APPENDIX H

TECHNICAL MEMORANDUM:
GEOLOGIC ASSESSMENT
Technical memorandum

To: Jay Schug, ACE
From: Joel Farber, Rob Venczel, and John Meyer
CC: 
Date: October 9, 2009
Re: Nowood River Watershed, Geological Assessment

Introduction

This memorandum summarizes the findings from a reconnaissance-level study and field evaluation of the geotechnical feasibility of potential reservoir sites completed by Trihydro Corporation in the Nowood watershed in north-central Wyoming. Investigation activities were performed from May through August of 2009. The scope of the investigation encompassed review of 35 potential reservoir storage sites identified by Anderson Consulting Engineers (ACE). Additionally ACE requested Trihydro provide an overview of the geologic characteristics of the watershed as part of this technical memorandum.

The first phase of the project involved a reconnaissance-level assessment of the 35 sites ACE provided. The assessment was based on statewide geologic mapping of bedrock, structures, surficial geology, and geologic hazards. Each reservoir site was evaluated in terms of the expected geologic conditions along the dam embankment, within the reservoir pool area, and within the contributing drainage area. Trihydro assigned a letter grade (A-F) to each of these three focus areas for each of the sites. A grade of “A” indicated favorable conditions and a grade of “F” indicated the site had a fatal flaw. No sites were determined to have a fatal flaw (received a grade of F) during the first phase of the investigation. Likewise, none of the sites advanced for further consideration received an “A” grade. The results of the first phase resulted in a highest letter grade of B and a lowest letter grade of D.

The results of the reconnaissance-level assessment are provided in Table 1. Bedrock geology had the greatest influence on the grading process because of the regional risks for karstic formations and formations comprised primarily of erodible gypsum. The formations determined at highest risk for karst features are as follows: Gypsum Springs, Madison, Goose Egg, and Ten Sleep.

General Geology

The following sections provide the general geology of the Nowood watershed. The watershed lies mostly within Big Horn and Washakie Counties in north central Wyoming. Small portions of the watershed however, overlap into Johnson, Natrona, Fremont and Hot Springs Counties. This assessment includes the surficial geology, bedrock geology, geological structure and geological hazards of the watershed.
**Surficial Geology**
The surficial deposits found within the Nowood watershed are presented on Figure 1. The figure shows the wide distribution of alluvium, glacial deposits, residuum, slopewash and colluvium within the watershed. These sediment types constitute the dominant exposed geology within the watershed. The remaining exposed geology is composed of bedrock, grus, landslide, and terrace deposits. A discussion of bedrock and landslides are presented in the bedrock geology and hazards sections below.

Alluvium is found adjacent to surface drainages and is of fluvial genetic origin. The extent of the alluvial deposits varies with the size of the respective fluvial system. Headwater deposits are typically narrower and shallower compared to downstream areas in the watershed. Alluvium ranges from 10-50 feet in thickness and is composed of sand, gravel, and loam (Cooley and Head 1979). These deposits are actively growing with the fluvial action of existing surface drainages. Fluvial action includes flooding (vertical deposition) and point-bar migration (lateral deposition).

Glacial till exists in the northwestern portion of the watershed and is associated with lateral and terminal moraines. The lateral moraines typically begin at an elevation of ~10,000 feet and can be traced to ~8,000 feet, where they meet the terminal moraines (Darton, 1906). Drift composition is dominantly igneous and metamorphic rock from upland areas. Some Paleozoic sedimentary rocks also exist within the till located at lower elevations. These deposits consist of unconsolidated, poorly sorted, angular rock fragments. Some areas may display greater levels of sorting due to esker formation.

Residuum is an in-situ deposit formed from the weathering of bedrock. Soluble components of the bedrock were transported from the area by fluvial, fluvioglacial, and groundwater processes. The insoluble portions of the rock experienced some mechanical weathering from freeze-thaw and rain-drop impact with little to no transport of the remaining materials. The residuum deposits within the Nowood watershed are primarily derived from late Paleozoic to Mesozoic rocks. The deposits are relatively young and are therefore thin compared to other quaternary deposits.

Colluvium exists throughout the watershed and has a genetic origin related to mass wasting mechanisms. These sediments were derived from the movement of material down slope under the influence of gravity. The colluvial deposits are composed of material derived from bedrock at higher elevations. Grain sizes range from silt to gravel, and grain shape is predominantly angular to subangular. These deposits have a maximum thickness of 15 feet (Cooley and Head 1979) but thin as they near the source material at higher elevations.

**Bedrock Geology**
The bedrock geology exposed and directly underlying the Nowood watershed contains rock formations with ages ranging from the Cambrian Period to present. The bedrock geology outcropping at or near the surface is presented on Figure 2. The dominant formations in the Nowood watershed (from youngest to oldest, top to bottom, then left to right) include the:
Other geological units exist within the Nowood watershed, but the above units have the greatest influence on the watershed’s geology. The starred units were encountered at the various reservoir sites and are described in greater detail.

The general chronological pattern of the units is that of younger formations on the eastern side of the watershed and older units on the western side (Susong et al. 1993). An exception to the pattern is the quaternary, surficial deposits discussed in the previous section. The youngest (Tertiary) rocks are of the Fort Union Formation and are approximately 2-68 million years old (ma). This formation consists of interbedded layers of sandstone and shale. Coal seams exist within the formation but are smaller and less frequent than those found in the Fort Union of southeastern Montana. In the area of the Nowood River, the Fort Union Formation is 1,000 to 1,500 feet thick (Cooley and Head 1979).

The next youngest rocks are of Cretaceous age (68-142 ma) and include units of the Mesaverde, Cody Frontier, Mowry, Thermopolis, and Cloverly Formations. Within the Nowood watershed, these formations comprise the bedrock (other than the Tertiary formations) found east of the Nowood River and the areas northeast of Hyattville, WY. They are comprised of thick shale layers with thinner beds of sandstone. Coal is present within these rocks as well (Darton 1906). The thickness of the entire sequence is from 6,600 to 7,500 feet (Cooley and Head 1979; Fischer 1906).

The Frontier Formation is Upper Cretaceous and composed of fine to medium lenticular sandstones with gray and black marine shales. Thin bentonite and tuff beds are present as well. The Mowry Formation is Lower Cretaceous and composed of black and gray thin-bedded resistant shale interbedded with thin sandstone and bentonite. The Thermopolis Shale is a soft black shale of the Lower Cretaceous. The Cloverly Formation is Lower Cretaceous and composed of light gray channel sandstones and pebble conglomerates interbedded with variegated bentonite mudstone (Weitz and Love 1952).

To the west of the cretaceous rocks are Jurassic to Pennsylvanian age (142-320 ma) rocks, and include the Morrison, Sundance, Gypsum Spring, Chugwater, Goose Egg, Tensleep, and Amsden Formations. These formations range from redish-brown shale to silty sandstone to sandstone. Thin beds of limestone also exist. The Tensleep Formation consists entirely of lightly cross-stratified sandstone. Gypsum exists in the Gypsum Spring and Goose Egg Formations, the solution of which has produced karst topography. The total thickness of these formations ranges from 2,000 to 2,400 feet (Susong et al. 1993; Cooley and Head 1979).

The Morrison Formation is Upper Jurassic and composed of calcareous gray silty sandstone and sandy claystone with lenticular limestone. The Sundance Formation is Middle Jurassic and is a greenish-gray
glauconitic calcareous sandstone and shale. The Gypsum Springs Formation is Middle Jurassic and an interbedded red claystone, shale, siltstone and limestone with massive gypsum beds. The Chugwater Formation is Triassic and composed of massive, cross-bedded very fine grained red sandstone, siltstone and shale.

Mississippian to Ordovician aged rocks (320-505 ma) exist further to the west and northwest. These rocks are composed of the Madison limestone and Bighorn dolomite. Both formations contain light-gray massive limestone with the Bighorn Formation also containing dolomite. Dissolution of these formations has also produced karst topography and cave systems in the Nowood watershed. The extensive cave systems associated with these formations suggests a high volume of water is exchanged during surface water-groundwater interactions. The Madison limestone has a thickness of 500 to 700 feet, while the Bighorn dolomite is 300 feet thick (Susong et al. 1993; Cooley and Head 1979).

The oldest Phanerozoic rocks in the watershed were deposited during the Cambrian Period (505-560 ma) and are the Gallatin and Gros Ventre Formations. Both formations are a greenish to gray shale. The formations are in the northwest portion of the watershed, adjacent to the Oldest Gneiss Formation and other plutonic rocks. These igneous and metamorphic rocks represent the basement, Precambrian rocks found in the center of the anticlinal structure of the Bighorn Mountains (Susong et al. 1993; Darton 1906; Fischer 1906).

Structure
The Nowood watershed is located in the southeastern portion of the Bighorn Basin. The basin was formed from folding and faulting during the Laramide orogeny, which occurred approximately 40-70 ma. The Laramide also produced the mountains that border the basin (Susong et al. 1993). To the east the basin is bordered by the Bighorn Mountains and to the west by the Absaroka, Beartooth, and Shoshone Mountains (Fischer 1906). The Nowood watershed drains the southwestern portion of the Bighorn Mountains, with no interaction with the mountains on the western border of the basin.

The general structure of the Bighorn Mountains is an anticline, and a portion of the Nowood watershed drains the southwestern limb. The axial plane of the anticline strikes northwest to southeast, causing the west-east age pattern in the Phanerozoic rocks. The attitude of Phanerozoic rocks is similar to the anticline, with strikes ranging from north to south to northwest to southeast. However, smaller scale anticlines and synclines are present within the watershed, and these local structures create variations in bed orientation.

The smaller scale anticlines and synclines are genetically related to the larger Bighorn anticline and therefore have similar orientations. The beds within them strike to the northwest and generally dip 5-12° to the southwest. Beds with an opposite dip direction (to the northeast) are present but less prevalent. This bed reversal typically indicates the presence of a local syncline (Hosterman et al. 1989; Cooley and Head 1979). Synclines can often be found associated with an anticline of similar size and extent. One anticline-syncline pair in the Nowood watershed can be found along the western side of the Nowood River with the axial plane running from Manderson, WY, to Crooked Creek (Cooley and Head 1979). Similar but less extensive structures are also found in the northeastern portion of the watershed, near Hyattville, WY, and north of Ten Sleep, WY.

Faulting is present within the western portions of the Nowood watershed (Figure 3). These faults are characterized as high-angle (60-90°) normal faults with the downthrown side located to the southeast of
the fault line (Hosterman et al., 1989; Darton, 1906). Faults of this type are associated with extensional tectonics. One distinctive fault that displays these characteristics is located adjacent to Big Canyon Creek and Ten Sleep. The fault displays a vertical displacement of 700 feet east of Big Canyon Creek. This displacement decreases towards the west, and the fault eventually merges into a south-dipping monocline located 4 miles west of Ten Sleep (Hosterman et al. 1989; Cooley and Head 1979; Darton 1906).

Hazards
Karst, landslide, and seismic geological hazards exist within the Nowood watershed. Karst creates sinkhole hazards and occurs from the dissolution of chemical rocks (limestone, gypsum, dolomite, etc.). Landslides occur when sediment moves downslope under the influence of gravity, potentially damaging structures and altering the hydrogeology of the watershed. Seismic events create a hazard to structures and tend to occur along fault lines, but earthquakes have occurred in areas with no known respective structural feature. The potential areas at risk for these hazards are presented on Figure 3.

Karst topography within the Nowood watershed is found west of the Nowood River. Closed depressions and solution collapse features are found on the surface and have been associated with the Goose Egg and Gypsum Spring Formations (Cooley and Head, 1979). These features were developed from the dissolution of gypsum and limestone underlying surficial deposits. The surficial deposits then reflected the karst topography below them. The limestone and dolomite of the Madison, Bighorn, and Gallatin Formations have also developed a karst topography. Some of this topography is concealed by the Amsden Formation, which unconformably overlies paleokarst features of the Madison (Hosterman et al., 1989). However, extensive, recently developed caves exist in the northeastern portion of the Nowood watershed, near Medicine Lodge Creek (Susong et al., 1993).

Collapse risk due to sinkholes can be difficult to determine due to their subsurface nature. Certain features can be indicative of karst: closed depressions, sinking streams, blind valleys, and others. However, subsurface investigations (including geophysical, tracer dye, and field surveys) need to be conducted to provide an adequate assessment.

Landslide hazards exist in areas where the resisting forces (friction and cohesion/adhesion between sediment particles) have the potential to be exceeded by the driving forces (gravity). This condition can be found throughout the upland areas of the Nowood watershed. Paleolandslides (“li” unit in Figure XX) are indicators of future landslide activity. Slopes experiencing undercutting due to lateral erosion of streams are also at high risk. Severe erosion problems have been noted on the Nowood River, with less severe erosion on the Paintrock, Ten Sleep, Otter, and Canyon Creeks (USDA 1971). The lateral erosion by streams undercuts the toe of slopes and removes their underlying support. Other factors for potential landslide areas include grain size and shape, lateral and underlying support, slope angle, sediment composition, and water content.

The Nowood watershed is an area with minor historical seismicity. Since 1350, epicenters of 11 earthquakes have been in or near the watershed. The largest magnitude earthquake, with a magnitude of 4.9, occurred in 1970. The epicenter was located approximately 8 miles southwest of Ten Sleep. The smallest magnitude earthquakes of 3.0 occurred in 1998 and 2000 (USGS 2009; Case et al. 2002). Two earthquakes recorded in 1925 and 1966, occurred before magnitude measurements were regularly recorded. The earthquakes were rated using the Modified Mercalli Intensity Scale. Intensity was not noted for the 1966 earthquake, and an intensity V level was applied to the 1925 event. The 1925 event
was felt in Ten Sleep, Sheridan, Fort McKenzie, and Dome Lake Resort, but damage was not reported (Case et al. 2002).

Two fault systems are located adjacent to each other in the southern portion of Nowood watershed: the Cedar Ridge and Dry Fork fault systems. Evidence suggests that the fault systems are inactive. However, one confirmed case of Pleistocene-aged movement, in the form of a fault scarp, was documented in northeastern Fremont County (Case et al. 2002). If either the Cedar Ridge or Dry Fork fault systems were to become active, they could potentially generate 6.7 and 7.1 magnitude earthquakes, respectively. A 6.7 magnitude earthquake at the Cedar Ridge System could produce a peak horizontal ground acceleration of 2.9%g at Ten Sleep and 2.0%g at Big Trails. A 7.1 magnitude earthquake at the Dry Fork System would produce a peak ground acceleration of 3.8%g at Ten Sleep and 7.4%g at Big Trails. In either case, minor damage could result from these earthquakes at Big Trails, WY (Case et al. 2002).

Although active fault systems are not currently located near the Nowood watershed, large earthquakes can still occur in areas without a known source structure. These earthquakes are known as “floating earthquakes.” Federal and state regulations require a floating earthquake analysis for certain structures (mill tailing sites, landfills, etc.). If a structure within the Nowood watershed required such analysis, a 6.25 magnitude earthquake with an epicenter 15 miles from the structure could be used as a conservative estimate for design ground accelerations. An earthquake of this magnitude and distance could produce ground accelerations of 15%g (Case et al. 2002). Some structures (e.g. dams) may require a more detailed risk analysis.

Another type of seismic hazard analysis, completed by the USGS, estimates the probability of exceeding the peak horizontal ground acceleration that could occur from an earthquake in the next 50 years. This analysis was most recently updated in 2008 and can be found at http://gldims.cr.usgs.gov/nshmp2008/viewer.htm. For the Nowood watershed, the peak horizontal ground acceleration that has a 10% chance of being exceeded from 2008 to 2058, is from 4-5%g. The peak ground acceleration that has a 2% chance of being exceeded from 2008 to 2058 is from 15-17%g. This methodology uses the frequency and magnitude of past earthquakes to estimate the frequency and magnitude of future earthquakes. A weakness to this method is that it can inaccurately predict earthquake risk in areas with a low frequency of earthquakes, like the Nowood watershed. However, few other alternatives for estimating the risk exist.

**Site Conditions**

After the reconnaissance-level assessment, ACE provided Trihydro a list of the following nine sites for additional field investigation: Little Canyon, Nowood-Crawford, Cottonwood Creek, Meadowlark Lake (enlargement of existing reservoir), Taylor Draw, Deep Creek, Bruner Gulch, Upper Nowood, and Big Trails. The field evaluations consisted of verifying and describing the bedrock conditions along the embankment alignment, collecting samples of foundation and potential embankment fill materials, identifying possible spillway locations, and photo documenting the site. The remainder of this memorandum provides summary findings from field investigations of the nine identified reservoir sites, an overview of the geology of the Nowood River watershed and detailed documentation of the results of the field investigations.
Little Canyon

The project was discussed in detail with the landowner, but access to the reservoir site was not granted. Therefore, ACE excluded this site from further consideration by Trihydro.

Nowood-Crawford

The proposed dam location for the Nowood-Crawford site is on the Nowood River, approximately 800 feet downstream of the Crawford Creek confluence. The embankment location is within the Jurassic part of the section, with sandstones of the Sundance Formation outcropping at the left abutment (Figure 4A) and siltstones of the Gypsum Springs Formations outcropping near the right abutment (Figure 4B). Sandstones of the Chugwater Formation were observed to the south of the right abutment. The beds near the left and right abutments are similarly oriented. Near the left abutment, the beds dip to the north at 15° (degrees) along a strike of 98°. Near the right abutment, the beds dip to the north at 20° along a strike of 101°.

Three samples were collected from this site. The first sample was collected from an outcrop to the south of the right abutment and consists of yellow, fine-grained sandstone with well-sorted, subrounded quartz grains and a very minor lithic fragment component. The sandstone is well-cemented but friable. The cement in the sandstone did not react with dilute hydrochloric acid. The second sample was taken from the alluvium near the right bank of the Nowood River and consists of red silty clay with sand and gravel. The fine fraction of the alluvium holds a weak thread when wet. The third sample was collected from an outcrop near the base of the left abutment and consists of greenish-gray, hard, glauconitic, very fine-grained sandstone or siltstone, with minor lithic fragment and gypsum components.

The proposed embankment alignment is near the contact between the Gypsum Springs and Sundance Formations and was observed in an outcrop on the left side of the drainage approximately 400 feet upstream of the left abutment. The Gypsum Springs Formation was also observed outcropping in the bottom of the drainage near the embankment location (Figure 4C) and is likely overlain by the alluvium and colluvium in the valley bottom and right abutment. Although this formation was flagged as a high risk in the reconnaissance-level assessment, an existing dam and reservoir is located in a similar geologic setting approximately 1 mile downstream of the identified site. (Figure 4D). The existing dam embankment appeared to be stable; however, observation of the sediment accumulated within the upstream portion of the existing reservoir indicates this portion of the watershed has a high siltation potential.

A sufficient volume of borrow material could likely be found in the valley bottom, assuming that the properties of this material are suitable for embankment fill. The second sample described for this site was collected to represent this locally available borrow material. A source of coarse material for riprap and embankment drainage was not observed near the site, and this material would likely need to be imported. Depending on the embankment height, a possible spillway location was identified near the right abutment (Figure 4B). For construction at this site, the Nowood River Road and the Bates Creek road would need to be rerouted.
Cottonwood Creek

The proposed dam location for the Cottonwood Creek site is on Cottonwood Creek approximately 4,400 feet upstream of its confluence with the Nowood River. The alignment evaluated in the field is located approximately 850 feet upstream of the alignment provided by ACE. The embankment location is within the lower Cretaceous part of the section, with sandstones of the Cloverly Formation outcropping at the left and right abutments (Figures 5A and 5B). The sandstone bedding planes in the area of the abutments dip to the south at 11° along a strike of 264°.

A small cave has eroded in the sandstone near the base of the left abutment (Figure 6B), which suggests a potential leakage risk for the reservoir that would need to be evaluated during a subsequent subsurface investigation. However, this erosional pattern did not appear to be widespread and may be an isolated occurrence.

Three samples were collected at this site. The first sample was collected near the right abutment and consists of dark red, hard, glauconitic silt shale. The second sample was taken from the alluvium in the bottom of the Cottonwood Creek valley and consists of light tan silty clay that holds a weak thread when wet. The third sample was collected near the base of the left abutment and consists of yellow-tan, fine-grained sandstone with well-sorted, frosted, subrounded quartz grains and a very minor mafic component. The sandstone is well-cemented but friable. The cement in the sandstone did not react with dilute hydrochloric acid.

A sufficient volume of borrow material could likely be found in the valley bottom, assuming that the properties of this material are suitable for embankment fill. The second sample described for this site was collected to represent this locally available borrow material. A source of coarse material for riprap and embankment drainage was not observed at the site, and this material would likely need to be imported. A possible spillway location was identified near the right abutment, which would utilize an existing drainage immediately downstream of the abutment (Figure 6A).

Meadowlark Lake Enlargement

Meadowlark Lake is an existing reservoir on Tensleep Creek near the confluence with East Tensleep Creek. The reservoir was constructed in the late 1930s as a work project for the Civilian Conservation Corps (CCC). An enlargement project would likely require consideration for preserving the historical value of the site.

The existing dam consists of a 30-foot tall embankment with a primary outlet channel near the right-center of the embankment, an emergency spillway near the left side of the embankment, and what appears to be a fish ladder adjacent to the spillway (Figure 7). The primary outlet and spillway channels are in need of repair, and the condition of the internal primary outlet plumbing could not be assessed. Based on the surface area of the reservoir from the SEO filing, raising the water level would yield approximately 300 acre-feet of additional storage per foot of water surface elevation.

Taylor Draw

The proposed dam location for the Taylor Draw site is near the mouth of Taylor draw approximately 2,100 feet upstream of the confluence with the Nowood River. The embankment location is within the
lower Cretaceous part of the section, with Thermopolis Shale outcropping near the left and right abutments (Figures 8A and 8B). The shale at the ground surface is easily erodible, but the material becomes more competent with depth. The shale in outcrops on both sides of the drainage consistently dips to the west.

Two samples were collected at this site. The first sample was taken from the right abutment and consists of moderately hard, but easily friable, black clay shale. The second sample was collected from the channel bottom and consists of brownish-tan silty clay that holds a fine-diameter thread when wet.

The channel morphology of Taylor Draw suggests that the drainage basin does not receive enough runoff to directly support a large reservoir (Figure 8C). However, the site may be feasible for an off-channel reservoir storing water from the Nowood. A sufficient volume of borrow material could likely be found in the valley bottom, assuming that the properties of this material are suitable for embankment fill. The second sample described for this site was collected to represent this locally available borrow material. A source of coarse material for riprap and embankment drainage was not observed near the site, and this material would likely need to be imported. A possible spillway location was identified near the left abutment.

Deep Creek

The proposed dam location for the Deep Creek site is just downstream of the Cherry Creek road crossing. The location is within the lower Mississippian part of the section, with limestone of the Madison Formation outcropping at the left and right abutments (Figure 9). The limestone in the area of the embankment appeared to be resistant, but karstic erosional features were observed in downstream outcrops (Figure 10A). Compared to the downstream outcrops, the outcrop near the left abutment appeared relatively resistant, with minor dissolution along fracture planes. A geode was observed in the outcrop, suggesting the potential for dissolution (Figure 10B).

Two samples were collected at this site. The first sample was collected from an outcrop at the left abutment near the bottom of the drainage and consists of massive gray limestone/mudstone with little to no allochems. The second sample was collected on the north side of the access road approximately 600 feet upstream of the provided dam location. This sample consists of a greenish-gray, hard siltstone or shale with quartz veins interbedded with a green conglomerate with subangular to subrounded, flat pebble clasts.

This site may be feasible for an embankment, but a significant subsurface investigation would be required to determine the competency of the underlying bedrock for holding water in the reservoir and serving as a foundation for the embankment. Borrow material for an earthen embankment may be difficult to locate in this part of the basin. Given the potential foundation conditions and the possible borrow limitations, a concrete structure may be more appropriate for this location than an earthen embankment. The dam would likely need to be designed with a spillway running down the downstream face, because a good spillway location was not identified at this site.

Bruner Gulch

The proposed dam location for the Bruner Gulch site is on Buffalo Creek immediately upstream of Bruner Draw. The embankment location is within the upper Cretaceous part of the section, with
sandstone of the Frontier Formation outcropping at the left abutment and sandstone and shale of the Frontier Formation outcropping at the right abutment (Figures 11A and 11B). The sandstone beds near the left and right abutments are similarly oriented. Near the left abutment, the beds dip to the west at 17° along a strike of 353°. Near the right abutment, the beds dip to the west at 17° along a strike of 350°. Shale of either the Frontier Formation or the Mowry Shale was observed downstream of the left and right abutments. Downstream of the left abutment, this shale dips to the west at 21° along a strike of 344°.

Four samples were collected at this site. The first sample was taken from the left abutment and consists of gray, fine- to medium-grained lithic arenite with poorly sorted, subrounded quartz grains and lithic fragments. The sandstone is well-cemented but friable. The second sample was collected from the channel bottom near the left abutment and consists of gray silty clay that holds a fine diameter thread when wet. The third sample was collected from a shale outcrop near the right abutment and consists of gray, easily friable, silt shale with faint, thin laminations. The fourth sample was collected from a shale outcrop downstream of the Bruner Draw confluence near the right abutment and consists of gray, moderately soft to hard, friable, silt shale.

A sufficient volume of borrow material could likely be found in the valley bottom, assuming that the properties of this material are suitable for embankment fill. The second sample described for this site was collected to represent locally available borrow material. A source of coarse material for riprap and embankment drainage was not observed at the site, and this material would likely need to be imported. A possible spillway location was identified near the left abutment, which would utilize an existing drainage immediately downstream of the abutment.

Upper Nowood

The proposed dam location for the Upper Nowood site is on the Nowood River approximately 3 miles upstream of the Little Canyon Creek confluence. Two potential embankment locations were evaluated at this site: one at the location provided by ACE (Figure 12) and one approximately 500 yards upstream of the provided location (Figure 13). This site is located in the upper Jurassic part of the section, with sandstones of the Sundance Formation outcropping near each abutment. The sandstones higher on the slope comprising the left abutment may be of the Morrison Formation. The sandstone beds near each abutment are similarly oriented. Near the right abutment of the upstream location, the beds dip to the west at 2° along a strike of 32°. Near the left abutment of the downstream location, the beds dip to the west at 7° along a strike of 36°. Along with sandstone outcrops, the hill slope comprising the left abutment at the upstream location consists of thick beds of soft, erodible siltstone or claystone (Figure 14A).

Three samples were collected from this site. The first sample was collected from the right abutment of the upstream location and consists of tan, well-cemented, very fine-grained quartz sandstone with calcareous cement. The second sample was collected in the floodplain on the left side of the river and consists of red silty clay. The clay holds a fine diameter thread when wet, but is less dense than the silty clays at the other sites. The third sample was taken from left abutment of the original location and consists of the same sandstone as the first sample.

The hydrology of the site would support a large reservoir, assuming that unappropriated water is available. For an earthen embankment, a sufficient volume of borrow material could likely be found in
the valley bottom, assuming that the properties of this material are suitable for embankment fill. The second sample described for this site was collected to represent this locally available borrow material. Gravel and cobble lenses were observed in the bank of the Nowood, representing former channel deposits (Figure 14B). Borrow material from the floodplain would need to be segregated to separate the fine material from these gravels and cobbles. The coarse material from the former channel deposits could likely be used for embankment drainage. A source of coarse material for riprap was not observed at the site, and this material would likely need to be imported. Depending on the height of the embankment, two small drainages east of the right abutments could be used in the construction of spillways (Figures 12C and 13C).

**Big Trails**

The proposed dam location for the Big Trails site is on the Nowood River, approximately 5 miles upstream of the Little Canyon Creek confluence. The embankment location is within the Jurassic part of the section, with both abutments primarily within the Gypsum Springs Formation (Figure 15A). Sandstones of the Sundance Formation were observed cropping out as capstone above both abutments, but the abutments themselves would be located within very soft, erodible gypsum (Figure 15B). Because of these foundation conditions, this site is not recommended for further consideration as a potential reservoir location.

Two samples were collected at this site. The first sample was taken near the base of the left abutment and consists of gypsum. The second sample was collected from the capstone outcropping at the top of the left abutment and consists of greenish-gray, glauconitic, hard, very fine-grained sandstone.

**Summary Findings**

The geologic conditions for each embankment location were evaluated by mapping outcrops at the surface and by inferring subsurface conditions based on observed structure and published regional stratigraphy. The findings presented in this memorandum regarding each site would need to be verified by subsurface investigations, including investigative borings.

Based on this surface investigation, Cottonwood Creek, Meadowlark Lake, Taylor Draw, Bruner Gulch, and Upper Nowood would warrant additional subsurface study to evaluate the competency of the foundation materials. Outstanding geologic risk was not found at these sites.

If other driving factors favor development of the Nowood-Crawford and Deep Creek sites, these sites would also warrant additional subsurface investigation. The geology at these two sites was not as favorable as the aforementioned. A high potential for karstic features exists in the foundation of Deep Creek, and there is a high risk of gypsum being one of the primary foundation materials for Nowood-Crawford.

The only site not recommended for further investigation is Big Trails because of the amount of gypsum outcropping at the embankment location. This material is too erodible to serve as an appropriate dam foundation.
References


Table 1 Reservoir Site Evaluation

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<th>Dam Name</th>
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<th>Site Name</th>
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<th>Reservoir pool area</th>
<th>Contributing watershed</th>
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<td>Medicine Lodge</td>
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<td>No outstanding geologic risk evident</td>
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<td>Lower Trout Creek</td>
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<td>Field verify alluvium and potential for seepage through Frontier</td>
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<td>Dam and Reservoir Site Name</td>
<td>Description of site geology</td>
<td>Dam embankment foundation</td>
<td>Reservoir pool area</td>
<td>Contributing watershed</td>
<td>Note</td>
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<td>31 South Fork Otter (Lower)</td>
<td>Tensleep/Amsden at embankment and in pool; Chugwater/Goose Egg in pool; Tensleep/Amsden, Chugwater/Goose Egg, Madison limestone, basement Gneiss in basin; mapped landslide in pool</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>Embankment on edge of mapped gypsum area, field verify Gypsum Springs versus Tensleep/Amsden mapping, field verify condition of Tensleep, field verify mapped landslide in pool</td>
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<tr>
<td>32 South Fork Otter (Upper)</td>
<td>Tensleep/Amsden at embankment; Madison Limestone in pool; Gneiss in basin; faulting near embankment and in basin; mapped landslide in pool and near embankment</td>
<td>D</td>
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<td>D</td>
<td>Karst risk from ACE layer, verify structure near embankment, field verify mapped landslides</td>
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<td>33 Canyon Creek</td>
<td>Madison limestone; Chugwater/Goose Egg, Tensleep/Amsden at embankment and in pool; Tensleep/Amsden and Madison in basin; fault at the embankment; mapped landslide deposits near embankment</td>
<td>D</td>
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<td>Karst risk from ACE layer, verify structure and landslides near embankment</td>
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<td>34 Lone Tree</td>
<td>Tensleep/Amsden, Goose Egg, and Gypsum Springs near embankment, pool and basin; Madison and Gallatin in basin; faulting near pool</td>
<td>D</td>
<td>D</td>
<td>D</td>
<td>Embankment within mapped Gypsum area</td>
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<tr>
<td>35 North Brokenback</td>
<td>Tensleep/Amsden at embankment and in pool; Madison/Darby in basin</td>
<td>C+</td>
<td>C+</td>
<td>D</td>
<td>Field verify Tensleep condition</td>
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</tbody>
</table>
Figure 1 of 15  Nowood River Watershed: Surficial Geology

Legend

- **Ri** - Bedrock
- **ai** - Alluvium
- **bdi** - Dissected Bench
- **fdi** - Dissected Alluvial Fan
- **fi** - Alluvial Fan
- **gi** - Glacial Deposits
- **li** - Landslide Mixed
- **mi** - Mesa
- **oai** - Glacial Outwash
- **ri** - Residuum
- **sci** - Slopewash and Colluvium
- **tdi** - Dissected Terrace
- **ti** - Terrace Deposits
- **ui** - Grus Mixed

County Boundary
Streams
Cities
Nowood Watershed

Scale: 1:90,000

P:\WYWDC29_Nowood\GIS\Figures\Nowood_Surficial_Geology.mxd
NOTES:
1. PHOTOS TAKEN ON JULY 27, 2009.
NOTES:
1. PHOTOS TAKEN ON JULY 28, 2009.
NOTES:
1. PHOTOS TAKEN ON JULY 28, 2009.

A VIEW OF POSSIBLE SPILLWAY LOCATION

B SMALL CAVE AT BASE OF LEFT ABUTMENT

FIGURE 6 OF 15
COTTONWOOD CREEK SITE PHOTOS
NOWOOD RIVER WATERSHED STUDY

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PHOTOS TAKEN ON JULY 28, 2009.
FIGURE 7 OF 15

MEADOWLARK LAKE SITE PHOTOS

NOWOOD RIVER
WATERSHED STUDY

NOTES:
1. PHOTOS TAKEN ON JULY 28, 2009.
NOTES:

1. PHOTOS TAKEN ON JULY 28, 2009.
FIGURE 9 OF 15

DEEP CREEK SITE PHOTOS

NOWOOD RIVER
WATERSHED STUDY

A VIEW OF LEFT ABUTMENT

MADISON LIMESTONE AT LEFT ABUTMENT

B VIEW OF RIGHT ABUTMENT

MADISON LIMESTONE AT RIGHT ABUTMENT

GALLATIN FORMATION PEBBLE CONGLOMERATE UPSTREAM OF RIGHT ABUTMENT

NOTES:
1. PHOTOS TAKEN ON JULY 29, 2009.
NOTES:
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NOTES:
1. PHOTOS TAKEN ON JULY 30, 2009.

A BASE OF LEFT ABUTMENT
UPPER LOCATION

B SOIL HORIZONS AND FORMER CHANNEL BED
RIGHT BANK OF NOWOOD RIVER
NOTES:
1. PHOTOS TAKEN ON JULY 30, 2009.