Nichols Ranch ISR Project U.S.N.R.C Source Material License Application

Volume V

Appendices D4-D5

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APPENDIX D4:

CLIMATOLOGY

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D4.1.0 METEOROLOGICAL DATA

D4.1.1 TEMPERATURE

Summer temperatures vary widely across the state of Wyoming, with the typical climate characterized by warm sunny days and cool nights. State record high and low temperatures are 116°F and -66°F, respectively (Curtis and Grimes 2004). The nearest meteorological station to the Nichols Ranch ISR Project area is the National Weather Service Midwest 1SW weather station, which is located approximately 27 mi southwest of the project area. Based on weather data collected at this station from 1971 to 2000, the annual average maximum temperature is 60.1°F and the annual average minimum temperature is 31.2°F (Curtis and Grimes 2004). On average, summer temperatures reach 90°F or above about 48 times per year, while winter temperatures fall to 0°F or below about 18 times per year (Martner 1986). The mean monthly temperatures for the project area are estimated from weather data collected at the Midwest 1SW weather station and summarized in Table D4-1. On average, there are 100-125 frost-free days a year in the project area, with the length of frost-free days decreasing with increasing elevation (Martner 1986).

Table D4-1 Mean Monthly Temperatures for Project Area.

Month	Daily Mean Temperature (°F)
January	23.3
February	29.1
March	34.7
April	44.7
May	55.0
June	64.6
July	72.4
August	70.5
September	60.3
October	49.5
November	34.5
December	27.1

D4.1.2 PRECIPITATION

Average monthly and annual precipitation values for data collected at the Midwest 1SW weather station for the 30-year period 1971-2000 are summarized in Table D4-2. During this 30-year period, average maximum precipitation occurs during the month of May, and average minimum precipitation occurs during the month of January (Curtis and Grimes 2004). In winter, mean annual snowfall totals are 45-53 inches (Curtis and Grimes 2004). The average number of days with snowfall totals of 1 inch or more is 16 to 26 days for the area, with the highest average monthly snowfall occurring from February to April (Martner 1986).

D4.1.3 WIND

No data are available for wind speed, wind frequency, or wind direction near the project area, and no wind measurements are available at the Midwest 1SW weather station. However,

Table D4-2 Average Precipitation Values.

Month	Inches
January	0.54
February	0.61
March	0.95
April	1.71
May	2.55
June	1.95
July	1.35
August	0.72
September	0.86
October	1.13
November	0.69
December	0.70
Annual	13.76

long-term wind data are available for the Natrona County International Airport (NCIA) located near Casper, Wyoming, approximately 60 mi south-southwest from the project area. Both the NCIA and the Nichols Ranch ISR Project area are on rolling hill country east of the Continental Divide. The NCIA weather station is slightly higher than the Nichols Ranch ISR Project area. The NCIA is located at an elevation of 5,338 ft above mean sea level (AMSL) and topography of the Hank Unit ranges from 5,055 to 5,209 ft AMSL to 4,670 to 4,900 ft AMSL in the Nichols Ranch Unit. Wind data from the NCIA weather station are reasonably representative of the climate in the general area and are consequently used as the basis for the following discussion.

D4.1.3.1 Wind Speed

In Figure D4-1, mean hourly wind speed by month for Casper from 1961-1990 reveals that the weakest winds occur in the mornings and the strongest winds occur in early to midafternoon, although the time of year for these extremes to occur is different (Curtis and Grimes 2004).

D4.1.3.2 Wind Speed Frequency

In Figure D4-2, the January wind roses for Casper from 1961-1990 are depicted and these data show prevailing (strongest) winds over from the southwest. In addition, January is generally the windiest month for this location (Curtis and Grimes 2004).

D4.1.3.3 Wind Direction

In Figure D4-3, the wind directions by hour and month for Casper (1950-1990) are shown. Although different sample averaging and periods are used, the effects of topography (mountain-valley) winds are suggested. For Casper, during the spring and summer, early evening winds are generally out of the south-southeast while, during the day, the winds are out of the south-southwest (Curtis and Grimes 2004).

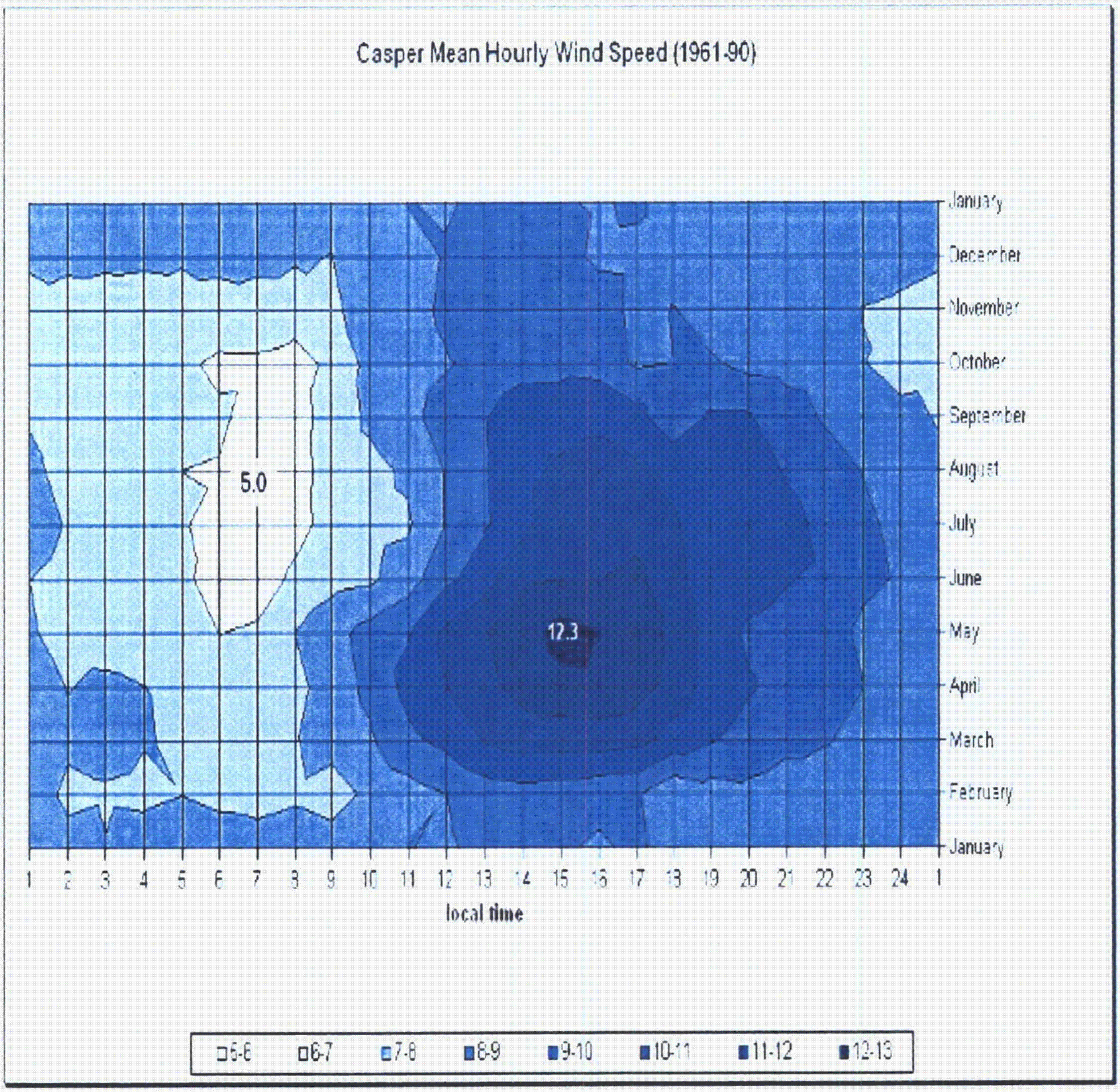

Figure D4-1 Casper Mean Hourly Wind Speed (mph) Based Upon Observations Taken Between 1961 and 1990. (Extreme Annual Values Are Depicted.)

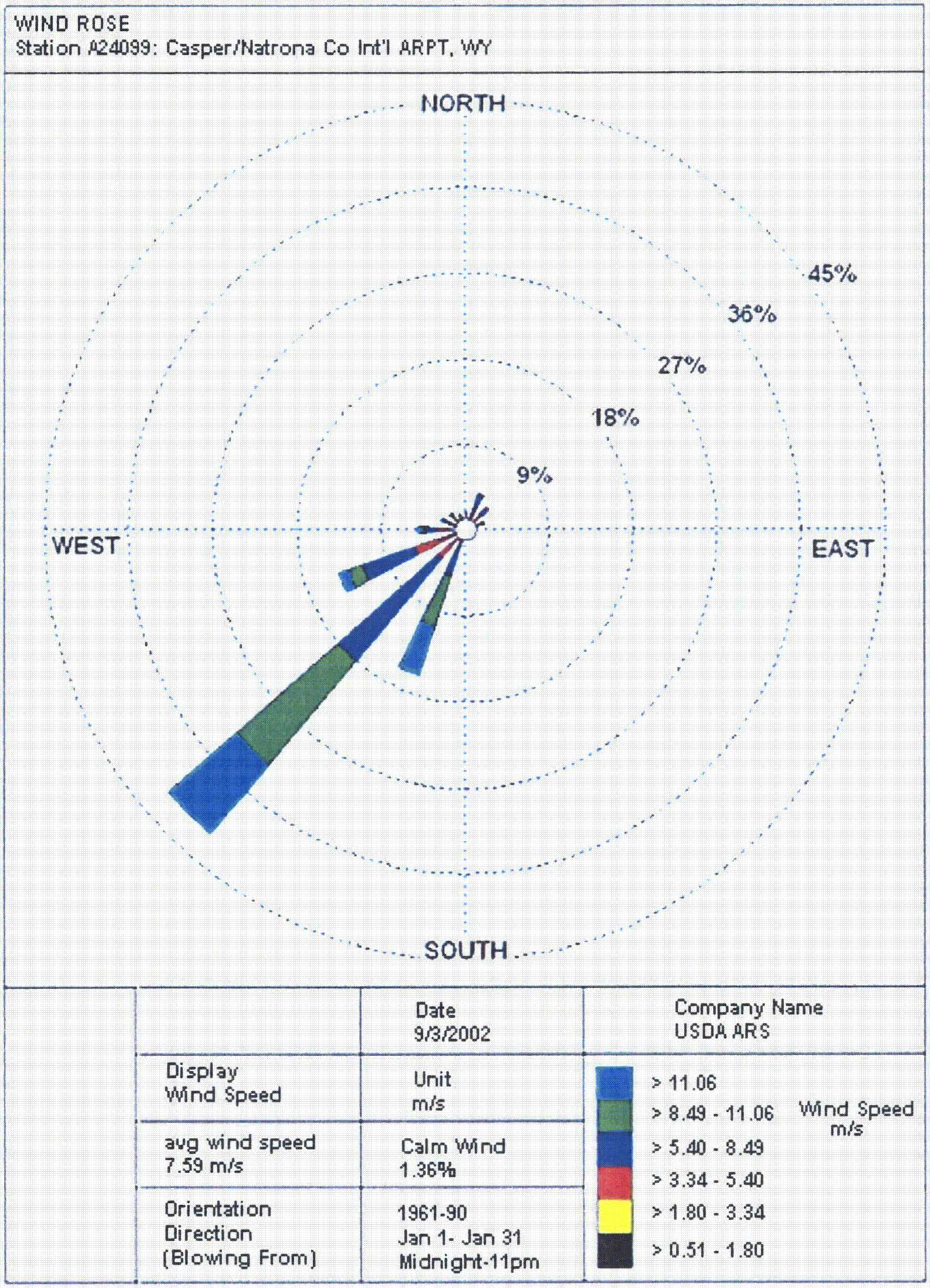

Figure D4-2 Casper January Wind Rose Based Upon Observations Taken Between 1961 and 1990. (Speeds Are Measured in m/sec. Double the Values to Approximate mph.)

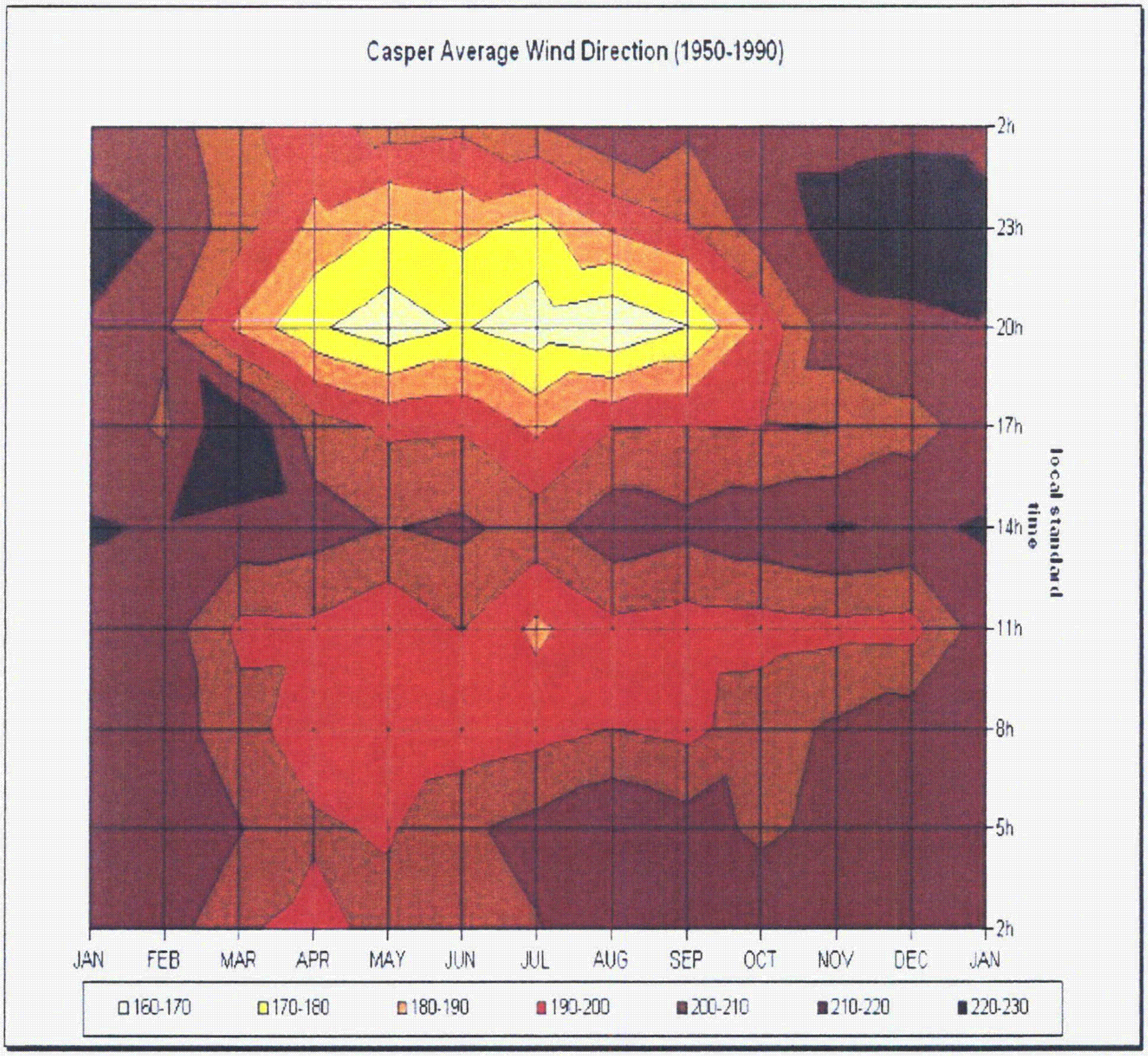

Figure D4-3 3-Hour Average Wind Direction by Month for Casper (1950-1990).

D4.1.3.4 Wind Direction Frequency

In Figure D4-4, the wind direction frequency by month for NCIA from 1961-1990 shows the maximum frequency is 230 degs and the maximum frequencies occur in December (Curtis and Grimes 2004).

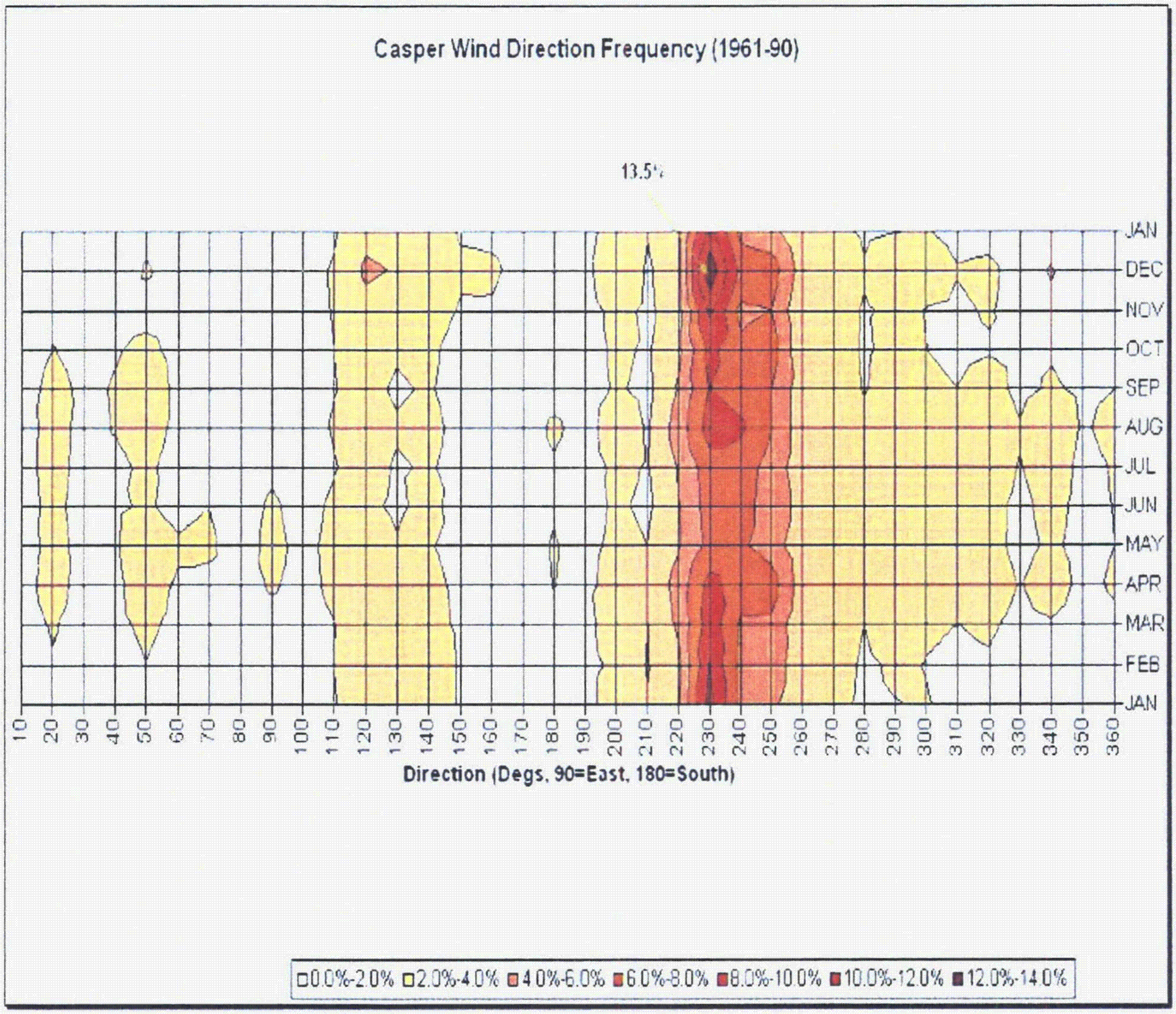

Figure D4-4 Casper Wind Direction Frequency Based Upon Hourly Observations Taken Between 1961 and 1990. The Maximum Annual Frequency Is Depicted.

D4.1.4 LAKE EVAPORATION AND EVAPOTRANSPIRATION

Average annual lake evaporation for the project area is estimated to be 45 inches, and annual potential evapotranspiration is estimated to be 23 to 24 inches (Martner 1986).

D4.2.0 AIR QUALITY PERMIT

4.2.1 GENERAL

There are no known air quality permits required for the Nichols Ranch ISR Project area, and there are no known air quality permits near the project area. A meeting between Uranerz Energy Corporation and the Wyoming Department of Land Quality-Air Quality Division (WDEQ-AQD) was held to discuss the potential air quality permits that may be required for the Nichols Ranch ISR Project. After discussing the Nichols Ranch ISR Project, Uranerz Energy Corporation agreed to submit an emission inventory to the WDEQ-AQD in order to establish if any air quality permits are needed. Because of the minimal amount of emissions produced by the plant operations and the minimal surface disturbance and vehicular traffic associated with the operation, Uranerz Energy Corporation believes that no air quality permits will be required. If any air quality permits are required by the WDEQ-AQD, then these permits will be obtained prior to beginning any construction activities for the Nichols Ranch ISR Project.

4.2.2 IMPACTS

Impacts on air quality associated with the operations of the Nichols Ranch ISR Project will be very minimal. Access to the project area will be via 8.5 mi of Campbell County maintained gravel road, 8.5 mi of gravel ranch roads if accessing the project area from Wyoming Highway 50, or approximately 22.3 mi of gravel ranch roads if accessing the property from U.S. Highway 387. Both the county and ranch roads are currently used by numerous oil/gas and coal bed methane companies that are active in the region. These roads have been developed and range from 18- to 24-ft wide crowned-and-ditch roads. The closest residence to the access route is the Pfister Ranch located approximately less than a 0.25 mi west of the route and approximately 0.6 mi north of the Hank Unit. With the prevailing wind direction out of the southwest, dust produced by the mining operations and vehicular traffic will generally be blown to the northeast, which should not affect ranching operations.

Particulate emissions associated with the Nichols Ranch ISR Project will also be minimal. Of the 3,370.53 acres within the project area, approximately 300 acres or less of lands will be disturbed with stripping of topsoil occurring on approximately 100 acres or less. In order to reduce particulate emissions in the well field by drilling equipment and well field maintenance vehicles, access roads will be maintained by motorized patrol. Natural vegetation will also be left undisturbed whenever possible to prevent wind erosion.

Vehicle traffic entering the Nichols Ranch ISR Project is estimated at eight passenger vehicles per day per week along with six tractor trailers per week. Fugitive dust emissions from this traffic are estimated at approximately 135.9 tons per year using the longer of the two access routes as a basis for the fugitive dust calculations. Well field fugitive dust emissions were not considered in calculating the overall fugitive dust emissions since the well field is not considered a major source of emissions. Estimated fugitive dust emissions during construction of the facilities of the Nichols Ranch ISR Project were also not included in the fugitive dust emission calculation since the amount of vehicular activity that will be taking place during the construction will be similar to the traffic of the actual operation. Figure D4-5 outlines the methods used to calculate the fugitive dust emissions.

Assumptions:

1. For the purpose of calculating fugitive dust emissions, the well field was not considered a significant emitting source.

2. Estimated daily vehicle traffic includes eight passenger/truck vehicles entering the Nichols Ranch ISR Project. Approximately six tractor trailers will also travel to the permit area per week.

3. Estimated disturbance within the 3370.53 acre Nichols Ranch ISR Project permit area is 300 acres or less.

4. All fugitive dust calculations were based on EPA AP-42 Chapter 13.2.2.

5. Calculation Data Givens:
   Wyoming Unpaved Road Surface Material Surface Silt Content = 4.2% (Source AP-42)
   Access road vehicle speed = 30 mph
   Access road length = 15 mi

Calculations:

Access Road Vehicle Miles per Day

$$\frac{8\ vehicles}{day} \times 15\ miles = \frac{120\ \ miles}{day}$$

$$\frac{0.86\ semi's}{day} \times 15\ miles = \frac{12.9\ miles}{day}$$

Vehicle Miles per Year

$$Passenger\ \ Vehicles \Rightarrow \frac{120\ miles}{day} \times \frac{7\ days}{week} \times \frac{52\ weeks}{year} = \frac{43{,}680\ miles}{year}$$

$$Semi's \Rightarrow \frac{12.9\ miles}{day} \times \frac{7\ days}{week} \times \frac{52\ weeks}{year} = \frac{4{,}695.6\ miles}{year}$$

Figure D4-5 Fugitive Dust Calculations (1 of 3).

Emissions for Unpaved Roads

$$E = \frac{\left[k \left(\frac{s}{12} \right)^{a} \left(\frac{S}{30} \right)^{b} \right]}{\left(\frac{M}{0.5} \right)^{c}} - C$$

Where:

E = size specific emission factor (lbs/vehicle mile traveled)
s = surface material silt content (%) from AP 42 Tables
W = mean vehicle weight (tons)
M = surface material moisture content (%)
S = mean vehicle speed (mph)
C = emission factor from AP 42 Tables

For PM-10:

k, a, b, and c are constants derived from AP 42 13.2.2
k = 1.5
a = 0.9
b = 0.45
c = N/A or 1

Correcting For Natural Mitigation:

$$E = \left[\frac{\left[k \left(\frac{s}{12} \right)^{a} \left(\frac{S}{30} \right)^{b} \right]}{\left(\frac{M}{0.5} \right)^{c}} - C \right] \left[\frac{(365 - P)}{365} \right]$$

Where: P = number of days in a year with at least 0.01 inches of precipitation from AP 42 charts

Figure D4-5 Fugitive Dust Calculations (2 of 3).

Therefore, using the following inputs:

s = 4.2
a = 0.9
b = 0.45
c = 1
S = 30 mph
M = 0.5
C = 0.0047
P = 100

E = 0.420 lbs/vehicle miles traveled
Total Fugitive Dust Emissions

Total Vehicle Miles Traveled Per Year = 47,375.6 mi per vehicle

9 vehicles total, so

$$\left(9 \text{ vehicles}\right) \times \left(47375.6 \text{ miles per year}\right) \times \left(0.42 \text{ lbs per VMT}\right) = 179{,}079.8 \text{ lbs per year or } 89.5 \text{ tons per year}$$

This is below the 250 tons per year standard established for PSD.

From the above calculations, it is estimated that an emission rate of 135.9 tons per year can be expected for the Nichols Ranch ISR Project. As this is below the 250 tons per year threshold for PSD review, an analysis to determine air quality impact is considered unnecessary.

All other emissions from the Nichols Ranch ISR Project are minimal. Table D4-3 details the other potential operation emissions and their potential emission quantity.

Figure D4-5 Fugitive Dust Calculations (3 of 3).

Table D4-3 Emissions Inventory.

Emission	Estimated Emission (tons/yr)
CO_2	353.70
HCL	0.017
H_2O_2	0.003
NaOH	0.0003
Fugitive Dust	135.9

D4.3.0 REFERENCES

Curtis, Jan, and Kate Grimes. 2004. Wyoming Climate Atlas. Office of the Wyoming State Climatologists, Laramie, Wyoming. <http://www.wrds.uwyo.edu/wrds/wsc/climate atlas>. Accessed September 2007.

Martner, Brooks E. 1986. Wyoming Climate Atlas. University of Nebraska Press, Lincoln, Nebraska.

APPENDIX D5:

GEOLOGY

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D5.1.0 GEOLOGY

D5.1 REGIONAL GEOLOGY

The Nichols Ranch ISR Project area is located in the Powder River Basin (PRB) which is a large structural and topographic depression parallel to the Rocky Mountain trend. The basin is bounded on the south by the Hartville Uplift and the Laramie Range, on the east by the Black Hills, and the Big Horn Mountains and the Casper Arch on the west. The Miles City Arch in southeastern Montana forms the northern boundary of the basin.

The PRB is an asymmetrical syncline with its axis closely paralleling the western basin margin. During sedimentary deposition, the structural axis (the line of greatest material accumulation) shifted westward resulting in the basin's asymmetrical shape. On the eastern flank of the PRB, sedimentary rock strata dip gently to the west at approximately 0.5 to 3 degrees. On the western flank, the strata dip more steeply, 0.5 to 15 degrees to the east with the dip increasing as distance increases westward from the axis. The Nichols Ranch ISR Project site location within the PRB is shown in Figure D5-1 (see map pocket).

The PRB hosts a sedimentary rock sequence that has a maximum thickness of about 15,000 ft along the synclinal axis. The sediments range in age from Recent (Holocene) to early Paleozoic (Cambrian - 500 million to 600 million years ago) and overlie a basement complex of Precambrian-age (more than a billion years old) igneous and metamorphic rocks. Geologically, the PRB is a closed depression in what was, for a long geologic time period, a large basin extending from the Arctic to the Gulf of Mexico. During Paleozoic and Mesozoic time, the configuration of this expansive basin changed as the result of uplift on its margins. By late Tertiary - Paleocene time, marked uplift of inland masses surrounding the Powder River Basin resulted in accelerated subsidence in the southern portion of the basin with thick sequences of arkosic (containing feldspar) sediments being deposited. Arkosic sediments were derived from the granitic cores of the Laramie and Granite Mountains exposed to weathering and erosion by the Laramide uplift. Near the end of Eocene time, northward tilting and deep weathering with minor erosion took place in the basin. Subsidence resumed in the late

Oligocene and continued through the Miocene and into the Pliocene. A great thickness of tuffaceous sediments were deposited in the basin during at least a part of this period of subsidence. By the late Pliocene, regional uplift was taking place, leading to a general rise in elevation of several thousand feet. The massive erosional pattern that characterizes much of the PRB began with the Pliocene uplift and continues to the present. Of particular interest in the project area are the Tertiary-age formations:

Formation	Age (Million Years)
White River (Oligocene)	25-40
Wasatch (Eocene)	40-60
Fort Union (Paleocene)	60-70

The White River Formation is the youngest Tertiary unit that still exists in the PRB. Locally, it's only known remnants are found on top of the Pumpkin Buttes. Elsewhere the unit consists of thick sequences of buff colored tuffaceous sediments interspersed with lenses of fine sand and siltstone. A basal conglomerate forms the resistant cap rock on top of the buttes. This formation is not known to contain significant uranium resources in this area.

The Wasatch Formation is the next unit down and consists of interbedded mudstones, carbonaceous shales, silty sandstones, and relatively clean sandstones. In the vicinity of the Pumpkin Buttes, the Wasatch Formation is known to be 1,575 ft thick (Sharp and Gibbons, 1964). The interbedded mudstones, siltstones, and relatively clean sandstones in the Wasatch vary in degree of lithification from uncemented to moderately well-cemented sandstones, and from weakly compacted and cemented mudstones to fissile shales. The Wasatch contains significant uranium resources and hosts the ore bodies for which this permit application is subject to.

The next unit is the Fort Union Formation. In the PRB this unit is lithologically similar to the Wasatch Formation. The Fort Union includes interbedded silty claystones, sandy siltstones, relatively clean sandstones, claystones, and coal. The degree of lithification is quite variable, ranging from virtually uncemented sands to moderately well-cemented siltstones and sandstones.

The total thickness of the Fort Union in this area is approximately 3,000 ft. The Fort Union contains significant uranium mineralization at various locations in the basin. The Fort Union is also the target formation for Coal Bed Methane (CBM) extraction activities. CBM target depths in the Nichols Ranch Unit are about 1,000 and 1,200 ft at the Hank Unit. A minimum of 300 ft of primarily mudstones and impermeable shales interspersed with fine and medium grained sands and siltstones separate the proposed uranium mining from CBM production horizons at both the Nichols Ranch and Hank Units. Since CBM wells have their casings cemented to the surface, no or little interference, water loss, or water invasion is anticipated other than for localized areas. Appendix D6 further discusses CBM.

D5.2 SITE GEOLOGY

The Nichols Ranch ISR Project is located in the Eocene Wasatch Formation about eight miles west of the South Pumpkin Butte and straddles the Johnson and Campbell County lines. The mineralized sand horizons are in the lower part of the Wasatch, at an approximate average depth of 550 ft. The host sands are primarily arkosic in composition, friable, and contain trace amounts of carbonaceous material and organic debris. There are locally sandy mudstone/siltstone intervals within the sands and the sands may thicken or thin to the point of removal in areas remote to the permitted area.

The Hank Unit satellite solution mining site is also located in the Eocene Wasatch Formation approximately six miles east-northeast of the Nichols Ranch Unit central processing plant in Campbell County. The mineralized sand horizons are in the lower part of the Wasatch, at an approximate average depth of 365 ft. The host sands are similar in composition and material make-up to those found at the Nichols Ranch Unit.

The ore bodies at the Nichols Ranch and Hank Units are typical Powder River Basin roll front deposits. Uranium ore, where present, is found at the interface of a naturally occurring chemical boundary between reduced sandstone facies and oxidized sandstone facies. The ore body at the Nichols Ranch Unit forms two lateral sides, an east side and west side. The two sides come together at a point to the north called the nose. The interior area formed by the sides and nose is the chemically oxidized sandstone facies and the exterior of the area is the reduced sandstone facies. At the Hank Unit the reduced sandstone facies is to the east and oxidized facies to the west.

Due to the complex nature of fluvial sandstone deposition in the Wasatch formation, the uranium ore bearing sandstone at both the Nichols Ranch and Hank Units are composed of at least two vertically stacked subsidiary roll fronts. The roll fronts have been designated the upper and lower fronts at each of the two properties. Stacked roll fronts develop due to small differences in sandstone permeability or the occasional vertical contact between sand members. The lateral distance between stacked rolls range from 0 to over 200 ft and may result in complex overlapping patterns.

The Nichols Ranch Unit and Hank Unit ore bodies have uranium mineralization composed of amorphous uranium oxide, sooty pitchblende, and coffinite. The uranium is deposited upon individual detrital sand grains and within minor authigenic clays in the void spaces. The host sandstones are composed of quartz, feldspar, accessory biotite and muscovite mica, and locally occurring carbon fragments. Grain size ranges from very fine-grained sand to conglomerate. The sandstones are weakly to moderately cemented and friable. Pyrite and calcite are associated with the sands in the reduced facies. Hematite or limonite stain from pyrite, are common oxidation products in the oxidized facies. Montmorillonite and kaolinite clays from oxidized feldspars are also present in the oxidized facies.

There are four notable Wasatch Formation sand units in the Nichols Ranch Unit mining area. The sand members have been identified as F, B, A, and the 1 (one) sand unit. The F Sand unit is the shallowest and the 1 sand unit is the deepest. The principle uranium ore bearing sand unit is the A Sand. The B Sand has been designated the overlaying aquifer and the 1 sand the underlying aquifer.

There are six notable Wasatch Formation sand units at the Hank Unit area. The sand units have been identified as the H, G, F, C, B, and A Sands. The H Sand unit is the shallowest and the A Sand unit is the deepest. The principle uranium ore bearing sand member at the Hank Unit is the

F. The G Sand has been designated the overlaying aquifer and the C or B Sand the underlying aquifer.

Both the Nichols Ranch Unit A Sand ore body and the Hank Unit F Sand ore body are bounded above and below by impermeable aquitardes. The upper and lower aquitardes are composed of shales or mudstones, silty shales and shaley (poor) coal horizons. Measured permeability of the mudstones and shales has been found to be less than 0.1 millidarcies whereas the permeability of the ore sands average between 250 and 2,000 millidarcies.

Site geology and stratigraphy are summarized in cross section Exhibits D5-1 and D5-2 for the Nichols Ranch Unit and Exhibits D5-3 and D5-4 for the Hank Unit. These cross sections each run north/south and east/west through their respective ore bodies. Exhibit D5-5 shows an electric cross section running from the Nichols Ranch Unit to the Hank Unit, a distance of approximately six miles. This cross section provides for correlation of the sand units, aquitardes, and the nomenclatures utilized for each in the project areas. It also illustrates the gentle 0.5 to 1.0° westward dip of the Wasatch formation. Figure D5-2 (see map pocket) details a typical stratigraphic column for the Nichols Ranch ISR Project.

Description of the Nichols Ranch Unit and Hank Unit aquifers and aquitards are as follows:

Beginning with the lower monitor aquifer sand at the Nichols Ranch Unit, this unit has been designated the 1 (one) Sand. This sand is variable ranging from 10 to 85 ft in thickness and occurs at depths of 560 to 710 ft below the ground surface. The sand is very fine to coarse grained and is gray in color throughout the Nichols Ranch Unit area. Available drill holes in the Hank Unit area have not been drilled deep enough to encounter this sand if it exists at that location.

The next unit up section is the Nichols Ranch Unit lower mining zone aquitard. It consists of dark and medium gray mudstones and carbonaceous shale with occasional thin lenses of poorly developed coal. This unit ranges in thickness from 20 to 35 ft thick.

The A Sand is the next unit up section. This is the mining zone sand at the Nichols Ranch Unit. With in the Nichols Ranch Unit boundary the unit has a thickness between 55 and 110 ft. The A Sand is thickest to the northeast and thins to the southwest. The A Sand is fine to coarse grained and is gray or red in color depending on location relative to the ore body as discussed above. The body of the A Sand is occasionally separated by lenses of mudstone and siltstone which rarely exceed 15 ft in thickness. The lenses are generally 50 to 100 ft wide and may extend for a few hundred feet in a north/south direction. The lenses are not expected to present any problem to mining or restoration. The A Sand is extensive and has been correlated across the gap between the Nichols Ranch and Hank Units. The A Sand at the Hank Unit occurs at a depth of 725 ft. It is over 300 ft below section from the F Sand ore mining zone at this location.

The next up section unit is the Nichols Ranch Unit A Sand upper aquitard. It varies from 25 to 90 ft thick, thickening to the northwest and thinning to the southeast. This unit consists of gray mudstones and thin discontinuous light gray siltstones. In the Hank Unit area this unit is at least 80 ft thick and is composed mainly of mudstones.

The next higher unit at the Nichols Ranch Unit is the B Sand upper monitor aquifer. The B Sand ranges in thickness from 100 to 160 ft. The B Sand is fine to coarse grained and red or oxidized with in the permit boundary. Elsewhere in the Pumpkin Buttes area the B Sand is host to some large known ore bodies including those at Christensen Ranch and North Butte. The body of the B Sand is occasionally separated by lenses of mudstone, siltstone and carbonaceous shale. Some of these mudstone splits exceed 25 ft in thickness and may extend for thousands of feet. The B Sand is very extensive and has been correlated at one horizon or another across the gap between the Nichols Ranch and Hank Units. The B Sand at the Hank Unit occurs at a depth of 500 to 545 ft and is 90 to 130 ft thick. In some locations at the Hank Unit the B Sand is the lower monitor aquifer where the C Sand is absent.

The next up section unit at the Nichols Ranch Unit is the upper B Sand aquitard. It varies in thickness from 40 to 150 ft depending on presence of the C Sand. This interval is characterized by dark and medium gray mudstones, discontinuous thin siltstones or fine grain gray sandstones and carbonaceous shales. At the Hank Unit, the upper B Sand aquitard is 70 to 110 ft thick depending on the presence of the C Sand. The unit at this location is mainly composed of gray mudstones.

The next unit at the Nichols Ranch Unit is the C Sand. This sand is discontinuous over most of the Unit area. There present, it has developed a thickness of 20 ft of mostly fine and very fine grained gray sand. This unit can not be tracked for large distances. Elsewhere in the Pumpkin Butte area the C Sand is closely associated with the B Sand. At the Hank Unit, the C Sand is the lower monitor aquifer sand where present. At this location, the sand is 5 to 20 ft thick, discontinuous, and is composed of fine and very fine grained gray sand. The B Sand substitutes as the lower monitor aquifer sand where the C Sand is absent.

The next unit up section at the Nichols Ranch Unit is the lower F Sand aquitard. This unit is composed of gray mudstones, siltstones, dark gray carbonaceous shales, and poor developed coal. It ranges in thickness from 45 to 110 ft depending on the presence of the C Sand. At the Hank Unit, this aquitard is nearly identical to the one at Nichols Ranch Unit but ranges from 30 to 110 ft thick depending on the presence of the C Sand.

The F Sand is the next unit up section. At the Nichols Ranch Unit this unit is the shallow monitor zone sand. This sand is medium and fine grained, red or gray and is 15 to 50 ft thick. This unit splits into as many as three separate sands at Nichols Ranch but then to the north, the lower sand pinches out. In the Pumpkin Buttes area, this sand is host to numerous occurrences of uranium mineralization including the production mining sand at the Hank Unit. At the Hank Unit the sand is fairly uniform at 75 to 85 ft thick and is composed of fine to coarse grained sand, which is gray or red depending on the location within the geochemical front. The F Sand mineralization occurs in two stacked roll fronts, the upper front and lower front. Depending on location at the Hank Unit, the two fronts may cross over each other or be separated laterally by several hundred feet.

The next up section unit is the Nichols Ranch Unit upper F Sand aquitard. It varies in thickness from 20 to 75 ft thick where the lower G Sand is present and up to 185 ft thick where only the upper G Sand is present. This unit consists of gray mudstones, dark gray to black carbonaceous shales and thin discontinuous light gray siltstones. At the Hank Unit this unit is 30 to 55 ft thick and is composed mainly of gray mudstones. This unit is the upper confining layer for the Hank Unit F Sand production horizon.

The next higher unit at the Nichols Ranch Unit is the G Sand aquifer. The G Sand is highly variable, discontinuous and lenticular. It is composed of fine to coarse grained red and gray sands that are up to 75 ft thick. This sand is discontinuous over the Nichols Ranch Unit area with the entire G Sand sequence ranging in thickness from 20 to 130 ft. The G Sand tops out at the surface at the Nichols Ranch Unit. The G Sand at the Hank Unit is the upper monitor aquifer. The G Sand is comprised of up to three individual sand units that are fine- to very fine-grained and red or gray in color and 10 to 25 ft thick. The entire G Sand sequence is up to 75 ft thick with inter-sand zones comprised of gray mudstone. Else where in the Pumpkin Buttes area the G Sand and F are closely related.

The next higher unit at the Nichols Ranch Unit is the upper G Sand aquitard. It is about 20 ft thick. This interval is characterized by brown mudstones. This unit tops out to the surface in the northern part of the Nichols Ranch Unit where the H Sand is absent. At the Hank Unit, the upper G Sand aquitard is 30 to 125 ft thick and composed of gray mudstones and thin siltstones.

The upper most unit at the Nichols Ranch Unit is the H Sand. This sand has a thickness of at least 20 ft and is composed mostly of fine to medium grained brown sand. This unit tops out at the surface in the northern part of the Nichols Ranch Unit. At the Hank Unit, the H Sand is the shallow monitor aquifer sand. At this location, the H Sand sequence is 50 to 170 ft thick, highly variable with numerous pinch-outs and composed of up to four individual sands. The H Sand is fine- to coarse grained and brown, red or gray in color. This unit is known to contain minor occurrences of uranium mineralization and is closely related to the G Sand..

The next unit up section at the Hank Unit is the upper H Sand aquitard. This unit is composed of brown mudstones and ranges in thickness from 25 to 90 ft. The unit tops out at the surface over a portion of the Hank Unit.

The final surface unit at the Hank Unit is the J Sand sequence. It is composed of at least two thin sands separated by mudstones and ranging in thickness from 10 to 30 ft thick. The sands are brown and occur only in the lower slopes of the middle Pumpkin Buttes. Else where in the mining district the J Sand is thicker but is largely an erosion remnant in the immediate area.

D5.3 ABANDONED DRILL HOLES

Section D6.5 of Appendix D6-Hydrology discusses all known abandoned exploration drill holes located in the area of the Nichols Ranch ISR Project.

D5.4 SEISMOLOGY

The area of central Wyoming where the Nichols Ranch Unit and Hank Unit sites are located lies in a relatively minor seismic region of the United States. Although distant earthquakes (such as the western Wyoming area) may produce shocks strong enough to be felt in the Powder River Basin, the region is ranked as a one (1) seismic risk as shown in Figure D5-3 (see map pocket). Few earthquakes capable of producing damage have originated in this region.

The seismically active region closest to the site is the Intermountain Seismic Belt of the Western United States, which extends in a northerly direction between Arizona and British Columbia. It is characterized by shallow earthquake foci between 10 and 25 mi in depth, and normal faulting. Part of this seismic belt extends along the Wyoming-Idaho border, more than 350 km (approximately 200 mi) west of the project area. More detailed information can be found in the report "Basic Seismological Characterization for Campbell County and Basic Seismological Characterization for Johnson County, Wyoming" by the Wyoming State Geological Survey, which is contained in Addendums D5A and D5B.

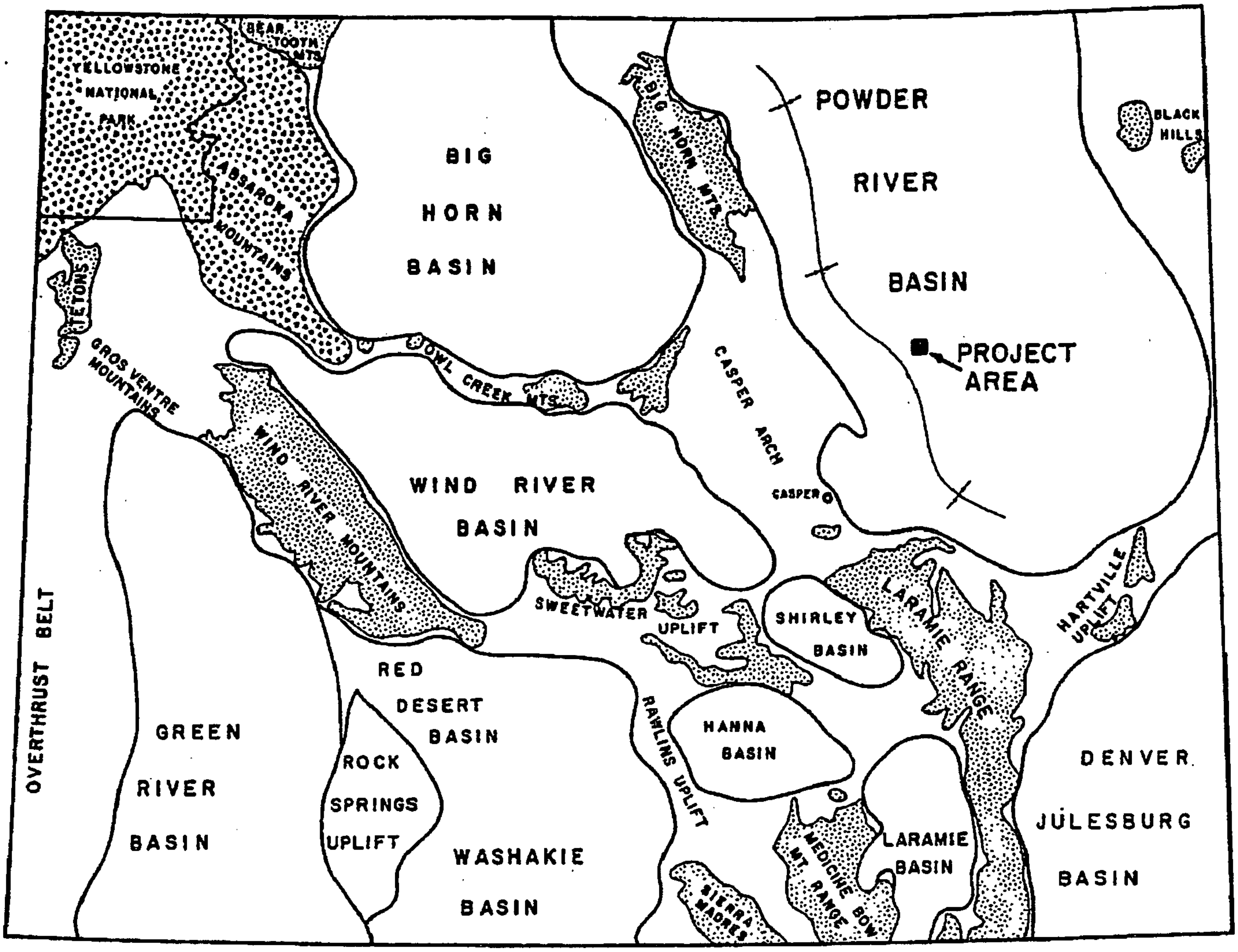
Table D5-1 lists the largest recorded earthquakes (greater than 4.0 magnitude on the Richter Scale) that have occurred within 200 km (120 mi) of the Nichols Ranch ISR Project site and gives the maximum ground acceleration that could be realized at the site as a result of these disturbances from the period 1873 through 2006 (Sources – Wyoming State Geological Survey, 2002 and

Table D5-1 Maximum Expected Earthquakes Intensities and Ground Accelerations at the Nichols Ranch ISR Project Site.

Earthquake Location and Year	Epicenter Intensity (Mercalli)	Magnitude (Richter)	Distance From Nichols Ranch ISR Project	Ground Accelerations at Nichols Ranch ISR Project
Casper (1894)	V	4.5	65	0.01g
Casper (1897)	VI-VII	5.7	64	0.04g
Kaycee (1965)	V	4.7	30	0.02g
Pine Tree Jct. (1967)	V	4.8	10	0.04g
West of Gillette (1976)	IV-V	4.3	38	0.02g
SW of Gillette (1976)	V	4.8	18	0.03g
Bar Nunn (1978)	V	4.6	56	0.01g
West of Kaycee (1983)	V	4.8	65	0.01g
West of Gillette (1984)	V	5.1	30	0.03g
West of Gillette (1984)	V	5	28	0.03g
Laramie Mtns (1984)	VI	5.5	95	0.01g
Mayoworth (1992)	V-VI	5.2	52	0.02g
W Convers Co. (1996)	IV-V	4.2	54	0.01g

USGS, 2007). The earthquake of highest intensity recorded during that time interval was the Casper, Wyoming earthquake of 1897. This earthquake has been assigned a probable maximum Mercalli shaking intensity of VI -VII (5.7 on the Richter scale) based on accounts of damage incurred.

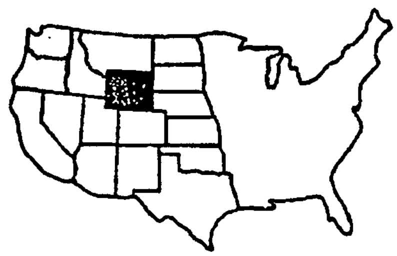
No surface faulting or fault traces in the project area has been reported, nor is any faulting evident from geophysical log interpretations. Based on historic data, the ground accelerations reported in Table D5-1 (.01g to .04g) are not considered to be of a magnitude that would disturb the operations or facilities in the event that an earthquake occurred.



PRECAMBRIAN ROCK

TERTIARY VOLCANICS

SYNCLINAL AXIS



SCALE: 1"=50 MILES

0 50 MILES 100 MILES

Uranerz
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NICHOLS RANCH ISR PROJECT

FIGURE D5-1
STRUCTURAL MAP
OF WYOMING

By: S.M.F.	Date: OCT. 11, 2007
Datum: N/A	Revision Date:
Scale: 1"=50 MILES	Contour Interval: N/A

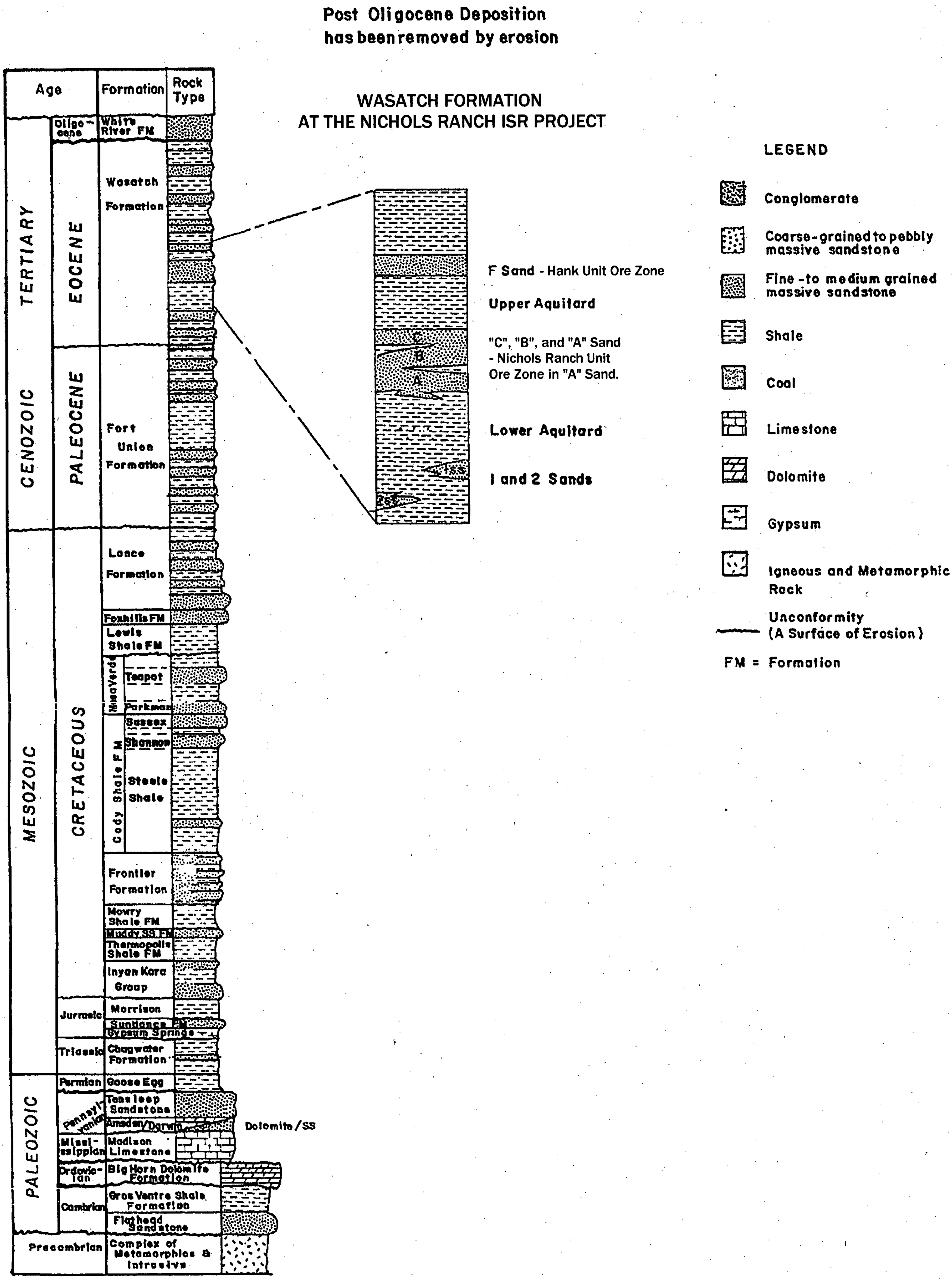

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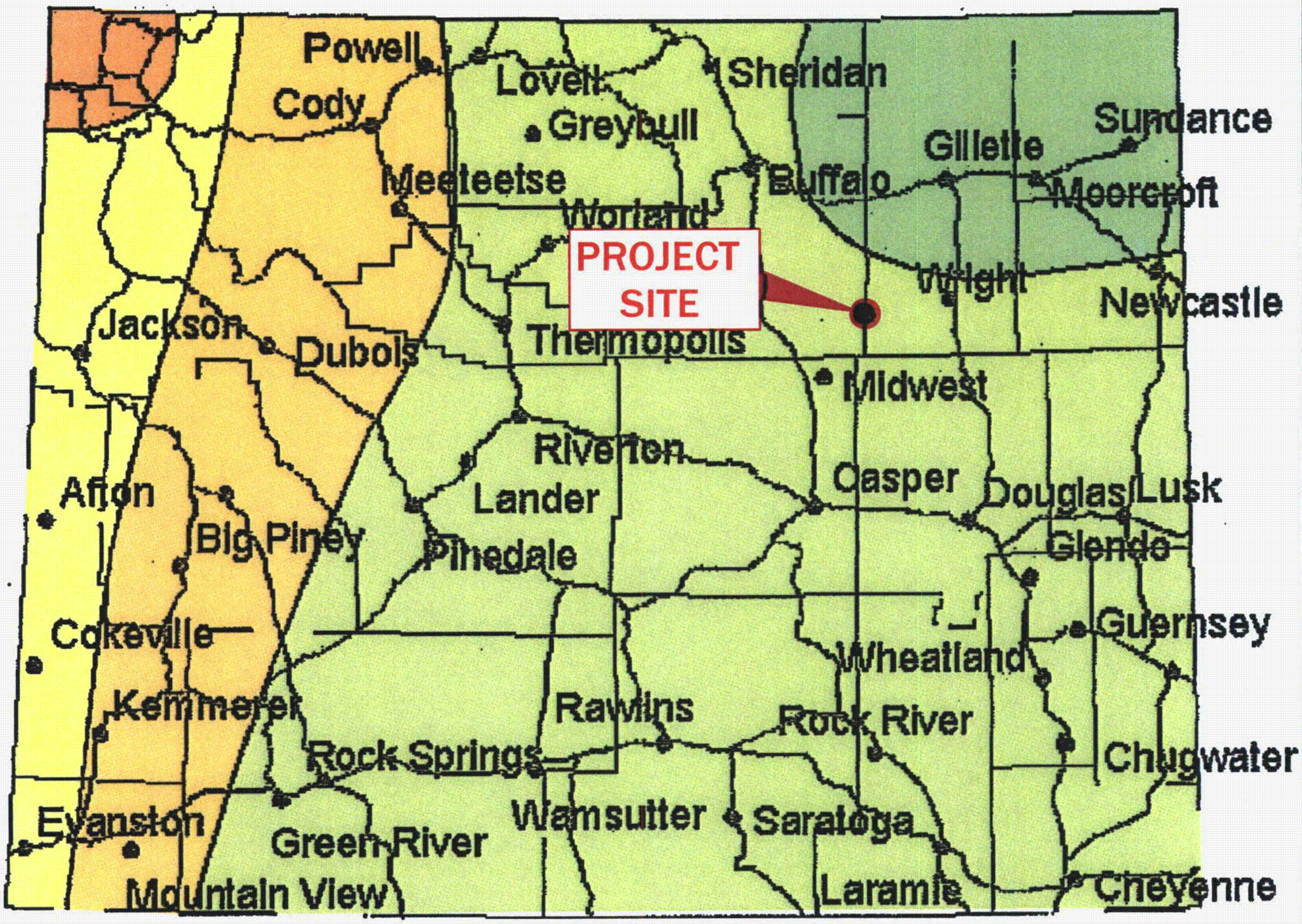
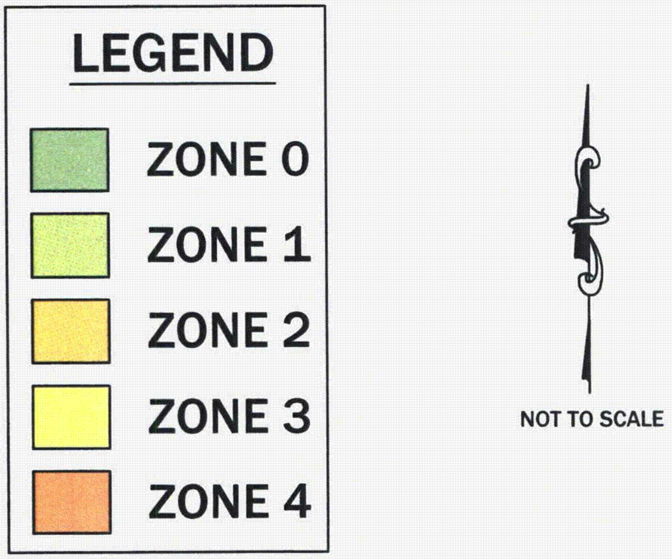
FIGURE D5-2
STRATIGRAPHIC COLUMN

By: S.M.F.	Date: OCT. 12, 2007
Datum: N/A	Revision Date:
Scale: NOT TO SCALE	Contour Interval: N/A





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NICHOLS RANCH ISR PROJECT

FIGURE D5-3

SEISMIC ZONE MAP OF WYOMING

By: S.M.F.	Date: OCT. 11, 2007
Datum: N/A	Revision Date:
Scale: 1"=50 MILES	Contour Interval: N/A

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D-01

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D-02

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D-05

ADDENDUM D5A:

BASIC SEIMOLOGICAL CHARACTERIZATION
FOR CAMPBELL COUNTY, WYOMING

Basic Seismological Characterization
for
Campbell County, Wyoming

by

James C. Case, Rachel N. Toner, and Robert Kirkwood
Wyoming State Geological Survey
September 2002

BACKGROUND

Seismological characterizations of an area can range from an analysis of historic seismicity to a long-term probabilistic seismic hazard assessment. A complete characterization usually includes a summary of historic seismicity, an analysis of the Seismic Zone Map of the Uniform Building Code, deterministic analyses on active faults, "floating earthquake" analyses, and short- or long-term probabilistic seismic hazard analyses.

Presented below, for Campbell County, Wyoming, are an analysis of historic seismicity, an analysis of the Uniform Building Code, deterministic analyses of nearby active faults, an analysis of the maximum credible "floating earthquake", and current short- and long-term probabilistic seismic hazard analyses.

Historic Seismicity in Campbell County

The enclosed map of "Earthquake Epicenters and Suspected Active Faults with Surficial Expression in Wyoming" (Case and others, 1997) shows the historic distribution of earthquakes in Wyoming. Five magnitude 2.5 and greater earthquakes have been recorded in Campbell County. These earthquakes are discussed below.

The first earthquake recorded in the county occurred on May 11, 1967. This magnitude 4.8 earthquake was centered in southwestern Campbell County approximately 7 miles west-northwest of Pine Tree Junction. The second event took place on February 18,1972, when a magnitude 4.3 earthquake occurred approximately 18 miles east of Gillette. No damage was reported for either event.

Two earthquakes were recorded in Campbell County during the 1980s. On May 29, 1984, a magnitude 5.0, intensity V earthquake occurred approximately 24 miles west-southwest of Gillette. The earthquake was felt in Gillette, Sheridan, Buffalo, Casper, Douglas, Thermopolis, and Sundance. A rancher, living 35 miles west of Gillette, reported that he could see the ground shaking, and he heard a loud noise similar to a sonic boom. Pictures were shaken from the walls of the ranch house, but no other damage occurred at the ranch (Casper Star-Tribune, May 30, 1984). Surprisingly, all other reports only indicated that dishes rattled. On October 29, 1984, a magnitude 2.5 earthquake occurred approximately 25 miles west-northwest of Gillette. No damage was reported.

Most recently, on February 24, 1993, a magnitude 3.6 earthquake occurred in southeastern Campbell County approximately 10 miles east-southeast of Reno Junction. No damage was reported.

Regional Historic Seismicity

Earthquakes have also occurred near the Campbell County-Johnson County border. On September 2, 1976, a magnitude 4.8, intensity IV-V earthquake occurred approximately 33 miles northeast of Kaycee and 38 miles west-southwest of Gillette. Although the event was felt in Kaycee, no damage was reported. A magnitude 5.1, intensity V earthquake was reported on September 7, 1984, approximately 27 miles west of Gillette. The earthquake was felt throughout northeastern Wyoming, including Buffalo, Casper, Kaycee, Linch, and Midwest, and parts of southeastern Montana. No significant damage was reported (Laramie Daily Boomerang, September 8, 1984).

Uniform Building Code

The Uniform Building Code (UBC) is a document prepared by the International Conference of Building Officials. Its stated intent is to "provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings and structures within this jurisdiction and certain equipment specifically regulated herein."

The UBC contains information and guidance on designing buildings and structures to withstand seismic events. With safety in mind, the UBC provides Seismic Zone Maps to help identify which design factors are critical to specific areas of the country. In addition, depending upon the type of building, there is also an "importance factor". The "importance factor" can, in effect, raise the standards that are applied to a building.

The current UBC Seismic Zone Map (Figure 1) (1997) has five seismic zones, ranging from Zone 0 to Zone 4, as can be seen on the enclosed map. The seismic zones are in part defined by the probability of having a certain level of ground shaking (horizontal acceleration) in 50 years. The criteria used for defining boundaries on the Seismic Zone Map were established by the Seismology Committee of the Structural Engineers Association of California (Building Standards, September-October, 1986). The criteria they developed are as follows:

Zone	Effective Peak Acceleration, % gravity (g)
4	30% and greater
3	20% to less than 30%
2	10% to less than 20%
1	5% to less than 10%
0	less than 5%

The committee assumed that there was a 90% probability that the above values would not be exceeded in 50 years, or a 100% probability that the values would be exceeded in 475 to 500 years.

Campbell County is in Seismic Zones 0 and 1 of the UBC. The seismic history of the area, however, does not support a Zone 0 classification. Since effective peak accelerations (90% chance of non-exceedance in 50 years) can range from 0%-10%g in these two zones, and there has been some significant historic seismicity in the county, it may be reasonable to assume that an average peak acceleration of 10.0%g could be applied to the design of a non-critical facility located in the county if only the UBC were used. Such an acceleration is significantly less than would be suggested through newer building codes.

Recently, the UBC has been replaced by the International Building Code (IBC). The IBC is based upon probabilistic analyses, which are described in a following section. Campbell County still uses the UBC, however, as do most Wyoming counties as of October 2002.

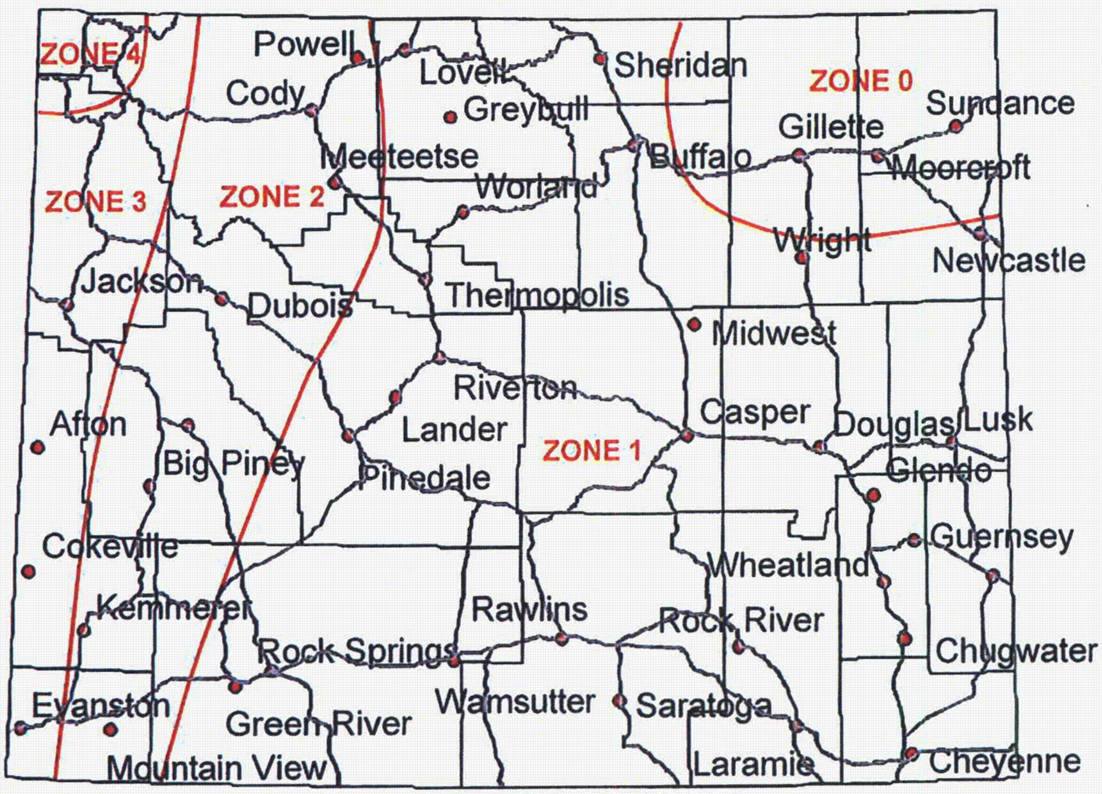

Figure 1. UBC Seismic Zone Map.

Deterministic Analysis Of Regional Active Faults With A Surficial Expression

There are no known exposed active faults with a surficial expression in Campbell County. As a result, no fault-specific analysis can be generated for Campbell County.

Floating or Random Earthquake Sources

Many federal regulations require an analysis of the earthquake potential in areas where active faults are not exposed, and where earthquakes are tied to buried faults with no surface expression. Regions with a uniform potential for the occurrence of such earthquakes are called tectonic provinces. Within a tectonic province, earthquakes associated with buried faults are assumed to occur randomly, and as a result can theoretically occur anywhere within that area of uniform earthquake potential. In reality, that random distribution may not be the case, as all earthquakes are associated with specific faults. If all buried faults have not been identified, however, the distribution has to be considered random. "Floating earthquakes" are earthquakes that are considered to occur randomly in a tectonic province.

It is difficult to accurately define tectonic provinces when there is a limited historic earthquake record. When there are no nearby seismic stations that can detect small-magnitude earthquakes, which occur more frequently than larger events, the problem is compounded. Under these conditions, it is common to delineate larger, rather than smaller, tectonic provinces.

The U.S. Geological Survey identified tectonic provinces in a report titled "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States" (Algermissen and others, 1982). In that report, Campbell County was classified as being in a tectonic province with a "floating earthquake" maximum magnitude of 6.1. Geomatrix (1988b) suggested using a more extensive regional tectonic province, called the "Wyoming Foreland Structural Province", which is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West longitude on the east, 40° North latitude on the south, and 45° North latitude on the north. Geomatrix (1988b) estimated that the largest "floating" earthquake in the "Wyoming Foreland Structural Province" would have a magnitude in the 6.0 – 6.5 range, with an average value of magnitude 6.25.

Federal or state regulations usually specify if a "floating earthquake" or tectonic province analysis is required for a facility. Usually, those regulations also specify at what distance a floating earthquake is to be placed from a facility. For example, for uranium mill tailings sites, the Nuclear Regulatory Commission requires that a floating earthquake be placed 15 kilometers from the site. That earthquake is then used to determine what horizontal accelerations may occur at the site. A magnitude 6.25 "floating" earthquake, placed 15 kilometers from any structure in Campbell County, would generate horizontal accelerations of approximately 15%g at the site. Critical facilities, such as dams, usually require a more detailed probabilistic analysis of random earthquakes. Based upon probabilistic analyses of random earthquakes in an area distant from exposed active faults (Geomatrix, 1988b), however, placing a magnitude 6.25 earthquake at 15 kilometers from a site will provide a fairly reasonable estimate of design ground accelerations in the northeastern and eastern parts of Campbell County, but will be inadequate in the southwestern part of the county.

Probabilistic Seismic Hazard Analyses

The U.S. Geological Survey (USGS) publishes probabilistic acceleration maps for 500-, 1000-, and 2,500-year time frames. The maps show what accelerations may be met or exceeded in those time frames by expressing the probability that the accelerations will be met or exceeded in a shorter time frame. For example, a 10% probability that acceleration may be met or exceeded in 50 years is roughly equivalent to a 100% probability of exceedance in 500 years.

The USGS has recently generated new probabilistic acceleration maps for Wyoming (Case, 2000). Copies of the 500-year (10% probability of exceedance in 50 years), 1000-year (5% probability of exceedance in 50 years), and 2,500-year (2% probability of exceedance in 50 years) maps are attached. Until recently, the 500-year map was often used for planning purposes for average structures, and was the basis of the most current Uniform Building Code. The new International Building Code, however, uses a 2,500-year map as the basis for building design. The maps reflect current perceptions on seismicity in Wyoming. In many areas of Wyoming, ground accelerations shown on the USGS maps can be increased due to local soil conditions. For example, if fairly soft, saturated sediments are present at the surface, and seismic waves are passed through them, surface ground accelerations will usually be greater than would be experienced if only bedrock was present. In this case, the ground accelerations shown on the USGS maps would underestimate the local hazard, as they are based upon accelerations that would be expected if firm soil or rock were present at the surface. Intensity values can be found in Table 1.

Based upon the 500-year map (10% probability of exceedance in 50 years) (Figure 2), the estimated peak horizontal acceleration in Campbell County ranges from approximately 3%g in the northeastern corner of the county to greater than 6%g in the southwestern corner of the county. These accelerations are roughly comparable to intensity IV earthquakes (1.4%g – 3.9%g) to intensity V earthquakes (3.9%g – 9.2%g). These accelerations are comparable to the accelerations to be expected in Seismic Zones 0 and 1 of the Uniform Building Code. Intensity IV earthquakes cause little damage. Intensity V earthquakes can result in cracked plaster and broken dishes. Gillette would be subjected to an acceleration of approximately 5%g or intensity V.

Based upon the 1000-year map (5% probability of exceedance in 50 years) (Figure 3), the estimated peak horizontal acceleration in Campbell County ranges from 4%g in the northeastern corner of the county to greater than 10%g in the southwestern quarter of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g) to intensity VI earthquakes (9.2%g – 18%g). Intensity V earthquakes can result in cracked plaster and broken dishes. Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Depending upon local ground conditions, Gillette would be subjected to an acceleration of approximately 9%g or greater and intensity V or VI.

Based upon the 2500-year map (2% probability of exceedance in 50 years) (Figure 4), the estimated peak horizontal acceleration in Campbell County ranges from 8%g in the northeastern corner of the county to greater than 20%g in the southwestern corner of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g), intensity VI earthquakes (9.2%g – 18%g), and intensity VII earthquakes (18%g – 34%g). Intensity V earthquakes can result in cracked plaster and broken dishes. Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Intensity VII earthquakes can result in slight to moderate damage in well-built ordinary structures, and considerable damage in poorly built or badly designed structures, such as unreinforced masonry. Chimneys may be broken. Gillette would be subjected to an acceleration of approximately 18%g or intensity VI to VII.

As the historic record is limited, it is nearly impossible to determine when a 2,500-year event last occurred in the county. Because of the uncertainty involved, and based upon the fact that the new International Building Code utilizes 2,500-year events for building design, it is suggested that the 2,500-year probabilistic maps be used for Campbell County analyses. This conservative approach is in the interest of public safety.

Table 1:

Modified Mercalli Intensity	Acceleration (%g) (PGA)	Perceived Shaking	Potential Damage
I	<0.17	Not felt	None
II	0.17 – 1.4	Weak	None
III	0.17 – 1.4	Weak	None
IV	1.4 – 3.9	Light	None
V	3.9 – 9.2	Moderate	Very Light
VI	9.2 – 18	Strong	Light
VII	18 – 34	Very Strong	Moderate
VIII	34 – 65	Severe	Moderate to Heavy
IX	65 – 124	Violent	Heavy
X	>124	Extreme	Very Heavy
XI	>124	Extreme	Very Heavy
XII	>124	Extreme	Very Heavy

Modified Mercalli Intensity and peak ground acceleration (PGA) (Wald, et al 1999).

Abridged Modified Mercalli Intensity Scale

Intensity value and description:

I	Not felt except by a very few under especially favorable circumstances.
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.
V	Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

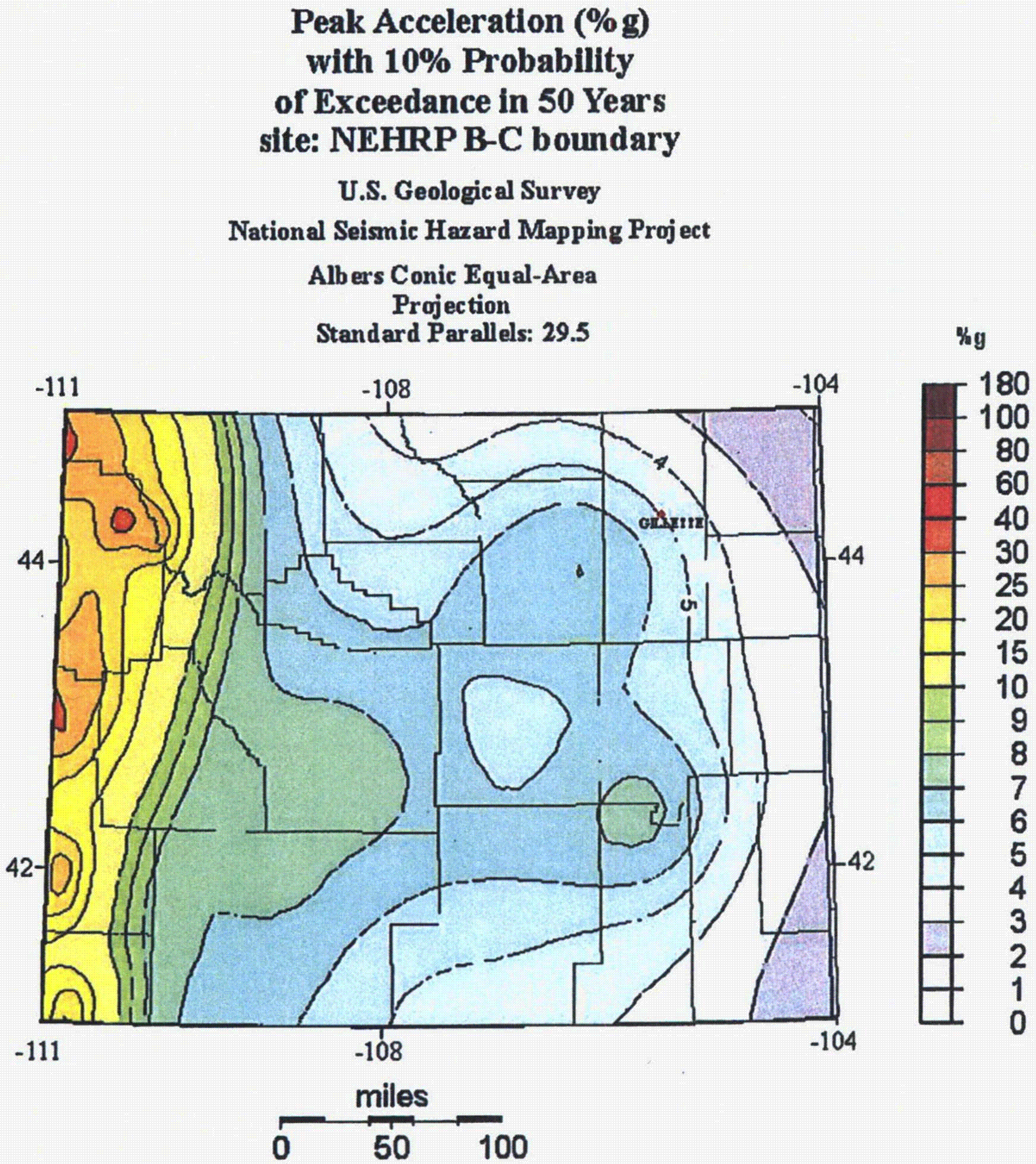

Figure 2. 500-year probabilistic acceleration map (10% probability of exceedance in 50 years).

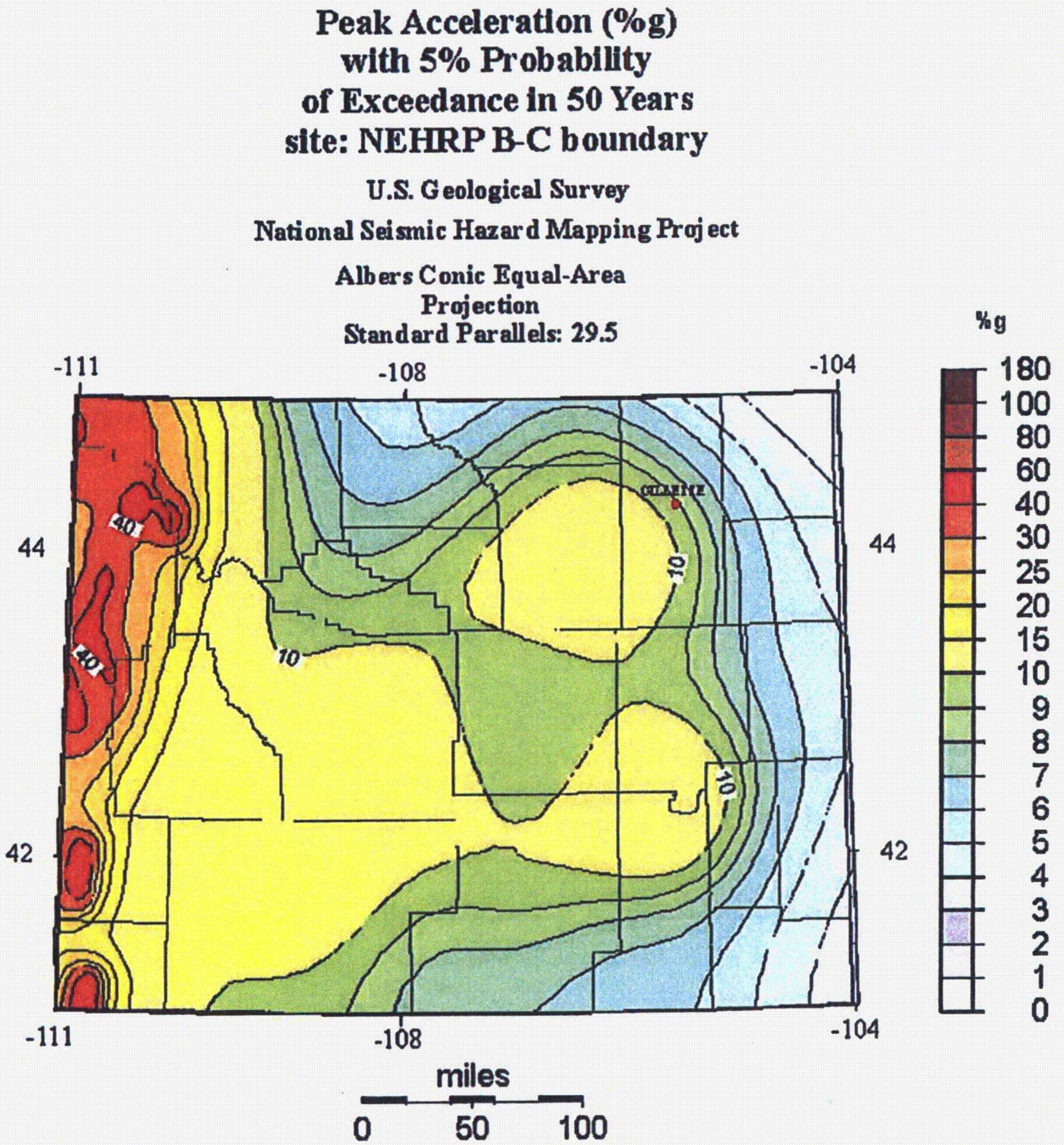

Figure 3. 1000-year probabilistic acceleration map (5% probability of exceedance in 50 years).

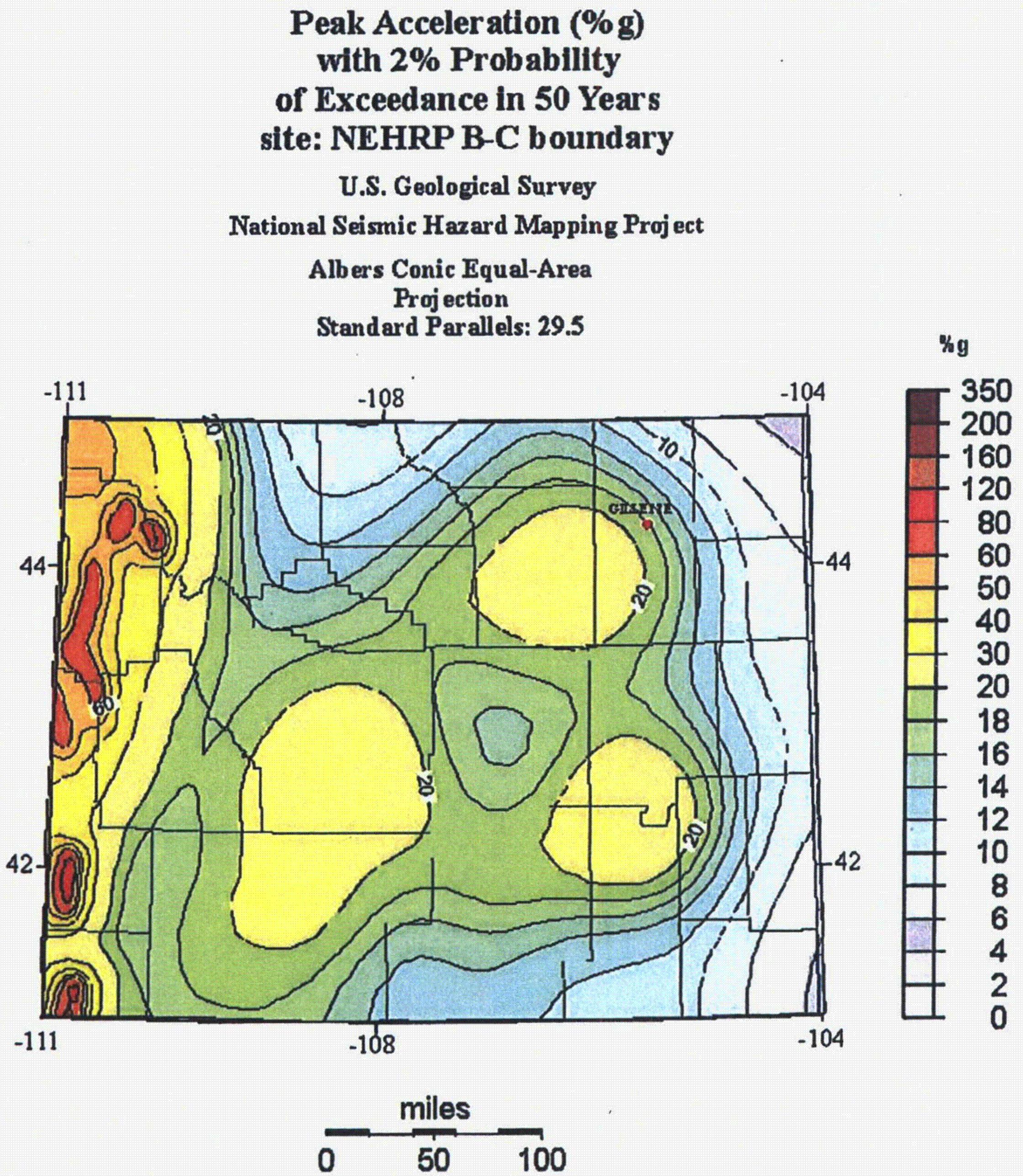

Figure 4. 2500-year probabilistic acceleration map (2% probability of exceedance in 50 years).

Summary

There have been seven historic earthquakes with a magnitude greater than 2.5 recorded in or near Campbell County. Because of the limited historic record, it is possible to underestimate the seismic hazard in Campbell County if historic earthquakes are used as the sole basis for analysis. Earthquake and ground motion probability maps give a more reasonable estimate of damage potential in areas without exposed active faults at the surface, such as Campbell County.

Current earthquake probability maps that are used in the newest building codes (2500 year maps) suggest a scenario that would result in moderate damage to buildings and their contents, with damage increasing from the northeast to the southwest. More specifically, the probability-based worst-case scenario could result in the following damage at points throughout the county:

Intensity VII Earthquake Areas

Gillette
Savageton
Wright

In intensity VII earthquakes, damage is negligible in buildings of good design and construction, slight-to-moderate in well-built ordinary structures, considerable in poorly built or badly designed structures such as unreinforced masonry buildings. Some chimneys will be broken.

Intensity VI Earthquake Areas

Recluse
Rozet
Spotted Horse
Weston

In intensity VI earthquakes, some heavy furniture can be moved. There may be some instances of fallen plaster and damaged chimneys.

Intensity V Earthquake Areas

Rockypoint

In intensity V earthquakes, dishes and windows can break and plaster can crack. Unstable objects may overturn. Tall objects such as trees and power poles can be disturbed.

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ADDENDUM D5B:

BASIC SEIMOLOGICAL CHARACTERIZATION
FOR JOHNSON COUNTY, WYOMING

Basic Seismological Characterization
for
Johnson County, Wyoming

by

James C. Case, Rachel N. Toner, and Robert Kirkwood
Wyoming State Geological Survey
September 2002

BACKGROUND

Seismological characterizations of an area can range from an analysis of historic seismicity to a long-term probabilistic seismic hazard assessment. A complete characterization usually includes a summary of historic seismicity, an analysis of the Seismic Zone Map of the Uniform Building Code, deterministic analyses on active faults, "floating earthquake" analyses, and short- or long-term probabilistic seismic hazard analyses.

Presented below, for Johnson County, Wyoming, are an analysis of historic seismicity, an analysis of the Uniform Building Code, deterministic analyses of nearby active faults, an analysis of the maximum credible "floating earthquake", and current short- and long-term probabilistic seismic hazard analyses.

Historic Seismicity in Johnson County

The enclosed map of "Earthquake Epicenters and Suspected Active Faults with Surficial Expression in Wyoming" (Case and others, 1997) shows the historic distribution of earthquakes in Wyoming. Eight magnitude 2.5 and greater earthquakes have been recorded in Johnson County. These earthquakes are discussed below.

The first earthquake recorded in the county occurred on October 24, 1922. Reagor, Stover, and Algermissen (1985) located the earthquake near Buffalo, and classified the event as an intensity II earthquake. Based upon a description of the earthquake in the October 27, 1922 edition of the Sheridan Post, however, the location and assigned intensity may be in error. The Sheridan Post reported that at Cat Creek, 8 miles east of Sheridan, houses were shaken and dishes were rattled. In addition, the October 26, 1922 edition of the Sheridan Post reports that only a slight earthquake shock was felt in Sheridan. Based upon this information, it seems reasonable to locate the earthquake 8 miles east of Sheridan, and to assign an intensity of IV-V to the event.
On September 6, 1943, an intensity IV earthquake was felt in the Sheridan area, although Reagor, Stover, and Algermissen (1985) located the epicenter approximately 3-4 miles south-southwest of

Buffalo. Beds and chairs were reported "to sway" in the Sheridan area (The Casper Tribune-Herald, September 7, 1943).

Two earthquakes were recorded in Johnson County in the 1960s. A magnitude 4.7 earthquake occurred on June 3, 1965. This event was centered approximately 12 miles south of Kaycee. On April 12, 1966, an earthquake of no specified magnitude or intensity was detected approximately 25 miles southwest of Buffalo. No one reported feeling these events (U.S.G.S. National Earthquake Information Center).

On September 2, 1976, a magnitude 4.8, intensity IV-V earthquake was felt in Kaycee. The event was located approximately 33 miles northeast of Kaycee. No damage was reported.

A magnitude 5.1, intensity V earthquake occurred on September 7, 1984, approximately 33 miles east-southeast of Buffalo. The earthquake was felt throughout northeastern Wyoming, including Buffalo, Casper, Kaycee, Linch, and Midwest, and in parts of southeastern Montana. No significant damage was reported (Laramie Daily Boomerang, September 8, 1984).

Two earthquakes were detected in Johnson County in 1992. The first occurred on February 22, 1992. This magnitude 2.9 event was recorded approximately 18 miles east of Buffalo. As expected with such a small earthquake, no damage was reported. Most recently, a magnitude 3.6, intensity IV earthquake occurred on August 30, 1992. The earthquake was centered near Mayoworth, approximately 22 miles west-northwest of Kaycee. It was felt in Barnum and Kaycee, but no damage was reported.

Regional Historic Seismicity

Several earthquakes have also occurred near Johnson County. The first occurred on May 11, 1967, in southwestern Campbell County. This magnitude 4.8 earthquake was centered approximately 13 miles east of Linch. No damage was reported. On March 24, 1977, a magnitude 3.6, intensity IV earthquake was reported in south-central Sheridan County approximately 22 miles northwest of Buffalo. Again, no damage was reported.

Two earthquakes occurred near the Johnson County-Campbell County border in 1984. On May 29, 1984, a magnitude 5.0, intensity V earthquake occurred approximately 38 miles east-southeast of Buffalo. The earthquake was felt in Gillette, Sheridan, Buffalo, Casper, Douglas, Thermopolis, and Sundance. A rancher, living 35 miles west of Gillette, reported that he could see the ground shaking, and he heard a loud noise similar to a sonic boom. Pictures were shaken from the walls of the ranch house, but no other damage occurred at the ranch (Casper Star-Tribune, May 30, 1984). All other reports only indicated that dishes rattled. On October 29, 1984, a magnitude 2.5 earthquake occurred approximately 35 miles east of Buffalo. No damage was reported.

Finally, on March 10, 1993, a magnitude 3.2 earthquake was recorded in northern Natrona County approximately 20 miles southeast of Barnum. No damage was reported.

Uniform Building Code

The Uniform Building Code (UBC) is a document prepared by the International Conference of Building Officials. Its stated intent is to "provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings and structures within this jurisdiction and certain equipment specifically regulated herein."

The UBC contains information and guidance on designing buildings and structures to withstand seismic events. With safety in mind, the UBC provides Seismic Zone Maps to help identify which design factors are critical to specific areas of the country. In addition, depending upon the type of building, there is also an "importance factor". The "importance factor" can, in effect, raise the standards that are applied to a building.

The current UBC Seismic Zone Map (Figure 1) (1997) has five seismic zones, ranging from Zone 0 to Zone 4, as can be seen on the enclosed map. The seismic zones are in part defined by the probability of having a certain level of ground shaking (horizontal acceleration) in 50 years. The criteria used for defining boundaries on the Seismic Zone Map were established by the Seismology Committee of the Structural Engineers Association of California (Building Standards, September-October, 1986). The criteria they developed are as follows:

Zone	Effective Peak Acceleration, % gravity (g)
4	30% and greater
3	20% to less than 30%
2	10% to less than 20%
1	5% to less than 10%
0	less than 5%

The committee assumed that there was a 90% probability that the above values would not be exceeded in 50 years, or a 100% probability that the values would be exceeded in 475 to 500 years.

Johnson County is in Seismic Zones 0 and 1 of the UBC. The seismic history of the area, however, does not support a Zone 0 classification. Since effective peak accelerations (90% chance of non-exceedance in 50 years) can range from 0%-10%g in these two zones, and there has been some significant historic seismicity in the county, it may be reasonable to assume that an average peak acceleration of 5.0%g could be applied to the design of a non-critical facility located in the county if only the UBC were used. Such an acceleration is significantly less than would be suggested through newer building codes.

Recently, the UBC has been replaced by the International Building Code (IBC). The IBC is based upon probabilistic analyses, which are described in a following section. Johnson County still uses the UBC, however, as do most Wyoming counties as of October 2002.

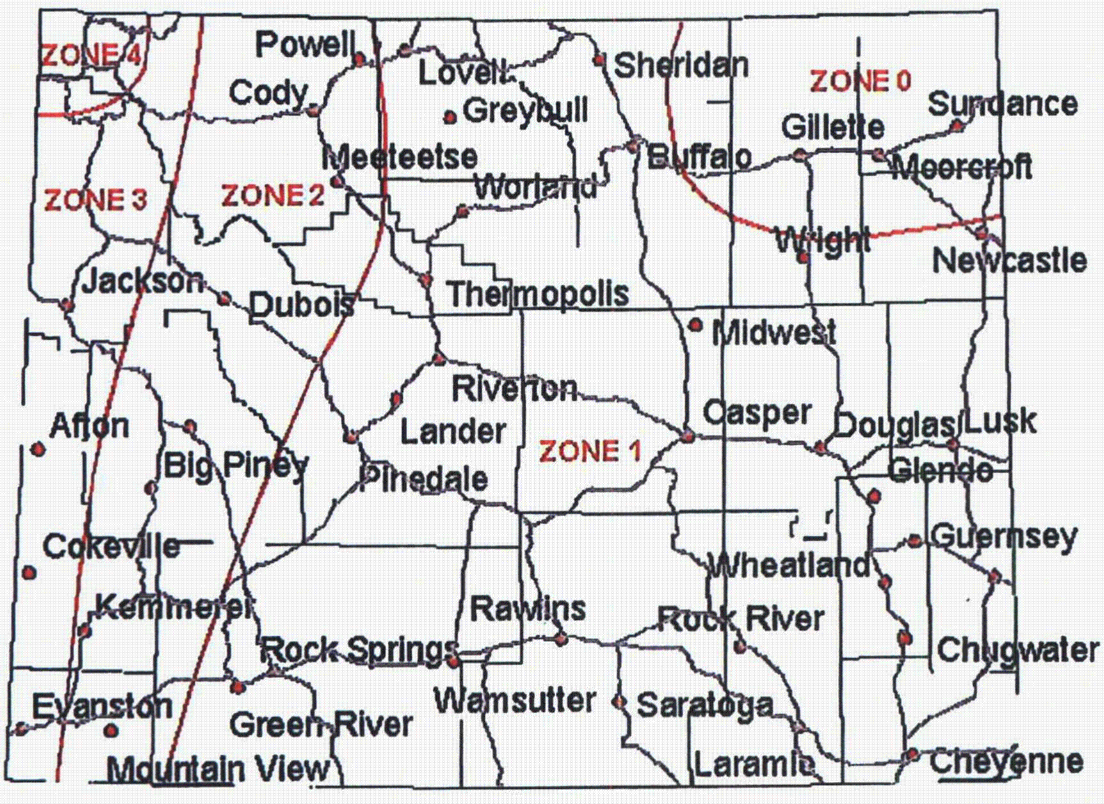

Figure 1. UBC Seismic Zone Map.

Deterministic Analysis Of Regional Active Faults With A Surficial Expression

An active fault system called the Cedar Ridge/Dry Fork fault system is present near the southwestern border of Johnson County in Natrona and Fremont Counties. The 35-mile long Cedar Ridge fault comprises the western portion of the fault system, and the 15-mile long Dry Fork fault makes up the eastern portion. The only Pleistocene-age movement on the fault system was found in northeastern Fremont County (T39N R92W NE ¼ Section 10). A short scarp on the Cedar Ridge fault, approximately 0.8 miles long, was identified at that location. Since the entire fault system is approximately 50 miles long, and only one small active segment was discovered, Geomatrix (1988a) stated that the "age of this scarp and the absence of evidence for late Quaternary faulting elsewhere along the Cedar Ridge/Dry Creek fault suggest that this fault is inactive." As a result of this assessment, it is not possible to conduct a reliable deterministic analysis on the fault system; however general estimates can be made.

The Dry Fork fault system is closest to Johnson County. Although there is no compelling reason to believe that the Dry Fork fault system is active, if it did activate as an isolated system, it could potentially generate a magnitude 6.7 earthquake. This is based upon a postulated fault rupture length of 15 miles (Wong et al., 2001). A magnitude 6.7 earthquake on the fault system could generate a peak horizontal acceleration of up to 12%g at the southwestern corner of Johnson County, approximately 5%g at Barnum, and approximately 3.3%g at Kaycee (Campbell, 1987). Those accelerations would be roughly equivalent to an intensity VI earthquake at the southwestern corner of the county, an intensity V earthquake at Barnum, and an intensity IV earthquake at Kaycee. Minor damage could occur in the southwestern portion of the county. Again, there is no compelling reason to believe that the Dry Fork fault system is active.

There is also no compelling reason to believe that the Cedar Ridge fault system is active. If the fault did activate, it could potentially generate a magnitude 7.1 earthquake. Because of its distance from Johnson County, however, any activation of the Cedar Ridge fault would probably not affect the county.

Floating or Random Earthquake Sources

Many federal regulations require an analysis of the earthquake potential in areas where active faults are not exposed, and where earthquakes are tied to buried faults with no surface expression. Regions with a uniform potential for the occurrence of such earthquakes are called tectonic provinces. Within a tectonic province, earthquakes associated with buried faults are assumed to occur randomly, and as a result can theoretically occur anywhere within that area of uniform earthquake potential. In reality, that random distribution may not be the case, as all earthquakes are associated with specific faults. If all buried faults have not been identified, however, the distribution has to be considered random. "Floating earthquakes" are earthquakes that are considered to occur randomly in a tectonic province.

It is difficult to accurately define tectonic provinces when there is a limited historic earthquake record. When there are no nearby seismic stations that can detect small-magnitude earthquakes, which occur more frequently than larger events, the problem is compounded. Under these conditions, it is common to delineate larger, rather than smaller, tectonic provinces.

The U.S. Geological Survey identified tectonic provinces in a report titled "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States" (Algermissen and others, 1982). In that report, Johnson County was classified as being in a tectonic province with a "floating earthquake" maximum magnitude of 6.1. Geomatrix (1988b) suggested using a more extensive regional tectonic province, called the "Wyoming Foreland Structural Province", which is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West longitude on the east, 40° North latitude on the south, and 45° North latitude on the north. Geomatrix (1988b) estimated that the largest "floating" earthquake in the "Wyoming Foreland Structural Province" would have a magnitude in the 6.0 – 6.5 range, with an average value of magnitude 6.25.

Federal or state regulations usually specify if a "floating earthquake" or tectonic province analysis is required for a facility. Usually, those regulations also specify at what distance a floating earthquake is to be placed from a facility. For example, for uranium mill tailings sites, the Nuclear Regulatory Commission requires that a floating earthquake be placed 15 kilometers from the site. That earthquake is then used to determine what horizontal accelerations may occur at the site. A magnitude 6.25 "floating" earthquake, placed 15 kilometers from any structure in Johnson County, would generate horizontal accelerations of approximately 15%g at the site. Critical facilities, such as dams, usually require a more detailed probabilistic analysis of random earthquakes. Based upon probabilistic analyses of random earthquakes in an area distant from exposed active faults (Geomatrix, 1988b), however, placing a magnitude 6.25 earthquake at 15 kilometers from a site will provide a fairly conservative estimate of design ground accelerations.

Probabilistic Seismic Hazard Analyses

The U.S. Geological Survey (USGS) publishes probabilistic acceleration maps for 500-, 1000-, and 2,500-year time frames. The maps show what accelerations may be met or exceeded in those time frames by expressing the probability that the accelerations will be met or exceeded in a shorter time frame. For example, a 10% probability that acceleration may be met or exceeded in 50 years is roughly equivalent to a 100% probability of exceedance in 500 years.

The USGS has recently generated new probabilistic acceleration maps for Wyoming (Case, 2000). Copies of the 500-year (10% probability of exceedance in 50 years), 1000-year (5% probability of exceedance in 50 years), and 2,500-year (2% probability of exceedance in 50 years) maps are included. Until recently, the 500-year map was often used for planning purposes for average structures, and was the basis of the most current Uniform Building Code. The new International Building Code, however, uses a 2,500-year map as the basis for building design. The maps reflect current perceptions on seismicity in Wyoming. In many areas of Wyoming, ground accelerations shown on the USGS maps can be increased due to local soil conditions. For example, if fairly soft, saturated sediments are present at the surface, and seismic waves are passed through them, surface ground accelerations will usually be greater than would be experienced if only bedrock was present. In this case, the ground accelerations shown on the USGS maps would underestimate the local hazard, as they are based upon accelerations that would be expected if firm soil or rock were present at the surface. Intensity values can be found in Table 1.

Based upon the 500-year map (10% probability of exceedance in 50 years) (Figure 2), the estimated peak horizontal acceleration in Johnson County ranges from approximately 4%g in the northwestern corner of the county to greater than 6%g in the central and southern portions of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g). These accelerations are comparable to the accelerations to be expected in Seismic Zones 0 and 1 of the Uniform Building Code. Intensity V earthquakes can result in cracked plaster and broken dishes. Buffalo and Kaycee would be subjected to accelerations of 6%g and greater, or intensity V.

Based upon the 1000-year map (5% probability of exceedance in 50 years) (Figure 3), the estimated peak horizontal acceleration in Johnson County ranges from 7%g in the northwestern corner of the county to greater than 10%g in the central and southern portions of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g) to intensity VI earthquakes (9.2%g – 18%g). Intensity V earthquakes can result in cracked plaster and broken dishes. Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Buffalo and Kaycee would be subjected to accelerations of greater than 10%g or intensity VI.

Based upon the 2500-year map (2% probability of exceedance in 50 years) (Figure 4), the estimated peak horizontal acceleration in Johnson County ranges from approximately 14%g in the northwestern corner of the county to greater than 20%g in the central and southeastern portions of the county. These accelerations are roughly comparable to intensity VI earthquakes (9.2%g – 18%g) and intensity VII earthquakes (18%g – 34%g). Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Intensity VII earthquakes can result in slight to moderate damage in well-built ordinary structures, and considerable damage in poorly built or badly designed structures, such as unreinforced masonry. Chimneys may be broken. Buffalo and Kaycee would be subjected to accelerations of 20%g and greater or intensity VII.

As the historic record is limited, it is nearly impossible to determine when a 2,500-year event last occurred in the county. Because of the uncertainty involved, and based upon the fact that the new International Building Code utilizes 2,500-year events for building design, it is suggested that the 2,500-year probabilistic maps be used for Johnson County analyses. This conservative approach is in the interest of public safety.

Table 1:

Modified Mercalli Intensity	Acceleration (%g) (PGA)	Perceived Shaking	Potential Damage
I	<0.17	Not felt	None
II	0.17 – 1.4	Weak	None
III	0.17 – 1.4	Weak	None
IV	1.4 – 3.9	Light	None
V	3.9 – 9.2	Moderate	Very Light
VI	9.2 – 18	Strong	Light
VII	18 – 34	Very Strong	Moderate
VIII	34 – 65	Severe	Moderate to Heavy
IX	65 – 124	Violent	Heavy
X	>124	Extreme	Very Heavy
XI	>124	Extreme	Very Heavy
XII	>124	Extreme	Very Heavy

Modified Mercalli Intensity and peak ground acceleration (PGA) (Wald, et al 1999).

Abridged Modified Mercalli Intensity Scale

Intensity value and description:

I Not felt except by a very few under especially favorable circumstances.

II Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.

IV During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.

V Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.

VII Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.

VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.

IX Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.

XI Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

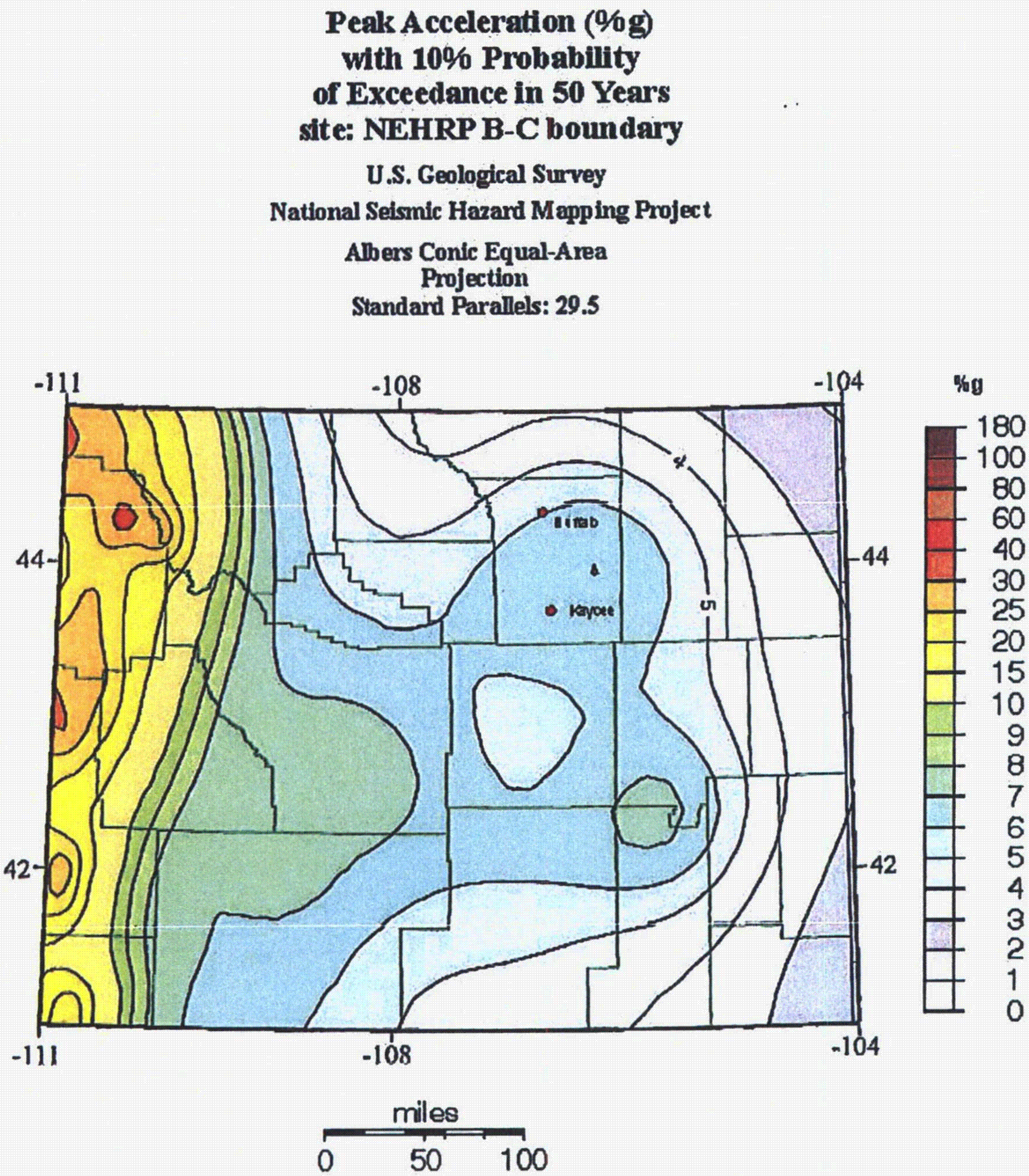

Figure 2. 500-year probabilistic acceleration map (10% probability of exceedance in 50 years).

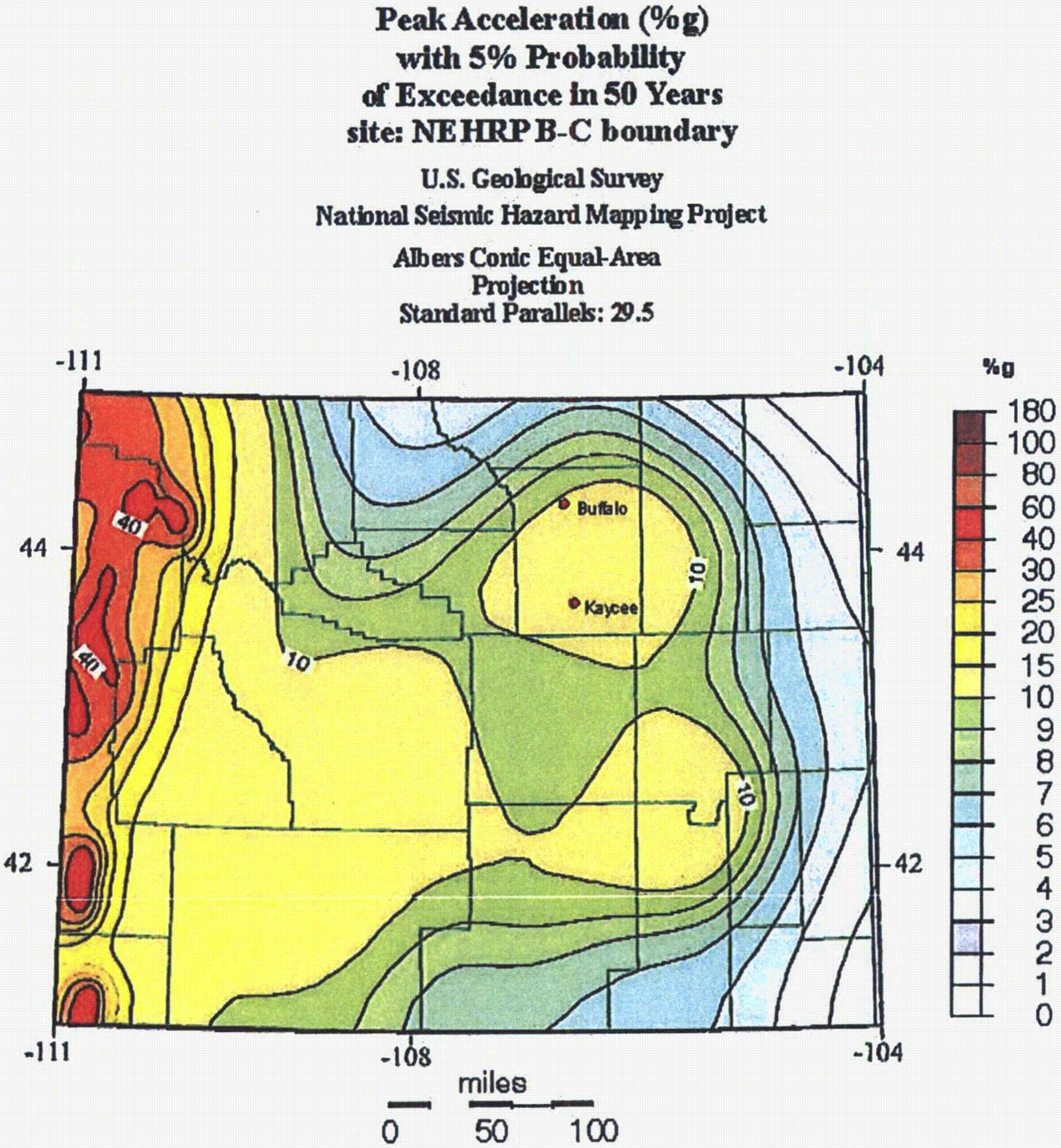

Figure 3. 1000-year probabilistic acceleration map (5% probability of exceedance in 50 years).

Peak Acceleration (%g)
with 2% Probability
of Exceedance in 50 Years
site: NEHRP B-C boundary

U.S. Geological Survey
National Seismic Hazard Mapping Project
Albers Conic Equal-Area
Projection
Standard Parallels: 29.5

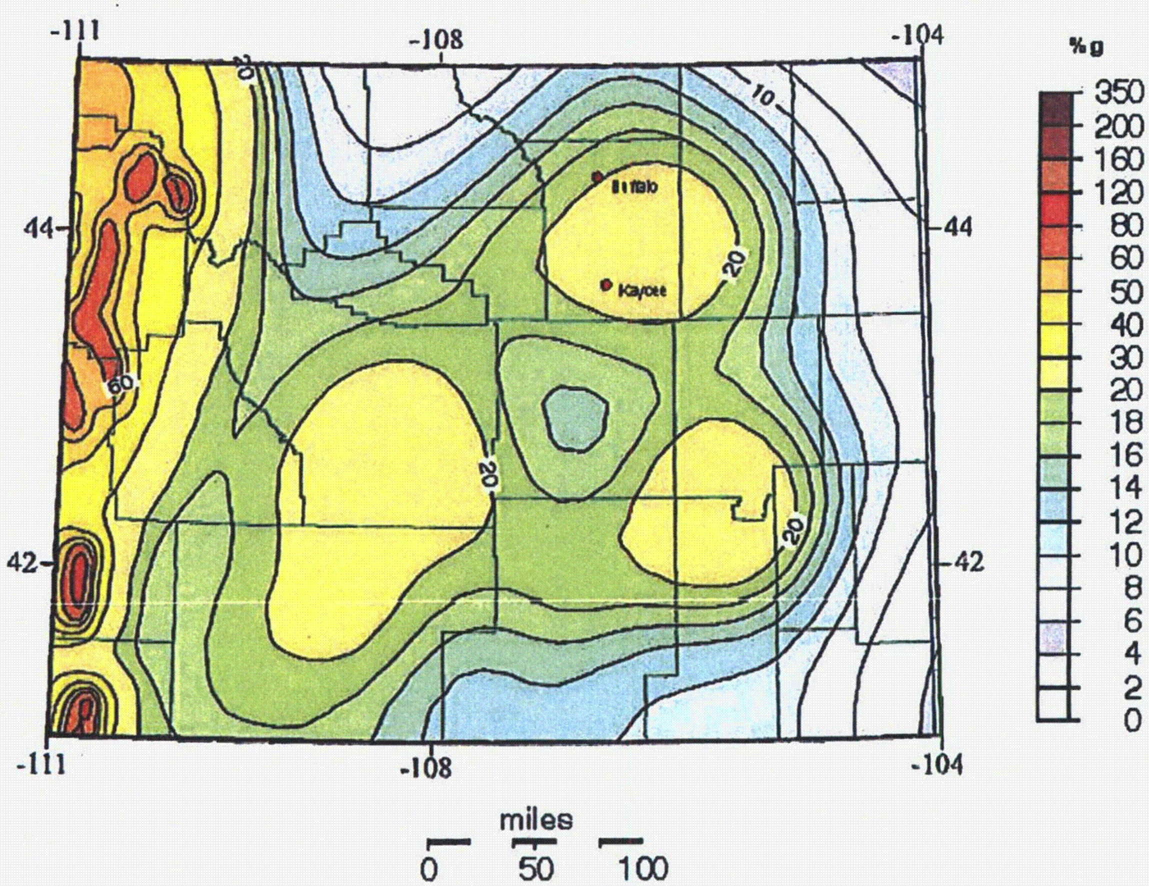

Figure 4. 2500-year probabilistic acceleration map (2% probability of exceedance in 50 years).

Summary

There have been thirteen historic earthquakes with a magnitude greater than 2.5 recorded in or near Johnson County. Because of the limited historic record, it is possible to underestimate the seismic hazard in Johnson County if historic earthquakes are used as the sole basis for analysis. Earthquake and ground motion probability maps give a more reasonable estimate of damage potential in areas without exposed active faults at the surface, such as Johnson County.

Current earthquake probability maps that are used in the newest building codes (2500 year maps) suggest a scenario that would result in moderate damage to buildings and their contents, with damage increasing from the northwest to the central and southeast areas of the county. More specifically, the probability-based worst-case scenario could result in the following damage at points throughout the county:

Intensity VII Earthquake Areas

Barnum
Buffalo
Kaycee
Linch
Mayoworth
Sussex

In intensity VII earthquakes, damage is negligible in buildings of good design and construction, slight-to-moderate in well-built ordinary structures, considerable in poorly built or badly designed structures such as unreinforced masonry buildings. Some chimneys will be broken.

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