FINAL

ENVIRONMENTAL IMPACT STATEMENT

LINCOLN-PIPESTONE RURAL WATER

Lake Benton, Minnesota

Existing System North/Lyon County Phase
Northeast Phase Expansion

United States Department of Agriculture

RURAL UTILITIES SERVICE

(THE LEAD AGENCY)

and

U. S. ENVIRONMENTAL PROTECTION AGENCY REGION 8

(A COOPERATING AGENCY)

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May 1999

Appendix C

BURR AREA SEISMIC REFLECTION SURVEYS
YELLOW MEDICINE AND LINCOLN COUNTIES, MINNESOTA
DEUEL COUNTY, SOUTH DAKOTA

By Todd Petersen and Jim Berg

Minnesota DNR Waters

March, 1999

BURR AREA SEISMIC REFLECTION SURVEYS
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SUMMARY AND CONCLUSIONS

Most of the seismic lines in the Burr Area have series of high reflectivity zones separated by quieter zones. These high reflectivity series correlate with interbedded sands and/or sand/clay interfaces. This correlation can be used to create a seismic stratigraphy to look for potential aquifer materials.

The Prairie Coteau aquifer can be traced on many, but not all of the seismic lines. The Prairie Coteau aquifer is found on lines DEUB, YELF, YELH, YELJ, YELK, and YELL (Figure 1). Lines YELA, YELD, and YELE have strong guided waves that obscure any potential Prairie Coteau reflections. Line LINA does not have any Prairie Coteau reflections. Lines DEUC, DEUD, and LINB have very poor data quality overall. The other three lines YELC, YELG, and YELI show poor shallow data quality.

Middle and deeper Quaternary reflections, which may be separated from the Prairie Coteau aquifer are seen on some lines. Seismic lines YELA, YELD, and YELE have strong reflection events from the lower Quaternary (Figure 2). The reflections on YELA and YELE probably correlate with Berg's (1997) units 4B, 5, and BQ. The reflections on YELD probably correlate with units 5 and BQ. Based on their seismic signatures, lines YELA and YELE may be the most promising areas for test drilling for lower Quaternary sands.

Other lines also show significant reflectivity in the Quaternary section. YELH has a strong reflection from approximately 1400 feet NGVD (National Geodetic Vertical Datum). YELK has two series of reflections: one might be associated with unit 4 (1350 – 1450') and a second may be associated with the BQ (Altamont) (1200 – 1300'). The adjacent test hole (87-7) contained approximately 20 feet of sand at the upper boundary of units 4a and 4b and about 40 feet of sand in the upper BQ. The strong reflectivity sequence associated with unit 4 might imply more sand than is actually present.

Line YELL has a reflection pattern very similar to YELK, implying that we might expect a similar stratigraphic sequence in the lower Quaternary.

Line YELC has a good reflector at about 1265 feet, which may be from a sand unit in the BQ section. It also has other reflections from the Quaternary, but they are more widely separated than those found on other seismic lines. The general absence of sand in test hole 87-8 may explain this different pattern.

INTRODUCTION

Seventeen seismic lines were made in Yellow Medicine and Lincoln Counties, Minnesota and Deuel County, South Dakota near the Burr Well Field during the 1998 field season. The objective of the surveys was to better define the Quaternary stratigraphy and to explore for a sand aquifer that is deeper than and not connected to the Prairie Coteau aquifer.

One of the first lines collected was a downhole hydrophone survey, which was used to determine time-depth relationships for this area. The deepest well in the area (approximately 440 feet) was surveyed. This survey provides direct velocity and time-depth information for all of the other seismic lines, which were gathered entirely on the surface.

Nine of the remaining sixteen lines were collected as walkaway surveys. The remaining seven lines were collected as CDP reflection lines.

A walkaway survey is the first step in collecting seismic reflection data in a new area. A string of geophones is laid out on the ground at a close spacing. (For the depths of interest in this area the geophones were placed between two feet and one meter apart.) The seismic source, usually a sledgehammer or accelerated wave drop (AWD), a two hundred pound hydraulically driven hammer, is placed one geophone distance off of the end of the geophone spread. The first shot is collected at that point. Next the source is walked away from the geophone spread at intervals equal to the length of the geophone spread. For example, if 48 geophones are placed 1 meter apart, the source is walked away in 48-meter increments. All of the data from the various source positions can be plotted together as a group of traces with increasing shot-geophone distance.

The walkaway survey allows for geometrical separation of the data into various wave types. With the walkaway survey, it is possible to discriminate reflections from refractions, surface waves, and the air wave. One can also make an estimate of the depth to a reflector and the average velocity from the surface to that reflector. But, these estimates are much less accurate than downhole surveys.

The walkaway survey also is used to determine the near and far offset distances and geophone spacings for subsequent CDP surveys in the same area.

The seven CDP reflection lines were made with specifications determined by the walkaway surveys. The near and far shot to geophone offset distances were 160 and 390 feet, with a geophone spacing of 10 feet. This focussed the data collection on the depths of interest, between 200 and 1000 feet. A series of shot gathers were collected along the line. These seismic traces are then regathered into common depth or mid point (CDP) gathers. A CDP gather includes all of the shot receiver pairs that have a common depth or mid point. Because all of the traces in a CDP gather represent different versions of the same depth point, they can be stacked (summed together) to improve the signal to noise ratio.

Fourteen of the seismic lines produced good results; three had a very poor signal to noise ratio (S/N) and were very hard to interpret. The main problem with these three lines was poor near surface conditions and extreme wind noise.

RESULTS

Figure 3 is a location map of all of the seismic data collected for this survey. It also contains relevant well locations. Four lines were collected in Deuel County, South Dakota and thirteen lines were collected in Minnesota: eleven in Yellow Medicine County and two in Lincoln County. Table 1 lists the line locations and type of survey: downhole, walkaway, or reflection. Figures 4 through 7 contain portions of the Canby 7.5 minute quad with line locations marked on them.

TABLE 1: SEISMIC LINE LOCATIONS AND SURVEY TYPE

SEISMIC LINE	TOWNSHIP	RANGE	SECTION	QUARTER	TYPE	COMMENTS
DEUA	114N	47W	3	C	DOWNHOLE	Hammer
DEUB	114N	47W	3	C	WALKAWAY	Hammer
DEUC	114N	47W	32	AA	WALKAWAY	Hammer Not interpreted due to poor quality
DEUD	114N	47W	32	AA	WALKAWAY	AWD Not interpreted due to poor quality
LINA	113N	46W	6	BB	WALKAWAY	Hammer & Kinepak
LINB	113N	46W	3	A	REFLECTION	Hammer and Kinepak Not interpreted due to poor quality
YELA	114N	46W	6		WALKAWAY	Hammer &Kinepak
YELC	114N	46W	34	A	WALKAWAY	Hammer & Kinepak
YELD	114N	46W	6	D	REFLECTION	Hammer
YELE	114N	46W	6	A	REFLECTION	Hammer & Kinepak
YELF	114N	46W	17	B	REFLECTION	Hammer

YELG	114N	46W	20	B	REFLECTION	Hammer & Kinepak
YELH	114N	46W	28	AAA	REFLECTION	Hammer & Kinepak
YELI	114N	46W	28	DAA	REFLECTION	Hammer & Kinepak
YELJ	114N	46W	28	C	WALKAWAY	Hammer
YELK	114N	46W	28	C	WALKAWAY	AWD
YELL	114N	46W	35	C	WALKAWAY	AWD

DEUA

Seismic line DEUA is a downhole hydrophone survey down well R2-96-02. A hammer and plate provided the seismic source. The first arrivals were picked for the hydrophones downhole. This provided a function showing depth vs. one-way time. In order to best use this data for comparison with seismic reflection data, the function was converted to elevation versus two-way time. With a reference (or datum) elevation of 1670 feet NGVD. This datum was chosen because all of the seismic reflection lines were corrected to that elevation.

This corrected time function for well R2-96-02 is shown in figure 8. This function is the best reference we have for time to elevation correlation in the Burr area, and is used to estimate depth for all of the seismic lines we collected there.

The velocity function is not 100 % accurate for all of the seismic lines, because sand and clay velocities are different, and the thickness of sand units varies from place to place. But, it provides a very good estimate of the elevation of a given reflector.

DEUB

Figure 9 contains the CDP stack from line DEUB (a walkaway survey). They have been corrected for normal moveout (NMO). The Prairie Coteau aquifer is seen as the series of reflections between 50 and 80 ms. (between 1450 and 1550 ft elevation). There are also strong reflections just below the Prairie Coteau aquifer (between 80 and 100 ms). These reflections are near the unit 4/ unit 5 boundary of Berg (1997). The reflection at 160 ms. is probably from about 1200 feet elevation. It may be the top of Cretaceous. The reflection from 195 ms is probably from the top of Precambrian. Because the top of Cretaceous and the Cretaceous material velocity are both poorly known, the depth to the Precambrian is not known.

Figure 10 is a CDP stack from line DEUB, produced with a fictitious geometry. Here it is assumed that 144 geophones were laid out every 1 meter in a row and the sledgehammer source was offset one meter from the nearest geophone. This is very similar to Figure 3, but the geometric relationships between shallow and deep reflections are easier to see. The same reflections can be seen in both displays, but the lateral continuity and the deepest reflection (> 250 ms.) are much easier to see in figure 4 than in figure 3.

YELA

Figure 11 shows walkaway survey YELA. The 80 to 100 ms window where the Prairie Coteau aquifer might be present is obscured by guided waves. But, there is a good set of reflections between 130 and 170 ms. (t0 = 100 to 140 ms.). These reflections come from between 1265 and 1400 feet elevation. They are probably associated with lower Quaternary sands, perhaps the units 5and BQ in Berg (1997). There is a strong reflector at 240 ms, which is probably from the top of Precambrian. If the Cretaceous velocity is approximately 8000 ft/sec, then the top of Precambrian is probably at about 960 feet elevation.

Figure 12 is an NMO corrected version of line YELA, where the data has been corrected to zero offset times.

YELC

Figure 13 shows walkaway test YELC. Figure 12 is an NMO corrected version of YELC. Seismic line YELC is located next to borehole 87-8. The strong event at 140 ms. is probably from the Quaternary/Cretaceous boundary. There are a few reflectors in the Quaternary section, but they are fairly widely spaced. They may represent till boundaries. There is very little sand in this borehole.

YELD

Figure 15 is a collection of shot gathers from seismic line YELD. Figure 16 is a CDP stack of the same line. In the shot gather display (figure 9) there are strong doublets at 100 and 140 ms. These events are both seen on the stacked section, but the separation of doublet events is less clear on the CDP stack. These two events are probably from about 1390 and 1270 feet elevation, respectively, which makes them from unit 4, 5 or BQ (Berg, 1997). The deepest reflection is at approximately 155 ms. or 1210 feet. This may be the top of Cretaceous.

YELE

Figure 17 and Figure 18 are the shot gathers and stacked section for line YELE. The shallow Prairie Coteau section is obscured by refractions and guided waves. There is a strong band of reflections between 110 and 150 ms. These reflections are associated with lower Quaternary sediments and perhaps, the top of Cretaceous. Corresponding elevations are between 1360 and 1265 feet. A strong top of Precambrian event is seen at 230 ms.

YELF

Figures 19 and 20 contain some shot gathers and the CDP stack for line YELF, respectively. There are strong reflections in the upper Quaternary at approximately 1445 and 1490 feet NGVD. There is also a reflection from about 1280 feet and 1230 feet NGVD. The 1230 foot reflection is probably the top of Cretaceous.

There are also strong reflections at 205, 215, 250 and 295 ms. The 205 and 215 ms. reflections may be from Cretaceous horizons. The deeper reflections are probably from the Precambrian. Their depth is unknown, because the Cretaceous velocities have not been measured.

YELG

Line YELG has generally poorer quality than most of the other seismic lines. There are some reflections from the lower Quaternary section between 1250 and 1330 feet NGVD. This suggests the presence of some sand and gravel in this interval. (See figures 21 and 22.)

YELH

Seismic line YELH has much better quality than line YELG. There are two versions, one that was shot with a sledgehammer and one that was shot with Kinepak. Shot gathers for line YELH are shown in figures 23 and 24. CDP stack sections are shown in figures 25 and 26. Figures 23 and 25 are hammer data, while figures 24 and 26 are Kinepak data.

There are a significant number of reflections in the upper Quaternary between 60 and 90 ms (~1530 to 1430 feet NGVD). These reflections fall in and below the Prairie Coteau aquifer zone.

A strong reflection is present at about 100 ms. (1400 ft. NGVD). This is probably somewhere in unit 4 from Berg (1997). The strong event at 215 ms. is probably the top of Precambrian. I am not sure of its true origin. The deepest reflections, between 240 and 290 ms., are probably from within the Precambrian section.

The Kinepak data have higher frequency and higher amplitudes than the hammer data. Because the Kinepak source was buried five feet below land surface, the reflected energy arrives a little sooner than the hammer data does. For example, the 100 ms. reflection on figure 24 correlates with the reflection at 110 ms. on figure 23.

YELI

Figure 27 contains shot gathers from line YELI. The S/N of reflections in the data is very poor. (There are strong first arrivals, guided waves and surface waves, but poor reflection data.) Shot point 85 has the best data. There are reflections at 120, 150 and 220 ms. The 120 ms reflection is probably from around 1330 feet NGVD. The 150 ms reflection is from approximately 1225 feet NGVD (near the top of Cretaceous). The reflection at 215 ms may be the top of Precambrian.

Shot gather 100 has a nice reflection from about 85 ms, or approximately 1445 feet NGVD. This is in the unit 4 region of Berg (1997).

Figure 28 is a CDP stack of line YELI. It shows the same data as in figure 25.

YELJ

Figure 29 contains a walkaway survey (line YELJ) done over boring 87-7. Figures 30 and 31 show walkaway survey YELK. Surveys YELJ and YELK were made using exactly the same source and geophone locations. The only difference is that the seismic source for YELJ is the sledgehammer and the source for YELK is the AWD. Both lines are very good, but the AWD section (YELK) is slightly cleaner because there is a stronger signal.

Figure 30 is an uncorrected walkaway survey; figure 31 has NMO correction applied and the refractions, air wave and surface waves muted out. The reflection events between 50 and 65 ms are from reflectors between 1510 and 1560 ft NGVD. These are probably related to the Prairie Coteau aquifer. There is a second set of strong reflections between 85 and 120 ms that are probably from reflections between 1350 ad 1460 feet NGVD. These are probably reflections from sand or sand/clay horizons in unit 4 of Berg (1997). The strong reflections between 120 and 160 ms., lie between 1200 and 1300 feet NGVD. They are probably associated with the Altamont aquifer. In borehole 87-7, approximately 40 feet of sub-quaternary sand sits on top of lake clay.

YELL

Walkaway survey YELL is shown in figure 32. The air wave, surface waves, and refraction data have all been muted. There are a number of strong reflection packages on this line. There are two shallow reflections at 60 and 80 ms. (~1530 and 1460 feet NGVD). These are probably associated with the Prairie Coteau aquifer.

A stronger set of reflections exist between 100 and 150 ms. This is about 1400 to 1230 feet NGVD. This is associated with units 4, 5 and BQ. The strong reflection at 150 ms. (1230 feet NGVD) may correspond to the top of Cretaceous. Not having a well at this location, we don't know for sure.

LINA

Walkaway survey LINA is shown in figure 33. It was shot next to borehole 41-1. There are very few reflections in the upper portion of the Quaternary (above 1400 feet). In the lower Quaternary there is a nice package of reflections between 100 and 150 ms. (approximately 1235 to 1400 feet NGVD). The strongest reflections are at 100 and 130 ms. (approximately 1400 and 1300 feet NGVD, respectively). The top reflector in this sequence is in the middle of unit 4B, the bottom reflector is at the unit 5 / BQ boundary.

There is also a strong reflection at approximately 270 ms. This may be from the top of the Precambrian section. There are a number of interbedded sands and clays in the lower Quaternary section in test hole 41-1. These correlate reasonably well with the reflections on line LINA. But the data quality is too poor to see one-to-one correlations of the sand-clay interfaces to the reflections.

Figure 34 shows LINA after mute and NMO correction. The same events are visible both before and after NMO. Figure 35 is also LINA, but with a different seismic source. This data was gathered with Kinepak high explosive. The strong reflection at 100 ms. is probably correlative with the reflector at 105 ms. on the sledgehammer data. This is due to the Kinepak charge being buried five feet below land surface. Because of this the downgoing seismic energy does not have to travel in the extremely slow near-surface material. Thus, it arrives faster than the equivalent hammer data, where the downgoing seismic energy must travel through the slow surface layer.

The Kinepak data is much cleaner. This is due to the large increase in S/N because of the larger shot energy.

REFERENCES

Berg, Jim, 1997, Southwestern Minnesota Ground Water Exploration Project 1996-1997, Progress Report.

LIST OF FIGURES

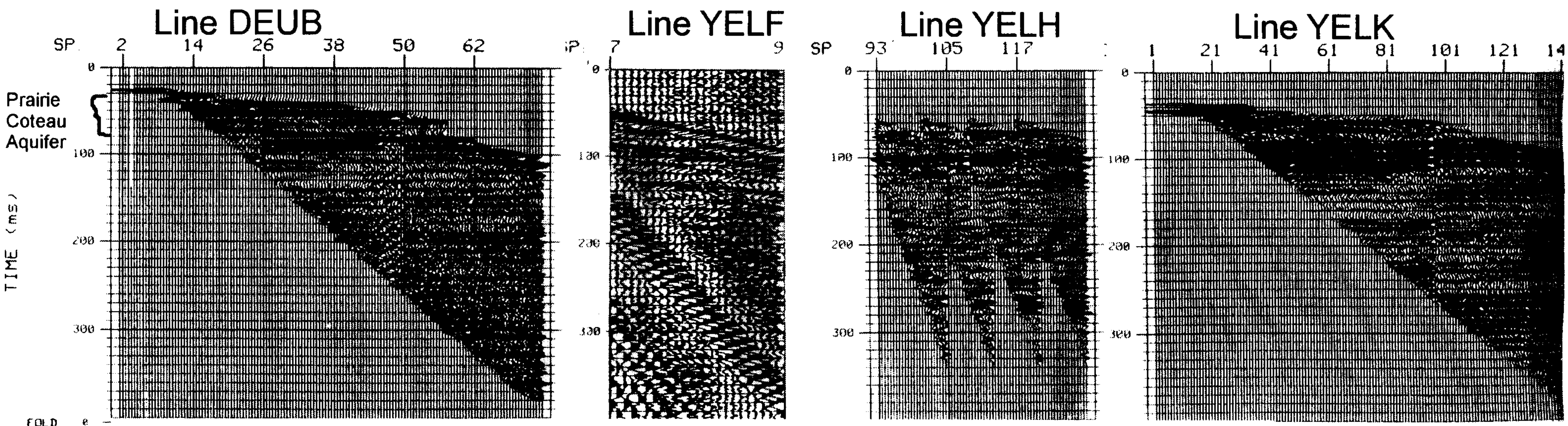


Figure 1: Example of seismic signature of Prairie Coteau Aquifer on various seismic lines.

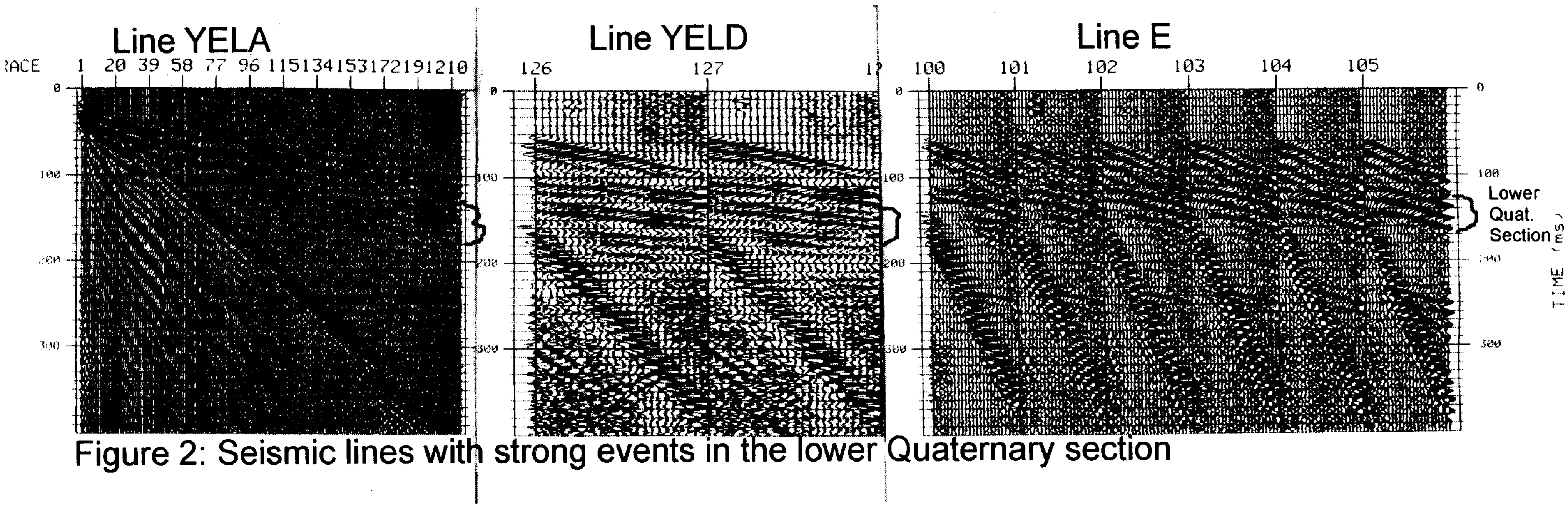
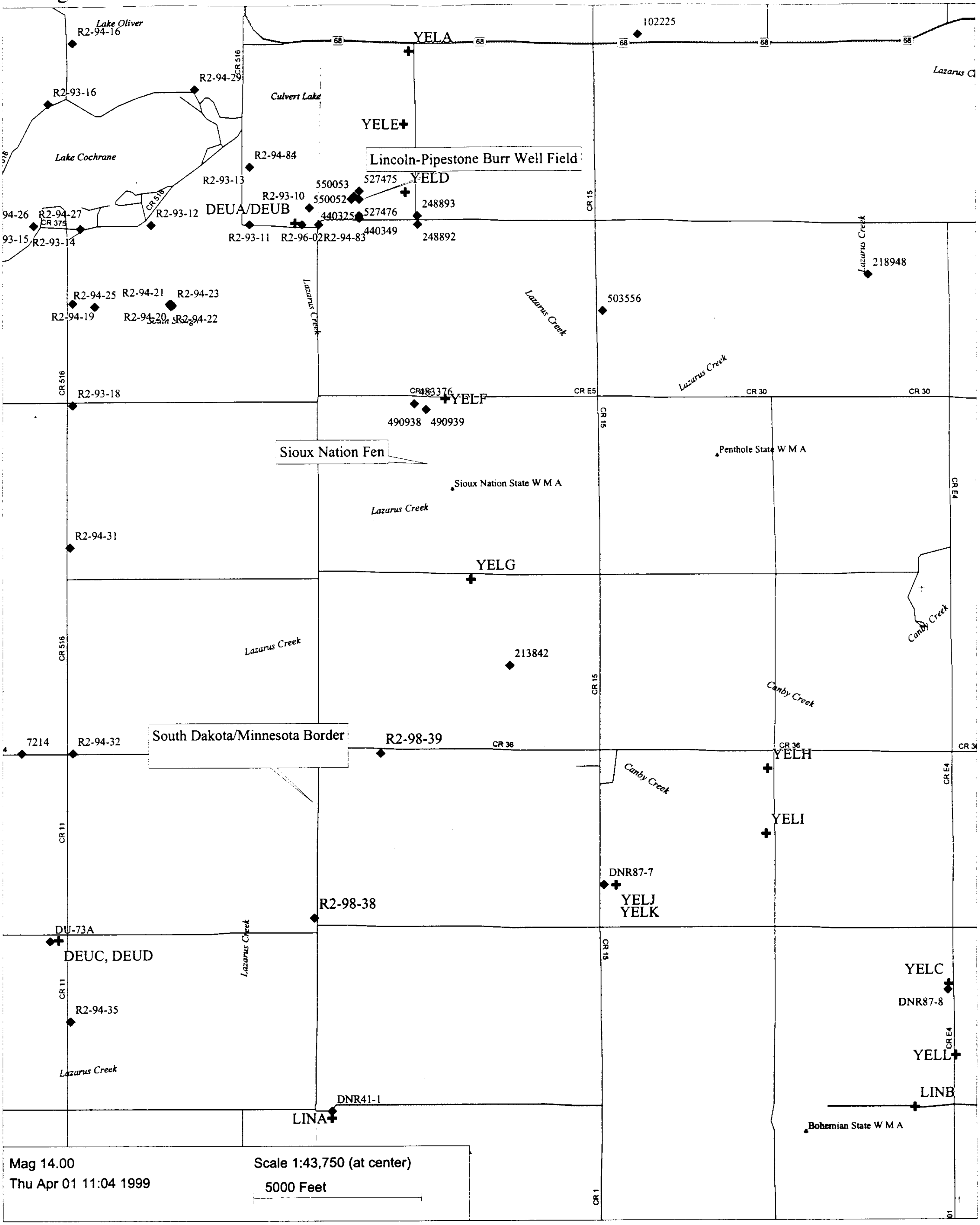


Figure 2: Seismic lines with strong events in the lower Quaternary section

Figure 3 - Burr Well Field/ Lake Cochrane Area Test Hole, Well and Seismic Locations



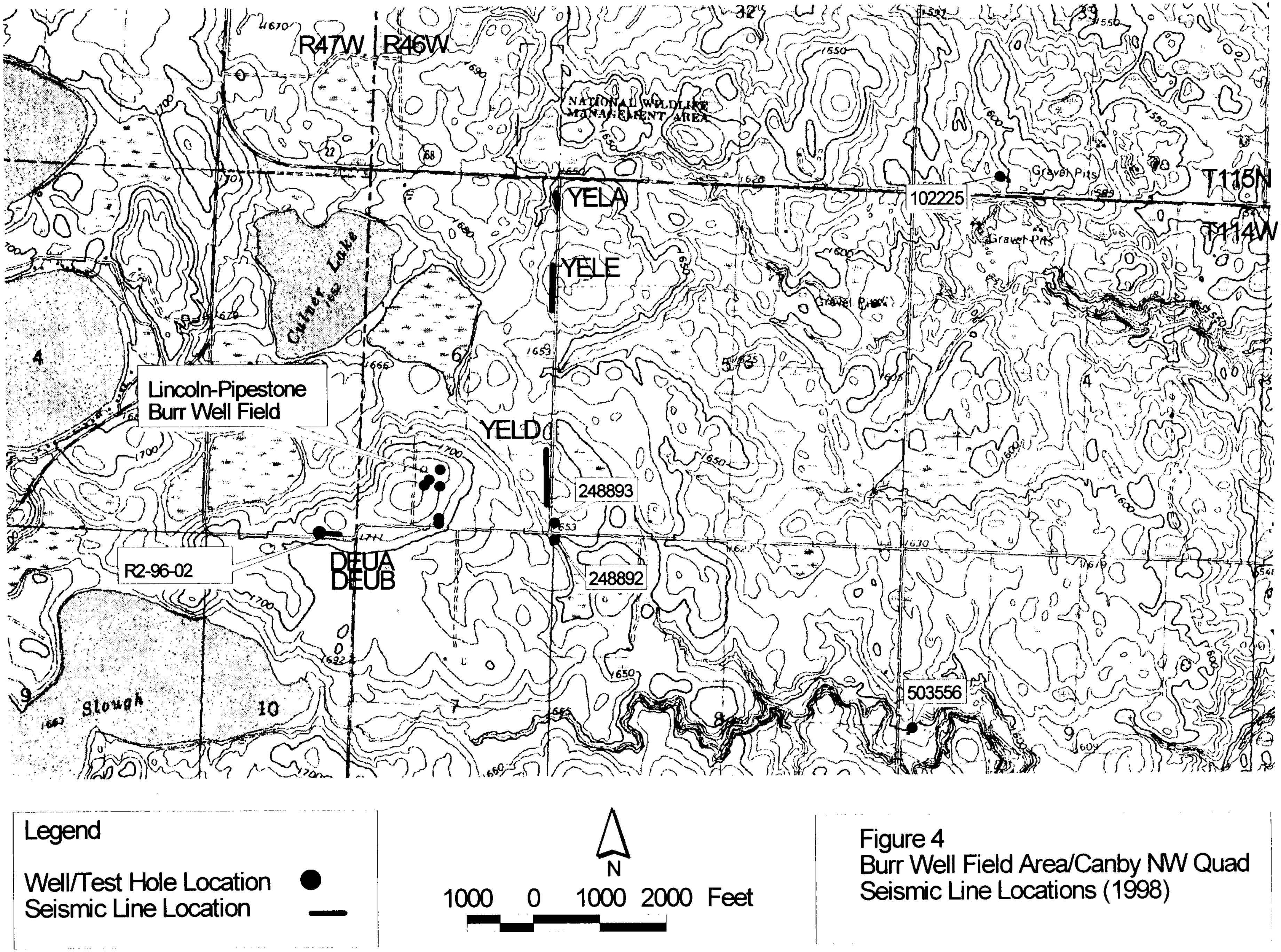


Figure 4
Burr Well Field Area/Canby NW Quad
Seismic Line Locations (1998)

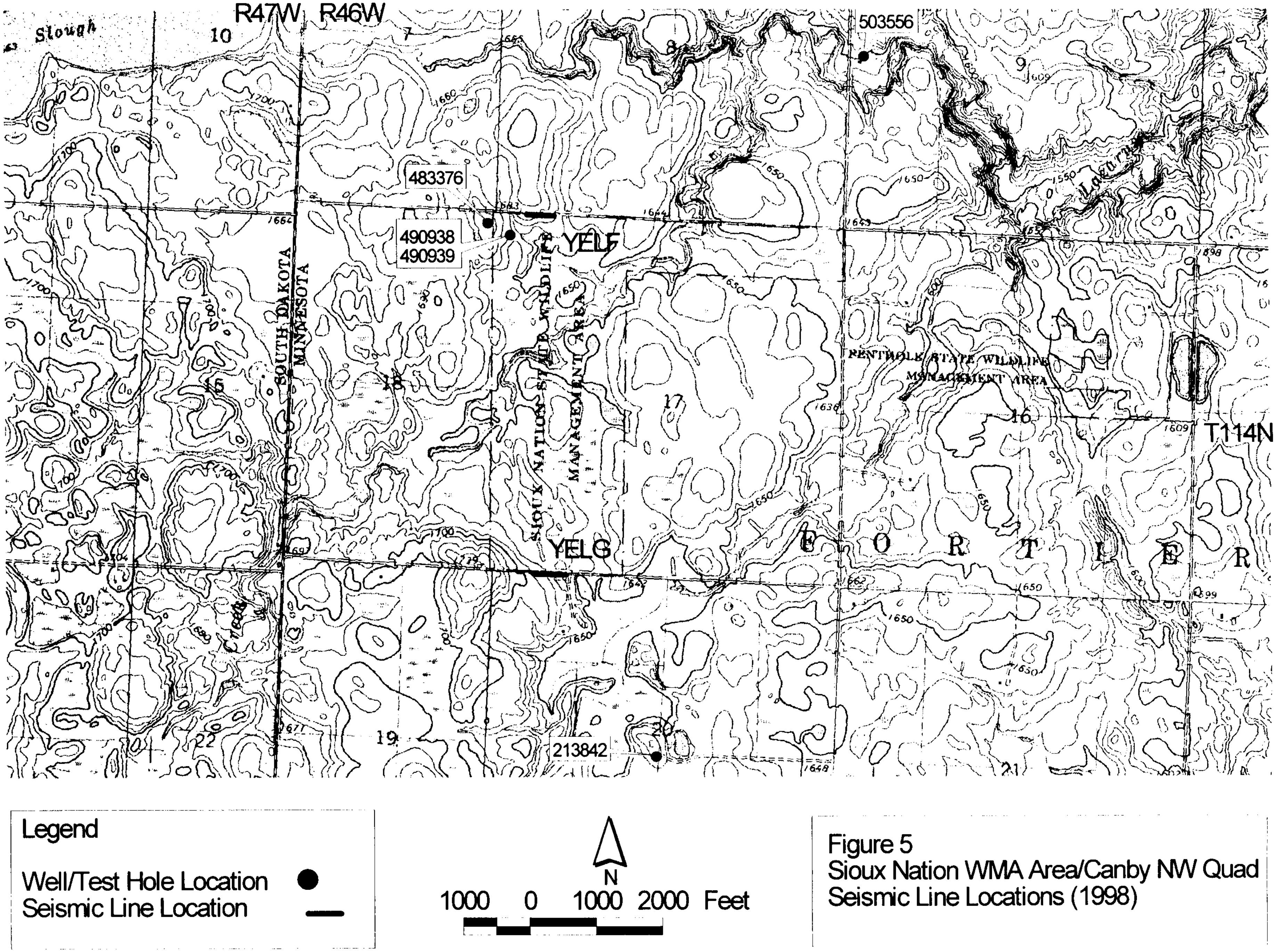


Figure 5
Sioux Nation WMA Area/Canby NW Quad
Seismic Line Locations (1998)

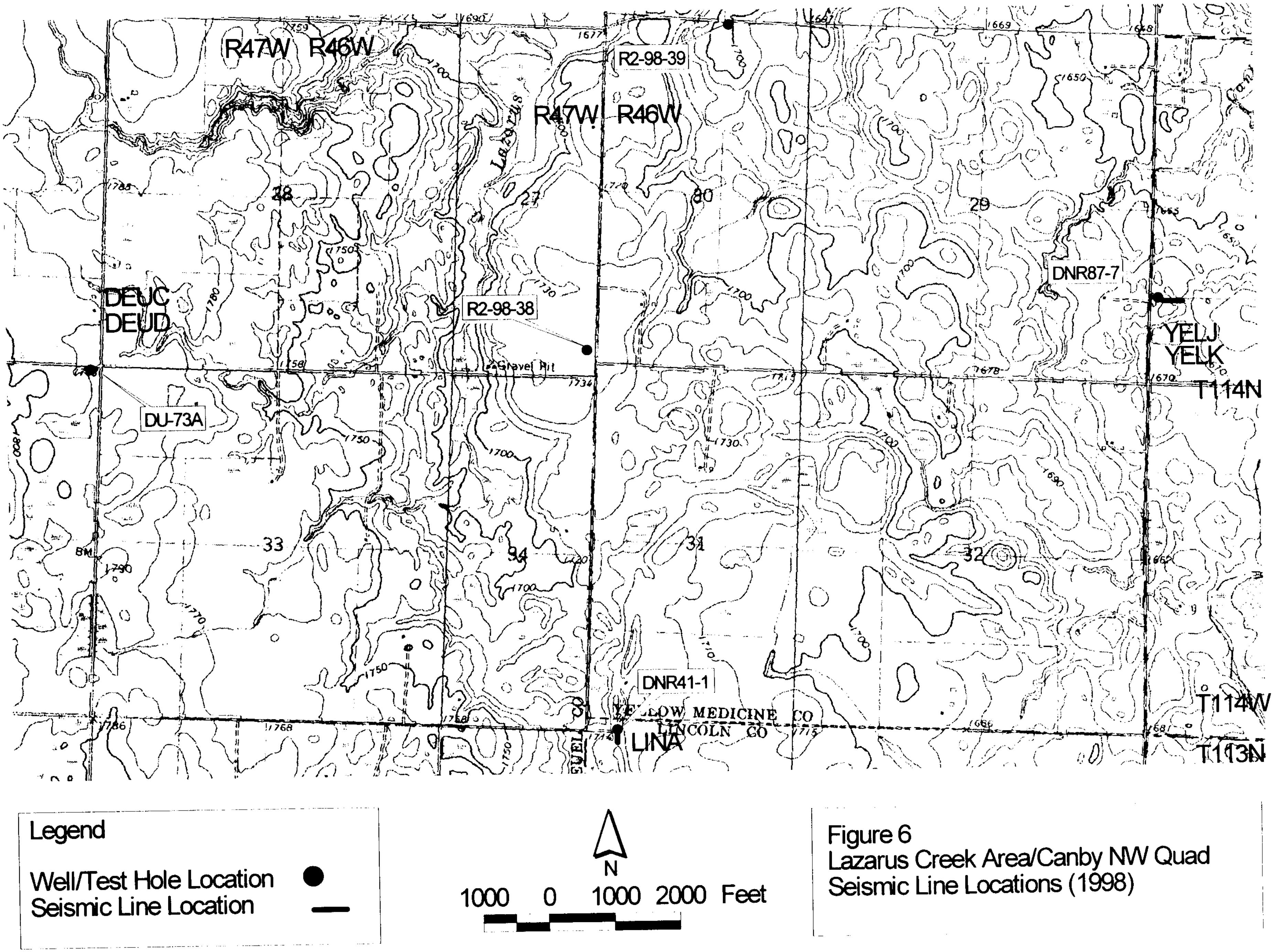


Figure 6
Lazarus Creek Area/Canby NW Quad
Seismic Line Locations (1998)

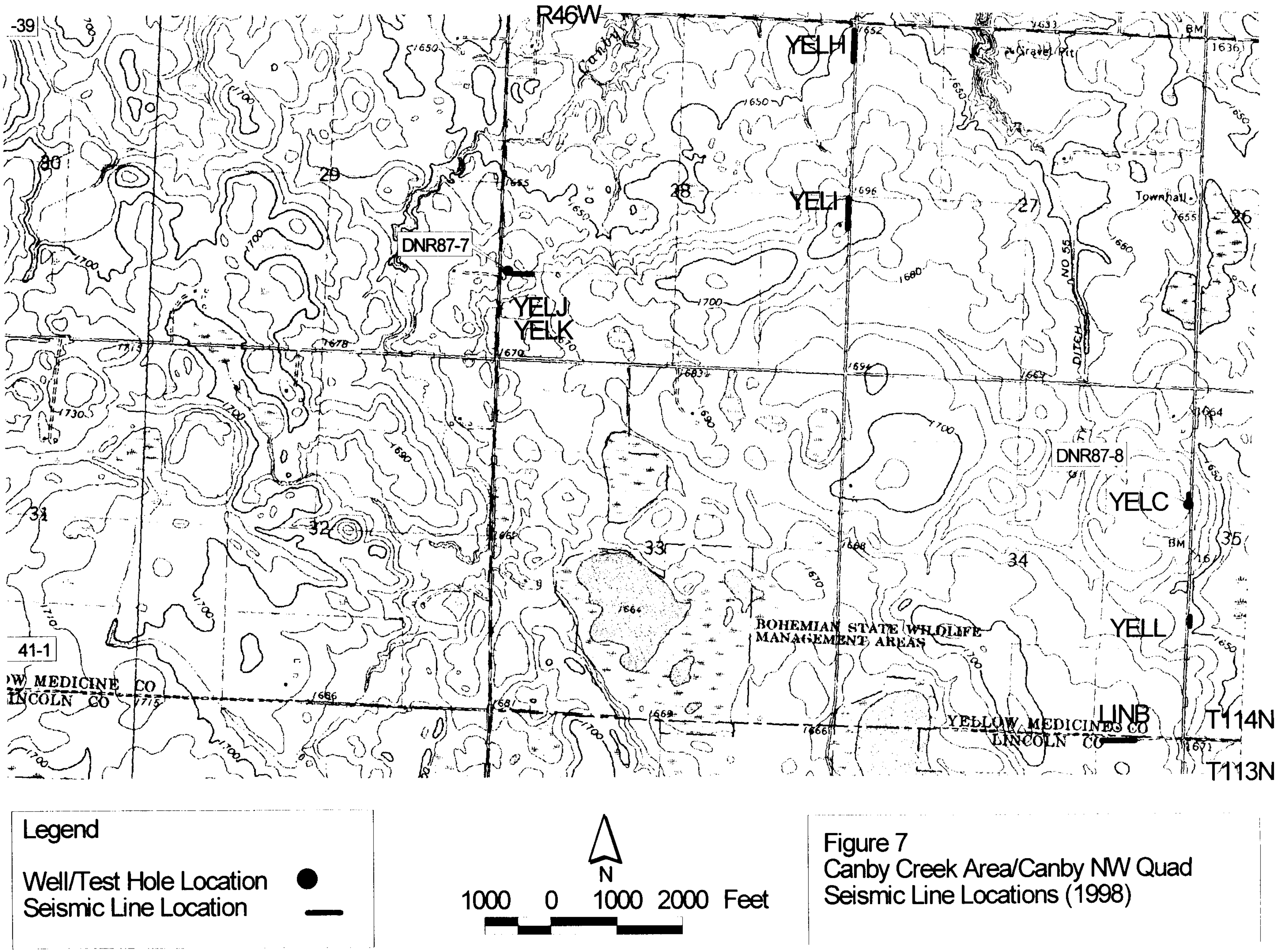


Figure 7
Canby Creek Area/Canby NW Quad
Seismic Line Locations (1998)

Minnesota Department of Natural Resources

500 Lafayette Road
St. Paul, Minnesota 55155-40__

February 26, 1999

Mr. Joe Weber, Chairman
Lincoln Pipestone Rural Water
East Highway 14, Box 188
Lake Benton, MN 56149

Dear Mr. Weber:

REPORT OF BURR WELL FIELD MONITORING THROUGH 1998

We have been working on the compilation of monitoring data for the Burr Well Field over the last few months. Enclosed is a memorandum that includes the results of this effort.

We are concerned that existing calcareous fen protection thresholds may not be adequate and need to be revised. We would like to meet with Lincoln Pipestone to discuss fen impacts and recommendations for monitoring and fen management.

Sincerely.
DNR Waters

John Linc Stine, Administrator
Permits and Land Use Section

enclosure

cc: Mark Plank, Rural Utility Service
Jim Maras, Rural Development
John Madden, DGR
David Watson

Interoffice Memo

February 19, 1999

To: John Stine

From: Dr. Jeanette H. Leete, Jay R. Frischman

Through: Brian Rongitsch

Subject: Report of Burr Well Field Monitoring through 1998

The Technical Analysis workgroup of the Ground Water Unit recently processed and calibrated data collected to monitor impacts of pumping at the Burr Well Field.

Brief Background

There is concern about the impact of the well field pumping on nearby calcareous fens including Cleveland, Fairchild, Fortier and Sioux Nation fens. Calcareous fens are wetlands which accumulate peat (peat is a soil formed from partially decomposed plant remains that are amassed over many hundreds of years) and which are always wet, but never (or extremely rarely) flooded, with persistent upwelling of calcium-bearing, oxygen poor ground water. The presence of a calcareous fen indicates that upwelling conditions are persistent, with ground water discharge always in excess over evapotranspiration and precipitation. Calcareous fens frequently harbor a number of endangered or threatened plant species that thrive in the harsh calcareous fen environment.

If water levels in the aquifer are on the decline, the sustainability of these resources is in doubt. For discharge into the fen to occur at all, heads in the aquifer must remain above the ground surface. Any declines in the head gradient will cause proportionate decreases in discharge into the fen*. Many aspects of calcareous fen hydrology are poorly understood, but what is known for certain is that the system is dependent upon constant upwelling of ground water and that upward gradients sufficient to supply the water needed for evaporation, plant transpiration, and overflow must be maintained. Ground water discharge must be so dominant that the water chemistry of the precipitation does not impact the water chemistry of the fen. If the water balance in a fen were to shift toward significant precipitation inputs, then the nature of the peat

* Ground water flow (Q) is proportional to Hydraulic Conductivity (K), Head Gradient (I) and Area (A) through which flow occurs. $Q=KIA$.

would change, leading to less hospitable conditions for the rarer plants of the sedge mat and a more welcoming situation for shrubs, reed, and cattail. Increased numbers of plants of these invading species have been noted in other areas where fens are impacted by land use or hydrology changes.

Monitoring History

Data collection began in 1991. An existing observation well (OW-3-90) completed in the Prairie Coteau aquifer (PC) at the Burr Well Field (Figure 1) was included in the monitoring program along with shallow monitoring wells which were installed by hand in the northern-most dome of the Sioux Nation Fen Wetland Complex (North Dome). The fen monitoring points at the North Dome include water table and subpeat piezometers.

Additional observation wells were drilled into the Prairie Coteau aquifer at the north boundary of the Sioux Nation WMA (Deep Steel) and within the Burr Well Field. Only the data from the well field observation well OW-1-93 (Figure 1) is discussed in this memo, but water level measurements were taken at several more observation wells, one of which is a flowing well (OW-2-90).

Fairchild fen was added to the monitoring program in 1994 (but no aquifer observation well could be added at the Fairchild site because a well at that location would be a flowing well). More details of well and piezometer construction are given in Table 1.

Well Name	*Unique Number*	*Aquifer**	*Substrate*	*Depth (ft)*	*Start of Monitoring*
OW-3-90	440349	PC	peat	170	1990
Dome 1 (WT)	547573	fen	peat	7.5	1991
USGS Dome	549730	subpeat	sand	12.9	1992
Deep Steel	490938	PC	aquifer sands	187	1991
OW-1-93	unknown	PC	aquifer sands	195	1993
Fairchild Deep	547578	subpeat	sand	19.7	1994
Fairchild WT	547577	fen	peat	2.3	1994

* PC= Prairie Coteau aquifer

Surveys to measure the elevations of the measuring points at each well and to measure the ground surface and control points within the study area have been conducted at intervals throughout the study. These surveys included elevations at the Cleveland fen and Fortier fen Wetland Complex, while species lists have been recorded for the Fairchild, Cleveland and

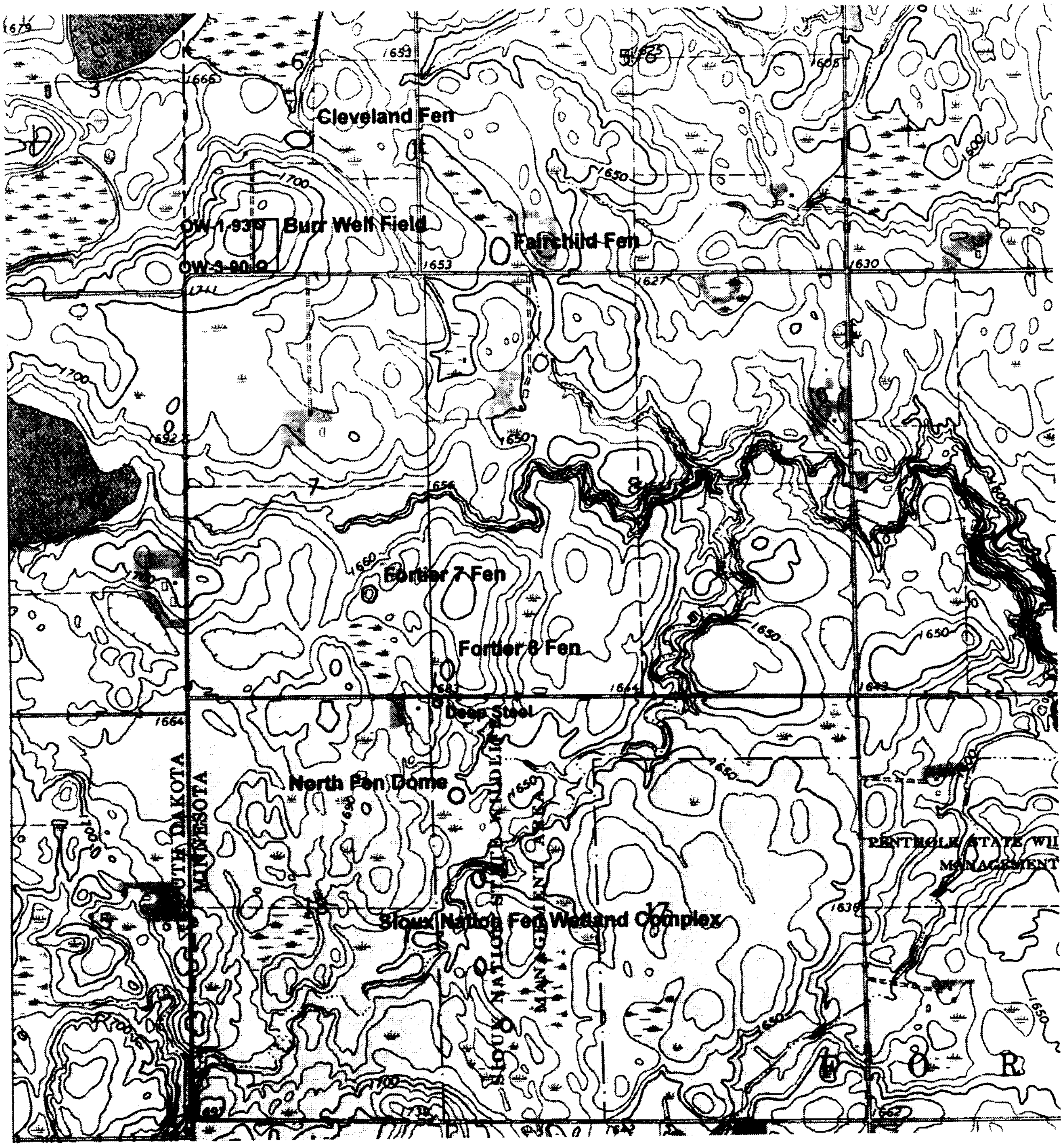


Figure 1: Map of the Study area (Yellow Medicine County T114N R46W and adjoining Deuel County South Dakota. This map does not depict all resources and features. For clarity, only those features and resources referred to in this memo are shown.)

Fortier fens. Field observations of changes in habitat have been recorded. Shrub height and density has increased while phragmites and cattail areas have expanded.

The fen hydrologist position has been unfunded since fall of 1996. These data sets had to be compiled, calibrated and interpreted during time taken from other tasks. Only now can we see the corrected data displayed in concert with recent surveys at the site.

Operation of the Well Field

After periods of trial pumping during 1993 and 1994, the well field began production in early spring 1995. Figure 2 is a record of pumping rates from the Prairie Coteau Aquifer.

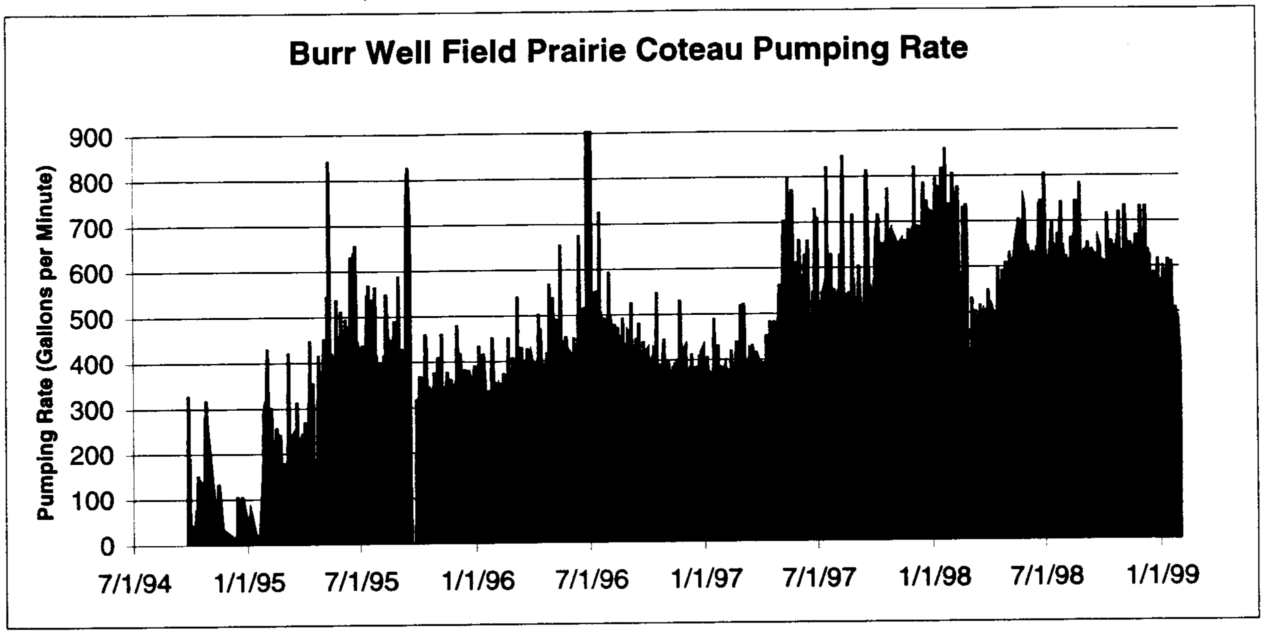


Figure 2: Summation of pumping rates from Prairie Coteau production wells PW-1, PW-2 and PW-3.

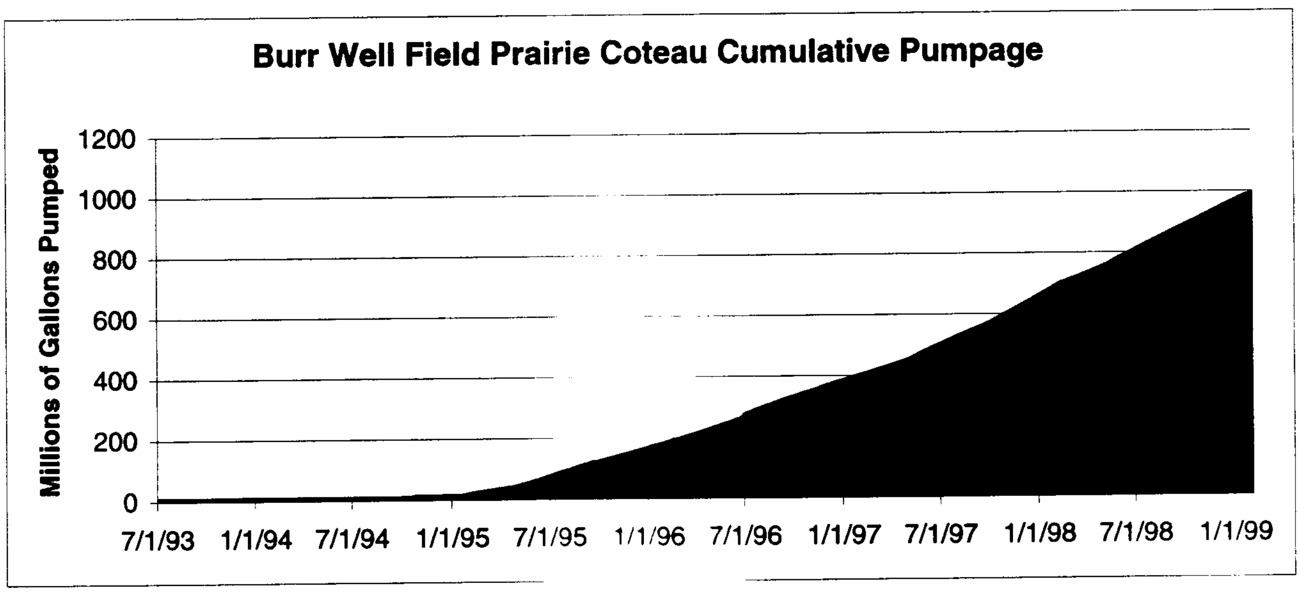


Figure 3: Cumulative volume removed from the Prairie Coteau aquifer.

Rates vary in response to both water demand and water treatment plant operations. The cumulative volume of water withdrawn is depicted in Figure 3.

Conditions in the aquifer

The Deep Steel well is currently the best Prairie Coteau aquifer monitoring point in Minnesota although it is within the cone of depression of the well field. Long range plans include the drilling of an aquifer observation well in Minnesota that is not within this cone of depression. The need for such a 'far field' observation well is clear upon inspection of the hydrograph for the Deep Steel well (Figure 4). Prior to the start of production pumping at the Burr Well Field, water levels in this observation well displayed a rising trend of 3 to 4 feet over three years (presumably in

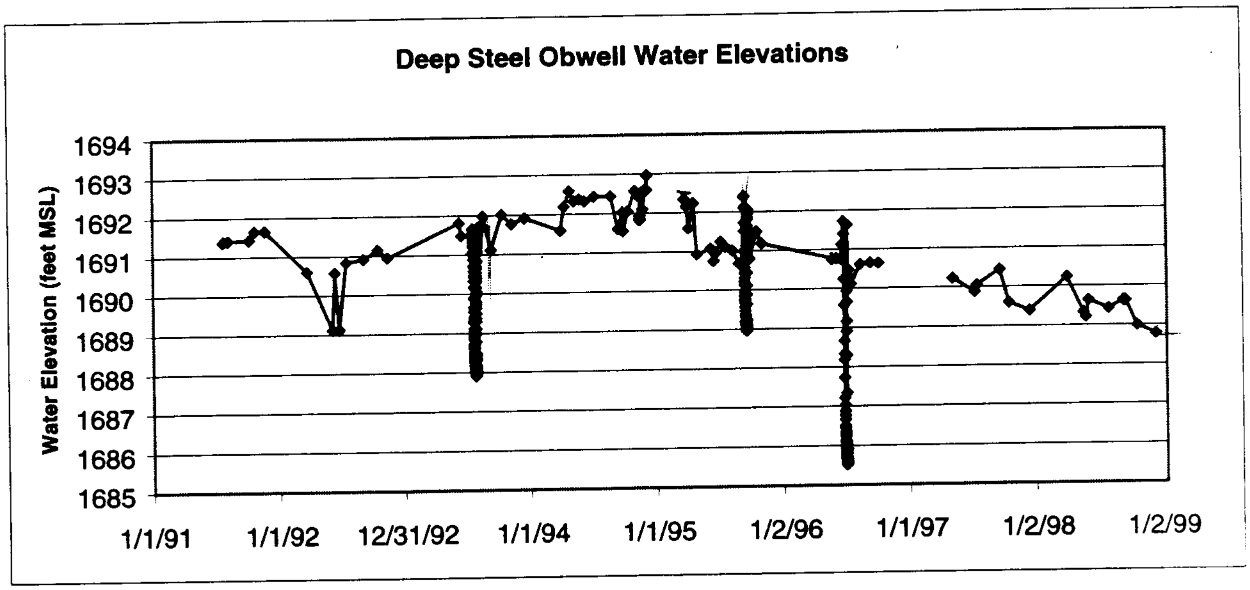


Figure 4: Water levels in the Deep Steel Observation well over the period of record.

response to recovery from drought effects). Aquifer tests explain the downward spikes in the data. Aquifer testing proved that this well is indeed within the cone of depression, and water levels in the well began an overall downward trend of four feet from 1995 to the present. Because we do not have another monitoring point in this aquifer outside of the cone of depression, we do not know if the aquifer continued to rise for a period of time\ If that has been the case, the total impact due to pumping from the Burr Well Field from 1995 through the end of 1998 could be as high as six to eight feet of water level decline.

The rate of decline at the Deep Steel well does not appear to be slowing, a fact that is cause for concern. Steadily declining water levels show that the cone of depression within the aquifer is still growing. The potential for impact to additional surface resources also grows, as does the threat to sustainability of the use of the aquifer.

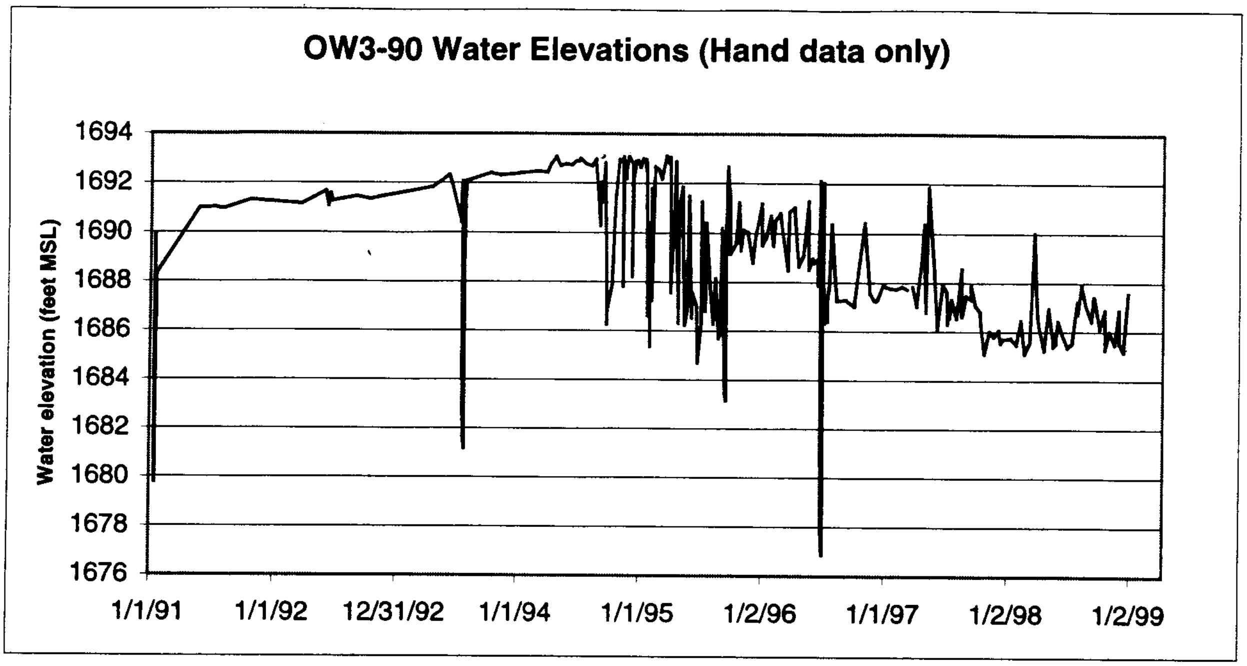


Figure 5: Hydrograph of water elevations in observation well OW3-90, south end of Burr Well field.

An inspection of the record at OW-3-90 (Figure 5) allows the same general conclusions to be drawn: there is a growing cone of depression in the supply aquifer. This well is adjacent to the pumping wells and thus the water level in the well responds quickly to pumping.

Resource Impacts

The Prairie Coteau aquifer has been determined to be the source of the ground water that sustains both ground water inflows to South Dakota's Lake Cochrane and ground water discharge to many of the region's springs, seeps, and calcareous fens.

Fortier Fen

The Deep Steel monitoring point is located just south of the Fortier fen complex. The Fortier 8 fen is a side-slope fen. The peat is mounded with three distinct discharge zones at the apex of the dome. A large population of orchids exists in this fen.

The elevation of one of the discharge zones at Fortier fen has been surveyed at 1685.16 feet above mean sea level (Figure 6). The head difference between the aquifer ground water level and the water level at the fen in late 1994 was approximately 7.8 feet, while it is now only 3.6

feet and dropping. This represents a loss of 54% of the available head and a proportionate decrease in discharge into the peat.

Pumping tests demonstrated that sustained high rate pumping at the Burr Well Field has the potential to draw aquifer levels below the discharge point at Fortier fen and cause potential impacts to the fen.

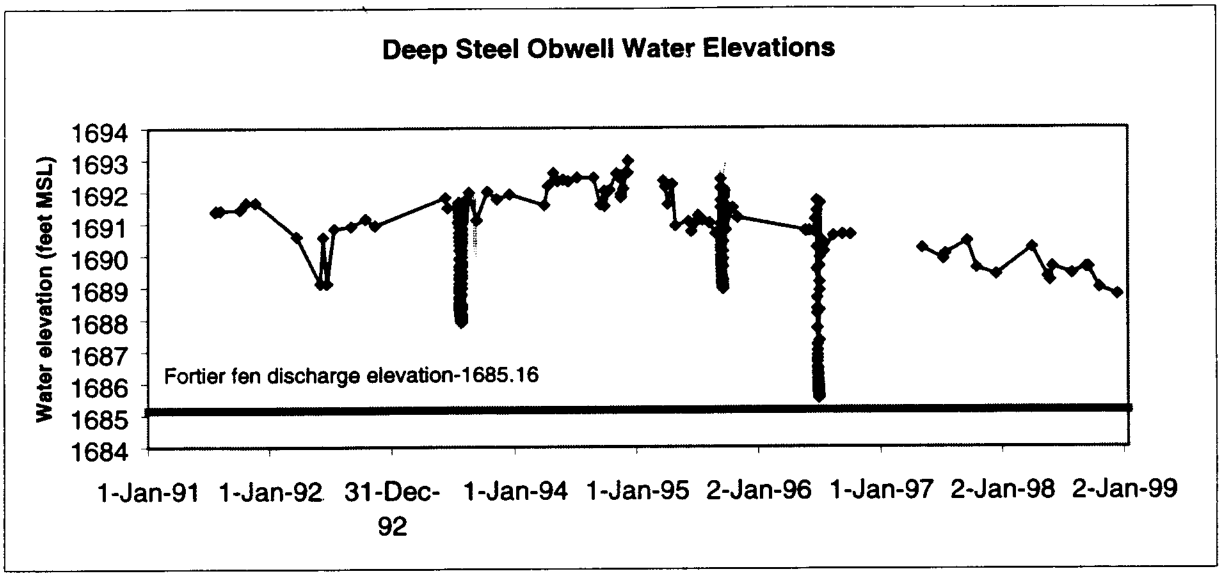


Figure 6: Water level elevation in the Deep Steel observation well relative to the discharge elevation in Fortier 8 fen.

Cleveland Fen

The Cleveland fen is a calcareous fen north of the Burr Well field. In spite of degradation due to past (and present) land use practices, this fen still provides habitat for plants that are specifically adapted to the calcareous fen environment. OW-1-93, the northern-most observation well within the Burr Well Field is between the pumping center and the fen. At the end of 1994 the available aquifer head above the discharge point was 24.9 feet, it is now only 13.8 feet, a loss of approximately 45%, which implies a proportionate decrease in discharge. Here too, it is possible to see (Figure 7) that high rates of pumping, seen here as the short term downward spikes in the hydrograph during the pumping tests, threaten to reduce heads and discharges to only 20% or less of the 1994 values.

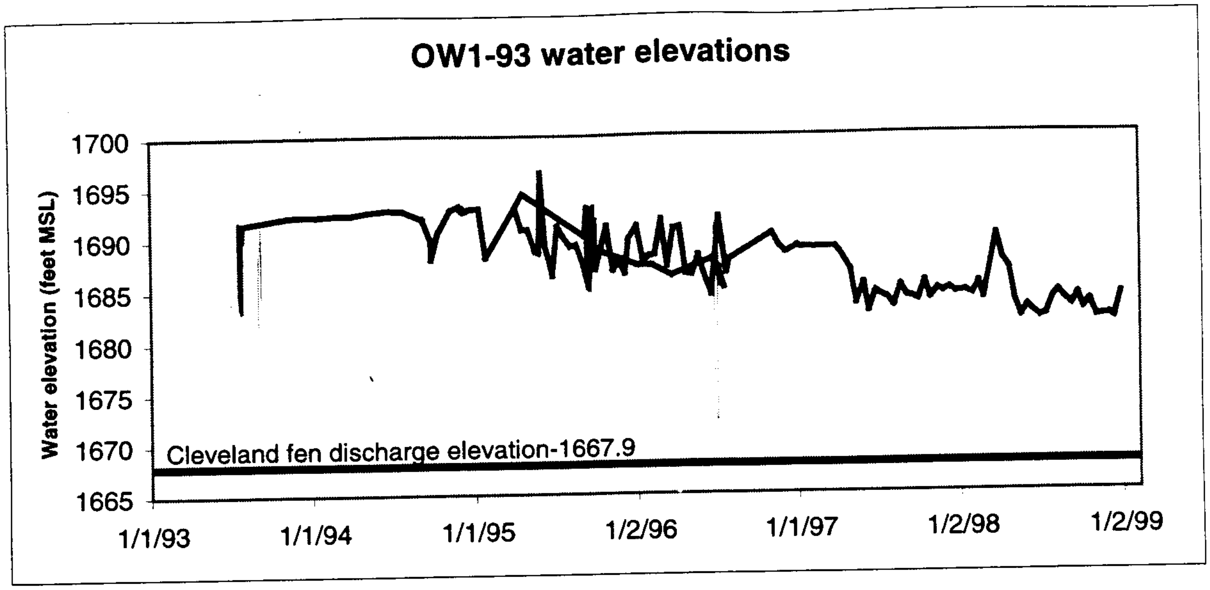


Figure 7: Water level elevations in well OW1-93 relative to the discharge elevation in Cleveland fen.

Sioux Nation Fen

The most-studied and arguably most beautiful of the region's calcareous fens is located 1.5 miles south of the Burr Well Field within the Sioux Nation Wildlife Management Area. The Deep Steel observation well is the closest Prairie Coteau aquifer level monitoring point to this fen at a distance of about 1200 feet. Aquifer tests conducted earlier in this study revealed the potential for ground water withdrawals to affect the region's wetlands and spring-fed systems. Because the potential threat to surface water and wetland resources had been recognized very early on in the planning process, protection levels (thresholds) were set at key locations. These protection levels set limits on how far water levels in the key wells could be allowed to drop without a significant threat to upwelling conditions, discharge volumes, or the degree of saturation in the peat. In addition, the peat domes were surveyed so that limits could be set on the amount of subsidence that could occur at the fen domes without significant threat to the existence of the rare and specialized plants in the fens. The limits were established by reviewing the limited data in hand at that time. To our knowledge this is the first attempt at aquifer management at a calcareous fen complex. It is not known whether the limits will accomplish the goal of preventing impacts to the calcareous fens in the area surrounding the Burr Well Field. Vegetation response to changes may lag the initiation of the change by a number of years and it may be irreversible at that time, thus we must be very conservative in our management approach. The thresholds on the Sioux Nation Fen North Dome (SNF Dome) were set relative to water levels in the USGS Dome well and the Dome 1 (WT) well. .

The hydrographs developed from the data collected at Sioux Nation Fen during pumping tests in 1993 (Figure 8) and 1996 (Figures 9 and 10) are given below.

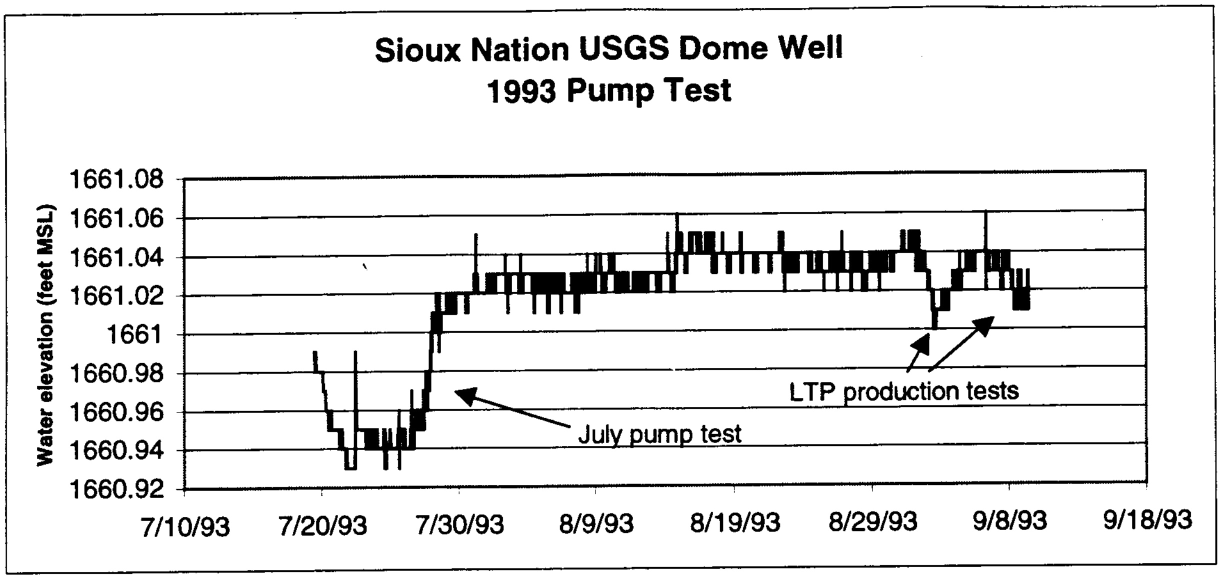


Figure 8: Water elevations recorded by a datalogger (discretization only to 0.01 feet) during pumping tests in 1993.

Water levels did not stabilize during the 1993 aquifer test, indicating that continued pumping could result in increased drawdowns. In 1996 an additional pumping test was conducted to investigate the potential impacts of requested increases in permitted Burr Well Field withdrawals on the wetland resources in the area of influence.

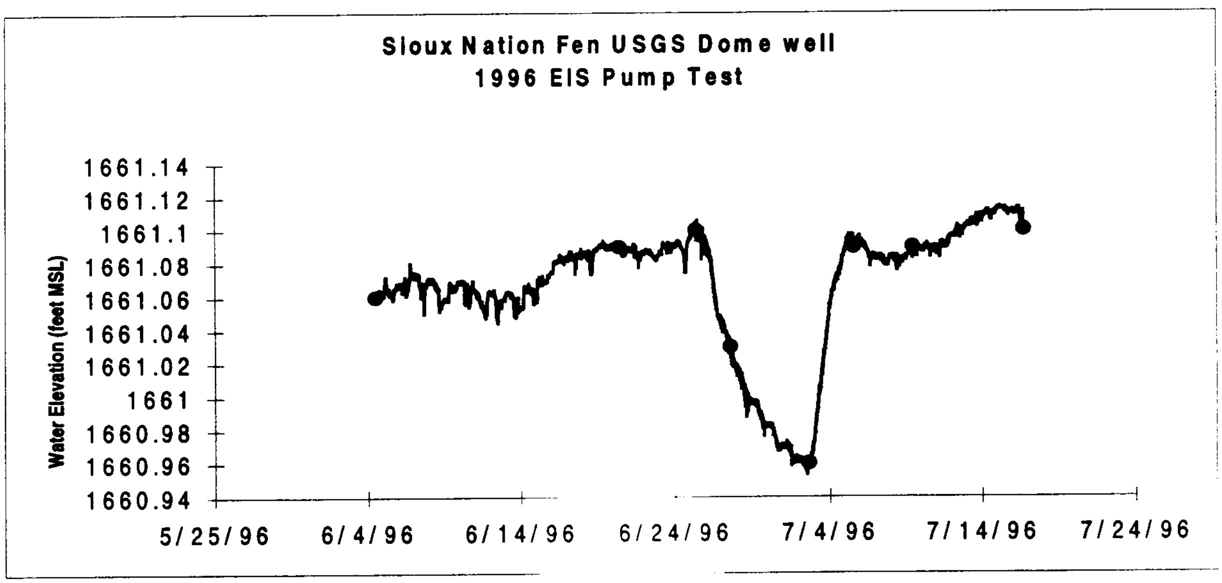


Figure 9: Water Level Elevations in the USGS Dome well during the 1996 Pump Test.

The dome well responds to pumping and recovers most of the drawdown rapidly once the test has ended. The water table well at the same location has a muted response to pumping and a very slow recovery (Figure 10). The fen wells in which these responses to well field withdrawals are evident are not screened in the aquifer which is being pumped (Table 1). The response is transmitted through the overlying materials to the wells in the fen and is considered unequivocal evidence of impact despite the small absolute change displayed.

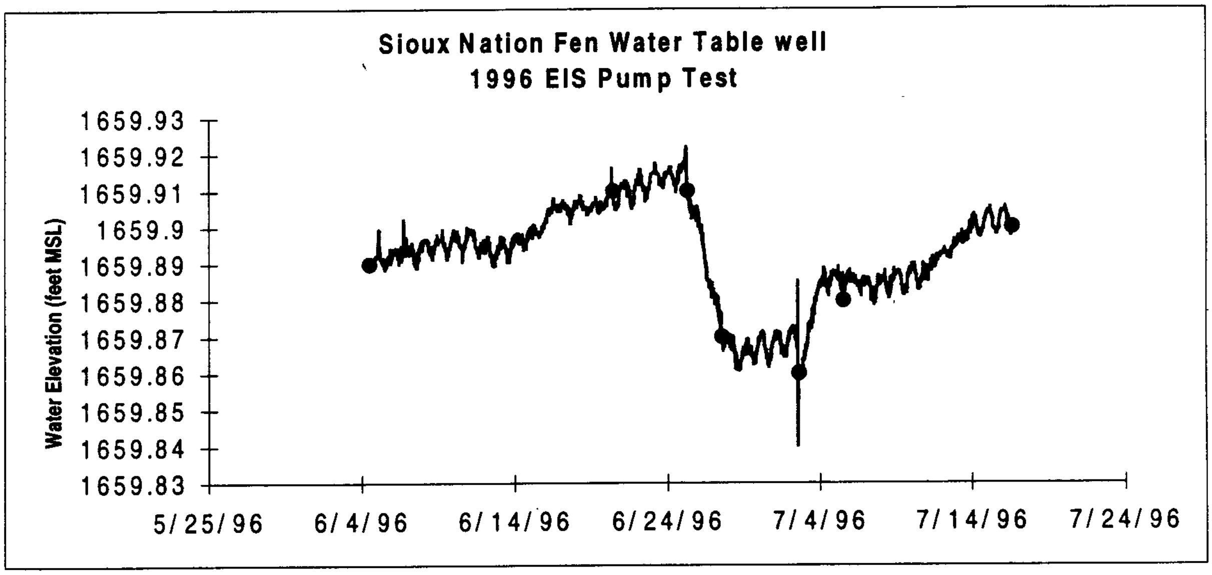


Figure 10: Water Level Elevations in the Sioux Nation Fen water table well during the 1996 pump test.

USGS Dome Well Thresholds and Water Levels

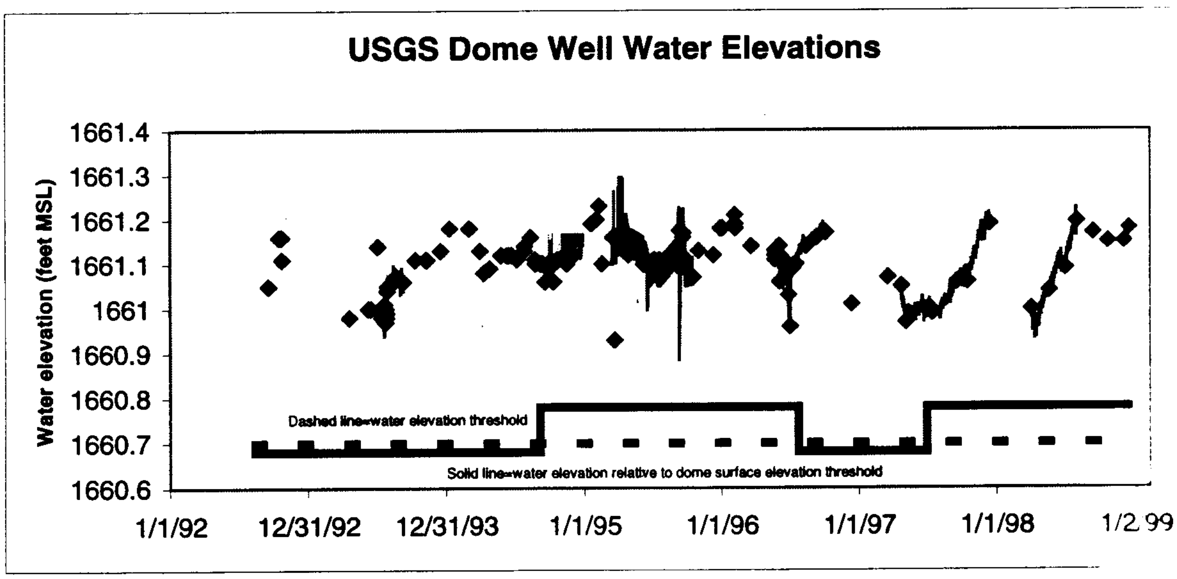


Figure 11: Water Level Elevations in the USGS Dome Well over the period of record.

Figure 11 displays the thresholds relative to ground surface (solid line-repeated surveys cause the threshold relative to dome surface elevation to be replotted) and relative to water level elevation (dashed line) at the USGS Dome well installed at the SNF Dome. Water levels in 1992 were few and under the influence of well development, flushing and sampling work. There was a general upward trend in these water levels from spring 1993 until the end of 1994, after which water levels appear to follow a pattern of early to late spring water level declines followed by summer through fall recovery. These cyclical responses are not thoroughly understood. The timing of the initial downturn in water levels coincides with the start of production pumping at the Burr Well Field, and perhaps with the high demand for water for spraying. The fact that this occurs at the same time that vegetation is greening in spring may be driving the pattern of water levels since the end of 1994. All of these changes are played out over a range of water levels totaling 4 tenths of a foot* only 2 tenths of a foot above the thresholds. Conservative management is indicated.

The head gradient available in December 1998 (31.8 feet) relative to the aquifer, as measured at the Deep Steel observation well, is about 13% less than the available head difference at the end of 1994 (27.6 feet). Peat mounds are vulnerable to decreases in head gradient that might leave the fen peat with dwindling ground water discharge during a period of high evapotranspiration or natural period of low aquifer recharge. Thus artificially induced (through pumping at the well field) decreases in available head have the potential to cause irreversible subsidence, aerobic decay and associated structural changes in the peat, which would in turn impact vegetation. Desirable species may decrease in number, while invading species might increase.

* The difference between the highest measured water level and the lowest measured water level

Water Table Thresholds and Water Levels

The water level record at the top of the Sioux Nation Fen dome is displayed in Figure 12.

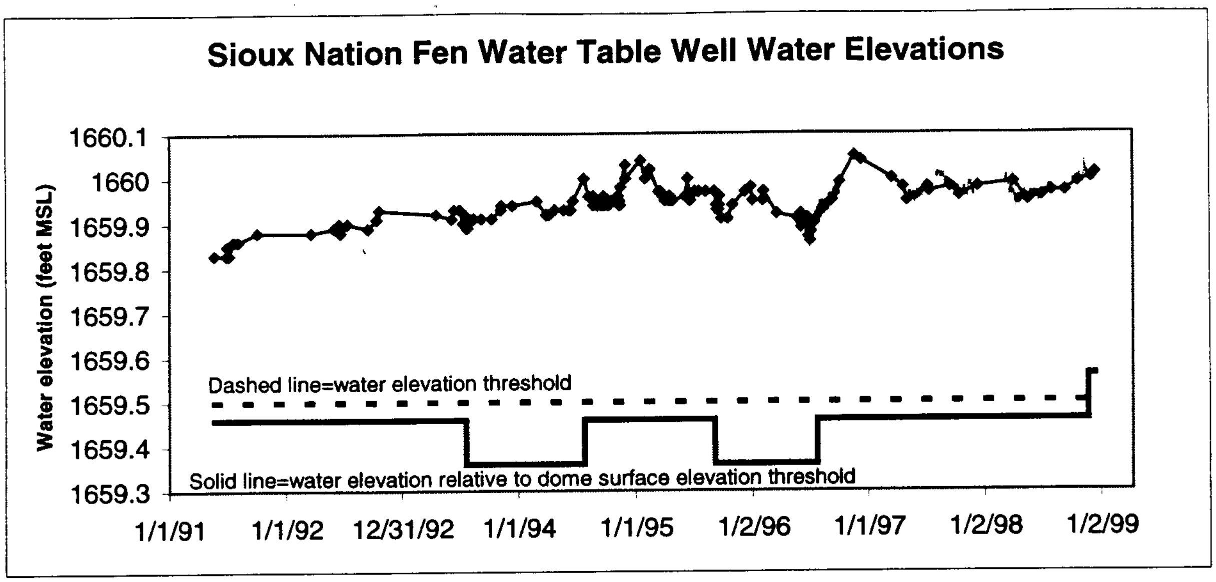


Figure 12: Water Level Elevations in the Sioux Nation Fen water table well over the period of record.

The discharge zone at the apex of this fen is surrounded by an approximately circular hardened marl rim. Discharging water flows through the peat sides of the mound and up and over the rim that acts as a dam. If ground water discharge is adequate, flow over the rim should be relatively constant and water levels should be stable or rising as the rim accumulates more calcium carbonate cemented plant remains. Flow over the rim keeps water available in excess over evapotranspiration in the sedge mat and pools can form and be maintained on the peat surface along the side slopes of the dome. Many of the rarer plants are found in these pool zones of the sedge mat.

The thresholds relative to both water level elevation (straight dashed line) and ground surface (solid line - changed as needed to reflect survey information) are shown (Figure 12). While the threshold for the deeper (subpeat) well is set with the intention of maintaining gradient and flow through the peat, the water table threshold is set to be certain that the surface of the discharge zone is always saturated.

A water table well only approximates the water table. It represents the summation of potentials over the length of the well screen. A perfect water table well would have a very tiny well screen right at the water table. In the real world, a well screen must have some length, or changes in water levels could not be measured. In soft peat soil, the well must also have enough length in the ground to be able to stand up straight and not be blown over in the next storm. Water table wells must be replaced when screens clog or when peat accumulation in the well cannot be removed. To deal with this dilemma, the water elevation threshold must be set somewhat above the ground surface. Recent topographic survey data reveal that the threshold determination at this site should be revisited.

Water levels in the water table well rose from installation until the end of 1994, along the same general trend as the aquifer response in this area. Then, over the next two years, water levels declined, coincident with the start of production pumping from the Burr Well Field. From late summer 1996 to the end of the year, the water elevation in the water table well recovered all of the head that had been lost the previous two years, corresponding to one of the cycles displayed in the subpeat well. The water table well does not continue to track well with the subpeat well for reasons we cannot currently explain with certainty. The well is scheduled to be replaced in Spring 1999.

Note that the hydrographs in Figures 11 and 12 show that the water levels have never dropped below the thresholds at Sioux Nation fen. Near the end of the pumping phase of the 1996 aquifer test, it was observed that the pools along the west side of the fen were empty. As the aquifer recovered from the pumping phase of the test, so did the pools at the fen dome. Withdrawals from the aquifer had apparently reduced the volume of upwelling ground water until it was no longer in excess of plant requirements.

Several confounding factors exist:

1) As the roots of vegetation recover around the installation site of the water table well, screen openings may become partially obstructed. If screen openings nearest the ground surface are clogged, then the well would tend to represent the head deeper below ground surface and water levels in the well will rise slightly – thus the record may show a combination of response to aquifer conditions and to well-specific changes.

2) The rim around the discharge zone has been breached on occasion by foot traffic. For a period of time during the vegetation survey, flow over the rim was concentrated on the weather station side of the dome (this may coincide with the decline in levels over 1995 and 1996 and the near entombment of the weather station in ice one winter). Barriers to flow were installed and flow appeared to equalize around the rim (this may coincide with improving conditions on the west side of the dome as water flow through the peat was augmented once again by flow over the rim).

3) Because the rim functions as a dam, but the dam itself can change, the interpretation of the relationship between water levels at the fen and pumping at the well field is not straightforward and all information must be taken into account.

Our conclusion is that the threshold set at this well is not adequately protective of the fen. Negative impacts have been observed and recorded in field notes (lack of flow to the sedge mat pools; increased dominance of dogwood shrubs, reeds and cattails in spite of a burn) during a period of time when the threshold was not exceeded. The confounding factors, which interfere with straightforward analysis of water levels in the fen also, interfere with aquifer management using the existing thresholds. We suggest referencing new thresholds to water levels in the Deep Steel Observation well.

Fairchild Fen

Fairchild fen is the monitored fen that is closest to the Burr Well Field. No aquifer monitoring point can exist adjacent to this fen without being a flowing well, with all of the maintenance problems that would entail. Indeed, the drilled well between the Fairchild fen and the well field is a flowing well and few recorded pressure readings exist. To calculate an approximate change in head difference relative to the aquifer at the Fairchild fen, a distance/drawdown relationship can be established from known distance/drawdown relationships. The resulting estimate of drawdown in the Prairie Coteau aquifer beneath Fairchild fen is 6.9 feet, and the estimated initial head is 1692.5 MSL. Relative to the aquifer beneath the fen and using the water table elevation at the fen as the reference (Figure 13), Fairchild fen has 18% less head available to push water up to the fen. Relative to the levels measured in the subpeat well (Fairchild deep),

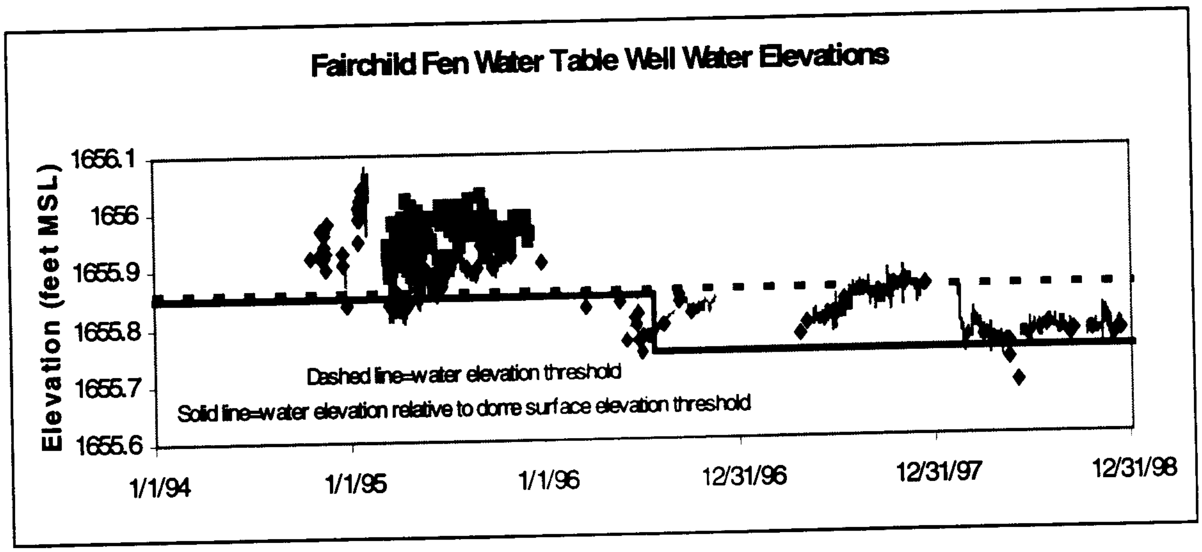


Figure 13: Water table elevation in Fairchild fen, thresholds indicated. The threshold relative to the dome surface has changed due to subsidence recorded by topographic survey.

Fairchild fen has lost 21% of the available head.

Subsidence at this fen has been documented from survey data. Survey data has indicated the fen surface elevation has declined 0.2 feet.

Given the inadvertent damage cause by foot traffic at the Sioux Nation fen, a board pathway to the dome wells at the Fairchild fen has been laid and foot traffic by DNR staff across the sedge mat to the discharge zone is purposely limited. This approach has been deemed successful: to date no channel has formed along the board pathway and the board pathway is substantially narrower than other pathways. The owners of the fen have used the discharge from the fen for the purpose of stock watering for thirty years or more. More than twenty years ago the stock were fenced out of the fen and a gravity fed discharge pipe (somewhat smaller than a garden hose) was installed from the dome to a watering tank in the cattle yard. Discharge from this pipe has continued since that time.

The pattern of water level elevations in the water table well at Fairchild fen is cause for concern (Figure 13). The threshold set to preserve upwelling conditions has been exceeded. Water levels have declined to below ground surface on occasion; the ground surface itself has subsided and not rebounded to date; and pumping cycles appear to express themselves directly on the water levels in the water table well. The wells were installed at a time when the other monitoring points began to show water level declines due to the start of production pumping at the Burr well field. The extent of the water table decline is approximately .25 feet, which corresponds with the magnitude of subsidence measured at this fen.

As discussed above, a water table monitoring well should display a level above ground surface to ensure that water levels do actually stay at or above the surface. In addition, water table wells at calcareous fens are conceptually more similar to staff gauges in reservoirs than to typical water table wells. Changes in conditions within the system are expressed in changes in discharge from the dome as well as in water level changes in the well. The water level changes in response to pumping should be subdued. Observable impacts at the Fairchild fen include increases in cattail stands and decreases in the area of typical sedge mat vegetation. Because no vegetation monitoring beyond species lists has been conducted at Fairchild fen, these changes cannot be quantified. Permanent vegetative monitoring plots should be established on Fairchild fen to more accurately document any future vegetative changes.

With regard to the exceedance of the threshold set at the water table well, it appears that ground water withdrawals during high demand periods are causing cyclical water level declines which are also very evident in the record at the Fairchild Fen Deep Well (Figure 14). These

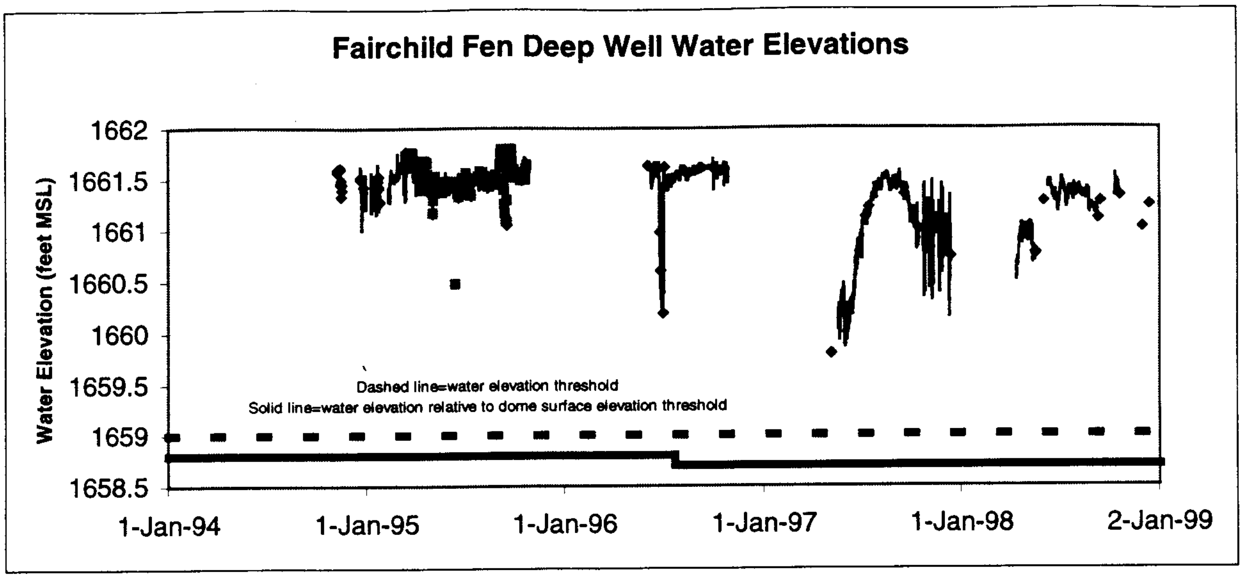


Figure 14: Water level elevations in Fairchild fen subpeat well 'Fairchild Fen Deep' Thresholds indicated.

water level declines appear to dewater the peat dome by a small amount, only part of which rebounds during recovery. After many of these cycles, cumulative subsidence is evident. Careful consideration of possible actions is needed. Two changes to water level management need to be made. They are: 1) Manage the high demand cycles in some other way – with the goal of avoiding dewatering during high evapotranspiration periods, and 2) arrange for a buyout or an alternative water supply for domestic stock watering at Fairchild's. That water, as small a volume as it may be, would then be available to flow through the peat and buffer the dewatering effects.

The hydrograph of the water levels in the subpeat well at the Fairchild fen (Figure 14) reveals an approximate loss of 0.7 foot of head overall, with alarming periodic responses to pumping events. Peak pumping periods result in maximum drawdown elevations that are trending lower as time passes, while recovery is less and less complete.

Conclusions

Impacts due to ground water withdrawals at the Burr Well Field are observable. The impacts on both the aquifer and the surface resources lead to concern that the current production of water from the Prairie Coteau aquifer is not sustainable. Modification to pumping volumes and schedules is necessary to maintain the water supply to the ground water dependent natural resources. The thresholds set at Fairchild fen and at Sioux Nation Fen may not be adequate to protect the calcareous fen resource.

Recommendations

1. Reevaluate the thresholds. Consider the transfer of the water level elevation thresholds at Sioux Nation Fen to the Deep Steel well for the non-freezing part of the year. Consider the transfer of the water elevation thresholds at Fairchild fen to a nearby aquifer monitoring point. There is a possible candidate well in existence between the well field and the Fairchild fen: OW-2-90.

2. Install an observation well in the Prairie Coteau Aquifer outside of the cone of depression from the Burr Well Field.

3. Establish permanent vegetation monitoring plots at Fairchild fen. This will allow assessment of change.

4. Work with landowners and neighbors of fens (e.g. LPRWD) to begin management of Cleveland fen and Fairchild fen.

Possible management actions:

- Fencing may improve the vegetation at Cleveland fen through prevention of cattle grazing and
- Replacement of the water supply for domestic stock watering at Fairchild fen may increase the volume of water available to the fen.
- A controlled management burn in spring at either fen when the surrounding land is plowed would be a possibility.

Test Hole Results (September 1998)

During September 1998, two deep test holes were drilled in an area located approximately 3 to 4 miles south of the Lincoln-Pipestone Burr Well Field by the South Dakota Geological Survey (SDGS) and the Minnesota Department of Natural Resources (DNR). Test holes R2-98-38 and R2-98-39 (Figure 1) were drilled into the top the Cretaceous Shale to depths of 549 feet and 541 feet respectively. The purpose of these test holes was to define the northwestern extent of the Altamont aquifer equivalent sand layers that were discovered in test holes DNR 41-1 and DNR 87-7 in 1996.

Both of the 1998 test holes were gamma logged by the SDGS. The logs of these test holes are shown on cross section E-E'. The location of this cross section is shown on Figure 2. Approximately 12 feet of the Altamont sand was found in test hole R2-98-38. No Altamont sand was found in test hole R2-98-39. The previously drilled test holes nearest R2-98-38 and R2-98-39 encountered Altamont sand layers with a thickness range of 35 feet (DNR 41-1 and DNR 87-7) to 100 feet (DU-73A). These wide variations of sand thickness within a relatively small area suggest depositional and stratigraphic complexities that require additional test drilling to define.

Figure 1 - Burr Well Field/ Lake Cochrane Area Test Hole and Well Locations

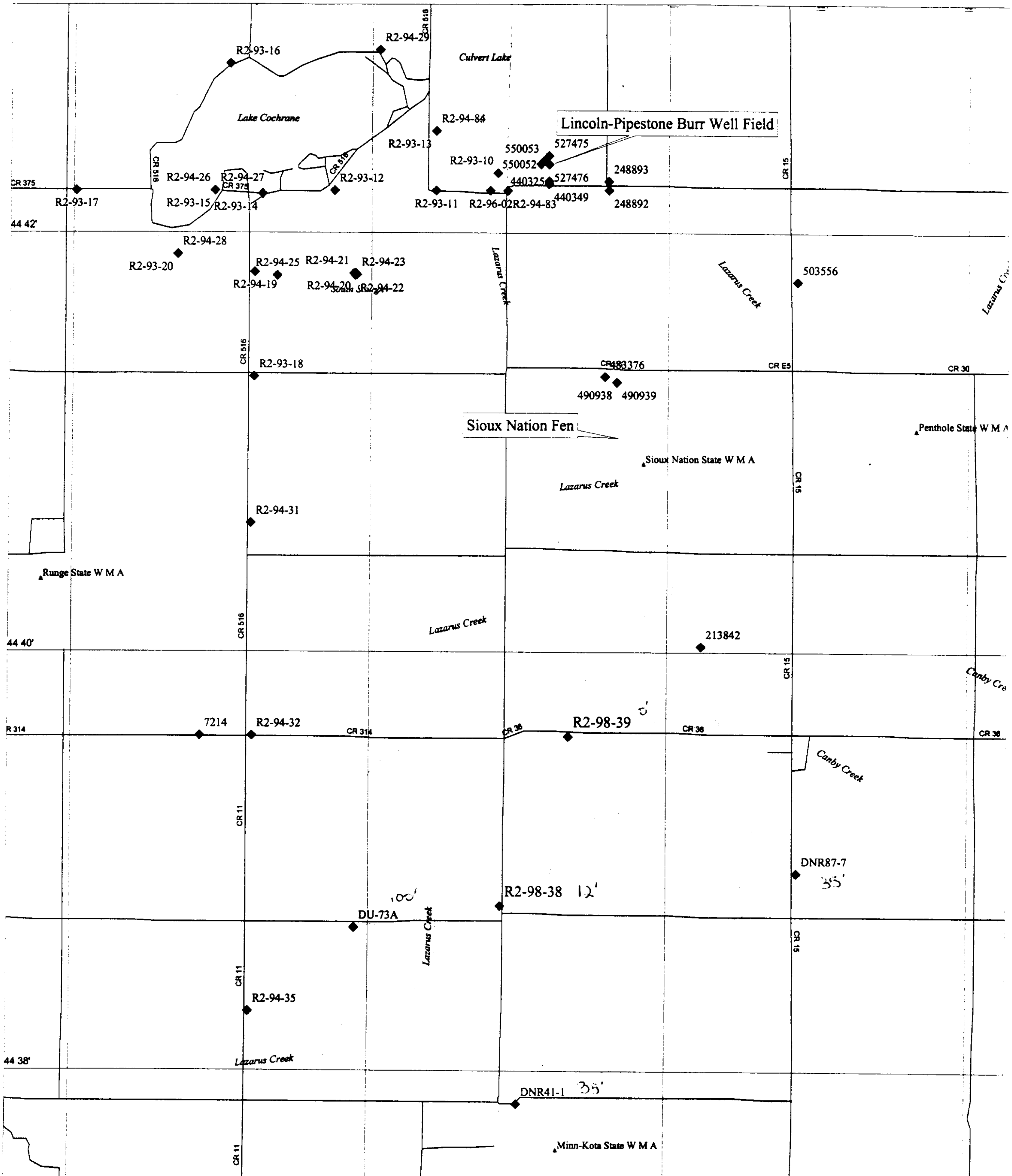


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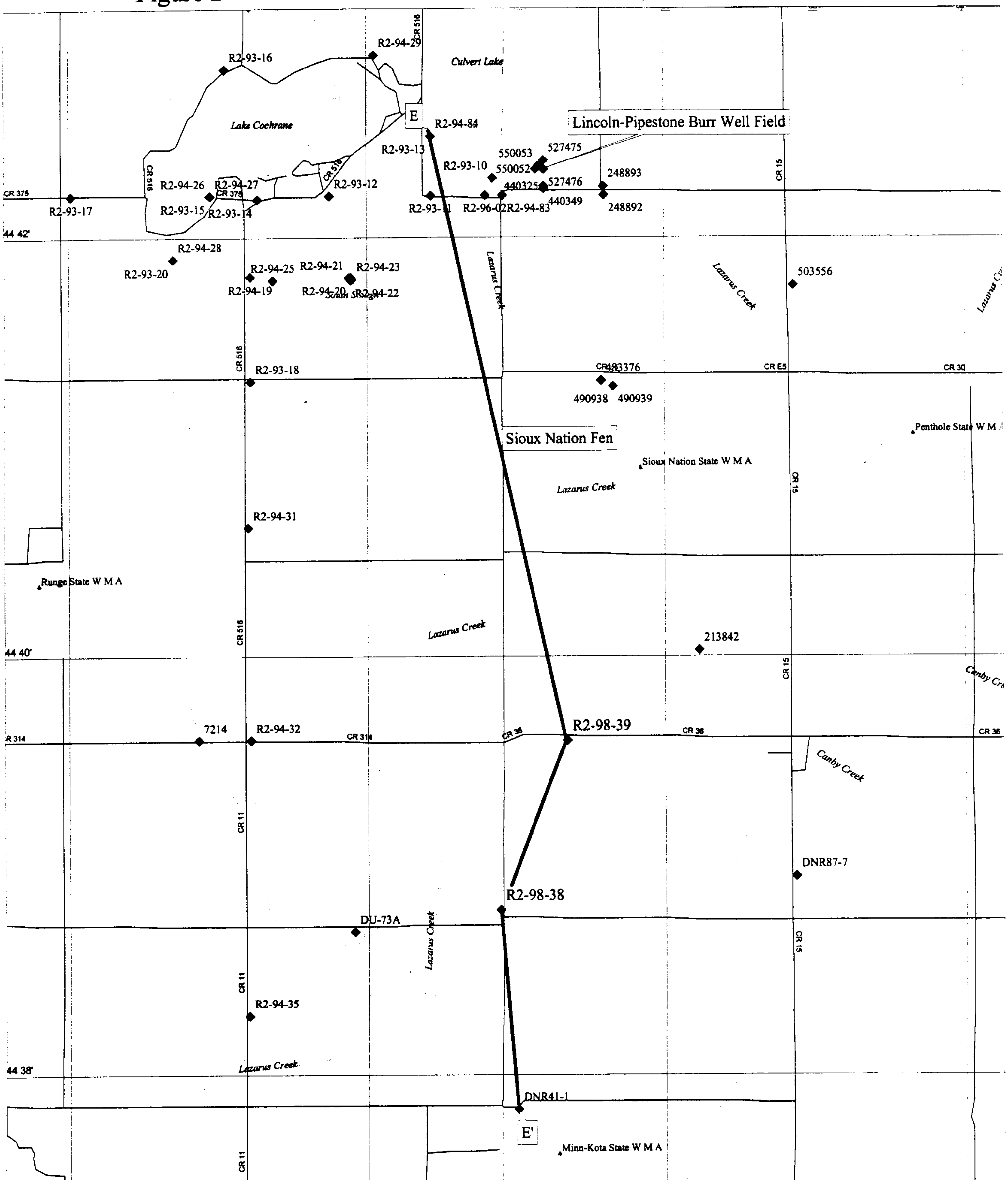
Figure 2 - Burr Well Field/ Lake Cochrane Area, Cross Section E-E'



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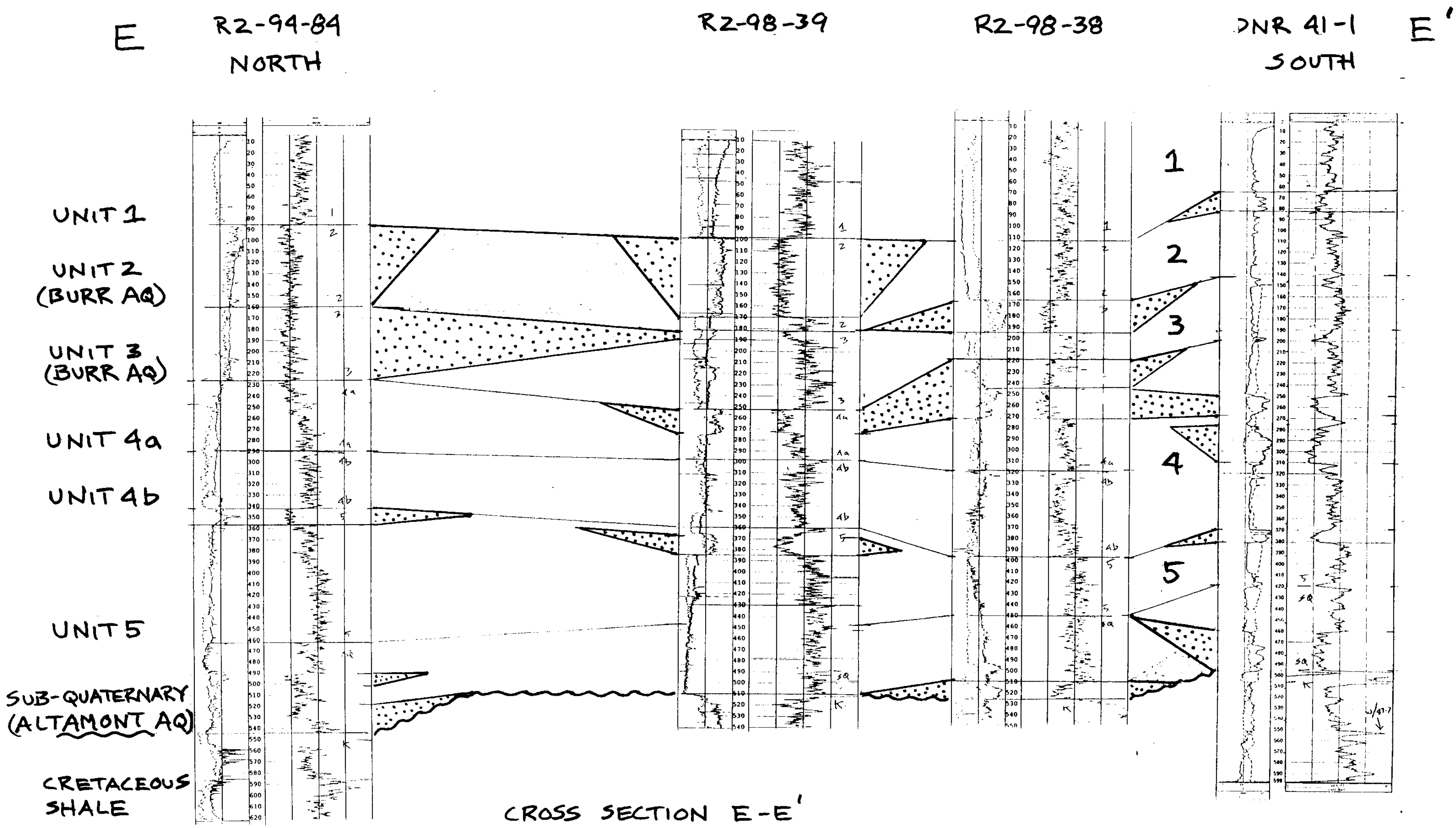

CROSS SECTION E-E'
BURR WELL FIELD/ LAKE COCHRANE AREA