UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# WATER SUPPLY AT PAINTED CANYON OVERLOOK THEODORE ROOSEVELT NATIONAL MEMORIAL PARK (SOUTH UNIT) SOUTHWESTERN NORTH DAKOTA

By

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Prepared in cooperation with the

National Park Service

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ILLUSTRATIONS

## METRIC CONVERSION TABLE

| Multiply English units | By | To obtain metric units |
|---|---|---|
| Inch (in) | 25.4 | millimetres (mm) |
| Foot (ft) | .3048 | metre (m) |
| Mile (mi) | 1.609 | kilometres (km) |
| Square mile ($mi^2$) | 2.590 | square kilometres ($km^2$) |
| Gallon (gal) | 3.785 | litres (l) |
| Million gallons ($10^6$ gal) | 3,785 | cubic metres ($m^3$) |
| Acre-feet (acre-ft) | 1,233 | cubic metres ($m^3$) |
| | $1.233 \times 10^{-3}$ | cubic hectometres ($hm^3$) |
| Gallon per minute (gal/min) | .06309 | litre per second (l/s) |
| Gallon per day (gal/d) | $3.785 \times 10^{-3}$ | cubic metres per day ($m^3/d$) |
| Million gallons per day (Mgal/d) | .04381 | cubic metre per second ($m^3/s$) |
| Acre | .4047 | hectare (ha) |
| Foot per second (ft/s) | .3048 | metre per second (m/s) |
| Cubic foot per second ($ft^3/s$) | .02832 | cubic metre per second ($m^3/s$) |
| Gallon per minute per foot (gal/min/ft) | .2070 | litre per second per metre (l/s/m) |
| Square foot per day ($ft^2/d$) | .0929 | square metre per day ($m^2/d$) |
| Foot per day (ft/d) | .3048 | metre per day (m/d) |

# WATER SUPPLY AT PAINTED CANYON OVERLOOK
# THEODORE ROOSEVELT NATIONAL MEMORIAL PARK (SOUTH UNIT)
# SOUTHWESTERN NORTH DAKOTA

By M. G. Croft

## ABSTRACT

A 1,930-foot (588-metre) water-supply well was constructed at the Painted Canyon Overlook, Theodore Roosevelt National Memorial Park (South Unit), southwestern North Dakota. Aquifers underlying the site are in rocks of Late Cretaceous and Tertiary age. These rocks have an aggregate thickness of about 2,000 feet (610 metres). The well screen is set in the Fox Hills Sandstone of Late Cretaceous age. The formation consists of about 200 feet (61 metres) of interbedded marine sandstone, siltstone, and claystone. The sandstone is very fine to fine grained.

The well was pumped for 24 hours with a submersible pump at rates from 72 to 77 gallons per minute (4.5 to 4.9 litres per second) and had a specific capacity of about 0.4 gallon per minute per foot (0.08 litre per second per metre). The water was a sodium bicarbonate type and contained 1,050 milligrams per litre dissolved solids.

## INTRODUCTION

The U.S. Geological Survey was requested by the National Park Service to provide technical assistance in planning, constructing, and testing a deep water-supply well at Painted Canyon Overlook, Theodore Roosevelt National Memorial Park (South Unit). The site is located in southwestern North Dakota about 7 miles (11 km) east of Medora, Billings County, in the SE¼NE¼SE¼ sec. 35, T. 140 N., R. 101 W. (fig. 1). A well yield of 25 to 50 gal/min (1.6 to 3.2 l/s) was considered to be adequate by the Park Service to meet forseeable needs. The purpose of this report is to describe the work done by the Geological Survey at the Painted Canyon Overlook site and provide general information that may be useful in solving future water-supply problems in the area.

## TOPOGRAPHIC FEATURES

Scenic Theodore Roosevelt National Memorial Park lies within an unglaciated undulating plateau area of southwestern North Dakota. The most striking topographic feature in the park is the large valley carved by the Little Missouri River. Steep bluffs, ridges, and badland features border the eastern and western margins of the main valley and tributary valleys. The Painted Canyon Overlook well site, at an altitude of 2,780 feet (847 m), is on a high ridge that overlooks canyons 300 to 400 feet (90 to 120 m) in depth on the north and west.

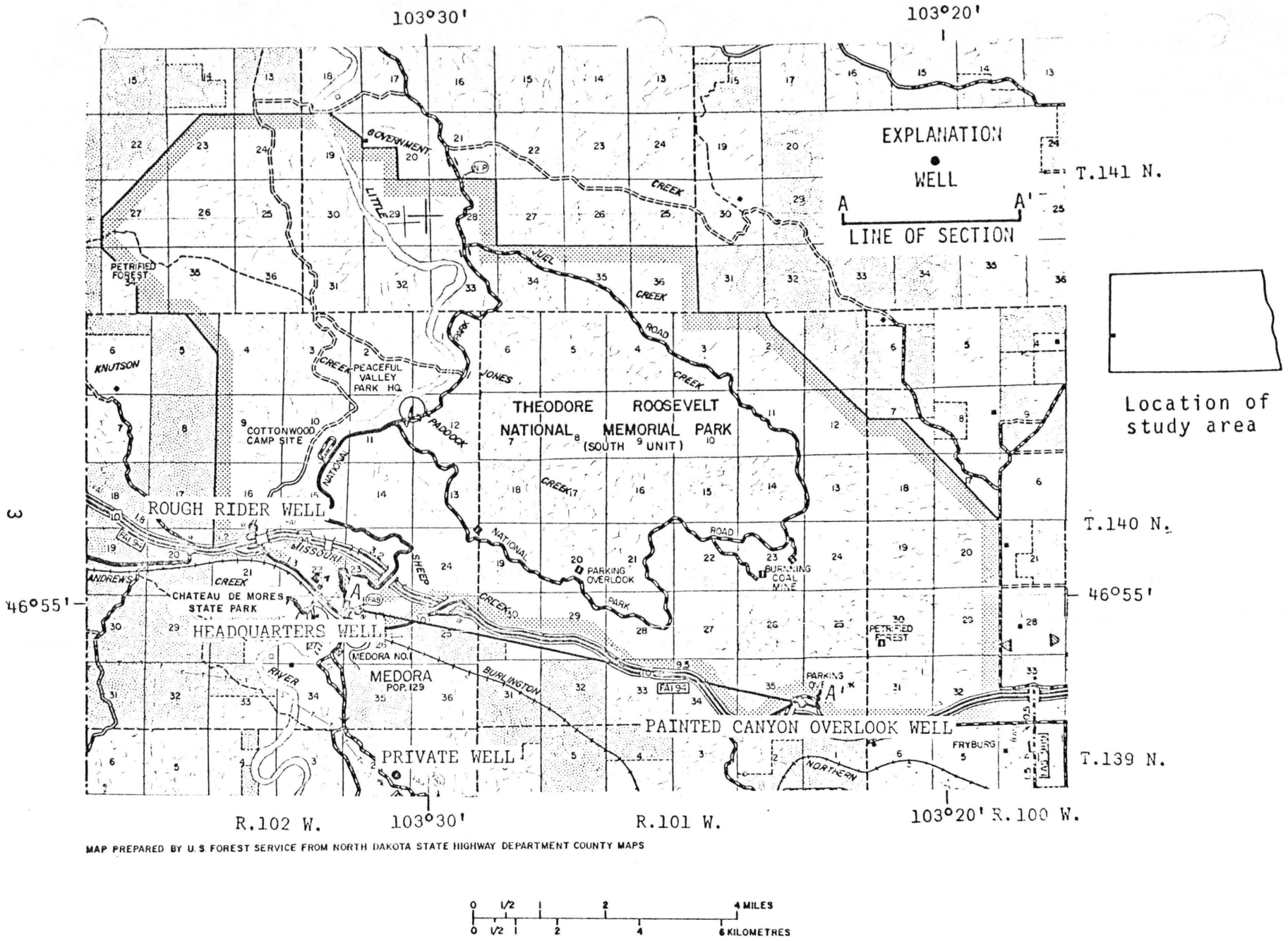


FIGURE 1.--Location of wells in the Theodore Roosevelt National Memorial Park (South Unit).

## GEOHYDROLOGIC SETTING

Aquifers underlying the Theodore Roosevelt National Memorial Park are in rocks of Late Cretaceous and Tertiary age. At Painted Canyon Overlook these rocks have an aggregate thickness of about 2,000 feet (610 m) and consist of the Fox Hills Sandstone and Hell Creek and Fort Union Formations (pl. 1).

The Fox Hills Sandstone, of Late Cretaceous age, consists of interbedded marine sandstone, siltstone, and claystone. About 200 feet (61 m) of the formation was penetrated in the well. Logs of adjacent oil and gas wells indicate the formation is about 300 feet (92 m) thick. Sandstone is more prevalent in the upper part of the formation. Particle-size distribution curves (app. 1) made from analyses of sidewall-core samples indicate the sandstone is generally very fine to fine grained.

The Hell Creek Formation, of Late Cretaceous age, consists of interbedded sandstone, siltstone, carbonaceous claystone, and limestone. The formation is 423 feet (129 m) thick at Medora in the Park Service's Headquarters well and 465 feet (142 m) thick in the Park Service's Painted Canyon Overlook well (app. 2). Sandstone in the lower part of the Hell Creek and upper part of the Fox Hills forms an important aquifer system (pl. 1).

The Fort Union Formation, of Tertiary age, has been subdivided into Ludlow, Cannonball, Tongue River, and Sentinel Butte Members. The Ludlow consists of continental claystone,

siltstone, sandstone, and lignite, whereas the Cannonball consists of olive-gray marine claystone, siltstone, and fine-grained sandstone. Brown (1962) and other investigators have shown that the Ludlow and Cannonball Members interfinger beneath southwestern North Dakota. The Cannonball is generally considered to be a confining bed to the movement of ground water.

The Tongue River Member consists of fine- to medium-grained sandstone, siltstone, claystone, and lignite of continental origin. The Tongue River is exposed in the Little Missouri River valley in the western part of the park and is 356 feet (109 m) thick at the Painted Canyon Overlook well. Lignite in the Tongue River and other members of the Fort Union Formation commonly causes the ground water to be dark colored. Lignite beds are identified on the formation density log (app. 3A) of the Painted Canyon Overlook well as strata having a density of 1.4 to 1.6 $g/cm^3$ (grams per cubic centimetre). The lignite between 750 and 770 feet (229 and 235 m) may be the seam known locally as the "Harmon Lignite." The lignite at the top of the member may be the HT Butte lignite (Royse, 1967).

The Sentinel Butte Member is extensively exposed in the park and has a total thickness of 429 feet (131 m) in the Painted Canyon Overlook well. The member consists of a sequence of lignite, claystone, siltstone, and sandstone, which with the "badlands" topography, provides the esthetic qualities of the area.

## DRILLING AND WELL CONSTRUCTION

The Park Service's Headquarters well (app. 2) was drilled by Midwest Well and Pipe Co. to a depth of 1,109 feet (338 m), and 279 feet (146 m) of 8-inch (203-mm) casing and 1,040 feet (317 m) of 4-inch (102-mm) casing was installed in the drill hole. In 1964 the well became plugged with what was believed to be particles of lignite or shale. The bore was cleaned and 962 feet (293 m) of 2-inch (51-mm) galvanized casing installed. The 2-inch (51-mm) casing was perforated from 940 to 962 feet (287 to 293 m). The hydraulic head (Hamilton, 1970) reportedly is 131 feet (40 m) above land surface. The flow from the well is adequate to supply the needs of the National Park Service staff and families at Medora.

The Painted Canyon Overlook well was drilled in June 1973 to a depth of 1,930 feet (588 m) with an 8-5/8-inch (219-mm) bit by Frederickson's, Inc., Hutchinson, Minn. At this stage, dual induction-laterolog and formation density logs were made (app. 3). The well bore was then reamed to 11-inch (279-mm) diameter and 1,800 feet (549 m) of 7-inch (178-mm) casing was installed and cemented into place (fig. 2) by Halliburton, Inc. The lower 60 feet (18 m) of the drill hole was filled with "pea" gravel. Seventy feet (21 m) of 4-inch (102-mm), stainless steel, 25-slot well screen was installed at the bottom of the casing. The screen was sandpacked in sandstone of the Fox Hills Sandstone.

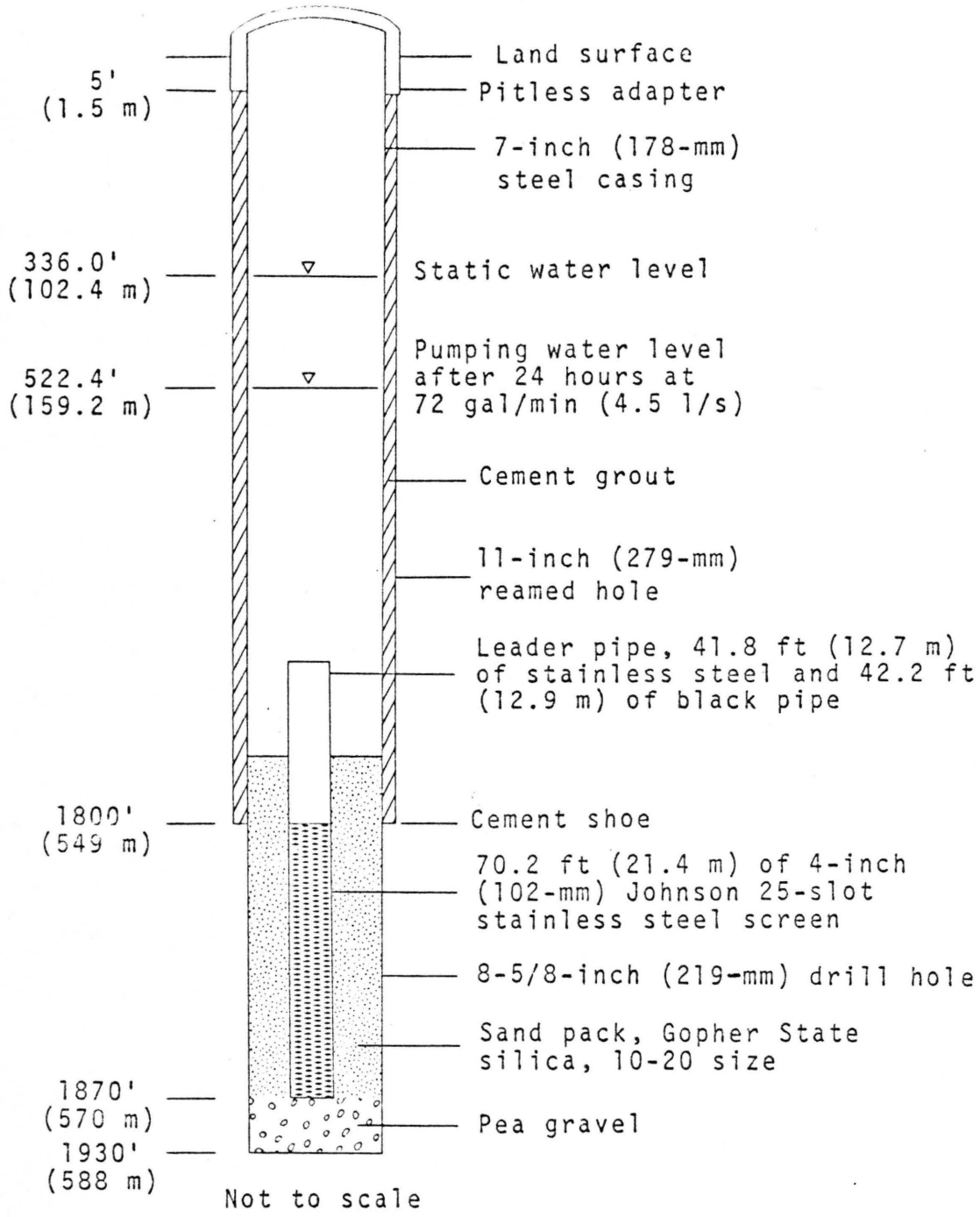


FIGURE 2.--Construction of Painted Canyon Overlook well.

## WELL DEVELOPMENT AND TESTING

The well was developed by jetting the screen with water containing trisodium phosphate and by surging with compressed air for about 25 hours. During development the well was pumped at 75 gal/min (4.7 l/s) and later at 100 to 125 gal/min (6.3 to 7.9 l/s). Development ceased when there was no sand pumped with the water.

On July 25, 1973, the well was pumped for 24 hours with a submersible pump at an initial rate of 77 gal/min (4.7 l/s). After 4 hours the pumping rate had declined to 72 gal/min (4.5 l/s), where it stabilized for the remainder of the test. During the test, the water level declined 186.4 feet (56.8 m) from a static level of 343.0 feet (104.5 m) below the measuring point to 529.4 feet (161.4 m) (app. 4). The 24-hour specific capacity was about 0.4 gal/min/ft (0.08 l/s/m). The water level recovered from 529.4 feet (161.4 m) to 365 feet (111.3 m) after 3 hours (app. 5). The transmissivity, calculated from the recovery data, was 74 $ft^2/d$ (6.9 $m^2/d$).

## WATER QUALITY

Water from the Headquarters well and Painted Canyon Overlook well was a sodium bicarbonate type and contained 1,130 and 1,050 mg/l (milligrams per litre) dissolved solids, respectively (app. 6A). The bicarbonate concentration was 677 and 746 mg/l and the sulfate concentration was 220 and 120 mg/l.

The water samples contained 3.0 and 3.1 mg/l of fluoride, which is above the optimum level recommended by the U.S. Public Health Service (1962) for drinking water. The water from the Painted Canyon Overlook well had a hydrogen sulfide odor and may require aeration before use. Trace elements in water from the Painted Canyon Overlook well are given in appendix 6B.

The Park Service's Rough Rider well is reportedly 364 feet (111 m) in depth and possibly taps thin beds of sandstone in the Cannonball Member of the Fort Union Formation. Water sampled from the well contained 1,200 mg/l dissolved solids. The concentration of sulfate was 340 mg/l and fluoride was 1.6 mg/l.

Water was also sampled from a private well south of Medora that is 450 feet (137 m) deep. The well probably taps an aquifer in the Ludlow Member of the Fort Union Formation and the upper part of the Hell Creek Formation. The water contained 1,330 mg/l dissolved solids, 490 mg/l sodium, 965 mg/l bicarbonate, and 210 mg/l sulfate. The sample also contained 4.4 mg/l fluoride.

## WATER SUPPLY

The Painted Canyon Overlook well can be used as soon as pumping equipment is installed and the well is disinfected. However, the water may need to be aerated to remove hydrogen sulfide gas. Aeration would require construction of a vented tank or a building containing aeration equipment.

A submersible pump capable of lifting 25 to 50 gal/min (1.6 to 3.2 l/s) to the land surface should be sufficient for present use. A pump of 50 gal/min (3.2 l/s) capacity will draw the water level in the well down about 125 feet (38 m) if set at a depth of about 600 feet (183 m). In the event more water is needed, a pump of about 75 gal/min (4.7 l/s) capacity could be installed in the well and set at a depth of about 660 feet (201 m).

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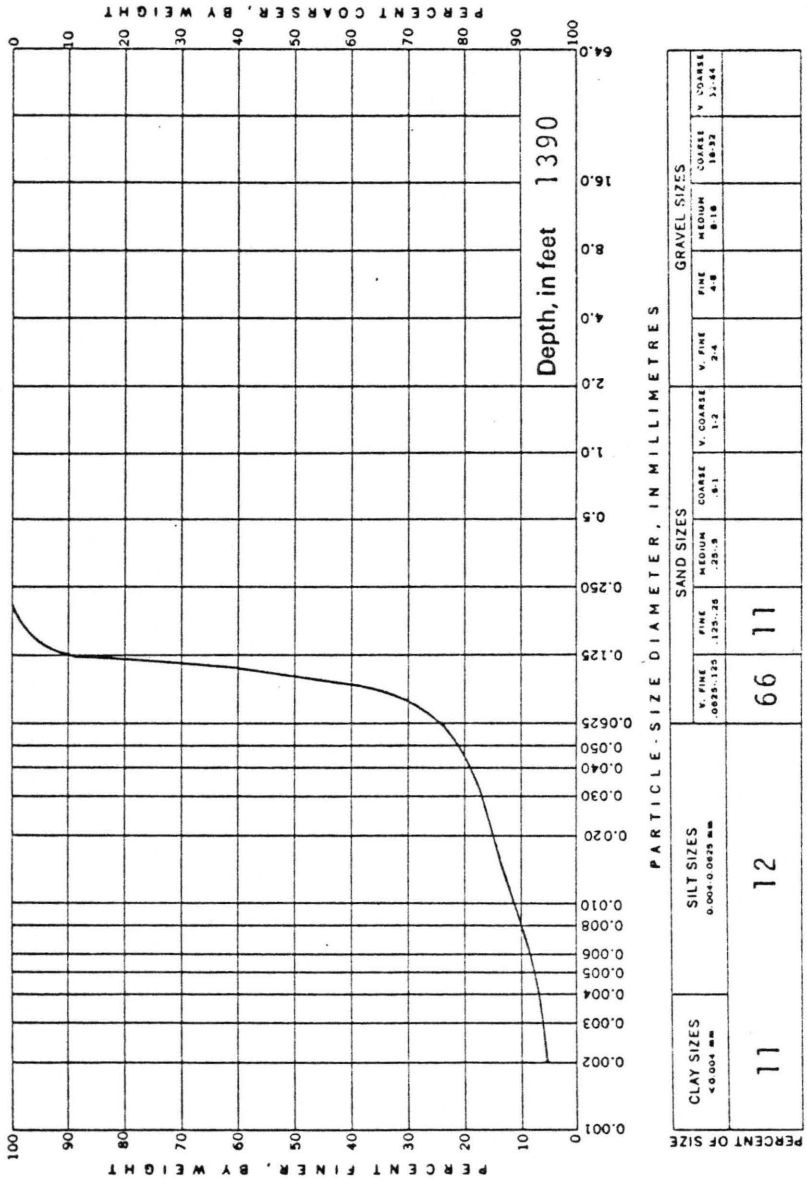
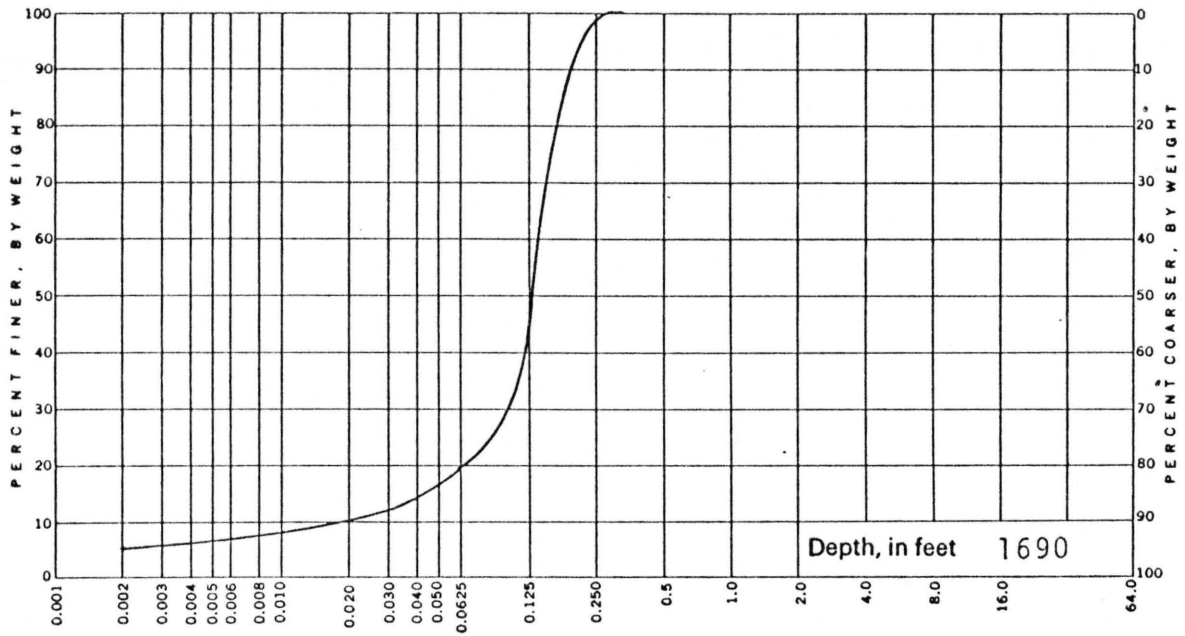
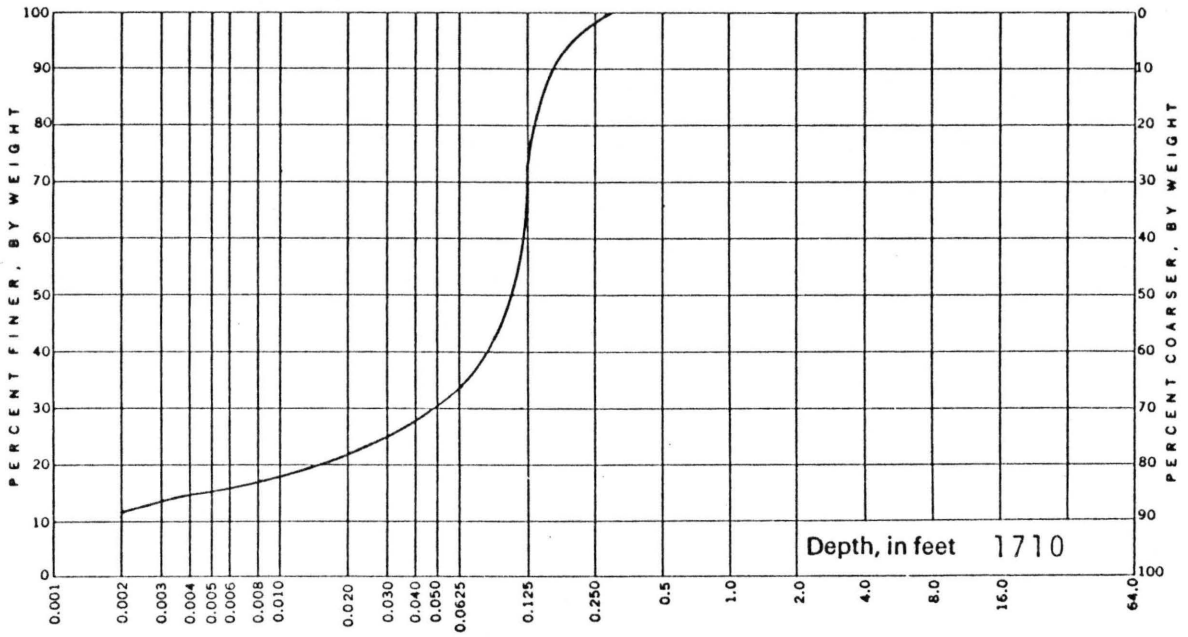
# APPENDIX 1

Particle-size distribution curves for samples collected from National Park Service's Painted Canyon Overlook well

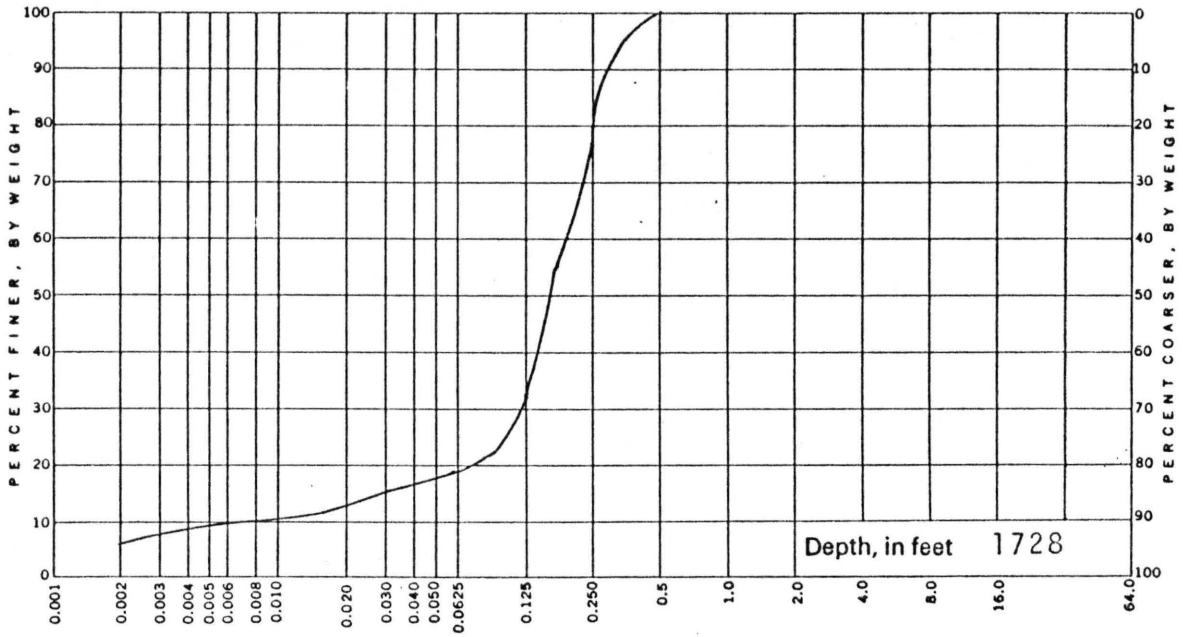




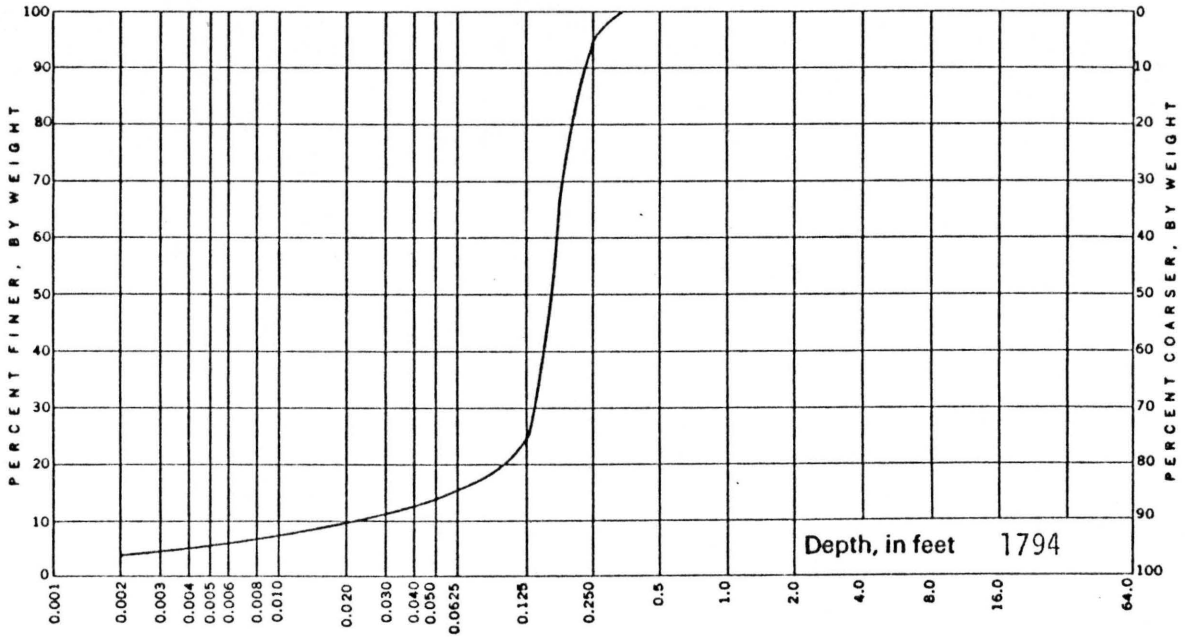

| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 9 | 11 | 30 | 49 | 1 | | | | | | | |



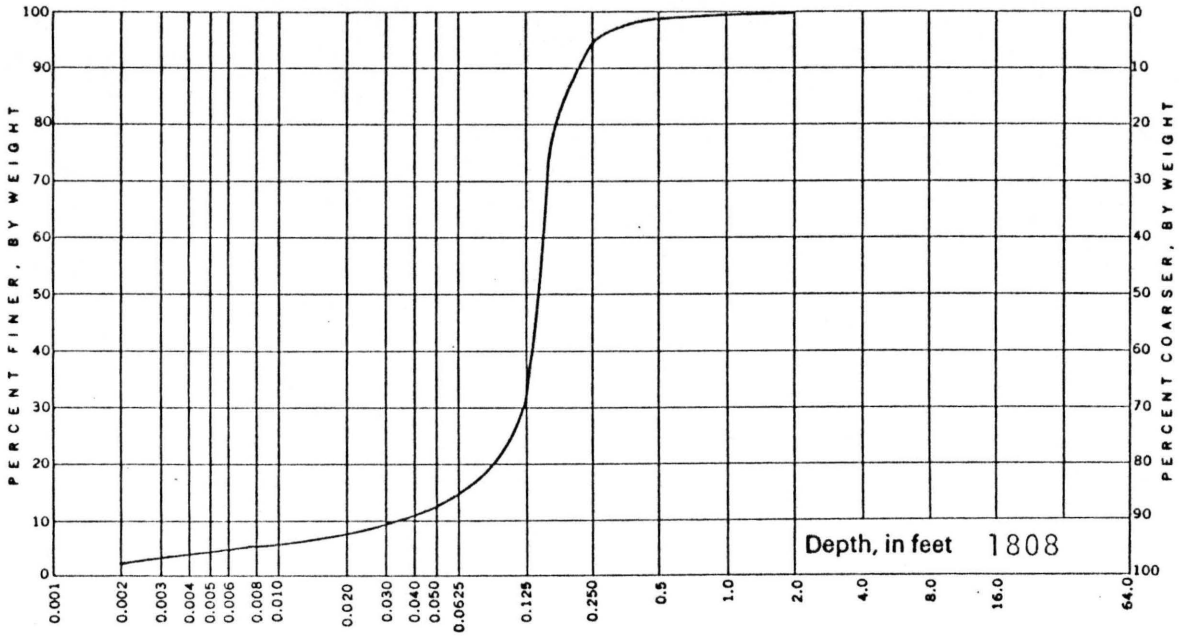

| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 15 | 19 | 39 | 26 | 1 | | | | | | | |



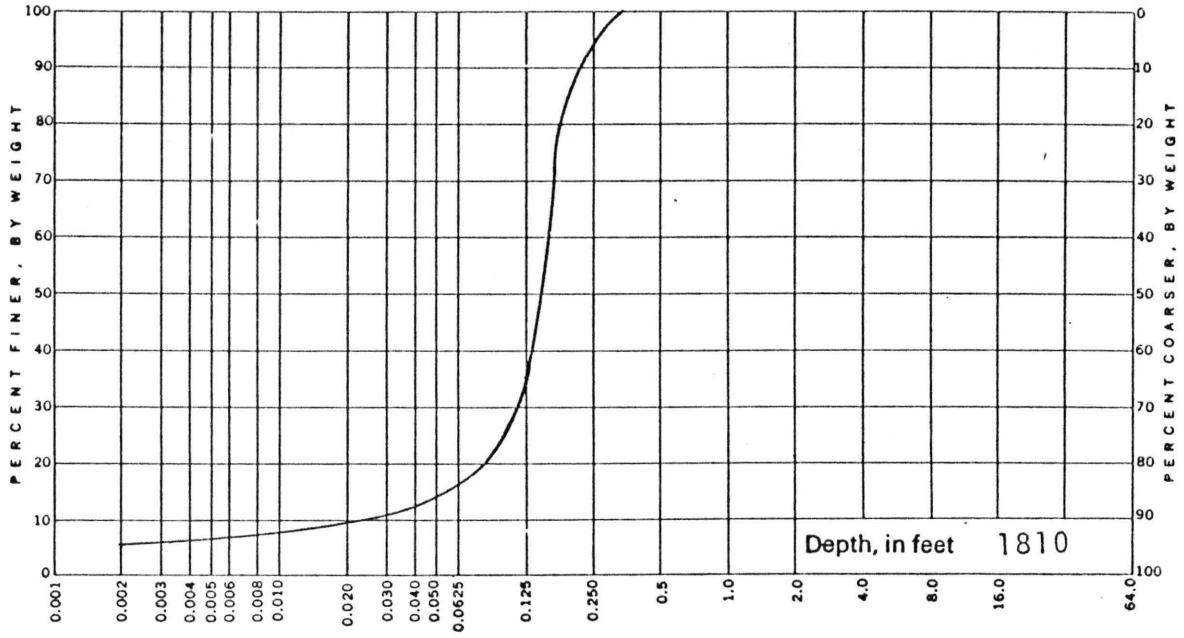

| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 8 | 11 | 13 | 45 | 23 | | | | | | | |



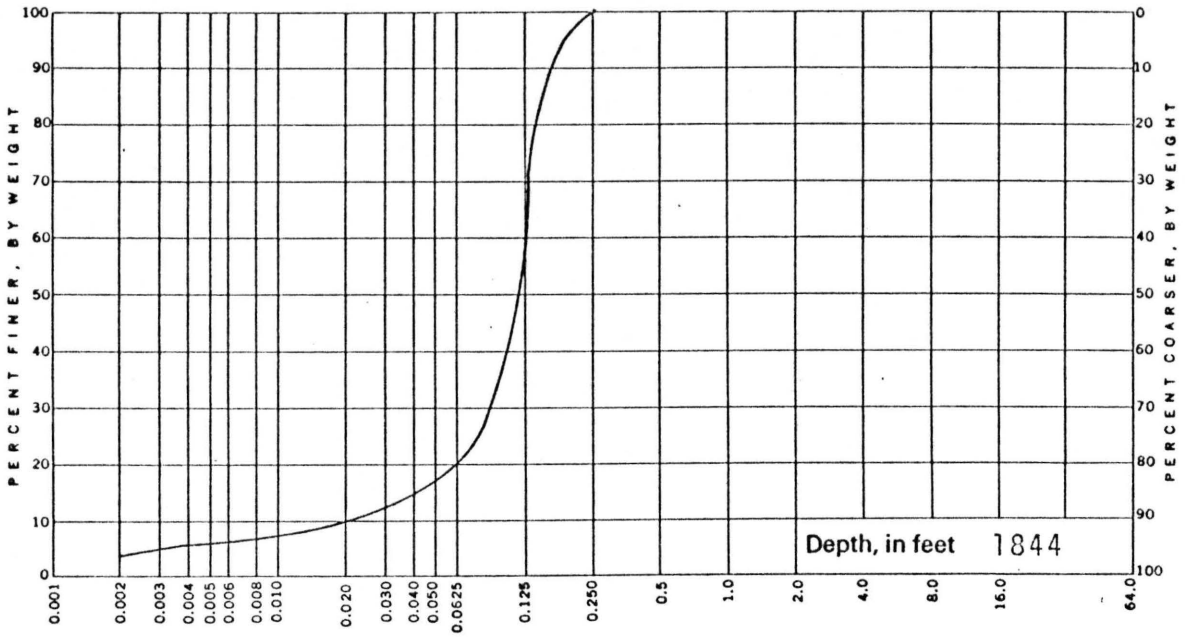

| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 6 | 11 | 8 | 70 | 5 | | | | | | | |



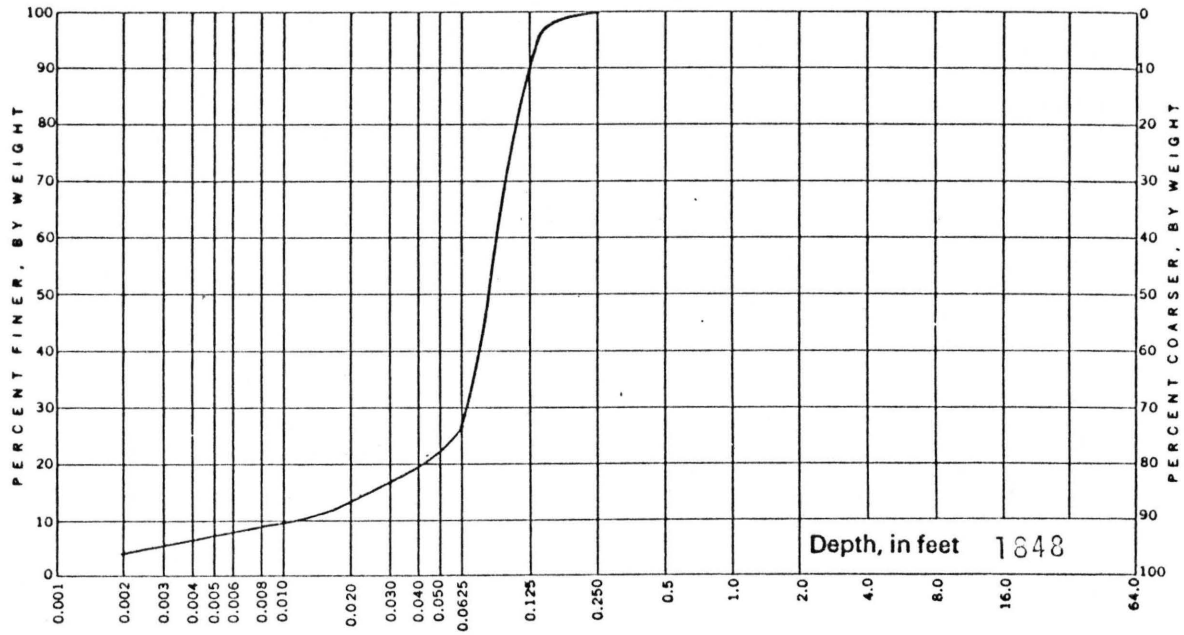

| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 4 | 10 | 18 | 63 | 3 | 1 | 1 | | | | | |



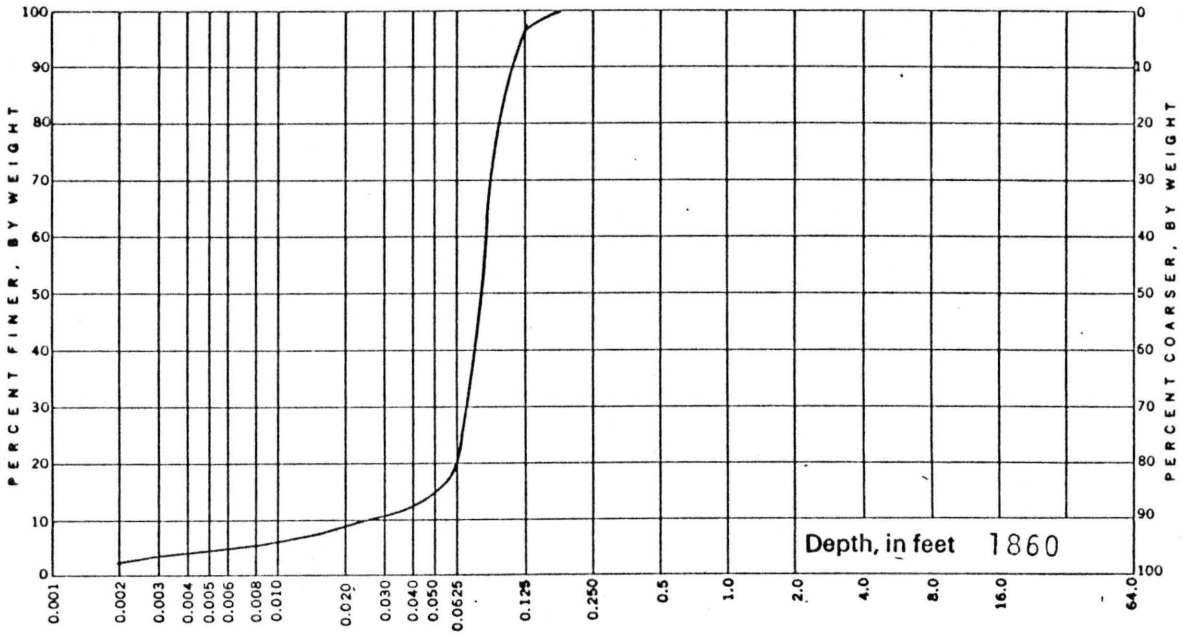

| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 6 | 10 | 19 | 60 | 5 | | | | | | | |



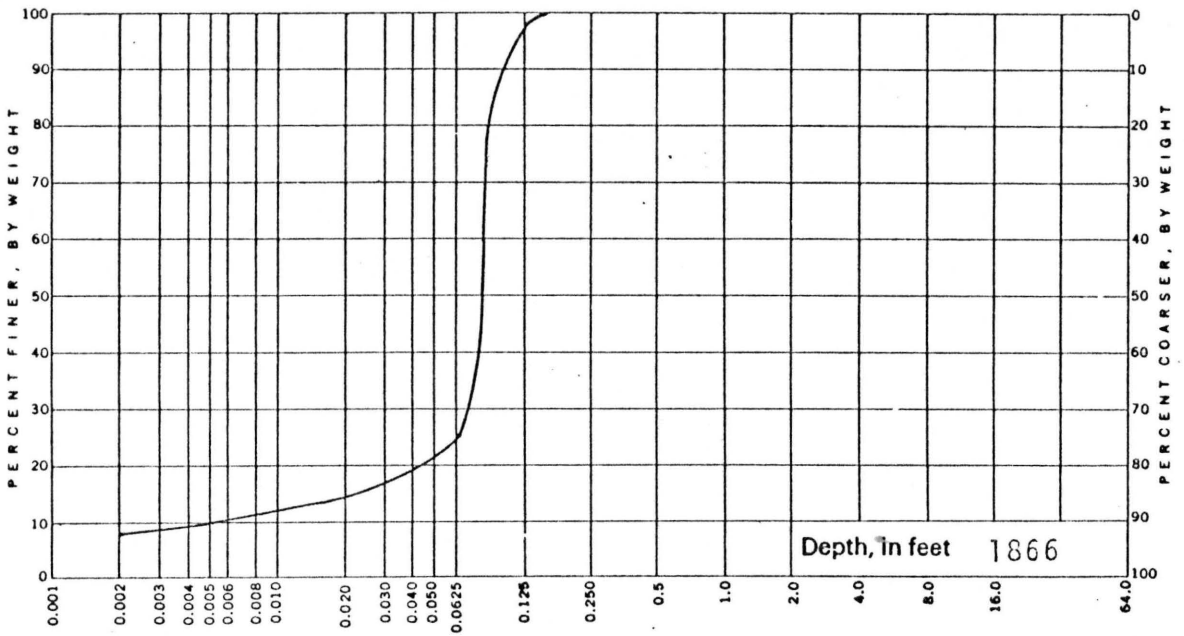

| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 5 | 16 | 51 | 28 | | | | | | | | |



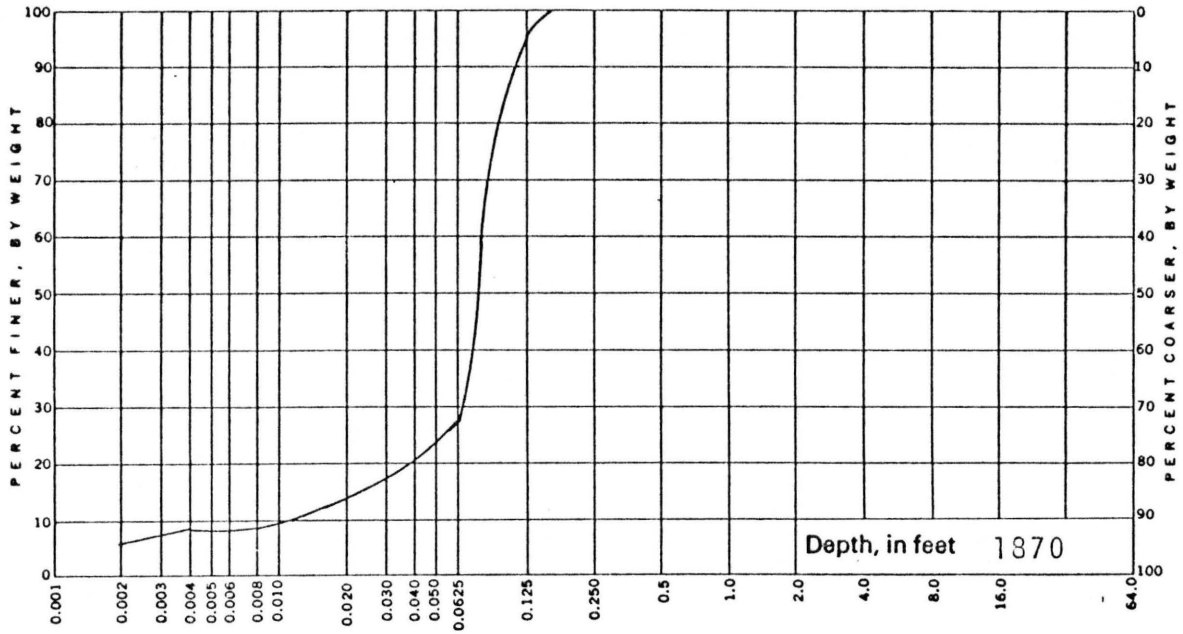

| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 6 | 20 | 65 | 9 | | | | | | | | |




| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 4 | 15 | 78 | 3 | | | | | | | | |




| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 9 | 17 | 72 | 2 | | | | | | | | |




| PERCENT OF SIZE | CLAY SIZES <0.004 mm | SILT SIZES 0.004-0.0625 mm | SAND SIZES | | | | | GRAVEL SIZES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | V. FINE .0625-.125 | FINE .125-.25 | MEDIUM .25-.5 | COARSE .5-1 | V. COARSE 1-2 | V. FINE 2-4 | FINE 4-8 | MEDIUM 8-16 | COARSE 16-32 | V. COARSE 32-64 |
| | 9 | 17 | 71 | 3 | | | | | | | | |

# APPENDIX 2

## Well logs

### National Park Service's Painted Canyon Overlook Well

Altitude 2,770 feet[1/]

| Geologic Source | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Fort Union Formation: | | | |
| Sentinel Butte Member | Claystone and sandstone, silty, light-olive-gray | 30 | 30 |
| | Claystone, silty, lignitic | 5 | 35 |
| | Claystone and sandstone | 5 | 40 |
| | Siltstone and claystone | 5 | 45 |
| | Siltstone, sandy | 25 | 70 |
| | Claystone, lignitic | 14 | 84 |
| | Lignite | 12 | 96 |
| | Claystone, silty | 4 | 100 |
| | Lignite | 8 | 108 |
| | Claystone, silty | 8 | 116 |
| | Limestone | 4 | 120 |
| | Claystone, silty, sandy, carbonaceous | 87 | 207 |
| | Limestone | 4 | 211 |
| | Claystone, silty, sandy, carbonaceous | 39 | 250 |
| | Lignite | 4 | 254 |
| | Claystone, silty, thin bed of limestone at 260 feet | 38 | 292 |
| | Lignite and shale, carbonaceous | 12 | 304 |
| | Claystone, silty | 12 | 316 |
| | Lignite | 12 | 328 |
| | Sandstone, silty, clayey | 8 | 336 |
| | Lignite | 6 | 342 |
| | Sandstone and claystone | 87 | 429 |
| Tongue River Member | Lignite | 5 | 434 |
| | Claystone, sandy, carbonaceous | 50 | 484 |
| | Sandstone | 26 | 510 |
| | Claystone, carbonaceous | 4 | 514 |
| | Sandstone | 50 | 564 |
| | Lignite | 14 | 578 |
| | Sandstone and claystone | 64 | 642 |
| | Lignite | 10 | 652 |
| | Sandstone and claystone | 64 | 716 |

National Park Service's Painted Canyon Overlook well
(continued)

| Geologic Source | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Tongue River Member (continued) | Limestone---------- | 4 | 720 |
| | Sandstone---------- | 30 | 750 |
| | Lignite---------- | 20 | 770 |
| | Sandstone---------- | 15 | 785 |
| Ludlow Member | Claystone---------- | 13 | 798 |
| | Lignite---------- | 6 | 804 |
| | Lignite and claystone------- | 62 | 866 |
| | Lignite---------- | 12 | 878 |
| | Claystone---------- | 18 | 896 |
| Cannonball Member | Lignite and claystone------- | 17 | 913 |
| Ludlow Member | Claystone, silty---------- | 27 | 940 |
| | Sandstone---------- | 23 | 963 |
| | Limestone ---------- | 5 | 968 |
| | Siltstone, sandy---------- | 26 | 994 |
| Cannonball Member | Limestone---------- | 4 | 998 |
| | Siltstone, sandy---------- | 32 | 1030 |
| | Limestone---------- | 4 | 1034 |
| | Claystone, sandy---------- | 30 | 1064 |
| | Limestone---------- | 2 | 1066 |
| | Claystone---------- | 36 | 1102 |
| Ludlow Member | Limestone---------- | 4 | 1106 |
| | Sandstone and claystone----- | 62 | 1168 |
| | Lignite ---------- | 4 | 1172 |
| | Claystone and lignite------- | 30 | 1202 |
| | Lignite---------- | 6 | 1208 |
| | Sandstone, silty---------- | 26 | 1234 |
| | Limestone ---------- | 4 | 1238 |
| | Siltstone and sandstone----- | 18 | 1256 |
| | Lignite---------- | 7 | 1263 |
| | Sandstone---------- | 43 | 1306 |
| | Lignite and claystone------- | 14 | 1320 |

National Park Service's Painted Canyon Overlook well
(continued)

| Geologic Source | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Hell Creek Formation: | | | |
| | Sandstone and siltstone----- | 30 | 1350 |
| | Limestone---------- | 4 | 1354 |
| | Sandstone---------- | 38 | 1392 |
| | Limestone---------- | 6 | 1398 |
| | Sandstone---------- | 32 | 1430 |
| | Claystone, carbonaceous----- | 18 | 1448 |
| | Limestone---------- | 2 | 1450 |
| | Claystone, carbonaceous----- | 44 | 1494 |
| | Lignite ---------- | 9 | 1503 |
| | Claystone---------- | 47 | 1550 |
| | Limestone---------- | 4 | 1554 |
| | Claystone, silty ---------- | 120 | 1674 |
| | Sandstone ---------- | 58 | 1732 |
| | Limestone---------- | 3 | 1735 |
| | Claystone and siltstone----- | 50 | 1785 |
| Fox Hills Sandstone: | | | |
| | Sandstone ---------- | 90 | 1875 |
| | Claystone, silty, sandy----- | 55 | 1930 |

National Park Service's Headquarters Well
(Log from Midwest Well and Pipe Co.)

Altitude 2,265 feet

| | | | |
|---|---|---|---|
| Fort Union Formation: | | | |
| Tongue River Member | Surface soil---------- | 3 | 3 |
| | Clay, gray---------- | 11 | 14 |
| | Clay, yellow---------- | 4 | 18 |
| | Gravel, sand---------- | 15 | 33 |
| | Clay, yellow---------- | 1 | 34 |
| | Coal---------- | 0.6 | 34.6 |
| | Sand, white---------- | 3.4 | 38 |
| | Sandstone, hard---------- | 2 | 40 |
| | Clay, white---------- | 11 | 51 |
| | Coal---------- | 1 | 52 |
| | Shale, carbonaceous -------- | 2 | 54 |
| | Clay, sandy, fine, white---- | 6 | 60 |

National Park Service's Headquarters well (continued)

| Geologic Source | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Tongue River Member (continued) | Sand, gray | 80 | 140 |
| | Clay, sandy | 8 | 148 |
| | Clay, dark | 4 | 152 |
| | Coal, hard | 30 | 182 |
| Ludlow Member | Soapstone, white | 26 | 208 |
| | Clay, dark | 11 | 219 |
| | Stone, hard | 0.6 | 219.6 |
| | Clay, light gray | 18.4 | 238 |
| | Stone | 1.6 | 239.6 |
| Cannonball Member | Clay, blue | 54.4 | 294 |
| Ludlow Member | Sand, fine, loose, blue | 26 | 320 |
| Cannonball Member | Clay, silty, sandy, fine | 10 | 330 |
| | Clay | 5 | 335 |
| | Clay, sandy | 15 | 350 |
| | Clay, blue | 11 | 361 |
| | Clay, sandy | 25.6 | 386.6 |
| | Sandstone | 0.4 | 387 |
| | Clay, blue | 15 | 402 |
| | Sandstone, hard | 1.6 | 403.6 |
| | Clay, blue | 41.4 | 445 |
| | Clay, sandy, blue | 11 | 456 |
| | Clay, blue, hard | 18 | 474 |
| Ludlow Member | Clay, sandy | 4 | 478 |
| | Sandstone | 2.4 | 480.4 |
| | Clay, sandy, fine, white | 9.6 | 490 |
| | Sand, fine, very silty | 31 | 521 |
| | Clay, blue | 2 | 523 |
| | Clay, dark, hard | 7 | 530 |
| | Soapstone | 8 | 538 |
| | Coal | 2 | 540 |
| | Sand, fine, hard | 31 | 571 |
| | Clay, sandy, fine | 35 | 606 |
| | Coal | 7 | 613 |
| | Sandstone | 1.6 | 614.6 |
| | Clay, gray | 2.4 | 617 |

National Park Service's Headquarters well (continued)

| Geologic Source | Material | Thickness (feet) | Depth (feet) |
|---|---|---|---|
| Hell Creek Formation: | | | |
| | Soapstone, hard---------- | 53 | 670 |
| | Quicksand---------- | 16 | 686 |
| | Stone, hard---------- | 3 | 689 |
| | Sand, fine---------- | 27 | 716 |
| | Coal---------- | 1 | 717 |
| | Soapstone---------- | 9 | 726 |
| | Coal---------- | 4 | 730 |
| | Clay, blue---------- | 10 | 740 |
| | Coal---------- | 4 | 744 |
| | Clay, dark---------- | 26 | 770 |
| | Coal---------- | 4 | 774 |
| | Clay, blue---------- | 30 | 804 |
| | Coal---------- | 5 | 809 |
| | Clay, blue---------- | 5 | 814 |
| | Coal---------- | 8 | 822 |
| | Soapstone, hard---------- | 38 | 860 |
| | Coal---------- | 4 | 864 |
| | Shale, dark, hard---------- | 16 | 880 |
| | Coal---------- | 10 | 890 |
| | Clay, dark, hard---------- | 50 | 940 |
| | Sand, fine---------- | 9 | 949 |
| | Sandstone---------- | 0.6 | 949.6 |
| | Sand, fine---------- | 1.4 | 951 |
| | Sandstone---------- | 1 | 952 |
| | Clay, blue---------- | 15 | 967 |
| | Shale, brown, carbonaceous-- | 8 | 975 |
| | Coal---------- | 2 | 977 |
| | Shale, soft---------- | 41 | 1018 |
| | Shale, hard---------- | 22 | 1040 |
| Fox Hills Sandstone: | | | |
| | Sand, silty, fine, soft, water flow started-------- | 69 | 1109 |

1/To convert feet to metres multiply feet by 0.3048.



PAGES 29 & 30 (LOGS)

APPENDIX 4

Drawdown test in National Park Service's Painted Canyon Overlook well, July 25, 1973

Datum is 7 feet above land surface.

| Time | Time since pumping began (minutes) | Water level (feet)[1/] | Drawdown (feet)[1/] | Remarks |
|---|---|---|---|---|
| 6:00 a.m. | 0 | 343.0 | 0.0 | |
| 6:01 | 1 | 346.7 | 3.7 | |
| 6:02 | 2 | 356.4 | 13.4 | |
| 6:04 | 4 | 429.5 | 86.5 | |
| 6:06 | 6 | 450.0 | 107.0 | |
| 6:07 | 7 | 454.2 | 111.2 | |
| 6:08 | 8 | 459.0 | 116.0 | |
| 6:09 | 9 | 463.3 | 120.3 | |
| 6:10 | 10 | 466.4 | 123.4 | 77 gal/min (4.9 l/s). |
| 6:15 | 15 | 476.7 | 133.7 | |
| 6:20 | 20 | 482.6 | 139.6 | |
| 6:25 | 25 | 487.0 | 144.0 | |
| 6:30 | 30 | 490.1 | 147.1 | |
| 6:45 | 45 | 497.6 | 154.6 | |
| 7:00 | 60 | 501.0 | 158.0 | 75 gal/min (4.7 l/s). |
| 7:15 | 75 | 504.3 | 161.3 | |
| 7:30 | 90 | 507.0 | 164.0 | |
| 8:00 | 120 | 510.5 | 167.5 | |
| 9:00 | 180 | 515.2 | 172.2 | |
| 10:00 | 240 | 517.3 | 174.3 | 72 gal/min (4.5 l/s). |

| Time | Time since pumping began (minutes) | Water level (feet)[1] | Drawdown (feet)[1] | Remarks |
|---|---|---|---|---|
| 11:00 | 300 | 518.4 | 175.4 | |
| 12:00 | 360 | 519.7 | 176.7 | |
| 1:00 p.m. | 420 | 521.2 | 178.2 | |
| 2:00 | 480 | 522.2 | 179.2 | |
| 3:00 | 540 | 523.4 | 180.4 | |
| 4:00 | 600 | 524.2 | 181.2 | |
| 5:00 | 660 | 524.3 | 181.3 | |
| 6:00 | 720 | 524.9 | 181.9 | water temp. 83°F (28°C) |
| 7:00 | 780 | 525.3 | 182.3 | |
| 8:00 | 840 | 525.8 | 182.8 | |
| 9:00 | 900 | 526.3 | 183.3 | |
| 10:00 | 960 | 526.8 | 183.8 | |
| 11:00 | 1020 | 527.2 | 184.2 | |
| 12:00 | 1080 | 528.0 | 185.0 | |
| 2:00 a.m. | 1200 | 528.2 | 185.2 | |
| 4:00 | 1320 | 529.1 | 186.1 | |
| 5:00 | 1380 | 529.3 | 186.3 | 72 gal/min (4.5 l/s). |
| 6:00 | 1440 | 529.4 | 186.4 | |

1/To convert feet to metres multiply feet by 0.3048.

## APPENDIX 5

Recovery test in National Park Service's Painted Canyon Overlook well, July 26, 1973

Datum is 7 feet above land surface.

| Time | Time since pumping ended (minutes) | Water level (feet)[1] | Recovery (feet)[1] |
|---|---|---|---|
| 6:00 a.m. | 0 | 529.4 | 0.0 |
| 6:05 | 5 | 425.6 | 103.8 |
| 6:07 | 7 | 419.4 | 110.0 |
| 6:10 | 10 | 411.9 | 117.5 |
| 6:12 | 12 | 408.2 | 121.2 |
| 6:15 | 15 | 403.7 | 125.7 |
| 6:18 | 18 | 400.0 | 129.4 |
| 6:20 | 20 | 398.0 | 131.4 |
| 6:25 | 25 | 394.0 | 135.4 |
| 6:30 | 30 | 391.0 | 138.4 |
| 6:40 | 40 | 386.0 | 143.4 |
| 6:50 | 50 | 382.0 | 147.4 |
| 7:00 | 60 | 380.0 | 149.4 |
| 7:15 | 75 | 376.5 | 152.9 |
| 7:30 | 90 | 373.5 | 155.9 |
| 8:00 | 120 | 370.0 | 159.4 |
| 8:30 | 180 | 367.0 | 162.4 |
| 9:00 | 210 | 365.0 | 164.4 |

[1]/To convert feet to metres multiply feet by 0.3048.

APPENDIX 6

Chemical analyses

6A.--Common constituents and properties of water from selected wells
(Results in milligrams per litre except as indicated; analyses by U.S. Geological Survey)

| Constituent or property | National Park Service Headquarters well June 13, 1973 | National Park Service Painted Canyon Overlook well July 25, 1973 | National Park Service Rough Rider well June 13, 1973 | Private stock well south of Medora June 13, 1973 |
|---|---|---|---|---|
| Silica ($SiO_2$) | 14 | 15 | 9.2 | 9.4 |
| Iron (Fe) | 0 | .09 | .01 | .01 |
| Manganese (Mn) | 0 | .01 | 0 | 0 |
| Calcium (Ca) | 2.7 | 1.5 | 2.0 | 2.1 |
| Magnesium (Mg) | .4 | .4 | .9 | 1.0 |
| Sodium (Na) | 410 | 420 | 420 | 490 |
| Potassium (K) | 1.3 | 1.5 | 1.4 | 1.7 |
| Bicarbonate ($HCO_3$) | 677 | 746 | 616 | 965 |
| Carbonate ($CO_3$) | 32 | 42 | 28 | 28 |
| Alkalinity, total (as $CaCO_3$) | 609 | 682 | 552 | 838 |
| Sulfate ($SO_4$) | 220 | 120 | 340 | 210 |
| Chloride (Cl) | 41 | 67 | 11 | 14 |
| Fluoride (F) | 3.0 | 3.1 | 1.6 | 4.4 |
| Nitrite plus nitrate (as N) | .06 | .05 | .02 | .03 |
| Phosphorus (as P) | .47 | .50 | .21 | .51 |
| Dissolved solids: | | | | |
| Residue at 180°C | 1130 | 1050 | 1200 | 1330 |
| Calculated sum | 1060 | 1040 | 1120 | 1240 |
| Hardness, total (as $CaCO_3$) | 8 | 5 | 9 | 9 |
| Noncarbonate hardness | 0 | 0 | 0 | 0 |
| Percent sodium | 99 | 99 | 99 | 99 |
| Sodium-adsorption ratio (SAR) | 62 | 79 | 62 | 70 |
| Specific conductance (μmhos/cm at 25°C) | 1070 | 1590 | 1750 | 1930 |
| pH (units) | 8.6 | 8.7 | 8.6 | 8.4 |
| Water temperature (°C) | 20.0 | 28.0 | 14.0 | 12.5 |
| Color (platinum cobalt scale) | 20 | 50 | 8 | 40 |
| Cyanide (CN) | -- | 0 | -- | -- |

6B.--Trace elements in water from National Park Service's Painted Canyon Overlook well

(Sample collected June 13, 1973; analyses by U.S. Geological Survey)

| Constituent | Micrograms per litre (µg/l) |
|---|---|
| Arsenic (As) | 2 |
| Barium (Ba) | 0 |
| Beryllium (Be) | 0 |
| Boron (B) | 1100 |
| Cadmium (Cd) | 1 |
| Chromium (Cr) | 0 |
| Cobalt (Co) | 1 |
| Copper (Cu) | 7 |
| Lead (Pb) | 4 |
| Lithium (Li) | 60 |
| Mercury (Hg) | 0 |
| Molybdenum (Mo) | 2 |
| Nickel (Ni) | 4 |
| Selenium (Se) | 0 |
| Silver (Ag) | 0 |
| Strontium (Sr) | 70 |
| Vanadium (V) | 2.3 |
| Zinc (Zn) | 10 |