Report to the Felton Stewardship Committee

On

Impacts of Sand and Gravel Mining in the Felton Prairie Fen Area on Down Gradient Calcareous Fens

Minnesota Department of Natural Resources

Division of Waters

February 2002

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Executive Summary

Situated on the Glacial Lake Agassiz Beach Ridge, the Felton Prairie Study area is approximately 3.5 miles east of Felton, Minnesota. Significant natural resources within the study area include rare native prairie, highly valuable construction grade gravel, many wetlands, and two calcareous fen peatlands that are protected under the No-Net-Loss Wetlands Protection Act. Several gravel pits dot the landscape within the Felton Prairie area. Two of the pits, one on State Trust Fund land and one on Clay County administered land, are the subjects of this report.

Conflicts between gravel mining and natural resources have arisen because of the high value of the gravel. Due to the potential incompatibility between gravel mining and native prairie protection, the Felton Prairie Stewardship Committee was formed to proactively address the inherent conflicts. While the Stewardship Committee was addressing the prairie and mining issues, they became aware that some of their mining proposals might impact two calcareous fens located down gradient of the gravel pits. To assess this aspect, the Committee asked DNR Waters to evaluate a number of mining scenarios.

Inasmuch as digital computer model simulation could not adequately recreate existing conditions, it was decided to employ traditional flow net modeling (Freeze and Cherry, 1979) to answer the questions posed by the Stewardship Committee. Ground water elevation contour maps were developed to facilitate flow net modeling and flow pattern analysis. These analyses revealed the following:

– The State Trust Fund pit has radically altered flow paths. Flow paths near the gravel pit were distorted from parallel northwest trending lines perpendicular to the beach ridge to radial flow towards the pit along its south and western borders. It is assumed that this phenomenon will be replicated whenever mining near and below the ground water table occurs.

– The slope of the water table east (upgradient) of the gravel pit pool is quite steep due to the vertical pit walls and loss of soil matrix. Ground water levels near the eastern edge of the Trust Fund pit drop approximately 21 feet over 790 feet.

– The regional effect due to excavation below the groundwater table in gravel pits is a decline in ground water levels by up to approximately 15 feet. Water level contours are being pulled eastward, away from the fens. It appears that this phenomenon has eliminated a major portion of the northern fen's ground watershed. The ground watershed of the southern calcareous fen has been negatively impacted to a lesser degree.

– Along the north end of the Felton Prairie complex, a steep ground water gradient has developed along the south Clay County Highway 34 road ditch. Water flows in the subsurface toward this ditch, emerging along its banks to flow downhill. If a more direct connection between the pool and the ditch is created, the pool could drain, wholly or partially, causing the loss of most of the rest of the ground watershed for the north fen. Extreme caution must be taken to ensure that this does not happen during excavation of a private 40-acre tract north of the Trust Fund pit.

– Every effort should be made to ensure that gravel mining does not occur at or near ground water elevations between the Trust Fund pit and the Clay County pit south of the Trust Fund pit. Additionally, expansion of the Clay County and Trust fund pits eastward near the unmined area between the pits will likely exacerbate ground water level declines.

Introduction

The Felton Prairie Study area is approximately 3.5 miles east of Felton, Minnesota on the Glacial Lake Agassiz Beach Ridge. Significant natural resources found within the study area include rare native prairie, highly valuable construction grade gravel, and a number of wetlands including two calcareous fens protected under the No-Net-Loss Wetlands Protection Act. Several gravel pits dot the landscape within the Felton Prairie area. Two of the pits, one on State Trust Fund land and one on Clay County administered land, and the two calcareous fens are the subjects of this report.

Because of the valuable gravel, conflicts between gravel mining and the prairie and fens have arisen. Gravel mining typically destroys any native prairie at the mined site, thus the Felton Prairie Stewardship Committee (FSC) was formed to proactively address the inherent conflicts. While the Stewardship Committee was addressing the prairie and mining issues, they became aware that some of their mining proposals might impact two calcareous fens located down gradient of the gravel pits. To assess this aspect, the Committee asked DNR Waters to evaluate a number of mining scenarios.

The two calcareous fens, simplistically named North Fen and South Fen, are downslope of and 30 feet lower in elevation than the Lake Agassiz beach ridge top. Shown on the aerial photograph mosaic in Figure 1, the South Fen is located in the SE 1/4 Sec. 36 T142N R46W; the North Fen is approximately 1,000 ft. northeast of the South Fen in the SW 1/4 NW 1/4 Sec 31 T142N R45W. Contrasting with the relatively flat North Fen (elevation 967) the South Fen slopes approximately 18 feet from its eastern, up gradient edge (elevation 980) to its western edge (elevation 962).

The North Fen lies down gradient of a large open water gravel pit, which is managed by the Department of Natural Resources (DNR) Division of Forestry for the Trust Fund (herein referred to as the Trust Fund pit). The Trust Fund pit is located in the SW1/4 NW 1/4 Sec 32 T142N R45W. Construction grade gravel has been removed from the aquifer on the Trust Fund parcel for the burgeoning Red River population since 1959. By 1995 the North Fen appeared to be degraded (due to encroaching shrubs and vegetation changes) and efforts began to monitor water levels at three locations: the gravel pit water surface; two wells sited between the gravel pit and the North Fen; and two wells within the North Fen. Water level monitoring was initiated to provide the framework for a conceptual model to assist in interpretation of the North Fen degradation mechanisms. Subsequent to the 1995 endeavors, a weather station was installed

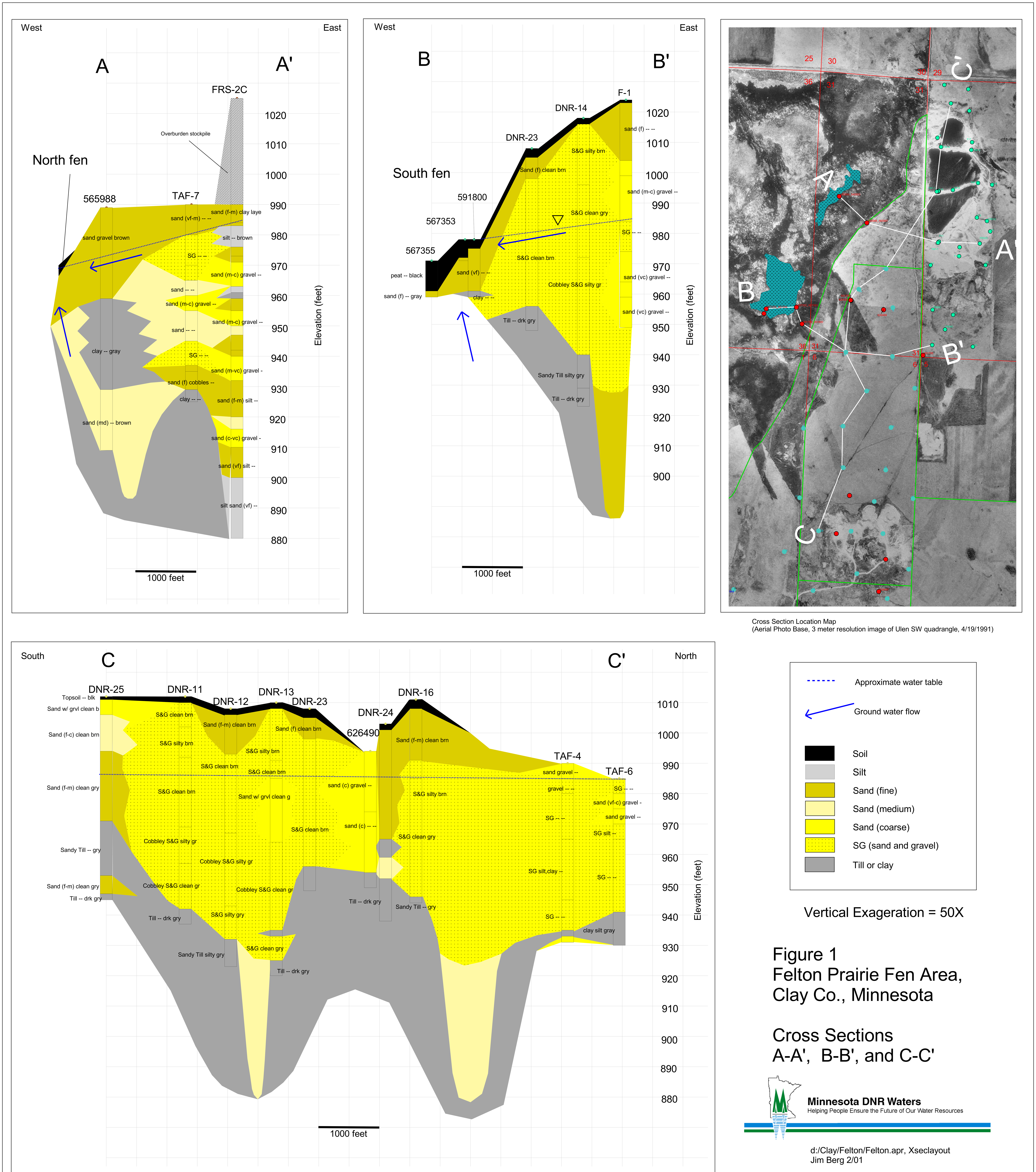

Figure 1
Felton Prairie Fen Area,
Clay Co., Minnesota

Cross Sections
A-A', B-B', and C-C'

on the southwestern edge of the South Fen, and a series of observation wells were added to the monitoring program. Table 1 provides the location and length of record for each observation well. Figure 2 depicts the observation well locations and Table 2 supplies a chronology of activities.

Mined to approximately the ground water table, the Clay County pit is situated in the S1/2 Sec 6 T142N R45W. Substantial gravel resources have been identified below the water table in and surrounding the pit. One of the study goals is to identify the potential to negatively impact the south fen under various Clay County pit mining configurations.

Table 1. Wells installed in the Felton Prairie Area

Site	Well Name	Unique Number	Depth (ft)	Period of Record	Latitude	Longitude
Fen Site 1	Shallow	540953	3.9	7/26/1995 to present	47 04 19.559	96 26 05.043
	Deep	540954	10	7/26/95 - present	47 04 19.559	96 26 05.043
Fen Site 2	Shallow	567352	4	7/27/95 - present	47.066283101	96.437603476
	Deep	567353	7.1	7/27/95 - present	47.066283101	96.437603476
Fen Site 3	Shallow	567354	4	7/27/95 - present	47 03 58.036	96 26 23.549
	Deep	567355	12	7/27/95 - present	47 03 58.036	96 26 23.549
	Shallow	565987	20	7/26/95 - present	47 04 14.834	96 25 57.094
Drilled Well Nest	Deep	565988	80	7/26/95 - present	47 04 14.837	96 26 57.209
	Shallow	591798	11.98	12/16/97 - present	47.040031966	96.260056856
South Intermediate Well Nest	Deep	626490	40.25	6/1/99 - present	47.040031966	96.260056856
	Shallow	591799	7.37	12/16/97 - present	47.06517	96.43718
Well Nest East of South Fen	Deep	591800	13.03	12/16/97 - present	47.06517	96.43718
Regional Ob Well	14-047	149504	108.75	7/29/85 - present	47.044384702	96.200042831
Regional Ob Well	USFW	626486	60.98	5/26/99 - present	47.030157320	96.223050219
Clay County	County Pit	626487	47.26	6/9/99 - present	47.030638806	96.254953745
Zilmer WMA	Zilmer Pit	626488	39.01	6/9/99 - present	47.030106809	96.263126929
Clay County	Clay Co. S31	626489	48.29	6/1/99 - present	47.035884650	96.255157524
Aggregate Industries	Mine Well	591795	31	12/16/97 - present	47.064094398	96.427843706

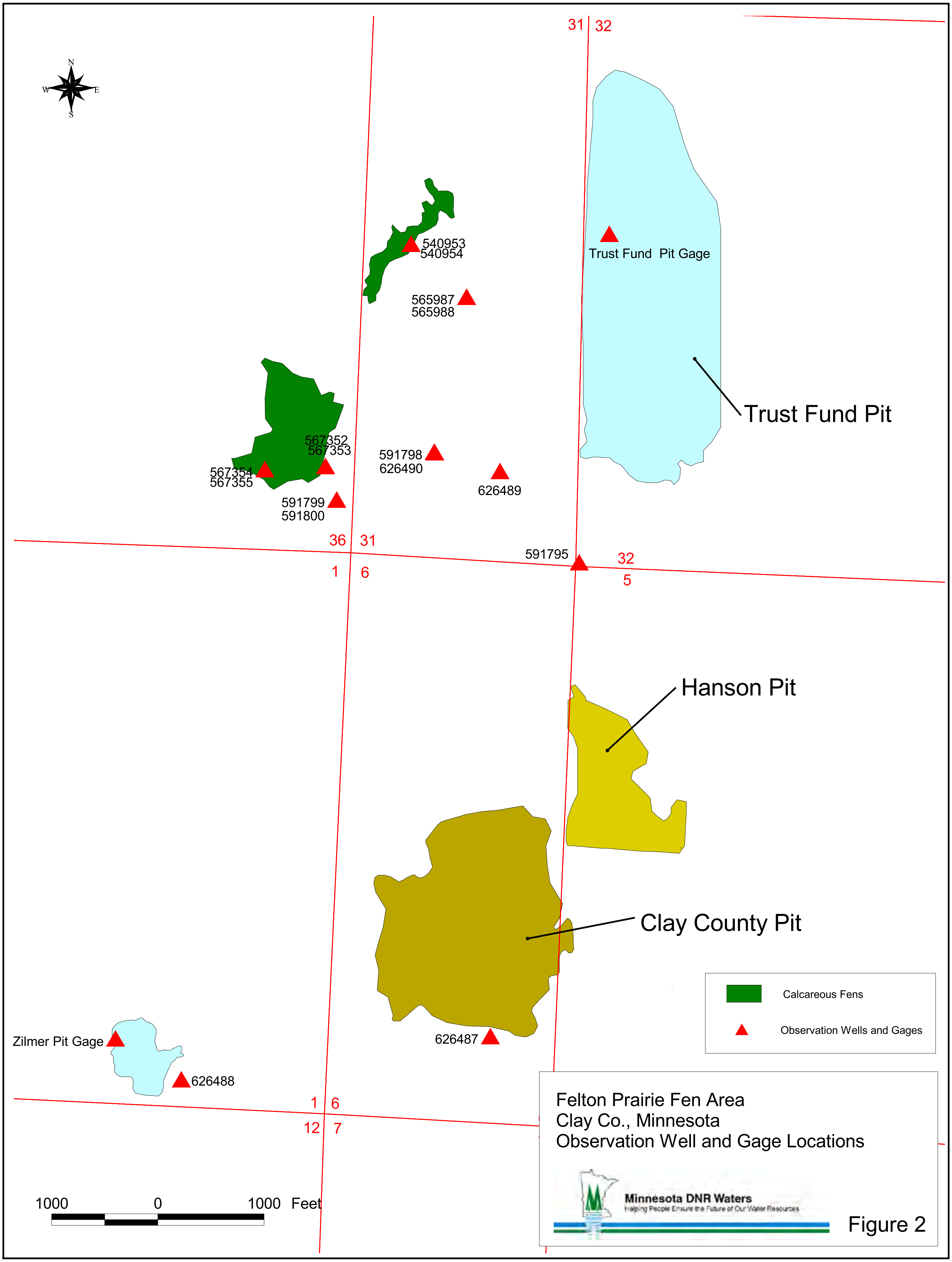
N
S
E
W
31
32
36
31
1
6
32
5
1
6
12
7
540953
540954
565987
565988
Trust Fund Pit Gage
Trust Fund Pit
567352
567353
567354
567355
591798
626490
626489
591799
591800
591795
Hanson Pit
Clay County Pit
Calcareous Fens
Observation Wells and Gages
Zilmer Pit Gage
626488
626487
1000
0
1000
Feet
Felton Prairie Fen Area
Clay Co., Minnesota
Observation Well and Gage Locations
Minnesota DNR Waters
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Figure 2

Table 2: Felton Prairie Fen Chronology

1959 Kost brothers begins mining of a portion of the parcel under a lease from the state of Minnesota.

Summer 1995 DNR-Waters begins its hydrologic investigation of the two fens in the Felton Prairie. Six fen wells (two in the north fen and four in the larger south fen) and two drilled wells upgradient of the north fen are installed to monitor water levels of the ground water feeding the fens.

Spring 1996 A weather station is installed on the edge of the south portion of the south fen to gather climate data. Included are sensors to measure barometric pressure, air temperature, relative humidity, wind speed and direction, soil temperature, solar radiation, precipitation, and water levels in two wells.

December 1997 Four more drilled wells are installed upgradient of the south fen.

May 1999 Three wells are drilled to the south and the southeast of the southern fen to gather information regarding the water level to the south of the fen. An additional two deep wells were drilled upgradient of the north fen to complete well nests with shallower wells drilled in 1997. Geophysical work was done on Felton Prairie by DNR staff to evaluate the subsurface geology and the gravel potential in undisturbed portions of the prairie.

Winter 1999-2000 A rotosonic drilling program was funded by LCMR to further evaluate gravel potential in the area and complement geophysical work.

Study Methods

Studies of the hydrology and hydrogeology of the Felton Prairie Fen area began in response to a request in 1992 by Kost Brothers (now Aggregate Industries) to increase by ten-fold the volume of water allocated under their dewatering permit for the Trust Fund pit. Concern for the nearby calcareous fens was acknowledged at that time and the mining plan for the State Trust Fund pit was accordingly altered to avoid dewatering. Subsequent formal studies of the area with relevance to ground water conditions are discussed in this document.

Soils Investigations

In January 2000, DNR Minerals contracted for 27 rotosonic drill holes. Heather Anderson's May 2000 report titled *Aggregate Resource Evaluation for a Portion of Felton Prairie; Clay County, Minnesota* supplies the result of this drilling program. Additional soils investigations conducted in the Felton Prairie area include soil borings by the aggregate industry, and soil auguring by the Department of Transportation (DOT).

In concert with the rotosonic drilling, DNR Waters conducted a geophysical survey of the Felton Prairie complex with the University of Minnesota. Principally comprised of surficial resistivity work, the geophysical investigation also included one down-hole resistivity log to correlate with the surficial survey. A graphical interpretation of the results of the geophysical survey is contained in Anderson's report.

Three other reports pertaining to the Felton Prairie geophysical investigation have been completed. They are: *2-D Electrical Resistivity Profiling on Felton Prairie, Clay County* by Benson and Alexander; *Comparison of Felton Resistivity versus Rotosonic Borings* by Petersen; and *Bicentennial Unit, Felton Prairie Resistivity Surveys* by Petersen and Anderson.

Hydrogeology

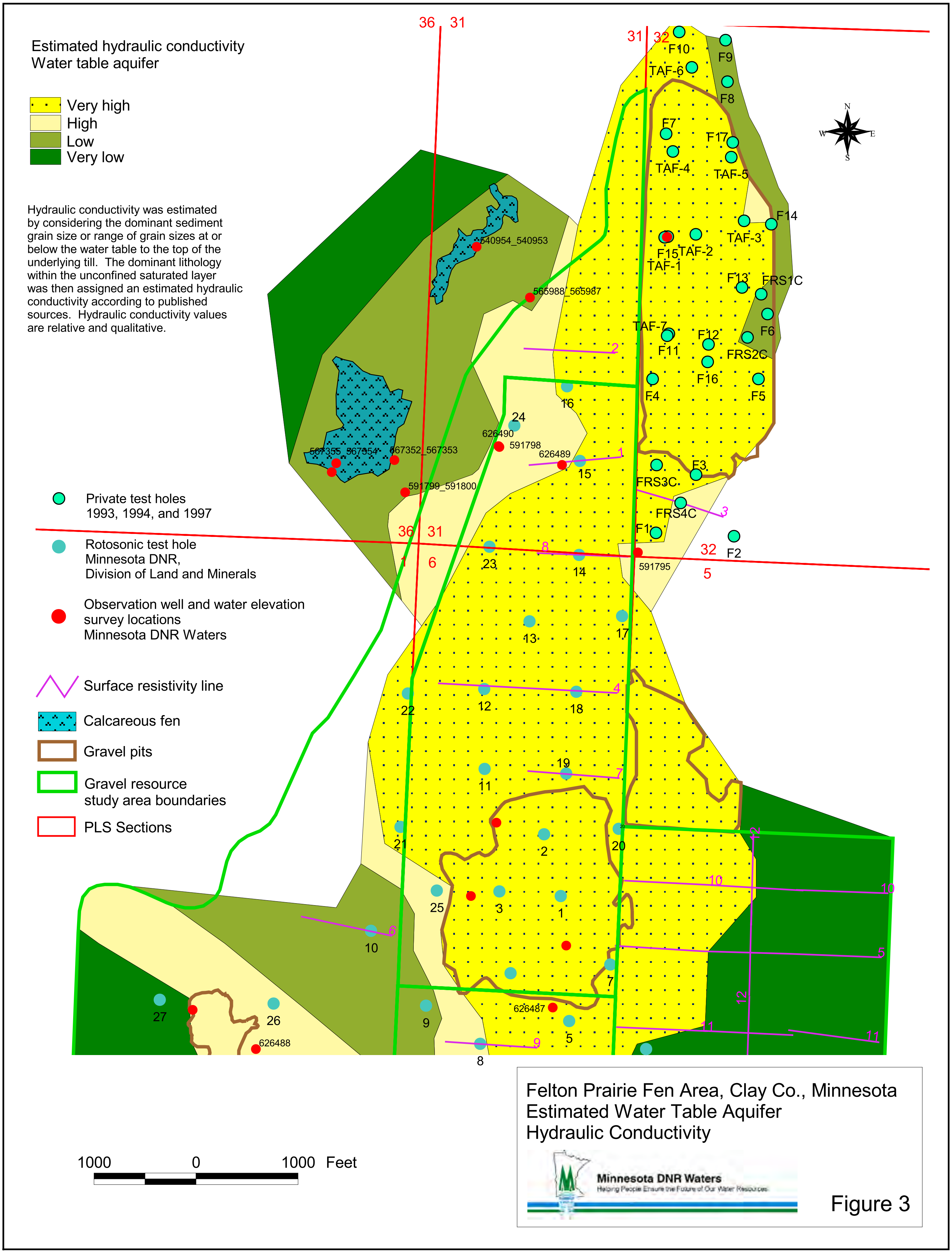
Anderson's May 2000 report presents the geologic events responsible for the present day Felton Prairie stratigraphy. To facilitate a stratigraphic interpretation of the Felton Fen Prairie area, the above discussed observation well logs, rotosonic bore hole logs, geophysical mapping, DOT soil auger logs, and aggregate industry data (combined herein referred to as the Felton Prairie stratigraphic data base) were employed to construct geologic cross-sections

(Figure 1 a, b, and c). Underlain by gray glacial till, a sequence of gravels, sands (herein termed outwash sediments) comprises the hydrogeologic environment of the fens and gravel pits.

Along with the stratigraphic interpretation, the Felton Fen stratigraphic database enabled an estimate of the sediments' relative hydraulic conductivity, a measure of a geologic formation's ability to transmit water. Figure 3 presents the results of the Felton Prairie water table aquifer hydraulic conductivity estimation. Much less transmissive than the outwash sediments, the gray, clayey till was assumed to convey very small quantities of water.

Because of the difference in the sediments' hydraulic conductivity, water will develop preferential flow paths around or above the till and through the outwash sediments. Though a meandering stream carved channels within the basal till prior to deposition of the outwash materials, drilling results showed that sediments less transmissive than the overlying sand and gravel had been deposited within the stream channel. Thus it was assumed that the ancient stream course sediments functioned similar to the basal clay till and would transmit only small quantities of water.

Upwelling ground water is a requisite physical element for calcareous fens. The head potential of ground water at depth is greater than that at the surface, causing upward movement of ground water toward the surface – conditions which are sometimes called 'artesian'. Two hydrogeologic mechanisms supply the upwelling ground water to the South Fen. The first, and more apparent, is the outcropping of ground water at the surface as it trends down slope. A hydraulic head of approximately 6 feet exists between the beach ridge and the fen. The second component is the redirection of ground water flow toward the surface due to the sudden rise in the basal till as shown in the cross sections of Figure 1. Deeper ground water flowing along the top of the basal till is forced upward through the more transmissive outwash sediments, converging with the upper level ground water flowing down slope from the beach ridge. The upward pressure combined with the volume of ground water due to convergence exceeds the soil's storage capacity. If, as is the case with the Felton Fens, an opening to the surface is available, the excess ground water spills over onto the ground surface, creating an environment conducive for the development of a fen or other wetland. Conditions for calcareous fen development are particularly favorable when the amount of upwelling groundwater is marginally in excess of the maximum evapotranspiration rate, thus providing ideal conditions for peat development.



Felton Prairie Fen Area, Clay Co., Minnesota
Estimated Water Table Aquifer
Hydraulic Conductivity

Figure 3

Ground Water Modeling with Computer Methods

Aggregate Industries hired a consultant to begin computer modeling of ground water flow early in the study when it became important to determine whether disposal of overburden spoil piles in the gravel pit lake would be an acceptable part of mine reclamation. Initial model results were promising in a regional sense, but current conditions near the fens could not be recreated. The model was used to make relative comparisons of different reclamation plans, but limited confidence could be placed in the results. The model's author postulated that improvements were needed in the geologic database and in the calculation of site-specific evapotranspiration from the data collected at the on-site weather station. Data gaps were addressed by drilling more water level observation wells and by conducting geophysical and geologic investigations as described above. Assistance from the State Climatologist's office was key to the refinement of evapotranspiration calculations. Evapotranspiration model input assumptions were:

- Plant species were well-watered (i.e. peat was saturated to the surface).
- Water-laden air was transported from the evaporating surface yielding a constant flow of unsaturated air to the plant surface.
- Fen species can be represented by a short crop that has an evapotranspiration rate already determined.
- Evapotranspiration is occurring at the maximum rate.

Evapotranspiration calculations are based on data collected at the weather station on the south fen which include the minimum and maximum air temperature, solar radiation, wind speed, and vapor pressure deficit. Several of the input parameters are depicted in Figure 4.

Evapotranspiration peaks in late April through June because fen plants begin respiring much earlier than many dry land plants and some of the early season evapotranspiration is due to evaporation of free water from the peat surface. Through the remainder of the summer, evapotranspiration decreases because humidity in the advected air increases and to a very limited extent because rain decreases towards the end of the summer. Evapotranspiration decreases through fall because the plants are beginning to senesce and are respiring at a much lower rate. A second order polynomial fits the growing season data fairly well (Figure 5).

Figure 4: Felton Solar Radiation & Soil Temperature

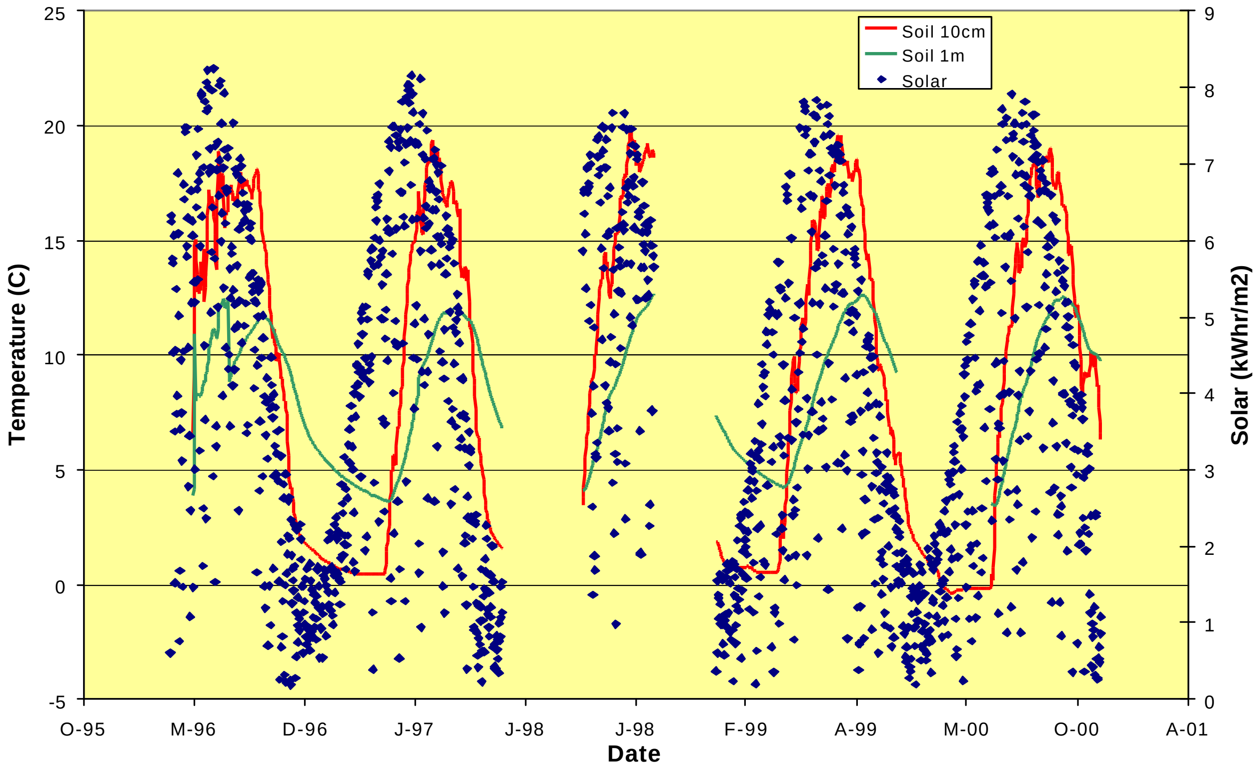
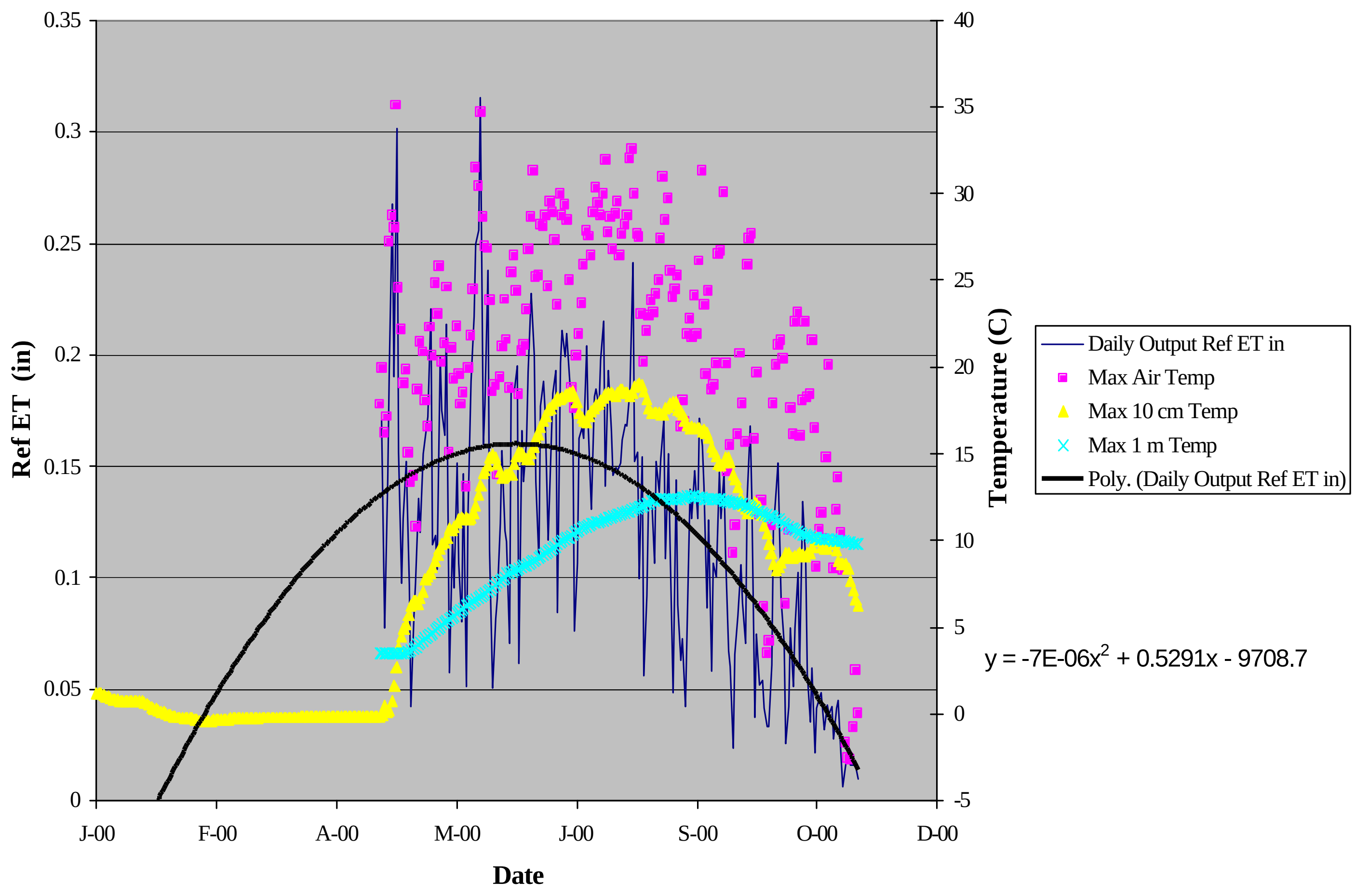


Figure 5: 2000 Reference ET for the Growing Season



Once all the most recent geophysical, geologic, hydrologic and climate data were combined, and a map of estimated hydraulic conductivities produced, efforts began anew to create a computer model of ground water flow in the Felton Prairie area using the improved database. Even with vast improvements in modeling software, the model could not be calibrated to existing conditions. It is thought that the calculations underlying the model are not robust enough to allow the steep gradients and above-ground-surface water levels that fens represent in the real world. In any case, it was not considered feasible to create a working calibrated computer model within the administrative time frame of the Felton Stewardship Committee. Thus, the decision was made to employ traditional hydrogeologic methods to answer the Committee's requests without delay.

Ground Water Modeling with Traditional Methods

The purpose of the hydrogeologic investigation was to determine the effect of mining on ground water levels and ground water flow paths. If mining alters ground water levels or ground water flow paths, it is possible that these changes would have negative impacts on the down gradient calcareous fens that are dependent upon a constant ground water supply in excess of evapotranspiration. A conceptual model of ground water flow for the beach ridge in the Felton Prairie area explains the presence of the calcareous fens as well as the observed water features in the area (Figure 6).

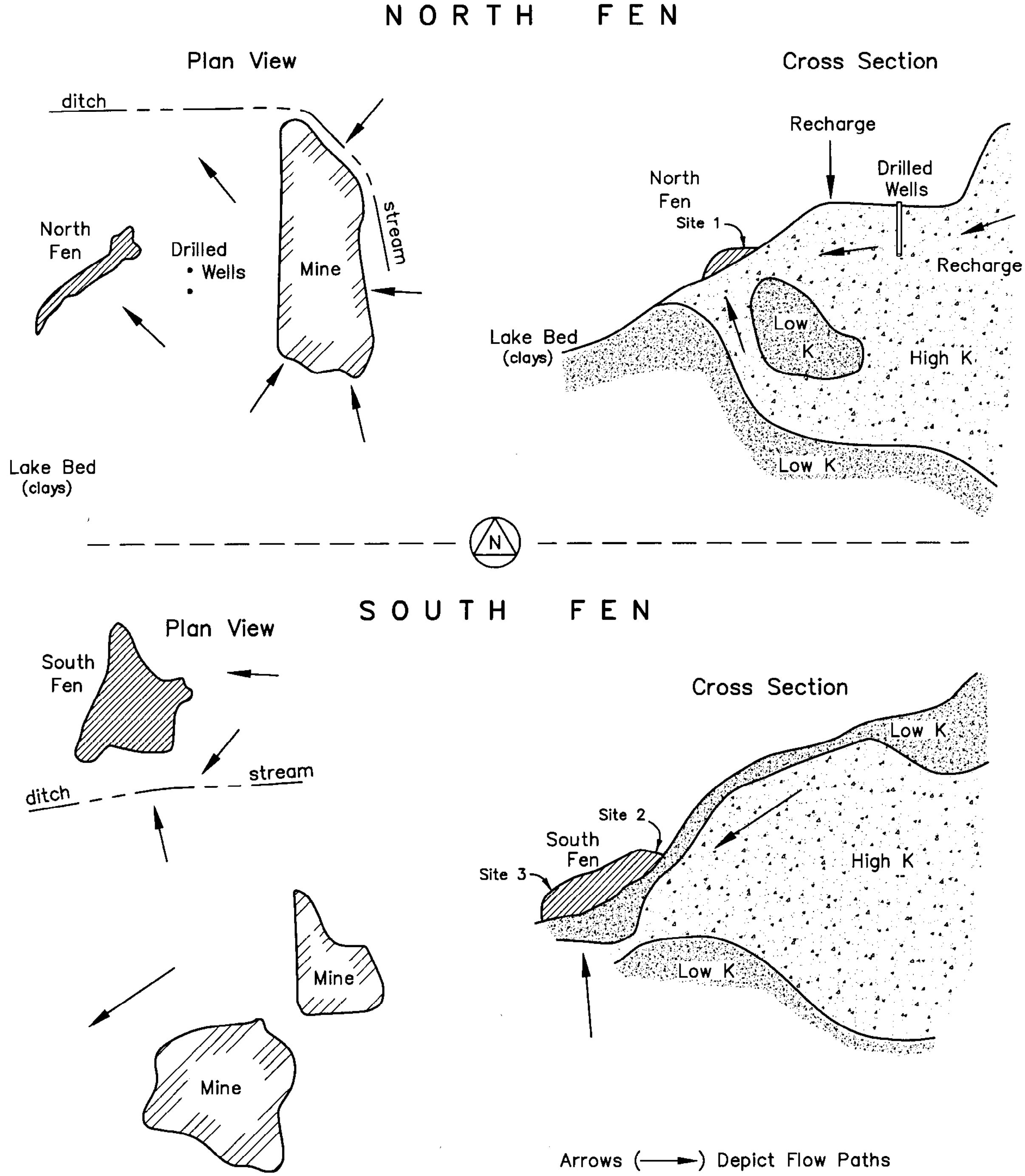
Three sources of ground water serve as input for the conceptual model.

1. Ground water in the topographically higher area east of the Felton complex. For example, the numerous wetlands were assumed to be water table outcrops, and the upgradient stream network was used to represent upgradient ground water levels. Serving to support these assumptions, a topographic survey of the eastern ephemeral stream revealed numerous bank seepage sites and flowing water due to the seepage.
2. Recharge occurring from precipitation and snowmelt over the sandy, relatively flat portions of the Felton Prairie.
3. Recharge from the losing portions of small streams that cross the sandy, relatively flat portions of the area.

Ground water discharge in the subsurface is limited on the downhill side of the beach ridge by very low permeability lakebed clays. Upwelling of ground water in response to occlusion of ground water flowpaths by these clays is documented by the presence of the fens and at least 2 flowing wells within 1.5 miles of the fens. Other ground water discharge occurs along the gaining portions of the streams (now ditched in the lower reaches) that flow off the slope of the ridge, and through evapotranspiration in the sloping wetlands and wet meadows where the water table is at or within a few feet of the ground surface.

Ground water levels have been measured in wells in the Felton Prairie Area for varying periods of record (Table 1). These water level measurements confirmed the assumptions of the conceptual model as follows:

Figure 6: Conceptual Model of Ground Water Flow at Felton Fen



– The well nest in the sandy, relatively flat area between the State Trust Fund pit and the North Fen revealed recharging conditions (Figure 7).

– The Site 1 well nest in the North Fen itself revealed moderately upwelling conditions (Figure 8).

– The water level measurements in the South Intermediate well nest shows minor upwelling (Figure 9).

– The Site 2 well nest in the South Fen revealed strongly upwelling conditions (Figure 10).

– The generalized head gradient from east to west across the area is documented by decreasing water levels from east to west (Figure 11).

Pre-mining and Existing Conditions

Preceding mining scenario flow net assembly, pre-mining and existing condition flow nets were constructed to provide insight into the affects associated with excavation of the existing pits, particularly the Trust Fund pit. Once an understanding of the mechanisms responsible for the existing conditions was achieved, hypotheses were developed to address the mining alternatives.

Because of the expanding nature of the study's objectives, wells were added throughout the entire study period. As a result, the period of record containing the entire suite of monitoring wells is short. Due to this limitation, two data sets of water level elevations were selected for analysis, one to represent relatively dry conditions, and one to represent relatively wet conditions (Figures 12 and 13, respectively).

A map of pre-mining water table conditions (Figure 14) was constructed using evidence from older topographic maps, older aerial photographs, and geologic logs from the rotosonic drilling project. Wetlands and streams were more extensive prior to mining and ditching; these points represented surface expressions of the premining water table. The rotosonic logs discussed above provided further confirmation of higher historic water levels.

Similar data collected since 1995 compiled with observed water levels were used to construct more comprehensive maps (Figure 15) of existing conditions (than provided by Figures 12 and 13).

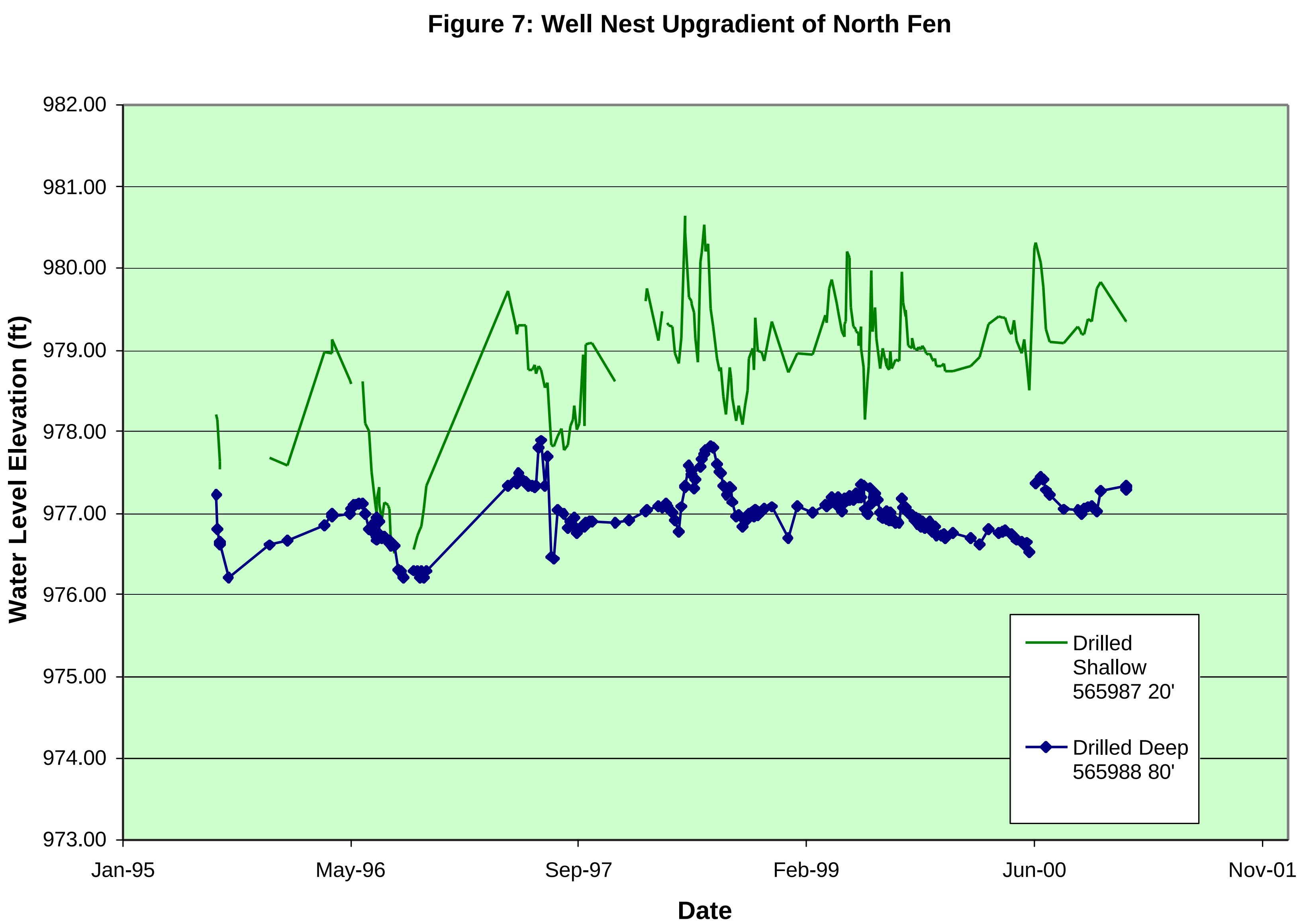


Figure 7: Well Nest Upgradient of North Fen
Water Level Elevation (ft)
982.00
981.00
980.00
979.00
978.00
977.00
976.00
975.00
974.00
973.00
Jan-95
May-96
Sep-97
Feb-99
Jun-00
Nov-01
Date
Drilled Shallow 565987 20'
Drilled Deep 565988 80'

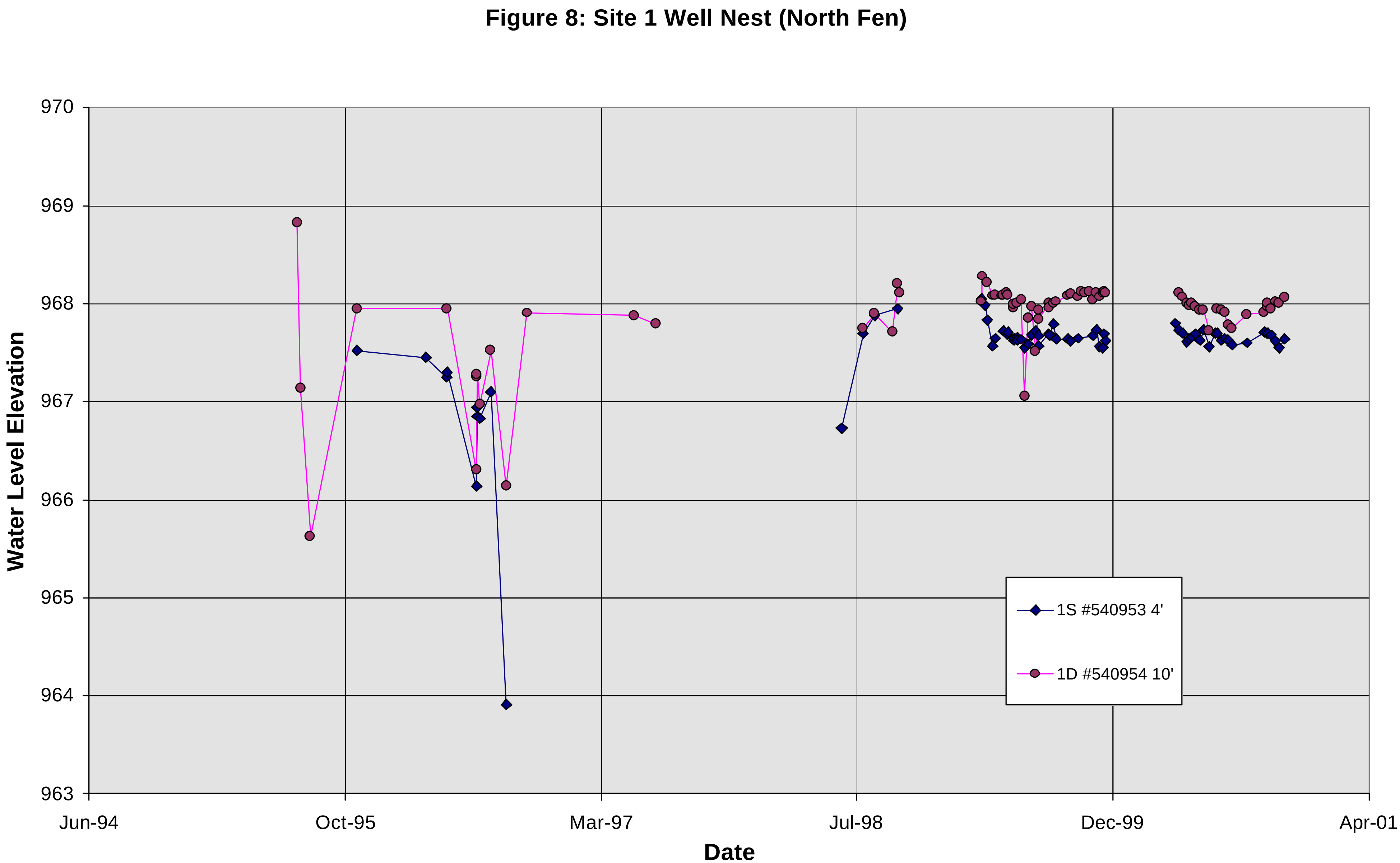


Figure 8: Site 1 Well Nest (North Fen)
Water Level Elevation
970
969
968
967
966
965
964
963
Jun-94
Oct-95
Mar-97
Jul-98
Dec-99
Apr-01
Date
1S #540953 4'
1D #540954 10'

Figure 9: South Intermediate Well Nest (591798 and 626490)

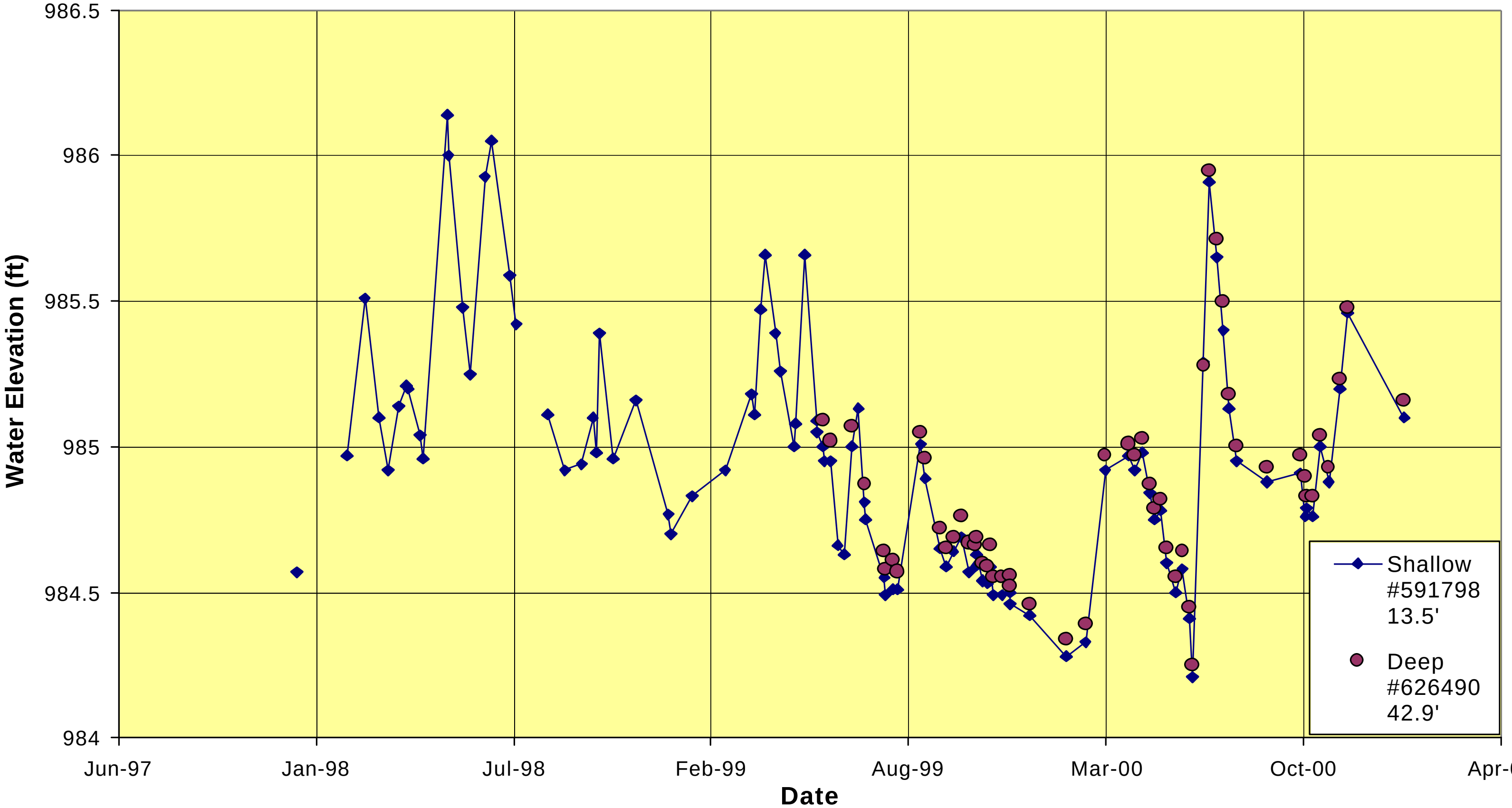


Figure 10: Site 2, East Edge of South Fen

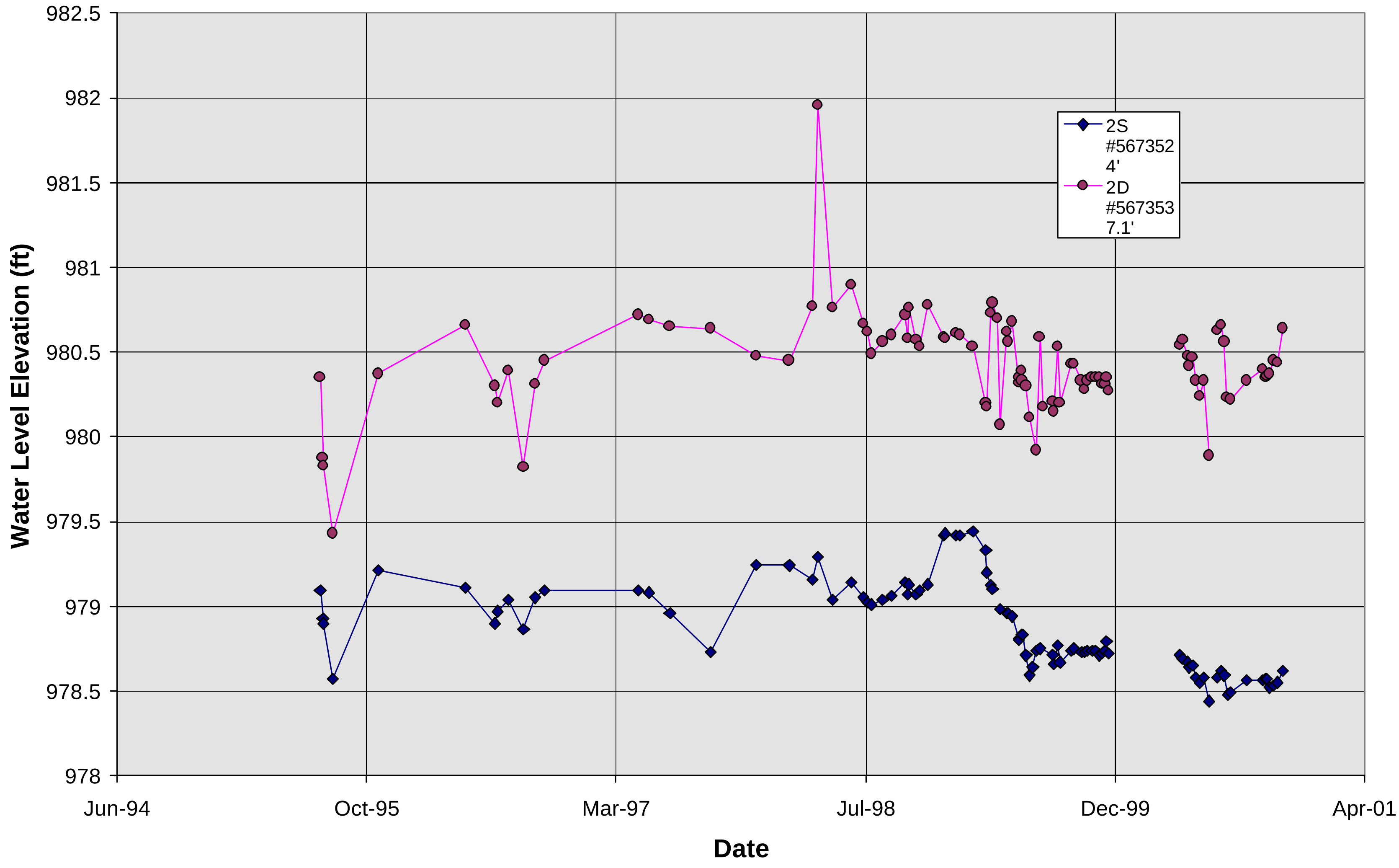
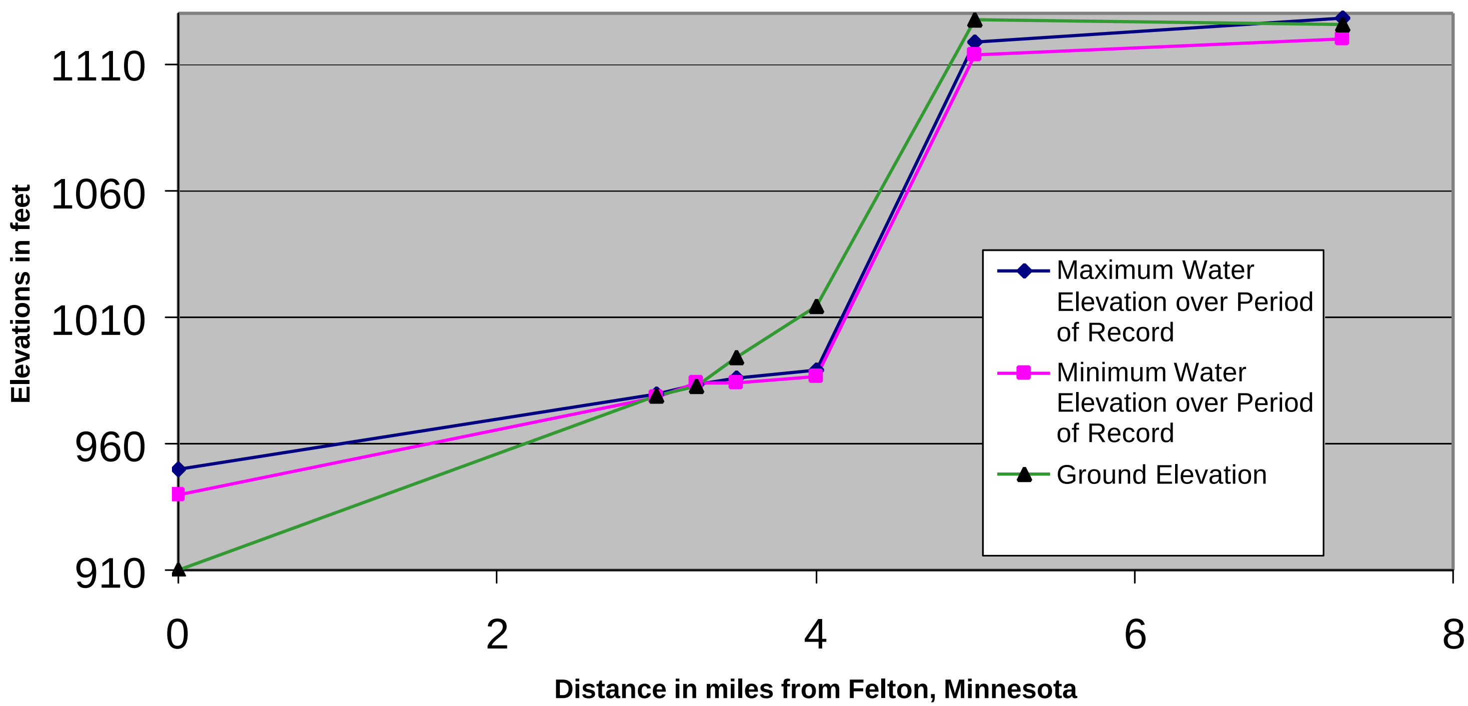
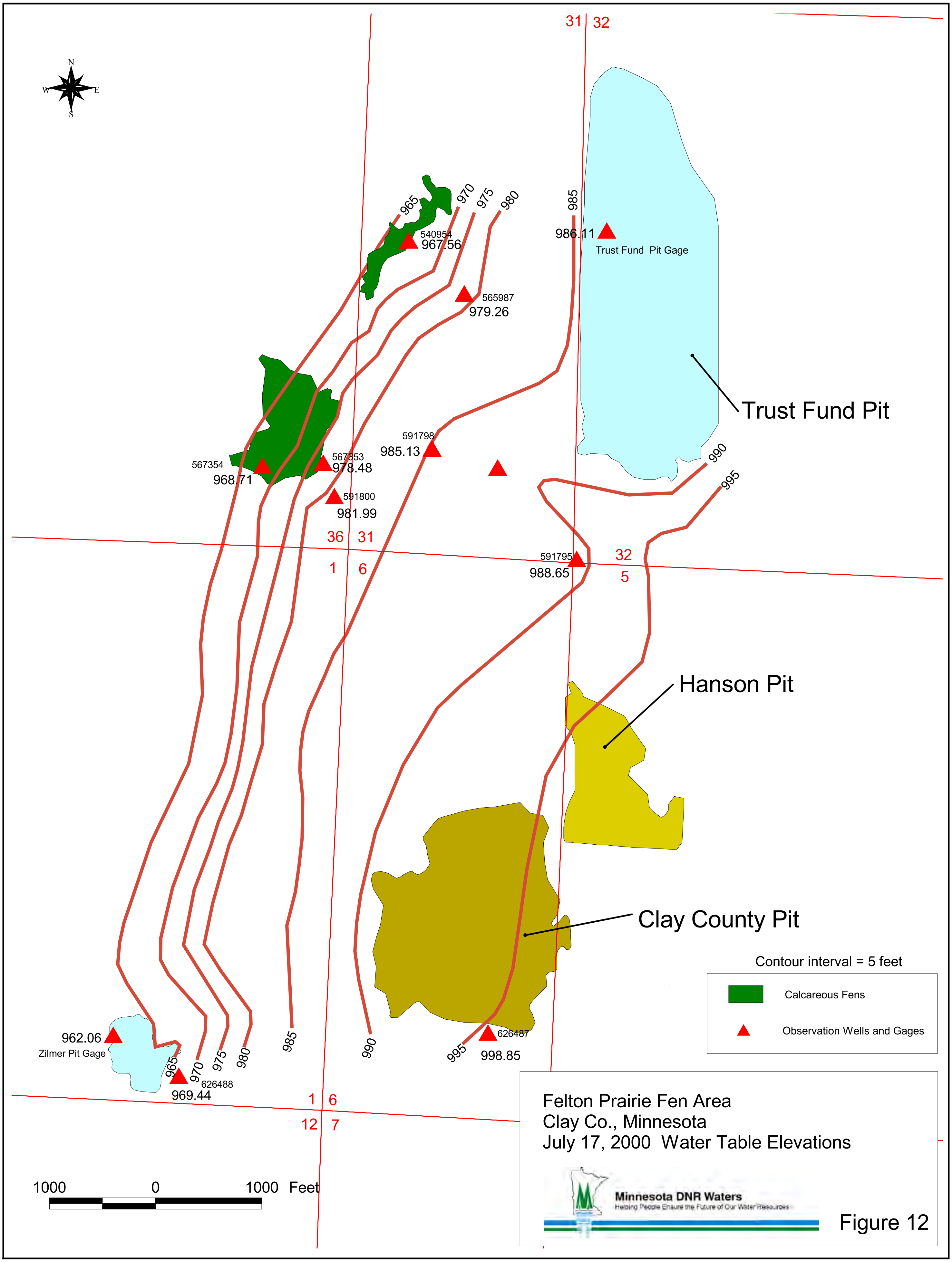


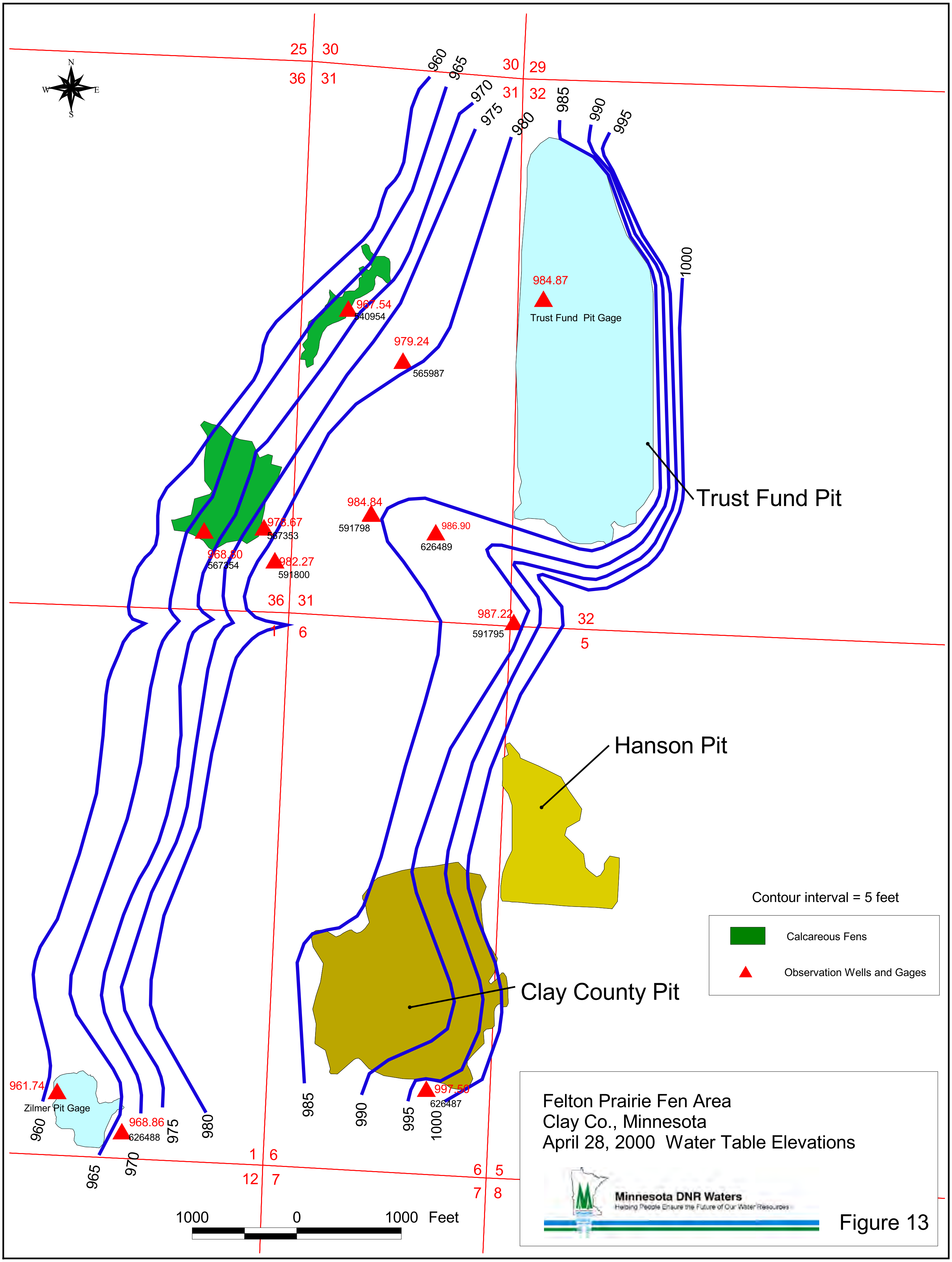
Figure 11: Ground and Water Level Elevations
on a transect across the beach ridge east of Felton





Felton Prairie Fen Area
Clay Co., Minnesota
July 17, 2000 Water Table Elevations

Figure 12


Felton Prairie Fen Area
Clay Co., Minnesota
April 28, 2000 Water Table Elevations
Trust Fund Pit
Hanson Pit
Clay County Pit
Contour interval = 5 feet
Calcareous Fens
Observation Wells and Gages
984.87
Trust Fund Pit Gage
967.54
540954
979.24
565987
984.84
591798
986.90
626489
976.67
567353
968.80
567354
982.27
591800
987.22
591795
997.50
626487
961.74
Zilmer Pit Gage
968.86
626488
960
965
970
975
980
985
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36
31
29
32
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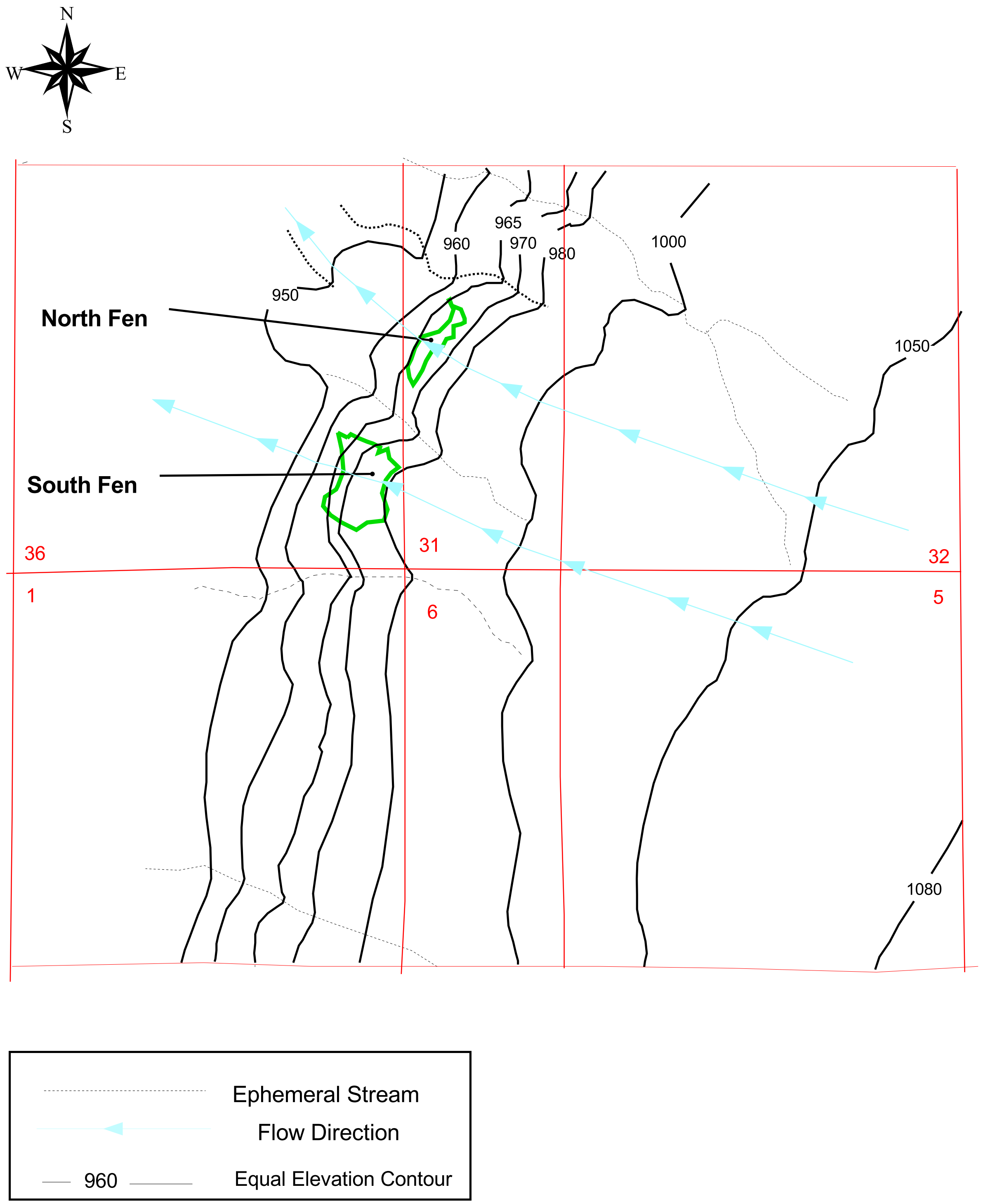
Figure 13



Felton Prarie Fen Area
Clay County, Minnesota
Pre-mining Conditions

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Figure 14

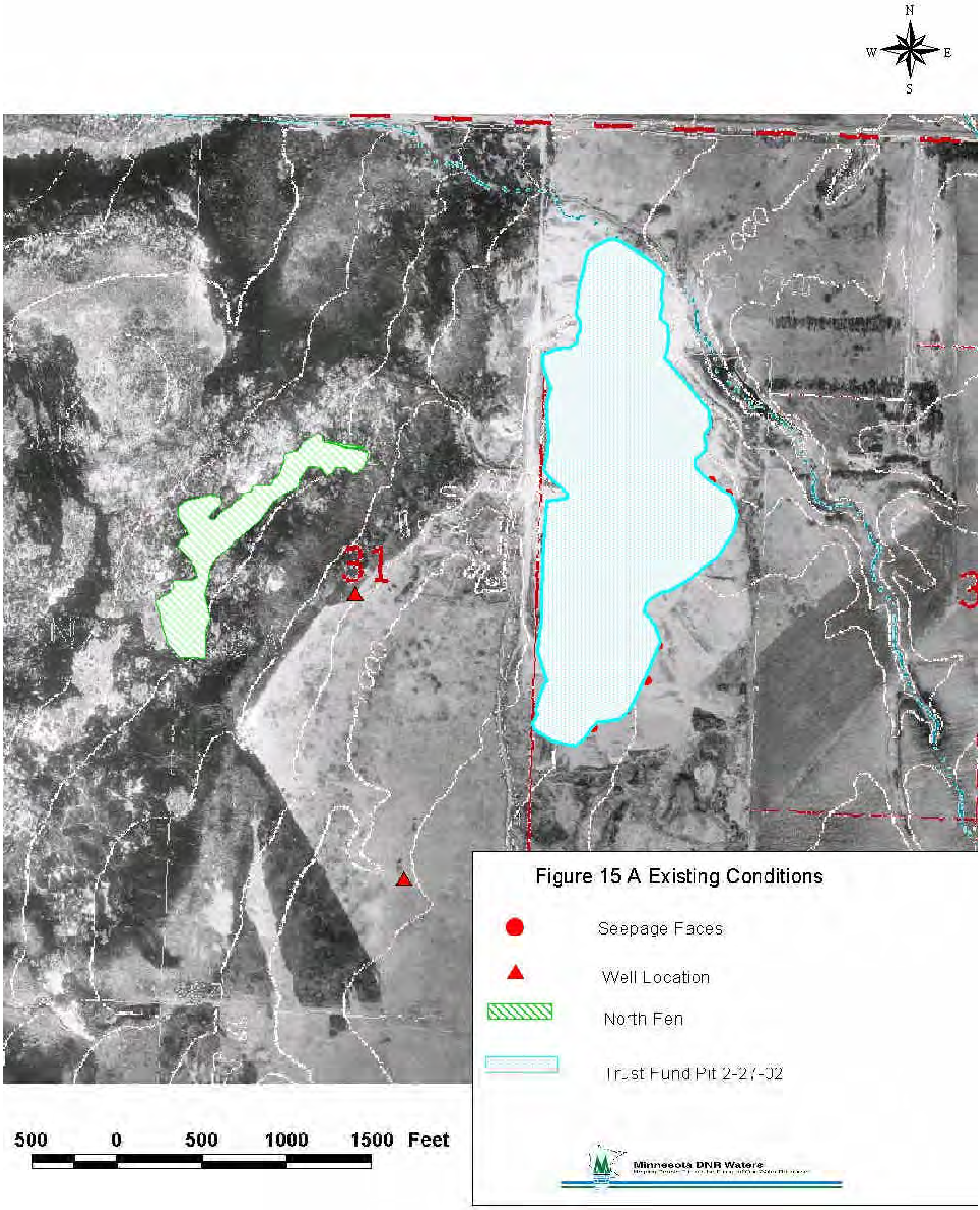


Figure 15 A Existing Conditions

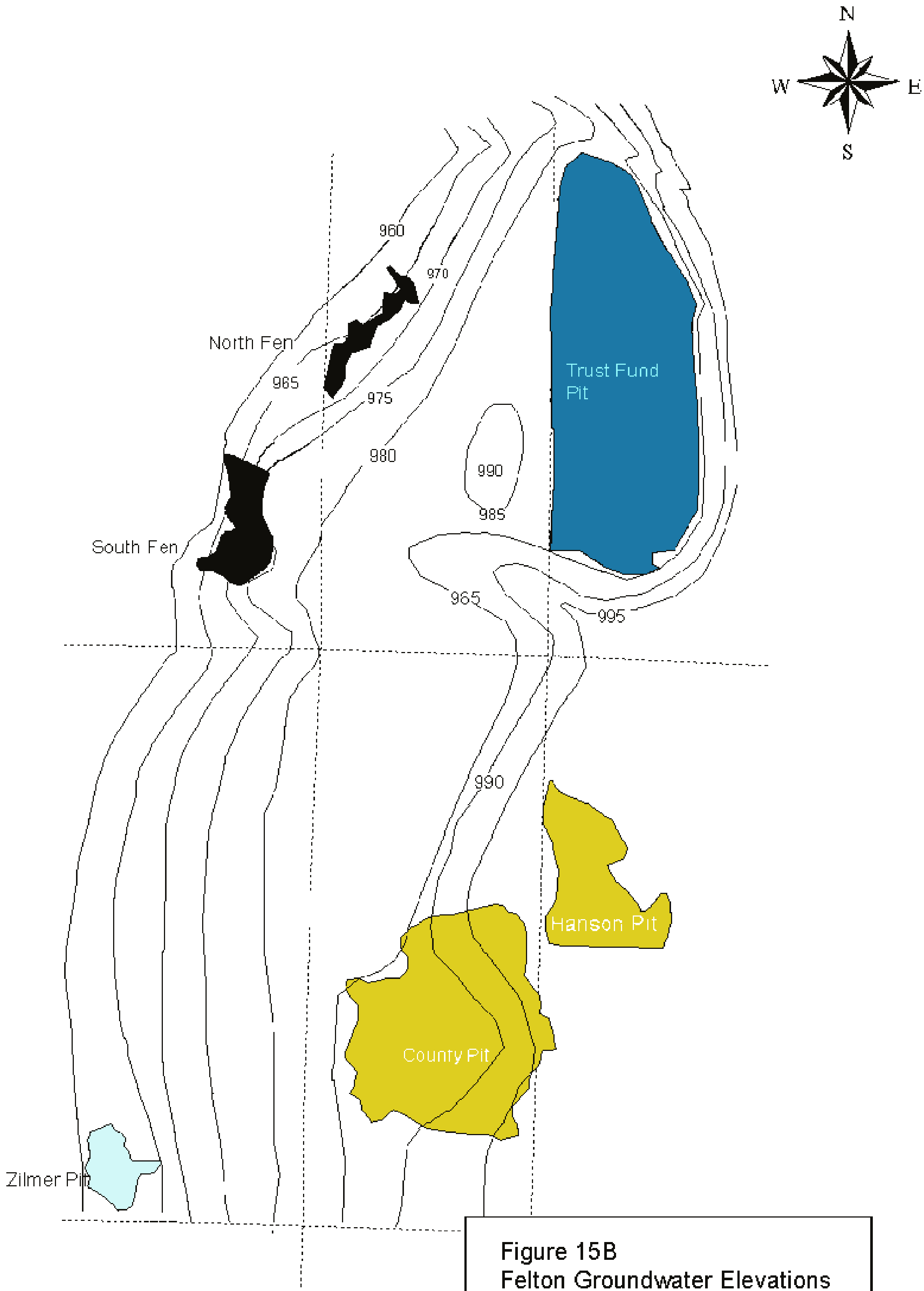


Figure 15B
Felton Groundwater Elevations

Minnesota DNR Waters

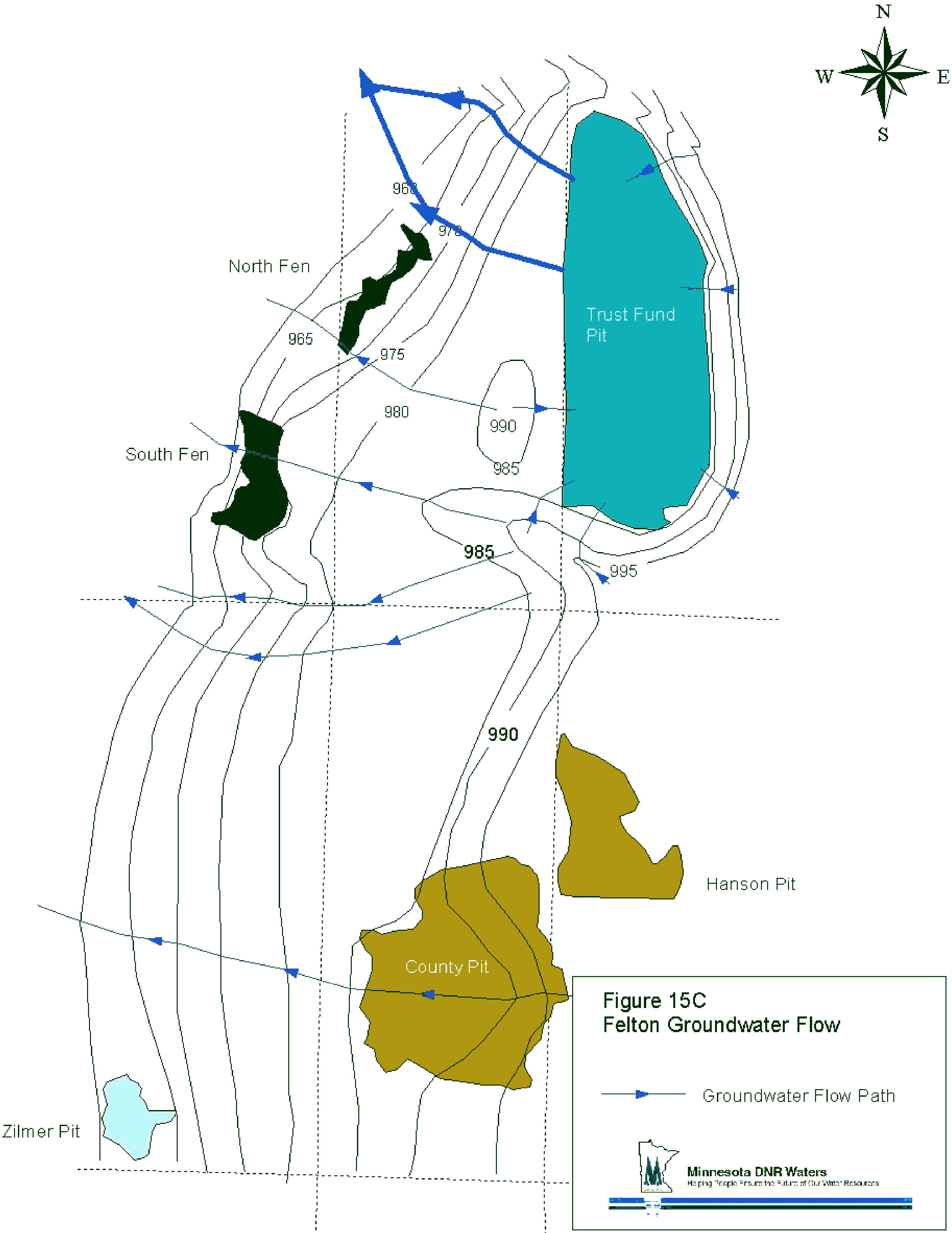


Figure 15C
Felton Groundwater Flow

Important points gleaned from a comparison of premining and existing conditions:

1. The ground water surface slope has become quite steep immediately up gradient of the Trust Fund and County pits. Data indicate that ground water levels now drop approximately 21 feet over 790 feet (140 ft/mile) between the eastern ephemeral stream and the southern portion of the Trust Fund Pit. The steep groundwater slope up gradient of the pits is likely due to the steep excavated faces surrounding the pits and the loss of soil matrix within the pits.

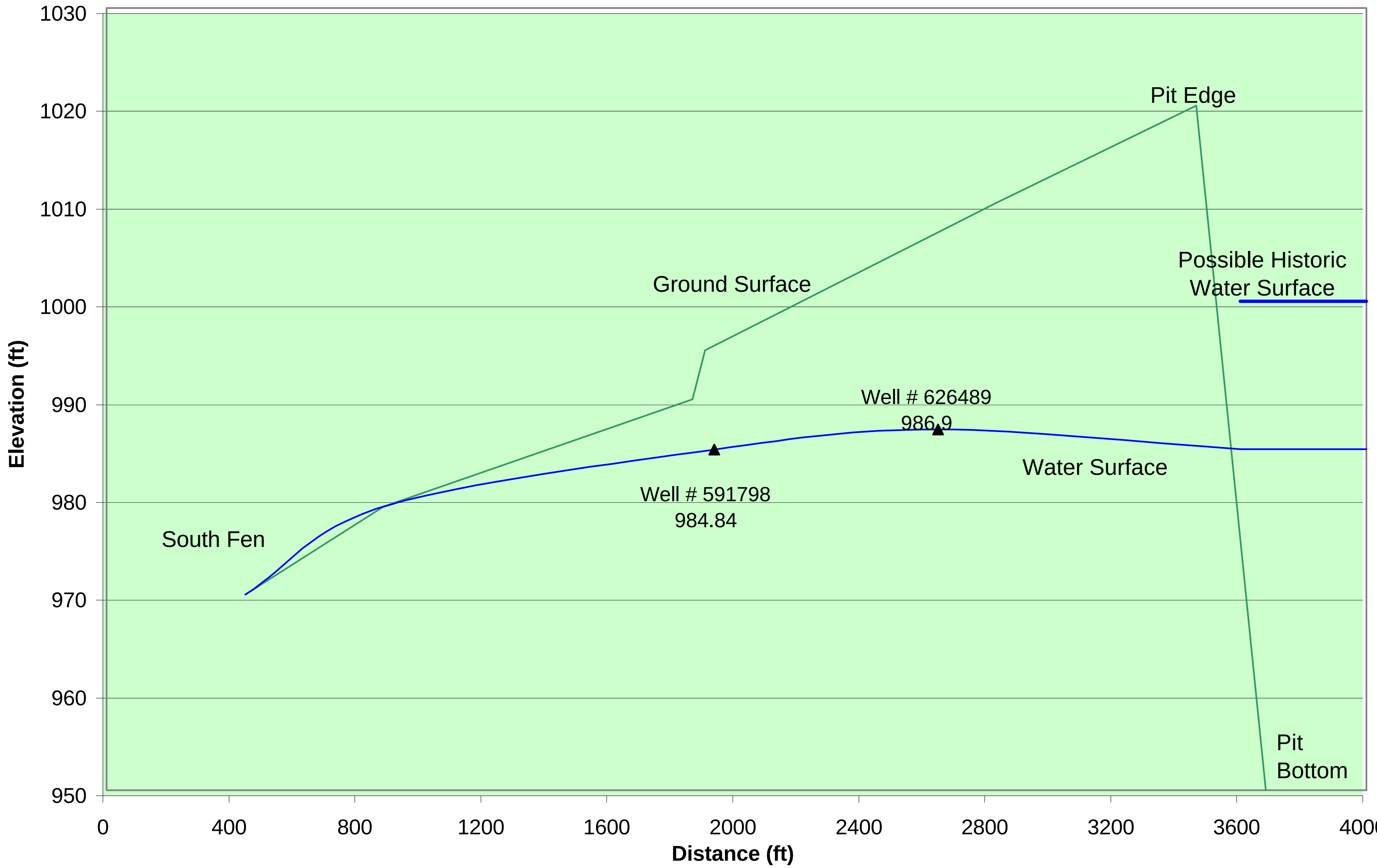
2. Along with the vastly different hydraulic conductivity of an open water body versus the surrounding media, the steep gravel pit faces induce a change in flow direction along the south and east faces of both pits and the north face of the County pit. Flow paths are greatly warped in certain places such as the south face of the Trust Fund pit where an elongated, 'nose' shaped structure is created in the ground water surface elevations due to the flow interception and redirection by the Trust Fund and open water face.

3. Due to the "nose" described in number 2 above, a substantial amount of the ground water that would have intersected the North Fen has been redirected into the Trust Fund Pit, robbing the North Fen of approximately half of its pre-gravel-pit ground watershed.

4. A ground water mound has been established between the Trust Fund pit and the South Fen. Ground water flow interruption by mounds has been described previously (Rosenberry and Winter, 1997). Displaying the mound between the Trust Fund pit and the South Fen, Figure 16 presents groundwater elevations between these locations. Because of the recharge between the Trust Fund Pit and the North Fen and the highly permeable soils, it is likely that the mound extends northward between the Trust Fund Pit and the North Fen. Due to the mounding effect, water that was originally supplied to the North Fen is now being blocked by the mound and directed to the pit. Only a small portion of the North Fen's pre-gravel-pit era ground watershed remains (Figure 15c).

5. A hydraulic gradient of approximately 100 ft./mile exists north of the Trust Fund Pit and along the south County Road 34 ditch. This is a very substantial gradient that directs ground water northward through the open water pit area and westward along the south County Road 34 ditch. Increases in the level of the water table along this corridor since 1995 has been documented in field notes by clear evidence on the landscape. The effect of this is to pull water away from the North Fen. It also sets up the potential for piping and dike failure if the private 40-acre tract between the Trust Fund pit and County Road 34 is mined. Extreme caution and

Figure 16: Water Elevation between the State Trust Fund Pit and the South Fen



protective steps must be taken if mining continues northward to County Road 34. The potential for catastrophic drainage of the gravel pit exists. Further water surface elevation reductions in the gravel pit would certainly have substantial negative impacts on the North Fen, and possibly on the South Fen.

6. Excavation of the pit has caused water levels to decline measurably in the immediate vicinity and down gradient. Originally, water coming off the beach ridge flowed northwesterly perpendicular to the ridge toward the fens. After the Trust Fund pit was excavated, the preferential flow paths near the pit were redirected toward the pit; some of the water that originally flowed toward the fens has been routed to the pits and thence to the stream and/or the wetland to the northwest. In essence, the pits altered ground water flow from the naturally occurring parallel northwestern flow lines to radial flow towards the pits. Evaporation from the gravel pit lake is also greater than evapotranspiration from the dry prairie, causing additional water table depression

7. The regional effect of the gravel pits, particularly the Trust Fund pit, is to pull the ground water level contours eastward and up gradient, thereby reducing the hydraulic head available beneath the fens by approximately 15 feet. This is an important phenomenon to recognize as mining scenarios begin excavation into the ground water along the beach ridge area.

Mining Scenarios

During the course of the FSC's considerations of future gravel mining on Clay County administered lands, it became apparent to them that activities on some of the County's land had potential to impact the calcareous fens. As a result, the FSC asked DNR Waters to address potential fen impacts under seven mining scenarios. Traditional ground water flow nets were constructed for each of the scenarios (Freeze and Cherry 1979). Along with the mining scenario components, Table 3 displays DNR Waters' impacts analysis and recommendations.

Impacts of Water Appropriation from the Trust Fund Pit

DNR Water Appropriation Permit 81-1291 and a Trust Fund lease allowing withdrawal of water for major crop irrigation from the Trust Fund pit(s) was issued in 1981 and transferred to new leaseholders in 1995. The permit allowed withdrawal of up to 430 acre-feet of water each year over the 5-month agricultural irrigation season. The presence and significance of the nearby calcareous fen was initially not known to the permitting and leasing authorities.

In 1981 the area of open water at the pit was about 9 acres and the pit was about 40 feet deep. The total permitted volume could be represented by a daily drop in the level of the pond of 4 inches, which dwarfs the daily evapotranspiration of 0.15 to 0.3 inches per day in the Felton area (Figure 5). Over the first decade of this operation, the average amount pumped in a given month of pumping was 52 acre-feet, or about 2.5 inches per day over the pond area, which still is about an order of magnitude more than evapotranspiration. Of course the pond was continually refilled from water flowing in from the adjacent gravel in response to the lowered water level in the pond, and this propagates the impact of the withdrawal preferentially downgradient, resulting in some decrease in ground water discharging at the North Fen. Recall that in healthy fens the daily maximum rate of evapotranspiration is in approximate balanced with groundwater discharge and that any decrease, especially during the growing season is likely to have negative impacts.

Over time the pond area was expanded and the area of high-permeability material (gravel and sand deposits) decreased as mining continued. By 1995, when the appropriation permit was transferred, the pond area totaled 33 acres. Management under the new leaseholder has been less intense, requiring pumping in only four of the 30 months during which pumping would have been allowed, and averaging only 19 acre-feet in each of those four months (Figure 17).

Monitoring data where pumping and water level collection coincide are very sparse because very little pumping has been done under the management of the new leaseholder. Even so, it is apparent (Figure 18) that pumping of water from the Trust Fund pit can decrease water levels between the pit and the North Fen and thus pumping will decrease the amount of ground water discharging at the fen.

Table 3: Mining Scenarios

	County Pit	Trust Fund Pit	Private Land (Hanson Bro's)	Fen Impacts	Other Questions/Comments
Ia.	Mine only within the current footprint of the pit Mine deep, into the water table to remove all gravel	Mine only within the current footprint of the pit Mine deep, into the water table to remove the remaining dikes and other material	Leave as is	Water levels have already dropped in N fen Some loss of head at S fen Most of impact already in place Don't want to increase connection of Aggregate. Ind. Pit to drainage channel to N.	
Ib.	Mine only within the current footprint of the pit Mine deep, into the water table to remove all gravel	Mine only within the current footprint of the pit Mine deep, into the water table to remove the remaining dikes and other material Aggregate Industries expands N onto private land	Leave as is	Water levels have already dropped in N fen Some additional loss of head at S fen Risks dropping water levels in pit due to leakage to road ditch along south side of County Road 34 that could result in dropping heads under both fens.	
Ic.	Mine only within the current footprint of the pit Mine deep, into the water table to remove all gravel	Mine only within the current footprint of the pit Mine deep, into the water table to remove the remaining dikes and other material	Mine up to the current permitted area (40 ac) Mine dry, stay above the water table	Water levels have already dropped in N fen Expect increased loss of head at S fen Risks additional leakage to road ditch along south side of County Road 34 that could result in dropping heads under both fens.	☒ *Does the depth of mining make any difference in the model (above and below the water table)?* *Must stay 5-10 above the highest water table on the entire site to avoid changing gw flow patterns*
II a.	Mine deep, into the water table to remove all gravel.	Mine only within the current footprint of the pit Mine deep, into the water table to remove the remaining dikes and other material	Mine up to the current permitted area (40 ac) Mine dry, stay above the water table	NW1/4 of BC SNA strongly redirects flowpaths, causing additional impacts to S fen recharge area	☒ *Does mining south under the water table make any difference in the model?* *No detectable difference at fens* ☒ *Would expanding the County Pit to include the NW¼ of Bicentennial make any difference in the model?* *Yes, impacts S fen even if only mined to gw table.*

	County Pit	Trust Fund Pit	Private Land (Hanson Bro's)	Fen Impacts	Other Questions/Comments
II b.	Expand the pit northward up to the haul road, and south to the property line Mine deep, into the water table to remove all gravel.	Mine only within the current footprint of the pit Mine deep, into the water table to remove the remaining dikes and other material	Mine up to the current permitted area (40 ac) Mine dry, stay above the water table	South fen impacted due to diversion of regional flow as Co. pit expands N. NW1/4 of BC SNA further redirects flowpaths, causing additional impacts to S fen recharge area	☒ *Does mining south under the water table make any difference in the model?* *No detectable difference at fens* ☒ *Would expanding the CountyPit to include the NW¼ of Bicentennial make any difference in the model?* *Yes, impacts S fen even if only mined to gw table.*
III.	Expand the pit northward up to the haul road, and south to the property line Mine deep, into the water table to remove all gravel.	Expand the pit southward to the property line, except for the SE corner of this 40 which has been determined not to have gravel and set aside for prairie preservation. Mine deep, into the water table to remove the remaining dikes and other material	Mine up to the current permitted area (40 ac) Mine dry, stay above the water table	Water levels in both N and S fens drop. Much of fens' water supply diverted	☒ *Would reclamation activities make any difference in the model? For example, what if the pit was filled/reclaimed as we mined* Strategically-placed fill can help prevent the loss of head out thenorth end of the Trust Fund Pooland perhaps change the locationof the stagnation point to encourageground water flow to the fens.
IV.	Expand the pit northward up to the haul road, and south to the property line Mine dry, above the water table	Mine only within the current footprint of the pit Mine deep, into the water table to remove the remaining dikes and other material	Mine northward up to the property line (up to 80 acres) Mine dry, stay above the water table	Diverts water from S fen. Destroys prairie resource and impacts water supply to fens without recovering all of the mineable resource	☒ *Expansion of the private pit > 40 ac would require a new permit and likely an EAW*
V.	Expand the pit northward up to the haul road, and south to the property line Mine deep, into the water table to remove all gravel.	Expand the pit southward to the property line, except for the SE corner of this 40 which has been determined not to have gravel and set aside for prairie preservation. Mine deep, into the water table to remove the remaining dikes and other material	Mine up to the north property boundary (~80 ac) Mine deep, into the water table to remove all the gravel	All of regional flow diverted from fens; only local recharge remains to supply them. Water levels in both fens drop.	☒ *Results in a continuous 'lake' from the Trust Fund pitdown to the County Pit* A continuous 'lake' is incompatible with the continuing existence of the fens. ☒ *Would reclamation activitiesmake any difference in the model? For example, what if the pit was filled/reclaimed as we mined* *Some reclamation activities would assist in maintaining water flow through the system. But asignificant amount of fill isrequired.*

	County Pit	Trust Fund Pit	Private Land (Hanson Bro's)	Fen Impacts	Other Questions/Comments
VI.	Expand the pit northward to include all County property with gravel potential, and south to the property line Mine dry, above the water table	Mine only within the current footprint of the pit Mine deep, into the water table to remove the remaining dikes and other material	Mine up to the current permitted area (40 ac) Mine dry, stay above the water table	Entire direct recharge area impacted Creates risks to both the S and N fens above those of Scenario I Water quality and water level impacts are predicted	
VII.	Mine only within the current footprint of the pit Mine dry, stay above the water table	Expand the pit to the west to include the area identified with high gravel potential, and which had been disturbed in the past. Mine deep, into the water table to remove the remaining dikes and other material	Mine up to the current permitted area (40 ac) Mine dry, stay above the water table	A major portion of the S fen's water supply diverted. North fen may receive water of different chemical or thermal quality. Water levels drop below ground surface at N fen.	

[Note: If mining 'dry' (above the water table) has no impact on the fen, then scenarios IV & VI are essentially the same.]

Figure 17: Millions of Gallons Pumped and Precipitation Cumulative Departure

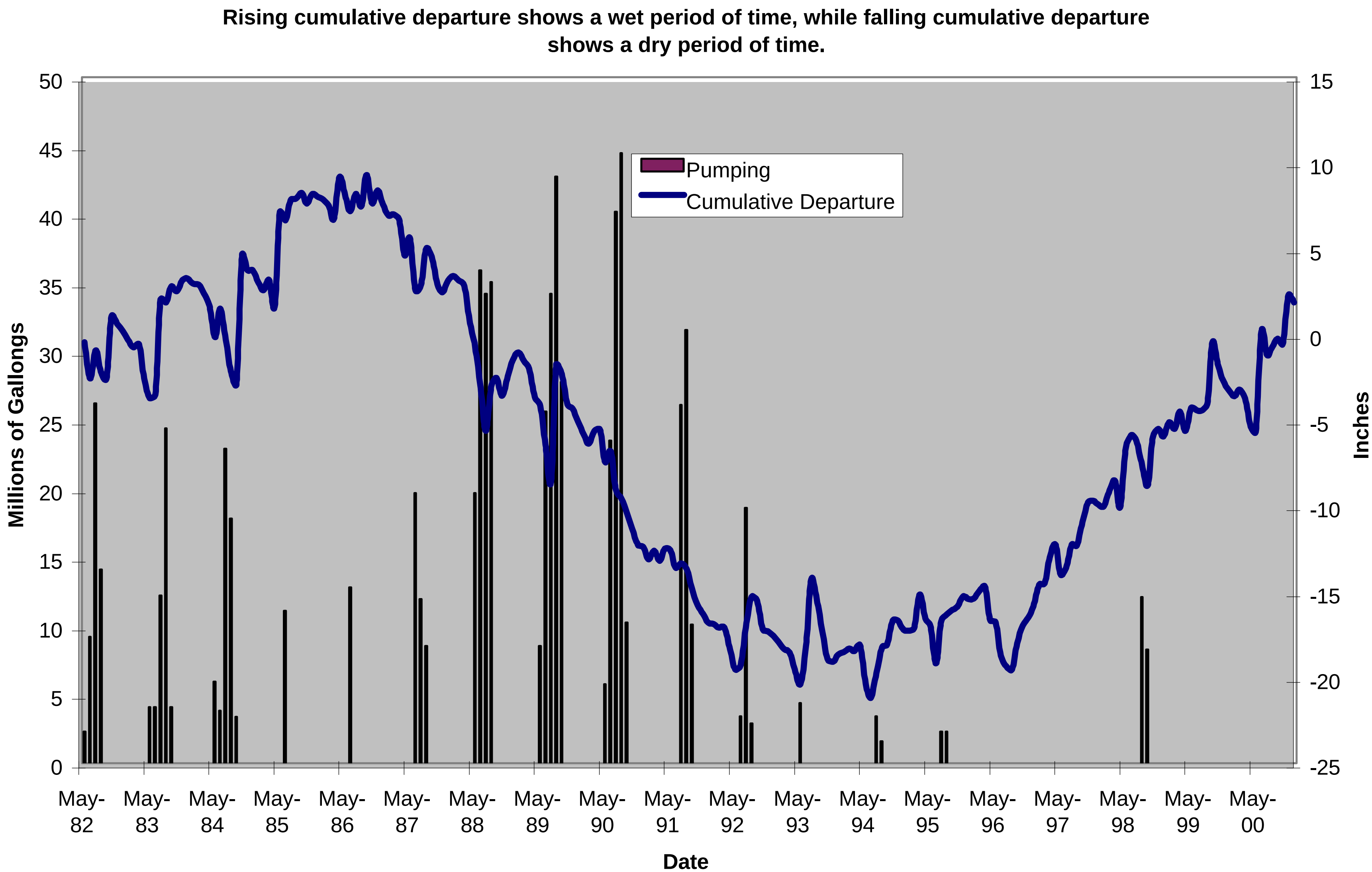
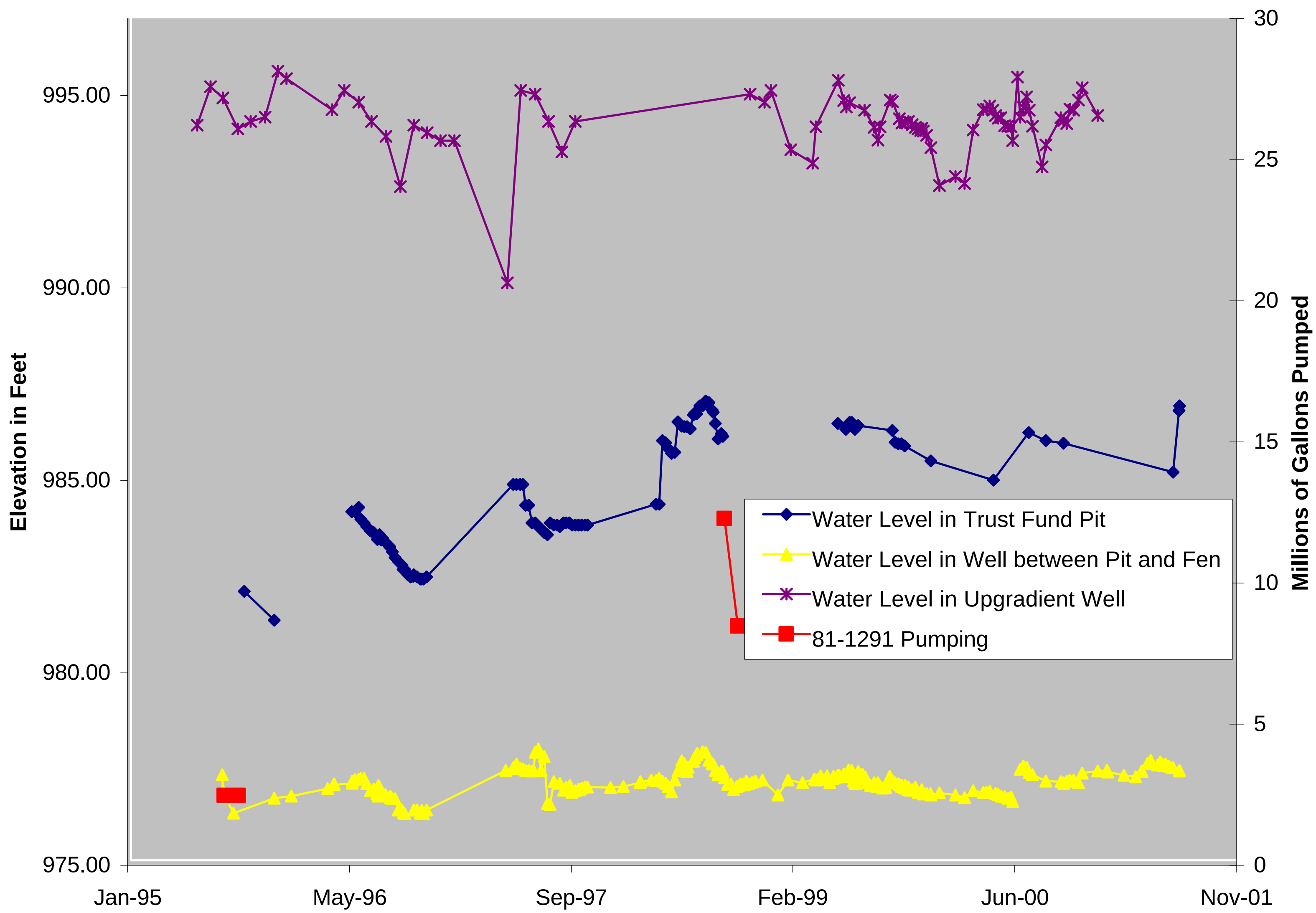


Figure 18: Pit Water Level, Well Water Levels, and Pumping



Conclusion

Analysis of pre-existing and existing ground water table conditions in the Felton Prairie area was conducted to provide the framework for prediction of potential deleterious effects two calcareous fens might suffer from seven mining scenarios postulated by the Felton Prairie Stewardship Committee. Important results of the analysis are:

- The State Trust Fund pit has radically altered flow paths. Flow paths near the gravel pit were distorted from parallel northwest trending lines perpendicular to the beach ridge to radial flow towards the pit along its south and western borders. It is assumed that this phenomenon will be replicated under future mining below the ground water table.
- Due to the vertical pit walls and loss of soil matrix, water levels east, up gradient, of gravel pits at or near the water table elevation are quite steep. Ground water levels near the eastern edge of the Trust Fund pit drop approximately 21 feet over 790 feet.
- The regional effect due to excavation below the groundwater table in gravel pits is a decline in ground water levels by up to approximately 15 feet. Water levels are being pulled eastward, away from the fens. It appears that this phenomenon has eliminated a major portion of the northerly fen’s ground watershed. To a lesser degree negative impacts are also displayed at the southern fen.
- Along the north end of the Felton Prairie complex, a steep ground water gradient has developed along the south Clay County Highway 34 road ditch. Extreme caution must be taken to ensure that bank failure and substantial drawdown of the Trust Fund pool does not occur when a private, 40 acre, tract is excavated north of the Trust Fund pit.
- Every effort should be made to ensure that gravel mining does not occur at or near ground water elevations between the Trust Fund pit and the Clay County pit south of the Trust Fund pit. Additionally, expansion of the Clay County and Trust fund pits eastward near the unmined area between the pits will likely exacerbate the ground water level declines.
- Water appropriation from the gravel pits has the potential to reduce the ground water upwelling at the fens and thus also has the potential to cause degradation of the fens.

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