Attachment A

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Memorandum

To: Terry Graumann, Otter Tail Power Company

From: Nels Nelson and Ray Wuolo

Subject: Preliminary evaluation of feasibility of groundwater supply for Big Stone Plant

Date: July 3, 2002

Project: 4125003

I. Introduction

This memorandum summarizes an initial evaluation of the potential of developing a backup water supply for the Big Stone Plant using groundwater sources. The goal would be to develop a supply capable of yielding at least 4,220 acre feet per year (2,600 gpm). This is the estimated current consumptive use of the Big Stone Plant. It would be desirable to have a source that could supply this amount for approximately two consective years in 20 years. It would also be desirable if the source could be expanded to twice this amount to accommodate future expansion of the plant. The quality of the water is of secondary importance because groundwater would be used infrequently and the plant has extensive facilities for dealing with dissolved solids in water. However, high quality is desirable since it reduces treatment costs.

This study first evaluates the groundwater supplies near the Big Stone Power Plant. The evaluation is based on existing and available information on the occurrences of groundwater in Grant County, South Dakota. The evaluation is limited to Grant County but much of the general hydrogeology in Grant County is also applicable east of the River in Minnesota.

The second step is a preliminary comparison of sources based on yield, proximity and rough estimates of cost and feasibility. The final step is a recommendation for next steps, should Otter Tail Power Company wish to pursue this strategy for water supply.

II. Review of Potential Water Sources

The Big Stone plant, like most of Grant County, is underlain by approximately 200-300 feet of glacial deposits overlying Cretaceous shale bedrock. The groundwater sources in the vicinity of the plant are found in both bedrock aquifers and unconsolidated aquifers. The best source of information is Hansen, D.S., 1990. *Water resources of*

Codington and Grant Counties, (South Dakota, U.S. Geological Survey Water Resources Investigations Report 89-4147, 47 p). This is the source for much of the following information and for the figures showing aquifer locations.

A. Aquifers in Unconsolidated Deposits

Unconsolidated deposits, refer to clay, silt, sand, and gravel materials. Nearly all of the unconsolidated deposits in the area are glacially derived or deposited by rivers associated with glaciation – this type of aquifer is sometimes called an "outwash" aquifer. Many small lenses and seams in the glacial deposits would yield water but only a few are extensive enough to be recognized as specific aquifers. In the vicinity of the plant, these include:: Antelope Valley aquifer; Lonesome Lake aquifer; Big Sioux aquifer; Revillo aquifer, Veblen aquifer, Prairie Coteau aquifer; and Altamont aquifer.

These glacial aquifers vary in thickness and hydraulic conductivity (permeability). The greatest yields (wells with yields greater than 800 gallons per minute) include the Big Sioux , Antelope, and Prairie Coteau aquifers. These higher yields have been attributed, in part, to the aquifers' good hydraulic connection with lakes and rivers, which provide rapid recharge. Unfortunately, as noted below, this characteristic also increases the potential for impacts to surface waters.

Good hydraulic connection with a surface-water body is certainly a factor in whether or not a glacial aquifer will provide sustainable high yields to wells. Other factors that lead to high yields include: the preponderance of high-permeability materials (e.g., sand or gravel); thicker deposits of high-permeability materials; good hydraulic connection with adjoining aquifers (i.e. thin or higher permeability aquitards and confining units); and extensive lateral extent of thick, permeable units. An aquifer unit in one area may possess most of these qualities but in another, may be a poor producer of groundwater. This is an inherent risk when dealing with aquifers that were deposited by glacial or river actions – sands and gravels can pinch out unpredictably.

1. Big Sioux aquifer

The Big Sioux aquifer is a sand and gravel outwash deposit, limited to the flood plain of the Big Sioux River and its tributaries, as shown on Figure 1. This aquifer is 20 miles from from the Big Stone plant but it is included in this evaluation because the Big Sioux aquifer is very productive – with irrigation wells yielding as much as 1,100 gpm. The Big Sioux aquifer is very productive because: (1) it is shallow (typically at ground surface to 10 feet below ground surface) and receives recharge directly from infiltrating precipitation; (2) it consists of coarse-grained outwash deposits, which are very permeable; and (3) it is in direct hydraulic connection with the Big Sioux River and it's tributaries, which provide recharge to pumping wells and limit drawdown. The aquifer is heavily used (over 2,100 acre-ft per year of pumping or 1.9 million gallons per day - MGD) for irrigation, domestic, municipal, and stock water uses.

The Big Sioux aquifer could likely yield substantially more water than the current withdrawals. However, because of the shallow depth of the aquifer a new, high-capacity well field in the Big Sioux aquifer would likely cause noticeable drops in the yield of existing wells and the drying up of other wells. It is likely that it would also cause impacts to the Big Sioux River.

2. Antelope Valley aquifer

The Antelope Valley aquifer is also an unconfined, glacial-outwash deposit. It is located in western Grant County, as shown on Figure 1, along the drainage divide between the Big Sioux and Minnesota Rivers. The Antelope Valley aquifer consists of coarse sand and gravel that is hydraulically connected to several small lakes. Recharge is by infiltrating precipitation and snow melt. Irrigation, domestic, and stock-water wells use the aquifer as a water supply. The total withdrawal rate is unknown but likely much lower than the Big Sioux aquifer.

During drought years, water levels in the Antelope Valley aquifer decline in response to decreased infiltration and increased water use (to compensate for decreased precipitation). During June and July, irrigation wells are typically at full operation and water levels near these wells drop noticeably. A new, high-capacity well field in this aquifer would have issues of declining yields to existing wells and/or drying up of wells.

3. Prairie Coteau aquifer

The Prairie Coteau aquifer is located in the western part of Grant County (Figure 2). This aquifer consists of coarse sand and gravel, the top of which may be as much as 380 feet below ground surface. Recharge to this relatively deep aquifer is primarily by downward leakage from a less-extensive glacial aquifer at ground surface called the Coteau Lakes aquifer and from the previously mentioned Big Sioux aquifer. Some irrigation, domestic wells, and stock-watering wells use this aquifer with annual withdrawals of about 1,700 acre-ft per year (1.5 MGD).

This aquifer seems to have the potential for further use. Because it is deeper than the Big Sioux aquifer and the Antelope Valley aquifer, there are fewer wells installed. It is also partially under confined conditions, which suggests that there is more available drawdown than with an unconfined aquifer. However, unlike the Big Sioux and Antelope Valley aquifers, it is not hydraulically connected to surface-water bodies, which would result in rapid replenishment of storage. Since power plant use would be intermittent this might be acceptable. Modeling of the aquifer would be needed to estimate whether the drawdown and recovery potential are compatible with the power plant needs.

4. Veblen aquifer

The Veblen aquifer is located in eastern Grant County and likely underlies the Big Stone plant, as shown on Figure 3. It is composed of coarse sand and gravel. In Milbank it is up to 150 feet thick but this thick section of aquifer is relatively limited in area. Pressures in the aquifer are generally artesian, indicating confined conditions. Recharge is by infiltrating precipitation where overlying glacial till layers are thin, such as along its western extent. Municipal wells include Milbank – there are also domestic and stock-water wells. Dewatering from granite quarries east of Milbank remove some water from this aquifer. The total withdrawal from the Veblen aquifer is not known.

The Veblen aquifer may be a good candidate for further consideration as a water supply for the Big Stone plant, primarily because of its proximity to the plant. It also does not appear to be as heavily used as other aquifers in the area. Issues of reduced pressure in wells, known to be artesian, could present an issue.

5. Lonesome Lake aquifer

The Lonesome Lake aquifer (extent shown on Figure 3) is located in western Grant County. This outwash aquifer consists of sand to fine gravel with as much as 20 percent clay near the bottom of the aquifer. The aquifer is confined and overlain by over 350 feet of clayey till. Recharge is through this till. Production and potential yield are unknown.

6. Revillo aquifer

The Revillo aquifer is located in central Grant County (see extent on Figure 4). It lies in a buried bedrock valley that trends northwest-southeast. The Revillo aquifer consists of glacial outwash gravel. The aquifer is between 100 and 650 feet below ground surface, with a projected areal extent of about 200 square miles. The average aquifer thickness is about 60 feet, making it one of the thicker aquifers. Over 1 million acre-feet of storage is estimated for the Revillo aquifer. Well yields vary from 50 to 150 gpm. Recharge is by infiltration through till layers. The aquifer is tapped by a municipal well at Revillo and at Twin Brooks for Milbank. Stock-water and domestic wells also pump from this aquifer.

The Revillo aquifer has the potential for large yields but may not be able to sustain these yields over long periods of time because the recharge rate may be slow. During summer months, there is noticeable drawdowns due to pumping of the municipal wells. Issues of drying up wells are lessened because of the depth of this aquifer.

7. Altamont aquifer

The Altamont aquifer is in western Grant County (see Figure 5). It is primarily a sand unit, with interbedded silt and clay layers. The aquifer is about 450 below ground surface, with an average thickness of about 40 feet. Recharge is by leakage through the overlying till. The aquifer is pumped by stock-watering and domestic wells but with the introduction of rural water systems, these wells are being abandoned. There is an estimated 3.3 million acre-feet of storage in this aquifer, with well yields typically ranging from 10 to 50 gpm. Dissolved solids concentrations of this aquifer are higher than the other glacial aquifers – about 2,100 mg/L.

This aquifer has attraction as a source of water for the Big Stone plant because of it is not being heavily used and because it has a large potential storage. However, many wells will likely be required to yield enough water.

B. Aquifers in Bedrock

1. Dakota Sandstone Aquifer

The Dakota Sandstone aquifer is also referred to as the Dakota-Newcastle aquifer system in South Dakota and is lumped with the Inyan Kara aquifer in portions of the State. In western South Dakota, as well as in large areas of Nebraska, the Dakota Sandstone aquifer represents a significant source of water and is known for having flowing wells. However, in eastern South Dakota, the Dakota Sandstone aquifer is much less used because it is typically deeper than in the western part of the State, its water quality is poorer, and there are much shallower alternative sources in the glacial deposits.

The Dakota Sandstone is recharged where it crops out around the Black Hills, from upward leakage from underlying units, and from downward vertical leakage through shale units. Groundwater flow is from west to east across the state. The estimated regional hydraulic conductivity in South Dakota is about 5 ft/day (compared to a typical sand and gravel aquifer, which has hydraulic conductivity values from 20 to 200 ft/day).

The Dakota Sandstone aquifer is a less attractive source because of its substantial depth (1,200 feet below ground surface) and very poor water quality (sodium and calcium-sulfate-type with high dissolved solids). Nonetheless, the aquifer is attractive since the unit underlies the site and is a highly dependable aquifer. Since the plant has a significant capacity to treat water through lime softening and brine concentration, the poor water quality might be an asset since there would not be competing users for the aquifer.

2. Granite Wash Aquifer

The Granite wash aquifer is much shallower than the Dakota Sandstone and is present in the vicinity of the Big Stone Plant. The extent of the Granite wash aquifer is shown on Figure 5. It is located in eastern Grant County and likely underlies the Big Stone plant area. It consists of uncemented, coarse, quartzose and felspar sand that was derived from weathering of the Milbank granite. Some stock-watering and domestic wells utilize this aquifer but not much is known about its potential for supplying large quantities of water. Depth varies from a few feet, where present, to 50 feet. The extent of the aquifer is unpredictable.

III. Comparison of Water Sources

A. Overall Comparison

Table 1 shows a comparison of the listed water sources and a preliminary ranking of the attractiveness of the sources. It is clear that the Veblen aquifer is the most promising; this confirms the decision made by ProGold in its investigations. However, the Dakota Sandstone might be an alternative if the high sulfate levels could be managed by the plant's water treatment system.

The other aquifers, though not as widely used, may be potential plant water supplies. In particular, the Revillo and Altamont aquifers are not extensively used but have the potential for yielding substantial quantities of water for a period of a few years. Withdrawals from several different aquifers may also be attractive in that the demands from any one aquifer unit could be reduced by spreading the demand out over several aquifers. Bedrock aquifers, such as the Granite wash aquifer, appear to be unpredictable and are likely not of substantial areal extent to be counted on as a dependable water supply.

B. Cost Comparison – Veblen and Dakota Sandstone

For purposes of initial evaluation of feasibility, we have considered the cost of obtaining 2,600 gpm from the Veblen aquifer at the site. A conservative estimate of well capacity would be 170 gpm per well. Drilling 15 wells required to produce 2,600 gpm would cost approximately $130,000 per well, including pumps, controls and surface improvements. Additional cost would be incurred in the connecting piping to the plant. A total cost range of about 1.5 to 3 million dollars would be a reasonable estimate for comparison with other strategic options.

Drilling to the Dakota Sandstone was also considered briefly. Because of the greater depth and lower yield, the cost of the wells would be much higher. A total cost of 5 tp 10 million dollars appears likely. This would assume typical well construction practices; from speaking to well drillers we understand that South Dakota may have stringent requirements for Dakota Sandstone wells that increase the cost.

It is possible that other aquifers could deliver the water at slightly lower cost if other issues shown in Table 1 can be overcome. Nonetheless, the Veblen source appears to be a good assumption for current planning purposes.

IV Recommendation

The decision on whether to pursue a groundwater backup system will depend on the economic balance between the risk of reduced generation during water shortage and the cost of creating a more reliable supply. We recommend that Big Stone Power look at water supply as a problem of optimizing the economic return of any additional investment.

Reliability can be obtained by increasing supply or increasing storage; it is important to evaluate the optimum system for supply. A more reliable supply could be obtained by increasing storage capacity or constructing wells for a backup supply. Different combinations of these approaches are possible; the Big Stone water model can help estimate the different possibilities. The well costs given in this report can give an approximate unit cost for groundwater. The cost of storage can be approximated for various amounts of storage (i.e., the storage cost may be a curve or broken line rather than a simple per-acre-foot cost.).

Once these costs have been determined, the optimum water supply could be reduced to a mathematical optimization problem. A plant optimum water supply might be determined by including the cost of reduced generation during times of drought.

If further evaluation of the feasibility of the groundwater alternative is desired, we recommend that a detailed study of the most attractive aquifers should be undertaken. This would include the Veblen and possibly re-evaluate the Revillo and Altamont aquifers. Actual well logs should be obtained for the area of interest and modeling of the aquifer should be done to evalute well yield and spacing and possible interference effects. More detailed cost estimates would be prepared, including estimates of easements and long-distance supply lines for more distant aquifers.

Table 1

Comparison of Groundwater Sources

Aquifer	Capacity to Yield 4220 AF/yr	Likelihood of Well Interference	Likelihood of Surface Water Impacts	Distance to Plant, Miles (total piping)	Possible number of wells required	Depth of Wells	Summary of Anticipated Cost level
Big Sioux	Very good	High	High	20-25	3 to 5	60	Moderate (due to distance)
Antelope Valley	Marginal/ uncertain	High	Low	35-50	10	100	High (due to number of wells and distance)
Prairie du Coteau	Good	Moderate	Low	30-40	10	200-300	Very High (due to number of wells, depth and distance)
Veblen	Very good	Moderate	Moderate	20-30	15	200	Low
Lonesome Lake	Uncertain, probably marginal	Low	Low	30-50	130	350	Very high (due to number of wells, depth and distance)
Revillo	Moderate	Moderate	Low	15-20	25	300	High (due to distance and depth)
Altamont	Moderate	Low	Low	30-50	65	500	High (due to distance, number of wells and depth)
Dakota Sandstone	Very good	Low	Very Low	0-15	50	1,200	Very High (due to depth & well construction)
Granite Wash	Uncertain	Moderate	Low	0-20	15	350	High

Table 2

Conceptual Cost Estimate -- Veblen Aquifer

Item No.	Description	Estimated Quantity	Unit	Unit Price	Extension
1	Mobilization/Demobilization Pilot Holes	1	L.S.	$3,000.00	$3,000.00
2	Mobilization/Demobilization Wells	1	L.S.	$8,000.00	$8,000.00
	SITE WORK				
3	Furnish and Install 6-Inch DIP Water Main Class 50	100	L.F.	$45.00	$4,500.00
4	Restrain Sleeve	3	EA.	$200.00	$600.00
5	60-Inch Valve Manhole and Appurtenances	1	EA.	$12,000.00	$12,000.00
6	48-Inch Meter Manhole and Appurtenances	1	EA.	$10,000.00	$10,000.00
7	Megalugs (All Sizes)	16	EA.	$130.00	$2,080.00
8	6-Inch Plug Valve	1	EA.	$1,600.00	$1,600.00
9	Hydrant	1	EA.	$1,500.00	$1,500.00
10	6-Inch Gate Valve	1	EA.	$1,000.00	$1,000.00
11	Insulation	230	S.F.	$7.00	$1,610.00
12	Granular Foundation	20	C.Y.	$27.00	$540.00
	PILOT HOLE CONSTRUCTION, MUD ROTARY METHOD				
13	Set Up/Take Down on Pilot Hole	1	EA.	$200.00	$200.00
14	Drill and Sample Pilot Holes	220	L.F.	$10.00	$2,200.00
15	Abandon Pilot Holes	220	L.F.	$2.00	$440.00
	WELL CONSTRUCTION, MUD ROTARY METHOD				
16	Set Up/Take Down on Well	1	EA.	$2,500.00	$2,500.00
17	Drill Main Well Bore-hole	200	L.F.	$38.00	$7,600.00
18	Furnish and Install 8-inch Diameter Casing	154	L.F.	$20.00	$3,080.00
19	Furnish and Install 8"-inch Diameter Telescoping Well Screen	50	L.F.	$55.00	$2,750.00
20	Furnish and Install Filter Pack	115	C.F.	$5.00	$575.00
21	Furnish and Install Neat Cement Grout	154	L.F.	$15.00	$2,310.00
22	Plumbness and Alignment Test	1	EA.	$250.00	$250.00
	WELL DEVELOPMENT				
23	Furnish Development Equipment	1	L.S.	$4,800.00	$4,800.00
24	Install and Remove Development Equipment	1	EA.	$1,000.00	$1,000.00
25	Operate Development Equipment	40	Hour	$60.00	$2,400.00
	TEST PUMPING				
26	Furnish Test Pumping Equipment	1	L.S.	$3,200.00	$3,200.00
27	Install and Remove Test Pumping Equipment	1	EA.	$2,000.00	$2,000.00
28	Operate Test Pumping Equipment	50	Hour	$30.00	$1,500.00
	PUMPING EQUIPMENT				
29	Furnish and Install Pitless Adapter	1	L.S.	$10,000.00	$10,000.00
30	Furnish and Install Pump Bowls (Goulds, Layne, Peerless)	4	Bowl	$300.00	$1,200.00
31	Furnish and Install Submersible Motor (Hitachi)	1	EA.	$9,000.00	$9,000.00
32	Furnish and Install 6-Inch Drop Pipe and 1-Inch PVC Probe Pipe	140	L.F.	$30.00	$4,200.00
	SITE RESTORATION				
33	Granular Borrow	100	C.Y.	$10.00	$1,000.00
34	Topsoil Borrow	50	C.Y.	$12.00	$600.00
35	Site Grading	1	L.S.	$1,500.00	$1,500.00
36	Seeding	0.5	Acre	$1,200.00	$600.00
37	Compacted Class 5 (100%) (Crushed)	50	C.Y.	$20.00	$1,000.00
38	Electrical at site only, across the line start	1	L.S.	$15,000.00	$15,000.00
33	Televise Well	1	EA.	$700.00	$700.00
34	Well Disinfection and Sampling	1	EA.	$900.00	$900.00
		Total Estimate			**$128,935.00**
				Lower range of possible costs(-30%)	**$ 90,000.00**
				Upper range of possible costs(+50%)	**$ 193,000.00**

	Lower range of possible costs for 15 wells @180 gpm each	**$1,350,000.00**
	Upper range of possible costs for 15 wells @180 gpm each	**$2,895,000.00**

Table 3
Conceptual Cost Estimate
Dakota Sandstone Aquifer

Item No.	Description	Estimated Quantity	Unit	Unit Price	Extension
1	Mobilization/Demobilization	1	L.S.	$15,000.00	$15,000.00
2	Furnish and Install 2-Inch ID HDPE Water Main	100	L.F.	$15.00	$1,500.00
3	Furnish and well flushing yard hydrant	1	L.F.	$200.00	$200.00
4	48-Inch Meter and Valve Manhole and Appurtenances	1	Each	$12,000.00	$12,000.00
5	2-Inch buried ball valve	1	Each	$200.00	$200.00
6	Insulation	230	S.F.	$7.00	$1,610.00
7	Granular Foundation	10	C.Y.	$30.00	$300.00
8	Drill and set 12-Inch Casing, mud rotary method	300	L.F.	$95.00	$28,500.00
9	Advance 11.25-Inch Borehole in Rock, mud rotary method	1100	L.F.	$55.00	$60,500.00
10	Furnish and Install 8-Inch Casing	1200	L.F.	$48.00	$57,600.00
11	Furnish and install 4-inch screen	200	L.F.	$26.00	$5,200.00
12	Furnish and Install Neat Cement Grout	1000	Bag	$15.00	$15,000.00
13	Furnish and Install Filter Pack	260	CF	$5.00	$1,300.00
14	Plumbness and Alignment Test	1	Each	$300.00	$300.00
15	Furnish Development Equipment	1	Each	$2,500.00	$2,500.00
16	Install and Remove Development Equipment	1	Each	$2,000.00	$2,000.00
17	Operate Development Equipment	100	Hour	$120.00	$12,000.00
18	Furnish Test Pumping Equipment	1	Each	$1,000.00	$1,000.00
19	Install and Remove Test Pumping Equipment	1	Each	$1,000.00	$1,000.00
20	Operate Test Pumping Equipment	30	Hour	$90.00	$2,700.00
21	Televise Well	1	Each	$900.00	$900.00
22	Furnish and Install Pitless Adapter	1	L.S.	$15,000.00	$15,000.00
23	Furnish and Install Pipe Bowls	12	Bowl	$250.00	$3,000.00
24	Furnish and Install Submersible Motor	1	Each	$2,000.00	$2,000.00
25	Furnish and Install 2-Inch Drop Pipe	700	L.F.	$20.00	$14,000.00
26	Well Disinfection and Sampling	1	Each	$600.00	$600.00
27	Granular Borrow	100	C.Y.	$20.00	$2,000.00
28	Topsoil Borrow	130	C.Y.	$20.00	$2,600.00
29	Site Grading	1	L.S.	$1,000.00	$1,000.00
30	Seeding	0.25	Acre	$2,000.00	$500.00
31	Compacted Class 5 (100%) (Crushed)	50	C.Y.	$25.00	$1,250.00
32	Electrical	1	L.S.	$18,000.00	$18,000.00
		Total Estimate			**$281,260.00**

Lower end of potential cost range for each well (-30%)	**$ 197,000.00**
Upper end of potential cost range for each well (+50%)	**$ 422,000.00**
Lower end of potential cost range for 26 wells (100 gpm each)	**$ 5,122,000.00**
Upper end of potential cost range for 26 wells (100gpm each)	**$ 10,972,000.00**
Lower end of potential cost range for 52 wells (50 gpm each)	**$ 10,244,000.00**

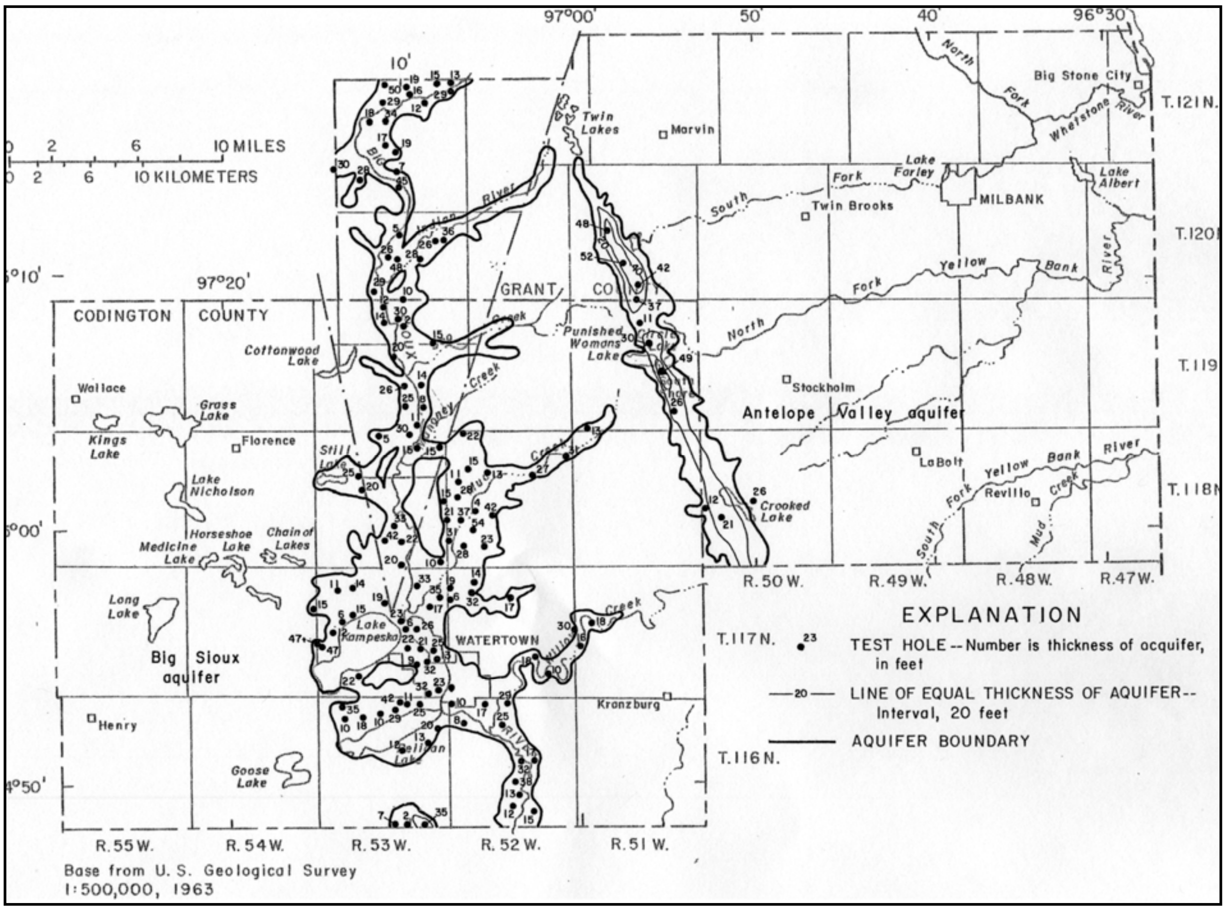

Figure 1: Extent of Big Sioux and Antelope Valley Aquifers

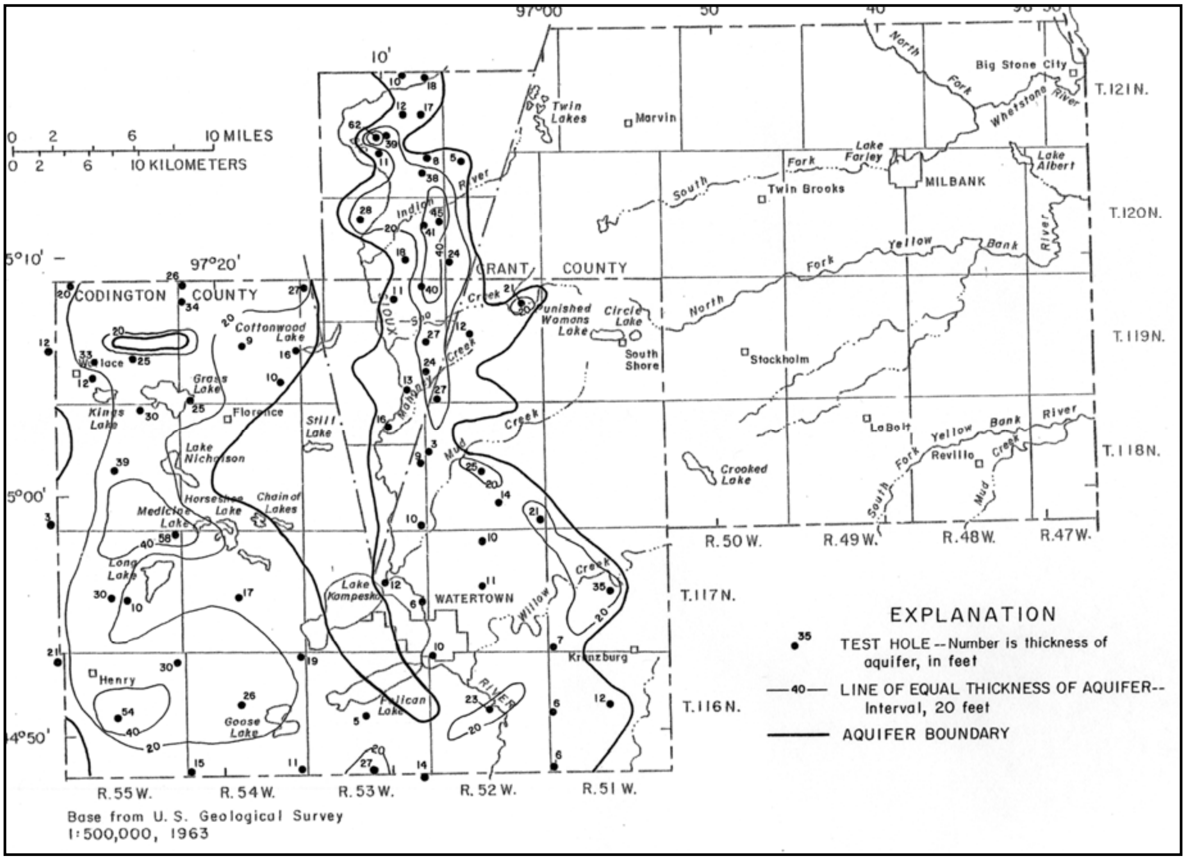

Figure 2 Extent of Prairie Coteau Aquifer

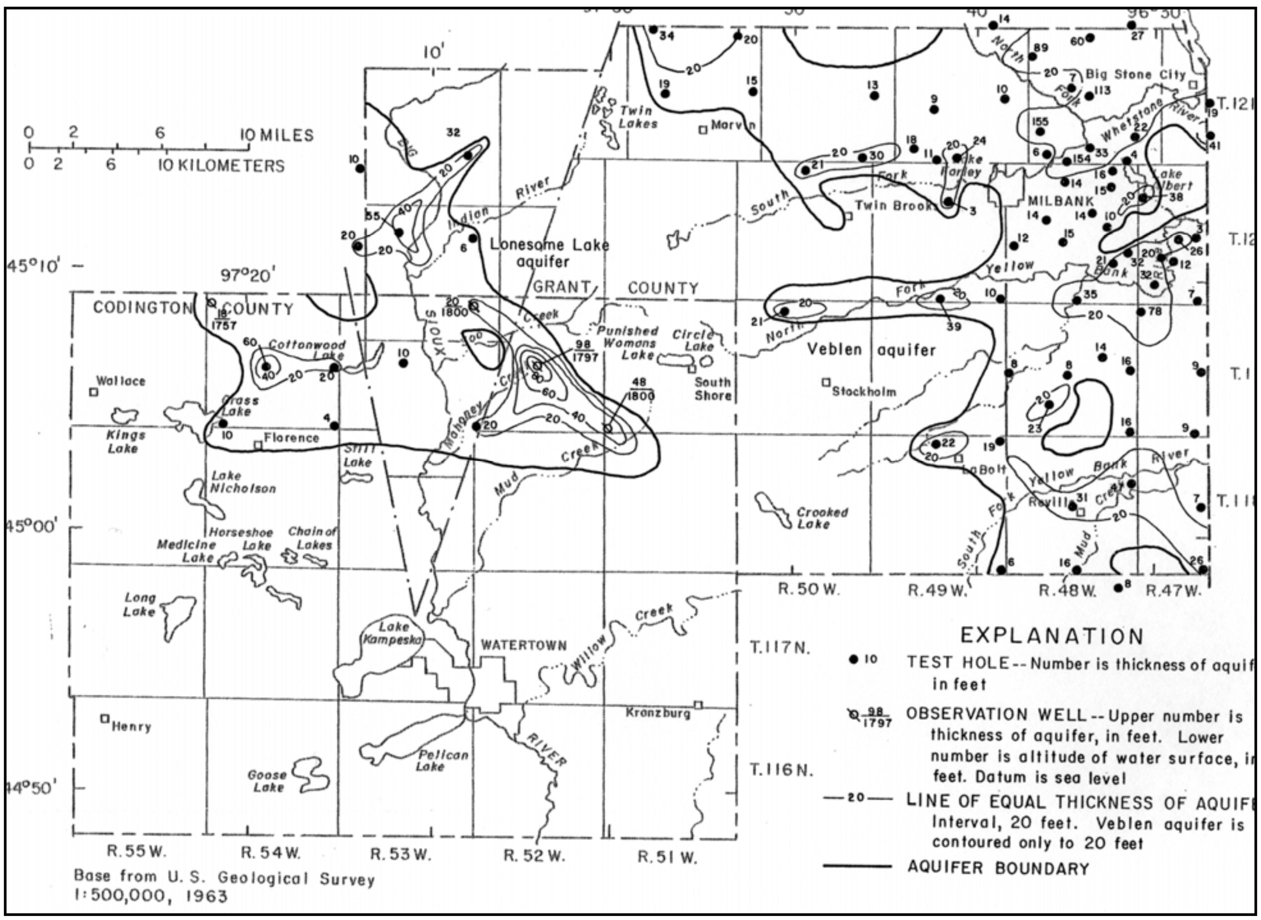

Figure 3 Extent of the Lonesome Lake and Velben aquifers

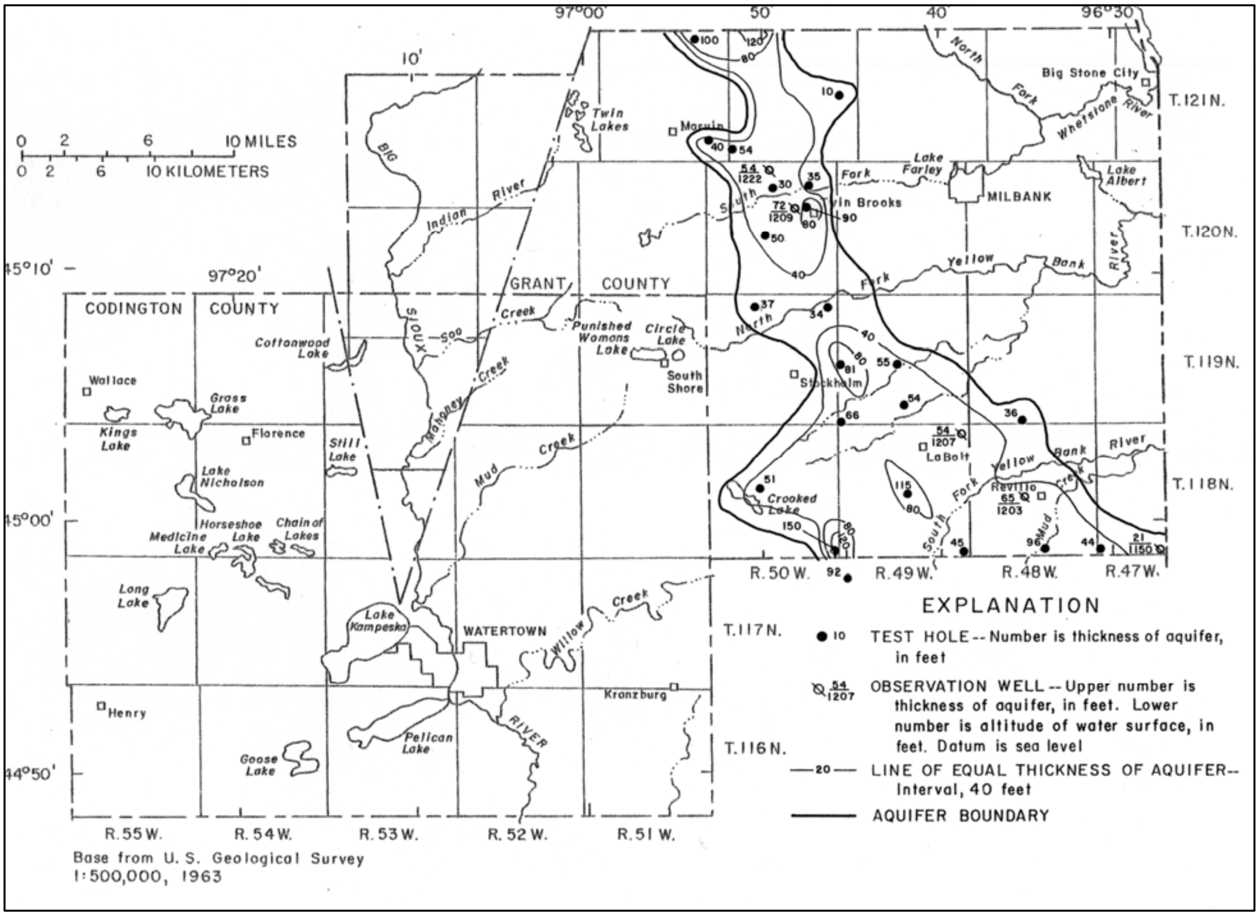

Figure 4 Extent of the Revillo aqufier

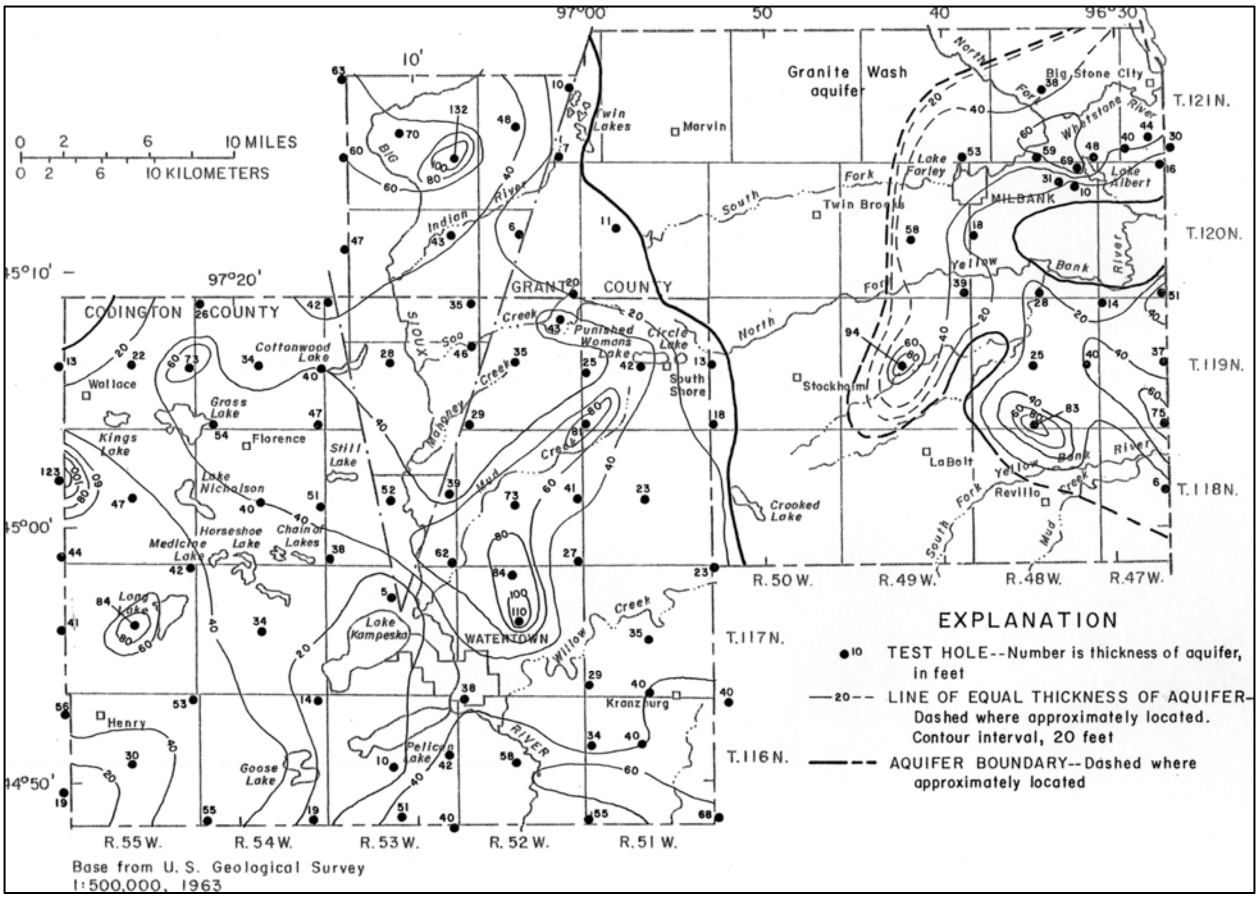

Figure 5 Extent of Altamont & Granite Wash Aquifers