LOCATION AND DEVELOPMENT OF GROUNDWATER RESOURCES FOR EVANSVILLE, WYOMING
Town of Evansville
City Hall
Evansville, Wyoming 82636

Attention: Mayor Anthony and Council
Mr. Akers, Director of Planning

Subject: Transmittal of "Report and Recommendations for the Location and Development of Groundwater Resources for the Town of Evansville, Wyoming."

Dear Ladies and Gentlemen,

The attached subject report sets forth and illustrates areas and specific locations which have been hydrogeologically evaluated as having the best prospects for development of large quantities of high quality waters for the Town of Evansville. The original draft of this report was reviewed by staff members of the Wyoming Water Development Commission and the State Engineer. As a result of that review the report and the recommendations have been revised to conform with their comments and suggestions as is explained in the body of the report.

Two potential source locations are identified and evaluated in this report. The final selection of a drill site will be the decision of the Town Council, in consultation with Sargent's geologist. The recommended drilling locations all have much hydrogeologic merit as sources of ground water. The cost estimates for each prospect are provided to assist in the evaluation of the prospects.

We are confident that if the recommendations contained in this report are followed, Evansville will have resolved its water supply problems for the foreseeable future.

Very truly yours,
Sargent Irrigation Company

Harold C. Mosher
Certified Professional Geologist
American Institute Professional Geologist, No. 2492

HCM:cb
Enclosure: Report
Report and Recommendations
For The
LOCATION and DEVELOPMENT
OF
GROUNDWATER RESOURCES
for
The Town of Evansville
Wyoming

By

Sargent Irrigation Company
Casper, Wyoming

August 1983
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POSSIBLE LOCATIONS FOR GROUNDWATER DEVELOPMENT

Scale: 1/4 in. = 1 mi.

PLATE I
INTRODUCTION

The purpose of this report is to indicate specific locations where drilling of high capacity wells will have good probabilities for success. Depth to aquifers and therefore drilling costs, as well as water quality considerations are the controlling parameters.

It is seldom possible to locate areas that satisfy the above requirements and still have selected well sites convenient distances from the point or points of use. For this reason, a rather expensive pipeline would be involved. Pipeline lengths and costs are estimated and included in the total cost estimates for the recommended drilling sites.

In the discussion of the first draft of this report with the State Engineer it was stated that the proposed site at Emigrant Gap would not be approved, or at least not approved without a stipulation requiring very extended testing. This problem is discussed in detail on subsequent pages of this report.

Land ownership or leasehold agreements have not been investigated or allowed to influence the selection of proposed drill sites. However, Wyoming State lands have been closely examined and one of the recommended locations is situated on State leased land.

It is believed that with the implementation of the recommendations presented, the groundwater exploration philosophy of the Wyoming Water Development Commision and the long term needs of the Town of Evansville should be satisfied.

EXECUTIVE SUMMARY

The geology of the entire Casper Mountain and a portion of Muddy Mountain has been reviewed on maps and numerous previously released reports and theses consulted. Air photos were studied of areas judged most favorable for development of groundwater resources. The areas were refined
to specific locations following actual checking in the field.

The results of these studies led to the selection of three sites which seemed to best satisfy the most criteria regarded as necessary to developing long term, high yielding groundwater supplies. The conclusion reached in the course of this study and by other reports, is that the hydrogeologically most feasible well sites are at distances from Evansville that will require pipelines which will escalate total system costs appreciably. It is beyond the scope of this report to detail pipeline costs. However, certain gross estimates are presented in order to facilitate evaluation of alternative prospect locations.

It is the objective of this report to provide the necessary geotechnical information to assist the Town of Evansville in selecting the alternative most feasible in terms of anticipated future water requirements and available financing. Regarding the prospects studied, the amount of positive information is limited at best because no such program has been implemented in this area, and no real hydrologic data is available for this area, particularly where the productivity and water quality is concerned.

It is believed, however, that the prospects presented are justified by the hydrogeological features which are presented and by the needs of the Town of Evansville.

NEGATIVE REVIEW COMMENTS

The "Draft" of this report was submitted to the staff of the Wyoming Water Development Commission and to Dick Stockdale of the State Engineer's Office for their comments and approval. These reviewing authorities approved the contents of the report in general but they stated that the possibility of receiving approval to drill at the Emigrant Gap-Highway site would be very much in doubt. Even in the event that this site received a conditional approval, a long term and very expensive testing program would be required to determine that the proposed water well was having absolutely no effects on the Speas
Spring.

Such a program would require monitoring of pressures at the Speas Spring in addition to those of the new well for probably no less than six months. Further, there is no base line data relating to any present decline of the Speas Spring. Without such base line data, it would not be possible to differentiate whether any pressure drops were from normal long term spring usage or due in part to pumping of a well at Emigrant Gap.

For the above reasons it becomes necessary to withdraw the recommendation to drill a test well at the Emigrant Gap-Highway location at this time. Because the hydrogeologic analysis of this area may prove to be of value at some future time this portion of the report has been included in the APPENDIX.

RECOMMENDATIONS

The recommendations presented below are in the order of their hydrogeological merit and least risk, while maximizing the prospects for immediate acquisition of the largest possible water appropriation.

These recommendations are to develop:
1) The South Hat Six-Pole Creek Syncline prospect.
2) The Hat Six Lakota Sandstone prospect.

The above order is also that of the estimated total project cost, including pipelines and financing, number One being the costlier alternative. It is probable that with the development of a large capacity source of potable water, some type of financing agreement could be arranged, possibly through the State of Wyoming, for a delivery system to the potential users.

WHY GROUNDWATER?

The Citizens of Wyoming have always suffered from insufficient water supplies. Municipal demands must compete with industrial and agricultural
users for limited and over-appropriated surface waters. Although, there are many small towns in Wyoming that have depended on groundwater for municipal supplies, it was not until the late 1970's that cities began looking seriously at major groundwater development programs as a way to augment their existing supplies in order to accommodate their rapidly growing populations.

It was recognized by the Wyoming State Engineer and the Interstate River Compact Commissions, that water pumped from the alluvium of rivers and their tributary valleys was actually river water and as such had to be regulated by the laws of appropriation governing surface waters.

The move to the serious consideration of groundwater was and always has been hampered by two principal factors. These are Geology and Economics.

Geology controls the location of feasible source areas and specific locations, as well as the quantity and quality of underground water.

Economics affects the development of groundwater because of the public perception that drilling and completing wells and the construction of pipelines is excessively expensive. This public perception has at its roots the fact that municipal water supplies have been provided at subsidized and/or bargain rates.

At the present time, the available supplies of water are keeping up with demand temporarily but this condition could change overnight if a dryer climatic cycle were to start or if a resurgence of business activity caused an accelerated population growth. It should be noted also that any municipality, situated such as Evansville is, will attract new business and population in proportion to the availability of water through its municipal system.

For the foregoing reasons, it appears that by initiating a program of developing groundwater and building the necessary pipelines, that Evansville could assure itself sufficient water supplies to accommodate its needs into the next century.
ESTIMATED WATER DEMANDS

At the present time Evansville is satisfying its water demands from very junior water rights to Platte River water. These water rights would be in jeopardy in the case of abnormally low flow of the Platte River due to a dryer climatic cycle. Also, present water rights would be insufficient in the future if even a moderate, 3 percent population growth is predicted.

On Figure 1, estimated possible future population numbers are plotted at several growth rates. Different studies by various engineers have yielded a large variation in these rates. The numbers presented on Figure 1, are based primarily upon the following figures.

Growth for the City of Casper between 1970 and 1980 was 3 percent per year. Natrona County's growth rate was 4 percent per year for that base period.*

During the 1980-83 period Evansville lost population due to the general recession, primarily in the energy and related industries. It was therefore decided in consultation with the Evansville planning Coordinator, Mr. Akers, to use a base figure of 2500 population in 1980 to project future growth.

Figure 1, includes population projections for annual rates of growth between 3 percent and 5 percent and extends to the year 2030. The population data presented on Table 1, is taken from the 3.5 percent projection on Figure 1.

* Source: Casper City Planner's office, personal communication.
POPULATION PROJECTIONS
FOR
EVANsville, WYOmiNg

FIGURE I

BASIS:
estimated Population = 2500(1 + r)^Y
Y = number of years
r = percent growth rate
2500 = base population 1980
This should tend to minimize any skewness that might develop as a result of any future economic aberrations. It should also provide realistic gross water demand figures.

A figure of 170 gallons per minute per capita is used to compute water demand. H.N.T.B. Engineers confirm that this figure is a good yearly average figure with allowances for residential, and industrial consumption as well as the demands of fire protection standards.

The following table gives an index of the water well capacities which would be required to satisfy the total demands of the projected population of Evansville for the years cited.

**TABLE I**

<table>
<thead>
<tr>
<th>Year</th>
<th>Estimated Population</th>
<th>Population Consumption @170 gpm/capita/day</th>
<th>Well(s) Production Required*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>2,969</td>
<td>504,730</td>
<td>505 gpm</td>
</tr>
<tr>
<td>1990</td>
<td>3,527</td>
<td>599,590</td>
<td>600 gpm</td>
</tr>
<tr>
<td>1995</td>
<td>4,188</td>
<td>711,960</td>
<td>712 gpm</td>
</tr>
<tr>
<td>2000</td>
<td>4,975</td>
<td>845,750</td>
<td>846 gpm</td>
</tr>
<tr>
<td>2005</td>
<td>5,908</td>
<td>1,004,360</td>
<td>1,005 gpm</td>
</tr>
<tr>
<td>2010</td>
<td>7,017</td>
<td>1,192,890</td>
<td>1,193 gpm</td>
</tr>
<tr>
<td>2020</td>
<td>9,898</td>
<td>1,682,660</td>
<td>1,683 gpm</td>
</tr>
<tr>
<td>2030</td>
<td>13,962</td>
<td>2,373,540</td>
<td>2,373 gpm</td>
</tr>
</tbody>
</table>

* Average, 1000 minutes per day pumping.

It can be seen from the figures given above that with an aggressive groundwater development program, all of the near term water requirements, possible to the year 2000 could be satisfied from groundwater sources. This statement is based on the expectation of developing between 500 gpm and 1000 gpm from one well.
EXPLORATORY APPROACH

The key to finding large quantities of potable water at moderate depths in the Evansville - Casper area lies in finding areas with the following characteristics:

1. There should be evidence of present or past faulting and/or fracturing.

2. Tear or cross faulting which intersects strike faulting (i.e. faulting parallel to the trend of the formations) provides the maximum possibilities for the existence of zones of high transmissivity.

3. There must be ample area to what may be termed the subsurface drainage basin. These are generally geological synclines or "lows" and in many cases do not coincide with the topographic lows.

4. There should be ample areas for recharge of aquifers.

5. The objective aquifers should be known to be highly productive within the general vicinity of any proposed test.

6. In the case of the Casper and Madison Formations a depth limitation of approximately 3500 feet should be observed to minimize the risk of unacceptable water quality.

At numerous places in Wyoming these criteria can be cited as the causes for the existence of springs, some of which have excellent flows. Further, the City of Worland is currently in the process of utilizing water from the Madison Formation from a well drilled on Paint Rock anticline off the west flank of the Bighorn Mountains. This well had all of the above favorable characteristics and has been tested for more than 10,000 g.p.m. flowing.

It must be recognized at the outset, in any drilling project in an entirely new area to formations as yet untested, an element of risk is involved. It is the function of the geologist to analyze all
hydrogeological aspects of the proposed location areas to reduce the size of the risk involved. For this reason two of the locations proposed for drilling in this report call for one small diameter test well. As will be detailed subsequently the test well will allow an evaluation to be made of the feasibility of drilling a production well nearby.

The evaluation of the aquifers penetrated should be facilitated by the information provided by a drill stem test and analysis of the geophysical logs.

STRATIGRAPHY

The stratigraphy of the general Casper Mountain area is outlined on the Composite Stratigraphic Section, Table II. Detailed measured surface sections are included in the Appendix.

It should be noted that many of the zone contacts between the limestones and sandstones of the Casper Formation are gradational over short distances and therefore the definition of some of the aquifers depends on the nature of the drill samples from any particular location.

STRUCTURAL GEOLOGY AND LAND FORMS

When sufficient force or stress is applied to any object it either bends or breaks. Bending causes fractures and breaking causes displacement. In this case geologic strata or units are involved. Complicating the geologic applications of simple natural laws is the presence of shales and bentonitic clays which respond as plastics and tend to "flow" under compression.

In the areas addressed in this report the primary source of vertical and transverse pressures is the basement or Pre-Cambrian rock masses which have moved along pre-existing lines of weakness. The forces applied by these rocks then caused tilting or folding, displacement (faulting) and fracturing of the hard formations such as the limestones and sandstones.
<table>
<thead>
<tr>
<th>ERA</th>
<th>PERIODS</th>
<th>SERIES</th>
<th>ROCK-STRATIGRAPHIC UNIT</th>
<th>THICKNESS (FEET)</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic</td>
<td>Quaternary</td>
<td></td>
<td>Landslide Deposits</td>
<td>Variable</td>
<td>Landslide and slump debris</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Windblown Deposits</td>
<td>Variable</td>
<td>Unconsolidated sand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Alluvial Deposits</td>
<td>Variable</td>
<td>Unconsolidated silt, sand and gravel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cody Shale</td>
<td>2950-3400</td>
<td>Gray soft shale and lenticular sandstone beds, gray limy shale at base.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Frontier Formation</td>
<td>850-900</td>
<td>Dark gray concretionary shale and white bentonite interbedded with sandstones.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower</td>
<td>Mowry Shale</td>
<td>250-300</td>
<td>Back siliceous shale, dark gray shale, bentonite with sandstone lenses, weathers silvery white.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Thermopolis Shale and Muddy Sandstone</td>
<td>75-100</td>
<td>Thermopolis shale - dark gray calcareous shale Muddy Sandstone Member - sandstone, siltstone, and shandy shale at top.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cloverly Formation</td>
<td></td>
<td>Brown, hard, chert pebble conglomerate at base of Cloverly formation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lakota Member</td>
<td>50-150</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Morrison and Sundance Formations</td>
<td>420-460</td>
<td>Morrison Formation - variegated claystone with gray silty sandstone lenses, Sundance Formation - olive gray sandstone with a persistent thin-bedded sandstone at the base.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Chugwater Group</td>
<td>640-700</td>
<td>Upper formation - red sandstone and siltstone, middle formation - gray laminated ledge-forming limestone, lower formation-red shale and siltstone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>Goose Egg Formation</td>
<td>380-400</td>
<td>Red shale with interbedded gray algal limestone and gypsum beds.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paleozoic</td>
<td>Permian</td>
<td></td>
<td>Casper Formation</td>
<td>500-1000</td>
<td>Gray and tan thick-bedded sandstone underlain by interbedded sandstone, pink and gray limestone and dolomite and red shale; red to gray sandstone at base.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Madison Formation</td>
<td>150-250</td>
<td>Gray to light-gray massive chert limestone and dolomitic limestone.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Upper</td>
<td>Cambrian-Mississippian Sandstone</td>
<td>50-100</td>
<td>Dull pink conglomeratic sandstone, grades upward into moderately well-sorted quartzose sandstone - increasingly calcareous upwards.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proterozoic</td>
<td>Precambrian</td>
<td>--</td>
<td></td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

*Tertiary, Devonian, Silurian and Ordovician units not present in study area.*
of the geologic section.

It is frequently necessary to infer faulting where actual displacement cannot be seen and measured. This is done by extending the faulting beyond where it is visible and by looking at the surface drainage and topography. For example on Plate II, in Section 4, T 31 N - R 78 W, the breaks in the continuity of the Cloverly Group (Kvc) which allow egress of the creeks are regarded as inferential evidence of faulting. Further, drainages which are long and very straight may indicate faulting at depth.

The next question that arises is the effect of meteoric or recharge and connate groundwaters on faults. If the extremely hard formations such as the Madison or Casper Formations are faulted, it can be assumed, in most cases, that chemical solution of any limestone, either formational or as the sand grain cementing agent, will have created a multiplicity of void spaces which have been enlarged through geologic time. These types of water filled void spaces are the expected sources of high volumes of water in the areas proposed for development of Paleozoic aquifers.

LANDSAT PHOTOGRAPHY

The landsat photograph for the entire project area was examined critically. The major structural components, faults, anticlines and synclines, show up clearly. However, due to the very small scale of the photo some suspected subsidiary faulting is ill-defined or lost in drainages. Further definition requires the use of normal air photos and is discussed below.

PHOTOGEOLOGY - SOUTH HAT SIX

Analysis of the photogeology of Casper Mountain (see Plate III) indicates a subsurface drainage divide which plunges south and is centered a mile east of the township line between R 79 and 80 West. This diverts the flow of the ground water to the south, southeast into the Muddy Mountain syncline. The Hat Six Fault probably acts as an aquitard or subsurface dam which deflects the ground waters present in the Paleozoic sediments of the eastern portion of Casper Mountain to the south, southwest.
There is a narrow, sharp "anticline" which is probably a reverse fault which extends five miles eastward from the middle of Section 3, T 31 N - R 79 W to Section 4, T 31 N - R 80 W. This latter locality is where the Hat Six Fault appears to terminate against a tear fault.

Summarizing, we have the crustal pressures from the south (Muddy Mountain acting against the eastern portion of Casper Mountain) to cause severe faulting and possibly fracturing at the south end of the Hat-Six Fault. This locality, Section 4, T 31 N - R 78 W is believed to be the "gate" through which the ground water escapes northeast to the Pole Creek syncline.

The well site which is believed to have the best probabilities for maximum yield from the Casper sandstone and Madison limestone is indicated on Plate V. The greatest number of favorable geologic characteristics are concentrated within close proximity to the recommended site. The site is not closer to the surface faulting because the topography and access would result in extreme difficulty and inordinate expense in site preparation. Further, drilling a straight hole would be complicated by the higher rates of dip of the formations southwest of the proposed location.

The arrows indicating underground flow on Plate II show the probable pattern of water flow from the recharge areas on Casper Mountain and the Muddy Mountain syncline. The localities of egress for the groundwaters are in the area of the Pole Creek Fault and subsidiary faults and at the south end of the Hat Six Fault. These faults and the recharge areas constitute a system which acts essentially as a "funnel" which tends to concentrate and direct the flow of the water into the Pole Creek syncline. The head or pressure at the well site at the top of the Casper Formation is estimated to be about 2700 feet or 1169 pounds per square inch. If the Casper Formation top is 2200 feet below ground level then a well would flow at the surface.

Figure 2, Cross Section N-S, is an end-on view of the possible fault configuration at depth.
CROSS SECTION N - S
South Hat Six Area

North

"The Funnel"

Pole Creek

Pc - Casper
Cm - Madison

Pre-Cambrian

Not To Scale

Figure 2
It is difficult to predict the rate of flow or sustained safe rate of pumping from the individual or combined Casper and Madison aquifers but an estimate in excess of 1000 gallons per minute or one million gpd is considered realistic. Such a supply could then satisfy a population of 5000 people.

HYDROLOGIC CONSIDERATIONS

From the surface geology and the small amount of subsurface control present it is possible to infer the general patterns of the groundwater hydrology, particularly at the east end of Casper Mountain.

The Subsurface Map, Plate IV, is contoured on the Cloverly Group, Dakota log top, in the map area east of the Hat Six fault. The long dash lines are contours on top of the Casper Formation geological mapping. The faulting provides a framework for the contouring.

The subsurface data points are, almost without exception taken from wells drilled for oil and gas. Where possible, the thickness of the Lakota formation is noted beside the depth for the formation. For the few wells which penetrated and were drill stem tested in the Casper Formation the elevation of the artesian head is given above the total depth figure for the well.

The elevation of the top of the Casper Formation at the common township corner, T 31 & 32 N - R 78 & 79 W, four miles west of the proposed water well location is 2700 feet higher than the estimate elevation of the Casper top in this water well location. It is also 3170 feet lower than the Tensleep Formation in the Texaco dry hole in Section 2, T 31 N - R 79 W. This suggests that at this location, if the expected porosities and transmissivities are realized, the well should flow with a pressure of approximately 217 pounds per inch (p.s.i.) at the well head. At this time the rate of flow cannot be estimated with assurance.
STRUCTURAL GEOLOGICAL MAP
OF SOUTHWAY SIX - POLE CREEK AREA
WITH HYDROLOGIC FEATURES SUPERIMPOSED

SARGENT IRRIGATION CO.
JULY, 1983

LEGEND

D FAULT, MAJOR REVERSE
U FAULT, TEAR
--- FAULT EXTENSION
(LENGTH OF DASH INDICATES CONFIDENCE)

- AXIS OF SYNCLINE
- AXIS OF ANTICLINE

I RECHARGE AREA LIMIT

- EFFECTIVE EXPOSURE AREA
(CASPER, MADISON and CAMBRIAN FORMATIONS)

= PROBABLE FLOW PATH
(LARGE ARROWS DENOTE CONCENTRATED FLOW)

Q QUATERNARY ALLUVIUM
Kcv CLOVERLY FORMATION
Pc CASPER FORMATION
Cm MADISON FORMATION
CCmd MADISON and CAMBRIAN UNDIFFERENTIATED

SCALE: 1" = 4000'

PLATE II
GEOLOGIC CROSS SECTIONS

The geologic cross section presented for the South Hat Six area is to show what may possibly have happened to the geologic strata at depth in response to the faulting which is known to have occurred.

For South Hat Six the tear or cross faulting is shown "end on" looking from west to east. What is shown below ground level is conjectural and based upon geologic extrapolation of fault evidence at the surface. It is possible that recharge waters from the north and south have established channels along these fault zones, thus delivering relatively large water flows down dip into the Pole Creek syncline and toward the proposed South Hat Six location.

OTHER AQUIFERS

This project is being recommended as primarily a Paleozoic testing program. However, an analysis of the section overlying the Casper Formation is in order. The Goose Egg sequence is a complex of red shales and thin limestones with some anhydrite and gysum present. From the top of the Goose Egg through the Chugwater, Sundance and Morrison Formations there are no known aquifers capable of moderate to large flows of acceptable quality waters.

The basal member of the Cloverly Group, the Lakota Formation, has given up as much as 250 gpm in Section 24, T 33 N - R 79 W, in what is now southeast Casper. The Lakota Formation tends to be lensatic with thickness variations from about 35 feet to 140 feet depending on location. The quality of Lakota water has been found to be consistently good.

This is second possible source of groundwater for Evansville. The potential well site is approximately one half mile southeast of McDonald Reservoir in the NE SW, Section 18 T 32 N - R 77 W. The Lakota would be at a depth of approximately 2600 feet here. About three quarters of a mile west of this site in Section 13, T 32 N - R 78 W an individual
named Claussen drilled a test well for oil and gas that bottomed in the Chugwater Formation at 2377 Feet. The electric log of this well has 150 feet of Lakota sand with extremely fresh water. A part of this logged thickness may be in part due to dip of the beds. However, the Subsurface Map, Plate IV indicates a quite extensive area of thick sand development.

The proposed drill site is about 12 miles from Evansville.

All of the remaining potential Cretaceous aquifer zones are sandstones: the Frontier sands, Mesaverde and Fox Hills Formations. These sandstones generally have low productivities and the quality of the water is from just barely acceptable to poor.
WATER QUALITY

The quality of the waters that may be expected from the Paleozoic Casper and Madison Formations is the greatest unknown involved with these well locations. However, in the Hat Six-Pole Creek area springs emanating from these formations yield good quality waters.

Water quality in the Madison Formation is a function of the depth from which it comes. Wells producing water from less than 3500 feet carry waters within the Environmental Protection Agency's Best range, less than 500 mg/l Total Dissolved Solids (T.D.S.) or within the Acceptable range, 501 to 1000 mg/l T.D.S. However, these waters are usually of less than 750 mg/l T.D.S. The same general rules follow for Casper Formation waters.

Lakota Formation is exceptional in that its waters have been found to be in the Best or Acceptable water quality range in wells as deep as 7000 feet.

SAFE YIELD

The term safe yield has been used in the attempt to define the amount of water which could be developed from a groundwater reservoir. The term has several proposed definitions and synonyms appear in the literature.

A composite definition, based on the ideas of many authors, could be expressed as follows:

Safe yield is the amount of naturally occurring groundwater that can be withdrawn from an aquifer on a sustained basis, economically and legally, without impairing the native groundwater quality or creating undesirable effects.

The best ways to determine safe yield is to assemble well parameter data from multiple wells under as nearly as possible controlled conditions. In the case of the Madison wells proposed within this report.
they are essentially isolated, with few, if any, wells hydraulically connected to them.

Further, where Madison wells have been drilled which have had observation well systems installed the formation has been proven to be essentially non-isotropic. This has been shown by significant variations in the computed transmissivities and storage coefficients. In addition, the few prolific Madison water supply wells completed within Wyoming have been completed in zones of faulting and/or fracturing. Localized fractures enlarged by the chemical activity of connate and meteoric waters have been responsible for abnormally large flows from wells completed within such zones.

For the foregoing reasons it is nearly impossible, at this time, to assign a value for safe yield to the proposed wells. In the event the wells are developed and producing satisfactorily, flow rate and draw-down or pressure data can be used to evaluate and extrapolate the longer term effects of production.

It is possible that it may be necessary to tie well production rates to annual estimated recharge quantities based on measured precipitation for a given year. In years of below average precipitation it might be necessary to exceed the figure for average recharge. During years of higher than average precipitation and recharge, the well production might be reduced to allow recovery of the well to occur.

**RECHARGE ESTIMATES**

In 1982 Wright Water Engineers and Western Water Consultants reported recharge rates for the Paleozoic aquifers in the Casper Mountain-Muddy Mountain area. Their assembled data indicated the rate to be about 10 percent of the annual average precipitation or approximately 95 acre-feet per year per square mile.

Using the recharge areas as shown on the Structural Geologic Map, Plate II, the effective area for recharge is 8420 acres or 13.156
square miles. These figures equate to 407,262,390 gallons per year or 1,115,787 gallons per day.* The projected average water demands of the Town of Evansville indicate that not until the year 2005, when the present population is estimated to double, will consumption (1,004,300 gpm/capita/day) begin to equal the above rate of recharge.

Because of its limited outcrop areas due to steep dips on the north flank and east end of Casper Mountain the recharge to the Lakota Formation is considered to be limited. In the few water wells completed in the Lakota seasonal changes in water levels have been noted and fragmentary data indicates moderate decline has been observed over a period of years.

*8420 ac. / 640 ac = 13.15625 sq. mi.
13.15625 sq mi x 95 ac-ft/mi/yr = 1249.84375 ac-ft/yr
43560 ac-ft/mi x 7.4805 gal/cu ft x 1249.84375 ac-ft/yr = 407,262,311 gal/yr
407,262,311 gal/yr/365 days = 1,115,787. gal/day
## TABLE III
**AREA EVALUATION SUMMARY**

<table>
<thead>
<tr>
<th>Area</th>
<th>1 South Hat Six</th>
<th>2 Hat Six Lakota</th>
<th>X Emigrant Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible Aquifers</td>
<td>Casper Lakota</td>
<td>Casper Madison Deadwood</td>
<td></td>
</tr>
<tr>
<td>Aquifer Thickness</td>
<td>800' Gross 140'</td>
<td>800' Gross 1900'</td>
<td></td>
</tr>
<tr>
<td>Depth to top Casper</td>
<td>2100'</td>
<td>2600' (Lakota)</td>
<td></td>
</tr>
<tr>
<td>Total Depth</td>
<td>2700'</td>
<td>2750'</td>
<td></td>
</tr>
<tr>
<td>Water Quality Prospects</td>
<td>Good</td>
<td>Excellent Moderate</td>
<td></td>
</tr>
<tr>
<td>Est. Possible Production</td>
<td>1000+GPM</td>
<td>250+GPM</td>
<td>1000+GPM</td>
</tr>
</tbody>
</table>

**Estimated Costs:**
- Observation Well*: $109,800.00 $110,000.00
- Production Well: 188,490.00 190,000.00 190,000.00
- Testing: 35,000.00 35,000.00 35,000.00
- Estimated Total: $333,290.00 $225,000.00 $335,000.00

**Estimated Pipeline Cost:** $3.2 Million $2.1 Million $1.0 Million

* If abandoned: $85,600. $87,000.

X This project cannot be recommended at this time.
WELL DESIGN CRITERIA

The design of the test/observation well, as shown in Figure 4, is quite straightforward. The 9-inch hole size is to permit the use of tools, drill collars in particular, of sufficient size and weight to facilitate the drilling of the expected hard formations. This hole size is also the minimum necessary to allow setting of 4 1/2 inch O.D. casing. This pipe size is the minimum which will accept the floats of automatic water level monitoring devices.

The final production well design will depend on the nature of the Casper Formation sands. They are expected to be naturally cemented sufficiently to preclude causing sanding problems for the life of the well. However, this supposition cannot be supported at this time without drill sample evidence.

Because there is no test data available for the objective formations at this time, it must be assumed that prolonged use will cause a drawdown of the pumping levels in the proposed well. The magnitude or rate of change, including the time, probably years, for these changes to occur can only be determined after aquifer testing is completed.

Alternative A as shown in Figure 5, presumes the Casper and Madison sections will not require casing. However, in view of the unknown future draw-downs it is judged safest to specify the drilling of a minimum 20 inch hole and cementing to surface 16-inch casing in the top of the Casper Formation or just above the uppermost aquifer zone. This casing size will permit lowering of any larger capacity pump at anytime in the future.

The open hole of 14-inch diameter within the Casper and Madison section would be large enough to allow even very high rates of flow with minimal head loss.

Alternative B, shown on Figure 6, would be used if it were judged necessary to case with slotted pipe to total depth.
For a Lakota well the design would be similar to Alternative B, except that the hole and casing diameters would be reduced and the upper pump chamber might be extended downward to 1500 feet.

**RECOMMENDED DRILLING PROGRAM**

South Hat Six - Pole Creek Area

There are no drilling records for this area for formations older than the Cretaceous Lakota sandstone. The affects of the faulting and the quality of any waters present in the potential Paleozoic aquifers are therefore unknown. This means that the initial drilling at the recommended location in Section 34, T 32 N - R 78 W would have to be a small diameter exploration well. If the anticipated favorable indications of high productivity of good quality water are realized then this well would be completed as an observation well and a second large diameter production well would be drilled nearby.

The test well would start in the Cretaceous Mowry Formation and be completed in the Mississippian Madison or Cambrian Deadwood Formation. The estimated tops for the various formations penetrated are as follows:

- Cloverly Group (Dakota, Fuson, Lakota) 415 feet
- Morrison Fm. 492 feet
- Chugwater Fm. 972 feet
- Alcova limestone 1122 feet
- Goose Egg Fm. 1762 feet
- Casper Fm. 2126 feet
- Madison Fm. 2587 feet
- Deadwood 2837 feet
- Pre-Cambrian 2947 feet

In order to test the quality of the waters of the Casper Formation at least one drill stem test would be required. The interval within the Casper Formation will depend on the appearance of the drilled samples and signs of water while drilling. It is expected, however, that the upper 100 to 150 feet will carry water and that 60 to 100 feet of this
LOCATION MAP
South Hat Six-Pole Creek Prospect
Natrona County, Wyoming
July 1983

PLATE V
zone would be tested. As indicated elsewhere in this report the well is expected to flow at the surface and therefore by allowing sufficient time with the D.S.T. tool open, it should be possible to allow the well to clean itself and to collect a good, representative sample of the water from the zone below the packer, i.e., Casper Formation water only.

Upon completion of the D.S.T. and assuming conductivity of the water showed it to be of good quality, the well would then be deepened into the Madison Formation. The total penetration would depend on the nature of the formation and the shows of water encountered.

It is felt if the indicated productivity of the Casper Formation is high, that the Madison Formation will also yield water at a high rate. This assumption is based upon the fact that the faulting expected to be present will have acted upon the Casper and Madison Formations as a unit.

**TEST/OBSERVATION WELL**

For completion of the test well as an observation hole it is proposed to run 4-inch casing in the 9-inch hole with slotting opposite the Casper and Madison aquifers. The annular space would be gravel packed to the top of the Casper Formation and a short cement plug emplaced above the gravel pack. The remaining annular space to just below surface would be filled with bentonite slurry. Cement would then be emplace from surface to a depth of approximately ten feet with some type of a collar or basket around the pipe to prevent settling of the cement. Figure 4 shows the proposed observation well design.

**PRODUCTION WELL**

For the production well the proposed design (See Figure 5) is basically a 20-inch hole to the top of the Casper Formation with 16-inch casing cemented to surface at that point, approximately 2100 feet below ground level. A 14-inch hole would then be drilled and left open to a total depth of approximately 2800 feet. This design presumes that no friable sands would be encountered in the Casper-Madison section.
Test/Observation Well
Standard, All Prospects

Ground Level
Surface-Mowry
Halliburton Basket @ 40'

Cement 14° Hole
10 3/4" Conductor Cemented

415'

Cloverly Gp 77±'

Morrison & Sundance 480±

972'

Chugwater 790±

Alcova @ 1122'

Bentonite Slurry

Note: Completion Depends on Results of Drilling and D.S.T.

1760'

Goose Egg 365±

460±

Casper, Fm.

DST Packer Seat

40° Cement

2126'

Gravel Pack

2587'

Madison Fm.

Mill Slotted Casing

250'

Deadwood Fm. 2837±

Evansville Project
Sargent Irrigation Company
August 1983

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Figure 3
Ground Level
Surface-Mowry

Cloverly Gp 77'± 492'

Morrison & Sundance 480'±

972'

Chugwater 790'±

Alcova @ 1122'

1760'

Goose Egg 365'± 2126'

Casper Fm. 460'±

2587'

Madison Fm. 250'± 2837'

Deadwood Fm. 110' 2947'

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Evansville Project
Sargent Irrigation Company
August 1983

Figure 4
SCHEMATIC DRAWING
Production Well
Alternative B

Ground Level
Surface-Mowry

415'

Cloverly Gp 77'± 492'

Morrison & Sundance 480'±

972'

Chugwater 790'±

Alcova @ 1122'

1760'

Goose Egg 365'±

2126'

Casper Fm. 460'±

2587'

Madison Fm. 250'±

2837'

Deadwood Fm. 110'2947'

Pre-Cambrian

Cement to Surface

Evansville Project
Sargent Irrigation Company
August 1983
Figure 5
In the event that an open hole completion was judged not to be feasible, based on information provided by the observation well, Design Alternative B (See Figure 6) would be used. This design would involve using 16-inch casing in a 20-inch hole to 1000 feet and then reducing the hole size to 14 inches. This lower portion of the hole would be cased to total depth with mill slotted 10 3/4 inch casing fastened by a reducer to the 16-inch casing. It is estimated that about 400 feet of mill sloting will be required for the 10 3/4 inch casing.

GEOPHYSICAL LOGGING

In order to maximize the information to be gained from the Casper-Madison section it is strongly recommended that the logging program be implemented as described below. In hard sandstones and limestones regular resistivity logs do not satisfactorily answer the needs for porosity, fluid content and fracture presence information. Therefore the Dual Laterolog, Gamma Ray, Caliper, Sonic Log and Sonic Wave Form Logs are recommended for this project. The Dual Laterolog and Gamma Ray are useful for correlation in both hard and the up hole softer formations. The Sonic Log provides indications of porosity and the Sonic Wave Form Log is used to detect fracturing. Taken together such a logging program would provide a greatly enhanced quality and quantity of data on these Casper/Madison aquifers when compared with what could be expected from the usual Induction Electric/Self Potential Log. The reason for this is that the high resistivities expected to be encountered in the Paleozoic section are beyond the range of the standard Induction Electric type logging tools.
WELL COST ESTIMATES

South Hat-Six (Casper-Madison Prospect)

The estimated total cost of drilling, completion, testing etc. for two wells, a test/observation hole and a production well are tabulated below.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cased to T.D.</th>
<th>Cased to Top Casper Fm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test hole (if abandoned)</td>
<td>$85,600</td>
<td></td>
</tr>
<tr>
<td>Completed as an observation well</td>
<td>$109,806</td>
<td></td>
</tr>
<tr>
<td>Production well, drilling and completion</td>
<td>$188,492</td>
<td>$210,232</td>
</tr>
<tr>
<td>Testing</td>
<td>$35,000</td>
<td>$35,000</td>
</tr>
<tr>
<td>Estimated Sub-Total</td>
<td>$223,492</td>
<td>$245,232</td>
</tr>
<tr>
<td>Total Cost Observation well plus Production well</td>
<td>$333,298</td>
<td>$355,038</td>
</tr>
</tbody>
</table>

Hat Six Lakota Sandstone

This second possible source of groundwater located near McDonald Reservoir would require an approximate 2800 foot well. If the Lakota section here were comparable to that in the Claussen well to the east, the well would probably be capable of producing approximately 250 gpm of good quality water. (See Plate IV) The possible location is about 12 miles from Evansville. It would probably be necessary to drill two or three wells in the general area to justify the cost of the necessary pipeline to Evansville.

Of concern here is that the subsurface drainage area which would be tapped by a Lakota well would be limited. Therefore, with relatively high withdrawal rates from one to three wells, the drawdowns could become excessive forcing greatly reduced pumpage and ultimately an unacceptable short well life.

The cost of constructing and testing one well into the Lakota here would
be approximately $190,000. Its pipeline would be approximately 12 miles long and cost $2,100,000. Since a minimum of two wells at 250 gpm each would be required, the total project cost would be approximately $2,480,000.

In this area the Casper Formation would be at a depth of about 4100 feet and the total depth of the well could be as deep as 4700 feet. Because of this considerable depth it becomes highly questionable that the quality of the Casper Formation water would be acceptable.

**TOTAL SYSTEM COSTS**

The Evansville water supply situation vis-a-vis possible groundwater supplies is a complex problem. An assured supply of 500 to 600 gpm could satisfy the town's near term needs. However, the cost for such a supply would exceed the cost for a 1000+gpm well on a per 1000 gallon basis, assuming full utilization of each well system. A two well, 500 gpm system, from the Lakota Formation, with its pipeline to Evansville would cost about $2,500,000., not including financing costs. The proposed one production and one observation well system from the Casper and Madison Formations at South Hat Six should supply 1000+gpm to system with an overall cost, including pipeline of $3,400,000., without financing costs.

For long term reliability, in addition to a much larger expected yield, the South Hat Six project is favored.

The question then arises, "What would Evansville do with one million gallons per day of water?" It is beyond the scope of this report to discuss this subject. However, the City of Casper is aggressively seeking additional water supplies for its system and some arrangement might be made for Casper to take a portion of any anticipated surplus after testing has shown the actual productivity of the well.

One advantage to the proposed groundwater developments is that if the delivered quantities of water are sufficient for Evansville's needs, there
would be no need for any treatment of the water other than on line chlorination. This should result in a net reduction in the cost of operating the Town's water system.

DEVELOPED WATER USAGE/CONVEYANCE

Since all of the proposed well sites are at inconvenient distances from Evansville, certain obvious methods of usage and conveyance are presented for consideration and evaluation.

South Hat Six  If upward of 1000 gpm or 1 million gallons per day is developed two methods of delivery suggest themselves-1) Build a 15 mile, 14 inch pipeline from the well to Evansville. The direct construction cost would be approximately $3 million. Or 2) Let the water run into the Pole Creek-Beaver Creek-Muddy system which drains into the Platte River. An exchange of North Platte water rights would then have to be worked out.

Hat Six Lakota  A 12 mile pipeline to Evansville appears to be the only practical method of delivery for this water. Further, long term considerations might dictate that the size of the pipe should be large enough to handle all or part of the water from any possible future developments in the South Hat Six area that might be necessitated by a decline of any Lakota wells.

SUMMARY

The foregoing material is a synthesis of all available information and hydrogeologic reasoning. Every effort has been made to keep numerical estimates, including cost estimates, realistic so that the need for future increments should be minimal. The proposed water well sites have been selected after much thought but with the primary objective of developing the maximum long term quantity of groundwater for the people of Evansville. Although the costs may seem high, once developed this resource should be of constantly increasing value.
SPECIFICATIONS AND BID DOCUMENTS

Because two alternative drilling sites are presented for selection by the Town of Evansville in consultation with the Wyoming Water Development Commission, it is impractical to submit detailed Specifications and Bid Documents for approval at this time. However, these can be delivered for review within ten days of notice of approval of the selection of a location.

Further, at that time the required forms will be submitted to the Wyoming State Engineer.
August 19, 1983

Mr. Ted Akers
Town Planner
Town of Evansville
P0 Drawer 158
Evansville, Wyoming 82636

Dear Mr. Akers:

This is to notify you that we have received and reviewed the report of Sargent Irrigation in regards to the Evansville Groundwater Exploration Project. We will approve the proposed drilling site at the South Hat Six site and also the Hat Six Lakota site. However, conversations with the Groundwater Division of the State Engineer's Office indicate that there may be problems with your second preferred site in the Emmigrant Gap area. I would suggest further communication with the State Engineer's Office before any decision is made to pursue drilling at that site.

If you have any questions concerning this matter please contact me directly.

Sincerely,

Evan J. Green
Water Resources Economist
EMIGRANT GAP-HIGHWAY AREA

When this report was initially planned and prepared the Emigrant Gap area was considered a hydrogeologically favorable location. Subsequent discussions with the Wyoming State Engineer lead to the conclusion that it would be fruitless to attempt a development in that immediate area at this time.

The reasoning behind this statement is that the prevailing philosophy of the State Engineer is that any developer of underground water must bear the burden of proving that other wells or springs in the area are not and will not be damaged by his development.

In this case the Speas Spring is the water source which must remain inviolate. Unfortunately, there is no scientifically collected base line data available concerning pressures or flow rates for this spring. Therefore it would be pointless to commence monitoring this spring at the time of drilling any other well or wells in the general area because any slight changes in the flow of the Speas Spring could not be attributed to a documented natural decline in flow or pressure. Further, with any mention of testing the Casper Formation in that area, it becomes a political and emotional issue which drowns out any scientific merit as logically designed data gathering and testing program might have. The proposal to drill a test well at the Emigrant Gap-Highway location was considered hydrogeologically non-hazardous to the Speas Spring because of the 3.3 mile distance between the two and the aggregate throw or vertical separation across three faults of approximately 1000 feet.

The Emigrant Gap-Highway cross section shows what subsurface conditions may be in this locality. The left or south portion of this section reflects what may be the subsurface conditions south of the proposed well location as a result of the Casper Mountain and Madison Creek faults. The center and right show the results of the crustal pressures which formed Emigrant Gap anticline. It should be noted that about 1000 feet west of the proposed location the Emigrant Gap fault intersects the Casper Mountain fault. Thus this set of faults, with associated fracturing probably results in a complex distribution of groundwaters at depth.
EMIGRANT GAP - HIGHWAY LOCATION

The Emigrant Gap - Highway Location is recommended to be 1000 feet east of the west line and 1200 feet north of the south line, Section 6, T 32 N - R 80 W (see Plate VII). This location situates the proposed well in a corner between the east-west trending Casper Mountain fault and the north, northwest trending Emigrant Gap axial strike fault. It is felt that this complex system of faults increases the probabilities of encountering highly fractured Casper sandstone and Madison limestone.

It should be noted that three generally east-west fault systems separate the fault block proposed for drilling from the Speas Spring fault block three miles to the southwest.

The proposed well would start in the Cretaceous Thermopolis shale and the top of the Casper Formation should be at approximately 2000 feet and the Madison at 2500 feet. The total depth of the well should therefore not exceed 3000 feet.

The productivity of this proposed well should be high because of the probability of highly fractured aquifer rocks. Since the location is at the south plunging end of the Emigrant Gap anticline and in a down-dropped fault block with faults radiating in at least three directions, it is anticipated that the associated fracturing and solution-enhanced porosity and transmissivity will be high and hence the well productivity.

The piezometric surface is not known and difficult to estimate due to the faulting. Recharge sources and patterns are also subject to question. Here again great dependence must be placed on the geometry of the faulting and fracturing.

The water quality is somewhat called into question by the high total dissolved solids, 3800 ppm, in the Mohawk well two miles to the north on the same structure. However, since the source of that water cannot be determined with any accuracy its high reading is discounted.
This well would start in the Thermopolis shale and be bottomed in the Madison or Deadwood Formation. The estimated tops are as follows:

- Cloverly Group (Dakota, Fuson, Lakota) 120 feet
- Morrison 210 feet
- Chugwater (Crow Mtn. Sd.) 780 feet
- Alcova 900 feet
- Goose Egg Fm. 1520 feet
- Casper Fm. 1900 feet
- Madison Fm. 2400 feet
- Deadwood Fm. 2700 feet
- Pre-Cambrian 2800 feet

The above figures are minumums and assume that no faults are cut and that the dips encountered will not be high. It is therefore proposed that in the planning for this well a possible total depth of 3200 feet be used in figuring costs.

As with the proposed South Hat Six operation, it is critical that a drill stem test of the Casper Formation be run after penetration of the zone indicates the presence of water. There is a possibility that the Casper Formation may flow at the surface as it is penetrated by the bit, but unless a check of the Conductivity of this water indicates the water to of acceptable quality, the D.S.T. should be run. This would be necessary to assure that contamination from up-hole waters and minerals are not affecting the waters from only the Casper Formation.

Here again it is assumed that the Madison waters will be akin to those of the Casper Formation. However, with an analysis of Casper waters in hand, any deterioration of water quality may be attributed in large part to being from Madison waters. The geophysical logging program should also be of great assistance in evaluating the waters of various zones.

In the event that this test well indicated the area to be worthy of development then the well would be completed as described for the South Hat Six well.
Scale 1" = 2,000'
Contour Interval 20'
Fault
— Formation Contact
Line of Cross Section ——

EMIGRANT GAP - HIGHWAY PROSPECT
Natrona County, Wyoming
By
Sargent Irrigation Company
August 1983

PLATE VII
CROSS SECTION S - NE
Emigrant Gap - Highway Area

Figure 6
Measured Surface Sections*

COMPOSITE STRATIGRAPHIC SECTION OF FRONTIER FORMATION MEASURED IN SEC. 23, 35, and 36, T. 32 N., R. 78 W.

Frontier Formation

<table>
<thead>
<tr>
<th>Wall Creek Sandstone Member</th>
<th>Feet</th>
<th>10ths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buff salt and pepper fine-grained cross bedded sandstone with yellow alteration and some limonite concretions.</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Yellow fine-grained sandstone.</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Grey salt and pepper fine-grained sandstone.</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Brown fine-grained thin-bedded lenticular calcareous sandstone interbedded with some black shale at the bottom becoming more massive to the top.</td>
<td>35</td>
<td>9</td>
</tr>
<tr>
<td>Grey-blue salt and pepper fine-grained calcareous sandstone with calcareous veins and it all weathers brown.</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Brown fine-grained calcareous sandstone with specimens of Inoceramus sp.</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Black fissile shale with lenses of brown fine-grained sandstone with specimens of Inoceramus sp. and a large specimen of a silicified tree.</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>Brown and tan fine-grained shaley sandstone.</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Brown fine-grained massive sandstone.</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Brown and tan fine-grained shaley sandstone with thin lenticular beds of more massive sandstone.</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>124</td>
<td>3</td>
</tr>
</tbody>
</table>

COMPOSITE STRATIGRAPHIC SECTION OF FRONTIER FORMATION MEASURED IN SEC. 23, 35 and 36, T. 32 N., R. 78 W.

Black to dark-grey fissile shale with very large and abundant concretions in the upper part. 407 2
Salt and pepper fine-grained thin bedded sandstone with a yellow streak. Forms a ridge in parts of the map area. 5
Brown and yellow fine-grained sandstone that weathers into a scaley surface. 4 4

Dark-grey to black fissile shale with
septarian concretions throughout.

STRATIGRAPHIC SECTION OF MOWRY SHALE MEASURED IN SEC. 23, T.
32 N., R. 78 W.

**Mowry Shale**

Dark-grey to black siliceous shale
which weathers a silver-grey.
Has a yellow material occurring
in films on the bedding planes.
Contains abundant fish scales and
specimens of *Inoceramus* sp.
Brown to dark-grey shale.

STRATIGRAPHIC SECTION OF THE MUDDY SANDSTONE AND THERMOPOLIS
FORMATION MEASURED IN SEC. 22, T. 32 N., R. 78 W.

**Muddy Sandstone**

Brown fine-grained thin to cross-
bedded sandstone

**Thermopolis Formation**

Hard grey shale with occasional
lenses of grey ferruginous
sandstone.

COMPOSITE SECTION OF DAKOTA GROUP (RESTRICTED) MEASURED IN
SEC. 23, T. 32 N., R. 78 W. and SEC. 11, T. 31 N., R. 78 W.

**Dakota Sandstone**

Hard yellow and white fine-grained
cross-bedded ferruginous sand-
stone with many small ironstone
concretions in it.

**Fuson Shale(?)**

Grey and blue calcareous shale. It
varies in thickness laterally and
is usually poorly exposed.
Lakota sandstone

Brown massive pebble conglomerate at the base with some cross-bedding. To the top the conglomerate inter-beds with a coarse-grained sandstone. The basal conglomerate thickens and thins throughout the area. In places it may be missing leaving only coarse-grained sandstone.

| 35 | 77 | 5 |

STRATIGRAPHIC THICKNESS AND GENERAL LITHOLOGY OF MORRISON FORMATION WAS MEASURED IN SEC. 11, T. 31 N., R. 78 W.

Morrison Formation

Variegated shales, and sandy shales containing some bentonite seams and occasional thin shaley sandstones and a few grey dense slabby lenticular limestones.

| 132 | 1-2 |

STRATIGRAPHIC SECTION OF THE SUNDANCE FORMATION AND NUGGET FORMATION MEASURED IN SEC. 15, T. 31 N., R. 78 W.

Sundance Formation

Grey-green fossiliferous shale
Grey and yellowish massive very fossiliferous limestone, with Ostrea sp.
Grey calcareous shale.
Yellow and white very fine-grained calcareous sandstone.
Yellowish-brown fine-grained sub-angular to sub-rounded grained clayey sandstone.
Mostly covered. From scattered outcrops it is a fine-grained interbedded calcareous sandstone and red shale.
Grey calcareous shale with some thin lenses of limestone.
Greenish very-thin bed of shaley limestone with ripple marks. To the bottom it grades into green shale.

| 45 | 3 |
| 9 | 7 |
| 63 | 3 |
| 9 | 9 |
| 1-2 |
Sundance Formation cont.

Grey-green fissile calcareous shale. 39 7
Yellow-brown fine-grained rounded 178 8
and frosted-grained calcareous and ferruginous sandstone with some larger coarse rounded quartz grains and calcite veins.

Nugget Formation (?)

White very fine-grained subangular to 38 2
sub-rounded grained extremely 38 2
friable sandstone.

Jelm(?) Formation

Light-red fine-grained calcareous sandstone. 2 5
Red fine-grained rounded and frosted calcareous cross-bedded friable shaley sandstone. 28 1
Red Fine-grained rounded and frosted-grained calcareous massive friable sandstone. These beds form a cliff in places. 11 5
Light red fine-grained rounded and frosted-grained fairly hard sandstone. 15 4
Red-orange fine-grained rounded and frosted-grained calcareous cross-bedded friable sandstone with white clayey inclusions in it. 35 5
93 0

STRATIGRAPHIC SECTION OF CHUGWATER FORMATION MEASURED IN SECTION 30, T. 32 N., R. 78 W.

Chugwater Formation

Alcova limestone member.
Grey massive oolitic limestone. The lower portion has some grey thin-bedded limestone interbedded with it. 2 6
Pink thin-bedded crenulated limestone that weathers to light-red beds. 14
Chugwater Formation cont.

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
<th>10ths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternating light and dark grey crenulated limestone with many calcareous</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>veins in it.</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Grey very fine-grained blocky and crenulated sandstone with dark bands in it.</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Red sandy calcareous shale with some ripple marks and a few interbedded</td>
<td>631</td>
<td>1</td>
</tr>
<tr>
<td>red fine-grained sandstones.</td>
<td>662</td>
<td>7</td>
</tr>
</tbody>
</table>

COMPOSITE SECTION OF PHOSPHORIA GROUP MEASURED IN SEC. 28 and 30, T. 32 N., R. 78 W.

Phosphoria Group

Freezeout shale member.

Brown massive fossiliferous limestone with some calcite inclusions in it. Fossils are Pleurophorus sp. 4 6

Red calcareous shale. 26 7

Brownish-red thin-bedded calcareous shale with calcite veins and black spots which may be organic matter. 1 7

Dark-grey thin-bedded limey shale with calcite veins and pyrolusite in it in dendritic patterns. 4 6

Grey fissile calcareous shale. 13

Red massive calcareous shale with calcite veins in it. 3

Red calcareous shale with lighter red streaks in it. 52 8

Grey-pink massive limestone with calcite crystals and black specks which may be organic matter. 5

Red sandy shale. 48 5

Light-grey to light-blue massive limestone with black specks which test in acid as petroleum. 1 4

Red sandy shale. 3 1

Medium-grey to pink limestone with white limestone inclusions in it. Also black specks of petroleum or organic matter. 6

Grey limestone with pyrite inclusions. The upper portion is slightly crenulated. 10 9
Phosphoria Group cont.

Grey massive limestone with inclusions of calcite crystals in it. 3
Grey thin-bedded limestone which weathers into small blocks. 5
Grey massive crenulated limestone with black specks of organic matter. 9
White finely crystalline limestone with thin black calcareous shale interbedded. 3
Medium-grey loosely consolidated thin-banded limestone. 5
Light-grey loosely consolidated clay with grey-green concretions in it. 6
Red sandy shale.

<table>
<thead>
<tr>
<th>Feet</th>
<th>10ths</th>
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<tbody>
<tr>
<td>84</td>
<td>3</td>
</tr>
<tr>
<td>245</td>
<td>2</td>
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</tbody>
</table>

Forelle Limestone
Dark-grey crenulated sandy limestone of varying thickness laterally, more massive at the top becoming more thin bedded and crenulated at the bottom. 1-3
Grey-pink limestone breccin which weathers as a small slope. 5 9
Grey-white foamy limestone with a white crenulated lenticular limestone at the base and black specks which indicated organic matter when tested. 2 2
Pink limestone breccia with blocks up to 1" in diameter and disseminated black specks which when tested in acid indicate petroleum. 1 5

| 12 | 6    |

Glendo Shale
Red hard sandy shales and shaly sandstones. 87 5

Minnekahta Limestone
White massive limestone with small calcite geodes. Black grains were identified as organic material. 3 4
Red paper shales interbedded with red thin-beded shales and small calcite inclusions. The upper portion is slightly crenulated. 10 9

B-6
Phosphoria Group cont.

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
<th>10ths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reddish-purple thick-bedded crystalline limestone with inclusions of white fine-grained crystalline limestone.</td>
<td>4</td>
<td>5</td>
</tr>
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<td></td>
<td>18</td>
<td>8</td>
</tr>
</tbody>
</table>

Opeche Shale

Mostly covered. Red calcareous shale. | 33 | 5 |
Tan to dark-grey banded coarse grained to fine grained slightly crenulated limestone. | 1 | 3 |
Brick-red calcareous shale with a few lenses of grey fine-grained sandstone. | 7 | 8 |
Brick-red massive calcareous very fine-grained sandstone with lenses of grey fine-grained calcareous sandstone. | 1 | 1 |
Brick-red sandy calcareous shale. | 48 | 7 |

COMPOSITE STRATIGRAPHIC SECTION OF CASPER FORMATION, MEASURED ON THE SOUTH SIDE OF HAT SIX CANYON IN SEC. 22, T. 32 N., R. 78 W.

Casper Formation

Partly covered. From scattered outcrops it is a buff fine-grained cross-bedded calcareous sandstone. | 115 | 9 |
Partly covered. Buff and yellow fine-grained cross-bedded calcareous sandstone. | 59 |
Mostly covered. From scattered outcrops it is a yellow and buff very fine sub-rounded grained cross-bedded and medium-bedded calcareous sandstone. | 98 | 2 |
Buff massive limestone with calcite geodes and black specks of hemitite scattered throughout. | 24 |
Buff fine-grained medium to cross-bedded sandstone with a thin yellow limestone bed about 10 feet from the base. | 27 |
Brownish-yellow very fine-grained cross-bedded sandstone that has a warty weathered surface.
Casper Formation cont.

Partly covered. Brownish-yellow very fine-grained cross-bedded sandstone. 43  8

Yellow-tan fine sub-rounded to sub-angular grained slightly calcareous sandstone. 5

Tan to white massive limestone with some yellow very fine-grained sandstone in cracks. Forms a high cliff locally. 37  4

Light-brown massive fossiliferous breccia. Grades from resistant at top to less resistant at bottom. The fossils are probably fragments of a crinoid stem. 13  5

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<th>Feet</th>
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<td>10</td>
<td>5</td>
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</tbody>
</table>

Medium-grey massive fossiliferous limestone. The upper 4' contains abundant fusulinids. 6  9

White-buff fine sub-rounded grained very thin-bedded calcareous sandstone. 1  2

Tan fine-grained massive calcareous sandstone. 18

Grey massive fossiliferous limestone with Linoproduc tus prattenianus. 15  2

Grey massive limestone which forms sharp cliffs. 13  6

Grey to red fine-grained very thin-bedded calcareous sandstone. 4  5

Tan very fine-grained massive calcareous sandstone. 10

Grey massive limestone which weathers grey-blue. 5  7

Clay-grey thin-bedded limestone with lenses of pink very fine-grained calcareous friable sandstone. 10  5

Red and green massive blocky breccia consisting of grey sandstone, green limestone and grey chert blocks. The sandstone blocks are about 2' in diameter, the chert 2 to 3' and the green limestone is approximately 6" to 1' in diameter. The matrix is a fine-grained calcareous sandstone. 10  2

<table>
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<td>43</td>
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<td>5</td>
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</tbody>
</table>

527  2
STRATIGRAPHIC SECTION OF DEADWOOD FORMATION AND MADISON LIMESTONE WAS MEASURED ON WEST WALL OF DEER CREEK CANYON IN SEC. 26, T. 32 N., R. 77 W.

### Madison Limestone

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
<th>10ths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buff to pink massive limestone with some chert beds about 1&quot; thick interbedded in it. Contains abundant specimens of <em>Spirifer centreratus</em>.</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Mostly covered. From limited outcrops it is a grey to pink massive-to thin-bedded limestone with some calcite crystals in geodal cavities.</td>
<td>48</td>
<td>5</td>
</tr>
<tr>
<td>Grey to pink massive limestone with abundant green calcite inclusions and calcite crystals in geodal cavities.</td>
<td>22</td>
<td>6</td>
</tr>
<tr>
<td>White thin-bedded limestone with yellow calcite veins present. Mostly covered. From scattered outcrops it is a buff and brown mottled thin-bedded limestone. with inclusions of chert and calcite veins.</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Lavender and yellow mottled thin-bedded limestones with scattered thin chert beds.</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Alternating beds of buff lavender and pink thin-bedded limestone with calcite crystals calcite veins and chert present in minor amounts.</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>151</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>

### Deadwood Formation

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
<th>10ths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow fine to medium angular to sub-angular grained thin-bedded calcareous sandstone.</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Orange coarse to grit angular grained calcareous sandstone with limonite concretions about 1/4&quot; in diameter present in minor amounts. Lower portion covered. Outcrops at top indicate a white to buff medium to coarse sub-angular grained calcareous sandstone with some yellow limonite alteration marks.</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>
Deadwood Formation cont.

| Light pink medium to coarse sub-angular grained sandstone more coarse and loosely cemented at base and grades into quartzite at the top. | 3 |
| Partly covered. Scattered outcrops reveal a salmon-pink coarse to grit sub-angular grained sandstone. | 12 6 |
| Light-pink medium sub-angular grained medium-grained bedded to cross-bedded sandstone with some grit sized quartz fragments in minor amounts. | 17 8 |
| Rust coarse sub-angular grained calcareous sandstone. Slightly cross-bedded toward the top. The weathered surface has a beaded appearance. | 4 1 |
| Grey coarse to medium sub-rounded grained slightly calcareous sandstone with some brownish red limonite alteration spots | 3 7 |
| Lavender medium sub-rounded grained thin-bedded friable calcareous sandstone with grey calcite veins. | 2 |
| Buff medium sub-angular grained sandstone with some calcite veining. | 3 1 |
| Light-brown coarse angular grained thin-bedded sandstone with some brown limonite alteration spots giving the rock a speckled appearance. | 8 |
| Red to buff arkosic sandstone containing some grit to pebble sized quartz fragments. Some limonite is present in small amounts. | 3 2 |
| Greyish-pink basal conglomerates with quartz fragments up to 4" in diameter in a coarse to fine-grained sandy matrix. The upper 8" is locally cross-bedded. | 1 3 |

The DEADWOOD formation lies unconformably on the pre-cambrian metamorphic and igneous rocks.
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