islands result from cutoff meander loops.

In contrast, the Little Wind River has a suspended-load channel typical of rivers in which the bedload forms a small part of the total load. The single-phase meandering channel has variable but high sinuosity (Table 5.11) averaging about 1.9 between the junctions with the Wind and Popo Agie Rivers. The average gradient for this reach is about 4.3 feet per mile.

6.0 GEOMORPHIC HAZARDS ASSOCIATED WITH RIVER BEHAVIOR

Because the site is located on the valley floor between the channels of two major rivers, the principal hazards to long-term stability of the tailings are associated with natural and man-induced changes in river behavior. Critical hazards include 1) channel migration toward the site; 2) channel filling (aggradation), which would increase the tendency for channel migration and 3) reactivation of the cut-off channels west and east of the site.

6.1 LATERAL SHIFTING OF MEANDER BELTS

Long-term lateral shifting of the meander belts of the Wind and Little Wind Rivers could cause erosion at the site. The time interval during which this could

TABLE 5.10 VARIATIONS IN GRADIENT & SINUOSITY ALONG THE WIND RIVER

Contour Elevation (feet)	Cumulative Direct Distance Up-Valley From Reservoir	Characteristics of Main Channel Length (miles)	Gradient (ft. per mi.)	Sinuosity
4726 (Boysen Res.)	0	--	--	--
4740	3.03	3.45	4.1	1.14
4760	5.44	3.02	6.6	1.25
4780	7.31	3.02	6.6	1.61
4800	9.12	2.43	8.2	1.34
4820	11.22	2.48	8.1	1.18
4840	12.83	2.06	9.7	1.28
4860	14.59	2.42	8.3	1.38
4880 (river jct.	16.22	2.09	9.6	1.28
4900 about 4890)	18.25	2.68	7.5	1.26
4920	19.22	1.29	15.5	1.33
4940 (site)	20.34	1.63	12.3	1.46
4960	21.51	1.28	15.6	1.09
4980	23.04	1.69	11.8	1.10
5000	23.93	1.05	19.1	1.17
5020	25.03	1.61	12.4	1.46
5040	26.03	1.10	18.2	1.16
5060	27.20	1.36	14.7	1.16
5080	28.05	0.92	21.7	1.08
5100	30.02	2.35	8.5	1.19
5120	31.32	1.45	13.8	1.11
5140	32.53	1.44	13.9	1.19
5160	33.38	1.08	18.5	1.27

TABLE 5.11 VARIATIONS IN GRADIENT & SINUOSITY ALONG THE LITTLE WIND RIVER

Contour Elevation (feet)	Cumulative Direct Distance Up-Valley	Channel Length (miles)	Characteristics Gradient (ft. per mi.)	Sinuosity
4880 (jct. Wind R.	0	--	--	--
4900 about 4890)	2.12	2.99	6.69	1.41
4920	4.22	4.01	4.49	1.91
4940 (jct. Beaver Cr.)	6.44	5.24	3.12	2.36
4960	8.85	4.60	4.35	1.91

occur is difficult to quantify, but the hazard is probably low for the next 200 years and moderate to high for the next 1,000 years. Because the controls on the behavior of the two channels are very different, the mechanisms of channel shifting are also different. Channel changes larger than about 50 feet, interpreted from successive maps and aerial photographs, are shown on Figure 6.1.

Along the Wind River, progressive changes in channel position were plotted from a point about 6 miles upstream from the site to a point about 3 miles downstream from the junction with the Little Wind River (a total distance of about 12 miles). However, the reach upstream from the site was examined in the most detail. In this reach, the channel evolves by downstream shift of islands and bars, in addition to downstream meander migration and chute cutoff. Meander amplitudes increase locally, but this process is not characteristic. The channel evolution is generally so rapid that it is difficult to recognize shifting features on successive maps or photographs. However, the few measurable rates of downstream meander shift vary from 9 to 32 feet per year.

In the 38 miles from Bull Lake to the Little Wind River, the channel of the Wind River tends to follow one side of the valley for a distance, and then cross the valley diagonally to follow the opposite side. Six crossings occur in this reach and the total length of the crossings roughly equals the total length of the segments that are confined on one side by a scarp. Channel patterns in the two positions tend to differ. North of the site, meanders of the semi-confined channel have relatively small amplitudes (averaging about 600 feet) and short wavelengths (averaging 2,700 feet). The maximum width of unit Qal2, representing the recently-active meander belt, is about 2,000 feet, but the unit is everywhere at least as wide as the average meander amplitude. This relationship suggests that future channel shifts are likely to occur within the area of unit Qal2. Unconfined meanders of the crossing directly upstream have relatively large amplitudes (averaging about 1,400 feet) and long wavelengths (averaging 4,900 feet). The maximum width of unit Qal2 in this area is about 3,400 feet, suggesting that growth in meander amplitude is more characteristic of unconfined than semi-confined channel segments.

The meander scars of unit Qal3 and the distribution of its sub-units suggest that they were deposited as the crossing upstream from the site migrated to the north and west. The reasons for the existence and migration of the crossings are uncertain, but are probably related to the pattern of aggradation on the valley floor. Average gradients and sinuosities for the two channel positions (crossing and valley-side) do not seem to differ significantly. The probable age range of the alluvium on the valley floor -- perhaps 2,000 years -- suggests that the crossings can migrate across and up the valley at relatively rapid rates. Although the channel north of the site now seems stable at its present position, it appears that the centerline could migrate relatively rapidly to the south (toward the site) if the appropriate triggering conditions occur. Aggradation or flooding could help to trigger this type of migration. It would be disadvantageous to excavate gravel for the cover layer of the impoundment from the north or northwest side of the site. In place, the gravel acts as a natural deterrent to lateral channel migration, whereas a depression could tend to localize the position of a future channel near the site.

Along the Little Wind River, channel shifts were studied for the reach from Beaver Creek to the Wind River and for the 51-year period from 1908 (original plats) to 1959 (topographic maps). During this time, about one quarter of the channel did not shift appreciably (Figure 6.1). The remainder shifted as much as 200 to 1,200 feet at the apices of meanders, where the rates of migration were highest and averaged 9 to 24 feet per year. In many cases, the increase in meander amplitude was accompanied by a component of upstream meander migration.

The average amplitude of meanders along this reach of the Little Wind River is about 2,000 feet, whereas locally the width of unit Qal2 is as little as 400 feet (Figure 5.1). This relationship suggests that gradual evolution of the meander pattern will tend to erode the adjacent units (Qal3 and Qal4) until the width of Qal2 is at least 2,000 feet. Directly southeast of the site, this local widening is likely to occur entirely toward the site because the scarp of terrace Qt2, located south of the channel, is more resistant to erosion than the alluvium of unit Qal4.

The maximum meander amplitude occurs about 1.5 to 2.0 miles southwest of the site and is approximately 4,500 feet. Because the necks between these meanders are becoming very narrow, it appears that the meanders will be cut off relatively soon. Thus, about 4,500 feet appears to be the maximum possible width of the meanders under present hydraulic conditions. The distance between the southwest corner of the site and the scarp of terrace Qt2 is about 3,700 feet, so the development of large meanders could conceivably affect the site within the next 1,000 years.

Along this reach of the Little Wind River, larger meander amplitudes and sinuosities tend to occur along channel segments with lower gradients (Table 5.11). In turn, the gradient of the Little Wind River appears to be controlled by changes in the location of the junction with the Wind River. Since late Pleistocene time, the long-term trend has been for this junction to shift downstream. However, the pattern of late Holocene channels (Figure 5.1) indicates that short-term shifts can occur in both upstream and downstream directions. If the junction were now to shift upstream as a result of aggradation and avulsion, the channel length and gradient of the Little Wind River would probably decrease and the width of the meander belt could increase. Although the channels of the two rivers are relatively close on opposite sides of Highway 789, future shifts in the position of the junction are likely to be restricted to the area downstream from the highway for as long as it remains a barrier to surface water flow. However, any significant shift of the junction below the highway could still affect the future behavior of the Little Wind River.

6.2 CHANNEL AGGRADATION

Because the site is only about 5 feet above the present low-flow level of the Wind River, a few feet of aggradation could force the river to shift toward the site. Conversely, because the site is about 20 feet above the present low-flow level of the Little Wind River, the hazard from aggradation along this channel is relatively low, even though this channel would aggrade if the other one did. Although the long-term Quaternary trend has been for cyclic incision and the

Wind River has been relatively stable during late Holocene time, aggradation appears likely during the next 1,000 years. The rate of aggradation is difficult to predict, but the hazard appears moderate to high for periods of 200 years or more.

6.2.1 Theoretical Effects of Climate Change

Based on the geomorphic relationships between glacial moraines and outwash terraces in many valleys, and on generalized variations in discharge and sediment load that accompany the glacial-interglacial cycle, Schumm (1965) has proposed the following sequence of changes in river behavior in basins that are partly occupied by valley glaciers:

late interglacial	stability
early glacial	deposition
full glacial	deposition
late glacial	erosion
early interglacial	erosion
interglacial	stability

The relative duration of glacial and interglacial stages, as indicated by varying oxygen-isotope ratios in marine sediments, indicates that we should now be nearing the end of the present interglacial (Richmond, 1972). Therefore, theory predicts that the present channels of the Wind and Little Wind Rivers should be essentially stable, that is, experiencing no significant aggradation or incision. However, brief periods of small-scale aggradation and incision can be caused by minor fluctuations in Holocene climate (Schumm, 1965; Knox, 1983). The sequence of alluvial units on the valley floor may result in part from late Holocene climatic changes. The effects of future changes could tend either to enhance or cancel the man-induced aggradation described below.

6.2.2 Geomorphic Evidence

Differences in channel pattern and gradient suggest that aggradation may be occurring in two different areas. Near Highway 789, the channel of each river has divided to form a large island transverse to the general trend (Figures 5.1 and 6.1). The elliptical shape of these islands is atypical for either river and suggests that they formed when local aggradation caused favorably located, abandoned channels to be re-occupied.

The gradient of the Wind River decreases near the island (Table 5.10; Figure 5.1), but the contour spacing along the Little Wind River is too large for any similar change in gradient to be detected.

Aggradation is also occurring near the inlet to Boysen Reservoir. In the 0.5 to 1.0 mile interval above the inlet, the artificially high water level has produced marshy conditions (Figure 6.2). The irregular, lobate shoreline and low, uneroding river banks probably reflect two processes: inundation of the pre-reservoir valley bottom with its minor relief from abandoned channels; and the development of a delta and an associated network of distributary channels.

Upstream from this area, the next 2 miles of the channel display an anabranched pattern that is relatively straight in compariso with areas farther upstream (Figure 6.2). Ae...l photographs of this reach show that the adjacent valley floor is covered with meander scars. Therefore, the change in channel pattern from meandering to anabranched must have occurred very recently. This change appears to predate the 1898 plat of the area and thus to pre-date Boysen Reservoir.

Because of the 20-foot contour interval, channel gradients could not be computed separately for the reaches adjacent to and just above Boysen Reservoir. Their average gradient is about 4 feet per mile, similar to that computed for the submerged part of the delta near the reservoir inlet (U.S. Bureau of Reclamation, 1965; see Section 6.2.5).

The cause of the pre-reservoir aggradation is unknown, although it could reflect a change in the behavior of Muskrat Creek, an ephemeral stream which joins the Wind River at this point from the east, or

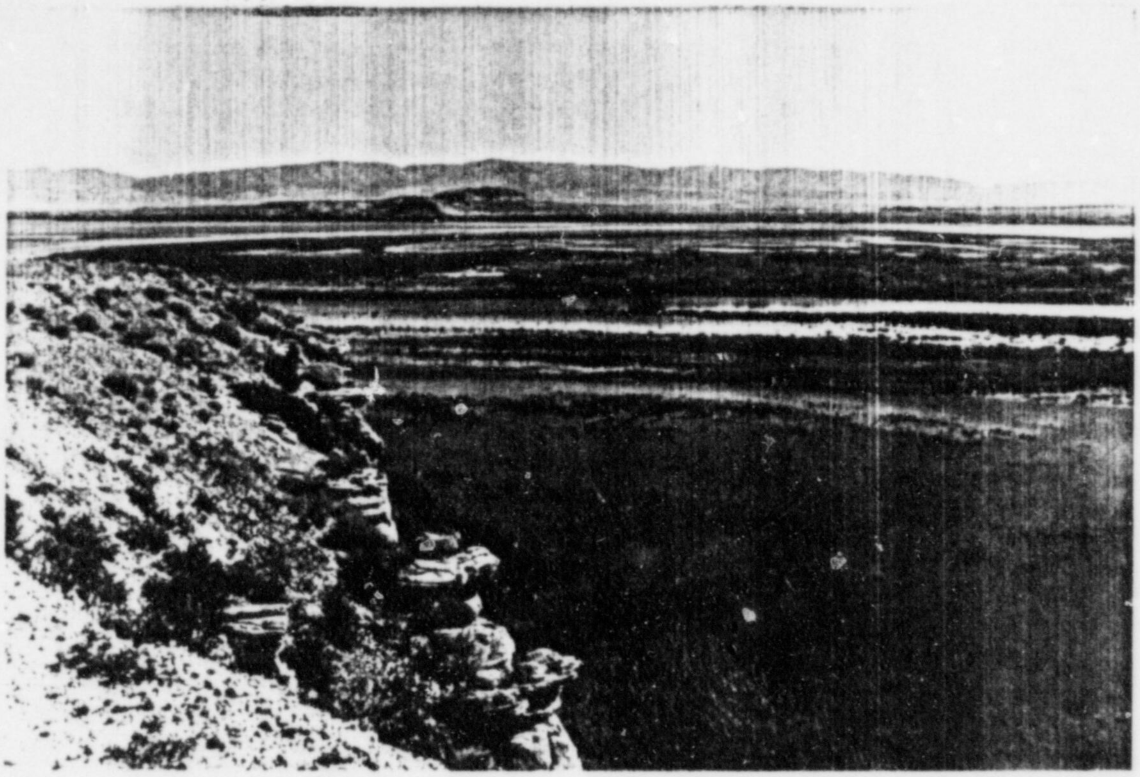

Figure 6.2 Wind River delta at the inlet to Boysen Reservoir (upper) and the channel about 3 miles farther upstream (lower).

local effects of overgrazing. In the future, aggradation associated with Boysen Reservoir is likely to overwhelm any further effects of this unknown cause.

6.2.3 Stratigraphic Evidence

Cross sections show that the alluvium flooring the Wind River valley near Riverton and the Little Wind River valley near Arapahoe ranges in thickness from roughly 5 to 15 feet (Figure 5.6). The thickness of alluvium increases upstream along the Wind River to about 20 to 30 feet near Kinnear. These moderate to low thicknesses do not suggest excessively rapid aggradation or incision, but can be interpreted in a variety of ways.

The downstream decrease in the thickness of alluvium along the Wind River could be interpreted as evidence of either down-valley aggradation or up-valley erosion during late Holocene time. Near the site, the low relief between units Qal4 to Qal2 suggests that the channel has essentially been stable during their deposition, with minor short-term periods of incision and aggradation. After deposition of unit Qal4, the Little Wind River has incised roughly 20 feet as a result of downstream shifting of its junction with the Wind River. If this unit is roughly 2,000 years old as proposed, the relative rapidity of the incision (10 feet per 1,000 years) could be interpreted in various ways. Such rapid incision seems unlikely in bedrock, even in the relatively soft Wind River Formation. Alternatively, the Little Wind River could be eroding alluvium previously deposited by either river, or its erosive power could be greater than expected.

Exposures of the alluvium near the site are not usually deep enough to show whether the deposits exhibit stratigraphic evidence of aggradation. However, local aggradation has occurred at the large sand pit roughly 0.5 mile east of the site, where two depositional units are separated by a buried soil (Figure 6.3).

6.2.4 Gaging Station Data

For a constant discharge rate and channel width, a progressive increase or decrease in water level

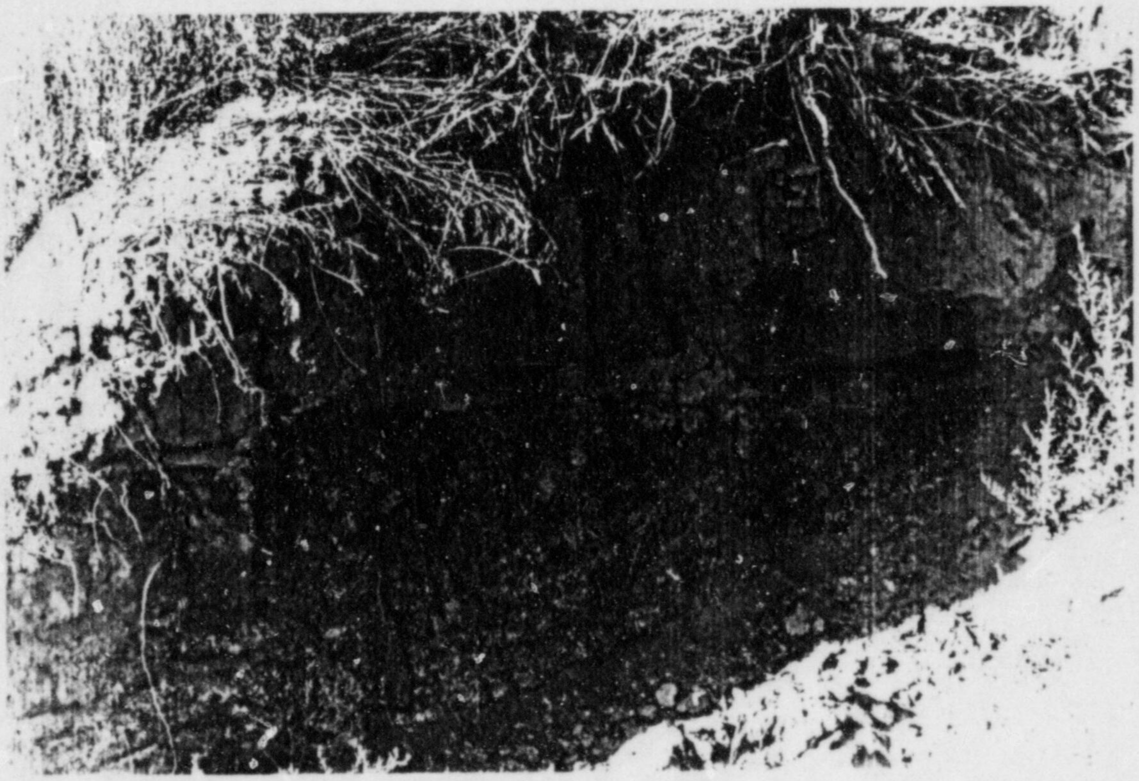

Figure 6.3 Two depositional units of Qal4 separated by a buried soil, at the large sand pit about 0.5 mile east of the tailings site.

with respect to a fixed gage indicates channel aggradation or degradation through time (Schumm and Chorley, 1983). The gage reading for the selected discharge must be estimated from a rating curve, which relates independently measured discharges (calculated from channel cross-sectional areas and water velocities) to gage readings. A new curve is computed periodically (usually at intervals of about one year) when deviations between the independently measured and predicted discharges show that changes in channel shape have made the old curve inaccurate. Through time, the sequence of rating curves indicates changes in channel shape, including both width and depth. A more detailed record of these changes could be obtained by examining the individual channel cross sections, measured at intervals of four to six weeks, but with much greater effort. For this study, data from the rating curves are judged to provide a reasonable level of resolution. The U.S. Geological Survey (1981) judges the quality of the predicted daily discharges as good during most of the year (about 95 percent of the predicted values are within 10 percent of the actual values) and poor during the winter (fewer than 95 percent of the predicted values are within 15 percent of the actual values).

Variations in the predicted gage readings are somewhat ambiguous because the readings depend on both channel depth and width. However, it is here assumed that the variations reflect primarily changes in depth. The similarity of the trends for different discharges, which are associated with different width to depth ratios, suggests that much of the variation is in depth. Furthermore, the decrease in discharge resulting from water diversion for irrigation suggests that the river should have little capacity for widening its channel. Under the decreased discharges, sediment accumulation is more likely to occur on the channel floor than on the banks. Finally, attributing the entire variation to changes in depth provides an indication of the maximum hazard to the site.

Rating curves were examined for three gaging stations (the Wind River at Riverton and Crowheart, and the Little Wind River near Riverton) and two discharge rates (300 and 1,000 cfs). These stations were selected for their relatively long records and proximity to the site. The lower discharge is near the average value for each river, whereas the larger discharge occurs annually, but is not associated with flooding (Bob Baumann, U.S. Geological Survey, Riverton, personal communication, 1984). For the Wind River at Riverton, the sequence of predicted gage heights was adjusted to compensate for a change in the elevation of the gage.

The predicted gage readings versus time for 300 cfs were plotted for the Wind River at Riverton and the Little Wind River near Riverton (Figure 6.4). Broadly similar trends were obtained for each station for 1,000 cfs.

The plot for the Wind River at Riverton displays varying channel behavior during three time intervals. Interval "a", from 1934 to 1968, exhibits long-term aggradation of about 1.7 feet (based on a visual estimate of the best-fit line) and short-term variations of about 0.1 to 0.5 feet. This aggradation is interpreted as a long-term response of the Wind River to water diversion for irrigation, which began in 1926 and increased during subsequent decades. It is consistent with recent channel changes around the large island upstream from the bridge (Figure 6.1; Section 6.2.2).

During the brief period between intervals "a" and "b", the highway bridge directly upstream from the gage was reconstructed and a levee was built to cut off part of a meander just above the bridge (Figures 5.1 and 6.1). The lower, decreasing gage readings during interval "b" are interpreted to reflect local channel erosion as a result of the artificially steepened channel gradient.

Between intervals "b" and "c", the gage was moved 220 feet downstream. Slow aggradation at the new location during interval "c" may reflect local deposition of the sediments that are being eroded from the channel floor at the previous location.

Data for the Wind River at Crowheart (summarized in Table 6.1) indicate long-term aggradation with small short-term variations, and resemble interval "a" at Riverton.

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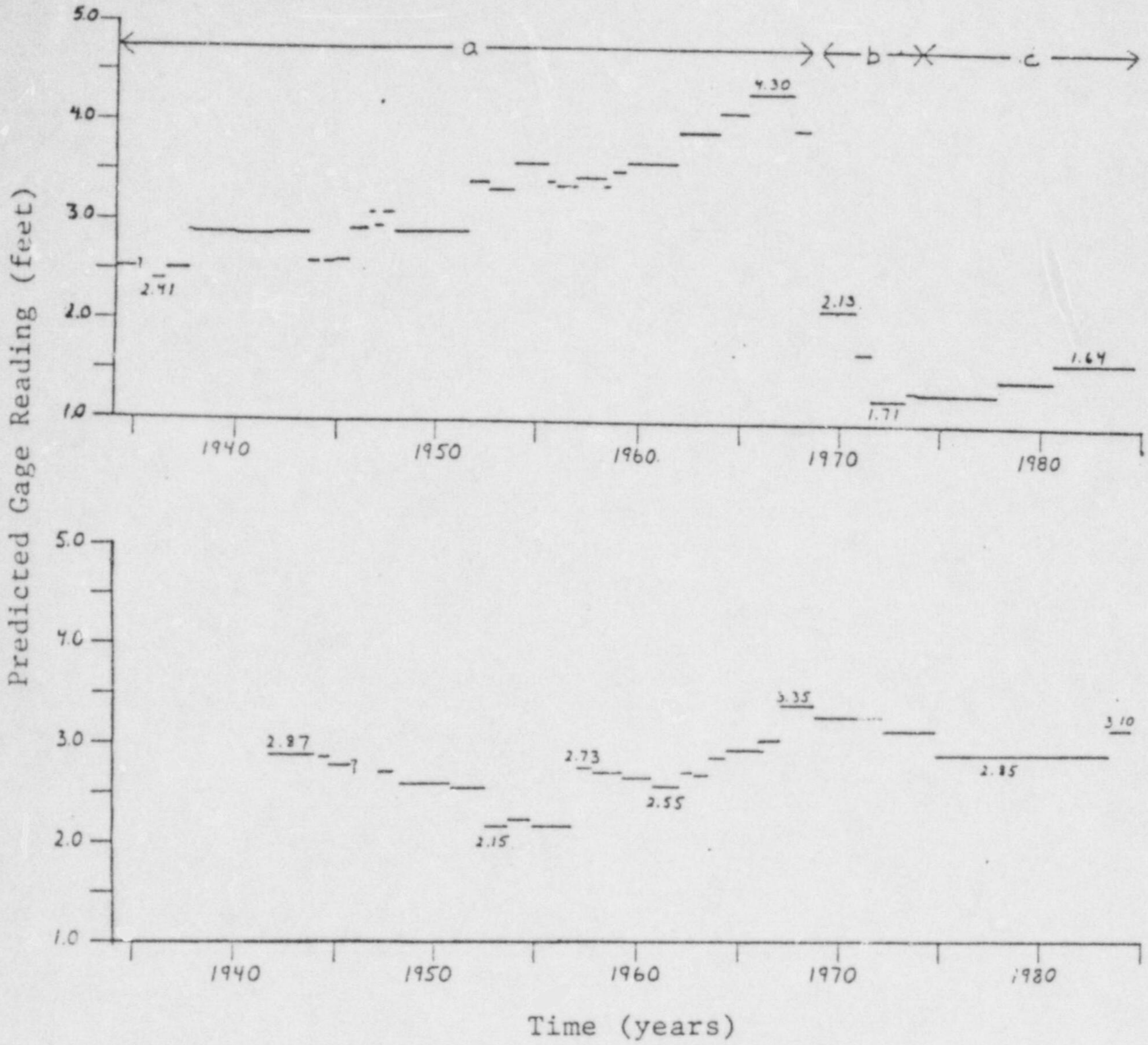


Figure 6.4 Gage reading (predicted from rating curves) versus time at a constant discharge of 300 cfs. Above, Wind River at Riverton. Below, Little Wind River near Riverton (for locations, see Figure 5.1).

TABLE 6.1 HISTORIC CHANNEL AGGRADATION AT GAGING STATIONS

Station Name, Number	Period of Record	Period Evaluated	Channel Behavior	Changes in Predicted Gage Reading Maximum minus Minimum	Visually Estimated Trend Line
Wind River at Riverton 06228000	1906-1908 (partial); 1911-present	1934-present (51 years); earler data more difficult to use	Aggrading 1934-1968	1.9' (300 cfs) 1.9' (1,000 cfs)	1.7' (300 cfs), or 5'/100 years
Wind River at Crowheart, 06225500	1945-present	1946-present (39 years)	Aggrading	1.7' (300 cfs) 1.5' (1,000 cfs)	not estimated
Little Wind River near 06235500	1941-present	1941-present (44 years)	Aggrading	1.2' (300 cfs) 1.0' (1,000 cfs)	1.2' (300 cfs) or 2.7'/100 years

The plot for the Little Wind River at Riverton displays long-term aggradation of about 1.2 feet (based on a visually estimated best-fit line). Superimposed on this trend are distinct oscillations with an amplitude of 0.5 to 0.6 feet and a period of 10 to 15 years. These oscillations probably represent the downstream shifting of sand bars.

These rates are equivalent to 5 feet per 100 years for the Wind River (interval "a") and 2.7 feet per 100 years for the Little Wind River (Table 6.1). Even if half of the variation in the predicted gage readings is attributed to changes in channel width instead of channel depth, continued aggradation at these rates could potentially affect the behavior of the Wind River in 100 to 200 years.

6.2.5 Effects of Boysen Reservoir

Where a river enters a reservoir, its flow velocity is reduced and most of the load is deposited to form a delta. This process raises the river's base level and causes channel backfilling (aggradation that progresses upstream). Examples of channel backfilling have been described at the inlets to Lake Mead on the Colorado River (Smith and others, 1960) and to Elephant Butte Reservoir on the Rio Grande (Happ, 1946). Boysen Reservoir is approximately 21 miles downstream from the Riverton site. Of critical interest to the integrity of the site is the time needed for reservoir-induced aggradation to reach the site. This depends on the sediment loads of the Wind River and other tributaries to the reservoir, the size and shape of the reservoir and of the Wind River valley, and the pattern of sediment accumulation through time. Because of the complexity of the problem, a definitive answer cannot be obtained within the scope of this study, but it appears that reservoir-induced aggradation could threaten the site in less than 1,000 years. This section discusses past sedimentation in Boysen Reservoir and future sedimentation in the reservoir and Wind River valley.

Boysen Reservoir has a length of 18 miles, an average width of 1.7 miles, and a water capacity of 819,132 acre-feet. The height of the permanent spillway is 4,725 feet, about 150 feet above the natural river channel, but the water level can temporarily be increased to 4,752 feet by raising the spillway gates. The reservoir was closed on October 11, 1951.

A preliminary review of potential reservoir sedimentation (Colby and others, 1956) was followed by a study of actual sedimentation in 1964 (U.S. Bureau of Reclamation, 1965). The following conclusions of the second study are pertinent to future sedimentation rates in the reservoir and the Wind River valley.

1. Repeat surveys of the reservoir bottom and shoreline in 1951 and 1964 showed that a few feet of aggradation had occurred along the subaerial channel of the Wind River near the shoreline, and that a small delta had formed along the submerged channel. The apex of this delta occurred near the mean reservoir elevation of approximately 4,707 feet and the average gradient of the top-set beds was about 4 feet per mile. Smaller deltas had also developed along the submerged channels of Fivemile and Muddy Creeks and thinner sediments covered the submerged channels of other creeks having lower sediment loads.

2. The volume of the sediment, excluding the effects of bank erosion, sloughing, and subsidence, was computed from the repeat surveys as 17,890 acre-feet.

3. The average particle size and specific weight of the uppermost, unconsolidated sediments were determined from 41 2-foot cores. The average particle size was 22 percent clay, 29 percent silt, 48 percent sand, and 1 percent gravel. The average weight of the samples was 80.6 pounds per cubic foot. An equation relating this initial specific weight, the average particle size distribution, and time was used to calculate an average specific weight of 83.0 pounds per cubic foot for the entire volume of sediment. With this specific weight, the volume of sediment may be converted to a weight of 32,340,469 tons or a 13-year average accumulation rate of 2,487,728 tons per year.

4. The influx of suspended sediment was computed from measurements at gaging stations, to cross-check the sediment weight estimated from the surveys and to study changes in the influx rate with time. For periods when no data on suspended sediment were collected, suspended sediment loads were estimated from the daily discharge data. The total weight of the suspended sediment from all of the tributaries was 28,983,200 tons and averaged 2,229,477 tons per year. With the average specific weight of 83 pounds per cubic foot, the total weight of suspended sediment was converted to a volume of 16,030 acre-feet. The total influx of suspended sediment is roughly 10 percent less than the actual sediment accumulation. This discrepancy was attributed to unmeasured sediment load, including bedload and suspended load carried below the maximum sampling depth at the gaging stations. The annual influx of suspended load varied by an order of magnitude from 331,428 to 4,776,790 tons per year. This range suggests that future sediment loads will be very difficult to predict. The average annual suspended load for the Wind River at Riverton was 359,317 tons per year.

5. The report estimated that about 600 years would be needed to fill the reservoir with sediment to the penstock invert elevation of 4,657 feet, located near the spillway but much lower in height. However, the assumed geometry of the sediment body and the calculation procedure are not given.

The time interval required for backfilling to reach the site depends strongly on the pattern of sediment accumulation in the reservoir and in the intervening part of the Wind River valley. The following topics are important: 1) the fraction of the reservoir capacity that must be filled with sediment in order to trigger rapid subaerial backfilling toward the site; 2) the gradient on the surface of the subaerial backfill.

With respect to the first topic, it appears that only a small fraction of the reservoir need be filled with sediment in order to initiate backfilling of the subaerial Wind River channel. Evidence discussed previously suggests that this has already begun to occur. At Elephant Butte Reservoir, aggradation of the subaerial channel began almost immediately and accelerated significantly during the first 25 years (Happ, 1946). Continued acceleration was predicted.

With respect to the second topic, Mackin (1948) states that the gradient of a mature delta should approximate the gradient of a pre-existing graded river. The meandering pattern of the Wind River suggests that it is roughly at grade, but the channel gradient decreases from about 15 feet per mile near the site, to about 4 feet per mile near the reservoir inlet (Table 5.10). If the surface of the backfill parallels the present channel, the volume of sediment needed to fill the channel as far as the site would be relatively small. In this case, the depth of aggradation at the present inlet and the fraction of the reservoir filled would also be relatively small. On the other hand, if the surface of the backfill has a lower gradient, the backfill would form a wedge thickening downstream and possibly covering the full width of the valley floor. In this case, the depth of aggradation at the present inlet would be much greater and the reservoir would be mostly or entirely filled. A very large volume of sediment and a very long time would be needed for the growing wedge of sediment to reach the site. An infinite number of intermediate accumulation patterns, with intermediate time frames, are also theoretically possible.

Considering the sensitivity of rivers to changes in base level, it appears that backfilling of the subaerial channel could reach the vicinity of the site at a time when the reservoir is partly filled with sediment, a thin wedge of sediment covers the valley floor near the present inlet, and sediment upstream from this wedge is restricted to the river channel. Some rough calculations were performed to indicate the general time range in which these conditions could occur.

The percentage of the water capacity of Boysen Reservoir that would be filled at 100-year intervals from the present was calculated from the average suspended sediment influx rate for 1952 to 1964 (2.49 x 10^6 tons per year) and an equation for specific weight (U.S. Bureau of Reclamation, 1964). This approach is greatly simplified by not modelling the actual distribution of the sediment, which may be visualized as forming several coalescing deltas. The results must be considered very rough because of several uncertainties. Annual suspended sediment influx varied by an order of magnitude between 1952 and 1964, and could deviate significantly from the period average during the time intervals considered in this calculation. Since large changes in sediment influx can accompany minor changes in climate (Schumm, 1965; Schumm and Chorley, 1983), the omission of bedload from the calculation is not considered important. As filling progresses, the rate should decrease because of continued compaction of the previously accumulated sediments, subaerial growth of the deltas, and incomplete retention of the sediment entering the reservoir (Smith and others, 1960; U.S. Bureau of Reclamation, 1965). The results (Table 6.2) suggest that roughly 40 to 70 percent of the reservoir capacity could be filled with sediment in 200 to 400 years.

The time required to fill the channel of the Wind River between the present reservoir inlet and the site was estimated as follows. The bankfull channel was modelled as having a length of 21 miles, an average depth of 10 feet, and an average width of 1,800 feet, yielding a volume of about 40,000 acre-feet or roughly 5 percent of the volume of Boysen Reservoir. The average annual suspended load at Riverton from 1952 to 1965, equalling 359,312 tons per year (U.S. Bureau of Reclamation, 1965) was arbitrarily rounded up to 365,000 tons per year to account for the additional load from un-gaged tributaries entering the river farther downstream. With an assumed unit weight of 85 pounds per cubic foot, roughly 200 years would be required to fill the channel. This time estimate may be considered a minimum because the calculation assumes that none of the load reaches the reservoir. Changes in sediment load and estimation of the specific weight and channel volume could affect the time period.

If long-term changes in average annual sediment load do not occur, these calculations suggest the following conclusions. First, aggradation caused by Boysen Reservoir is very unlikely to affect river

TABLE 6.2 PREDICTED SEDIMENTATION IN BOYSEN RESERVOIR

Elapsed Time (Years After 1984)	Average Unit Weight of Sediment (lbs/cu. ft.)	Total Weight of Accumulated Sediment (tons x 10^6)	Volume of Accumulated Sediment (ac-ft. x 10^3)	Sediment Volume as Percentage of Reservoir Capacity
0	84.2	82.2	44.8	5.5
100	86.0	331	177	21.6
200	86.7	580	307	37.5
300	87.2	829	435	53.1
400	87.5	1080	565	69.0

Note: Based on annual suspended sediment influx of 2.49 x 10^6 tons per year since 1951.

behavior near the site in less than 200 years. Second, a significant fraction of the reservoir may fill with sediment in roughly 200 to 400 years. Considering the relative sediment loads of the various tributaries to the reservoir, the probable patterns of sediment accumulation, and potential changes in sediment loads, it does appear possible that river behavior near the site could be affected in less than 1,000 years, perhaps as early as 400 to 800 years.

6.3 REACTIVATION OR CREATION OF CUT-OFF CHANNELS

Significant aggradation of the present Wind River channel could force the river to re-occupy one of its abandoned cut-off channels near the site, or to create a new one. Without detailed topographic maps having a one- or two-foot contour interval, potential flow paths toward the site cannot be identified with confidence. However, the difference in elevation between the present channels of the Wind and Little Wind Rivers indicates an unstable situation with a high potential for reactivation of old cut-off channels, or for the development of new ones. The existing cut-off channel zones near the site would probably be the preferred pathways, especially the western channel because the flow would be confined and directed by the adjacent scarp of terrace Qt1. The migration of meanders within the channel east of the site suggests that these channels can remain active for a minimum of several decades, and conceivably they could carry the entire flow of the Wind River for a much longer time.

7.0 FLOODING

Information related to potential flooding suggests that moderately large floods may be consistent with the late-Holocene geologic history of the valley floor, but that inundation of the entire floor during the PMF is not.

No flood hazard evaluation has been prepared by the U.S. Army Corps of Engineers, but the Billings office of the U.S. Bureau of Reclamation (1982, 1983) has prepared inundation maps for the Bull Lake and Pilot Butte Reservoirs. The maps address two situations: controlled passage of the PMF at each dam, and dam failure (apparently independent of the PMF). Controlled passage of the PMF at Pilot Butte Dam would not affect the site, but the site would be inundated by each of the remaining events.

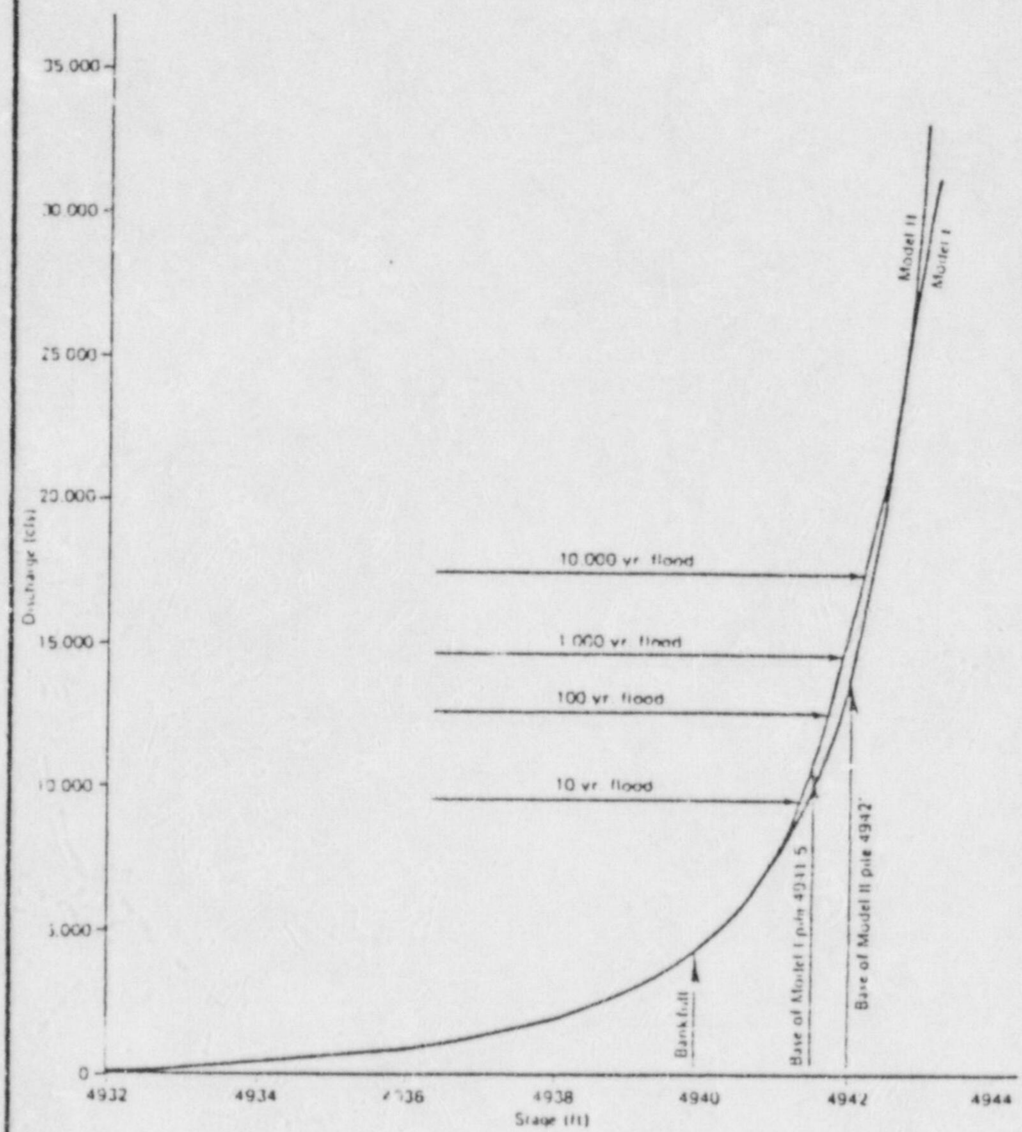
Curves showing flood level versus discharge were developed by Ford, Bacon and Davis Utah Inc. (1981) from discharge data collected by the U.S. Geological Survey. These curves (Figures 7.1 and 7.2) indicate that the Little Wind River would not reach the base of the tailings during the 1,000-year flood, but that the Wind River would approach or reach the base of the tailings during such an event. Long-term extrapolation of historic discharge records is commonly regarded as problematic (Nelson and others, 1983). However, geologic evidence does not preclude the possible occurrence of relatively large floods during the last 1,000 years as discussed below.

Nearly all of the late Holocene alluvium on the valley floor displays meander scars indicating that the uppermost gravels were not deposited under flood conditions. Where observed on unit Qal4, the stratigraphy of the uppermost gravel and sand deposits also supports this interpretation. However, one or more moderate floods could fit into the stratigraphic sequence in two ways.

First, flow along the cut-off channels from the Wind to the Little Wind River could have begun during floods. Along the cut-off channel at the southwest corner of the site, a delicate braided-channel pattern suggests shallow, rapid overbank flow (Figure 2.2). A similar pattern occurs locally at the boundary between units Qal1 and Qal2 at Riverton.

Second, large floods with flows as wide as 3,000 feet could have covered the valley north of Qal4. Any associated flood deposits could have been buried or reworked and therefore made unrecognizable after re-establishment of the normal meandering river pattern and the channel shifting that produced unit Qal3. Because the age difference between Qal4 and Qal3 is unknown, several floods could conceivably have occurred during this interval and not be detectable at the present time. Similar reasoning suggests that smaller floods could have occurred during deposition of Qal3 and Qal2.

Discharges associated with the PMF are expected to be very large and may either cover the valley floor or separate into several channels along minor depressions (Mike Bone, Jacobs Engineering Group, personal communication, 1984).



Stage-Discharge curve-North of the Riverton site on the Wind River, Wyoming.

Figure 7.1 Stage-Discharge curve - north of the Riverton site on the Wind River (Ford, Bacon and Davis Utah Inc., 1982).

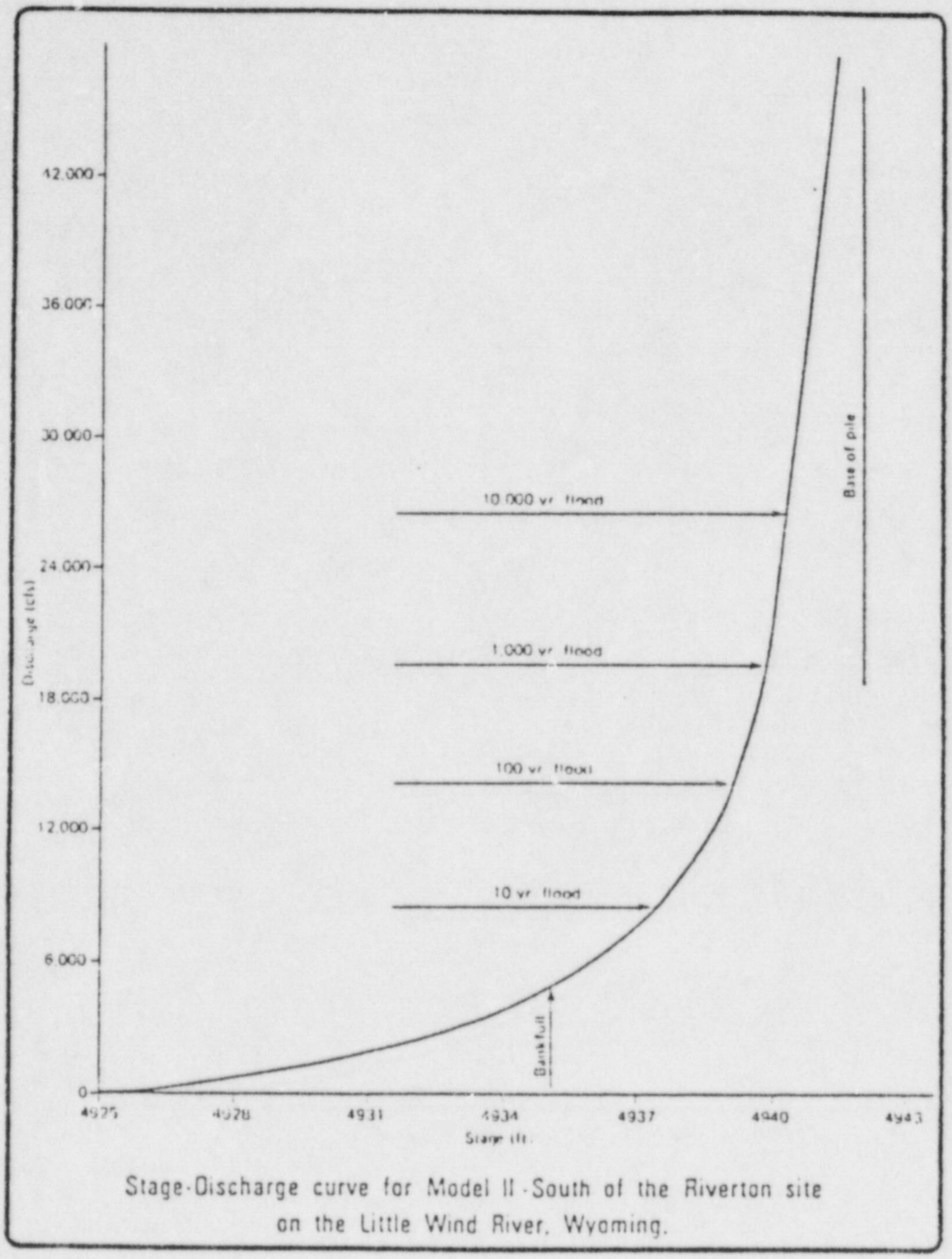


Figure 7.2 Stage-Discharge curve for Model II - South of the Riverton site on the Little Wind River (Ford, Bacon and Davis Utah Inc., 1982).

These depressions may include the present river channels, the abandoned cut-off channels near the site, and new channels that could form at any location on the valley floor. The flood channels would have a large capacity for local erosion, deposition, and lateral migration, although this behavior cannot be predicted by computer simulations of the PMF.

A PMF covering the entire valley floor would be comparable to glacial meltwater flows. Such a large flood is incompatible with the underfit character of post-glacial rivers in general and with the stratigraphy of the Wind River valley after deposition of Qal4. However, the concept of a PMF covering part of the valley floor, in a single channel or multiple channels, is consistent with the present distribution of units Qal4 and Qal3 and with the existing cut-off channels. Water from the Wind River would be likely to spill over to the Little Wind River in the vicinity of the site.

Historic floods on both rivers have been associated with high spring runoff. The hazard from ice dam flooding is more difficult to predict. Although such a flood occurred on the Little Wind River once during historic time (on February 11, 1962), the discharge of 10,300 cfs was considerably lower than the recorded historical high discharge of 14,700 cfs (on June 17, 1963). Residents state that floodwaters have occasionally come very close to the tailings, but such subjective reports are difficult to evaluate. No photographs of high water conditions in the Riverton area were located during this study.

8.0 GEOMORPHIC PROCESSES ACTING ON THE IMPOUNDMENT

8.1 EROSION BY RAINSPLASH & SURFACE RUNOFF

Any protective structure placed to isolate the tailings at the Riverton site would be exposed to erosion by rainsplash and runoff during intense summer storms.

Rainsplash erosion occurs when raindrops, often buffeted by high wind, expend their energy of impact by dislodging and moving soil grains on the surface. On sloping surfaces, the overall movement of surface grains is downslope. Walters (1983) reports that grains 0.16 inch in size (fine gravel) can be moved as much as 7.8 inches on a 10 percent slope. Ritter (1978) reports that particles up to 0.4 inch in size can be displaced into the air by rainsplash.

Surface runoff begins as sheet flow, but as the flow gathers into minor channels, the flow turbulence increases and incised rills and gullies form. The extent of gully formation and erosion is determined by the amount of runoff, slope steepness, and particle size. Sloping surfaces which are composed of sufficiently permeable, coarse-grained soils do not experience excessive sheet runoff. This lack of sheet flow eliminates or greatly reduces the formation of rills and gullies, if the particle size of the surface soils is large enough. Rainsplash erosion is also reduced or eliminated.

Several large gullies have breached the protective cover along the west edge of the site (Figure 8.1) indicating that the existing cover is not sufficiently coarse to contzol gullying. An improved choice of grain size for the aggregate cover will provide high porosities and permeabilities that will reduce or eliminate sheet runoff and gullying on the slopes.

8.2 FROST HEAVE & SOLIFLUCTION

Frost heave and solifluction are processes which pose a hazard to the long-term performance of iny structure constructed to isolate the tailings at the site. Climatic conditions at the site favor the occurrence of these processes in winter.

Frost heave is the vertical displacement of matter in response to freezing, and generally is largest during the summer-winter freezing cycle (Ritter, 1978; Lindell and Lobacz, 1980). The process requires that adequate moisture be present to form ice lenses within a fine-grained soil. Further water percolation and growth of the ice lenses causes upward expansion, displacing the surface. In the tailings impoundment, ice lenses could form in the upper part of the radon attenuation layer. This process can be mitigated by using a radon attenuation layer that is sufficiently impermeable to prevent significant water penetration and an aggregate cover that is sufniciently porous to restrict water buildup over the clay.

Solifluction is the slow flowage of saturated soils above frozen subsoils (Ritter, 1978). The saturation prerequisite for this process can also be mitigated by using premeable aggregate and impermeable radon attenuation materials.

Figure 8.1 Gully breaching gravel cover along west edge of tailings pile. Headcut is about 3 feet high. Note redeposited tailings in foreground.

8.3 WIND EROSION

The average wind speed of 14 to 15 mph in the winter and less in the summer (Young, 1974) would not pose a hazard to the site. However, gusting winds in excess of 75 mph during intense summer storms could erode the protective cover of the site.

Although silty to fine-sandy eolian deposits occur on the tops of older Pleistocene terraces and minor wind scour was observed locally, the processes and products of wind erosion are not prominent near the site. Proper selection of aggregate cover to mitigate the gullying and solifluction hazards will also mitigate this problem.

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