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REVIEWS AND ANALYSES

Managing Nitrogen for Water Quality—Lessons from Management Systems Evaluation Area

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ABSTRACT

The Management Systems Evaluation Area (MSEA) project was initiated in 1990 to evaluate existing and develop new N management technologies to reduce the potential adverse impacts of agricultural practices on surface and ground water quality. Field research sites were established in nine Midwestern states. Results from MSEA research showed that nitrate leaching was greatly reduced by changing from furrow to sprinkler irrigation. At least 95% of the nitrate N percolating through tiled soils was intercepted and discharged into surface waters. Computer models indicated that routing tile discharge through wetlands would greatly reduce the nitrate load. Nitrate losses also were reduced by establishing controlled water tables using drainage lines for subirrigation. Preplant and presidedress soil nitrate tests were effective in determining proper N fertilizer rates and reducing nitrate losses. Banding ammoniated fertilizers slowed nitrification rates and nitrate leaching, especially if soil over the bands was packed. A major new technology was proof that crop greenness can be used to monitor crop N sufficiency, and that N deficiencies after the V8 stage can be corrected by sidedressing or fertigation (reactive N management). Inexpensive sensors or aerial photographs can be used to assess crop greenness. Using Global Positioning Systems (GPS), N–deficient areas of the field can be managed differently from the remainder of the field. These results point to the need to develop site-specific or precision farming systems to control nitrate losses to water resources and reduce the impact of natural variability in both soils and weather.

THE MSEA projects discussed in this paper were initiated in response to the 1989 Presidential Water Quality Initiative, enacted by the U.S. Congress. The initiative was led by the U.S. Department of Agriculture to assess capabilities of present crop production technology and to develop improved technologies to control nitrate leaching from soils. The MSEA project, initiated in 1990, focused on the Corn Belt of the USA, with supplemental research on specific topics conducted at other locations. The primary goals of the MSEA program were to: (i) evaluate the distribution of agricultural chemicals in water resources and identify the factors that affect distribution, and (ii) develop new, improved, and acceptable agricultural management systems that enhance water quality (Onstad et al., 1991).

Five major sites were funded by USDA for five years to conduct research to evaluate the effectiveness of existing technologies and to develop new technologies that would lessen the nitrate pollution problem. The major sites were located in Ohio, Minnesota, Iowa, Missouri, and Nebraska (Fig. 1). At some locations satellite sites were also established to provide wider coverage, including sites in Kansas, North Dakota, South Dakota, and Wisconsin. This was the largest research and education effort ever organized in the USA to study this problem, led by the Agricultural Research Service and Cooperative Research, Extension, and Education Service of the U.S. Department of Agriculture. The MSEA project was cooperative with State Agricultural Experiment Stations in these states, as well as the USDA Federal

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Abbreviations: MSEA, Management Systems Evaluation Area; GPS, Global Positioning Systems; PPNT, preplant nitrogen test; PSNT, presidedress nitrogen test; GLEAMS, Ground water Loading Effects of Agricultural Management Systems; RZWQM, Root Zone Water Quality Model; NLEAP, Nitrate Leaching and Economic Analysis Package; SWAT, Soil and Water Assessment Tool.

Fig. 1. Location of MSEA research sites.

Extension Service and Natural Resources Conservation Service, the U.S. Geological Service, and the Environmental Protection Agency. Various other state and local agencies participated at many sites.

The purpose of this paper is to review the results of the N management research associated with the MSEA projects, which officially terminated in 1996. We discuss the capabilities of existing technology and the development of new technologies and practices for agricultural N management that resulted from these projects, and point out the direction of future research needed to follow up on this new information.

Managing fertilizer N inputs is a major factor in managing soil N availability and N losses to water resources. However, for the first 60 to 70 yr of the 20th century, we had no reliable soil tests to guide us in N fertilizer management (Nelson, 1987). About the only useful test for N availability was soil organic matter content. However, correlation coefficients between this parameter and N fertilizer response were usually only 0.5 to 0.7, suggesting only 25 to 50% accuracy in predicting soil N availability. This lack of a reliable soil test for soil N availability left agronomists with a challenge (Dahnke and Vasey, 1973; Meisinger, 1984; Keeney and Bremmer, 1996). Fortunately, within recent decades, major improvements in soil testing for N availability have been made.

About 35 yr ago, Professor Robert Olson and others at Nebraska (Olson et al., 1964) developed useable correlations between soil nitrate content to the 90 cm depth and crop response to N fertilization when soil samples were collected in the late fall or before planting in the spring. In higher rainfall regions, this approach had limited value because much nitrate leaching usually occurred during winter and spring months. In more recent years, Magdoff et al. (1984) and others found that workable correlations could be developed in humid climates if soils for nitrate analysis were sampled to the 30 to 60 cm within a few weeks before corn (*Zea mays* L.) planting (preplant nitrogen test—PPNT). Also, it was found that if only part of the N fertilizer requirement was applied at planting, the amount of additional fertilizer required later as a sidedressing could be predicted with reasonable accuracy from nitrate analysis of soil samples collected to the 60 to 90 cm depth before sidedressing (presidedress nitrogen test—PSNT). In later years the PPNT and PSNT techniques have been modified and calibrated to fit conditions prevailing in most Midwestern states, and now are used widely.

A major difficulty with the soil testing approach is that one must predict with acceptable accuracy both growing season weather and final crop yield at the time of applying the fertilizer. Historical records show great variation in both weather and crop yields from season to season, making prediction of either of them several months in advance unreliable. Because soil water is such an integral key in regulating soil microbial activity and subsequent N transformations and availability (Linn and Doran, 1984), inability to predict rainfall accurately during the coming crop season limits utility of soil N tests made prior to or shortly after planting. Because of this variability in weather between years and also variability of soils within a field, nitrate leaching still frequently occurs even when we use the best technology available. Kranz and Kanwar (1995) estimate that at least 70% of the nitrate N leached typically comes from less than 30% of a field. This problem will become more acute in future decades as increased world population will require greater crop yields, and presumably use of more added N in crop production enterprises. Thus, the need for additional research to address this problem is recognized.

ESTABLISHMENT OF MSEA PROJECTS

The MSEA project was conducted in the Midwestern USA because of the frequency of water quality problems in that region (Madison and Bennett, 1985). About

80% of the corn and soybeans [*Glycine max* (L.) Merr.] produced in the USA are grown in the Midwest, and over 50% of the fertilizer N used in the nation is applied in that region. Thus, the decision was made to focus this research project on the corn- and soybean-producing regions of the Midwest. However, some funding was also provided for additional research on specific topics or unique situations in other states.

The locations selected for the MSEA field research sites provide considerable diversity in conditions (Ward et al., 1994). The site in Ohio is characterized as being an alluvial river valley with a relative high water table in a humid climate. The Minnesota site was on a sandy outwash plain. Other sandy soil-shallow aquifer situations were studied in Wisconsin, North Dakota, and South Dakota. In Iowa sites selected included a tiled glacial till watershed, a tiled small plot research site, and field scale studies of nitrate leaching in deep loess soils. In Missouri the research concentrated on the fate of fertilizer N on clay-pan soils and watersheds. Research in Nebraska, and related research in Kansas, studied water and nitrate movement on irrigated alluvial soils. Collectively, these sites represented a good cross section of the soils on which crops are produced in the Corn Belt, especially those soils where a nitrate pollution problem is most likely to develop. Corn was the primary crop studied at all locations, grown both as continuous corn and in rotation with soybeans. In most instances, currently used production practices were compared with practices designed to improve the efficiency of use and conservation of N and water. Emphasis was placed on the impacts of these practices on crop yields and water quality. Frequently the effects of crop rotations, tillage practices, animal manures, and other such agricultural production practices were also evaluated. Most field studies were conducted 1991 through 1995. Observation wells were used at all sites to monitor the effects of the practices studied on water quality. Several lysimeter studies were also conducted. It is recognized that for many hydrological situations, there is little likelihood of observing significant effects on ground water quality within five years, when practices are modified.

RESULTS—LESSONS LEARNED FROM MSEA

Results obtained from MSEA research both verified information obtained from earlier research and provided knowledge on which to build new N management strategies. A number of these research results related to factors involved in N management are discussed in the following pages.

Water Management Practices Affecting Water Quality

The effects of a number of water management practices on nitrate movement and water quality were investigated at the different MSEA sites. These included irrigation practices, tile drainage, water table controls, terracing, and use of wetlands. Much of the irrigation research was conducted to evaluate the effects of conventional furrow, improved furrow (surge), and sprinkler irrigation on water use, nitrate leaching, N recovery by crops, and crop yield. Compared with conventional furrow irrigation, use of a center-pivot sprinkler in Nebraska reduced annual water application rate from 100 to 140 cm to about 25 to 40 cm, and provided much better water control while maintaining or improving crop yields (Watts and Schepers, 1995; Watts et al., 1998). As a consequence, nitrate movement below the root zone was likewise greatly reduced (Fig. 2). Effects of surge irrigation were intermediate between these other two treatments. Other irrigation research showed that nitrate leaching could be reduced for furrow irrigation by running irrigation water through every other furrow, rather than every furrow, and applying the N fertilizer in the nonirrigated furrow (Martin et al., 1995). Generally, any furrow irrigation technique studied failed to provide uniform depth of water and nitrate movement over the entire field.

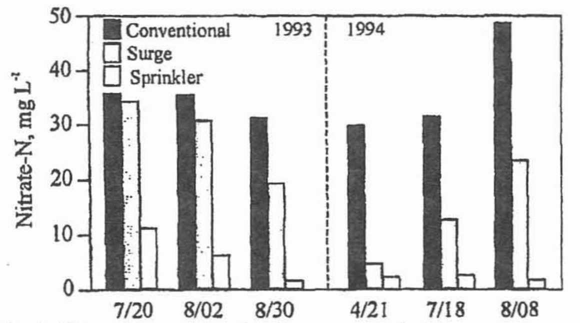

Fig. 2. Nitrate N concentrations in root zone drainage water at the Nebraska site under conventional, surge (modified furrow), and center pivot sprinkler irrigation (Watts and Schepers, 1995).

Approximately a third of the crop land in the Midwestern states of the USA is tile drained. Typically, tile drains are placed at least 1 m deep, with spacing between tile lines dictated by the permeability of the soil. Discharge from these tile lines is normally emptied into a surface water body, usually a drain ditch or natural stream. A well-designed tile drain intercepts at least 95% of the percolating water and nitrates and diverts most of this water through the tile line to the surface water body, carrying with it any nitrates dissolved in the percolating water (Hatfield et al., 1998). Thus, use of tile drainage converts potential ground water quality problems into potential surface water quality problems. The MSEA research results from Iowa showed that in some instances the equivalent of more than 100% of the fertilizer N applied could be accounted for in tile drainage discharge (Table 1). Thus, on a watershed ba-

Table 1. Loss of nitrate expressed as a fraction of that applied per subbasin for 1992–1994 (Jaynes et al., 1999).

Year	Subbasin no. 110	210	220	230	310	320	330
	Nitrate N loss (%)						
1992	0.15	0.12†	0.26	0.21†	0.37	0.40	0.40
1993	0.29	0.70	0.57	1.19	0.91	1.02	1.15
1994	0.03	0.10	0.04	0.06	0.08	0.07	0.06

† Flow not monitored for entire year.

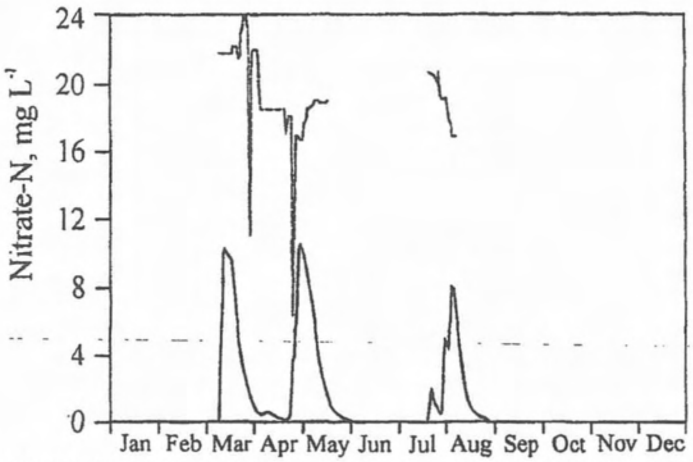

Fig. 3. Inlet (*top line*) and outlet (*bottom line*) nitrate N concentrations for a 1-ha wetland receiving tile drainage water from a 100-ha watershed (Crumpton and Baker, 1993).

sis, tile drain discharge can add large nitrate loads to surface waters, impairing their quality if not sufficiently diluted. Nitrogen balance sheets and delta-^{15}N data collected by Clay et al. (1997) in South Dakota suggest that denitrification may be significant in poorly drained soils, but is negligible if these soils are tile drained.

The potential for reducing the nitrate load of tile discharge water by routing it through a wetland was investigated in Iowa by Crumpton and Baker (1993). From the data collected they developed a model to determine the size of wetland required to reduce tile inflow of a given nitrate concentration and volume to levels meeting drinking water standards. Their calculations show that tile discharges containing up to 24 mg nitrate N L^{-1} from a 100 ha drainage field can be cleaned up to less than 10 mg nitrate N L^{-1} by passing it through a 1 ha wetland (Fig. 3).

Studies were conducted on the potential for using subsurface drains as a means of controlling water table depth through drainage and subirrigation (Fausey et al., 1995). Results showed that nitrate concentrations in column leachates and quantity of nitrate leached were reduced as depth to water table decreased and time between fertilizer application and initiation of leaching treatments increased (Jiang et al., 1997). This suggests that such treatments may increase nitrate removal by denitrification. This conclusion agreed with results obtained by Jacinthe et al. (1999) who showed that nitrous oxide emissions were greater for water tables less than 50 cm deep compared with those for water tables more than 50 cm deep (Table 2), and that emissions increased with time for shallow water tables. In field plots, Fausey and Cooper (1995) showed that corn and soybean yield could be increased by maintaining the water table 10 to 50 cm below the soil surface during most of the growing season by using tile drains for subirrigation (Table 3).

Table 2. Cumulative amount of N_2O and N_2 emitted from the surface of the soil columns with a static water table (WTM1) and dynamic water table (WTM2) (Jacinthe and Dick, 1996).

Soil	Treatment†	Total N_2O emitted during period: Day 13–35	Day 91–116	Total amount emitted during experiment as: N_2O	N_2	$N_2O + N_2$ emitted as % initial N
		mg N column^{-1}				
Blount	WTM1	12 (1.3)‡	42 (34)	93 (39)	151 (96)	9 (4)§
	WTM2	125 (90)	59 (0.1)	251 (91)	373 (152)	24 (7)
Clermont	WTM1	22 (11)	90 (76)	189 (84)	174 (71)	14 (5)
	WTM2	164 (98)	40 (18)	311 (172)	765 (435)	43 (20)
Huntington	WTM1	24 (14)	80 (86)	192 (128)	89 (65)	9 (5)
	WTM2	297 (334)	130 (115)	565 (529)	329 (268)	29 (20)
Analysis of Variance						
Source		$P < F$				
Soil (S)		0.638	0.489	0.472	0.668	0.652
WTM (T)		0.054	0.883	0.131	0.030	0.039
S × T		0.688	0.512	0.685	0.698	0.859

† WTM1 = water table 50 cm below soil surface for first 92d, 10 cm thereafter. WTM2 = water table 50 cm below soil surface first 4d, increased to 10 cm by d8, decreased gradually to 70 cm by d44, increased to 50 cm by d50, then to 10 cm on d92.
‡ Value in parentheses is standard deviation.
§ Indigeneous NO_3-N present in Blount, Clermont and Huntington columns was 513, 414 and 1075 mg N column^{-1}, respectively. Initial N = (indigeneous N + added N).

Table 3. Effects of water table depth (controlled by tile drainage and subirrigation) on corn and soybean yields at Hoytville, Ohio (from Fausey and Cooper, 1995).

Water table depth	Corn yield	Water table at 25 cm	Soybean
cm	Mg ha^{-1}		Mg ha^{-1}
25	11.5	Full season (to 9/30)	4.8
50	11.3	Early season (to 8/15)	4.1
Free drainage	10.2	Free drainage	3.8

Nitrogen Fertilizer and Manure Management Practices

Research was conducted at almost all locations on improving the management of N fertilizers and manure used in crop production. These included studies to evaluate existing soil testing procedures, technologies to improve fertilizer application practices, and new technologies using various crop growth parameters as monitors to determine crop N sufficiency. This latter approach will be discussed in a separate section that follows.

Soil N Tests

On deep loess soils in western Iowa, cropped to continuous corn for 26 yr, Karlen et al. (1998a) found that about 50% of the fertilizer N applied at conventional rates could not be accounted for by crop removal. The PSNT and other soil nitrate testing indicated that there was a large accumulation of residual nitrate in these soils, suggesting that previous crops had been overfertilized. Stalk nitrate analysis supported this conclusion. Their results indicated that soil tests such as PSNT could be used to improve N fertilizer application rates. Nitrate moved through these deep loess soils at a rate of 0.5 to 1.0 m yr^{-1} and eventually showed up in base flow of streams fed by springs at the loess–till interface. In Wisconsin, Bundy and Andraski (1995) also found that both the PSNT and the PPNT were useful guides for determining proper N fertilizer rates. Kanwar et al. (1995) found that use of the PPNT soil test reduced nitrate losses in tile drainage, when compared with that for a standard 110 kg N ha^{-1} rate (Fig. 4).

From N rate response studies at 54 locations in Minnesota, Schmitt and Randall (1995) concluded that no fertilizer N should be applied to sites that have 19 or more mg nitrate N kg^{-1} soil at planting (PPNT). For Maryland, Steinhilber and Meisinger (1995) determined that little or no corn yield response could be expected for soils with a PSNT test of 22 or greater (Fig. 5). Data collected by Schepers et al. (1993) in the Platte River Valley of Nebraska showed that basing N fertilizer rates on the deep soil nitrate testing recommended in that state reduced ground water nitrate concentrations by about 0.5 mg L^{-1} yr^{-1} over a several-county area. Clay et al. (1995) in South Dakota concluded that soil samples collected for soil nitrate testing should be taken about 7.5 cm from the band for most representative results. There is ample evidence from MSEA research that the modern soil testing procedures currently recommended in many states do have potential to improve crop N

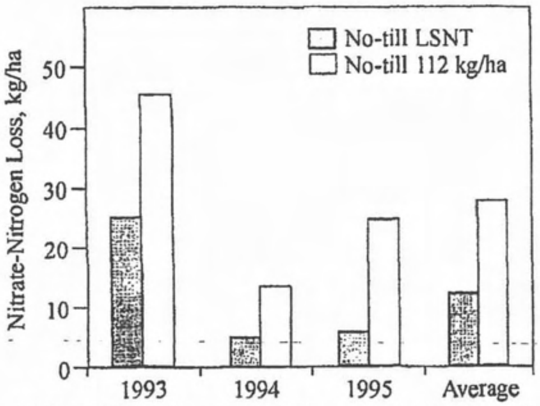

Fig. 4. Nitrate N lost through tile drainage for no-till plots fertilized according to Late Spring Nitrate Test (LSNT) compared with those receiving 112 kg N ha^{-1} (100 lb N acre^{-1}) annually (Kanwar et al., 1995).

management and thereby reduce nitrate leaching and water quality deterioration.

Fertilizer N Application

Effects of method of N fertilizer application were also investigated at several sites. At most locations it was demonstrated that N fertilizer applications were most effective and nitrate leaching was reduced by applying fertilizers in split application, with part added before planting and the remainder sidedressed later. Also, banding, compared with broadcast application, slowed the rate at which fertilizer N was nitrified, thereby reducing nitrate accumulations in the soil and subsequent nitrate leaching potential. Fertilizers also could be applied in the irrigation water (fertigation). Watts and Schepers (1995) found fertigation was practical with sprinkler irrigation, but cannot be recommended for furrow irrigation because water is not applied uniformly. MSEA scientists in Iowa (Ressler et al., 1997; Baker et al., 1997) showed that packing soil over a fertilizer band reduced water infiltration into the fertilizer band, slowing rate of nitrification and nitrate movement (Fig. 6). Lowery et al. (1995), working on sandy soils in Wisconsin, Iowa, and South Dakota, reduced nitrate leaching and improved N fertilizer use efficiency by banding fertilizer N on the shoulders of the ridges used in ridge-

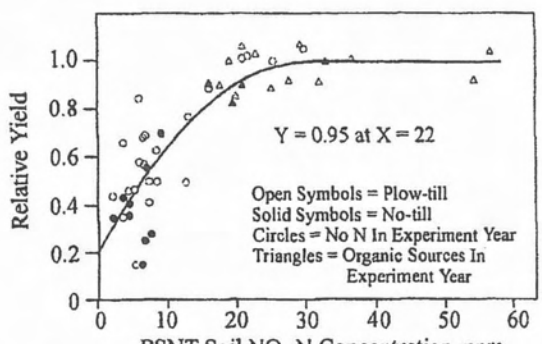

Fig. 5. Relation of corn relative yield to soil NO_3–N concentrations in the upper 30 cm of soil (Steinhibler and Meisinger, 1995).

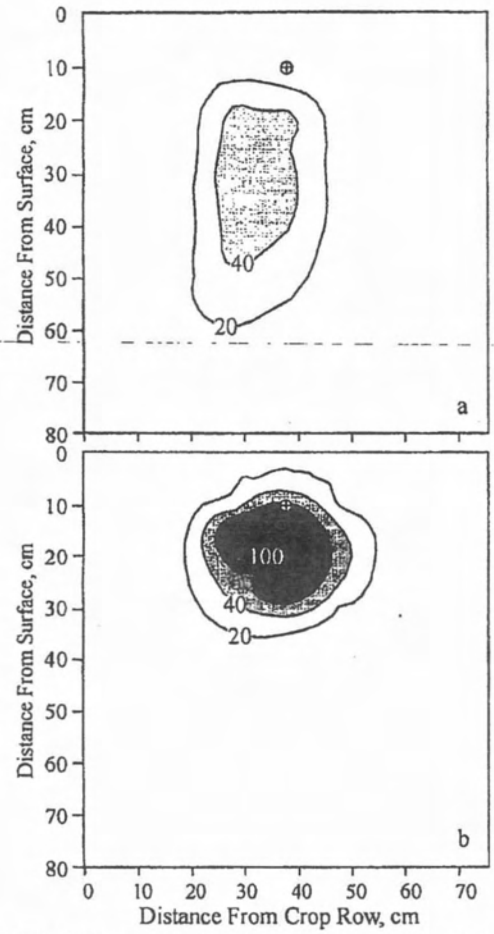

Fig. 6. Nitrate N concentrations 83 days after application: (*a*) conventional knife application; (*b*) soil compacted above fertilizer band. ⊕ Denotes location of fertilizer band. Units are kg ha^{-1} (Ressler et al., 1997).

Table 4. Tillage and crop rotation effects on total NO_3–N loss in tile drainage water (Kanwar et al., 1998).

Year	Rain	Rotation†	Chisel plow	Moldboard plow	Ridge-till	No-till
	mm		NO_3–N loss with drainage water (kg ha^{-1})			
1990	1049	Cont. Corn	112a‡	64a	94a	120a
1991	973	Cont. Corn	85a	70a	70a	70a
1992	742	Cont. Corn	21a	21a	12a	22a
Average			73a	52a	61a	71a
1990	1049	Corn–Soy	60a	42a	34a	41a
1991	973	Corn–Soy	41a	40a	33a	34a
1992	742	Corn–Soy	19a	11a	13a	6a
Average			40a	31a	26a	25a
1990	1049	Soy–Corn	58a	46a	38a	41a
1991	973	Soy–Corn	51a	47a	36a	37a
1992	742	Soy–Corn	9a	13a	11a	6a
Average			39a	35a	28a	27a

† Cont. Corn = Continuous corn; Corn–Soy = Soybean after corn; Soy–Corn = Corn after soybean.

‡ Values followed by the same letters in the rows are not statistically different.

till systems, compared with banding in furrows. Clay et al. (1994) showed that if open soil slots remained after banding anhydrous ammonia, leaching of nitrate during the next 85 d was much more rapid than when slots were closed. Doran et al. (1995) and Jacinthe and Dick (1997) determined that denitrification from well-drained corn fields was normally equivalent to only a few percent of the fertilizer N added to the crop.

Animal Manures

Effects of animal manures as a source of available crop N were investigated at only a few locations. However, at several locations longterm (more than 10 yr) residual effects of previous manure applications were observed, and several scientists concluded that previous manuring practices may have prolonged effects on N nutrition. Bundy and Andraski (1995) and Kanwar et al. (1995) concluded that use of the PPNT and PSNT soil tests should be recommended for manured soils. Francis et al. (1995) found that N in some manures, especially those with wide C/N ratios, are slow to mineralize during spring months, which may result in a temporary N deficiency during early crop growth. They concluded that use of N starter fertilizers would be desirable in such situations.

Impacts of Cropping Systems, Tillage, and Other Production Practices

Scientists have long known that certain cropping systems, tillage practices, and other production practices can have major effects on the availability and uptake of N by a crop. The MSEA research results added to this bank of knowledge and identified practices and situations where these choices greatly influenced nitrate leaching.

Cropping System Effects

At most locations the effects of continuous corn versus a corn–soybean rotation on crop production and water quality were investigated. When proper N credits were given for the soybean crop, nitrate leaching was usually less for the corn–soybean rotation than for continuous corn (Rice et al., 1995; Subler et al., 1995; Varvel et al., 1995; Albus and Knighton, 1998; Kanwar et al., 1997) (Table 4). There are several reasons for this. First, the soybean crop did not receive N fertilizer, and when credits were given for the soybean, amount of N fertilizer applied over two years was reduced well over 50% for the rotation compared with continuous corn. Second, soybeans are good scavengers for soil nitrate. They often leave less residual soil nitrate after harvest than continuous corn, again reducing nitrate leaching potential during fall and winter months. The relatively high N content of soybean residues and their rapid rate of decomposition may increase soil N availability for the following corn crop, further reducing fertilizer N requirement for corn (probably accounting for much of the N credit for soybeans). Omay et al. (1997) found that while the corn–soybean rotation had little effect on total N mineralized after 350 days of incubation, compared with continuous corn, the percent of total soil organic N mineralized was greater for soils in the rotation for a silt loam, but not for a loam. Thus, conclusions from all these

Table 5. Average yearly NO_3-N concentrations in subsurface drain water as a function of N management practice, tillage, and crop rotation for 1993 and 1994 (Kanwar et al., 1995).

Tillage	Rotation	N mgt. system	N application rate		NO_3-N concentrations in drain water: In corn plots		In soybean plots	
			1993	1994	1993	1994	1993	1994
			kg ha^{-1}		mg L^{-1}			
NT	CS	LSNT	160	147	9.8	7.3	4.2	4.5
NT	CS	Single N	112	112	8.8	11.9	4.9	5.1
CP	CS	LSNT	103	167	11.1	9.7	4.6	7.0
CP	CS	Single N	112	112	8.9	11.2	8.4	6.1
CP	CS	Manure	84	237	11.6	13.2	4.8	7.0
CP	CC	Single N	134	134	11.6	14.0	–	–
CP	CC	Manure	82	280	11.1	18.6	–	–
CP	Strip C	N in corn strip	112	112	7.0	2.8	–	–
NT	Forage	No N app.	0	0	6.0	2.7	–	–

NT = No tillage; CP = Chisel plow; CS = Corn–soybean; CC = Continuous corn; LSNT = Late spring nitrogen test; Single N = Single application of N at planting time; Manure = Swine manure slurry injected in fall of previous year; Strip C = Strip cropping having strips of corn–soybeans–oats–berseem/clover; Forage = Three-year rotation of alfalfa.

studies indicate that nitrate leaching can be significantly reduced by rotating corn and soybeans compared with producing continuous corn if a proper N credit is given for the soybeans. Magnitude of these differences depends on soil and weather.

If insufficient N credits are given for the soybean crop, lysimeter studies (Klocke et al., 1999) showed that nitrate leaching with the corn–soybean rotation was significantly greater than for continuous corn. Using tagged N fertilizer, Rice et al. (1995) found that 94% of the applied fertilizer N could be accounted for in the soil and crop for the corn–soybean rotation, compared with only 84% for continuous corn. Much of this difference may be accounted for by differences in soil N immobilization or losses of ammonia gases to the atmosphere during corn maturation (Francis et al., 1993).

At a few locations a rotation of corn with alfalfa (*Medicago sativa* L.) was investigated. The PSNT soil test accurately showed that normally no N needs to be applied to corn following alfalfa (Bundy and Andraski, 1995). Kanwar et al. (1995) measured their lowest nitrate concentration in tile drainage water for corn following alfalfa compared with other cropping systems and also concluded that the PSNT soil test was reliable for this situation. At the Nebraska MSEA site soil and water nitrate concentrations were greatly reduced by five years of alfalfa (Watts et al., 1997). Rotations that included wheat (*Triticum aestivum* L.) were investigated in Ohio and Missouri (Ward et al., 1994). In general, almost all cropping systems studied exhibited less nitrate leaching potential than that observed for continuous corn, but generally profitability was also reduced (Batte et al., 1998). Also, with rotations annual fertilizer N inputs into the production system were reduced.

Effects of Tillage Practices

At many MSEA sites the effects of tillage practices on nitrate leaching potential were investigated. Ridge-till was compared with conventional tillage (usually chisel plow) in many of these studies. No-till and other reduced tillage practices were also often included. The effects of tillage practices on nitrate leaching potential were often site specific. In Iowa, Kanwar et al. (1997) found little difference among tillage practices in regard to soil nitrate leaching potential for tile-drained soils (Table 5). On a sandy soil in North Dakota, Albus and Knighton (1998) measured less residual nitrate after soybeans in ridge-till than in mulch tillage soils, but no differences after corn. On clay-pan soils in Missouri no-till generally exhibited less nitrate leaching than other tillage methods (Hughes et al., 1995). Nitrate leaching in these clay-pan soils generally occurs only after heavy rains are received at times when the clay-pan is dry and has cracks up to several cm in width (Kitchen et al., 1997). No-till tends to reduce cracking and subsequent movement of nitrate-containing water through the clay-pan (Table 6). However, for the deep loess soils of western Iowa, reduced tillage methods, compared with plowing or disking, resulted in greater water infiltration and movement of nitrate into the vadose zone (Steinheimer et al., 1998). Where measured, tillage method generally had little overall effect on total quantity of nitrate mineralized during a growing season, but did affect the timing of the mineralization activity. Bare tillage resulted in much more rapid mineralization early in the season, whereas reduced and no-till systems exhibited greater mineralization during midsummer, when N uptake by the corn crop was greatest.

Monitoring Crop Greenness and Variability

Approaches to managing the availability of N for crops in the past have generally been based on anticipated crop yield as estimated near planting time. Suffi-

Table 6. Seasonal root-zone water nitrate N (NO_3-N) concentrations at the summit landscape position for MSEA farming system, Centralia, MO, 1993–1994† (Hughes et al., 1995).

Year	Farming system‡	NO_3-N concentration range (mg L^{-1}): Pre-planting	Post-planting	Mid-season	Physical maturity	Post-harvest fallow
1993 (Corn)	MT 190 CS	3.0–6.6	4.2–*42.7*	0.1–*19.8*	0.0–2.1	0.0–*19.2*
	NT 140 CS	2.7–5.9	2.0–*15.7*	0.8–6.5	0.7–0.8	0.0–5.1
	MT 118 CSW	0.6–8.7	0.0–8.2	0.4–6.3	0.6–7.7	0.1–5.4
1994 (Soybean)	MT 190 CS	6.0–8.2	3.0–*10.4*	2.7–8.1	4.0–*12.8*	*24.5–27.3*
	NT 151 CS	4.8–*10.2*	0.6–*11.0*	1.2–1.4	0.0–1.0	8.7–*20.0*
	NT 151 CSW	1.1–3.9	0.8–4.6	0.7–3.1	0.1–0.5	No water

† Italic values exceed the U.S. Environmental Protection Agency's maximum contaminant level for drinking water (10 mg L^{-1}).
‡ MT = Mulch tillage; Numbers are N fertilizer rate in kg N ha^{-1}; C,S,W = Corn, soybean, and wheat, respectively.

cient fertilizer N was then applied before or shortly after planting to insure that the predicted yield could be obtained, ideally basing the application rate on the amount of residual nitrate in the soil at that time (nitrate soil testing) and on anticipated rate of soil N mineralization during the growing season. If the crop yield prediction was accurate within 5 to 10%, and if fertilizer N had been applied based on the best soil tests for the region, often crop yields were near optimum and nitrate leaching potential was minimized. However, crop yield frequently varies at least twofold from year to year because of differences in weather patterns, insect or disease incidence, or other reasons (Lamb et al., 1997; Birrell et al., 1995). In years when harvested yields are greatly below yield goals, even when we use our best N management practices, large amounts of nitrate may accumulate in the soil and be subject to leaching during the noncrop period after corn harvest. Also, soils are seldom uniform throughout a field, so applying sufficient fertilizer N to assure high yields for more productive areas of the field often results in overfertilization of the less productive areas. This may lead to greater nitrate leaching, particularly in those areas of the field that are more susceptible to leaching.

To address this problem, several MSEA scientists used a different approach to determining crop N needs and how these needs vary over a field. They documented that plant greenness was closely related to plant chlorophyll content, plant total N content, and potential crop yield. Schepers et al. (1995) demonstrated that plant N sufficiency could be adequately quantified by use of a chlorophyll meter if greenness of the plant was referenced against greenness measurements of a well-fertilized plant (Table 7). These observations were verified by Dystra et al. (1995) in South Dakota. Before the 6- to 8-leaf stage, significant plant N deficiencies reduced crop yield potential (probably by reducing the number of kernel primodoria formed), so permanent yield loss occurred. However, plant N deficiencies could be corrected by N fertilization after the 8-leaf stage of growth if N sufficiency did not fall below about 95% that of the well-fertilized reference plant (Varvel et al., 1997a). These results were obtained where N deficiency was the only factor limiting crop yield. These findings opened the door to a new approach for managing N fertilization of crops. By monitoring crop greenness relative to that of a well-fertilized crop strip through the field, followed by sidedressing or fertigating (applying fertilizer in irrigation water), the crop could essentially be spoon-fed the N it needs. This process vastly reduces frequency of large nitrate accumulations in soil profiles, thereby reducing opportunity for nitrate leaching to occur. Watts and Schepers (1995) successfully used this approach for fertilization of irrigated corn. Blackmer and Schepers (1995) obtained best correlation between plant greenness and final crop yield at the R4 to R5 stages of corn development (Ritchie et al., 1996). Varvel et al. (1997b) found that both the chlorophyll meter and end-of-season stalk nitrate analysis accurately predicted N sufficiency levels. However, on sandy soils in Minnesota, Lamb et al. (1995b) measured low correlations between chlorophyll meter readings taken 30 to 60 days before crop maturation and final grain yields, possibly because the low water-holding capacity of sandy soils permitted more nitrate leaching to occur, when compared with finer textured soils.

Table 7. Effect of N fertilizer rate on corn leaf N content, chlorophyll meter readings, and corn grain yield (Schepers et al., 1995). Values in parentheses are percent of maximum value.

N rate	Leaf N	Chlorophyll meter reading	Corn grain yield
kg ha^{-1}	mg g^{-1}		kg ha^{-1}
0	18.9 (0.52)	27.7 (0.48)	4 010 (0.34)
75	27.3 (0.75)	42.6 (0.74)	7 900 (0.67)
150	33.5 (0.93)	51.3 (0.90)	10 410 (0.88)
225	34.8 (0.96)	56.4 (0.98)	11 040 (0.93)
300	36.2 (1.00)	57.3 (1.00)	11 750 (1.00)

While the chlorophyll meter was useful in assessing crop N fertilizer needs in medium and fine-textured soils, it was not without problems. The major problem was crop growth variability within a field. This variability could be caused by a number of factors—variability in soil properties, soil water content, insect and disease problems, or other factors. In using the chlorophyll meter, it is essential that the status of nutrients other than N be approximately equal for both the measured area of the field and the reference strips to which the measured area is compared. With variable soil conditions within a field, this would require a number of reference areas, one on each soil condition. This often is not practical. For example, Sudduth et al. (1995) found that productivity of clay-pan soils in Missouri is closely related to depth to clay-pan. Thus, reference strips would be needed for each change in soil depth.

For these reasons and because of other factors that affect crop greenness, MSEA scientists investigated the possibility of remotely sensing crop greenness. This approach allows the producer the option of using a GPS to differentially apply N fertilizer to those areas of the field that are in need. Three methods of remote sensing were investigated—use of aerial photographs, mounting economical crop greenness sensors (550 nm wavelength) on sidedressing or sprinkler irrigation equipment as it moves through the field, and use of satellite imagery. Several technical problems clearly indicated that use of satellite imagery was not yet a viable option (clouds, time delays in receiving images, cost).

Blackmer et al. (1994) determined that light reflectance from the corn canopy at 550 or at 710 nm could be used to assess crop greenness. In another investigation, Blackmer et al. (1996) showed that areas of a corn field needing N fertilizer could be assessed from inexpensive black-and-white photographs taken with a 536 nm filter (Fig. 7). However, Schepers et al. (1996) found that these relationships were less useful for water-stressed crops. On sandy soils in Minnesota, Tomer et al. (1997) also concluded that aerial infrared photographs could be used to monitor crop growth and N nutrition. Senay et al. (1998) demonstrated in Ohio that aerial multispectral band imagery was useful in predicting corn grain yields. Thus, remotely sensing crop greenness with aerial photography appears to be a practical method of as-

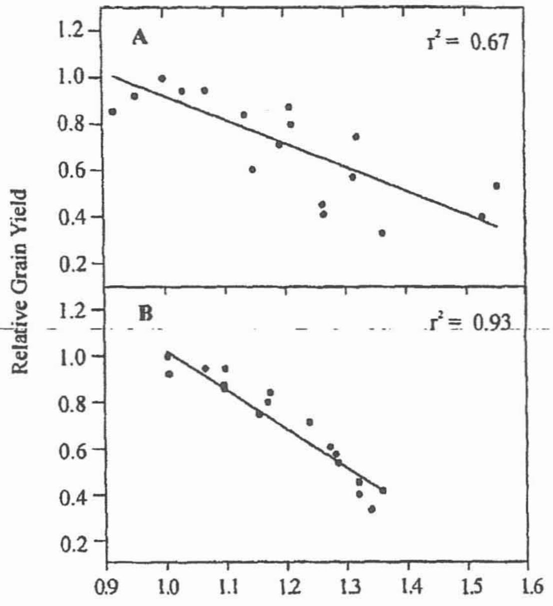

Fig. 7. Relationship between relative grain yield and relative digital counts for (*a*) raw data and (*b*) data corrected for vignetting, across four corn hybrids and five N rates (Blackmer et al., 1996).

sessing N sufficiency of the crop over the entire field. By use of GPS, those areas of the field needing additional N could then be sidedressed or fertigated. For this approach to be useful, however, it must be ascertained that differences in crop greenness are caused by N deficiencies and not by other factors.

Blackmer et al. (1996) described an inexpensive photometric cell, with a peak light sensitivity at 550 nm, that could be mounted on field equipment to measure crop greenness. Such cells could be mounted on irrigation machines or on high-clearance sidedressing machines to assess crop N needs as the machines traverse the field. The signal from these cells could then be used to turn fertilizer application equipment on and off as the machine moved through various parts of the field.

The new knowledge attained from the studies cited in this section opens up a new approach for N management for crop production—using the crop as a monitor of its N needs. It also provides a practical framework upon which to develop site-specific or precision farming systems. By using crop greenness as a monitor, it should be possible to control soil nitrate level at a sufficient but not excessive level in all parts of the field, thereby greatly reducing opportunity for nitrate leaching. Clay et al. (1997) showed that relative amounts of N mineralized and denitrified in a 65 ha field varied greatly from site to site, primarily depending on soil drainage. Kitchen et al. (1995) concluded that the variable rate approach holds much promise for use on the clay-pan soils of Missouri. However, for the sand plains in Minnesota, Lamb et al. (1995a) indicate that variable rate technology may be less useful because of difficulty in relating yield variability to soil properties and climate. One problem with this approach is that sometimes in

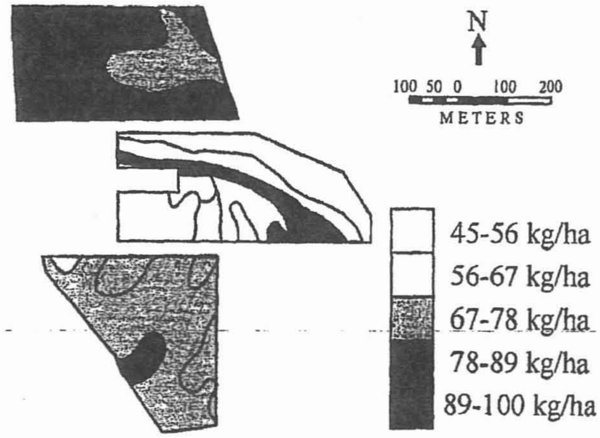

Fig. 8. Annual nitrate N leaching estimated from CREAMS for three adjacent fields in Ohio. Lines represent soil type boundaries (Wu et al., 1996).

the Midwest prolonged rainy periods may prevail during midsummer, limiting the time available for sidedressing. Thus, much more research and development are needed to bring these technologies to acceptable levels of application. At many MSEA locations research on the next steps in developing precision farming methods is underway.

Evaluation of Computer Simulation Models from MSEA Data

A number of factors influence soil N transformations and water movement through soils. Because of the complexity of these processes, coupled with the multitude of soil types and cultural practices involved in crop production, the potential combinations and interactions of all factors affecting N transformations and water movement are almost limitless. Therefore, realistic computer simulation models are desirable to determine the best combination of practices to use for any given situation. A number of such models have been developed in recent years. At several MSEA locations some of these models were evaluated in regard to their ability to assess crop yield, water movement, and nitrate leaching, using field data collected from MSEA experiments as a reference.

In Ohio, Wu et al. (1996) found that the model Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) provided reasonably accurate predictions of nitrate leaching through soil columns. They subdivided three 10-ha fields into 34 different hydrological environments, and using MSEA field data on hydrology and nitrate loading, estimated nitrate leaching losses from each of these units. Results showed that there was large variation in estimated leaching losses both among and within fields (Fig. 8). Annual nitrate leaching losses up to 120 kg N ha^{-1} were estimated. Neiber et al. (1995) applied the GLEAMS model to data collected from the sand plains in Minnesota and found the model useful, within limits, in helping to identify combinations of best management practices that minimize nitrate leaching and maintain crop yields.

Also in Ohio, Landa et al. (1999) estimated crop growth and nitrate movement and losses using the Root Zone Water Quality Model (RZWQM) using Ohio MSEA data. In most instances model assessments of crop growth and yield were fairly satisfactory. Assessments of residual soil nitrate after corn harvest were also reasonably accurate, but residual nitrate following soybeans was underpredicted, probably because soil water and N mineralization predictions were also in error. Also in Ohio, Nokes et al. (1996) used one year of MSEA field data to calibrate RZWQM, then applied the parameterized model to the next two years of field data. With this approach, the model reliably simulated data obtained on soil water content, nitrate in the root zone, corn growth, and yield. Using Missouri MSEA data, Ghidey et al. (1999) found that the RZWQM adequately predicted corn and soybean yields with minimum tillage, but overpredicted corn yield and underpredicted soybean yield with no-till. This model overpredicted runoff when these clay-pan soils were dry with large cracks. Karlen et al. (1998b) in Iowa found that the RZWQM adequately predicted effects of tillage practices on corn yields and N uptake, but the model was inadequate for predicting the fate of the fertilizer N applied, including leaching losses.

Using the Nitrate Leaching and Economic Analysis Package (NLEAP) on ground water quality data from northeast Colorado, Shaffer et al. (1995) accurately identified those areas in northeast Colorado that had relatively high nitrate concentrations in the ground water. This model appeared to be a very good tool for identifying potential hot spots for leaching. Follett (1995) calibrated NLEAP on a set of irrigated and nonirrigated plots on a sandy soil in North Dakota, then used the calibrated model to simulate nitrate movement for an identical set of plots. Variable N rates were applied. Predicted values were accurate and results showed that residual soil nitrate values in this soil were very sensitive to spring precipitation.

In Missouri, Heidenreich (1995) used the model Soil and Water Assessment Tool (SWAT) to study agricultural chemical movement from the 7250 ha watershed for Goodwater Creek. Subdividing the watershed into 73 virtual subbasins based on land use and soil characteristics, four yr of data were used to simulate nitrate movement. Only by adjusting parameters in the model could they obtain acceptable agreement between measured and simulated nitrate and yields. Tomer and Anderson (1995) developed a model for the sandy soils in Minnesota which described variation in soil water storage across a Sand Plain hillslope, which in turn appears to be related to crop yield potential for these soils. Both topography and presence of clay lenses in these sandy soils affected water storage.

The above are a few examples of the evaluation of the use of computer models in organizing and simulating data collected from the MSEA projects. It appears from these results that several of these models, with proper calibration and modifications, can frequently be used to assess the consequences of various agricultural practices on many soils, especially the effects of these practices on crop yield and nitrate leaching. In many instances, however, information upon which to base the calibration and modification procedures may be lacking, reducing the utility of some of these models. Also, it is apparent that none of the models is capable of accurate simulations in all situations at all times. Thus, it appears that existing models are useful tools for general planning of management practices, but failure rate is sufficiently frequent to limit their universal or site-specific use. Output from most models was less accurate as size of the target area evaluated decreased. Use of MSEA data with existing models demonstrated that in some instances these models gave grossly erroneous results. Unfortunately, there is frequently no convenient method by which we can evaluate the accuracy of the output of these models. Thus, at their present stages of development, it is extremely hazardous to base management or regulatory decisions on such model output. As we gain more knowledge from further research, the prediction capability of many of these models will likely improve and new models will be developed.

SUMMARY

The MSEA project was a comprehensive multistate multiagency research and education effort designed to improve our knowledge of factors causing agricultural pollution of our water resources and to lead us to practical new technologies by which such pollution can be reduced. The MSEA project was successful in achieving these goals. In many instances MSEA results identified and verified practices reported earlier to be beneficial in maintaining water quality. As examples, MSEA results showed that the recently developed soil nitrate tests used to guide N fertilization practices do greatly improve N management, resulting in maintenance of crop yields while reducing nitrate leaching, and often reducing fertilizer costs. MSEA results also verified the need to control water in order to control nitrate movement. Improved water and fertilizer management practices for irrigated agriculture were identified and evaluated. The effects of tile drainage on surface and ground water quality were measured, and practices (such as use of wetlands) that can be used to reduce the concentration of nitrates discharged by tile drains were studied. Improved N fertilizer management practices were identified, such as packing soil over a fertilizer band, applying water and fertilizer to alternate rows for furrow irrigation, and banding fertilizers on the shoulder of ridges used in ridge-till systems.

Probably the most significant result of the MSEA project was the recognition and initial development of practical technologies whereby N sufficiency for a crop can be determined by monitoring plant greenness. This finding has led to the development of remote sensing technologies to assess crop N sufficiency, followed by differential (site specific) application of fertilizer N to those areas of the field showing need. This research also strikingly demonstrated the variability that exists in crop growth and yield both within a field and between years. These MSEA results have led most locations into research to develop site specific or precision farming systems. Development and identification of limitations of computer simulation models were also provided by the MSEA research. This paper has summarized some of the achievements documented from the MSEA project and has identified instances in which this information is being used to improve water quality.

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Controlling Nitrate Leaching in Irrigated Agriculture

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ABSTRACT

The impact of improved irrigation and nutrient practices on ground water quality was assessed at the Nebraska Management System Evaluation Area using ground water quality data collected from 16 depths at 31 strategically located multilevel samplers three times annually from 1991 to 1996. The site was sectioned into four 13.4-ha management fields: (i) a conventional furrow-irrigated corn (*Zea mays* L.) field; (ii) a surge-irrigated corn field, which received 60% less water and 31% less N fertilizer than the conventional field; (iii) a center pivot-irrigated corn field, which received 66% less water and 37% less N fertilizer than the conventional field; and (iv) a center pivot-irrigated alfalfa (*Medicago sativa* L.) field. Dating ($^3H/^3He$) indicated that the uppermost ground water was <1 to 2 yr old and that the aquifer water was stratified with the deepest water ~20 yr old. Recharge during the wet growing season in 1993 reduced the average NO_3–N concentration in the top 3 m 20 mg L^{-1}, effectively diluting and replacing the NO_3-contaminated water. Nitrate concentrations in the shallow zone of the aquifer increased with depth to water. Beneath the conventional and surge-irrigated fields, shallow ground water concentrations returned to the initial 30 mg NO_3–N L^{-1} level by fall 1995; however, beneath the center pivot-irrigated corn field, concentrations remained at ~13 mg NO_3–N L^{-1} until fall 1996. A combination of sprinkler irrigation and N fertigation significantly reduced N leaching with only minor reductions (6%) in crop yield.

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ASSESSMENTS of ground water NO_3 contamination report that many major areas of nonpoint-source contamination are located in the irrigated semiarid and arid regions of the western USA (Madison and Brunett, 1985; Anderson, 1989; Power and Schepers, 1989; Spalding and Exner, 1993). The thrust of these reports provides a clear association between nonpoint-source ground water NO_3 contamination and irrigated agriculture.

Irrigated agriculture has a major impact on the economy of several states both in the west and in the western Corn Belt. In Nebraska, 3.4 million ha of irrigated agriculture and related spin-off service industries add approximately $3 billion annually to the state's economy. Controlling leachates from irrigated crop land, especially from the 2.3 million ha of irrigated corn, requires fundamental changes in farm practices that not only lead to solutions but are acceptable to producers and regulators. Nebraska's dependence on ground water as the primary source of potable water is the major thrust for a sustained impetus to develop and implement more effective agricultural management strategies to reduce ground water NO_3 contamination.

Beginning in 1990, the USDA sponsored Management Systems Evaluation Area (MSEA) projects in five midwestern states in the corn and soybean [*Glycine max* (L.) Merr.] belt. The projects concentrated both on understanding the mechanisms involved in nonpoint-source contamination of surface and ground water by agrochemicals and on developing economically accept-

Abbreviations: MLSs, multilevel samplers; ET, evapotranspiration; MSEA, Management Systems Evaluation Area; NE-MSEA, Nebraska MSEA; CPNRD, Central Platte Natural Resources District; MCL, maximum contaminant level; DOC, dissolved organic carbon.

able farming practices that reduce leaching. The Nebraska MSEA (NE-MSEA) project focused on the impact of irrigated agriculture on ground water quality and the development of methods to mitigate agrochemical leaching in irrigated agriculture.

This paper demonstrates that (i) seasonal responses to agricultural practices can be detected by monitoring shallow ground water quality; (ii) management can impact NO_3 loading; and, most importantly, (iii) innovative agricultural practices can maintain NO_3 concentrations at more acceptable levels without significantly compromising crop yields. The project was designed to provide regulators and irrigators with research results needed to promote environmentally sound management.

STUDY SITE

Water Quality and Agricultural Practices

The principal target area of the NE-MSEA lies within the Central Platte Natural Resources District (CPNRD) in the central Platte River Valley (Fig. 1). It is located within 202 000 contiguous hectares underlain by a shallow, NO_3-contaminated, sand and gravel aquifer (Spalding and Exner, 1993). Nitrate concentrations within this large zone vary from 10 to >50 mg NO_3–N L^{-1}. In this area dominated by furrow-irrigated corn production, most of the contamination is derived from commercial fertilizer leachates (Gormly and Spalding, 1979). While N applications in the 1960s and 1970s ranged from 250 to 300 kg ha^{-1}, recent surveys suggest that, as a result of educational programs and regulations, most applications have declined to ~150 to 180 kg ha^{-1}, although 20% of the producers continue to apply more than is recommended (Supalla et al., 1995).

In the study area, precipitation and evapotranspiration (ET) during the growing season average 420 and 690 mm, respectively, which resulted in a seasonally dependent net irrigation requirement of 0 to >450 mm during the 30 yr ending in 1996 (Martin and Watts, 1997). Although strategies for improved furrow irrigation efficiency have been introduced, the availability of abundant shallow ground water fosters inefficient irrigation practices that promote leaching (Cahoon et al., 1995). Beneath the NE-MSEA and adjacent areas, NO_3–N concentrations generally range from 30 to 40 mg L^{-1} (Spalding et al., 1993).

The NE-MSEA consists of an upgradient buffer area (~130 ha), a component research site (~32 ha), and a research/demonstration site (~54 ha). The latter is subdivided into four 13.4-ha management fields. Three are cropped to corn and the fourth to alfalfa (Fig. 2). Each spring the farmer prepared the three corn fields by shredding stalks and tilling twice with a tandem disk harrow. The corn fields received banded applications of atrazine–metolachlor mix[1] (Bicep) at planting, and 24 kg N ha^{-1} as UAN were applied with the seed. Each corn management field was subject to different irrigation and N management practices (Table 1). Applications of N fertilizer and irrigation water were controlled in the buffer to reduce recharge upgradient of the management fields.

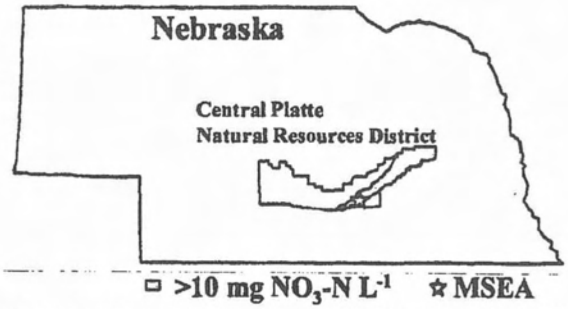

Fig. 1. Location of Central Platte Natural Resources District (NRD), shallow ground water nonpoint NO_3–N plume, and the Nebraska Management Systems Evaluation Area (NE-MSEA) research/demonstration site.

Conventional Furrow-Irrigated Corn Management Field

The conventional field was managed by the land owner, who applied preplant NH_3 and irrigated through gated pipe into furrows using 12-h continuous sets. Irrigation was on an every-furrow basis and runoff water accumulated behind the end-of-field dike (Fig. 2). With the exception of periods of significant precipitation or very cool temperatures, weekly water applications ranged from ~160 to 200 mm. During the first 2 yr of the project, preplant NH_3 was applied without nitrification inhibitor. Subsequent CPNRD regulations required the use of an inhibitor when more than half the seasonal N application was applied preplant.

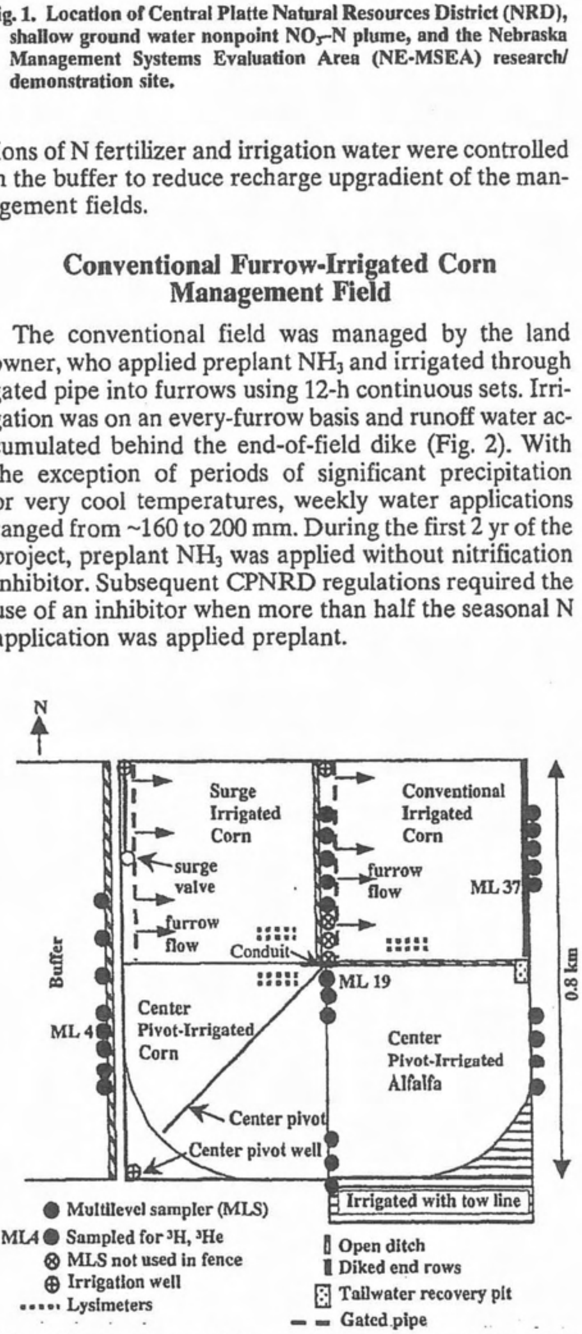

Fig. 2. Layout of research/demonstration site and sampling locations.

[1] Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine), metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide].

Table 1. Summary of annual precipitation, irrigation, irrigation-applied N, soil N, fertilizer N, and yield data for management fields.

Year/management field	Precipitation growing season	Irrigation water	Annual precip.	Residual N	Preplant N	Starter N	Sidedress (S) and/or fertigation (F) N	Irrigation N	Grain yield
	mm			kg ha^{-1}					Mg ha^{-1}
1991									
Conventional	297	942	468	95	180	24		288	12.51
Surge	297	455	468	150		24	101(S)	141	12.32
Center-pivot corn	297	335	468	85		24		92	12.20
Center-pivot alfalfa	297	328	468					88	
1992									
Conventional	319	744	520	108	168	24		223	13.01
Surge	319	231	520	121		24	51(S)	51	12.57
Center-pivot corn	319	208	520	70		24	22(F)	54	11.00
Center-pivot alfalfa	319	303	520					78	
1993									
Conventional	635	203	879	59	168	24		64	8.93
Surge	635	114	879	51	58	24	79(F)	39	8.05
Center-pivot corn	635	79	879	21	68	24	66(F)	24	8.17
Center-pivot alfalfa	635	84	879					25	
1994									
Conventional	385	767	542	93	187	24		253	8.00†
Surge	385	297	542	97	99	24	55(F)	99	7.98†
Center-pivot corn	385	107	542	68	98	24	38(F)	31	7.13†
Center-pivot alfalfa	385	396	542					115	
1995									
Conventional	377	582	607	106	180	24		181	11.63
Surge	377	264	607	93		24	134(S)	72	11.32
Center-pivot corn	377	307	607	83		24	164(S and F)	95	11.82
Center-pivot alfalfa	377	249	607					77	
1996									
Conventional	579	1275	684	74	167	24		356	13.45
Surge	579	241	684	60	80	24	56(S)	68	13.20
Center-pivot corn	579	152	684	74	112	24	61(S)	45	12.70
Center-pivot alfalfa	579	114	684					34	

Management field	6-yr Total applied water (mm)	6-yr Total applied N (kg ha^{-1})	5-yr Avg. grain yield (Mg ha^{-1})
Conventional	8213	3094	11.91
Surge	5302	1899	11.49
Center-pivot corn	4888	1515	11.18

† Not used in average yield calculation.

Surge-Irrigated Corn Management Field

Surge irrigation provides a more uniform water application than conventional furrow irrigation (Musick et al., 1987) and, therefore, is considered an improved technique. The field was graded using a laser-guided system in fall 1990 to obtain better water distribution on the gently sloping land. Irrigation water was delivered to the surge valve, distributed to furrows on both sides of the surge valve through gated pipe, and conveyed through the furrows with the excess discharged into a ditch at the lower end of the field and then into a lined tailwater recovery pit (Fig. 2). A combination of alternate furrow surge-flow irrigation and runoff recovery is designed to reduce deep percolation and total pumping. Irrigations were scheduled by standard water balance techniques according to ET computed from daily weather data. Typical beginning-of-season net irrigation applications (gross application minus runoff) ranged from 55 to 75 mm. Subsequent applications usually averaged ~50 mm.

During the first, second, and fifth growing seasons, NH_3 was applied as sidedress when the crop was in the 4 to 6-leaf stage. In 1993 and 1994, the N application was split between preplant NH_3 and UAN solution injected into the irrigation water (fertigation), while in 1996 the application was split between preplant and sidedress N.

Center Pivot-Irrigated Corn Management Field

Irrigations via a 379-m long center pivot followed the same scheduling technique employed on the surge-irrigated field. Typical irrigation applications were ~25 mm. After mid-July, a soil–water deficit of ~25 mm was maintained to provide storage of rainfall, thereby reducing leaching. In late summer, the deficit was gradually increased as the crop matured. This enhanced storage of off-season precipitation reduced the leaching of residual soil NO_3 the following spring.

With the exception of the first year, when only starter N was applied, N applications were split in 4 of 5 yr between either preplant or early sidedress NH_3 and incremental applications of UAN via fertigation. The latter were based on chlorophyll meter readings in the crop canopy (Schepers et al., 1995). In 1992 all the N was applied by fertigation. The approach minimized both the N application required for good production and the residual N available for leaching in the off-season.

Center Pivot-Irrigated Alfalfa Management Field

Most of the alfalfa field was watered with the same center pivot used for the pivot-irrigated corn. The corner not covered by the pivot and an additional 2.8 ha on the south were irrigated with a tow-line sprinkler system (Fig. 2). Between cuttings, water was applied

Table 2. Baseline (1990) concentrations in the water table aquifer.

Analyte	Concentration
pH	6.8 ± 0.3
Conductance, μS cm^{-1}	930 ± 170
NO_3–N, mg L^{-1}	26.1 ± 4.7
$\delta^{15}N$–NO_3, ‰	6.1 ± 0.8
NH_4–N, mg L^{-1}	0.15 ± 0.05
TKN, mg L^{-1}	0.63 ± 0.39
DOC, mg L^{-1}	3.3 ± 0.3
HCO_3^-, mg L^{-1}	315 ± 80
Cl^-, mg L^{-1}	24 ± 3
SO_4^{2-}, mg L^{-1}	211 ± 54
Na^+, mg L^{-1}	68 ± 19
K^+, mg L^{-1}	20 ± 11
Ca^{+2}, mg L^{-1}	144 ± 25
Mg^{+2}, mg L^{-1}	29 ± 5

based upon precipitation, ET, and the need to keep the field dry during hay harvest. Four cuttings of alfalfa were removed annually.

Hydrogeology

The unsaturated zone beneath the four management fields is a 1.1-m thick, well-drained, silt loam primarily of Eolian origin overlaying a 4.3-m thick zone of fine to medium-textured sands (Diffendal and Smith, 1996). The predominant soil at the site is a well-drained Hord silt loam (Pachic Hapustoll) with small areas of Hall silt loam (Typic Agriustoll). Both shallow water table and deep confined aquifers exist at the site. The water table aquifer is 14.3 to 17.3-m thick and composed of Quaternary age sand and gravel that overlie an aquitard composed of clayey silt interbedded with clay, sand, and some gravel. Deep boreholes in three corners of the research/demonstration site indicated that the clayey silt is 9 to 20-m thick and forms the upper confining bed of the Ogallala aquifer. The confining clayey silts lie uncomformably on Miocene age sandstone of the Ogallala formation, which rests on impermeable Pierre shale (Diffendal and Smith, 1996).

During the 6-yr investigation, the depth to water in the primary aquifer fluctuated from ~3 to ~6 m beneath the land surface, and the direction of horizontal ground water flow switched from east–northeast, to east, and back to east–northeast. A pump test utilizing the irrigation well in the southwest corner of the research/demonstration site indicated that the horizontal hydraulic conductivity in the primary aquifer averages 130 m d^{-1}, and the vertical conductivity is 10.4 m d^{-1} (Zlotnik et al., 1993). Using Darcy's Law, a nonretarded solute would be transported beneath the research/demonstration site at an average horizontal rate of 0.55 m d^{-1} and traverse the management fields in a little more than 4 yr. Upward leakage from the Ogallala aquifer to the primary aquifer was not detected during the pump test. Because the Ogallala formation remains NO_3 and pesticide-free, it is the domestic water supply for most homes.

Hydrochemistry

Initially a network of 11 multilevel samplers (MLSs) was installed at the research/demonstration site and in the upgradient buffer. These MLSs provided the baseline data (Table 2) (Spalding et al., 1993) for strategizing the locations of the 31 permanent MLS shown in Fig. 2. Nitrate-N concentrations exceeded the 10 mg L^{-1} maximum contaminant level (MCL) for potable water (Federal Register, 1975) and were relatively uniform throughout the primary aquifer. Ammonia-N levels were <0.1 mg L^{-1}. The N_2/Ar ratios indicated N_2 was not in excess of air-saturated water values in most of the sampled cluster wells (Martin et al., 1995), which suggests that denitrification is extremely limited in the shallow ground water. Dissolved organic carbon (DOC) concentrations are too low to be actively involved in significant levels of denitrification and were similar to those reported 20 yr ago (Spalding et al., 1978). The average $\delta^{15}N$–NO_3 value (+6.1‰) in the primary aquifer is slightly enriched relative to commercial fertilizer leachates (Gormly and Spalding, 1979). The enrichment is believed associated with manure-derived N from wintering cattle at the site. The relatively uniform NO_3–N concentrations, low DOC concentrations, uniformly low $\delta^{15}N$–NO_3 values, and the lack of excess N_2 in the sand and gravel aquifer suggest that the NO_3 is not denitrified and acts as a conservative ion.

FIELD PROCEDURES AND LABORATORY METHODS

The impact of irrigation and fertilizer management on water quality was assessed with pore-water lysimeters and MLSs. Each of the 31 MLSs permits water sampling from as many as 16 different depths throughout the water table aquifer. The MLSs act as a fence to intercept contaminant transport from each of the management fields. Most of the MLSs consist of 8 stainless steel gas-drive samplers, 16 suction sampling tubes, and 4 piezometers (Fig. 3). The suction sampling tubes were placed at the same inlet depths as the gas-drive samplers and also at eight shallower depths. The gas-drive samplers ensured that samples could be collected if the water table declined below the peristaltic pumping level of ~6.5 m. This situation, however, did not occur during the 6-yr study, and all samples were collected from the suction sampling tubes. Each of the 31 MLSs was assembled on site and placed in the borehole in a continuous string.

Two sets of five suction lysimeters (Soil Moisture Equipment model no. 1920) were installed at a depth of 1.4 m in each field. Within each corn field, the lysimeter sets were separated by 7 rows (~6.3 m). The lysimeters in each set were 60 cm apart and aligned along a corn row. Pore water was collected primarily during the irrigation season. A 250-mL side-arm flask was attached to a vacuum pump manifold, and the lysimeter was placed under a vacuum to pull the pore water from the adjacent soils into the porous cup. After about 2 h the vacuum line was closed, the sample line opened, and the soil pore water transferred from the side-arm flask to a 250-mL polypropylene bottle and acidified with H_2SO_4.

Water table measurements and sample collection occurred three times each year: during the preplant period (late March), before irrigation season (late June), and after irrigation season and harvest (early October). Normally preirrigation sampling coincided with the peak in the water table elevation, while postirrigation sampling was associated with the lowest annual water table elevations beneath the fields. Before each sampling event, depth to water was measured in the four piezometers of each MLS using an electronic tape (± 0.61 cm). The measurements were used to contour the water table to determine the direction of ground water flow. The change in direction from east–northeast to due east during the wet 1993 growing season necessitated reevaluating the effectiveness of

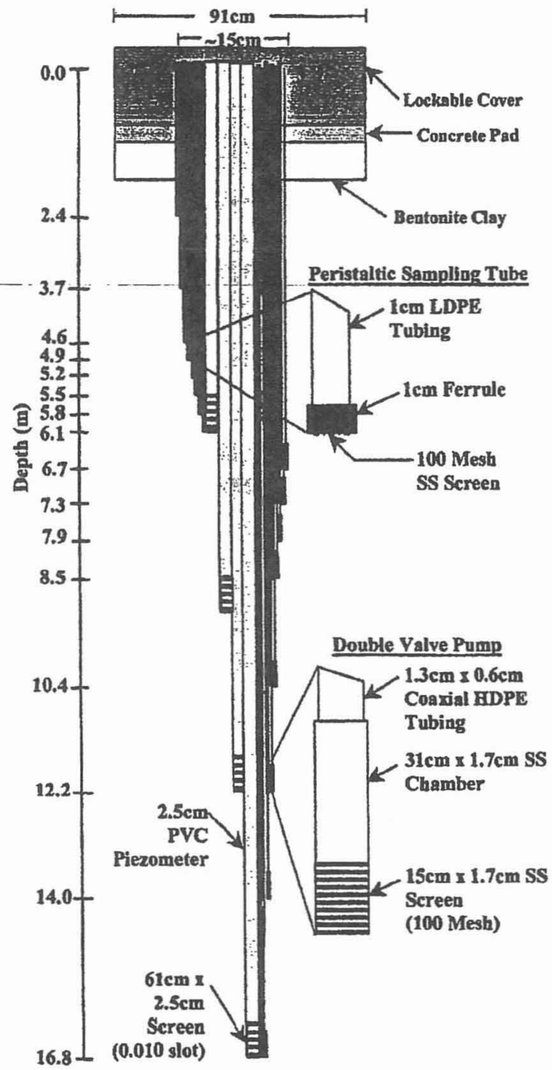

Fig. 3. Multilevel sampler construction.

the MLS locations for intercepting ground water flow downgradient from the pivot-irrigated corn field and resulted in eliminating three MLSs from the downgradient data set (Fig. 2). The change in flow direction did not compromise the locations of the MLSs downgradient from the other fields.

After three purge volumes were removed from the suction sampling tubes, conductivity and pH were measured in the field using portable meters (APHA, 1989), and bicarbonate was analyzed by potentiometric titration with standardized H_2SO_4 to pH of 4.5 using an expanded scale pH meter (APHA, 1989). Samples for Na, K, Mg, and Ca analysis were collected in 500-mL polyethylene bottles; preserved with nitric acid; and analyzed by atomic absorption spectrophotometry (APHA, 1989). Samples for NH_4 and NO_3 were collected in polyethylene bottles and acidified with H_2SO_4. Ammonium-N concentrations were determined by the automated phenate method, and NO_3–N concentrations were quantified using the cadmium reduction method (APHA, 1989). Method detection limits for NH_4–N and NO_3–N were 0.1 mg L^{-1}. Samples for chloride and sulfate analysis were collected in polyethylene bottles and analyzed by ion chromatography (APHA, 1989). Samples for total Kjeldahl N analysis were digested with H_2SO_4 (APHA, 1989).

Samples for $\delta^{15}N$–NO_3 determinations were collected in polyethylene bottles and kept on ice until they reached the laboratory where they were frozen until the time of analysis. Nitrate in the samples was converted to $(NH_4)_2SO_4$ by steam distillation (Bremner and Keeney, 1965) with a modification by Gormly and Spalding (1979). The $(NH_4)_2SO_4$ subsequently was oxidized to N_2 in a vacuum preparation system similar to that of Krietler (1975). The purified N_2 samples were analyzed with a VG Optima dual inlet isotope ratio mass spectrometer.

Samples for DOC analysis were collected in precombusted 250-mL glass bottles with ground-glass stoppers and preserved with mercuric chloride. The DOC was determined using the wet oxidation method (APHA, 1989). An aliquot of sample was filtered through a binderless, glass fiber filter; acidified; and purged to remove dissolved inorganic C. The DOC was oxidized to CO_2 using persulfate and the CO_2 was measured with a linearized detector. Each sample was analyzed in triplicate and the average DOC concentration was reported.

Samples for ^3He and tritium (^3H) measurements were collected from three MLS locations in spring 1993 (Fig. 2). For the ^3He determination, ground water was removed from the piezometers with a positive displacement pump, passed through 0.8-m copper tubes, and collected by crushing the ends of the tubes. The samples were shipped in trunks and analyzed at the Rare Gas Facility at the University of Rochester by the method of Solomon et al. (1992). Tritium samples were collected in 1-L glass bottles, shipped to the University of Rochester with the ^3He samples, electrolytically enriched, and analyzed by scintillation counting techniques.

Precipitation at the site was measured daily with a tipping bucket rain gauge.

Corn yields were determined gravimetrically using a calibrated scale. Grain from 16-row strips across each management field was harvested and weighed to provide a measure of field variability. The N content of the grain was determined by the Dumas-combustion procedure (Schepers et al., 1989).

RESULTS AND DISCUSSION

Ground Water Dating

Atmospherically derived ^3H and its stable daughter (^3He) have been used successfully to date ground water <50 yr old (Solomon and Sudicky, 1991). The method is especially applicable to shallow unconfined sand and gravel aquifers with characteristically low dispersion rates (Schlosser et al., 1989). Application of the dating technique at the NE-MSEA provides reasonably accurate dates because: (i) the layers are consistently older with depth (Fig. 4); (ii) the ages are quite consistent for water collected from the same depths across the site; and (iii) a concentrated ^3H slug indicative of the mid-1960s bomb peak is absent from this active ground water system.

Recharge to an unconfined aquifer is defined as the fluid flux normal to the water table surface and is related to the average linear fluid velocity according to

$$r = v_0 \theta$$

where r = recharge rate (L/T); θ = effective porosity ($L^3\ L^{-3}$), and v_0 = component of the average linear velocity normal to the water table (Solomon et al., 1995).

Solomon et al. (1993, 1995) have shown that the $^3H/^3He$ age gradient in multilevel piezometer nests can ac-

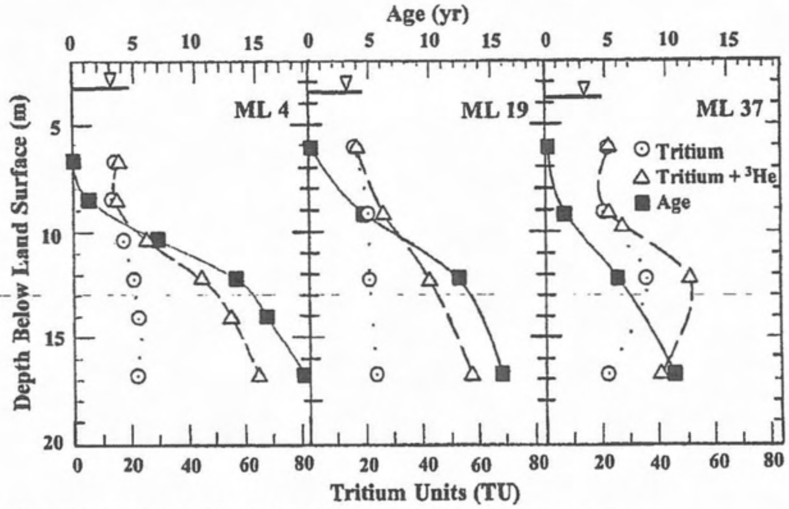

Fig. 4. Ground water age, ^3H, and ^3H + ^3He profiles in April 1993 from three piezometer clusters.

curately establish the average recharge to an aquifer. The slopes derived from linear regressions of the age profiles (Fig. 4) using all but the deepest piezometers in each cluster establish a recharge rate for the NE-MSEA. Data from the deepest sampling interval at the aquitard–water table aquifer interface are excluded due to mixing caused by pumping the high-capacity irrigation well, which is screened in the bottom third of the shallow aquifer. Across the site, recharge ranges from 90 mm yr^{-1} at the upgradient location (ML-4) to 250 mm yr^{-1} downgradient (ML-37) which represents 10 to 20% of the water input. The highest recharge rate occurs in the well cluster downgradient from the conventional field. It receives the greatest amounts of irrigation water (Table 1), and recharge is further enhanced by the blocked-end furrows (Fig. 2).

Investigations by Solomon et al. (1992, 1993) have shown that gas exchange at the water table, the enhanced diffusion coefficient for He, and the seasonal nature of recharge cause the $^3H/^3He$ *clock* to start at or near the seasonal low water table. At the NE-MSEA, the low water table normally occurs in early autumn and coincides with the harvest. Higher than normal precipitation between October 1992 and early summer 1993 caused a rise in the water table from 5.5 m to ~4 m. In spring 1993 the shallowest sample from each piezometer cluster had an $^3He/^4He$ ratio indistinguishable from air-saturated water. The estimated $^3H/^3He$ age of 0.0 ± 0.5 yr in these shallow samples supports their origins as seasonal recharge.

Nitrate-Nitrogen Profiles

Fall 1991 and 1992 NO_3–N concentration profiles of ~1000 samples collected from the 31 MLSs (Fig. 5) show that the average concentrations were consistently high (28.5 ± 5.5 mg L^{-1}) regardless of depth in the unconfined aquifer or areal location. The uniformly high concentrations with depth do not conform to profiles commonly reported in the literature, which, almost without exception, describe decreasing NO_3–N concentrations with increased depth (Hallberg, 1989; Libra et al., 1993; Spalding and Exner, 1993; Bohlke and Denver, 1995). The initial invariable NO_3 concentrations with depth appear related to a relatively homogeneous aquifer matrix, constant upgradient agricultural sources, and mixing that results from extensive pumping of large-capacity irrigation wells screened in the bottom third of the shallow aquifer (Zlotnik et al., 1995).

In response to heavy rainfall, NO_3–N concentrations in the fall 1993 profile declined ~10 to 20 mg L^{-1} and concentrations in many samples from the top 3 m of the aquifer declined below the MCL (Fig. 5). Nitrate–N concentrations (n = 85) in the uppermost 3 m averaged 11.6 ± 6.9 mg L^{-1}. The effect of the relatively low NO_3 recharge is clearly shown 3 to 6 m below the water table, where there is a linear increase (r = 0.96, n = 8) in the average concentration from approximately 12 to 25 mg NO_3–N L^{-1}. The precipitous decrease in average NO_3–N concentrations in the top 6 m of the aquifer accompanied a 2.4-m rise in the water table. Thus, infiltration of precipitation with relatively low concentrations of NO_3–N significantly improved the quality of the shallow ground water.

Improvements in NO_3 quality from the 1993 recharge were limited to the upper ground water, and NO_3–N concentrations in water deeper than 9 m did not decrease (Fig. 5). This deeper water with a ground water residence time >5 yr originated as infiltrate from upgradient fields and was laterally transported beneath the NE-MSEA at ~0.5 m d^{-1}. Thus, the first 3 yr of ground water NO_3–N data confirm that seasonal changes in water quality brought about by recent recharge can clearly be detected in shallow ground water (≤6 m) and that the depth of impact is limited by the volume of recharge. While the 1993 climatic conditions were anomalous, the NO_3–N concentrations in municipal wells in nearby Wood River and Shelton also were significantly reduced during another very wet spring in 1967 (Spalding, 1975). The data indicate that although extremely wet years and floods can cause agricultural and urban

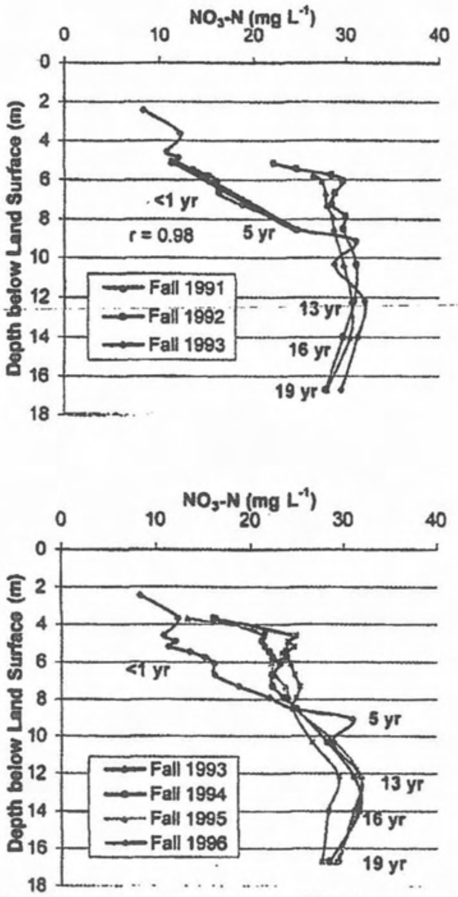

Fig. 5. Vertical profiles of ground water NO_3–N concentrations, fall 1991–1996, with regression line for NO_3–N concentration vs. depth below land surface in the mixing zone and 1993 ground water ages.

disasters, the recharge can be highly beneficial to shallow ground water quality.

For 3 successive years after 1993, average NO_3 concentrations in the shallow ground water rose (Fig. 5). Increases in the average NO_3–N concentration to approximately 25 mg L^{-1} in 1996 indicate concentrations were approaching premanagement levels of 30 mg L^{-1} under some management fields.

Each fall, NO_3 levels were lowest in the shallowest ground water sampler (Fig. 5), indicating that irrigation water had flushed most of the mobile NO_3 from the vadose zone, and that NO_3 concentrations in the most recent recharge were less than in the irrigation water. The latter is partially the result of uptake of NO_3 from irrigation water during the latter part of the irrigation season.

Shallow Ground Water Nitrate-Nitrogen Loading

An understanding of the controlling mechanisms and associations involved in long-term nonpoint-source shallow ground water loading are fundamental to the implementation of scientifically based management practices. During the 6 yr, seasonal average NO_3–N concentrations in the shallow ($\leq$1.5 m) ground water at the fences downgradient of the management fields were correlated with water levels and generally were cyclic (Fig. 6a and b). With the exception of 1993, when above normal precipitation resulted in a rising water table, the water table usually declined between summer and fall measurements, and NO_3–N concentrations in most shallow ground water increased. The declines are caused by irrigation withdrawals, which begin in mid-June and generally continue through the first week of September. The irrigation water, which is primarily pumped from the bottom third of the water table aquifer and has a concentration of 30 mg NO_3–N L^{-1}, as well as the NO_3 in the irrigation water, are partially utilized by the crop. The returning irrigation water leaches additional nitrate from the soils and transports it to the aquifer. Consequently, irrigation returns tend to increase NO_3–N concentrations in the shallow ground water. Hotter and drier growing seasons like 1994 require the application of more irrigation water with a resultant increase in shallow ground water NO_3 loading.

Differences in N leaching beneath the management fields can be further elucidated by the pore-water NO_3 concentrations (Fig. 6a and b). Pore-water NO_3–N concentrations reflect the timely monitoring afforded by lysimeters, which make the instrumentation useful in predicting trends in shallow ground water NO_3 concentrations (Watts et al., 1997). Concentrations in the pore water, however, can be significantly more variable than in the shallow ground water where pore-water inputs are attenuated.

Shallow ground water quality downgradient of each management field was impacted by irrigation and nutrient management strategies as evidenced by discernable differences in correlation coefficients and the magnitude of the standard deviations of the NO_3–N concentrations (Fig. 6a and b). The R values for seasonally averaged NO_3–N concentrations vs. seasonally averaged water levels ranged from +0.28 for the surge-irrigated field (Fig. 6a) to +0.92 for the center pivot-irrigated corn field (Fig. 6b). Since physical characteristics of the unsaturated zone beneath the fields are similar, NO_3–N concentrations downgradient of each management field likely reflect not only the different water and nutrient practices, but also the presence of *hot spots* associated with sites of deep preferential percolation. The regression plots showed more variability in NO_3–N loading occurred at the surge-irrigated field than at the conventional furrow-irrigated field. The most uniform NO_3 fluxes occurred beneath the pivot-irrigated corn field where as much as 84% of the variability in NO_3–N concentrations was associated with water level. The higher average NO_3–N concentrations and the larger fluctuations in NO_3–N concentrations associated with both furrow irrigation practices suggest that center-pivot application of irrigation water is the vastly superior practice for controlling NO_3 leaching.

Peak concentrations in pore-water NO_3 were especially pronounced beneath both furrow-irrigated fields

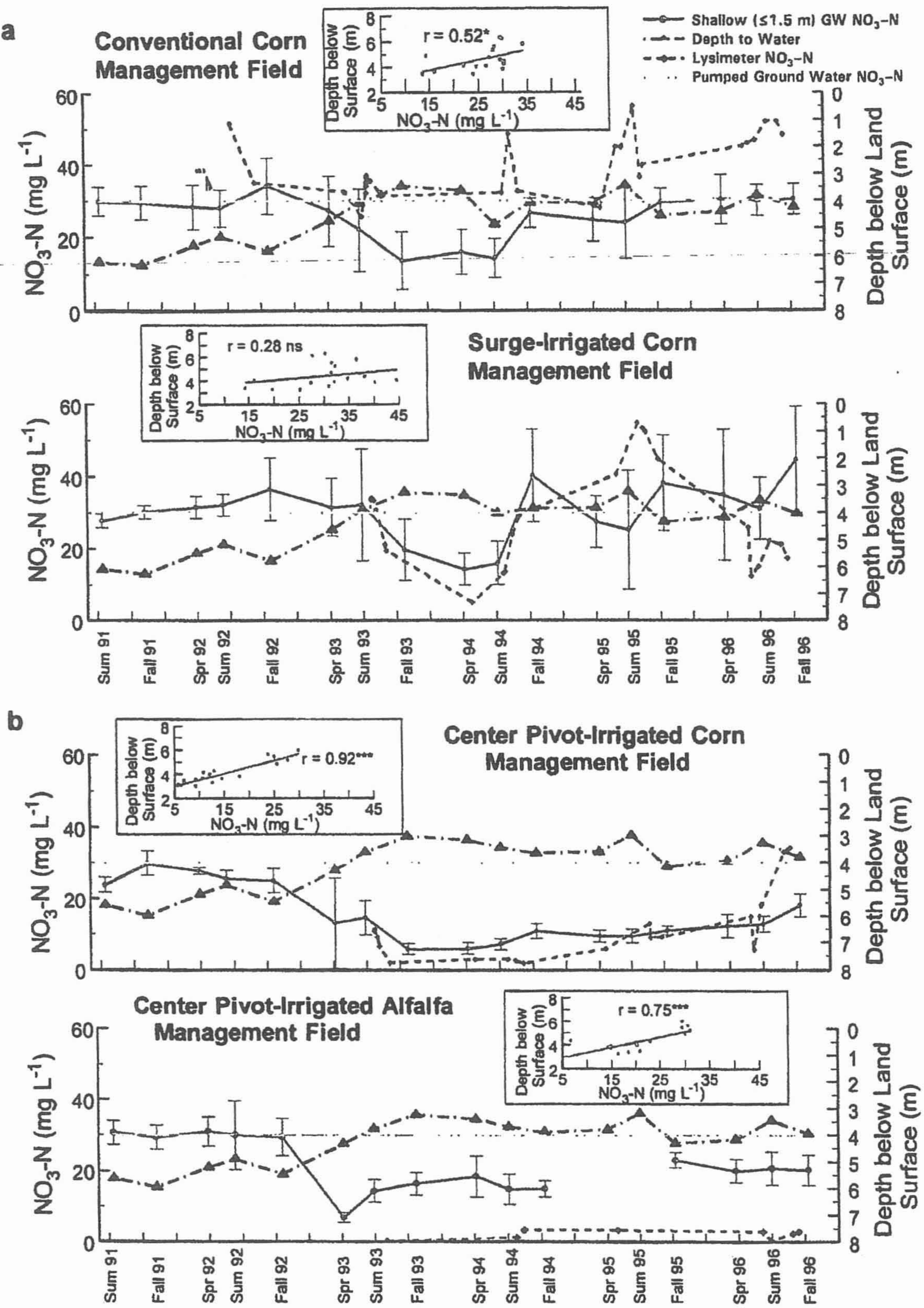

Fig. 6. Seasonal plots of average pore-water and shallow ground water NO_3–N concentrations and depth to water with inset plots of the regression line of the seasonal average shallow ground water NO_3–N concentrations vs. depth to the water table at the (*a*) furrow-irrigated and (*b*) pivot-irrigated management fields. Levels of statistical significance of *r* values are as follows: ns = not significant, * = significant at 5% level, and *** = significant at 0.1% level.

during the 1994, 1995, and 1996 growing seasons (Fig. 6a). Although Cahoon et al. (1995) documented that deep percolation occurred at the upper end of furrow-irrigated fields and also behind diked end-rows at the lower end of conventionally irrigated fields, these NO_3^- leachates were detected in the center of the fields (Fig. 2). Average pore-water NO_3–N concentrations rose approximately 20 mg L^{-1} at both fields (Fig. 6a) before the fall 1994 ground water sampling when concentrations rebounded to near or above the initial project levels of 30 mg NO_3–N L^{-1} and remained at that level for the duration of the study. At the surge-irrigated field, deep percolation of NO_3–N appeared enhanced by the preferential leaching of fertigation-applied N when the highly concentrated water ponded in furrows choked by storm-downed corn and weeds. Nitrate concentrations in ground water collected downgradient from the surge-irrigated field after the 1995 and 1996 irrigation seasons suggest that applying all or part of the N fertilizer requirement as sidedress was also detrimental to water quality (Fig. 6a). The fence downgradient of the conventional field first intercepts percolate from diked end-rows (Fig. 2) that were flooded during periods of excessive irrigation in 1996. The upgradient highly concentrated pore water appears to have been attenuated by the 30 mg NO_3–N L^{-1} recharge from excess irrigation water at the diked end-rows during ground water transport to the downgradient fence.

In contrast to the post-1993 rapid rebound in NO_3 at the fences downgradient of the furrow-irrigated fields, average shallow ground water concentrations at the pivot-irrigated corn field were considerably <10 mg NO_3–N L^{-1}, and pore-water NO_3–N concentrations remained <5 mg L^{-1} through spring 1995. Only after operator error resulted in a preplant application of an extra 22 kg N ha^{-1} before heavy spring rains in 1996 did the NO_3 levels in the pore water increase significantly (Fig. 6b). The rise in pore-water NO_3–N concentrations was accompanied by a marked increase in shallow ground water NO_3–N. Thus, a small overapplication of fertilizer N clearly was detected in the shallow ground water and caused NO_3 concentrations to rapidly exceed the MCL.

By design there were large discrepancies in total N applied to the conventional field compared with the surge and pivot-irrigated management fields (Fig. 7). On the other hand, the total amount of N applied to the surge and center pivot-irrigated management fields was quite similar. Differences in the amount of applied N were caused mostly by differences in the quantity of applied water. When irrigating corn with NO_3-contaminated water, leaching is limited by reducing fertilizer applications below recommendations, thereby causing the crop to extract N from the water. Hergert et al. (1995) suggested reducing the N recommendation for furrow-irrigated corn by the amount of N in 230 mm of irrigation water, which is less than the minimum amount of water applied by most conventional irrigators during the crop's rapid N uptake period that ends about 1 August. Irrigation applications on the conventional management field far exceeded 230 mm in all but 1993 (Table 1), the only year in which there was a reduction in shallow ground water NO_3 concentrations. Nitrogen fertilizer applications also exceeded recommendations in all but 1993. The 6-yr total fertilizer N application exceeded the amount of N removed in the grain by 438 kg ha^{-1}. Irrigation water in excess of the prescribed 230 mm was applied in 4 of 6 yr on the surge-irrigated field (Table 1); however, only in 1991 was this total exceeded before the end of the rapid N uptake period. Although N fertilizer was applied below or at recommended rates, the 6-yr total fertilizer N application exceeded the amount removed in the grain by 129 kg ha^{-1}. In theory, the expected reduction in NO_3–N leaching from the surge-irrigated field should have resulted in less adverse impact on shallow ground water than the conventional field. In practice, it did not. The surge technology was unable to adequately control leaching of N fertilizer, even when applied by split application for fertigation. In only the first year did irrigation water applied at the pivot field exceed 230 mm (Table 1). Total applied N was less than or equal to the recommended amount during the first 4 yr (Fig. 7). During the 6 yr, total applied N was only 80 kg N ha^{-1} in excess of that removed in

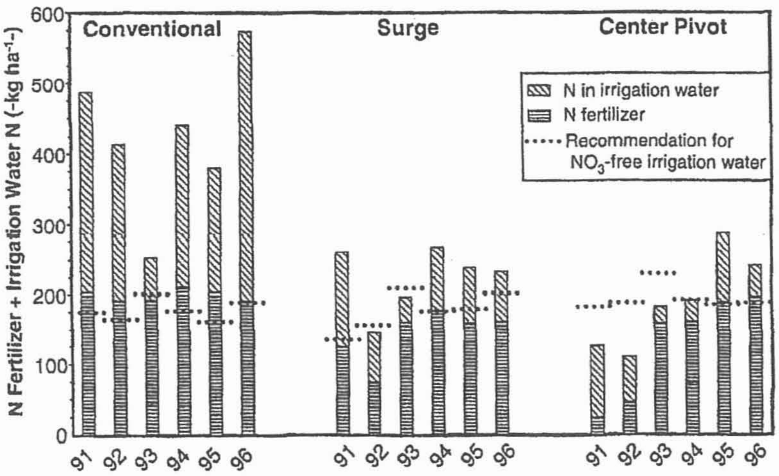

Fig. 7. Recommended N fertilizer application and N inputs from fertilizer and irrigation water for corn management fields. Recommended N for an expected yield of 12.6 Mg ha^{-1} is based upon 2% soil organic matter and residual NO_3–N in the upper 0.9 m of the root zone.

the grain, and the N application was 32% less than that on the conventional field. Thus, significant improvement in shallow ground water quality occurred only beneath the pivot-irrigated corn field.

Most year-to-year variability in grain yield was directly associated with weather (Table 2). Yields in 1992 and 1996 were outstanding while those in 1991 and 1995 were good. During the 1993 growing season, cloudy weather, excessive rainfall, and stalk breakage caused by high winds reduced corn yields to ~30% below average, while hail and high winds during the 1994 growing season stripped and knocked down the corn, reducing yields ~40%.

Even when a technology successfully reduces NO_3 leaching, farmer acceptance largely depends on yield. Yield variations ascribed to differences in management activities were not large and were sometimes misleading. The location of a tree-row partially shielded the furrow-irrigated corn, but not the center-pivot irrigated corn, from damage by wind and hail in 1994. Since the damage was preferential and not related to management differences, the yields were not used in the average yield calculations (Table 1). In 1992 the 15% reduction in yield on the pivot-irrigated field as compared to the conventional field was related to spatial variability in residual soil N and could be overcome with better knowledge of soil nuances and the use of precision fertilizer applications. An ~6% reduction in the 5-yr average yield for the pivot-irrigated management field relative to the conventional field should not adversely affect farmer acceptance, could be averted with a better understanding of the system, and was partially offset by lower fertilizer expense.

Nitrogen fertilizer was not applied to the irrigated alfalfa; however, the NO_3–N levels in the downgradient shallow ground water exceeded the MCL during all but one sampling period (Fig. 6b). The field was converted from continuous corn to a normal N_2-fixing alfalfa in 1990. Normal N_2-fixing cultivars remove about one-third less NO_3 from subsoils than do nonfixing N_2 cultivars (Blumenthal and Russelle, 1996). Reported interest in using alfalfa to remediate NO_3-contaminated soils has continued for the past 40 yr (Allos and Bartholomew, 1959; Stewart et al., 1968; Peterson and Russelle, 1991). Alfalfa can be very deep-rooted (Jodari-Karimi et al., 1983) and has been reported to remove water and N from 4-m deep capillary fringe zones (Lipps and Fox, 1964). By Fall 1992, the 3 yr old alfalfa roots probably reached the capillary fringe about 6 m beneath the surface. After the initial vadose zone inundation in Spring 1993, water table rises of >2 m during the next three successive sampling periods were accompanied by increases in average downgradient NO_3–N (Fig. 6b). The number of lysimeter samples collected beneath the alfalfa field was sparse because there was insufficient pore water for NO_3–N analysis during several sampling periods. However, when the volume of pore water was adequate, the NO_3–N concentrations did not exceed 5 mg L^{-1}. Thus, the NO_3 in the irrigation return flows appears to be removed in the shallow root zone and is not a significant contributor to the ground water contamination. This suggests that the N source must be deeper in the vadose zone, where water-logged alfalfa roots and nodules decayed and released substantial amounts of N after the water table rose. In alfalfa-dominated areas, shallow ground water NO_3 contamination has been reported by the Minnesota Pollution Control Agency (1998) and Robbins and Carter (1980), who reported significant levels of NO_3 from the mineralization of root material.

CONCLUSIONS

Well-designed and instrumented sites with MLSs give a clear indication of the impact of management changes on nonpoint-source–impacted shallow ground water quality. Nitrate concentrations in samples collected from lysimeters and MLS networks together with $^3H/^3He$ age dating of water at the Nebraska Management Site Evaluation Area indicated that weekly movement of N in the unsaturated zone was detectable, as were season-to-season changes in shallow ground water NO_3 concentrations. Fluctuations in pore-water NO_3 concentrations were more extreme than those in the more integrated shallow ground water.

The results demonstrate that the conversion from furrow to well-managed sprinkler irrigation would significantly benefit shallow ground water quality in the central Platte region and other corn-growing areas in the western USA. Uniform water application and the ability to apply supplemental N on an as-needed basis through fertigation substantially controlled NO_3 leaching beneath the pivot-irrigated management field. Farmers should be encouraged to adopt center pivot or linear spray irrigation techniques and best nutrient and water management practices to lower and maintain ground water NO_3 at or near compliance levels. It is recognized that water quality improvements will require a serious effort and probably include strategies for setting slightly lower yield goals and increasing crop use of NO_3 in irrigation water.

Surge irrigation was unable to satisfactorily limit NO_3–N leaching, negating any inherent water quality benefits of applying less water and N.

Although the sprinkler-irrigated alfalfa field did not receive N fertilizer during the 6-yr study, NO_3 concentrations in the shallow MLSs downgradient of the field showed there was significant leaching. The leaching appears to be associated with the age of the alfalfa and the timing of the rise in the water table that initiated root and nodule decay, releasing N to the shallow ground water.

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USDA United States Department of Agriculture

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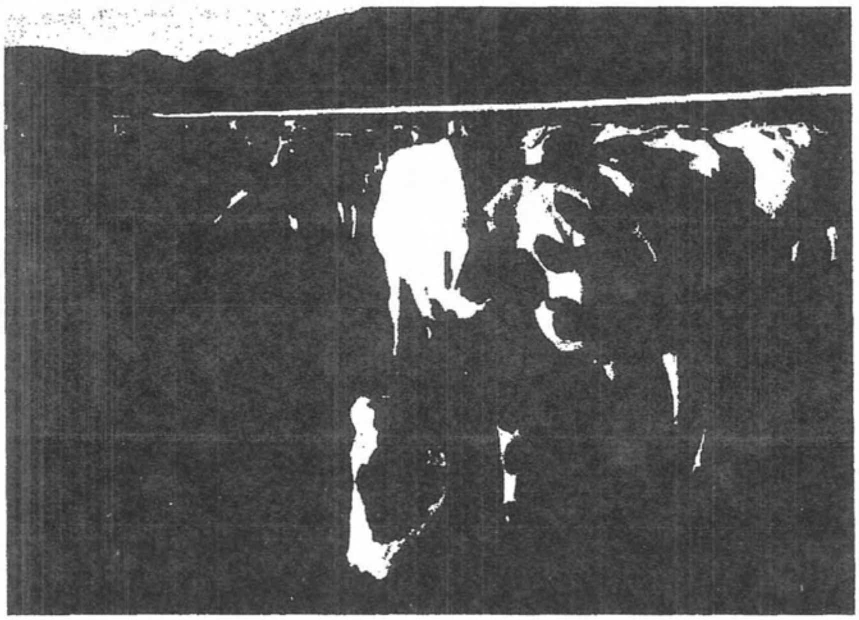
May 2007

Technical Note No. 1

Profitable Grazing-Based Dairy Systems



EXHIBIT

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Numerous people have provided source information, as well as expert reviews and comments. Their contributions are acknowledged and very much appreciated. This publication is intended to support and encourage the start-up of grazing-based dairy farms across the Nation whether they are organic or "conventional." With the interest in grazing-based dairies on the rise, this publication is timely. It is a helpful guidepost to those wanting provide their dairy cows fresh pasture for as long as their growing season permits. As an editor recently stated in a grazing magazine, pasturing dairy cows is conventional when we look at the long history of dairy farming here in the United States and the World. It has been a brief moment in history that we have confined dairy cows and hauled everything to them that they eat.

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Profitable Grazing-Based Dairy Systems

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Profitable Grazing-Based Dairy Systems

Introduction

This technical note provides background and general guidance on the concept of grazing-based dairy systems, defined as land management systems that seek to *optimize* dairy production through grazing. As a companion technical note to the Natural Resources Conservation Service sustainable agriculture tech note series, it focuses on associated economic, environmental, and social benefits.

Well-managed grazing-based dairies help protect soil, water, air, plant, and animal resources by maintaining dense vegetative cover on the soil, increasing soil organic matter, improving the distribution of nutrients on fields, and reducing the potential for odors, spills, or runoff from concentrated animal waste storage areas. Compared with traditional confinement dairies, grazing-based dairies harbor more wildlife, more diverse plant communities, and healthier cows with longer productive lives. In addition, grazing-based dairies often boost income by reducing feed, labor, equipment, and fuel costs. Less tractor time frequently increases leisure time or allows for expanded farmer enterprises. Grazing-based dairy systems also provide a lower-cost option to help some small family farms survive without expanding their business, or start dairying with less debt incurred.

This technical note has three parts. Part I defines grazing-based dairies and describes their ecological, social, and economic benefits. It may be of greatest interest to those wanting to know about the advantages and disadvantages of grazing-based dairy systems. Part II describes the considerations involved in developing or making the transition to a grazing-based dairy. It may be of greatest interest to those who have decided on grazing, but want more information on what is involved. Part III is a series of case studies from different parts of the country. Interest in individual case studies may depend on the geographic location of the individual reader.

Part I

Background

While dairy farming is undergoing rapid expansion in arid environments across the country, the overall number of dairies and dairy cows has decreased, but the number of cows per farm has increased. Dairy farm profits are increasingly affected by urban encroachment, rising land costs and taxes, and industry pressure to use the latest milk production technologies. Production per cow and total production have increased more rapidly than demand for milk, keeping pressure on dairy producers either to improve or to get out of the business. Nutrient management regulations to improve water quality are increasing the cost of manure handling. Recently, air quality constituents, such as odors and particulates, associated with confinement and manure storage facilities have come under more scrutiny, as well. Meanwhile, long-term average milk price trends have remained static, whereas short-term milk prices are unpredictable, often falling to unprofitable levels for several months during a production year.

As profitability of dairy farms declined in the 1980s and 1990s, it was common for managers to expand herd size, attempting to maintain or increase net income. As demand for feed and forage increased on a fixed land base, confinement systems seemed to be the appropriate response. However, dairy farmers soon found that large, confined herds required large waste management systems, greater housing investments, and more feed storage and handling equipment. After investments are made, the dairy manager often feels financially "locked in" to a confinement system, and thus, a cycle of ever-increasing herd size to spread fixed costs and increase net income continues.

Grazing-based systems are alternatives to highly capitalized systems of equipment, storage, and housing infrastructure. Grazing systems rely on two primary resources: pasture, the lowest cost source of feed available (Soder and Rotz 2001), and the dairy farmer's management skills. Because the cow ingests the standing crop, all intermediate steps required to feed the cow are eliminated during the pasture season. Forage reaches the rumen in high quality condition. Less purchased feed and manure handling is required. Fewer acres need to be harvested as stored forage.

Some time is shifted to moving herds and portable fences in rotational pastures. Yet, with well-designed layout of lanes and field divisions, this can be done in minutes rather than hours. Some time must also be devoted to honing skills on feeding supplements to pastured dairy cows, maintaining standing forage quality, and consistently providing enough forage throughout the grazing season.

What is a grazing-based dairy system?

Grazing-based dairy production systems that focus on specific application of grazing principles and practices are a subset of grassland agriculture. Grazing-based dairy production systems are broadly defined as *land use and feed management systems that optimize the intake of forages directly harvested by grazing cows*. This is in sharp contrast to confinement-based dairy systems, which are broadly defined as *land use and feed management systems that optimize milk production with confined cows consuming harvested forages*. Both systems generally use feed supplements to balance the dietary ration.

Grazing-based dairy systems are not "one size fits all." Landowner objectives, soil types, forage species, livestock genetics, land base, and climatic conditions differ from farm to farm. Production methods and management practices vary among farms, within regions and across the continent. Thus, while all grazing-based dairy farms share the common objective of optimizing the intake of forages harvested through grazing, differences in application are often necessary and appropriate.

The characteristics for an efficient, productive grazing-based dairy system are listed below. They focus on practices that optimize livestock performance (whether milk production or live-weight gain), pasture quality and dry matter yield, and the efficiency of forage utilization.

- Lactating animals are pastured using a rotational stocking method where the whole herd grazes a fresh paddock at least every other day and leaves an adequate forage residual (stubble) for optimal forage regrowth. Many graziers provide fresh paddocks after each milking.
- Lactating animals are stocked on pasture at least 75 percent of the grazing season (time of year when adequate grazable dairy forage supply and quality are present). Dry cows and heifers are stocked on pasture at least 90 percent of the grazing season.
- During each grazing season, lactating animals obtain at least 50 percent of their forage intake through grazing. Meanwhile, dry cows and heifers obtain at least 90 percent of their forage intake through grazing.
- Water is provided to the herd in the paddock in which they are grazing or in the laneway near the paddock.
- Paddocks are sized every rotation cycle to provide enough on-offer forage for adequate livestock intake during their time on each paddock while keeping adequate forage residual to maintain stand vigor and desired species composition. A back fence prohibits access to just-grazed paddocks while a front fence limits how much fresh, ungrazed grass is made available to the cows.
- Adequate, stabilized laneways are provided for ease of movement between milk parlor and paddock.
- Fields are sized and laid out so that forage on-offer is sufficient to meet grazing herd demand at all times throughout the grazing season. Fields are also designed for ease of mechanical harvest when needed to remove maturing forage in excess of herd demand during the current rotation cycle.

Pasture and pasture use

Pasture is fundamentally different from other livestock feed crops in three principal ways:

- It must be fenced.
- It is used while actively growing or standing.
- It is harvested by livestock.

Fencing is essential to successful pasture-based livestock feeding. Fences define areas of "feed" so that the dairy manager can ration the amount of forage provided to the livestock. Most systems have permanent perimeter fencing and single-strand, portable interior fences.

Dairy pasture differs from all other feed crops in that it is used while it is alive and actively growing (fig. 1). Consequently, it can change in quantity and quality on a daily basis, losing quality if allowed to get too old before being grazed. Pasture also changes in quality as the growing season progresses. Other feeds are generally harvested and preserved or conserved near or at full maturity and then fed to animals in measured amounts and qualities. Pasture also can be fed in measured amounts by estimating forage dry matter production and sizing a paddock accordingly to feed the herd for the length of the planned stay. However, pasture is generally harvested before maturity, when it is vegetative and very high quality. Pasture has no loss of dry matter by respiration and no shatter, leaf loss, or loss of quality by spoilage or rain damage that generally accompany perishable, stored forage production procedures despite efforts to reduce such losses.

Finally, pasture is harvested by livestock. Animals are the harvesting machines, but unlike mechanical machines they choose what and where they harvest and where they deposit animal wastes. These choices affect forage utilization and manure distribution. Cows shun urine and dung spots and unpalatable plants and plant parts. They often return the nutrients in manure to the pasture in a nonuniform pattern if shade, permanently placed water troughs, mineral feeders, or hay bunks are present that cause them to linger near those areas.

Grazing-based dairy pasture: *A unit of fenced land with productive soil that is managed to provide high quality forage for lactating dairy cows, replacement heifers, or dry cows as a significant portion of their diet throughout the pasture growing season.*

Manure distribution in intensive dairy grazing management can vary in warm versus cool weather (White et al. 2001). However, a structured grazing and clipping system can cause animal grazing to mimic closely the uniformity achieved by mechanical harvest and nutrient application. Cows are also extremely efficient harvesters. They leave behind forage that they neither desire nor need. Typically, this includes more mature forage. Grazed forage is usually less mature than mechanically harvested forage. This selectivity cannot be achieved by machines that harvest the good and the bad above the cutter bar.

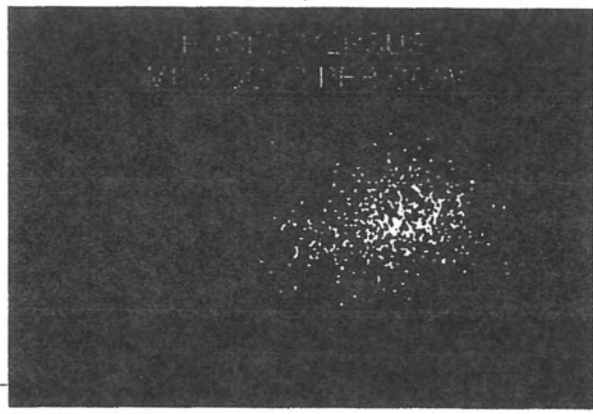
Grazing-based dairy systems require the simultaneous management of a forage production system, a livestock production system, and a forage harvest system. The grazing-based dairy replaces high input costs of a confinement dairy with the managerial skill of the grazier to ration high quality pasture well throughout the grazing season. Understanding forage plant growth patterns and responses to grazing is critical for effective management.

Characteristics of grazing-based dairy system

Dairy producers and supporting businesses and agencies often use milk production (rolling herd average) as the primary indicator to assess the economic success of various practices or systems. Despite the popularity of this indicator, the apparent correlation between milk production and net profit is weak (fig. 2), and its use is often misleading. In fact, it is possible for dairy

Figure 1 A healthy dairy pasture, note legume content

Figure 2 Profit as a function of milk sold per cow



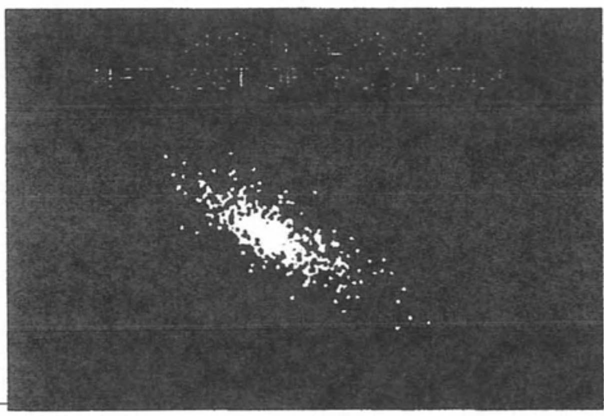
producers with high rolling herd averages to go broke (Smith et al. 2002). A much better indicator is net farm income from operations (NFIFO) per cow or net cost of production per hundred-weight (CWT) of milk produced (fig. 3).

Many grazing-based systems intentionally forgo maximum milk production to meet family and lifestyle goals. Even so, cases exist where grazing-based dairy herds exceed 20,000 pounds of milk per cow per year, and some individual producers routinely report herd averages of 24,000 to 26,000 pounds of milk per cow per year. Some grazing-based dairy herds are still quite profitable producing 15,000 pounds of milk per cow per year or less (Kriegel 2000). As shown in figure 3, dairies with the lowest cost of production generate the highest net profits. Using grazing-based systems can significantly reduce production costs.

Obstacles to grazing-based dairy systems

The greatest obstacle to the adoption and use of grazing as the central part of a production system for dairy cows may be custom and culture. Over the past 40 years, most dairy producers abandoned grazing-based systems for confinement-based systems to maximize milk production. As a result, confinement dairying is the only system many producers know. In spite of high debts and low profit margins resulting from increased mechanization and facilities costs and low milk prices, farmers are reluctant to try a grazing system and learn how to operate it. A mistake farmers sometimes make is to prolong the decision to switch to a grazing-based system until their debt margin is too great to be easily overcome, even with improved profitability.

Figure 3 Profit as a function of net cost of production



Other obstacles, real or imagined, include:

- Physical location of the barn or milking facility in relationship to the cropland that could be used for improved pasture. For example, it is too far for the animals to walk, or there are intervening physical barriers such as roads or watercourses.
- Good management skills are necessary, and new skills are needed. This requires the ability to adapt and the desire to learn.
- The concept of "optimum" milk yield versus "maximum" milk yield can be a tough sell given the dairy industry's tendency to equate high milk yield producers as the most successful dairy managers.
- Former confinement herds placed on pasture must become adapted both genetically and behaviorally to grazing. The genetics takes time.
- The kind of necessary equipment changes, resulting (sometimes) in the misconception that more equipment is needed and older equipment is being underused.
- Balancing rations with grazing selectivity and changing pasture quality throughout the season requires more attention to both the pasture and the animal.
- Herd size is too large for the land base. There is not enough available or potential pastureland to support the herd for the full length of the grazing season.
- Features or characteristics of the climate or land base (rough, broken terrain, wet soils, heat and humidity, periods of drought, or prolonged wet or cold weather) prevent efficient pasturing of dairy cows.
- A misconception persists that pastures are low yielding and, therefore, inferior to row and hay crops as a land use. This often results in managers relegating pastures to marginal lands and not improving them nor managing the grazing of them, thus ensuring poor yields and risking long-term sustainability.
- Forage base is not suitable in the short term to meet the quality or quantity requirements for dairy production. Fields that have been row-cropped or in hay production for many years take time and management to become densely grassed, highly productive pastures.
- Some or all paddocks lack a water supply. Developing a water system requires up-front capital, but some Farm Bill programs may provide cost-share assistance for water development.

- Farmers may also be concerned about the labor needed to move portable troughs, but moving these smaller troughs can be a part of the cattle moving routine.
- Current debt load requires consistent income to service debt. The producer cannot tolerate drops in milk income that might occur by switching to grazing either completely or partially while learning the tricks of the trade.

A good rule of thumb for grazing-based systems is that at least an acre of productive pasture is required for each lactating cow. This ideal acre would be within 1 mile of the milking facility or closer in hot weather. Typically, herd size is only limited by the ability of the soil to yield forage adequate to meet the requirements of the herd. Grazing-based herds of 200 cows or fewer are common, 500 are less common, and 1,000 or more cows are rare. Some producers use portable or low-cost, stationary milking facilities to handle pastures and tracts of land that are more remotely located from the main milking facility.

Lower milk production associated with grazing-based herds is the most frequently cited reason that some dairy producers do not adopt this system. The rationale does not necessarily consider both costs and return, however. Milk production levels at less than maximum can produce greater economic returns if costs are reduced significantly, as has been observed by some dairy graziers and economists. It really is more realistic to consider the optimum milk production level that will return the best economic results over input costs.

What are the benefits of this system?

This system of dairy farming provides more options than confinement dairy systems. Since grazing cows can produce milk at lower cost than confinement systems, grazing-based dairy farmers have a lower cost base, allowing for retention of a higher percentage of gross income in contrast to confinement farms. Producers can also try alternative forage crops to extend their herd's grazing season into fall or winter, or earlier into spring than is typical for their climate. Because less overall labor is required, farmers can spend leisure time off the farm, develop more efficient milking parlors, or pursue other income-providing or value-added enterprises that complement the dairy system.

Perhaps the greatest benefit to well-planned and managed grazing-based dairy systems is that they become more sustainable. This is achieved through a mix of practices that combine social, environmental, and economic advantages. Table 1 summarizes the ecological and social benefits of well-managed, intensive grazing systems. Further discussion of the social, economic, and environmental advantages follow.

Social advantages

Dairy farmers often cite improvements in quality of life as one of the greatest benefits when switching from confinement-based to grazing-based dairying. It still takes time and work to operate a grazing-based dairy, but the kind of work and amount of time changes. Labor involved in growing and harvesting forage and grain crops is reduced or eliminated and is replaced by labor to maintain fences and watering sites and to move cows. In fact, many people report they have more time to spend with family, or doing things other than routine essential confinement-based dairy chores (Ostrum and Jackson-Smith 2000).

Grazing-based systems can help young people become interested in and stay content with the lifestyle of dairy farming by reducing the long hours of hard work common to confinement systems. Start-up costs are also lower for grazing-based systems. This can eliminate a significant problem for young people with little equity to purchase a herd, acquire basic equipment, and rent or buy a farm.

Local communities and rural landscapes also benefit from family-sized grazing-based farms. These farms are more likely to recirculate agriculturally generated dollars locally to support the local community. Large, confinement dairies buy in bulk from the lowest bidder and often use outside businesses for their supplies, bypassing the local economy.

Rural landscapes with cows in pastures tend to be more appealing as tourism grows in importance in various regions of the country such as in the Northeast (fig. 4) and parts of the West. As an example, Whatcom County, a rural county in northwest Washington State, is dominated by small dairies, but ranks fifth in the state for visitor spending. Tourism, according to the Bellingham/Whatcom County Visitor's Bureau, directly creates 6,560 jobs, or 6 percent of the employment in the county in 2006 (Bellingham/Whatcom County 2006).

Economic advantages

Grazing-based dairy systems achieve an economic advantage primarily by using homegrown perennial forage crops. Perennial forage crops are long-lived feed sources whose establishment costs can be spread out over many years. Their yields may be

Table 1 Social and ecological benefits of intensive grazing systems

Ecological/social effects							
Human time	Little time devoted to managing herd	Planting, harvest, storage, and daily feeding required	Planting, harvest, storage, and daily feeding required	Multiple harvest, storage, and daily feeding required	Multiple harvest, storage, and daily feeding required	Multiple harvest, storage, and daily feeding required	Moving and maintaining temporary fences and watering systems and moving cows required
Animal health	Animal stress, soil ingestion, parasite ingestion possible	Confinement: hoof and leg problems, acidosis, udder health, animal stress possible	Confinement: hoof and leg problems, acidosis, udder health, animal stress possible	Confinement: hoof and leg problems, acidosis, udder health, animal stress possible	Confinement: hoof and leg problems, acidosis, udder health, animal stress possible	Confinement: hoof and leg problems, acidosis, udder health, animal stress possible	Improved leg/foot/udder health and less parasite ingestion and climatic stress
Soil quality	Compaction, erosion, reduced OM, reduced permeability likely	Wheel compaction when soils are wet	Reduced OM, erosion, reduced permeability, compaction	Compaction when soils are wet	Compaction when soils are wet	Compaction when soils are wet	Increased OM, compaction minimized, little to no erosion
Nutrient cycling	Nutrient hot spots. Nutrient deficiencies elsewhere. Nutrients may exceed plant needs on long-term overstocked pastures	Close fields tend to receive more nutrients. Higher use of commercial fertilizer due to nitrogen losses in confinement operations and often inefficient collection, storage, and utilization of manures	Nutrient uptake not uniform throughout growing season. Close fields tend to get more nutrients. Higher use of commercial fertilizer due to nitrogen losses in confinement operations and often inefficient collection, storage, and utilization of manures	Close fields tend to get more nutrients. Manure not often applied since it can be harmful to alfalfa stand maintenance. Requires commercial fertilizer applications instead, unless preceding crop receives excess manure	Close fields tend to get more nutrients. Nutrients used throughout the growing season. Higher use of commercial fertilizer due to nitrogen losses in confinement operations and often inefficient collection, storage, and utilization of manures	Close fields tend to get more nutrients. Nutrients used throughout the growing season. Higher use of commercial fertilizer due to nitrogen losses in confinement operations and often inefficient collection, storage, and utilization of manures	Nutrients in balance with plant needs. Nutrients used throughout the growing season. Good nutrient distribution
Perennial characteristics	Most are perennial, but annuals tend to invade. Re-establishment often needed	Frequent reestablishment of some species required	Reseeded annually	Re-established every 3-5 years	Periodic reestablishment of perennials. Annuals reseeded yearly	Perennial, but may be in a crop rotation with corn or other crops	Most are perennial. Occasional, optional reestablishment or overseed necessary
Water quality	Runoff and loss of sediment, nutrients, organics, and pathogens likely	Confinement: Water collection and management, manure storage, manure distribution, and nutrient management required to protect water quality	Confinement: Water collection and management, manure storage, manure distribution, and nutrient management required to protect water quality. Silage leachate potential rapid depletion of dissolved oxygen	Confinement: Water collection and management, manure storage, manure distribution, and nutrient management required to protect water quality	Confinement: Water collection and management, manure storage, manure distribution, and nutrient management required to protect water quality	Confinement: Water collection and management, manure storage, manure distribution, and nutrient management required to protect water quality. Silage leachate potential rapid depletion of dissolved oxygen	Water quality maintained with adequate buffers as needed

Table 1 Social and economic benefits of intensive grazing systems—Continued

Forage production	Less than soil potential; unpalatable or low producing species increase. Quality high on close grazed pastures. Spot grazed or zone grazed pastures have variable quality	High quality but more variable than other harvested forage. Lower production than other harvested forage. Stand loss occurs sooner	Good quantity, quality dependant on harvest and storage conditions	Good quantity, quality dependant on harvest and storage conditions	Good quantity, quality dependant on harvest and storage conditions	Good quantity, quality dependant on harvest and storage conditions	Generally high quality but slightly lower quantity than mechanically harvested forage
Air quality–odor	Fresh manure less offensive than stored manure. Manure build up around haybunks and near shade	Confinement: Concentrated animals and stored manure produce strong odors	Confinement: Concentrated animals, stored manure, and silage effluent produce strong odors	Confinement: Concentrated animals and stored manure produce strong odors	Confinement: Concentrated animals, stored manure, and silage effluent produce strong odors	Confinement: Concentrated animals, stored manure, and excessive silage effluent produce strong odors	Fresh manure less offensive than stored manure. No manure buildup
Energy–fossil fuel	Significant supplemental feeding or return to confinement required. Manure spreading energy costs are low. Futile reseeding efforts take energy	Energy costs associated with tilling, planting, harvesting, fertilization, manure spreading, etc., are higher than for grazing systems	Energy costs associated with tilling, planting, harvesting, fertilization, manure spreading, etc., are higher than for grazing systems	Energy costs associated with tilling, planting, harvesting, fertilization, manure spreading, etc., are higher than for grazing systems	Energy costs associated with tilling, planting, harvesting, fertilization, manure spreading, etc., are higher than for grazing systems	Energy costs associated with tilling, planting, harvesting, fertilization, manure spreading, etc., are higher than for grazing systems	Electric fencing required. ATV often used to move fencing, waterers, and cows. Some energy used to clip, harvest excess forage, and fertilize fields

reduced during years of less than ideal growing conditions, but they generally still provide a product without the annual costs of establishment. Annual crops, on the other hand, must be planted or seeded every year, requiring an annual outlay of cash for fuel, equipment use, labor, pesticides, fertilizer, and seed. These costs generally must be paid back with a single year's production, often a difficult task when the weather refuses to cooperate, sharply reducing yields or crop quality. In other years, insects or disease may reduce the yield or eliminate it. When crop production falls short, feed must be purchased. This dramatically increases the cost of milk production, because money is spent twice, first on a short crop and second on feed purchased to replace the reduced or failed crop. However, annual crops used wisely can complement perennial forage species to improve overall dairy cow performance, or grazing efficiency on some farms, particularly during transitions as perennial pastures are renovated.

Economic studies have demonstrated that well-managed grazing-based dairy systems tend to have higher net incomes per cow than similar sized confinement-based farms (Winsten et al. 1996; Cornell Dairy Farm Business Summary 1996–2000; Kriegel 2000, 2003). These increased economic benefits are primarily related to lower overall production costs, including crop production costs such as the following:

- labor, machinery and fuel to plow, plant, and harvest
- fertilizers, pH remedials, pesticides, and herbicides
- transport and storage costs

Figure 4 Rural landscapes with cows in pastures tend to be more appealing where tourism is important.

On most dairy farms, these crop production inputs account for 25 to 30 percent of the total costs of production (Ford and Hanson 1994; LaDue et al. 2000). Total feed (purchased and homegrown) costs run about 50 percent (Ford and Hanson 1994).

Any significant reduction in input costs will most likely improve net farm income. The amount of forage that has to be mechanically harvested, placed into storage, and then fed back out of storage is reduced by one day for every day that the cows harvest their own feed through grazing. This generally amounts to at least 5 months, depending on growing season length. It can be profitable to extend the grazing season by widening the mix of forage crops by planting cool- and warm-season grasses and forbs that grow or maintain their quality when other forage crops are dormant or low quality.

Grazing-based systems can also lower the costs for animal care and replacement. Cows tend to be healthier and have longer productive lives when they can get fresh air, eat high quality feed, walk more, are less stressed from milk production demands, and get off concrete or "dry" lots. Cows not pushed for maximum milk production tend to breed back more quickly and have fewer reproduction problems. As a result, cull rates and overall veterinary expenses are lower on grazing-based rather than confinement farms (Muller et al. 2002). Grazing-based dairies can also earn additional income by selling higher value springing heifers rather than cull cows, because fewer cows are culled. Alternatively, if they so desire, these dairies can more easily build herd numbers because they have more springing heifers than needed as replacements. However, seasonal calving grazing-based dairies may not enjoy reduced culling rates or fewer reproduction problems. Their cows must all breed back ideally in a narrow 60-day period, so they will calve in the same narrow time frame.

The collective and compounding advantage of reducing all of the production costs is what makes grazing-based dairy production profitable across many geographic areas.

Environmental advantages

Properly managed, intensive grazing systems can benefit soil quality, nutrient cycling, water quality, air quality, energy conservation, and wildlife and animal health (fig. 5).

Soil quality—Indicators of soil quality, including soil erosion, soil compaction, soil tilth, and soil organic matter content, improve when cropland is converted to pasture. The continuous vegetative cover provided by well-managed perennial pasture virtually eliminates soil erosion. This contrasts with erosion on poorly managed pasture that is sometimes only marginally better than cropland. Erosion occurs in abused pastures where plant cover is thin, and along streambanks where livestock have direct access and are not provided with off-stream water or shade.

Well-managed grazing systems can cause dramatic improvements to soil quality from organic matter or soil carbon accumulation. This contrasts with row crops, especially such crops as corn silage that return little in the way of root or aboveground biomass to the soil. In the southeastern United States, converting tilled cropland back to grassland increased soil carbon about 3.5 percent per year for up to 40 years until a higher soil carbon stability level was reached (Conant et al. 2000). Owens and Hothem (2000) found higher levels of soil carbon in pastures than in no-till cropland on the same soil types after 20 years.

Soil tilth is the physical structure of the soil that allows movement of water and air and plant root growth with the least restraint. Tilth is significantly improved with increased soil organic matter and decreased tillage, both direct results of conversion from a row crop based system to a grazing-based dairy system.

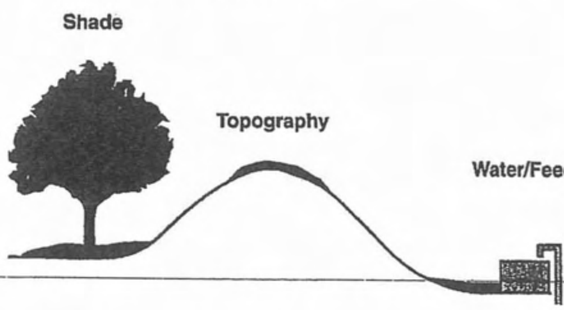
Nutrient cycling—Nutrients are effectively cycled onsite in well-managed grazing systems. Between 75 and 80 percent of the nitrogen consumed by grazing dairy cattle in feeds and forages passes through them and is returned to the pasture (Whitehead 1995). High producing dairy cattle on pasture are typically fed supplemental forages and concentrates to balance their diet. But the nutrients brought into the system tend to match or exceed the nutrients going out through milk production, creating a balanced system and making frequent fertilizer additions unnecessary. This is a clear advantage over hayland or cropland where most nutrients in the harvested crop leave the field and must be replaced with manure or inorganic fertilizer to maintain fertility levels. Between 70 and 90 percent of the phosphorus, potassium, calcium, and magnesium consumed is also excreted back onto the pasture (Mott 1974).

Confinement systems, which do not necessarily balance the number of cows they support with the land base available, are likely to import far more nutrients than the growing crops need, especially if manure is applied in addition to recommended fertilizer applications. This nutrient imbalance can lead to accumulation of phosphorus and potassium in particular. Excess potassium in the soil can lead to problems with plant growth and animal health. Excess phosphorus can lead to water quality problems.

While grazing-based systems are usually superior overall in nutrient cycling, management of the pasture system determines individual success because distribution of nutrients on pastures will be uneven if left unmanaged. In intensive dairy grazing systems, manure deposition is highly correlated with the amount of time spent in various areas (White et al. 2001). In areas where animals congregate, dung and urine spots disproportionately concentrate (fig. 6). In fact, the rates of nitrogen (N) application at urine spots can range from 200 to 900 pounds per acre (Barnes et al. 1995; Whitehead 1995; Stout et al. 1997). Intensive rotationally stocked pastures have a more even distribution of nutrients than continuously stocked pastures (Mott 1974). In either case it is extremely important to space water, feeding areas, salt and mineral boxes, and shade frequently and evenly on a rotational pasture so that animals are not inclined to loiter routinely in small, isolated areas.

Figure 5 Properly managed intensive grazing systems provide many environmental benefits.

Figure 6 Effect of preferential animal movement on manure distribution



Water quality—Erosion is minimal on healthy pastures. In general, sediment transport to water bodies is reduced as permanent pasture replaces tilled cropland. This does not, however, mean that nutrient loading to water bodies is reduced, since surface applied manure and urine nutrients may leave pastures during runoff events in overland flow. Factors that influence whether pastures will reduce nutrient loss to water include:

- stocking density/plant cover
- animal distribution
- rainfall intensity and duration
- water balance
- soil infiltration/percolation characteristics
- amounts and timing of surface applied fertilizer
- proximity to surface water

Pastures typically need fewer chemical applications than do annually tilled row crops. This reduces the potential for chemical pollutants to enter surface or ground water. Grazing-based systems have reduced risk of accidental animal waste spills since there are fewer or smaller manure collection, storage, and disposal facilities. Finally, these systems are not as subject to pollutant loss as are confinement areas and crop fields that receive recent unincorporated, high-rate applications of manure just before transport or runoff events. Where less manure storage is required, better application procedures, including application timing, are possible.

Air quality—Odors associated with fresh manure and silage effluent can be reduced on well-managed pastures as compared with poorly managed pastures or confinement systems. On well-managed pastures, animals tend to herd less, so there is less potential for concentrated manure areas to develop from which strong odors can arise. Manure and undigested feed decompose more rapidly in aerobic conditions found in pastures. In confinement systems, wet, accumulated waste can intensify the odor problem. The co-mingling of urine and dung in confinement systems increases ammonia volatilization. Ammonia combines with other chemicals in the air to form a regulated particulate (Tyrell 2002).

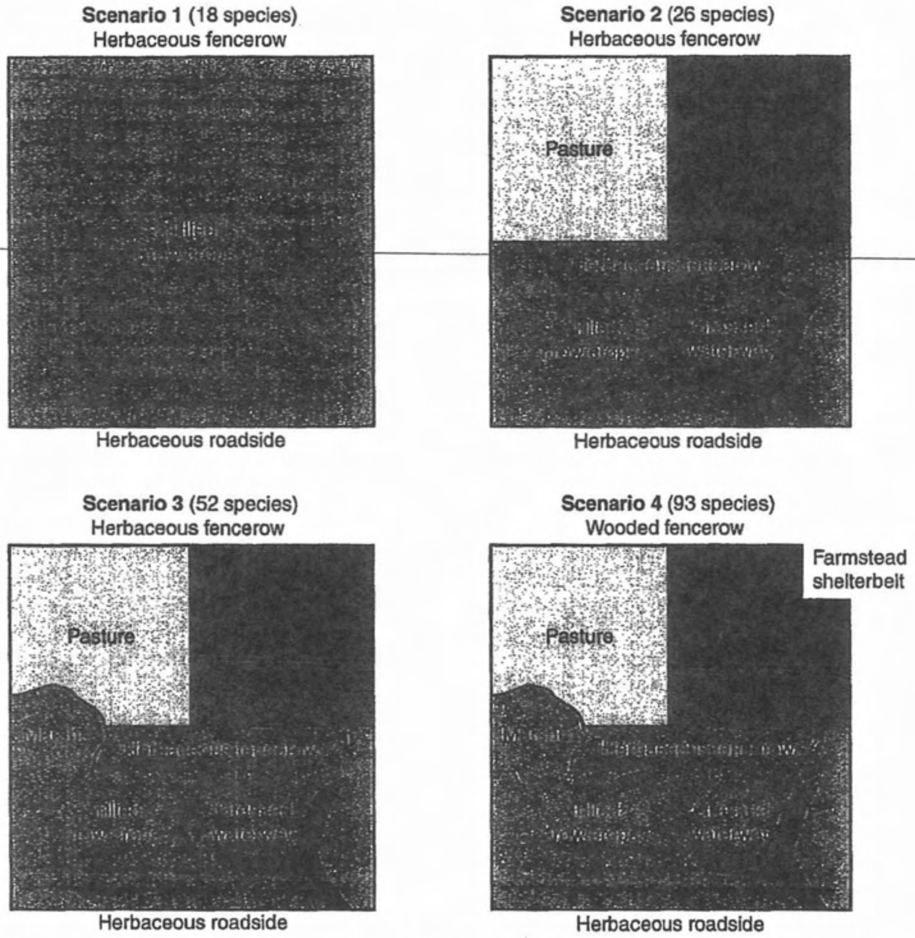
Energy conservation, wildlife and animal health—Under well-managed grazing systems, energy costs associated with tilling, planting, harvesting, fertilization, and manure handling are dramatically reduced. The handling of manure may be reduced from daily collection and spreading to once a week or less during the grazing season.

Pastures along with woody perennials can add an element of landscape diversity to row-cropped land. Wildlife that use grassland habitat or edges between land cover types are favored. Figure 7 shows how songbird numbers increase as pastureland and other perennial habitats are restored on a quarter section of farmland (Best et al. 1995). The perennial nature of most well-managed pastures reduces the need for soil disturbance and external chemical inputs. The diversity of soil flora and fauna also increases because of increased organic matter and decreased soil disturbance and farm chemical inputs.

Finally, a grazing-based system has marked advantages for animal health when compared with confinement. Dry cows get more exercise, which can facilitate calving ease and easier transition to lactation (fewer metabolic health issues). Hoof and leg problems, acidosis, udder sores, mastitis, and general animal stress associated with confinement are largely alleviated under pasture, although some animal health issues remain and new ones emerge. For example, under pasture, the potential increases for animals to ingest parasites. Also, if shelter is not provided, excessive heat or cold may cause stress. On the other hand, pastured cows exercise while they eat and walk to and from the milking parlor, allowing them to maintain better overall physical condition than cows in confinement. As a result, grazing-based animals remain productive over more lactations compared with cows kept in confinement systems.

Landscape-scale impacts—Grazing-based dairies are valued for their appearance in the landscape and often enhance regional tourism economies. The aesthetically pleasing and nostalgic characteristics of traditional barns, silos, open pasture, and tidy farmsteads attract visitors to a dairy area. These landscapes become even more valuable as larger, industrial appearing confinement dairies replace smaller dairies.

Figure 7 Effect of agricultural landscapes on nesting bird species (modified from Best et al. 1995)



These four agricultural landscapes (scenarios) represent a range from an intensive row-crop monoculture to a diverse mixture of crop and noncrop habitats. Each illustration is intended to represent a quarter section (160 acres) of land. The maximum number of nesting bird species is given in parentheses.

Who should implement a grazing-based dairy system?

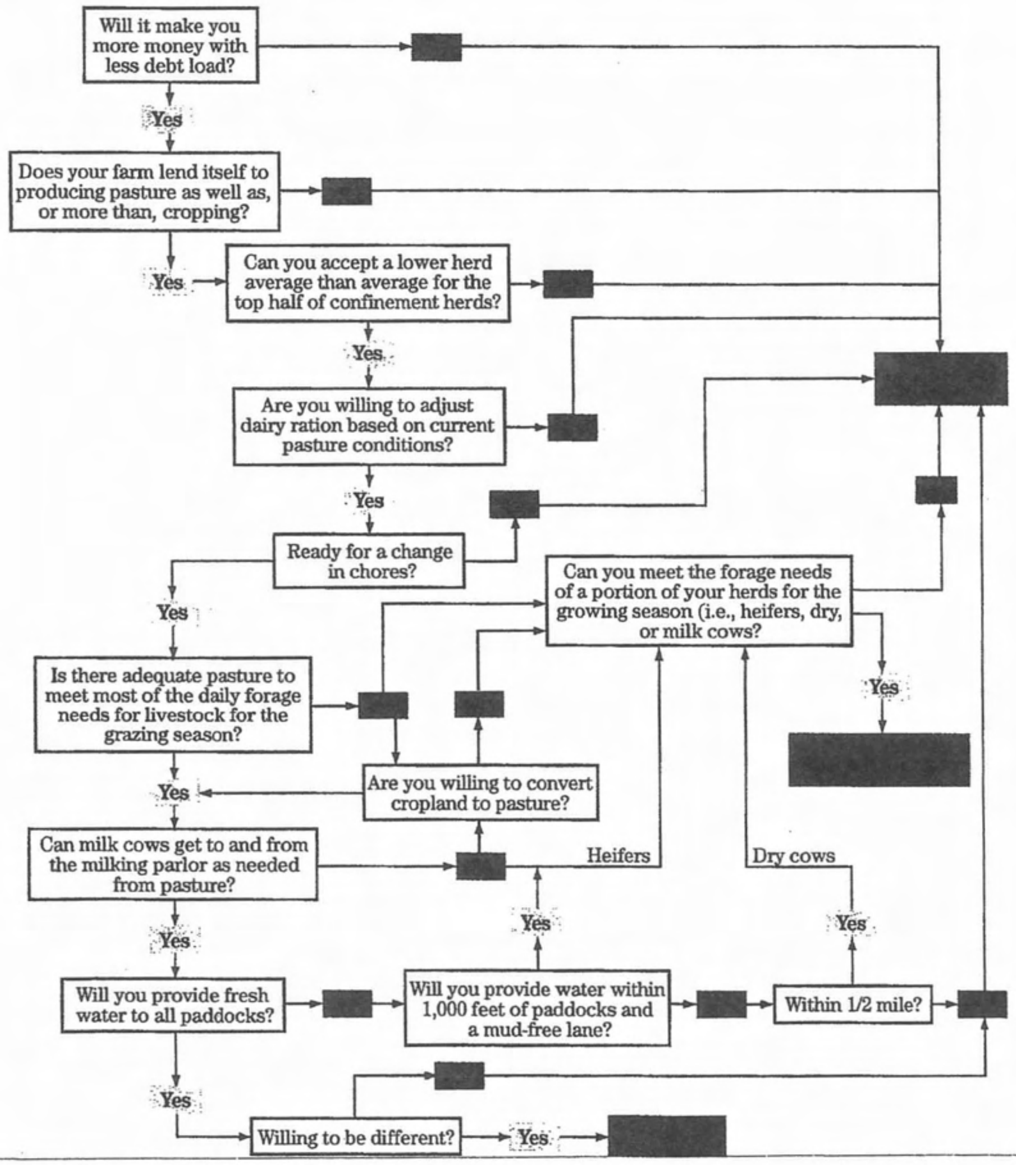
Despite many advantages, a grazing-based system is not for all dairy farmers. Figure 8, based on a list of questions developed by the Cooperative Extension Service in New York, Iowa, and Wisconsin, provides a schematic of a thought process for determining when intensive grazing is an appropriate system for a given dairy. If the answers lead to consideration of a grazing-based dairy system, the farmer should contact the local USDA, NRCS, Conservation District, Cooperative Extension office, or a private consultant to explore available options or alternatives for solving resource problems and increasing profitability.

Question: Is it really hard mentally to go from confinement operation to the grazing level?

Answer: [illegible]

[illegible]

Figure 8 Is intensive grazing for you?



Part II

Considerations for implementing a grazing-based dairy system

Economic considerations

Farmers need to clearly understand their economic goals, whether they propose to start up a dairy or remain in the dairy business. How many hundredweight of milk are needed to produce the desired net return to meet principal and interest payments and other costs of running the farm? For the start-up grazing farm, this analysis may be simple because investment can be limited at the outset to purchase only the absolute essentials in equipment, cows, and land to get started. It may mean renting for a while to keep capital costs down. Existing confinement dairy farms that carry holdover debt from machinery and facilities, may find transitioning to grazing more difficult. However, selling unneeded machinery, equipment, and other items can help lower debt principal, making payback easier.

Another economic consideration will be the transition from cropland to pasture. This transition requires substantial time and reinvestment in fences, forage seed, lanes, and watering facilities. Whatever the case, planning for the possibility of low milk prices that would make it difficult to meet all cash flow needs is imperative. Then, determine what other outside income sources are available to meet this low milk price contingency. Farm expenses must be satisfied before discretionary family living expenses. A planning horizon of at least 3 years is needed to project income, expenses, and cash flow if major changes are to be implemented.

Marketing—A marketing strategy is essential for economic success when starting or changing to a grazing-based dairy business. Some fundamental questions to consider are:

- What kind of milk market is already in the area?
- Can you sell to either the fluid milk market or a processing milk market?
- How many processors within hauling distance are willing to buy and pick up your milk?
- On what basis is the milk priced (butterfat, solids, protein, and volume)?
- Are specialized milk market opportunities available for milk produced in a pasture-based system?

Direct marketing may be an option for some. It may use much of the extra time gained by going to a grass-based system. A "people-focus" is required to win over a customer base and keep them happy and returning. Another skill set, licenses and permits, and additional equipment must be acquired to process the milk into the product to be sold. Direct marketing also requires taking some level of risk as it goes against the established, consolidated milk industry that is specialized in function. A misstep in direct marketing can be costly.

Sustainable Agriculture Technical Note 2, Marketing Tips for Sustainable Agriculture, provides a variety of references that may help you develop a marketing strategy for your dairy. It can be found electronically at *http://policy.nrcs.usda.gov/media/pdf/TN_SA_2_a.pdf.*

Transition period—All economic aspects of a changeover must be considered when attempting major shifts in production and operations. Once the decision to change has been made, a set of transition actions and considerations should be prepared. Needed actions include:

- Improving the milking facilities so that more cows can be milked in a shorter time.
- Improving pasture fertilization by soil testing and following recommended fertilizer rates.
- Keeping fixed costs low—avoiding the purchase of expensive farm machinery without careful analysis.
- Rationing pasture forage based on estimated herd dry matter intake for the grazing period used, quantity of standing forage presented to the herd within the paddock, and a nutritional analysis of forage samples collected from pastures throughout the season.

Seasonal calving, a potential modification to a grazing-based dairy, can be a successful venture, but there are many aspects to consider before making such a move. Transition from confinement to grazing is a major step, and switching to seasonal calving at the same time would not be advisable. Consider the following when embarking on a seasonal calving operation:

- Plan to transition the lactating herd into a seasonal calving herd so that it can provide cash flow to meet debt payments. For example, it may mean prolonging the lactation period of some cows and delaying their being bred back to get all the cows on the same breeding schedule. Also, some breeds and individual cows within breeds may be difficult to maintain in a seasonal system because of lower estrus detection and fertility (Washburn et al. 2002)

- Milk production will be much lower during the transition.
- Will the processor accept milk when the amount of milk supplied daily is more variable?
- Facilities and labor must be available to feed and care for all of the newborn calves simultaneously. Additional laborers may be needed to handle all the cows calving at once.

Ongoing evaluation—Another factor in achieving desired economic goals is ongoing evaluation of changes and analysis of how these changes affect performance outcomes. Some of the more important evaluation tasks include:

- keeping good production records and using a reliable accounting system to track farm performance, preferably on an enterprise-by-enterprise basis
- monitoring quality and quantity of milk produced by its measurable constituents
- monitoring forage quality regularly and adjusting rations accordingly
- monitoring animal health
- monitoring pasture growth at least weekly in all paddocks
- establishing a good advisory team (e.g., veterinarian, nutritionist, economic consultant)

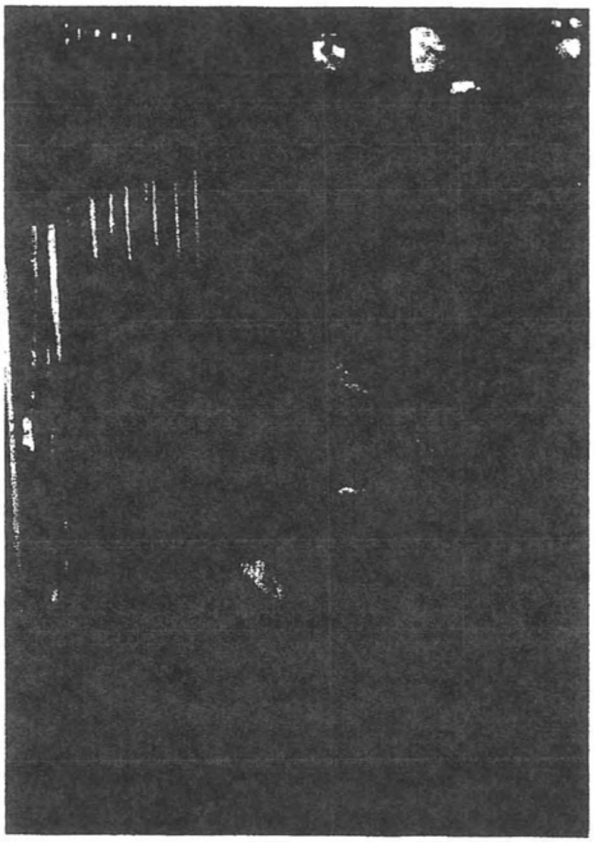
Animal-plant interactions

Grazing animals and pasture plants have co-evolved over time. This plant-animal co-evolution occurred in an uncontrolled setting, however. Once grazing animals are enclosed in a pasture, it is essential to plan stocking densities so that the animals do not undergraze or overgraze the plants. If too densely stocked, desirable grasses are overused and can weaken and die out. Chronic overgrazing leads to a dominance of unpalatable and/or low-yielding species. If under stocked, little-grazed or ungrazed areas may appear as random patches or in less accessible places or more distant places from water. These areas become less productive and even less desirable over time because of invasion by taller plant species and the presence of standing dead residue that shade and slow new shoot growth, causing further livestock avoidance. Good pasture management ensures that both the animals and the grass prosper.

Animal nutritional requirements—Under United States economic conditions, dairy cows are usually supplemented with concentrates for optimal milk production (fig. 9), whether they graze standing forage or eat stored forages (Peyraud et al. 1999). Most United States herds will not reach their genetic potential to produce milk on a grazed grass-only diet (Mayne 1998) without supplemental rations to account for nutritional deficiencies and changes in the quantity or chemical constituents of the grass being grazed. Optimal amounts of supplements for grazing dairy cows may vary by farm and across seasons within a farm. Methods to gauge the quality of the ration balance include the following:

- Testing the forage frequently to monitor changes in quality across seasons, weather conditions, and forage species and maturity. Send forage samples to a nearby certified forage-testing laboratory. Check this Web site: *http://www.foragetesting.org/*.

Figure 9 Under United States economic conditions, dairy cows are usually supplemented with concentrates in a mixed ration for optimal milk production.



- Monitoring milk production and constituents to see how cows are responding to changes in diet quality and climatic conditions. For instance, monitoring milk fat production to ensure the herd is ingesting enough effective fiber for cud chewing.

Applying proper supplementation strategies requires experience. New producers and those thinking about substantial grazing-based dietary changes should work with an animal nutritionist familiar with pasture ration building to ensure the optimal ration balance for the dairy herd at all times.

Forage species selection—Proper selection of forage species is needed to ensure that forage is high quality and highly digestible. Guidelines for selecting forage species follow:

- Use a mix of disease-resistant varieties of forage species (4–5, includes legumes) adapted to local soils and climate that will produce adequate forage on-offer during each grazing period throughout the grazing season.
- When different desired forage species do not grow well together because of competition or maturity differences, grow them in separate pastures.
- Use seasonal pastures if forage species can be chosen that grow best at different times of the year and the number of grazing days can be extended by doing so.
- Use species with the best regrowth potential during the grazing season. Offer the cows 80 to 100 pounds of forage dry matter per cow per day in the paddock at turn-in (Muller et al. 2002).

Animal selection—Dairy graziers need to select the best artificial insemination (AI) bulls. Bull genetics can be evaluated using the following Animal Improvement Programs Laboratory (AIPL) Web site: *http://www.aipl.arsusda.gov/*, and then clicking on **Active AI Lists** or **Top Bull Lists**. A bull's predicted transmitting ability (PTA) values are useful for predicting daughter performance on pasture (McAllister 2002). The only exception for this is the PTA for milk fat. Grazing herds can have significantly lower average milk fat percent and milk fat production than confined herds. PTA fat is, therefore, a poor predictor of a sire's daughter fat production in grazing herds (Weigel and Pohlman 1998). Another Web site for selecting AI sires is *http://www.dairybulls.com/*. This Web site identifies bulls by specific trait, background, and location.

Reproductive traits are important for seasonal calving (Washburn et al. 2002). Cows must conceive as a group (within 60 days) so that a 12-month calving interval is maintained and all cows can be dried off at the same time. Seasonal graziers may benefit from using the USDA productive life (PL) and daughter pregnancy rate (DPR) trait information at the AIPL Web site, by either clicking on **Active AI Lists** or **Top Bull Lists** and going to the **PL** and **DPR** columns for each bull of interest. Another good indicator is estimated relative conception rates (ERCR) now at the AIPL Web page: *http://www.aipl.arsusda.gov/eval/summary/ercr.cfm*.

Generally, dairy graziers, seasonal or not, need to select animal traits that allow for high dry matter intake, ease of gain, survivability, and the relationship these factors have on timely breed-back. However, before deciding on the crossbreeding option, read the McAllister paper in its entirety and gather more facts. Crossbreeding needs to be done with care. Cows with a high genetic trait to produce over 66 pounds of milk daily during early lactation (Sayers 2001) often fail to breed back easily on pasture. If not supplemented well, their feed intake becomes too low to maintain weight, thus they lose too much body condition to conceive at first or second service. Success with a sire is measured by having daughters with good milk yield that have been successfully rebred on grazing-based dairies (Mayne 1998). This technique requires patience because it will be 3 years before the outcome is known with a first calf milk-producing heifer.

Paddock layout and design

For lactating dairy cow herds, paddock systems should be set up to efficiently strip graze fields. Strip grazing involves using movable front and back fences so that new forage is offered to the herd after each milking. The pasture itself works best as a rectangle about a quarter mile wide with a lane lengthwise through the middle (fig. 10). With this configuration, the paddocks on either side do not extend beyond 660 feet from the lane to the perimeter fence. This ideal set-up keeps the distance to water in each paddock relatively short. However, other configurations can work where terrain and farm boundaries do not allow for the most efficient setup. The animals are watered from a portable trough moved with each move to fresh grass. The water is furnished to the trough through convenient coupling attachments from a pipeline traveling along the lane.

Another advantage of this layout is its suitability for cutting and harvesting excess forage. With only two permanently fenced subdivisions and a laneway, forage too mature for grazing can be easily cut and harvested for later use with a minimum of turns. The pasture field(s) should be allocated to ensure that just enough vegetation is cut so cows will not be grazing overmature forage at times or regrazing paddocks where forage is too immature and short at other times.

The following design considerations are effective in installing long-lasting serviceable laneways:

- Construct laneways with a relatively flat grade, but allow some elevation change for drainage along the length. Side-to-side drainage can be achieved by crowning the lane or using graded deflectors to collect water and redirect it into a stable grassed area (fig. 11).
- Harden steep or heavily used laneways. A layered, compacted composite of filter fabric cloth (bottom layer), coarse stone or gravel, and fine granular material (top layer) are typical components (fig. 12).
- Maintain laneways regularly to avoid trail ruts that can deliver sediment, nutrients, and bacteria to nearby waterbodies.
- Make sure the topcoat material of laneways is foot-friendly and does not bruise or injure feet.

Water distribution

A single, fixed watering site should be avoided when distance to water is greater than 800 feet. Multiple, dispersed water sites ensure that lactating dairy cows do not spend too much time in laneways. Excessive travel time:

- degrades laneways and gate openings
- increases the potential to move nutrients and other pollutants offsite
- increases the potential for nutrient transfer to those areas not needing additional nutrients
- reduces milk production by depressing water and forage intake (cows at a watering facility are unlikely to return to the paddock if far away or during hot weather)
- increases the amount of energy used by the animal for nonproductive activity (walking to/from water), energy otherwise devoted to foraging or lactation

The equipment necessary to hook up a portable water trough is readily available and inexpensive. A pressurized delivery system is best for portable troughs. Troughs should be kept full at all times to keep cows well watered and prevent them from overturning them. Install a pipeline to serve all paddocks. Pipelines can be laid on the soil surface at the lane fence if polyethylene water tubing is used. Burying in a trench is preferred to deliver cooler water and reduce maintenance. However, burying involves a long-term commitment to the layout as it is now. Do not restrict flow by using a narrow diameter pipe. Winterize as needed.

Figure 10 Hypothetical paddock layout design

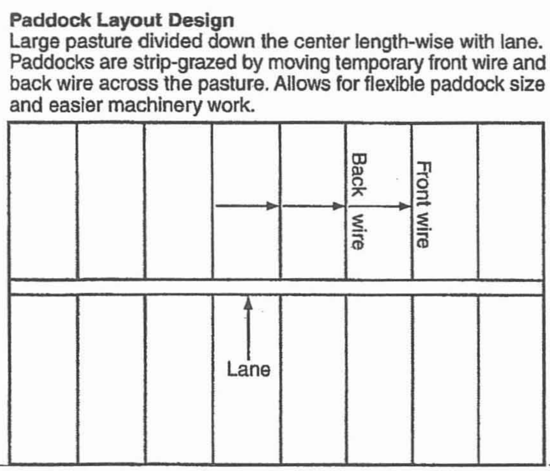


Figure 11 Water bar design

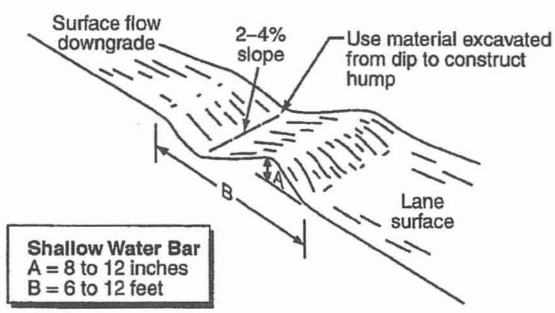
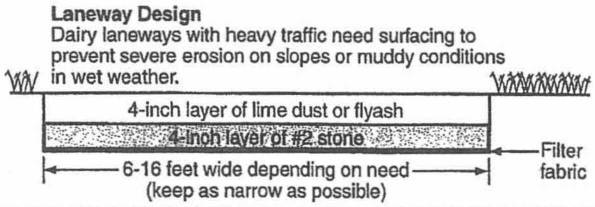


Figure 12 Laneway design



Pastures with live streams in them should have an alternative livestock watering facility to decrease livestock visitation to the streambed and banks. Ideally, these pastures should also be isolated as a separate treatment unit and grazed less intensely, and only under firm soil conditions. This sharply reduces problems associated with water contamination from bed and bank erosion, as well as from manure and urine. Water in ponds and streams can be of questionable quality. An improved stream crossing may be necessary when cows must cross the creek in a streamside pasture or gain access to a set of pastures flanking either side of a stream. Livestock ponds should be fenced and an appropriate grassy buffer established between the fence and pond's edge. If pond water must be used to water livestock, use a siphon hose or gravity flow pipe to convey water to a trough outside the pond fence. These actions improve water quality for receiving bodies and often improve herd health by reducing the transmission of water-borne diseases and parasites through direct udder contact or ingestion. This can contribute to the production of higher quality milk and a healthier herd.

Avoiding environmental problems

Soil compaction is perhaps the most serious resource concern that can occur because of livestock on poorly managed pasture. Compaction can occur wherever cattle tread on moist soils. It increases runoff, reducing plant-available moisture, (Dickerson and Rogers 1941), and reduces soil pore space, making root penetration and nutrient uptake more difficult (Hodgson 1990; Gradwell 1965; Tanner and Marmaril 1959; Kok et al. 1996). However, rotationally grazed pastures are less likely to be compacted by cattle traffic than continuously grazed pastures in that they limit access of dairy cattle to a small area at any one time and are vacated between rotations and during the dormant season (fig. 5). Cropland soil compaction often occurs from wheel traffic on moist soils. This compaction can penetrate deep into the soil and be difficult and expensive to correct. Soil compaction by livestock traffic is most severe at the surface, but can extend 1 foot into tilled soil of annual forage crops (Krenzer et al. 1989).

Streambank and shoreline erosion accelerated by livestock can be prevented or remedied by

- providing alternative watering sites
- controlling the grazing duration and leaving a higher stubble
- providing abundant forage outside the immediate banks
- providing shade away from the stream
- providing cattle watering ramps to water's edge
- improving stream fording areas
- fencing off sensitive (or easily disturbed) areas to control or prohibit access

Managing overall plant growth

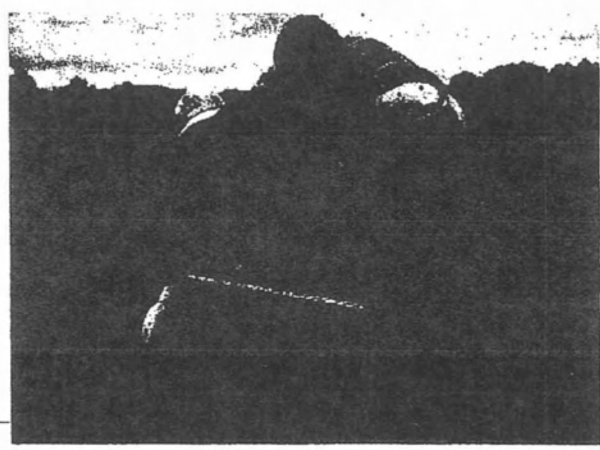
All effective grazing systems require a grazing plan. Knowing when to start grazing a paddock based on estimating dry matter production and monitoring grass growth helps the farmer determine when the paddock will be ready to be grazed again. There must be enough paddocks to complete the rotation cycle so that the first-grazed paddocks are ready for regrazing.

When forage plants are experiencing high growth rates, excess pasture can be machine harvested and stored. This extra output is crucial during periods of low forage production, such as mid-summer for cool-season species pastures or where freezing weather or drought causes forage production to cease. During periods of slow growth, additional paddocks are required so that a rotational cycle can be lengthened to a maximum of 40 to 42 days to ensure sufficient regrowth while maintaining forage quality. If the current and projected weather might prevent sufficient regrowth, then stored forage can be fed along with pasture to maintain intake.

Monitoring forages

Grass growth should be monitored and recorded in a log at least once every 2 weeks. For the greatest accuracy, forage should be measured in the paddock just vacated and the paddock to be occupied. Take several measurements on each paddock using a ruler, pasture stick, or rising plate meter (fig. 13). These measuring devices must be calibrated to convert height into forage dry weight. Experienced graziers can often

Figure 13 Monitoring forage regularly is important for determining the number and size of paddocks needed and proper feed ration for the herd.



estimate forage production by eye, but it is useful to calibrate the eye with field measurements from time to time. Forage from several random small areas of known size may be clipped, dried, and weighed for accurate yield determination. Visual checks may be inadequate for changes generated by climate or soil conditions because grass stands change in composition and thickness over a grazing season.

Complete records should be kept by individual paddock even when strip grazing. This information can be used to predict in advance how many paddocks are needed and how big they should be.

Monitoring forage quality through regular testing (at least every 2 weeks or when forage species or quality is noticeably different) aids in formulating a proper feed ration. Proper ration balancing is needed to keep milk flow and constituents at their best for the season and lactation cycle of the herd.

Monitoring animals

To keep grazing cows at the body condition score (BCS) appropriate for the portion of the lactation cycle they are in, their BCS must be monitored throughout the cycle. Body condition is extremely important at breeding to keep the cow on a 12-month calving cycle. Using the dairy cow BCS scale of 1 to 5, they should freshen (calve) with a BCS of 3+ to 4– (Wildman et al. 1982). Pastured cows tend to be trimmer and will score lower than this at 3 or slightly less (Washburn et al. 2002). They should lose no more than 1 BCS during early lactation to avoid ketosis and rebreeding difficulties (Mahanna 1998). The following Web sites may provide additional information on BCS:
http://cahpwww.vet.upenn.edu/dairy/bcs.html
http://www.dasc.vt.edu/extension/nutritioncc/ELANCO.html

Monitor dry matter intake—Cows generally reach maximum daily intake 10 weeks after freshening (calving). At this point, they should be eating 4 percent of their body weight. For every 2 pounds of expected milk production, the cows should eat 1 pound of dry matter. Otherwise, they lose too much body condition and become prone to metabolic disorders. Forage consumption should be at least 2 percent of body weight to assure proper rumen function. Hot weather depresses intake. Temperatures above 75 degrees Fahrenheit cause a 3.3 percent drop in dry matter intake for each 2.2 degrees Fahrenheit increase. Heat stress occurs when temperatures exceed 80 degrees Fahrenheit, relative humidity exceeds 80 percent, or the two combined exceed 140 (Mahanna 1998).

In warmer regions, mid-day shade is needed to maintain intake (West 1995). Either provide portable shade in pastures or keep the milking herd off pasture and furnish stored feed under cover during the heat of the day. Pasture the herd at night when air temperatures are cooler. If possible, paddocks with natural shade areas should be rotated to avoid excessive nutrient accumulation in any one area when heat and/or humidity are extreme.

Monitor milk production—Ideally, milk production should be monitored for individual cows. If this is impossible, then farmers should monitor the bulk tank at end of each milking. Chart milk production and compare it with a normal chart for your region, dairy breed, and rolling herd average. Instructions on how to chart milk and use milk charts is in Dairy Production and Management Benchmarks, University of Georgia College of Agriculture and Environmental Sciences Extension Publication B1193 (Smith et al. 2002).

Monitor milk quality—Milk protein-to-fat ratios should be near 0.9 for Brown Swiss and Milking Shorthorns, 0.85 to 0.88 for Holsteins and Ayrshires, and near 0.8 for Guernseys and Jerseys. Higher values may indicate a fat test problem. Lower values may mean protein test problems from too much fat, or too little total or undegraded protein in the feed ration. Make sure the ration has enough effective fiber to produce a desirable fat test (Mahanna 1998). Lush cool-season grasses often do not have enough effective fiber if they test lower than 35 percent neutral detergent fiber (NDF). Fresh grass fiber is readily fermented in the rumen so only 40 to 50 percent may be effective (Kolver 2001).

Summary

A grazing-based dairy system can be a profitable alternative to a confinement dairy system (Jackson-Smith et al. 1996; Kriegel 2000; White et al. 2002). It requires a different skill set for the manager that involves managing and feeding a live, standing crop of forage rather than a forage crop that is cut, cured or fermented, and stored before feeding. Transitioning to a grazing-based system takes time, knowledge, patience, and experience. Find an experienced grazier or pasture group that can give advice or examples to follow at the outset. Attend grazing conferences where dairy grazing is a part of the program. Focus on accepted and tested practices that optimize livestock performance while sustaining the quality of the natural resources of the farm, watershed, and airshed.

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Part III

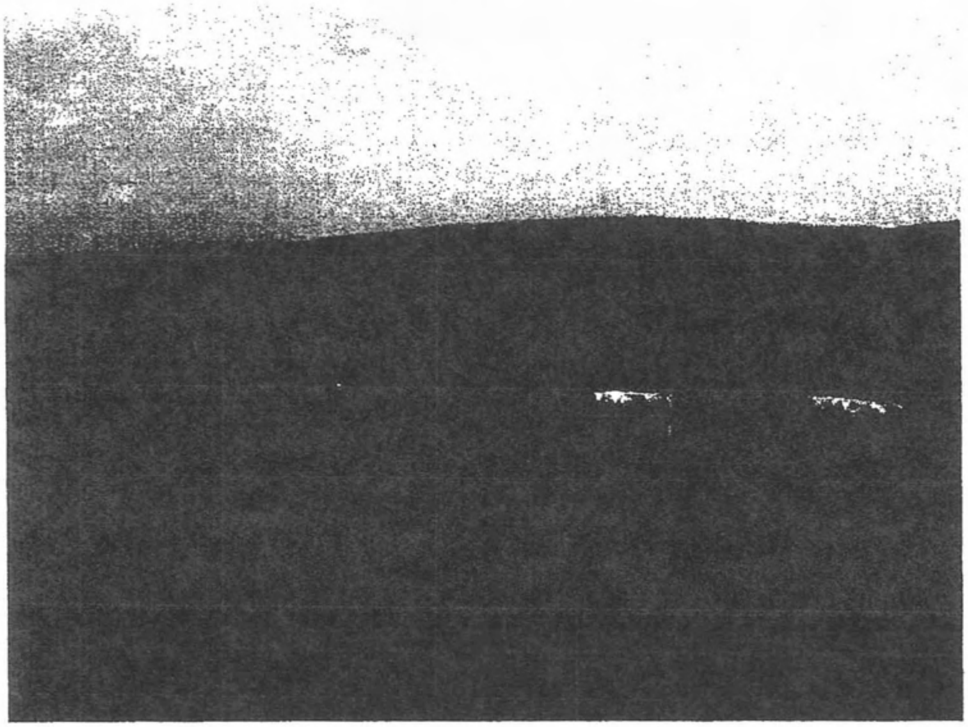
Case studies

Six case studies of farmers who have successfully implemented grazing-based dairies begin on the next page. These dairy farms span the Nation showing that any dairy farm situation can make grazing work. A commitment is required to make pasture the primary feed source and land use near the milking facilities. Pasture should be treated as a crop and as a feeding and housing facility. This means:

- keeping tabs on its soil fertility needs
- meeting soil test recommendations
- removing excess water
- providing irrigation water in more arid parts of the Nation
- scheduling harvests with at least as much care as if it were an alfalfa field
- creating an infrastructure in the pasture (fences, gates, water troughs, laneways, and perhaps shade structures) as is done with confinement operations at the farmstead to feed, water, and house livestock

Each of the six different farms takes a different approach to grazing-based dairying. This is because of the uniqueness of the individual or partners operating each farm and the uniqueness of the soil, water, and climatic resources each farm is faced with. All of them find it a rewarding experience.

Figure 14 Dairy cows returning to a fresh grass paddock along a laneway on this Pennsylvania farm. Heifer pasture is the back pasture just in front of the mountain range.



Owned by:
Dr. Edward and Peg Clarke

Operated by:
Peg Clarke

Location:
Lowman, Chemung County, New York

Local contact:
USDA NRCS
Waverly Service Center
109A Chemung St.
Waverly, NY 14892–1306
(607) 565–2106

No. acres:
600

No. pasture acres:
200

Breed(s) of cows:
Registered Jersey

No. lactating cows:
140

Average milk yield:
13,000 lb/cow/yr

Number of years grazing:
18

Grazing-based dairy issues:
Grazing system
Pasture management
Feed and water management
Challenges

Upon completion of her education in dairy production at Pennsylvania State University, Peg Clarke knew that she wanted to have her own dairy farm. However, it was not until she and her husband, Edward, visited New Zealand that she envisioned it as a grass-based system.

Peggy began dairy farming in 1984 with 30 cows and 40 acres of pasture divided into twenty-six 1.5-acre paddocks. In 1991, the Clarke's purchased an adjoining farm and expanded their enterprise to nearly 90 cows and 140 acres of pasture. Currently, they milk 140 cows, maintain 45 to 50 dry cows and bred heifers, and own or lease nearly 600 acres. To accommodate the larger herd size and make milking the herd easier and faster, a new barn with a double four-side opening milking parlor was built in 1995.

Milking is on a twice a day schedule year-round with peak cow numbers coming late in summer or early in fall. During the grazing season, only about 110 cows are in the milking herd at any one time.

Grazing system

Peggy grazes her herd of Jerseys using a rotational stocking method with the cows moved to a fresh paddock every day. Grazing generally begins in April and continues through October, with 180 days an average length of grazing season. Winter is the primary limit to the grazing season, followed by wet saturated spring soils. The farm receives about 33 inches of precipitation a year, and while drought can be a hindrance, it is a rare occurrence.

Pasture management

The pastures consist of mixed forage stands of orchardgrass, bluegrass, reed canarygrass, and red and white clover. They are fenced with two strands of high-tensile smooth wire and are subdivided into paddocks with polywire. Nearly 150 acres of the 200 acres in the system are harvested mechanically each year before being grazed. In some cases, this land is mechanically harvested twice before becoming part of the grazing system. As a rule, Peggy plans to harvest all of the land that is not too steep to harvest mechanically at least once every 3 years.

The soils are described as typical hill soils for the region, with moderate water holding capacity and good drainage. Soil fertility is maintained in the medium to high range, and pH is maintained in the low to mid 6s. The pastures receive 100 pounds of nitrogen per acre per year, as well as "brown water" from the manure storage lagoon. The barn is cleaned with a flush system, and after the solids are separated, the water is used to irrigate the pastures. The solids are spread as a dry material on the cropland.

Feed and water management

In addition to pasture, the herd also receives a total mixed ration consisting of corn silage, high moisture shell corn, cottonseed, and a mineral mix. On average, Peggy plans on the cows obtaining approximately 60 percent of their diet from pasture.

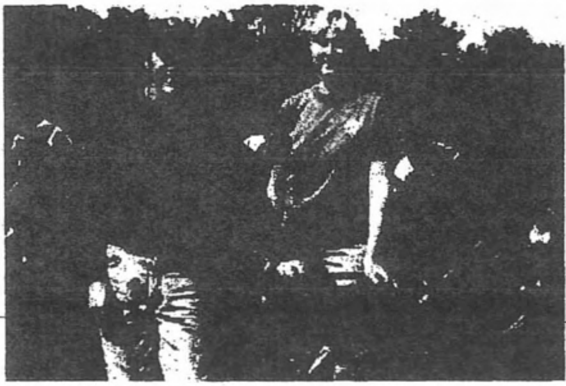
Water is pumped from the barn to troughs in each paddock. The cows are generally moved to a fresh paddock every day. The furthest paddock from the barn is nearly two-thirds of a mile distant, or about a 20-minute walk by the cows. There are no hoof or leg problems associated with this walk, and Peggy suggests that the fact that she has some 8- to 10-year-old cows in her herd, pasturing promotes healthy cows.

Challenges

Grazing is often described as a less labor-intensive method of dairy production compared with confinement dairying. While Peggy finds the work involved with grass-based dairying both enjoyable and satisfying, she is also quick to point out there are still plenty of things that need to be done and problems that need to be addressed. For example, with increased herd size, the layout and design of fencing systems takes more time and thought. The same can be said for getting water to the paddocks. Controlling flies is a little more problematic, and certainly the year-to-year differences in weather, and thus plant growth, make every year a unique challenge.

Despite these observations, Peggy has always grazed her dairy cows, and she is in no hurry to change. Future plans may include another herd expansion and a second barn. Grazing will be very much a part of the process as well as the possibility of manure composting.

All in all, Peggy is very satisfied with operating her farm as a grass-based dairy. In her view, grazing is an alternative production practice that, while not for everyone, is a method that works on her farm and others might consider trying.



Owned by:
Kevin and Amy Sullivan

Operated by:
Kevin, Amy, and their children, Sara and Brian

Location:
Carthage, Northern Lewis County, New York

Point of contact:
USDA–NRCS
Lowville Service Center
P.O. Box 9
Lowville, NY 13367
(315) 376–7021

No. acres:
210 Total

No. pasture acres:
100–120

Breed(s) of cows:
Holstein, Jersey-Holstein cross

No. Lactating Cows:
65

No. of heifers and calves:
40

Average milk yield:
17,000 lb/cow/yr

Number years grazing:
15

Grazing-based dairy issues:
Pasture management
Grazing system
Challenges and advantages

The Sullivan family dairy farm is a seasonal grass-based dairy system located in a part of northern New York known for its long, cold winters and where snow-falls are often measured in feet. Despite the length and harshness of winter in this area, the moderate summer temperatures and generally adequate rainfall make the Tug Hill region nearly ideal for the production and utilization of perennial grasses.

The Sullivans began dairy farming with a conventional tie stall barn where the cows were fed in confinement the year round. However, because of the high production costs and labor associated with this type of feeding program, they soon began to look for a more cost-effective and less labor-intensive means to produce milk. In 1987, they turned their herd out to graze.

The Sullivans currently graze their 65 Holstein and Jersey-Holstein cross cows using a seasonal approach to milk production. The herd is spring freshened so that peak milk production coincides with the availability of the greatest amount of high-quality spring pasture. During the grazing season, milking is done twice a day in a homemade six-unit, step-up milking parlor. The entire herd is dried off during February and March.

This approach allows the Sullivans to produce the greatest amount of milk for the lowest cost during the summer months and reduce their winter feed costs by feeding only a low-cost maintenance ration to their herd during the drying-off period. It also allows them to take the 2 months off from milking.

Pasture management

The Sullivan's pastures consist mostly of orchardgrass-clover or orchardgrass-alfalfa mixtures with a small amount of perennial ryegrass. They are frost seeded with clover almost every spring. The primary hay fields are reseeded about every 6 years. Fertility is maintained using liquid manure from storage. All pastures are mowed at least once per season to control weeds and to eliminate vegetation that has become overmature. Little commercial fertilizer is used.

Grazing system

In a normal year, Kevin and Amy find they can graze their herd for nearly 6 months. The grazing season begins late in April or early in May and winds down by the end of October. The grazing system is constructed using a combination of electrified, high-tensile strength, smooth wire to form perimeters and polywire to create individual paddocks. The cows are generally moved to fresh grass three times a day. In addition to the pasture, each cow receives about

12 pounds a day of a supplemental total mixed ration (TMR) consisting primarily of high-moisture shell corn and rolled oats. If drought limits pasture growth, chopped balage is fed along fencelines. Spring and fall transitions are accomplished by slowly decreasing or increasing the amount of TMR fed corresponding with pasture growth and forage availability. Some balage is also fed during the fall as pasture growth begins to slow.

The furthest paddock from the barn is a 20-minute walk for the herd or between a half and two-thirds of a mile distant. To keep the herd grazing once they get to a pasture, water is pumped from the barn through either 3/4- or 1-inch plastic pipes to portable tanks in each paddock. Kevin notes that while he occasionally sees a cow with a sore foot, herd health is generally excellent. As evidence of this, Kevin points out he has some 8-year old cows in his herd. This means that instead of culling cows because of problems, he has the opportunity to sell cows and heifers at a profit. Veterinary costs, including vaccinations and dry cow treatments, average $16 to $18 per cow per year.

Challenges and advantages

Kevin is quick to point out that "grazing is not easy and is not a magic bullet. It works for people who are willing to take the time to make it work. However, it takes thinking and dedication to stick with it until you learn and understand the process. It takes more management than conventional dairying." He cites his biggest problem is keeping track of his feed supply. "Guessing what the weather is going to do to forage yield and quality is not easy. However, you get back what you put into it."

Kevin suggests that grazing has allowed them to handle 65 cows with about the same amount of time and effort that it took them to handle 40 when they were a conventional dairy. Furthermore, Kevin concludes, "they can make a good living without pushing the cows' production." This in turn allows the cows to last longer and breed back sooner. Being seasonal means that April, May, and June are extremely busy on the Sullivan farm. However, the winter months are so enjoyable for the Sullivans, especially February and March, that Kevin states, "they would never go back to milking cows the year round."

In addition to improving the quality of their lives and the lives of their cows, Kevin also points out both the environmental, as well as economic benefits. "Being sod-based, soil erosion is little to nothing. As well, we use very little chemicals, either in herbicides or in fertilizers. We have lower inputs for fuel, electricity, feed supplements, fertilizers, and repair bills, which simply adds to our bottom line."

While seasonal grass-based dairying is not suitable for every dairy farm or dairy producer, for the Sullivans it is the perfect blend of lifestyle and standard of living. Also, milk processing plants in their area are less concerned about fluctuations in milk production at the farm caused by all the cows in a seasonal calving herd being nearly in the same number of days in lactation.

[illegible]

Case Study 3—Mallonee Dairy

Owned and operated by;
Maynard and Kim Mallonee, parents John and Mary, and son Jack

Location:
Lewis County, Washington

Local contact:
USDA–NRCS
Chehalis Service Center
1554 Bishop Rd.
Chehalis, WA 98532–8710
(360) 748–0083

No. acres:
215

No. pasture acres:
90

Breed(s) of cows
Holsteins

No. cows:
65

No. heifers:
60

Average milk yield:
65 lb per day

Grazing-based dairy issues:
Overview
Grazing system layout
Pasture management
Additional farm activities

Mallonee Dairy is owned and operated by Maynard and Kim Mallonee along with their parents, John and Mary, and son, Jack. The Mallonee Dairy is a transitional-organic grazing dairy located in Lewis County in western Washington. The dairy is home to approximately 65 Holstein cows and 60 heifers. Of the 215 acres on the farm, 90 acres are pasture for grazing dairy cows.

Grazing has been a tradition on the Mallonee Dairy for several generations, and they plan to continue grazing in the future. According to Maynard, maintaining a high level of milk production has been one of the greatest advantages of grazing. In addition, the Mallonees feel that grazing has played an important role in preventing cow health problems and increasing cow longevity.

The Mallonee Dairy is an organic dairy. The land has been certified organic for several years. Organic dairying assures the Mallonees that they are decreasing health concerns for their animals as well promoting a safe product for consumers. Although the Mallonee Dairy was always close to being organic, economic considerations led them to seek certification to sell their product as organic.

To diversify farm income, Mallonee Dairy also supports a small organic beef cattle enterprise. The beef enterprise combines easily with the grazing system already present for the dairy cattle and is an additional enterprise for the farm. It includes breeding stock and organically raised, grass-fed steers.

In addition to the usual daily activities on the dairy, the Mallonee family is also making an effort to advance nutrient management knowledge by volunteering an area of their pasture for university research studies. A research study was started in January 2002 to determine the effects of manure application during winter months.

The wet conditions of western Washington are among the greatest challenges for the Mallonee Dairy. Average rainfall in this part of Washington is 60 inches. About 80 percent of the rainfall occurs from September through April. The saturated field conditions during winter limit the grazing season and require feeding of stored forages for about 6 months.

Cows are milked twice a day in a double two-side release parlor. The cows average around four lactations, with several cows reaching 6 or more.

Overall, few health problems are seen on this dairy. The health problems of greatest concern are milk fever occurrences in early spring when cows are moved to pasture and an occasional case of foot rot if conditions become wet and muddy.

Grazing system layout

The grazing season lasts from around May 1 to November 1. The lactating cows are on a management intensive grazing program and are moved to a new strip of pasture at least once a day. In spring when grass growth is lush, cows are moved to a new strip of pasture on a daily basis. As the grass growth slows in summer and fall, cows are moved twice a day to provide adequate amounts of grass. Each pasture is grazed four to five times per year. The grazing season is limited by soil saturation resulting from the high rainfall during the winter. In contrast to the lactating cows, heifers are on a rotational grazing system and are moved once every 3 or 4 weeks throughout the summer months.

The pastures are located less than a quarter mile from the milking parlor and have a terrain that is fairly flat. Moving the cows from pasture to the milking parlor takes about 15 minutes. Once in the milking parlor, cows receive a grain supplement while they are milked. During the grazing season, lactating cows are given 25 pounds of grain per day. Besides the grain, cows are supplemented with a mixture of salt and trace minerals, which they have access to while they are grazing. Water is made available through a hose and trough system that is moved with the cows from pasture to pasture. Water accessibility is one of the main factors that prevent the grazing pastures from extending further from the milking facility.

Forage supplementation begins in October to help transition cows into a winter-feeding system that includes preserved forages. During the winter months, cows are housed in a freestall barn where they are fed a combination of forage harvested from pastures and purchased hay.

Pasture management

Pastures are maintained in native (i.e., commonly occurring, but mostly introduced species that have naturalized) forage species and are not replanted on a regular basis. Tall fescue is the main grass species though a variety of other grass species occur, and several pastures are approximately 25 percent clover. In the spring, grass species overtake the clover, thus the best clover growth occurs after the first cutting of grass has been removed from the pasture. Pastures with sandy loam soil are the first pastures grazed each spring because they dry faster than those with more clay in the soil. The Mallonee Dairy has not had any particular problems with weed species. Grazing and clipping the pastures appears adequate to control weeds.

In addition to grazing, pastures are mechanically harvested at least once a year and may be harvested a second or third time if weather conditions allow. Harvested forage is stored as dry hay or wrapped silage bales and used as a feed source during the winter.

During the summer months, pastures are irrigated after cows finish grazing and are moved to another pasture. The irrigation system is a hand-line sprinkler system that is manually moved from pasture to pasture. Besides the normal summer irrigation, pastures are also irrigated after they are fertilized to encourage fertilizer incorporation. Pastures are fertilized with manure once per year using broadcast application.

Additional farm activities

Besides the ongoing winter application study, the Mallonee Dairy plans to continue assisting with research projects and was part of a research study that began in November 2003. The second research trial monitored fecal bacteria in runoff from fields receiving applications of dairy manure slurry. This research trial was an important component to determine the risks of winter manure application. The research results formed the basis for writing Agronomy Technical Note 14, *Winter Period Application of Manure in Washington State* by the Washington State NRCS office. Risk of transport of dairy slurry nutrients nitrogen, phosphorus, and potassium were also studied.

Another research trial conducted at the farm measured nitrogen uptake of forage crops where manure slurry was applied at two different rates. Reports of all these findings have been produced by Washington State University Extension at Puyallup.

Case Study 4—Mike, Beth, and Ross Wangsgard

Owned and/or operated by:
Wangsgard family

Location:
Cache County, Utah

Local contact:
USDA–NRCS
North Logan Service Center
1860 North 100 East
North Logan, UT 84341-1784
(435) 753-5616

No. acres:
290 (two farms)

No. pasture acres:
80 (+ 20) + 150 on home farm

Breed(s) of cows:
Holstein

No. cows:
150

No. heifers:
250–300

Average milk yield:
15,000 lb/cow/yr

Grazing-based dairy issues:
Objectives
Pasture Grasses
Grazing System Layout
Irrigation, Fertilization and Manure
Pests
Economics

Mike Wangsgard, his wife Beth, and his father Ross manage a 150-cow dairy herd with approximately 250 to 300 heifers in Cache County, Utah. Their farm business is split between two farms of approximately 150 acres each, Young Ward Farm and Cornish Farm. Grazing currently takes place on about 150 acres on Young Ward Farm. Cornish Farm and the remainder of Young Ward produce primarily alfalfa for winter feeding. Cornish Farm has 80 acres in pasture with 20 more planted in 2002.

Mike and his family run a semi-seasonal pasture dairy. The cows are turned out on pasture around May 1. The Wangsgards begin supplemental feeding around October 1, but the animals are outside for most of the year, remaining in the barn only when it becomes too muddy in the spring. Breeding is timed so the cows are dry during the winter so supplemental feeding is cheapest.

Objectives

Mike's main objective is to maintain a profitable dairy over the long term. The family has been milking for two generations, and Mike would like his children to have the opportunity to continue if they so choose. To this end, the Wangsgards are contemplating converting one of their two farms to an organic dairy, using the other to manage any cows that might become sick and need to be isolated or receive antibiotic treatments.

Pasture grasses

Each pasture at Young Ward Farm has one grass species mixed with one or more legumes. The grass species include a mixture of different fescues, orchardgrass, bromegrass, perennial ryegrass, and native (naturalized, not intentionally planted) quackgrass. Each grass species has its own growth rate, nutritional value, palatability, and maturity. The Wangsgards keep the grass species separate so they can be more effectively managed.

The fescue on the farm forms a dense sod and starts growing early in the spring. Cows are turned onto fescue pasture first. They graze it lightly, but frequently, as it is less palatable than many of the other grasses, especially when it is allowed to mature. Perennial ryegrass is a highly palatable species, so it is allowed to grow taller and be grazed lower and rested longer than the fescues. Orchardgrass is the highest yielding forage species on the farm. It must often be mechanically harvested to prevent it from growing too rank before it can be grazed. Some grasses and some fields are easier to mechanically harvest than others are. They are often saved for mechanical harvesting. Mike

Case Study 4

advises farmers contemplating a grazing-based system to get to know their grasses and learn to manage what they have. "Native (naturalized) grasses are there for a reason—because they work best," he says.

Grazing system layout

Young Ward Farm is a quarter-mile wide and three-quarters-mile long, with an alley down the center. Gates and water troughs are located about every 300 feet along the alley. Portable fences that allow access to one or two water troughs are moved every 12 hours so that the cows receive new pasture after every milking. A grain supplement and minerals are fed in the barn as the cows are being milked. These are supplied by the local grain elevator.

Irrigation, fertilization, and manure

A quarter of the farm is flood irrigated every week so at least half of the fields are accessible to grazing at any one time (allows the irrigated ground to dry for 1–2 weeks). Grazing is timed to avoid conflict with the irrigation schedule.

Soil tests have shown phosphorus and potassium to be adequate, but not excessive in the pastures. Fields are generally fertilized with nitrogen once in early spring and again during the summer. What little manure is produced in the barn during the summer is stockpiled and applied to the fields in the fall. Manure collected over the winter is applied in the spring before grazing begins and usually before green-up. Manure contamination of feed has not been a major issue when manure is applied in this fashion.

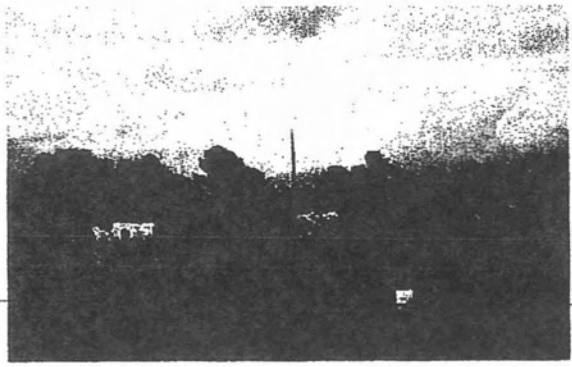
Pests

The biggest pest problems the Wangsgards have encountered have been biting flies, mosquitoes, and weeds. The flies and mosquitoes result (they expect) from the farm's location in bottomlands where they thrive. Grazing probably does not exacerbate the problem. Weed pressures are most severe in new pastures, so weed control is critical during establishment. In mature pastures, barley headed foxtail and thistles are the worst weeds. Spot spraying is used to control thistles. Irrigation ditches that harbor barley headed foxtail are sprayed before the grass heads out and when ditch is empty of water.

Economics

The advantages of this system over confinement dairies include cheap feed, healthier cows, and reduced labor. As the farm is largely a family run business, labor savings are important. Cost savings are also important. Mike points out that, "Whatever you put into a cow produces a return in milk, but the return diminishes depending on the input." Water is the most cost-effective input you can supply. Next is alfalfa grass, and finally grain. In this part of Utah, adequate water and forage produce approximately 45 pounds of milk per animal day. Grain produces another 5 pounds per day. Whether a major grain supplement is justified depends on the price of milk and the price of grain.

Case Study 5—Buck Shand



Owned and operated by:
Buck and Dorothy Shand

Location:
Dallas County, Alabama

Local contact:
USDA–NRCS
105 Moseley Dr., Suite A
Selma, AL 36701
(334) 872–2611 ext. 3

No. acres:
1,650 total

No. pasture acres:
1,450 (200 dairy; 1,250 beef)

Breed(s) of cows:
Holstein-Jersey Cross

No. cows:
100

No. heifers:
30–35

Average milk yield:
14,000–15,000 lb/cow/yr

Variable cost/100 wt. milk:
$5.04–$8.52, $6.52 average
(2003 data)

Grazing-based dairy issues:
Grazing system
Animals
Future plans

Buck Shand and his wife Dorothy have a 1,650-acre farm in Dallas County in central Alabama. Two hundred acres of the farm is devoted to dairying. Buck has been around the dairy business his entire life. He began the transition from confinement to a grazing-based system in the mid 1990s when it became apparent that the price of milk was not keeping up with inflation and quality labor was becoming difficult to find. Based on fairly detailed recordkeeping, he realized he needed to cut costs to stay in business. Dallas County is in the black belt of Alabama where the dominant soils are heavy black clays and rainfall is usually plentiful. This is ideal grass-growing country—perfect for grazing. Buck looked backward to the time when most farmers were grazing their dairy cows and forward to a grazing system developed in New Zealand, and decided to convert to a grazing-based dairy system.

To get started, pastures had to be developed and fencing, laneways, and watering facilities were needed, but a lot of equipment could be retired. One step in the transition was to start breeding the Holstein herd with Jersey bulls. Jerseys are a smaller breed than Holstein. On grass the two breeds produce about the same amount of milk. Breeding smaller animals that consume less feed seemed a logical step.

Grazing system

The dairy has four pastures that are subdivided by permanent and portable electric fencing. Water is provided for each pasture. Laneways have drainage tile to keep them from becoming muddy. Pastures are rotated daily. Each pasture is rested for 30 to 45 days after being grazed. In the spring when grazing cannot keep up with the lush growth, pastures are mechanically harvested and saved for use later when dry matter is low.

The primary forage crops on the dairy are dallisgrass, white clover, Persian clover, and several hardy fescue varieties with beneficial endophytes. The clovers and dallisgrass grow naturally on the farm, but Buck is planting the fescue over time and eventually hopes to have 200 to 300 acres of fescue pasture (some of which may be used by the beef cattle). The forage species are seasonal. White clover is a winter perennial that is grazed early and sets seed by mid June. Persian clover is an early annual that grows during most winter months. The fescues are cool-season grasses that do best early in spring and late in fall. Dallisgrass is most active in the summer months. This variety of forage crops permits grazing 10 months of the year.

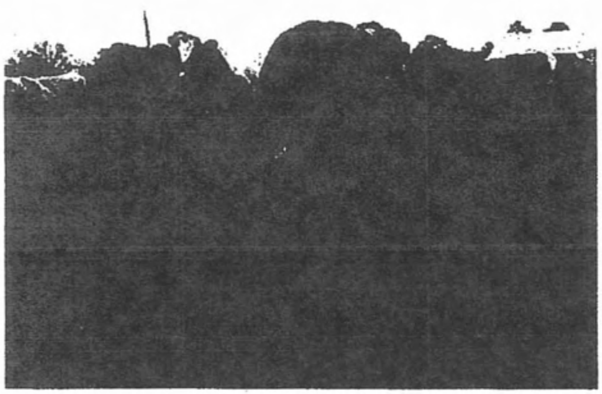
Pastures are fertilized strictly according to soil test recommendations and rarely need any additions except phosphorus. During drought, feed is supplemented with cottonseed to prevent overgrazing. In the barn, cows are also fed soy hull pellets.

One of Buck's challenges is weeds in the pastures. Buttercup in the spring and camphorweed, ironweed, and cocklebur in the summer are some of the main problems. These generally can be controlled with 2,4–D when necessary. Wild onion in winter pastures can affect milk flavor. To avoid this problem, cows are taken off winter pasture 2 hours before milking.

Animals

The cows on Buck Shand's dairy farm are generally very healthy. As long as the cows are kept out of the mud, mastitis and other health problems have been minimal. The pastures are rotated daily using electric fencing to keep the cows out of the mud. Drainage tile has also been placed under areas that tend to pond water.

Cows are milked twice a day in a double-4, straight-through milking parlor. "It's old, but effective," says Buck. With this system 8 cows can be milked every 10 minutes. Travel time from the pastures to the barn is about 15 to 20 minutes. Cows tend to remain productive for 5 lactations. The average number of lactations per cow in this part of Alabama, according to a University report, is 1.5.



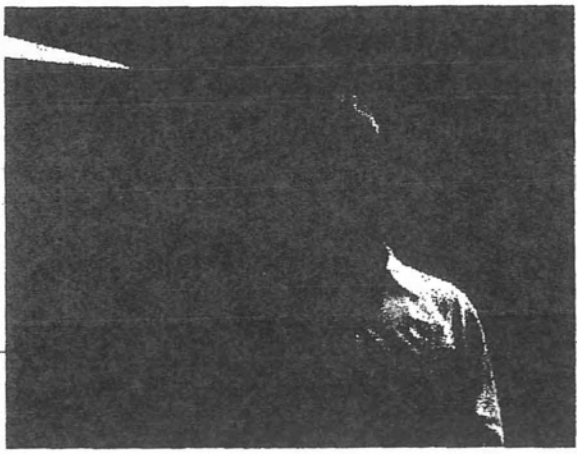
Manure management

Animal waste management has become relatively simple since the transition to grazing. Most of the waste is spread on the pasture by the cows themselves. Waste that is produced in the barn is pushed into a dry stack where solids and liquids are separated. Liquids flow to a treatment pond, and solids are periodically spread on the pastures.

Future plans

Buck plans to develop a calf feeding operation on the farm once the pastures have been renovated. He thinks this will be a profitable new enterprise. He also plans to do a better job of managing farm records to increase the profitability of the dairy. Overall he is happy with his move to grazing. "It's an enjoyable enterprise, and it's reasonably profitable," he says. "We think this part of the country could stand some more dairy operations. If they're sustainable and grass-based, they could be profitable. Our heavy clay soil is well adapted for growing grass."

Case Study 6—Tom Trantham*



Owned and operated by:
Tom Trantham

Location:
Pelzer, South Carolina

Local contact:
USDA–NRCS
301 University Ridge, Suite 3900
Greenville, SC 29601
(864) 467–2755 ext. 108

No. acres:
97.6

No. pasture acres:
70

Breed(s) of cows:
Holstein

No. cows:
75 (10% dry)

No. heifers:
59 (off farm/contracted with neighbor farmer)

Average milk yield:
19,600 lb/cow/yr

No. years grazing:
15

Grazing-based dairy issues:
The herd
Facilities
Forage management
Waste and irrigation
Economics
Transition

Tom Trantham owns a 97.6-acre dairy in Pelzer, South Carolina. The dairy is 25 years old, and Tom has been farming it since 1978. The farm was struggling in April 1988, when the milk cows pushed through the confinement feeding area and began grazing a vacant field that had been scheduled for chemical burndown. The next milk pick up averaged 2 pounds more milk per cow than the previous milk pick up. Thus began Tom Trantham's transition from a confinement dairy to a grazing-based system. Prior to the "accident," the farm had been winning South Carolina milk production awards, but still could not pay the feed bills.

From 1994 to 1997, Tom participated in a Sustainable Agriculture Research and Education (SARE) research grant with Clemson University to determine the feasibility of a minimum input, financially sound grazing dairy. He has also participated in a Southern SARE Professional Development project that took him to Ireland where he learned about the importance of paddock size and irrigation for improving production.

The herd

The herd consists of 75 milk cows, 10 percent of which are dry at any time of the year, but most of which are still producing at 10 to 14 years old. Tom selects bulls of smaller stature that pass on what he calls "dairiness" traits, such as strong feet, deep barrel, and high quality udders. He also looks for bulls with a lot of white in their color pattern to help compensate for the South Carolina heat. He used to raise his own heifers, but now contracts them out at 3 months old, getting them back 2 months before their first calving. This way he can concentrate on the milk cows, and the contract farmer can concentrate on the heifers.

Milking occurs twice a day. Tom uses a side opening, single-4 milking parlor rather than the more efficient herringbone design because it places the cow broadside where he can see her entire body twice a day.

Facilities

The farm consists of 25 paddocks (2.5–3.2 acres each) surrounding the farmhouse and milking barn, a manure sediment lagoon that now only receives wash water, a trench silo now used as a well-water reserve for diluting liquid from the manure sediment lagoon, and a harvestore silo that has been converted to a milk processing plant to bottle the dairy's own milk. The perimeter fence has three to five strands of high tensile wire. Fence along the lanes has two strands, and one strand is used for temporary cross fencing. All fences are electric. The rest of the essential equipment consists of an 80–HP tractor, manure spreader, no-till planter, and rotary mower.

Forage management

The paddocks are typically managed as follows. New forage is no-till planted into each paddock where the recently grazed crop is no longer productive. After the cows move off, any remaining ungrazed pasture is cut and baled for dry cows and heifers. The timing of each task depends on weather, maturity date of the crop, and how much the cows graze the paddock during the growing cycle. Knowing the crop maturity date is critical to the management system. Different forage crops mature at different rates, and once they mature their value for grazing is diminished. The exception is alfalfa, which maintains its nutrition throughout its life cycle. Tom's rule of thumb for the pasture is to graze when the crop is below the knee and bale when it is above the knee.

The forage crops planted on Trantham Dairy Farm include corn (grazing maize), trudan, millet, small grains, alfalfa, and clover. Tom continues to experiment with forage crops, looking for crops with the right vigor, nutrition, and growing season to improve the grazing system. He uses a notebook to keep track of the planting and grazing schedule. He monitors the soils regularly for nutrient imbalances and applies lime periodically to offset the export of calcium in the milk. He also monitors the forages closely to determine the need for supplemental feeding. Tom estimates that currently about 50 percent of the cows' nutrients come from supplemental feeding, though a lot depends on the weather.

Animal comfort, waste, and irrigation

Most of the paddocks have some natural shade. In hot weather, early morning grazing is scheduled in those paddocks without shade.

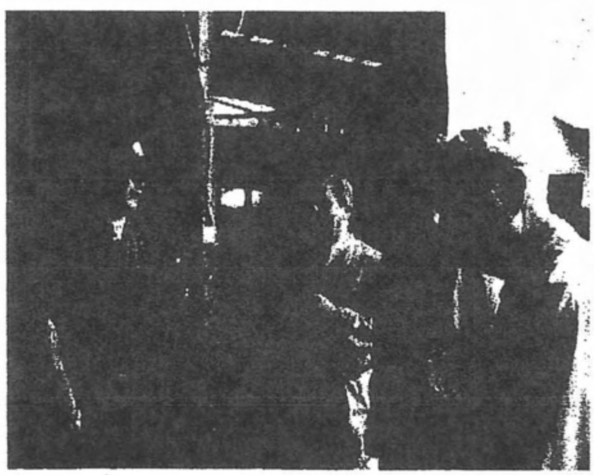
Cows are watered from 300-gallon Rubbermaid® troughs on geotextile pads in each paddock. A 40-foot-long watering trough is also supplied along the path as cows leave the milking parlor. Tom is experimenting with a variety of materials for his laneways, which need to be mud-free for animal health.

Manure is scraped daily from the cement milking and feeding areas. Solids are separated out and spread on pastures weekly using a calibrated side-opening spreader. Cows are kept off freshly manured paddocks for 5 to 25 days. The wastewater is stored in the waste lagoon along with wash water from the milking parlor. The trench silo currently holds well water. A suction hose and gate valves connect the two reservoirs and allow for mixing. Newly planted or freshly grazed paddocks receive more manure and less water. During droughts, paddocks receive more water and less manure. Of the 25 paddocks, 16 are fitted with an irrigation system that carries water underground from the trench silo/waste lagoon. The system is currently being expanded to collect all runoff water from the farm and store it in a newly constructed reservoir that can be pumped back to the paddocks.

Transition

Tom shares his experiences with other dairy farmers considering transition to grazing. "I believe the farmers of today have the responsibility of leaving things in better shape for the next generation of farmers," he says. "What I've learned would go to waste if it stopped with me." He recommends the first step in a transition is to "get the herd grazing." A good place to start in his region might be to plant a winter grazing crop, such as rye, after the corn harvest. Milk production may initially drop, but TMR costs immediately go down, and over time production should increase as the system develops. As profit margins increase with each transition stage, more improvements can be made, but the job is never done. "That's the beauty of this kind of dairying," says Tom. "Every day you wake up with more ideas you want to try."

**Information for this case study was gathered from a former web site before the current updated and expanded one listed here: http://www.southernsare.uga.edu/twelve/trantham.html with permission from Tom Trantham.*



Nitrate Leaching from Cattle Urine and Feces in Northeast USA

W. L. Stout,* S. A. Fales, L. D. Muller, R. R. Schnabel, W. E. Priddy, and G. F. Elwinger

ABSTRACT

Management intensive grazing (MIG) is a grazing system in which animals at a high stocking density are rotated frequently through a series of paddocks in a manner that maximizes both forage yield and quality. Although MIG has the potential to increase dairy farm profitability in the U.S. Northeast, the uneven recycling of N through feces and urine can increase NO_3–N leaching. The extent to which NO_3–N can leach from beneath urine and fecal spots under soil and climatic conditions of the Northeast is not known. We conducted a field study to measure NO_3–N leaching loss from spring-, summer-, and fall-applied urine and summer-applied fecal beneath N-fertilized orchardgrass (*Dactylis glomerata* L., cv. Pennlate) using 60-cm-diameter by 90-cm-deep drainage lysimeters. The study site was located in central Pennsylvania on a Hagerstown silt loam soil (fine, mixed, mesic Typic Hapludalf). Averaged across the 3 yr of the study, NO_3–N losses were 1.17, 1.68, 22.0, 24.0, and 31.5 g m^{-2} for the control, feces, and spring-, summer-, and fall-applied urine, respectively. These losses represent about 2% of the N applied in the feces and about 18, 28, and 31% of the spring-, summer-, and fall-applied urine N. If dairy farmers in the Northeast continue to increase the utilization of MIG, the amount of N leached to the groundwater from beneath pastures could become substantial if not mitigated by improved grazing management.

DAIRY FARMING is the largest single agricultural enterprise in the U.S. Northeast, with milk receipts accounting for >25% of the farm income in this region (U.S. Department of Agriculture, 1991). Milk production in this region accounts for about 20% of the milk production nationwide. Thus, maintaining a profitable dairy industry in the Northeast is desirable at both a regional and national level.

To maintain dairy farm profitability in the face of rising fuel and machinery costs, tighter environmental constraints, and decreasing federal subsidies, some researchers and extension specialists in the Northeast are advocating inclusion of MIG as a component of dairy production in this region (Fales et al., 1993). Management intensive grazing is a grazing system in which animals at a high stocking density are rotated frequently through a series of paddocks in a manner that maximizes both forage yield and quality. Management intensive grazing systems have been the mainstay of dairy production in the temperate oceanic climatic zones of Europe and New Zealand for many years, and MIG has the potential to increase farm profitability in the Northeast (Emmick and Toomer, 1991; Parker et al., 1992). However, the higher rates of N used in these grazing systems compared with mechanically harvested forages and the uneven recycling of this N through feces and urine in pastures has increased N leaching, which can pose a threat to water quality (Ball et al., 1979; Ryden et al., 1984; Steenvoorden et al., 1986).

Nitrate leaching from intensively grazed pastures occurs in humid regions where precipitation exceeds evapotranspiration and results from the high levels of N fertilization and the uneven recycling of N in urine and feces (Petersen et al., 1956a). Nitrate leached from grazed grasslands receiving high N inputs far exceeds that leached from similarly fertilized cut grasslands and is affected by soil type and grazing density (Steenvoorden et al., 1986; Garwood and Ryden, 1986). Nitrate-N concentrations averaged 25 mg L^{-1} in groundwater draining an intensive grazing area in New Zealand (Barber and Wilson, 1972).

Grazing density affects NO_3–N loss through leaching, because the bulk of the N consumed by the animal is excreted in the urine as urea (Ball and Ryden, 1984; Jarvis et al., 1989). Depending on temperature, some of this N is volatilized as NH_3 (Harper et al., 1983a,b); however, most of the urea rapidly nitrifies to NO_3 and is subject to leaching or denitrification (Ball et al., 1979).

Urine and fecal spots cover about a 60-cm-diameter area (Petersen et al., 1956b; Garwood and Ryden, 1986), and N concentrations under urine spots are often equal to a 700 kg ha^{-1} fertilizer N application. Nitrate leaching from grazed grasslands has been shown to increase substantially when N application exceeds 425 kg ha^{-1} (Barraclough et al., 1992).

Since MIG has the potential to increase NO_3–N leaching and MIG use is increasing in the Northeast, baseline leaching data needs to be developed for dairy production systems that are both economically and environmentally sustainable. Our objective was to determine the NO_3–N leaching loss from fertilizer N, urine, and feces under the temperate continental climatic conditions common to the northeastern USA.

METHODS AND MATERIALS

The study was conducted at The Pennsylvania State University Dairy Research Center located in central Pennsylvania (40°48′N, 77°52′W, 350 m elev.). The predominant soil on the site is a Hagerstown silt loam. This soil is a deep, well-drained soil formed in relatively pure limestone residuum. Although the subsoil texture of the Hagerstown series is a clay loam, drainage through the subsoil is rapid because of a high degree of well-defined blocky structure (Shuford, 1975).

Our leaching loss study took place in conjunction with a MIG study on this site. During the 3 yr of the study, N application rates on the pastures ranged from 19.6 to 28.0 g m^{-2} (196–280 kg ha^{-1}) as NH_4NO_3, depending on the weather and the number of grazing cycles in a given year (Table 1). The lysimeters were located adjacent to the paddocks of the MIG study, but were protected from being directly impacted by grazing cattle with 3 by 1.25 m steel gates. Both control and treatment lysimeters were fertilized and harvested at the same time as the paddocks were grazed and fertilized (Table 1). The paddocks were managed by turning the animals onto the

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Table 1. Blanket N fertilization dates and rates for pastures, urine lysimeters, feces lysimeters, and control lysimeters.

1993		1994		1995	
Date	N rate	Date	N rate	Date	N rate
	g N m^{-2}		g N m^{-2}		g N m^{-2}
8 Apr.	5.6	11 Apr.	5.6	11 Apr.	8.4
6 May	5.6	28 Apr.	5.6	1 May	5.6
18 May	5.6	16 May	5.6	9 June	2.8
20 Aug.	5.6	8 June	2.8	12 July	2.8
21 Sept.	5.6	15 June	2.8		
		15 Aug.	2.8		
Total	28.0	Total	25.2	Total	19.6

pasture when the sward height was approximately 30 cm and removing them when the sward height was reduced to 7.5 cm. The lysimeters were managed by cutting the herbage to 7.5 cm with electric grass shears at the same time the paddocks were grazed. Cutting dates were 5 May, 18 May, 15 June, 8 July, 20 August, 21 September, and 26 October in 1993; 28 April, 16 May, 6 June, 6 July, 15 August, 20 September, and 31 October in 1994; and 1 May, 9 June, 12 July, 24 August, and 31 October in 1995.

The monolith lysimeters used in this study were constructed in the winter of 1992–1993 using the design developed by Moyer et al. (1996) at the Rodale Research Farm. First, an intact soil core was taken by driving a 100 by 60 cm section of schedule 40 steel well casing 90 cm into the N-fertilized orchardgrass paddocks before the grazing study started. Ninety centimeters was assumed to be the bottom of the root zone and 60 cm was the diameter of influence of a urine or fecal spot (Petersen et al., 1956a). Next, the core was retrieved and a bottom and collection system were installed onto the bottom of the core. Finally, the core was replaced into the soil. No suction was applied to the bottom of the lysimeters, thus leachate volume may have been lower and denitrification rates may have been higher than under an intact soil column. However, monolith lysimeters of such design generally provide the most effective method of measuring NO_3–N leaching from many types of soils (Whitehead, 1995).

Lysimeter installation was complete in time for the 1993 grazing starting in April. The lysimeters were checked for leachate weekly or after major storm events. Leachate was removed from the lysimeter with a small electric pump, leachate volume was recorded, and subsamples stored under refrigeration at 4°C and filtered with 0.45-μm membrane filters using Millipore apparatus (Millipore Corp., Bedford, MA). The NO_3–N analysis was performed (U.S. Environmental Protection Agency, 1979) using a Waters ILC/1 ion chromatograph (Waters Chromatography Div., Milford, MA) using an Altech 269-013 column with a phthalic acid mobile phase. The analysis was performed as soon as possible after sampling, but in any case, delayed by no more than 30 d.

Urine and feces were collected on the day of treatment or 1 or 2 d prior to treatment from the animals grazing the paddocks while they were in the holding area for milking. If collected prior to treatment, urine was stored at 4°C. A 3-L urine application (Petersen et al., 1956a) was made in the spring, summer, and fall (Table 2) to urine treatment lysimeters, coincident with the paddocks being grazed. A 2-kg feces application (Petersen et al., 1956a) was made to the feces lysimeters only in the summer after a midsummer grazing. The excreta was applied to the center of the urine and feces lysimeters to simulate animal deposition. There were control lysimeters that received no urine or feces, only the blanket N application (Table 1). The same lysimeters received urine or feces each year, received urine or feces at the same time each year, and the same control lysimeters were used every year. There were five replications of each treatment for a total of 25 lysimeters.

Air temperature, precipitation, radiation, relative humidity, and wind velocity were measured on site using two Campbell Scientific weather stations; additional measurements were made off site by The Pennsylvania State University Meteorology Department.

The experiment was analyzed as a randomized complete block using the GLM procedure in SAS (SAS Institute, 1988). Initial analysis indicated that there was a significant year × treatment interaction for leachate volume, NO_3–N concentration, and NO_3–N loss. Consequently, the data were analyzed and presented by year. Since diagnostic procedures indicated that the variances of both the NO_3–N loss and concentration values were correlated with their means, cube root transformations were used to stabilize the variances. Analysis of variance and mean separation procedures were performed on the transformed scales. The use of the word *significant* throughout the text indicates $P < 0.05$.

RESULTS

Weather

Temperature and precipitation data for the 3 yr of the study are summarized in Fig. 1. While the temperature pattern remained fairly constant during the 3 yr of the study, there was quite a bit of variation in the precipitation pattern. In the 1993 and 1994 grazing seasons (i.e., April–October) precipitation was evenly distributed. However, from mid-July to mid-September in the 1995 grazing season, there was <25 mm of precipitation. This is only about 15% of the precipitation that is usually received at this location during this time of the year. Consequently, N fertilization was reduced to 19.6 g m^{-2} in the 1995 grazing season (Table 1).

Nitrogen Application

Nitrogen application rates to lysimeters resulting from excreta applications averaged 92.9 g m^{-2} for urine and 28.4 g m^{-2} for feces (Table 2). The difference in N application between seasons and years was due to the variation in the N concentration in the urine. Urine N concentration reflected the N content of the herbage in the pastures and was highest in the spring or fall. Even

Table 2. Amounts of N applied in urine and feces treatments to lysimeters containing N-fertilized orchardgrass.

	1993		1994		1995	
Treatment	Date	N applied	Date	N applied	Date	N applied
		g N m^{-2}		g N m^{-2}		g N m^{-2}
Urine in spring	18 May	96.6	29 Apr.	112.0	1 May	141.8
Urine in summer	9 July	69.9	14 Aug.	81.2	12 July	95.6
Feces in summer	9 July	28.9	14 Aug.	28.9	12 July	27.3
Urine in fall	21 Sept.	107.9	2 Nov.	103.8	31 Oct.	88.4

at the highest urine or feces N application rate, the grass in the lysimeters was not damaged.

Leachate volumes, NO_3–N concentrations, and total NO_3–N loss are summarized in Table 3. The N application rate from urine is about three times higher than that from feces, but the potential impact of urine on leachate NO_3–N concentration was disproportionally higher for two reasons. Urine immediately infiltrates into the soil where the urea is readily hydrolyzed to NH_3, nitrified, and becomes more subject to leaching than to volatilization. In contrast, feces remains on the surface where organically bound N is subject to volatil-

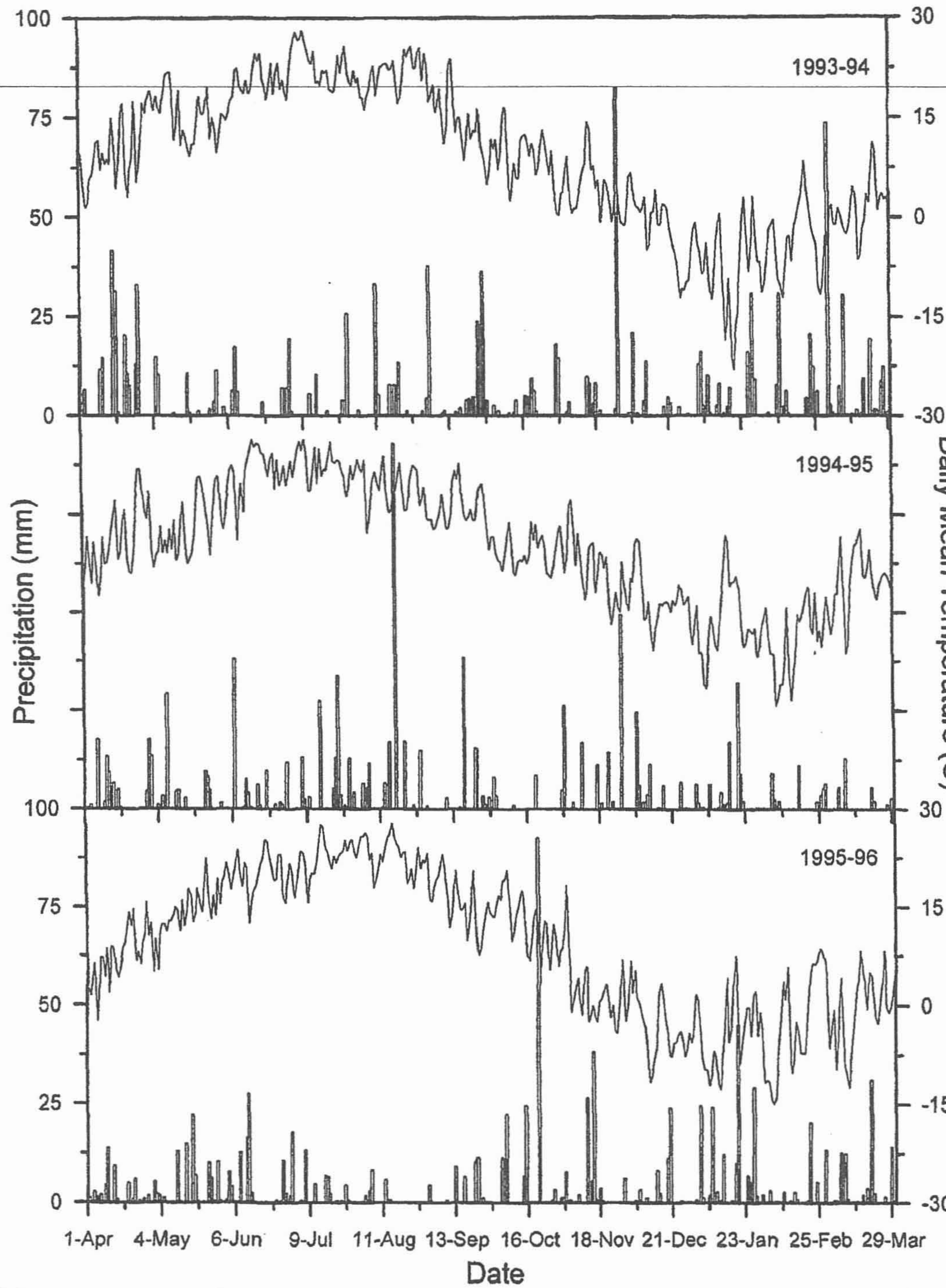

Fig. 1. Daily mean temperature and precipitation at the study site.

Table 3. Summary of leachate amount, NO_3–N concentration, and NO_3–N loss from drainage lysimeters for 3 yr.

Year	Control	Feces	Urine		
		Summer	Spring	Summer	Fall
		Leachate amount, mm			
1993	267a†	259a	203a	205a	234a
1994	325a	249ab	215b	264ab	217b
1995	246a	242a	234a	276a	228a
		NO_3–N concentration, mg L^{-1}			
1993	5.0c	5.8c	78.9ab	52.1b	90.7a
1994	4.6c	4.8c	88.9b	76.5b	152a
1995	4.9b	9.0b	164a	151a	176a
		NO_3–N leaching loss, g m^{-1}			
1993	1.16b	1.51b	10.5b	16.1ab	21.5a
1994	1.15c	1.50c	18.9b	14.6b	32.4a
1995	1.19b	2.04b	36.8a	41.4a	40.5a

† Means in the same row followed by the same letter are not significantly different ($P \leq 0.05$). Year × treatment interaction significant ($P \leq 0.05$) for all parameters.

ization as NH_3 is produced during the mineralization process.

Leachate Amount

The leachate patterns were similar for all 3 yr of the study (Table 3, Fig. 2). Leachate volumes were lower during the grazing season when evapotranspiration was the highest and increased in the fall as evapotranspiration decreased.

In 1993 and 1995, there was a clear pattern of leachate flow beginning in the fall, followed by a decrease during the winter months when the ground was frozen, and an increase again after the spring thaw. In the fall of 1994, however, leachate flow remained relatively high throughout the winter and did not decrease until evapotranspiration increased in late spring. During 1994, leachate flow continued into late summer (Fig. 1) due to precipitation and a large storm event of almost 100 mm.

There was a significant year × treatment interaction for leachate amount resulting from leachate amount being significantly higher under the control than under the spring and fall urine treatments in one of the 3 yr (1994). This was due to increased N fertility imparted by the urine treatments enabling the grass growing in the lysimeters to make better use of the increased precipitation in 1994, consequently increasing evapotranspiration. This response was not evident in 1993 and 1995 because there was less precipitation in these years and soil water rather than N limited grass growth and water use.

Nitrate Concentration

The pattern of NO_3–N concentration in leachate from the lysimeters was similar for the 3 yr of the study (Fig.

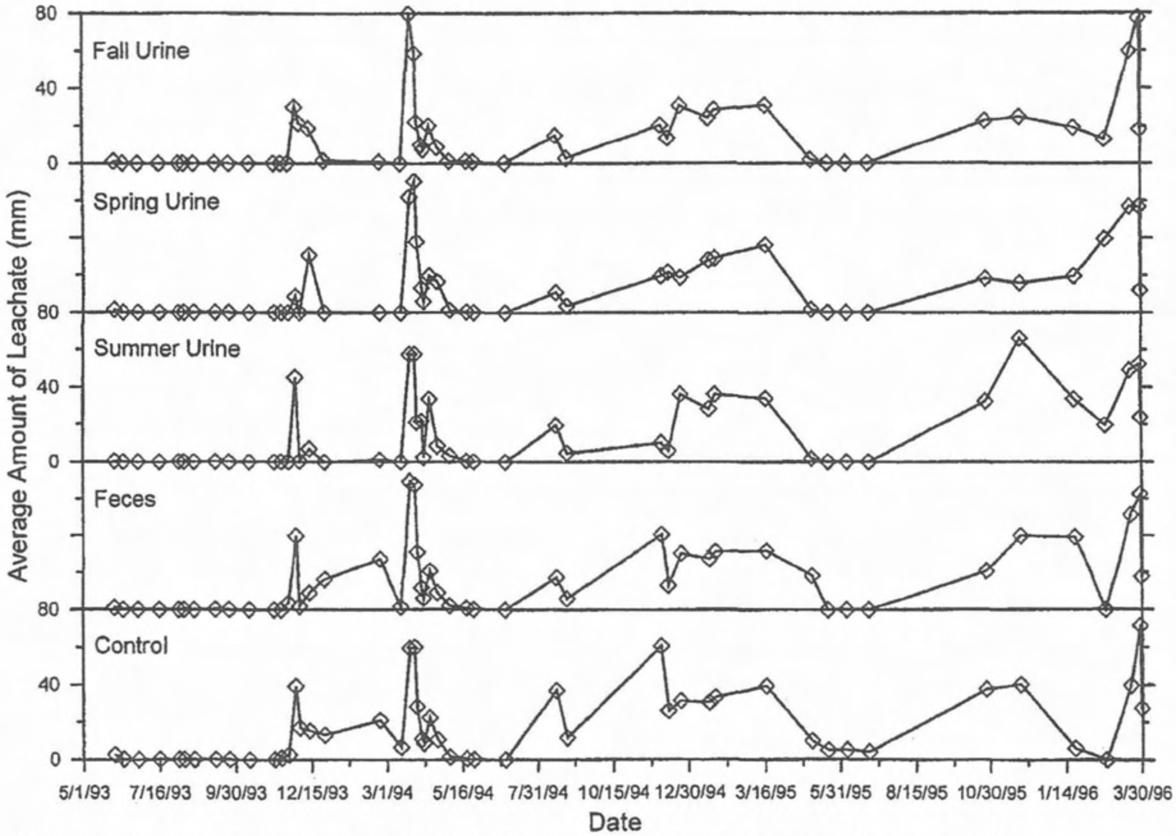

Fig. 2. Average leachate volumes for April 1993 to March 1994, April 1994 to March 1995, and April 1995 to March 1996.

3). Although there was a significant year × treatment interaction for NO_3–N concentration, NO_3–N concentrations beneath fall-applied urine were always highest (Table 3). This was because there was insufficient time left in the growing season for this N to be assimilated by the grass before it was subject to increased leaching in the fall.

Nitrate-N concentrations in leachate beneath spring- and summer-applied urine were generally lower, despite the fact that N application rates under spring-applied urine tended to be higher during the study (Table 2). Lower NO_3–N concentrations beneath spring-applied urine are likely because grass receiving urine in the spring has most of the growing season to assimilate the applied N. The lower NO_3–N concentrations beneath the summer-applied urine can be attributed to higher N volatilization from urine during the summer (Harper et al., 1983b).

In contrast to urine, NO_3–N concentrations in leachate beneath feces were not significantly different from those beneath the control (Fig. 3, Table 3). This was a result of the much lower amount of N applied in the feces than in urine, the potential volatilization of N from the feces (Ryden, 1986), and the lower availability of N in feces. Nitrate-N concentrations beneath all treatments were greatest in 1995, the driest year of the study when N assimilation by the grass was limited by a lack of soil moisture.

Nitrate-Nitrogen Leaching Loss

In general most NO_3–N was leached beneath the fall-applied urine in all years of the study (Table 3, Fig. 4). However, there was a significant treatment × year interaction caused by NO_3–N leaching beneath spring- and summer-applied urine being equal to that under fall-applied urine in 1 yr of the study. This was due to low precipitation (Fig. 1) during the middle of the grazing season in 1995, which retarded grass growth and N assimilation. Consequently, more N was available for leaching from spring- and summer-applied urine in 1995 than in the other 2 yr.

The leaching of NO_3–N from beneath the feces was not significantly different than that from beneath the control (Fig. 4, Table 3). During the 3 yr of the study, the additional NO_3–N leaching loss (i.e., treatment minus control) that could be attributed to feces-applied N was 0.51 g m^{-2} or about 2% of the N applied in the feces. In contrast, additional NO_3–N leaching losses that could be attributed to spring-, summer-, and fall-applied urine were 20.9, 22.9 and 30.3 g m^{-2}, respectively. These amounts represent 18, 28, and 31% of the spring-, summer-, and fall-applied urine N, respectively.

DISCUSSION

The observations that grazed grasslands have higher N leaching losses than cut grasslands (Ryden et al., 1984)

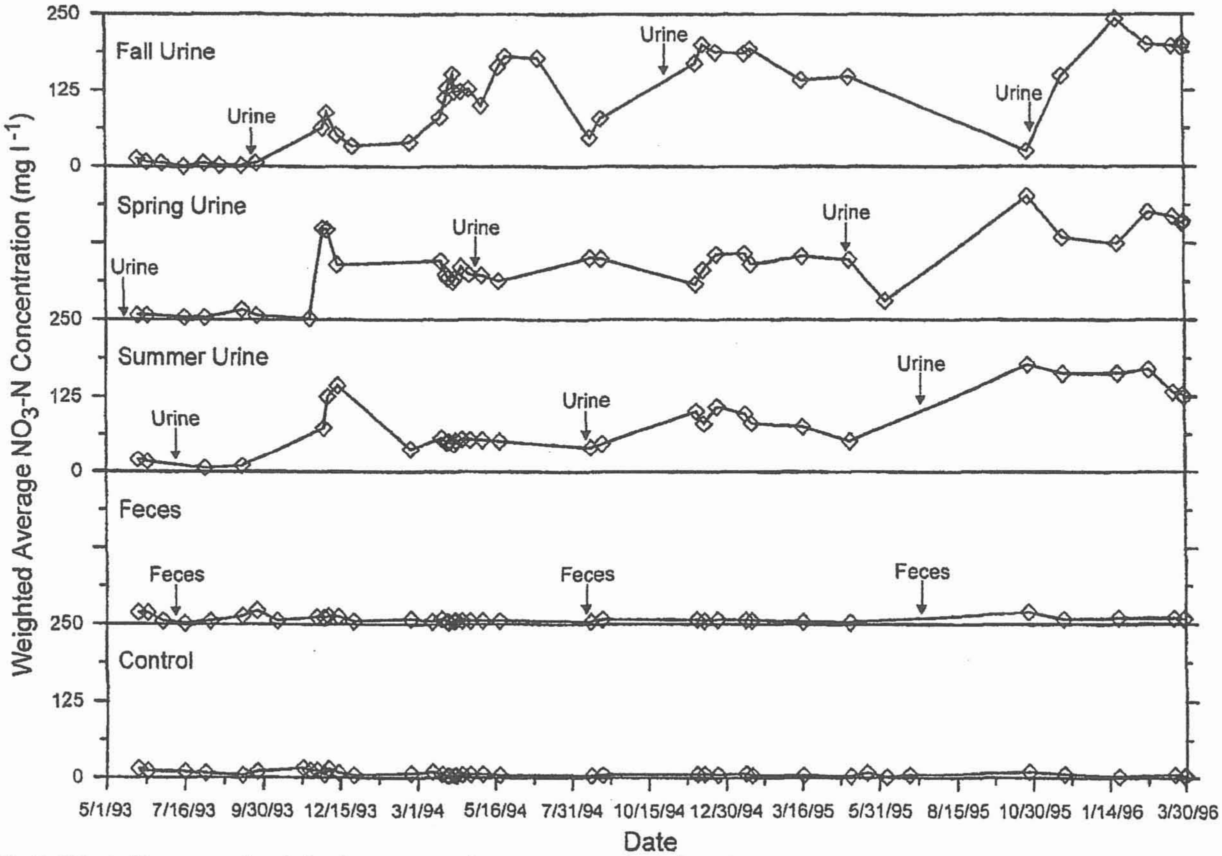

Fig. 3. Nitrate-N concentrations in leachate under spring-, summer-, and fall-applied urine, summer-applied feces, and an untreated control.

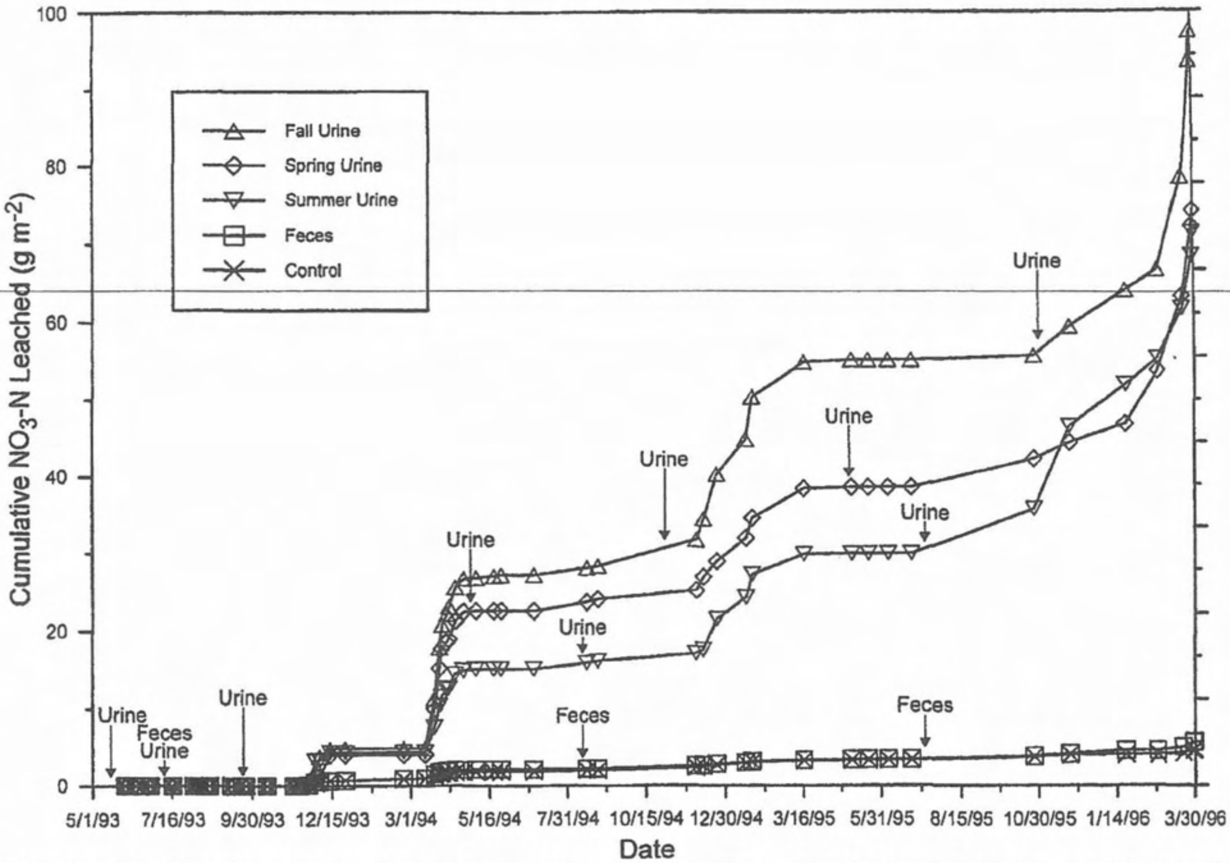

Fig. 4. Cumulative NO_3–N loss beneath spring-, summer-, and fall-applied urine, summer-applied feces, and an untreated control for the water years April 1993 to March 1994, April 1994 to March 1995, and April 1995 to March 1996. The words *urine* and *feces* indicate times of application.

and that the concentration of herbage N in urine spots is a major contributor to these increased losses (Ball et al., 1979) are not new and, as previously stated, have long been a focus of research in the UK, Europe, and New Zealand. Although this research has identified the important mechanisms (leaching, volatilization, and denitrification) by which N is lost from grazed ecosystems, the climatic conditions of the U.S. Northeast are going to determine the relative importance of these mechanisms in this environment.

In a laboratory lysimeter study using synthetic urine conducted under simulated New Zealand climatic conditions, peak leachate NO_3–N concentration from urine was only 42 mg L^{-1} and only 8% of the N applied was lost to leaching (Frazier et al., 1994). This is a sharp contrast to average leachate NO_3–N concentrations of 163 mg L^{-1} beneath urine and the almost 26% N losses that we observed in this study. The temperate oceanic climate (Willy Rudloff, 1981) of this area of New Zealand with a mean winter (June–August) temperature of 6.0°C and a mean summer (December–February) temperature of 16.3°C allowed for year-round cool-season grass growth and uptake of N. In contrast, the temperate continental climate of central Pennsylvania with a mean winter (December–February) temperature of −2.9°C and a mean summer (June–August) temperature of 21.2°C, as measured in our study, only allowed for a growing season of about 7 mo for cool-season grasses. Also, the high winter temperatures and high and consistent water inputs (1600 mm as simulated precipitation + supplemental irrigation) in the New Zealand study allowed for substantial amounts of denitrification. Frazier et al. (1994) estimated that 28% of the N applied as synthetic urine was lost through denitrification, which was attributed to wet soil conditions in their lysimeters. In contrast, water inputs into our lysimeters were less (1071 mm as precipitation) and more erratic (Fig. 1) than in the New Zealand study. At the time of the year when temperatures were the highest (Fig. 1), soil water levels in our study were the lowest as evidenced by the low amount of leachate collected at this time (Fig. 2). Conversely, in the winter when soil water levels and leachate amounts were highest, soil temperatures were lowest. These conditions would not be conducive to denitrification.

Climatic conditions can also interact with the time of year at which urine is deposited to affect the amount of NO_3–N leached. In Ireland and the UK (temperate oceanic climates), it was estimated that only 3% of the urine-N applied from May to September was subject to leaching (Sherwood, 1986; Cuttle and Bourne, 1993). In contrast, 18% of the urine-N applied in May and 28% of the urine-N applied in August was leached in our study. However, when urine was applied in September to November in the Irish and UK studies, about 30 to 66% of the N in the urine was subject to leaching. This is similar to the results from our study in which 31% of the urine-N applied in September through November leached through our lysimeters.

The overall impact of urine deposition on the total amount of N leached from a pasture can be large. Data from the UK (Garwood and Ryden, 1986) show potential NO_3–N leaching was about three times greater under grazing than it was under cut swards of either N-fertilized perennial ryegrass (*Lolium perenne* L.) or white clover (*Trifolium repens* L.) and perennial ryegrass. Similarly, in the Netherlands, 75% of the N leached from grazed grassland was attributed to N returned to the grassland in excreta (Kolenbrander, 1981). Estimates using the data from our study (Stout et al., 1996) indicate that, for a stocking rate of 2.2 mature (682 kg) Holstein cows ha^{-1} d^{-1} for a 180-d grazing season, about 70% of the NO_3–N leached would come from urine deposited on the pasture. This stocking rate would result in an average annual NO_3–N concentrate in the leachate of about 15 mg L^{-1}, a concentration in excess of the 10 mg L^{-1} U.S. primary drinking water standard (U.S. Environmental Protection Agency, 1987). Clearly this indicates that MIG, in and of itself, is not a means of reducing NO_3–N loss from agriculture in the Northeast, and must be considered a livestock production system component that can have negative water quality impacts if not properly managed. One possible management technique would be mechanical harvest and ensilage of late-season herbage growth (Garwood and Ryden, 1986). This would remove animals from the pasture at the time of the year when NO_3–N from their urine would be most subject to leaching.

CONCLUSIONS

As previously observed in the humid maritime climates of the United Kingdom and New Zealand, an appreciable amount of the N excreted as urine in intensively grazed pastures can be leached from the root zone. On a deep, well-drained soil in the temperate continental climate of the northeastern USA, this leaching loss is about 25% of the N contained in the urine. Nitrate-N leaching losses beneath feces amounted to only about 2% of the N in the feces during the relatively short time of this study. Given more time, feces may have more impact on NO_3–N leaching.

If dairy farmers in the Northeast continue to increase the utilization of MIG, the amount of N leached to the groundwater from beneath urine patches could become substantial unless mitigated by improved grazing management. This would be especially true under grazing programs using high N inputs and highly digestible forages, such as ryegrass or brassica species where a larger portion of the N in the pasture is excreted in the urine. Also, grazing programs that involve extension of the grazing season into the fall or involve wintering dry cows on pasture may increase the potential for NO_3–N leaching from urine.

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TITLE 19 NATURAL RESOURCES AND WILDLIFE
CHAPTER 27 UNDERGROUND WATER
PART 4 WELL DRILLER LICENSING; CONSTRUCTION, REPAIR AND PLUGGING OF WELLS

19.27.4.1 ISSUING AGENCY: Office of the State Engineer.
[19.27.4.1 NMAC - N, 8-31-2005]

19.27.4.2 SCOPE: The rules for well driller licensing, drill rig supervisor registration, and well drilling within the state of New Mexico. These rules also apply to mine drill holes that encounter water. These rules do not apply to oil wells, gas wells, or cathodic protection wells.
[19.27.4.2 NMAC - N, 8-31-2005]

19.27.4.3 STATUTORY AUTHORITY: Section 72-12-1 NMSA provides that the water of underground streams, channels, artesian basins, reservoirs, or lakes having reasonably ascertainable boundaries are declared to be public waters which belong to the public and are subject to appropriation for beneficial use. Section 72-2-8 NMSA gives the state engineer authority to adopt regulations and codes to implement and enforce any provision of any law administered by him. Section 72-12-12 NMSA states that it shall be unlawful for any person, firm, or corporation to drill or to begin the drilling of a well for water from an underground source without a valid, existing license for the drilling of such wells issued by the state engineer of New Mexico. Section 72-12-13 NMSA states any person desiring to engage in the drilling of one or more wells for underground water within the boundaries of any underground source shall file an application with the state engineer for a driller license. Sections 72-12-14 through 72-12-17 NMSA further detail requirements for well drillers in New Mexico. Sections 72-13-1 through 72-13-12 NMSA detail the requirements for the drilling of artesian wells.
[19.27.4.3 NMAC - N, 8-31-2005]

19.27.4.4 DURATION: Permanent.
[19.27.4.4 NMAC - N, 8-31-2005]

19.27.4.5 EFFECTIVE DATE: August 31, 2005, unless a later date is cited at the end of a section.
[19.27.4.5 NMAC - N, 8-31-2005]

19.27.4.6 OBJECTIVE: To update written rules for well driller licensing, drill rig supervisor registration, and well drilling within the state of New Mexico.
[19.27.4.6 NMAC - N, 8-31-2005]

19.27.4.7 DEFINITIONS: Unless defined below or in a specific section of these rules, all other words used herein shall be given their customary and accepted meaning. The use of a masculine pronoun to refer to individuals is for grammatical convenience and is intended to be gender neutral.

A. Artesian well: A well that penetrates a saturated hydrogeologic unit and allows underground water to rise or move appreciably into another geologic unit, or allows underground water to rise to freely flow at the land surface. For regulatory purposes, the determination of whether a well or bore hole is artesian shall be made by the state engineer, taking into consideration the potential for loss of water at the land surface or into another geologic unit.

B. Drill rig supervisor: A person registered by the office of the state engineer who may provide onsite supervision of well drilling activities. A drill rig supervisor shall only provide onsite supervision when he is operating under the direction of a licensed well driller.

C. Drilling: see definition for well drilling.

D. Mine drill hole: A deep narrow hole drilled to explore for or delineate deposits or accumulations of ore, mineral, or rock resources.

E. Well: A bore hole, cased or screened bore hole, or other hydraulic structure that is drilled, driven, or dug with the intent of penetrating a saturated geologic unit. The intended use may be for developing a source of water supply, for monitoring water levels, for monitoring water quality, for exploratory purposes, for water remediation, for injection of water, for geothermal purposes, or for other purposes.

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F. Well drilling, well drilling activities: The activities associated with the drilling of a well, including, but not limited to, the construction, drilling, completion, repair, deepening, cleaning, plugging, and abandonment of a well.
[19.27.4.7 NMAC - N, 8-31-2005]

19.27.4.8 LICENSE REQUIRED: Any person who engages in the business of well drilling within the state of New Mexico shall obtain a well driller license issued by the state engineer (except, under New Mexico state law, a well driller license is not required for driven wells that do not require the use of a drill rig and which have an outside casing diameter of two and three-eighths (2⅜) inches or less). A person found engaged in the business of well drilling within the state of New Mexico without a license can be prosecuted in accordance with New Mexico Statutes. A well driller license is not required for work on pumping equipment.
[19.27.4.8 NMAC - Rp, SE 66-1, Article 4-1, 8-31-2005]

19.27.4.9 EXISTING WELL DRILLER LICENSE RECOGNIZED: A person holding a valid and current well driller license in the state of New Mexico on August 31, 2005 shall have his license recognized. Any amendment or change to a license shall be made pursuant to the requirements of 19.27.4.16 NMAC and 19.27.4.17 NMAC. A licensed well driller may request that his license be renewed by filing an application with the state engineer prior to the expiration of the current license (see 19.27.4.20 NMAC). A well driller that allows his license to expire and does not reinstate the license within the grace period provided for under 19.27.5.19 NMAC shall apply for a new license in accordance with the requirements of 19.27.4.12 NMAC.
[19.27.4.9 NMAC - N, 8-31-2005]

19.27.4.10 - 19.27.4.11 RESERVED

19.27.4.12 APPLICATION FOR A NEW LICENSE: An applicant for a well driller license shall meet the following requirements to be considered for licensure.

A. Qualified applicant: A qualified applicant for a well driller license shall:

(1) have passed the national ground water association general exam; and

(2) have passed the appropriate national ground water association methodology exam(s) for each type of drilling method for which the applicant has requested to be licensed (the state engineer shall make the final determination of the test(s) necessary should a question arise regarding applicability of available test(s) to applied method(s) of well construction); and

(3) have at least two (2) years of relevant, on-site experience working under the supervision of a licensed well driller; and

(4) effective July 1, 2006, have passed the New Mexico general drilling exam.

B. Application - form and content: An application for a well driller license shall be completed on a form prescribed by the state engineer. The application shall include the name, address, and the phone number of the applicant, the state of residency of the applicant, three letters of reference (one of which shall be from a well driller licensed in New Mexico, or a state's licensing authority, attesting to the applicant's well drilling ability), documentation of prior well drilling experience, proof of required bonds, proof of required insurances, documentation that applicant has passed the required exams listed in Paragraphs (1), (2) and (4) of Subsection A of 19.27.4.12 NMAC, the name of each registered drill rig supervisor that the applicant plans to supervise, if known, the type of well drilling methods the applicant is applying to be licensed for, and other information deemed necessary by the state engineer. The application must also contain a description of each active drill rig owned or controlled by the applicant. The description of the drill rig shall be on a form prescribed by the state engineer and shall include a side-view photograph of the rig.

C. Filing fee: A fee of fifty dollars ($50) is required to accompany an application for a new license.

D. Bond requirements: Each applicant for a well driller license shall file a bond in the penal sum of five thousand dollars ($5,000) on a form acceptable to the state engineer. The surety backing the bond shall be acceptable to the state engineer. A well driller license shall be valid only so long as the bond remains in effect. The bond shall:

(1) be conditioned upon proper compliance with state law and the rules and regulations of the state engineer; and

(2) be effective for the period of time for which the license is issued; and

(3) stipulate the obligee as the "office of the state engineer"; and

(4) not be represented to the public as a performance bond.

E. Insurance requirements: Each applicant for a well driller license shall file with the state engineer proof of general liability insurance in the minimum amount of three hundred thousand dollars ($300,000) and proof of appropriate insurance under the Workers' Compensation Act.
[19.27.4.12 NMAC Rp SE 66-1, Article 4-2, 8-31-2005]

19.27.4.13 NATIONAL GROUND WATER ASSOCIATION EXAMS: The national ground water association exams shall consist of the general drilling exam and the appropriate drilling methodology exam(s) developed and administered by the national ground water association. If an applicant has passed the national ground water association general exam and appropriate methodology exams in another state, the applicant shall provide written proof to the state engineer. The fee to take the national ground water association exams will be established by the national ground water association.
[19.27.4.13 NMAC - N, 8-31-2005]

19.27.4.14 NEW MEXICO GENERAL DRILLING EXAM: This section has an effective date of July 1, 2006. The New Mexico general drilling exam will be offered at least four (4) times a year by the state engineer or his authorized representative.

A. Exam fee: The fee to take the New Mexico general drilling exam will be based on the approximate cost of administering the test.

B. Test - content: The New Mexico general drilling exam may include questions on the following subjects:

(1) New Mexico water law as it pertains to well driller licensing, well drilling and construction, and the administration of underground water;

(2) the state engineer's rules and regulations pertaining well driller licensing, well drilling and construction, and the administration of underground water;

(3) New Mexico environment department's rules, regulations, and guidelines pertaining to set back requirements, well disinfection, sampling of underground water, and water analysis;

(4) the proper methods and techniques for well drilling;

(5) geologic formations and proper terminology used in describing underground material types;

(6) basic groundwater geology and the occurrence and movement of underground water;

(7) legal description of well location, latitude and longitude, and the New Mexico coordinate system;

(8) global positioning system terminology and receiver operation;

(9) other topics and subjects related to well driller licensing, well construction, and well drilling within the state of New Mexico.

C. Passing the exam: The applicant shall obtain a minimum score of seventy percent (70%) to pass the New Mexico general drilling exam.

D. Re-examination: An applicant who fails to obtain the minimum passing score on the exam may retake the exam.

(1) The fee to retake the New Mexico general drilling exam will be based on the approximate cost of administering the test.

(2) Any applicant found cheating on the exam, as determined by the tester or testing agency, will not be permitted to reapply to take the exam for a period of one (1) year from the date of the transgression.
[19.27.4.14 NMAC - N, 7-1-2006]

19.27.4.15 APPLICATION REVIEW AND LICENSING REQUIREMENTS: If the state engineer finds that an applicant has fulfilled the requirements for licensure as set forth in 19.27.4.12 NMAC, the state engineer shall issue a well driller license to the applicant. The license shall set forth the conditions under which the well driller shall operate his well drilling activities within the state of New Mexico. The license shall also state which drilling methods the well driller may engage in.

A. License duration: A license issued by the state engineer will be valid for a period of two (2) years.

B. Driller identification card: The state engineer will issue a well driller identification card to each licensed well driller. When drilling within the state of New Mexico, a well driller shall have his identification card available for inspection upon request.

C. Drill rig marking: The name and license number of the well driller shall be clearly displayed on each drill rig under his control.

D. Oversight of registered drill rig supervisor: A licensed well driller may allow a registered drill rig supervisor to provide onsite supervision of well drilling activities. The licensed well driller is responsible for the actions of each drill rig supervisor that he directs to provide such onsite supervision of well drilling activities.
[19.27.4.15 NMAC - Rp, SE 66-1, Articles 4-4 and 4-5, 8-31-2005]

19.27.4.16 CHANGES TO LICENSE: A licensed well driller shall notify the state engineer in writing within 10 days of any change to his current license, including:

A. change in address or any other contact information; or

B. change in drill rig supervisor; or

C. severing ownership or control of an active drill rig; or

D. acquiring ownership or control of an active drill rig (the description of the drill rig shall be on a form prescribed by the state engineer and shall include a side-view photograph of the rig).
[19.27.4.16 NMAC - Rp, SE 66-1, Article 4-9, 8-31-2005]

19.27.4.17 REQUEST TO BE LICENSED IN ADDITIONAL DRILLING METHODOLOGY: A licensed well driller shall apply in accordance with the requirements of 19.27.4.12 NMAC to be licensed in an additional drilling methodology.
[19.27.4.17 NMAC - N, 8-31-2005]

19.27.4.18 RESERVED

19.27.4.19 LICENSE EXPIRATION: A well driller license shall expire on the date set out on the license. An application to renew a license shall be filed in accordance with 19.27.4.20 NMAC at least ten (10) days prior to the expiration date. If an application to renew a license is not filed with the state engineer prior to the expiration of the current license, the license shall automatically expire. The state engineer will allow a forty-five (45) day grace period after the expiration of a well driller license during which time a well driller may file an application to renew his well driller license and request to have the expired license reinstated. If an application to renew a well driller license is not filed within this time period, the license shall be considered expired without option for reinstatement. A well driller that allows his license to expire and does not reinstate the license within the forty-five (45) day grace period must apply for a new license in accordance with the requirements of 19.27.4.12 NMAC.
[19.27.4.19 NMAC - N, 8-31-2005]

19.27.4.20 LICENSE RENEWAL: A licensed driller may request that his license be renewed by filing an application with the state engineer prior to the expiration of his current license. The application for renewal of a well driller license shall be completed on a form prescribed by the state engineer.

A. Form - content: The application for renewal of a well driller license shall include the name, address, phone number, and license number of the well driller, the state of residency of the well driller, proof of required bonds, proof of required insurances, a list of registered drill rig supervisors that the well driller supervises, evidence of meeting the continuing education requirements, and other information deemed necessary by the state engineer.

B. Filing fee: A fee of fifty dollars ($50) shall accompany the application.

C. Continuing education requirements: During each two (2) year licensing period, a licensed well driller shall complete a minimum of eight (8) continuing education hours approved by the state engineer. The continuing education hours shall relate to well drilling. At least two (2) hours of the continuing education shall be specific to regulatory requirements regarding well drilling in the state of New Mexico.
[19.27.4.20 NMAC - Rp, SE 66-1, Article 4-6, 8-31-2005]

19.27.4.21 REPRIMANDS, SUSPENSION OR REVOCATION OF WELL DRILLER LICENSE: The state engineer may issue a written reprimand, a compliance order issued pursuant to Section 72-2-18 NMSA, or, after notice and hearing held pursuant to 19.25.2 NMAC and 19.25.4 NMAC, suspend or revoke a well driller license if it is found that a well driller:

A. made a material misstatement of facts in his application for license; or

B. failed to submit or submitted an incomplete well record or well log; or

C. made a material misstatement of facts in a well record or well log; or

D. drilled a well in any declared underground water basin without a state engineer permit; or

E. violated the conditions of the state engineer permit under which the well was being drilled; or

F. violated the conditions of his well driller license; or

G. the licensed well driller or his registered drill rig supervisor was not present at the drilling site during well drilling activities; or

H. violated the rules and regulations of the state engineer; or

I. failed to assure the protection of the public safety, health, welfare, and property in the well construction process.

[19.27.4.21 NMAC - Rp, SE 66-1, Article 4-10, 8-31-2005]

19.27.4.22 - 19.27.4.24 RESERVED

19.27.4.25 APPLICATION FOR REGISTRATION AS A DRILL RIG SUPERVISOR: A person registered by the office of the state engineer as a drill rig supervisor may provide onsite supervision of well drilling activities. A drill rig supervisor shall work under the direction of a licensed well driller. The licensed well driller is responsible for the actions of each drill rig supervisor that he directs to provide onsite supervision of well drilling activities. An applicant for registration as a drill rig supervisor shall meet the following requirements.

A. Qualified applicant: A qualified applicant for a registration as a drill rig supervisor shall:

(1) have at least two (2) years of relevant, on-site experience working under the supervision of a licensed well driller; and

(2) be at least eighteen (18) years of age; and

(3) effective July 1, 2006, have passed the New Mexico general drilling exam.

B. Application - form and content: An application for registration as a drill rig supervisor shall be completed on a form prescribed by the state engineer. The application shall include the name, address, and phone number of the applicant, a letter of reference from a well driller licensed in New Mexico, or a state's licensing authority, attesting to applicant's well drilling ability, the license number and contact information of the well driller the applicant plans to work for, if known, documentation of prior well drilling experience, documentation that the applicant has passed the New Mexico general drilling exam, and other information deemed necessary by the state engineer.

C. Filing fee: There is no filing fee for the application.

[19.27.4.25 NMAC - N, 8-31-2005]

19.27.4.26 APPLICATION REVIEW AND REGISTRATION REQUIREMENTS FOR DRILL RIG SUPERVISOR: If the state engineer finds that the applicant has fulfilled the requirements for registration as set forth in 19.27.4.25 NMAC, the state engineer shall register the applicant as a drill rig supervisor. The registration shall set forth the conditions under which the drill rig supervisor may provide onsite supervision of well drilling activities within the state of New Mexico.

A. Registration duration: A registration issued by the state engineer will be valid for a period of two (2) years.

B. Identification card: The state engineer will issue a drill rig supervisor identification card with the registration. Each drill rig supervisor, when providing onsite supervision of well drilling activities within the state of New Mexico shall have his identification card available for inspection upon request.

[19.27.4.26 NMAC - N, 8-31-2005]

19.27.4.27 RENEWAL OF DRILL RIG SUPERVISOR REGISTRATION: A registered drill rig supervisor may request that his registration be renewed by filing an application with the state engineer prior to the expiration of his current registration.

A. Form - content: The application shall be on a form prescribed by the state engineer and shall include the name, address, phone number, and registration number of the drill rig supervisor, the license number and contact information of the well driller the drill rig supervisor is currently working under, evidence of meeting the continuing education requirements, and other information deemed necessary by the state engineer.

B. Filing fee: There is no filing fee for the application.

C. Continuing education requirements: During each two (2) year registration period, a registered drill rig supervisor shall complete a minimum of eight (8) continuing education hours approved by the state engineer. The continuing education hours shall relate to well drilling. At least two (2) hours of the continuing education shall be specific to regulatory requirements regarding well drilling in the state of New Mexico.

D. **New Mexico general drilling exam:** Persons registered as drill rig supervisor in the state of New Mexico on or before July 1, 2006 shall be required to pass the New Mexico general drilling exam on or before August 31, 2010.
[19.27.4.27 NMAC - N, 8-31-2005]

19.27.4.28 RESERVED

19.27.4.29 WELL DRILLING - GENERAL REQUIREMENTS: All wells shall be constructed to prevent contamination, to prevent inter-aquifer exchange of water, to prevent flood waters from contaminating the aquifer, and to prevent infiltration of surface water. A licensed well driller shall ensure that an appropriate well permit or ~~emergency authorization has been granted by the state engineer prior to the well drilling.~~ A licensed well driller shall ensure that the well drilling activities are made in accordance with 19.27.4.30 NMAC, 19.27.4.31 NMAC, and the following requirements:

A. **On-site supervision of well drilling:** A licensed well driller or registered drill rig supervisor shall be present at the drilling site during well drilling.

B. **Materials:** Materials used in well drilling shall conform to industry standards acceptable to the state engineer. Acceptable standards include, but are not limited to, standards developed by the American water works association (AWWA), the American standard for testing materials (ASTM), the American petroleum institute (API), and the national sanitation foundation (NSF). The state engineer shall make the final determination of applicability of standards if any of the acceptable standards are different from one another. Materials used in well construction shall be in new or good condition. No materials shall be used that may cause water contamination. Only potable water shall be placed in a well during well drilling.

C. **Cleaning of drilling equipment:** All down-hole equipment shall be maintained in a clean and sanitary condition to prevent contamination and to protect the public health. To reduce the potential of contaminating a well, equipment shall be disinfected prior to well drilling with a chlorine solution of household chlorine bleach diluted at one part bleach to nine parts water. Adequate contact time shall be allowed for the disinfectant to sanitize the equipment before rinsing (laboratory testing will not be required).

D. **Well setbacks:** All wells shall be set back a minimum of fifty (50) feet from an existing well of other ownership, unless a variance has been granted by the state engineer. All wells shall be set back from potential sources of contamination in accordance with New Mexico environment department regulations and other applicable ordinances or regulations.

E. **Casing height:** The top of all well casings shall extend a minimum of eighteen (18) inches above land surface. All vents installed in the well casing shall be protected against the entrance of foreign material by installation of down-turned and screened "U" bends. All other openings in casings shall be sealed to prevent entrance of foreign material and flood waters.

F. **Subsurface vault:** The completion of a well within a subsurface vault is not recommended due to difficulty in performing well repairs and cleaning. If a well is completed within a subsurface vault, the casing shall extend a minimum of eighteen (18) inches above the floor of the vault.

G. **Surface pad:** A concrete pad is recommended on all wells. It is recommended that:

(1) the surface area of the concrete pad be a minimum of four (4) square feet; and

(2) the concrete pad be centered around the well; and

(3) the pad be at least four (4) inches in thickness and slope away from the well; and

(4) when surface casing is used, the surface pad should seal the top of the annular space between the production casing and the surface casing.

H. **Access for water level monitoring:** Every well shall be constructed with a wellhead opening of at least one half (½) inch diameter to allow the water level to be measured. A water-tight removable cap or plug shall be securely placed in the opening. An artesian well that flows at land surface upon completion of the well shall be equipped with a valve to which a pressure gauge may be attached.

I. **Requirement to cover or cap wells:** During well drilling, a well shall be securely covered or capped unless a licensed well driller or registered drill rig supervisor is on-site attending to the well. A permanent well cap or cover shall be securely affixed to the well casing upon completion. All permanent caps shall have a well access opening in accordance with Subsection H of 19.27.4.29 NMAC.

J. **Well identification tag:** The state engineer may require that a well be tagged with a well identification tag. If a well tag is required, the well driller shall affix the tag in plain view. The state engineer will provide a well tag when a permit is issued. Replacement well tags will be issued upon request. The permit holder is responsible for maintaining the well identification tag. A missing, damaged, or illegible well identification tag shall be replaced with a duplicate tag.

K. Well record: The well driller shall keep a record of each well drilling activity as the work progresses.

(1) Time for filing: The well driller shall file a complete well record with the state engineer and the permit holder no later than twenty (20) days after completion of the well drilling.

(2) Form - content: The well record shall be on a form prescribed by the state engineer and shall include the name and address of the permittee, the well driller's name and license number, the state engineer file number, the name of each registered drill rig supervisor that supervised well drilling activities, the location of the well (reported in latitude and longitude using a global positioning system (gps) receiver capable of five (5) meters accuracy), the date when drilling or other work began, the date when drilling or other work concluded, the depth of the well, the depth to water first encountered, the depth to water upon completion of the well (measured by a method approved by the state engineer), the estimated well yield, the method used to estimate well yield, the size and type of casing, the location of perforations, the location of the sanitary seal, and other information deemed necessary by the state engineer. The well record shall include a completed well log. The well log shall include detailed information on the depth and thickness of all strata penetrated, including whether each stratum was water bearing.

L. Geologic formation samples: When requested by the state engineer, the well driller shall furnish lithologic samples ("drill cuttings") of the geologic units penetrated during drilling operations. The method of sampling, interval of sampling, and the quantities required will be specified by the state engineer. Lithologic samples shall be placed in sample bags supplied by the state engineer.
[19.27.4.29 NMAC - Rp, SE 66-1, Articles 4-11, 4-12, and 4-13, 8-31-2005]

19.27.4.30 WELL DRILLING - NON-ARTESIAN WELL REQUIREMENTS: A licensed well driller shall ensure that the well drilling activities associated with the drilling of non-artesian wells are made in accordance with 19.27.4.29 NMAC and the following requirements:

A. Annular seal: All wells shall be constructed to prevent contaminants from entering the hole from the land surface by sealing the annular space around the outermost casing. When necessary, annular seals will be required to prevent inter-aquifer exchange of water, to prevent the loss of hydraulic head between geologic zones, and to prevent the flow of contaminated or low quality water. Sealing operations shall be made with cement grout or bentonite-based sealing material acceptable to the state engineer. Casings shall be centered in the bore hole so grout or sealing materials may be placed evenly around the casing.

(1) Annular space: The diameter of the hole in which the annular seal is to be placed shall be at least four (4) inches greater than the outside diameter of the outermost casing. The diameter of the hole in which the annular seal is to be placed may be reduced to three (3) inches greater than the outside diameter of the outermost casing if pressure grouting from the bottom up is used for grout placement and the well casing is centralized in the bore hole. If surface casing is used, the inside diameter of the surface casing shall be at least three (3) inches greater than the outside diameter of the production casing.

(2) Annular seal completed to land surface: Annular seals shall extend from land surface to at least twenty (20) feet below land surface. If a well is completed less than twenty (20) feet below land surface, the seal shall be placed from land surface to the bottom of the blank casing used. The annular seal shall extend to land surface unless a pitless adapter is installed. For wells completed with a pitless adapter, the top of the seal shall extend to one (1) foot below the pitless adapter connection. All sealing materials placed deeper than twenty (20) feet below land surface shall be placed by tremie pipe or by pressure-grouting through the well casing and up the annulus.

(3) Annular seals to prevent inter-aquifer exchange of water or loss of hydraulic head between geologic zones: Sufficient annular seal shall be placed to prevent inter-aquifer exchange of water and to prevent loss of hydraulic head between geologic zones. Sufficient annular seal shall be placed to prevent loss of hydraulic head through the well annulus, through perforated or screened casing, or through an open bore interval.

(4) Annular seals to prevent the contamination of potable water: Wells which encounter non-potable, contaminated, or polluted water at any depth shall have the well annulus sealed and the well properly screened to prevent the commingling of the undesirable water with any potable or uncontaminated water. The use of salt-tolerant sealing materials may be required by the state engineer in wells that encounter highly mineralized water.

(5) Annular seal requirements for community water supply wells: Community water supply wells shall also be completed with annular seals in accordance with New Mexico environment department regulations and other applicable ordinances or regulations.

B. Well casing: The well casing shall have sufficient wall thickness to withstand formation and hydrostatic pressures placed on the casing during installation, well development, and use.

C. Well plugging: A non-artesian well that is abandoned or not properly constructed shall be immediately plugged. A plan for plugging the well shall be filed with - and approved by - the state engineer prior to plugging. The state engineer may require that the plugging process be witnessed by an authorized representative.

(1) Methods and materials: To plug a well, the entire well shall be filled from the bottom upwards to land surface using a tremie pipe. The well shall be plugged with neat cement slurry, bentonite based plugging material, or other sealing material approved by the state engineer for use in the plugging of non-artesian wells. Wells that do not encounter a water bearing stratum shall be immediately plugged by filling the well with drill cuttings or clean native fill to within ten (10) feet of land surface and by plugging the remaining ten (10) feet of the well to land surface with a plug of neat cement slurry, bentonite based plugging material, or other sealing material approved by the state engineer.

(2) Contamination indicated: Wells encountering contaminated water or soil may require coordination between the office of the state engineer and the New Mexico environment department (or other authorized agency or department) prior to the plugging of the well. Specialty plugging materials and plugging methods may be required.

(3) Plugging record: A licensed well driller shall keep a record of each well plugged as the work progresses. The well driller shall file a complete plugging record with the state engineer and the permit holder no later than twenty (20) days after completion of the plugging. The plugging record shall be on a form prescribed by the state engineer and shall include the name and address of the well owner, the well driller's name and license number, the name of each drill rig supervisor that supervised the well plugging, the state engineer file number for the well, the location of the well (reported in latitude and longitude using a global positioning system (gps) receiver capable of five (5) meters accuracy), the date when plugging began, the date when plugging concluded, the plugging material(s) used, the depth of the well, the size and type of casing, the location of perforations, the location of the sanitary seal, and other information deemed necessary by the state engineer. The plugging record shall include a completed well log. The well log shall include detailed information on the depth and thickness of all strata plugged, including whether each stratum was water bearing.

D. Repair requirements: A well driller license is not required to install or repair pumping equipment.

[19.27.4.30 NMAC - Rp, SE 66-1, Article 4-14, 8-31-2005]

19.27.4.31 WELL DRILLING - ARTESIAN WELL REQUIREMENTS: No artesian well shall be constructed that allows ground water to flow uncontrolled to the land surface or move appreciably between geologic units. For regulatory purposes, the determination of whether a well is artesian shall be made by the state engineer. A licensed well driller shall ensure that well drilling activities associated with the drilling of artesian wells are made in accordance with 19.27.4.29 NMAC and the following requirements:

A. Plan of operations: The permittee or owner of the land upon which the well drilling is planned shall provide a description of the proposed work on a form prescribed by the state engineer. The plan of operations shall list the materials to be used and include the cementing and testing procedures. The plan of operations shall be completed by a licensed well driller. A plan of operations must be approved by the state engineer before the drilling of any artesian well. Drilling of an artesian well shall be made in accordance with a plan of operations approved by the state engineer.

B. Construction inspection: The casing, cementing, plugging, and testing of an artesian well shall be witnessed by an authorized representative of the state engineer.

C. Artesian wells - no prior knowledge of artesian stratum: In the course of drilling a well, if a previously unidentified artesian stratum is encountered, such that underground water is flowing uncontrolled to the land surface or between geologic units, the flow shall be controlled immediately. The state engineer shall be immediately notified that an artesian stratum was encountered, and a plan of operations shall be submitted in accordance with Subsection A of 19.27.4.31 NMAC.

D. Casing and coupling material requirements: Couplings and threaded steel casing used in the construction of an artesian well shall meet minimum American petroleum institute (API) specifications (the API casing specifications are listed in the table below). If the well casing or joint connection proposed in the plan of operations is not listed in the table below, the specifications for the casing and connections shall be approved by the state engineer prior to well drilling. If casing length exceeds one thousand (1,000) feet and the diameter of the casing is thirteen and three-eighths (13⅜) inch diameter or larger, H-grade or better shall be used. The casing for artesian wells shall be inspected by an authorized representative of the state engineer prior to well construction.

Outside Diameter (inches)	Weight with Couplings (lbs/ft)	Wall Thickness (inches)	Coupling O.D. (inches)	Coupling Length (inches)	Threads per Inch	Minimum Grade of Casing
4½	9.50	.205	5.000	5	8	F-25
5½	13.00	.225	6.050	6¾	8	F-25
6	15.00	.233	6.625	7	8	F-25
6⅝	17.00	.245	7.390	7¼	8	F-25
7	17.00	.231	7.656	7¼	8	F-25
7⅝	20.00	.250	8.500	7½	8	F-25
8⅝	24.00	.264	9.625	7¾	8	F-25
9⅝	29.30	.281	10.625	7¾	8	F-25
10¾	32.75	.279	11.750	8	8	F-25
11¾	38.00	.300	12.750	8	8	F-25
13⅜	48.00	.330	14.375	8	8	F-25
16	55.00	.312	17.000	9	8	F-25
20	94.00	.438	21.000	9	8	F-25

E. Casing installation requirements: The casing shall be centered within the bore hole so grout may be evenly placed around the casing. A commercially made float shoe shall be installed on the lowermost joint of casing to be landed unless an alternate method for cementing has been approved by the state engineer. The casing shall be un-perforated and the well shall be designed in a manner to prevent the commingling of water from the artesian stratum with water in an overlying or underlying geologic unit.

F. Annular space: The diameter of the hole in which the cement seal shall be placed shall be at least four (4) inches greater than the outside diameter of the casing set through the confining formation overlying the artesian aquifer. The diameter of the hole in which the cement seal shall be placed may be reduced to three (3) inches greater than the outside diameter of the casing set through the confining formation overlying the artesian aquifer if pressure grouting from the bottom up is used for grout placement and the well casing is centralized in the bore hole. If surface casing is used, the inside diameter of the surface casing shall be at least three (3) inches greater than the outside diameter of the production casing.

G. Annular space cementing requirements: The annular seal shall consist of a neat cement slurry acceptable to the state engineer. The cement seal shall originate within the artesian stratum and shall be continuously placed to land surface. The cementing process shall be witnessed by an authorized representative of the state engineer. When necessary, sufficient annular seal shall be placed to prevent inter-aquifer exchange of water and to prevent loss of hydraulic head between geologic zones.

H. Annular space - cement placement: The cement slurry shall be placed in the annular space by one of the following methods:

(1) Tremie method: The neat cement slurry shall be pumped using a tremie pipe to fill the annular space of the well from the origin of the seal within the artesian stratum to land surface. Flow of undiluted cement out of the top of the annular space shall be established with the tremie pipe suspended in the annulus. The lower end of the tremie shall remain immersed in the cement slurry for the duration of pumping. The tremie pipe may be gradually removed as cement level in the annulus rises.

(2) Pressure grout method: The neat cement slurry shall be pumped down the inside of the casing, through the float shoe, and up the annular space until undiluted cement slurry circulates out of the annulus at land surface. Excess cement may be displaced out of the casing from behind with drilling fluid, but the drilling fluid shall not be pumped entirely to the level of the float shoe except to lodge a drillable plug at the bottom of the casing. Should undiluted cement slurry not be displaced out the top of the annulus in a continuous pressure grouting operation, the cementing job may be completed by the use of the tremie method. If the tremie method is employed, a tremie pipe shall be suspended in the annulus to the approximate level of the competent cement grout. The neat cement slurry shall be pumped to fill the annular space of the well from the top of the competent cement grout to land surface.

I. Sealing off formations: The compressive strength of neat cement shall be five hundred (500) psi or more before well drilling is resumed. Cement must be allowed to set a minimum of forty-eight (48) hours before well drilling is resumed. Shorter set times may be requested if approved accelerants are used. Sealing off of the formations shall be checked by a method acceptable to the state engineer. In the case of remediation of unanticipated artesian bore holes, the compressive strength of neat cement shall be one thousand (1,000) psi or more before artesian head is shut-in at the wellhead.

J. Repair requirements: When an artesian well is in need of repair, the permittee or owner of the land upon which the well is located shall provide a plan of operations to the state engineer. The plan of operations shall be prepared in accordance with Subsection A of 19.27.4.31 NMAC. Before repairs are made to an artesian well, the well shall first be inspected by an authorized representative of the state engineer to determine if the condition of the well is such that it may be repaired. When a leak in the casing is found and the casing and well are otherwise in good condition, the state engineer may allow the well to be repaired. A packer or bridge plug may be required to complete necessary well repairs. The use of a lead packer is prohibited. An inspection shall be made at the completion of the work to determine if the repair is satisfactory. During an inspection, the well shall be open to allow for the entrance of equipment for testing and inspection.

K. Plugging requirements: An artesian well that is abandoned or not properly constructed shall be immediately plugged. Plugging of an artesian well shall require submittal of a plan of operations in accordance with Subsection A of 19.27.4.31 NMAC. The well shall be plugged from the bottom upwards with a neat cement slurry. The well plugging shall be witnessed by an authorized representative of the state engineer.

(1) Well plugging, contamination indicated: Wells encountering contaminated water or soil may require coordination between the office of the state engineer and the New Mexico environment department (or other authorized agency or department) prior to the plugging of the well. Specialty plugging materials and plugging methods may be required.

(2) Plugging record: A licensed well driller shall keep a record of each well plugged as the work progresses. A plugging record shall be filed in accordance with Paragraph 3 of Subsection C of 19.27.4.30 NMAC.
[19.27.4.31 NMAC - Rp, SE 66-1, Articles 4-15, 4-16, 4-17, 4-18, and 4-19, 8-31-2005]

19.27.4.32 - 19.27.4.35 RESERVED

19.27.4.36 REQUIREMENTS FOR MINE DRILL HOLES THAT ENCOUNTER WATER: Any person drilling a mine drill hole that encounters a water bearing stratum shall plug that hole in accordance with Subsection C of 19.27.4.30 NMAC or Subsection K of 19.27.4.31 NMAC within 30 days of encountering the water bearing stratum.

A. Well record required: Within thirty (30) days after the date of the discovery of water, a well record shall be filed in accordance with Subsection K of 19.27.4.29 NMAC.

B. Artesian water encountered: If artesian water is encountered in the process of drilling a mine drill hole, the drill hole shall be constructed or plugged in accordance with 19.27.4.31 NMAC.
[19.27.4.36 NMAC - Rp, SE 66-1, Article 4-21, 8-31-2005]

19.27.4.37 REQUEST FOR VARIANCE: The rules in 19.27.4.29 NMAC, 19.27.4.30 NMAC, and 19.27.4.31 NMAC are not intended to cover every situation encountered during well drilling. Geologic conditions vary across the state, and may warrant the need to deviate from the rules contained in 19.27.4.29 NMAC, 19.27.4.30 NMAC, or 19.27.4.31 NMAC. A request for a variance to a rule in 19.27.4 NMAC shall be submitted in writing by an qualified applicant, permit holder, or licensed well driller. It is recommended that a request for variance be prepared by a licensed well driller. The request shall include a detailed justification for the variance and shall demonstrate that such a variance is necessary to preclude unreasonable hardship or that application of a rule in 19.27.4 NMAC would not be practicable. The state engineer may grant the variance if he finds the request to be reasonable and just. The state engineer shall respond in writing to the request for variance and, if the variance if granted, the state engineer may impose terms and conditions.
[19.27.4.37 NMAC - Rp, SE 66-1, Article 4-22, 8/31/2005]

19.27.4.38 LIBERAL CONSTRUCTION: This part shall be liberally construed to carry out its purpose.
[19.27.4.38 NMAC - N, 8/31/2005]

19.27.4.39 SEVERABILITY: If any portion of this part is found to be invalid, the remaining portion of this part shall remain in force and not be affected.
[19.27.4.39 NMAC - N, 8-31-2005]

HISTORY OF 19.27.4 NMAC:

Pre NMAC History: The material in this part was derived from that previously filed with the State Records Center and Archives.
SE-66-1, Rules and Regulations Governing Drilling of Wells and Appropriation and Use of Ground Water in New Mexico, Article 4, Well Drillers Licensing, Construction, Repair and Plugging Of Wells, originally filed with the Supreme Court Law Library 11/1/66. Filed with the State Records Center 6/27/91.

History of Repealed Material:
SE-66-1, Rules and Regulations Governing Drilling of Wells and Appropriation and Use of Ground Water in New Mexico, Article 4, Well Drillers Licensing, Construction, Repair and Plugging of Wells - Repealed 8/31/2005.

Inspection Report
Ground Water Quality Bureau

Start Date: 10/30/2008 11:00 AM **End Date:** 10/30/2008 03:00 PM

Facility Information

Facility Name: Parkland Dairy, DP-737
Type of Operation: Agricultural Service
Contact: Alice Visser (Owner)
Location: Portales

Inspector(s): Bill Pearson, Kathie Deal, John Rebar

Inspection Summary

Purpose: Compliance Monitoring Evaluation

Activities

Samples Taken: Yes

Observations and Information Obtained

Inspected the MW's for compliance with the 2008 MW guidelines. All three wells are vertically cuts for screens and will need to be replaced. Runoff pond had significant amounts of wastewater standing in pond. Looks to be pumped from the lagoons and been setting in the pond for sometime due to the water marks on the sides of the pond.

Below is the MW camera data:

Parkland

MW-1
DTW measured with sounder: 89.29'
Top of screen: no screen observed…the joint above the water is at 2587 cm = 84.9'
water: 2698 cm = 88.5'
bottom of well: 3162 cm = 103.7'
metal at bottom with hole

MW-4
DTW measured with sounder: 86.43'
Top of screen: hacksaw screen…joint above water at 2474
water: 2608 cm = 85.6'
bottom of well: 2930 cm = 96.1'
sand bottom

MW-2
DTW measured with sounder: (86.78' – 1.5' of steel casing) = DTW of 85.28' to top of PVC casing
Top of screen: hacksaw screen; joint above water at 2265 cm = 74.3'; hacksaw above water is at 2603 cm = 85.4'
water: 2620 cm = 85.95'
bottom of well: 3167 cm = 103.9'
rocks at bottom

Action Required

Write NONC for replacement of all MW's and require a new well done gradient of the runoff pond.

EXHIBIT
tabbles
3223 - 19

Parkland Dairy, LLC

2807 S RR 2
Portales, NM 88130

Certified Mail # 7006 3450 0003 7402 2122

GROUND WATER

SEP 04 2008

BUREAU

August 28, 2008

Mr. Bill Pearson
Ground Water Quality Bureau
New Mexico Environment Department
1190 St. Francis Dr.
P.O. Box 26110
Santa Fe, New Mexico 87502

Reference: Monitoring Well Installation Report; DP-737

Dear Mr. Pearson

With this letter I am submitting the well record for MW-4. This well was installed on January 14, 2008. I have notified EnviroCompliance Services, Inc. and they will start sampling this well for our quarterly reports.

As I understand your recent letter regarding our monitoring wells, we are not to use the parlor supply well for up-gradient monitoring. I am being required to use the well on the northwest corner of the property, by the old house. We are to remove the pumps from MW-1 & 2 and these two wells will continue to be used for monitoring. With these 4 monitoring wells I will have satisfied the requirements of our September 20, 2005 permit. Please send me a brief note confirming that this is correct. As soon as I receive your confirmation I will order the monitoring well survey and complete the required survey report.

If you have any questions about this information, please contact me or EnviroCompliance Services, Inc.

Sincerely

Alice Visser

Alice Visser

Enclosures: MW-4 Log
Revised MW Map

PARKLAND DAIRY D1-737

DRILLING
~~WELL~~ AND CASING LOG MW-4
DRILLED 1-14-08

DRILLING LOG

0-2" TOPSOIL
2-22' WHITE CALICHE CLAY W/ ROCK
22-95' TAN PACKED SAND
95-115' TAN WATER SAND AND GRAVEL
STATIC WATER LEVEL 95'

CASING LOG

0-90' 5" PVC CASING ONOFLEX SCH 40 FLUSH JOINT THREADED
90-110' 5" PVC .010 SCREEN
SCH 40 FLUSH JOINT THREADED CASING WITH CAP ON THE BOTTOM

3/8" GRAVEL PACK FROM BOTTOM OF HOLE TO 75'

73'-75' BENTONITE CHIPS

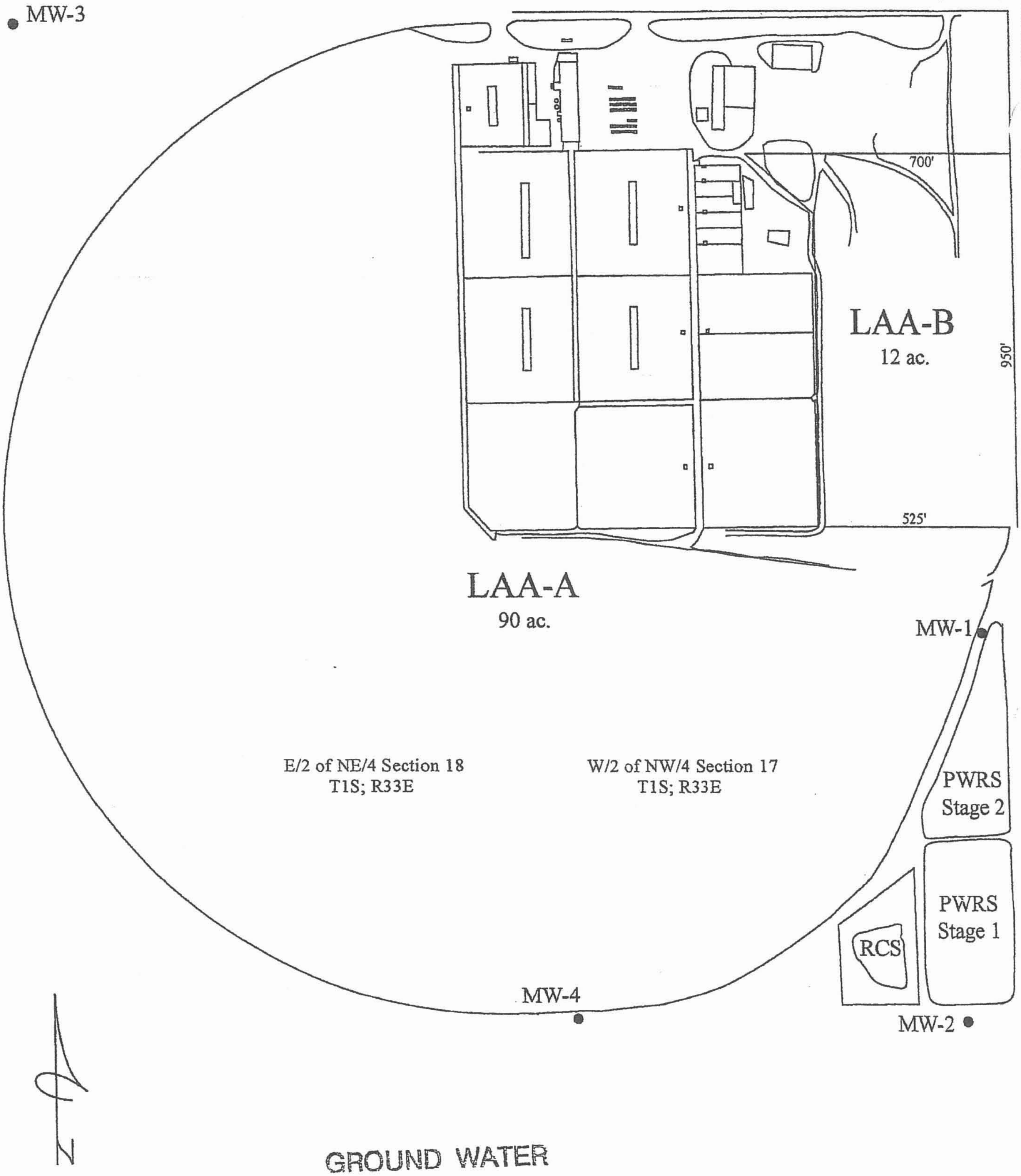
73'-20' BACK FILL WITH DRILL CUTTINGS

20-2' BENTONITE SEAL

CAPPED WITH 4'x4'x2" CEMENT PAD WITH A 6" STEEL TUBEING WELL CAP (LOCKING)

5" ENVIRONMENTAL WELL SEAL

[signature]



GROUND WATER

Enviro Compliance Services, Inc.

Office: (505) 762-9674 Fax: (505) 762-3749

Providing Management Assistance for Environmental Compliance Since 1981

SEP 04 2008

BUREAU

Title: Parkland Dairy Overall Site Layout		DP-737
Date: 8/28/2008	DWG/Doc Ref Scale 1"= 350'	Sheet No 1/1

COVER SHEET

FAX

To: Bill Pearson
Fax #: 505.827.2965
Subject: Parkland Dairy monitor well proposal update
Date: 9/19/2006
Pages: 3 pages, including cover

RECEIVED

BY: ____________________

COMMENTS:

Bill,

Attached is a copy of the records for the existing wells at Parkland Dairy. We had a difficult time obtaining this information from the driller as he had to go back to old records, finding it had not been logged at that time. He then gathered the information, forwarding it to us this afternoon.

I think you will find that these wells currently in place will be acceptable for monitoring purposes up-gradient and down-gradient of the PWRS. We would like to have your approval of such.

We have already forwarded to you the log for the well on the north side of the dairy. It should be suitable as an up-gradient well location. If you approve this also, that would leave only one well to be installed down-gradient of the cropland.

Please review this information and advise us of your decision. If you need further information or have questions, please give me a call.

Thank you!

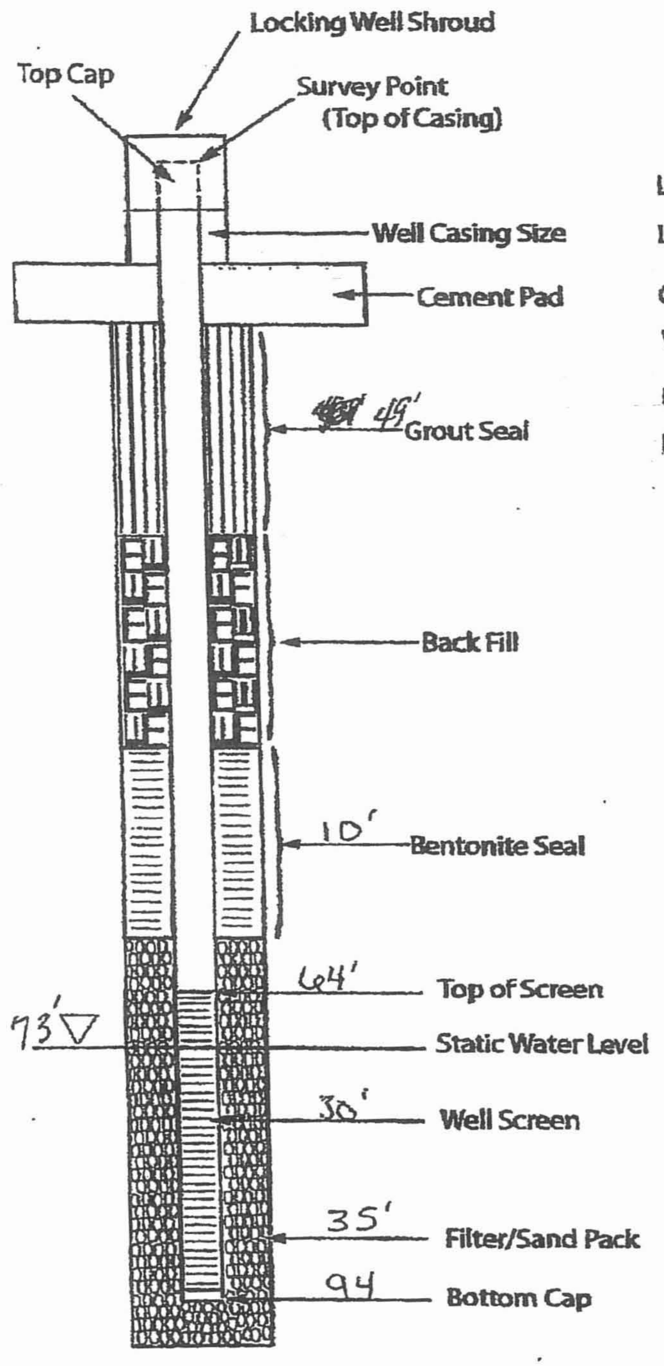
Chet.

From the desk of...

Desiree Hodges

EnviroCompliance Services, Inc.
564 SR 523
Clovis, NM 88101

(505) 762-9674
Fax: (505) 762-3749



Monitor Well Completion Record

Location: E+C Dairy / Visser

Legal Description: ________

County: Roosevelt State: NM

Well # North (MW-1)

Date Well Completed: Oct. 1990

Drilling Company: L+J Well Service

Casing Record:
- Casing Type: PVC
- Casing Size: 5"

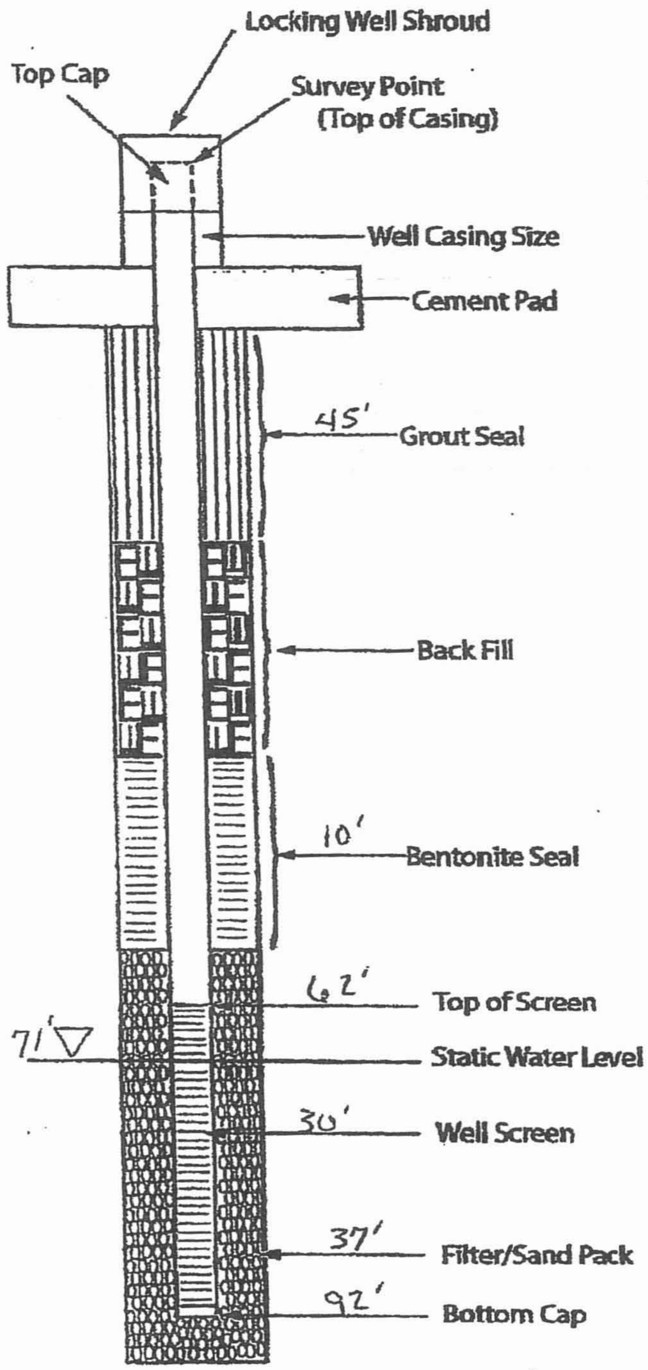
Pump Record:
- Type of Pump: N/A
- HP: ____
- Depth of pump intake ____ ft below static water level.

Drilling Log:

Depth in Feet		
From	To	Type of Material Encountered
0	1	Top soil Brown
1	22	Caliche White
22	41	Sand Brown
41	76	Clay Red
76	92	Sand + Gravel Red
92	94	Red + Blue Clay

I, Larry Jewell, certify that to the best of my Knowledge and belief, the information on this record is true and accurate. (signature) Larry Jewell

9-19-06



NOT TO SCALE

Monitor Well Completion Record

Location: E+C Dairy / Visser

Legal Description: __________

County: Roosevelt State: NM

Well # South (MW-2)

Date Well Completed: Oct. 1990

Drilling Company: L+J Well Service

Casing Record:

Casing Type: PVC

Casing Size: 5"

Pump Record:

Type of Pump: N/A

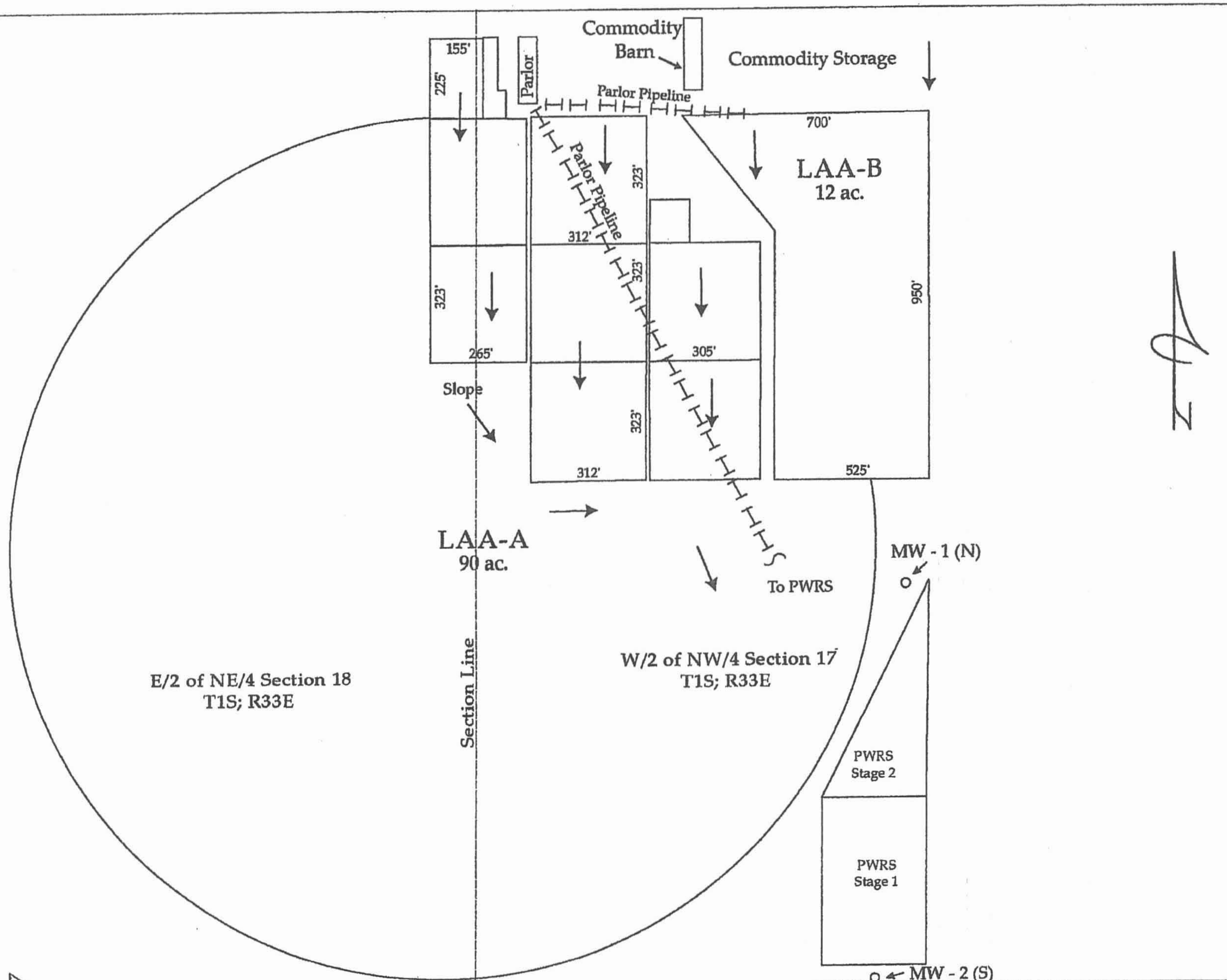
HP: ______

Depth of pump intake _____ ft below static water level.

Drilling Log:

Depth in Feet		
From	To	Type of Material Encountered
0	2	Top Soil Brown
2	18	Caliche White
18	36	Sand Brown
36	78	Clay Red
78	90	Sand + Gravel Red
90	92	Red + Blue Clay

I, Larry Jewell, certify that to the best of my Knowledge and belief, the information on this record is true and accurate. (signature) Larry Jewell



Enviro Compliance Services, Inc.

Office: (505) 762-9674 Fax: (505) 762-3749

Providing Management Assistance for Environmental Compliance Since 1981

Title: E & C Dairy Overall Site Layout		DP-1313
Date: 11/13/2003	DWG/Doc Ref Not to Scale	Sheet No 1/1

NEW MEXICO
ENVIRONMENT DEPARTMENT

Ground Water Quality Bureau

1190 St. Francis Drive
P.O. Box 26110, Santa Fe, NM 87502
Phone (505) 827-2918 Fax (505) 827-2965
www.nmenv.state.nm.us

BILL RICHARDSON
Governor
DIANE DENISH
Lieutenant Governor

RON CURRY
Secretary
JON GOLDSTEIN
Deputy Secretary

CERTIFIED MAIL – RETURN RECEIPT REQUESTED

August 15, 2008

Walter Bradley
Southwest Area Council
Dairy Farmers of America
3500 William D. Tate Ave., Suite 100
Grapevine, TX 76051-8734

RE: Dairy Industry Group and New Mexico Environment Department Meetings

Dear Mr. Bradley:

The New Mexico Environment Department (NMED) was pleased to meet with you and the Dairy Industry Group during the last nine months to address industry concerns over permit requirements for dairies. The NMED and Dairy Industry Group meetings were held in Clovis and Albuquerque, New Mexico on November 29, 2007, May 13, 2008, June 2, 2008 and June 24, 2008. The discussions focused on the following topics which were identified by the industry: soil sampling, livestock grazing, ground water monitoring wells, qualifications of persons submitting monitoring plans, wastewater infrastructure, lagoon/impoundment surveys, scaled site maps, and monitoring reporting frequency. This letter summaries the outcome of our joint meetings.

Soil sampling of land application areas

During the meetings, extensive discussion focused on soil sampling. NMED previously required soil samples to be collected between the months of March and May each year. This timeframe accounts for nitrogen accumulation, from wastewater and/or stormwater, applied through the winter months. The Dairy Industry Group stated that it is not logistically possible to collect and analyze soil samples in a timely manner in order to use this data for spring nutrient management planning. NMED believes that to properly assess nitrogen accumulation, soil sampling should be conducted prior to spring planting. However, NMED agreed to change the soil sampling conditions to allow for an extended sampling period between December 1 and May 31 to address industry concerns.

EXHIBIT
3223-20

NMED cautions that soil sampling is intended as an initial indication of whether nitrogen overloading is occurring in the land application area. With the extended sampling timeframe (between December 1 and May 31), nitrogen accumulation during the winter months may not be adequately captured. Ultimately, the permittee is still required to comply with the ground water quality standards as set forth in Section 20.6.2.3103 NMAC of the Water Quality Control Commission Regulations.

Additional changes to the soil sampling permit conditions that NMED agrees to modify include the timing for analyzing for specific constituents as follows:

1. For the initial soil sampling event following the effective date of the Discharge Permit, the permittee shall collect and analyze soil samples from each field and/or management unit in the permitted land application area. Composite soil samples shall be collected between December 1st and May 31st for all fields regardless of whether the field is cropped, remains fallow, or has received wastewater and/or stormwater. One surface composite soil sample (1st-foot) and two sub-surface composite soil samples (2nd and 3rd-foot) shall be collected from each field.

   Composite soil samples shall be collected according to the following procedure:

   - Each surface and sub-surface soil sample shall consist of a single composite of 15 soil cores collected randomly throughout each field. If a field is divided into differing management units (i.e., two separate crops on a single pivot), soil samples shall be collected from each management unit. Should a field or management unit consist of considerably different soil textures (i.e., sandy and silty clay); soil samples shall be collected from each soil texture within each field or management unit.
   - Surface soil samples (1st-foot) shall be collected from a depth of 0 to 12 inches.
   - Each 2nd-foot sub-surface soil sample shall be collected from a depth of 12 to 24 inches.
   - Each 3rd-foot sub-surface soil sample shall be collected from a depth of 24 to 36 inches.

   Each surface and sub-surface composite sample shall be analyzed for:

   - pH, electrical conductivity (EC), TKN, NO_3-N, Cl, organic matter (OM), potassium (K), phosphorus (P), sodium (Na), calcium (Ca), magnesium (Mg), bicarbonate (HCO_3), sulfate (SO_4), soil texture and determination of the sodium adsorption ratio (SAR).

2. Following the first year, subsequent annual soil sampling shall be conducted that includes a reduced set of constituents:

   Surface (1st-foot) samples shall be analyzed for:

   - pH, EC, NO_3-N, Cl, OM, K, P, Na, Ca, Mg, and determination of the SAR.

   Sub-surface (2nd and 3rd-foot) samples shall be analyzed for:

   - EC, NO_3-N, and Cl

Discussion also centered on annual soil sampling for permitted fields actively receiving wastewater versus permitted fields not actively receiving wastewater. NMED agreed that following the initial soil sampling event, annual soil samples are to be collected and analyzed from each field and/or management unit within the permitted land application area that has received or is actively receiving wastewater and/or stormwater during the term of the current permit. Fields that do not receive wastewater during the term of the permit would only need to be sampled during the first year of the permit.

Livestock grazing on land application areas

The Dairy Industry Group requested that livestock grazing be allowed to be used for nitrogen removal from land application areas during winter months. NMED believes it is difficult to quantify nitrogen removal through grazing. However, NMED agreed, with reservations about the effectiveness of this proposal, to consider this practice if submitted for review as part of an overall comprehensive nutrient management plan for land application areas. In order to be approved, the proposal must adequately demonstrate that nitrogen removal can be quantified with reasonable certainty.

Ground water monitoring wells

The discussions regarding monitoring wells centered on the ground water monitoring network design and monitoring well construction including appropriate screen lengths and annular space sealing as follows:

1. NMED agreed with the Dairy Industry Group that the ground water monitoring network design shall be based on monitoring source areas for the entire facility for which the Discharge Permit has been approved.

2. NMED requires ground water monitoring downgradient of all potential sources of contamination including wastewater lagoons, stormwater impoundments, and fields within the land application area. The Dairy Industry Group requested a reduced number of monitoring wells near land application areas with multiple fields. NMED will consider these requests on a case by case basis, based on site-specific information and proposals submitted to NMED during the permit development period (new or renewed permits). In appropriate circumstances, monitoring wells can be shared facility wells located at suitable locations.

3. The Dairy Industry Group proposed that monitoring wells be constructed with long well screens that fully penetrate the aquifer. Upon review of published peer-reviewed literature, NMED has concluded that monitoring wells constructed with long well screens (i.e., greater than 15 feet in length) are problematic for monitoring of contaminant releases because they may cause sample dilution (resulting in underreporting of actual contaminant concentrations in ground water) or allow shallow contaminant plumes to migrate to deeper, previously unaffected portions of an aquifer. In general, NMED will continue to require that monitoring wells be constructed with 20 feet of screen, with no

more than 15 feet of screen positioned below the water table. In cases where site-specific ground water monitoring data indicates that the water table is currently dropping at a rate greater than two feet per year, NMED will consider requests to install monitoring wells with screen lengths greater than 20 feet.

4. Concerns were expressed by the Dairy Industry Group regarding the potential for monitoring wells to serve as conduits for the movement of contaminants to ground water. While NMED believes their current monitoring well construction guidance addresses this issue, published peer-reviewed literature indicates that placement of bentonite grout, cement grout, or bentonite-cement grout in the annular space around monitoring well casing more effectively seals the annular space and prevents the migration of contaminants to ground water via the monitoring well borehole. NMED agrees to amend its monitoring well construction condition to require that newly-installed monitoring wells be constructed with grout-sealed annular spaces.

Qualifications of the person submitting monitoring plans

The Dairy Industry Group proposed that monitoring plans submitted to NMED shall be prepared by a competent person. Demonstration of competency shall be provided with each comprehensive monitoring plan and each competent person shall seal or affirm the adequacy of the contents therein. A "competent person" shall mean:

a. for ground water hydrology and vadose zone monitoring, a competent person shall mean geologist or hydrogeologist with other state registration or professional certifications; and
b. for agronomic rates, nutrient management plans and vadose zone monitoring systems, only, an agricultural scientist or professional with NRCS (Technical Service Provider with CNMP) or state registration or professional certification (CCA, CPAg, CPSS, CNMP).

NMED agreed that monitoring plans submitted to the agency should be prepared by a competent person but that NMED lacked the statutory or regulatory authority to require this. However, NMED agreed to modify its discharge permit guidance to recommend that plans be prepared by such a person.

Wastewater infrastructure for the land application area

The Dairy Industry Group indicated that, at times a facility may include more acreage in their Discharge Permit than they intend to actively apply wastewater and/or stormwater to throughout the permit term. This allows the facility to use the acreage in the event that it is needed.

For fields not intended to receive active wastewater and/or stormwater discharges, NMED agreed that infrastructure shall be installed and NMED notified prior to discharging to these fields rather than requiring that infrastructure be installed to all fields at the start of the permit term.

Wastewater lagoon and stormwater impoundment surveys

NMED agreed to remove permit language requiring that capacity calculations from the survey of pre-existing wastewater lagoons and stormwater impoundments be certified by a licensed New Mexico registered professional engineer. In lieu of the requirement for the involvement of a professional engineer, the survey and capacity calculations of pre-existing lagoons and impoundments shall be done by a licensed New Mexico professional surveyor.

Scaled facility maps

NMED requires scaled maps for each facility but agreed to remove language requiring that facility map be prepared by a licensed New Mexico professional surveyor. Documentation identifying the means used to locate the mapped objects (i.e. GPS, land survey, digital map interpolation, etc.) and the relative accuracy of the data (i.e. +/- XX feet or meters) will instead be required to be included with all scaled maps.

Monitoring reporting frequency

At the request of the Dairy Industry Group, NMED agreed to allow submittal of annual monitoring reports. Actual soil, ground water and other monitoring activities will continue to be conducted as required by the Discharge Permit (quarterly, semi-annually, etc.). However, the data shall be submitted in an annual monitoring report rather than four quarterly reports submitted to NMED in a given year. Consideration of the annual monitoring report requirement will be assessed during the permit development period (new or renewed permits). NMED reserves the right to require more frequent reports based upon the compliance history of a facility.

NMED appreciates the time and effort that the Dairy Industry Group expended in working with us as well as the cooperative nature of the discussions. NMED hopes that the outcome of these issues has been satisfactory to the Dairy Industry Group. NMED looks forward to continuing discussions with the Dairy Industry Group as needed. I would especially like to thank you for your help in organizing and facilitating these discussions.

If you have any questions, please feel free to contact me at (505) 827-2919.

Sincerely,

William C. Olson, Chief
Ground Water Quality Bureau

cc: Ron Curry, Secretary
Jon Goldstein, Deputy Secretary

Marcy Leavitt, Director, Water and Waste Management Division
Sharon Lombardi, Executive Director, Dairy Producers of New Mexico, PO Box 6299,
Roswell, NM 88202-6299
George Schuman, NMED-GWQB

Exhibit Summary

Dairy Facility: Faria Dairy, DP-923

Description: Maps submitted by the permittee to the department indicate that two monitoring wells have been mislabeled such that a well intended to be hydrologically downgradient of a contamination source was switched with one that is intended to be hydrologically upgradient of the facility.

On the maps dated 11/12/2004 and 10/16/2006, monitoring well MW-2 is intended to be located hydrologically downgradient of a stormwater impoundment and monitoring well MW-1 is intended to be located hydrologically upgradient of the facility. The map dated 10/08/2008 has the wells reversed such that MW-1 is intended to be located hydrologically downgradient of a stormwater impoundment and MW-2 is intended to be located hydrologically upgradient of the facility.

Dairy Facility: Carter's Milk Factory, DP-926

Description: Maps submitted by the permittee to the department indicate that two monitoring wells have been mislabeled such that a well intended to be hydrologically downgradient of a contamination source was switched with one that is intended to be hydrologically upgradient of the facility.

On the map dated 05/22/2003, monitoring well MW-5 is intended to be located hydrologically downgradient of the land application area and monitoring well MW-4 is intended to be located hydrologically upgradient of the facility. The map dated 06/09/2004 has the wells reversed such that MW-4 is intended to be located hydrologically downgradient of the land application area and MW-5 is intended to be located hydrologically upgradient of the facility.

Dairy Facility: Ridgecrest Dairy, DP-1346

Description: Maps submitted by the permittee to the department indicate that two monitoring wells have been mislabeled such that a well intended to be hydrologically downgradient of a contamination source was switched with one that is intended to be hydrologically upgradient of the facility.

On the map dated 09/01/2004, monitoring well MW-1 is intended to be located hydrologically downgradient of the land application area and monitoring well MW-3 is intended to be located hydrologically upgradient of the facility. The map dated 02/19/2009 has the wells reversed such that MW-3 is intended to be located hydrologically downgradient of the land application area and MW-1 is intended to be located hydrologically upgradient of the facility.

EXHIBIT
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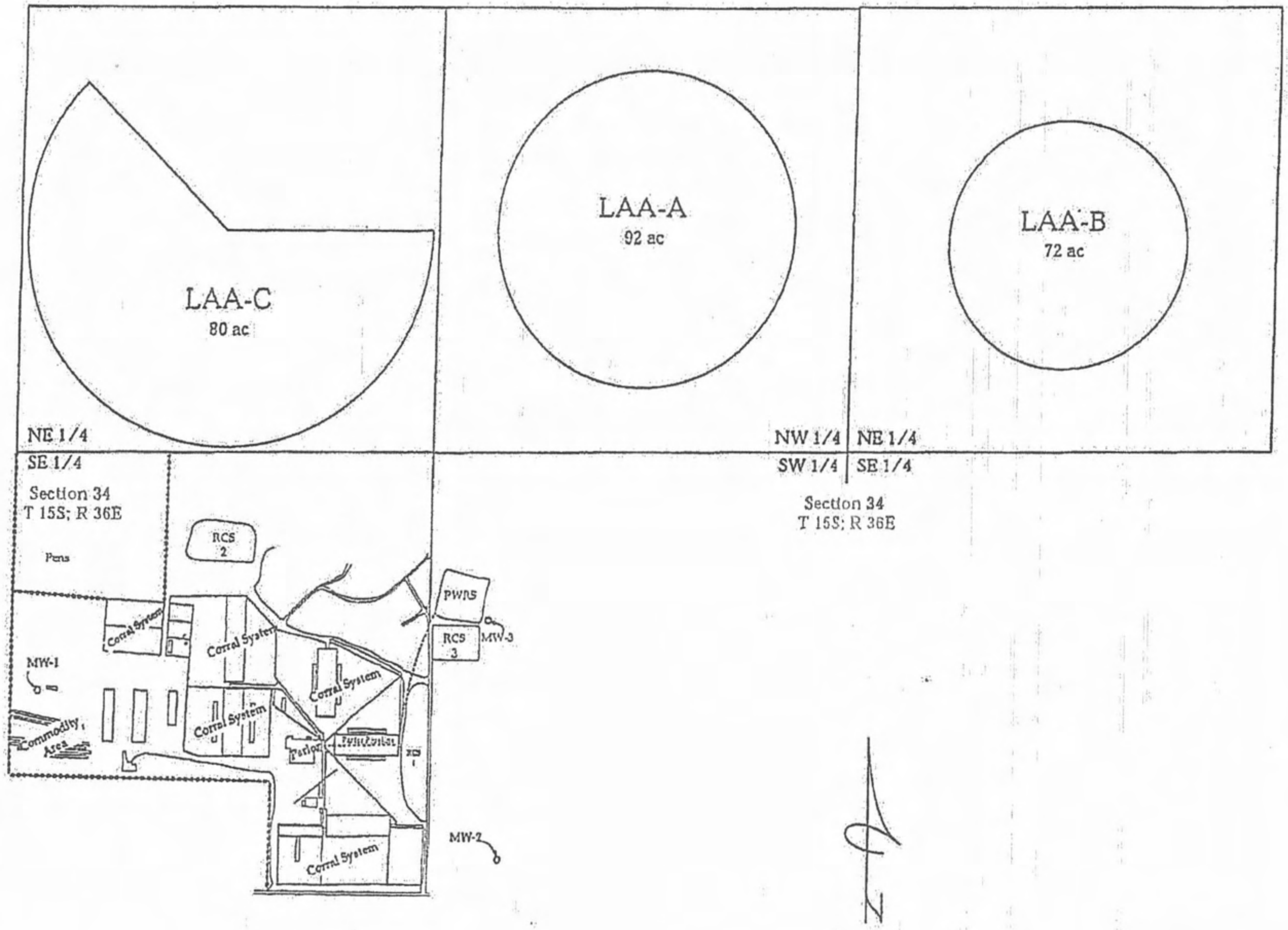
Dairy Facility: Nutt Dairy, DP-1391

Description: Maps submitted by the permittee to the department indicate that two monitoring wells have been mislabeled such that a well intended to be hydrologically downgradient of a contamination source was switched with one that is intended to be hydrologically upgradient of the facility.

On the map submitted in 2003, monitoring well MW-2 is intended to be located hydrologically downgradient of the wastewater impoundment and monitoring well MW-1 is intended to be located hydrologically upgradient of the facility. The maps submitted in 2005 and 2009 have the wells reversed such that MW-1 is intended to be located hydrologically downgradient of the wastewater impoundment and MW-2 is intended to be located hydrologically upgradient of the facility.



Enviro Compliance Services, Inc.
Office: (505) 762-9674 Fax: (505) 762-3749
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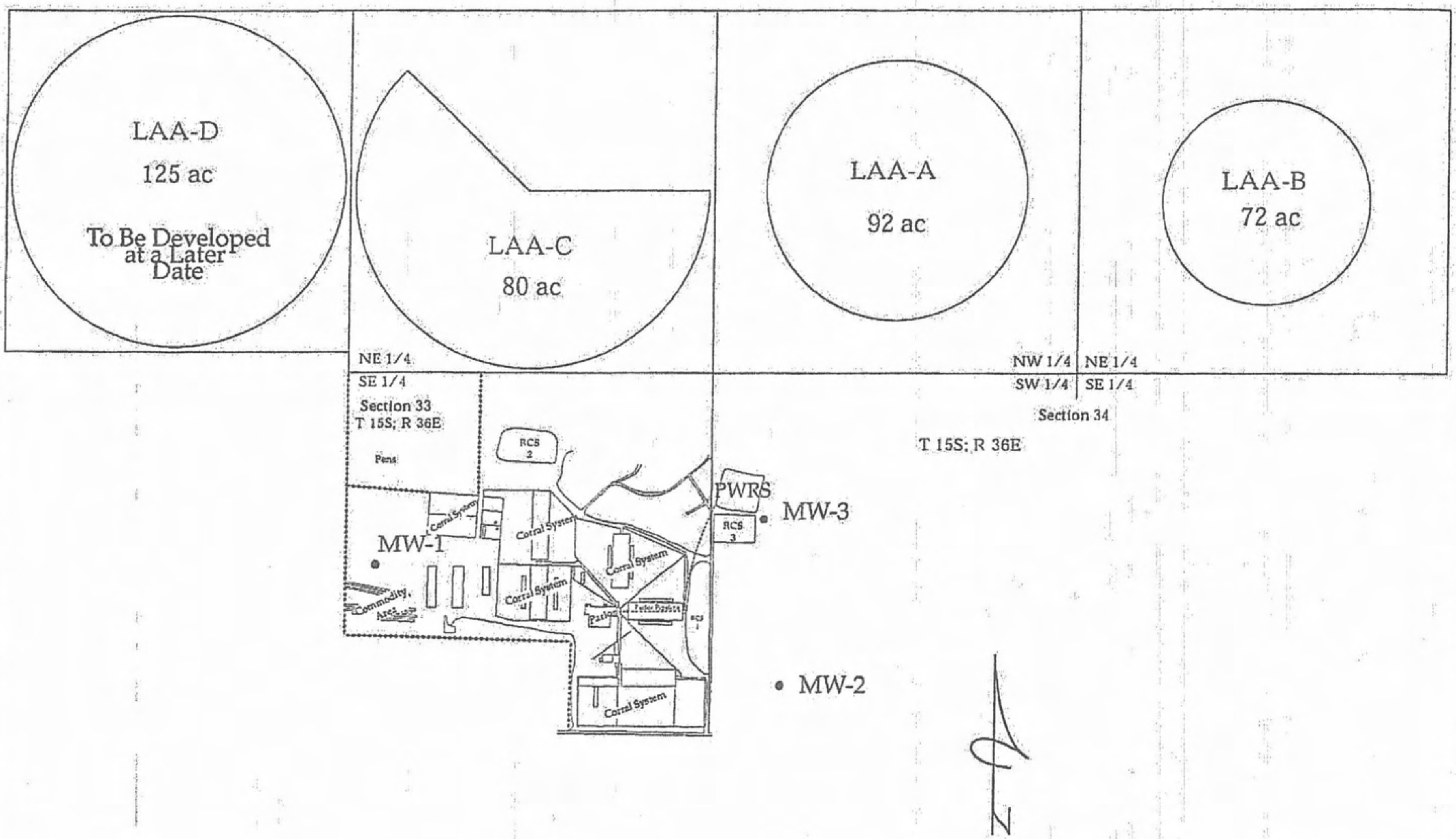
Title: Faria East Dairy Overall Site Layout		DP-923
Date: 11/12/2004	DWG/Doc Ref: Scale 1" = 1000'	Sheet No 1/1



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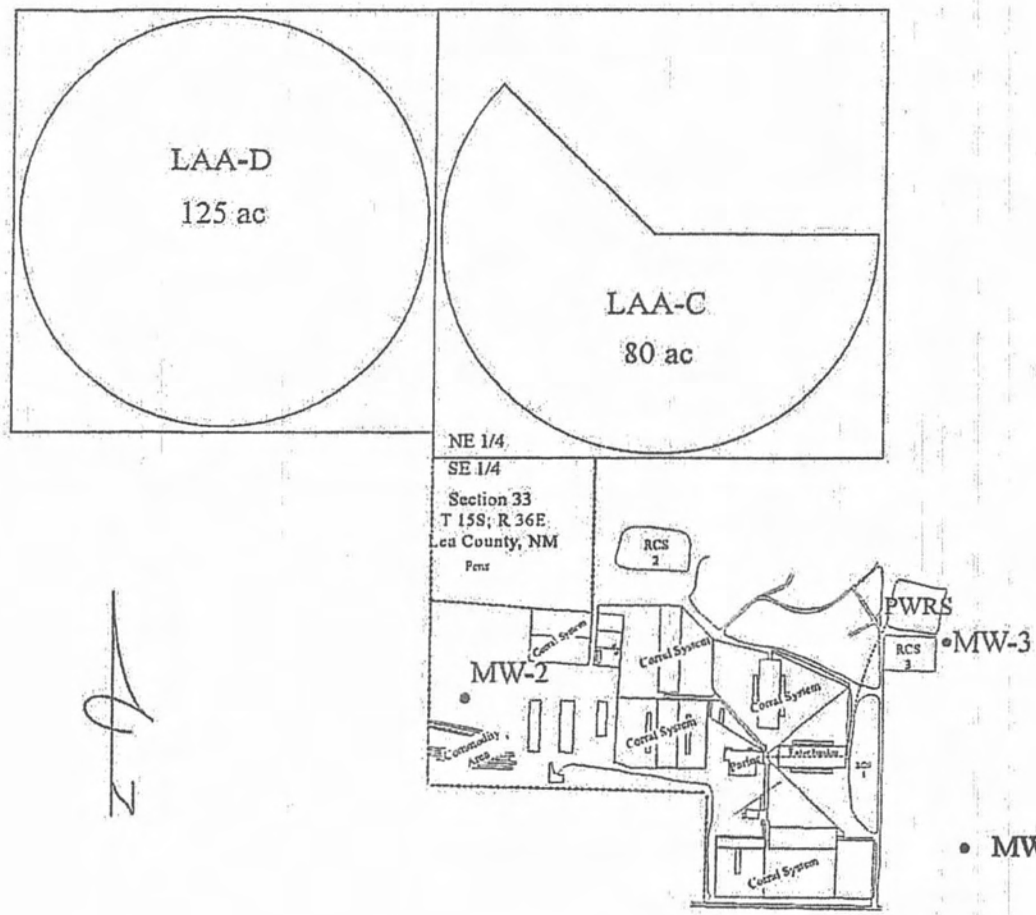
Title: Faria Dairy East Overall Site Layout		DP-923
Date: 10/16/2006	DWG/Doc Ref: Not to Scale	Sheet No 1/1

DP-923



GROUND WATER

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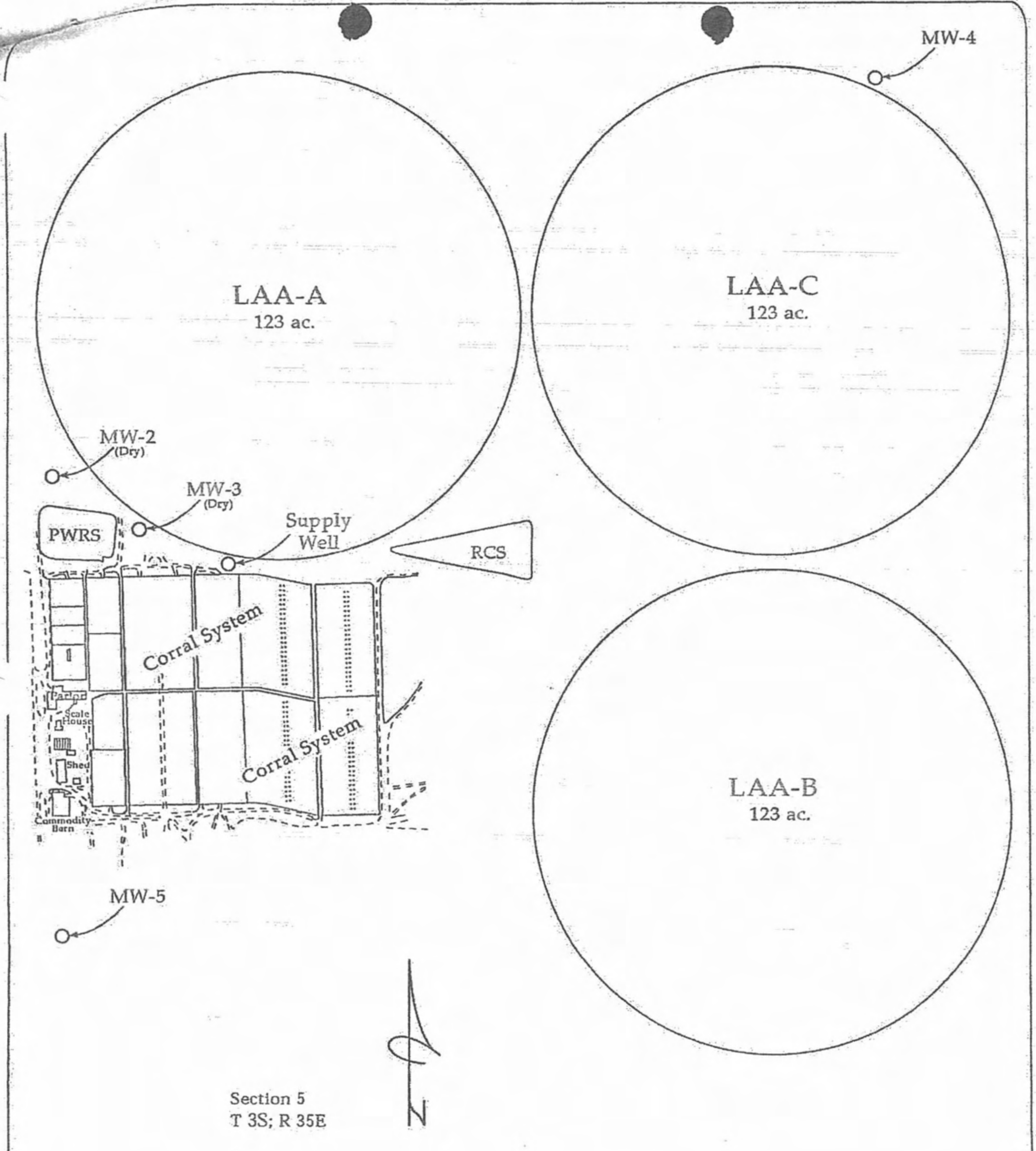
Title: Faria Dairy East Overall Site Layout		DP-923
Date: 10/08/2008	DWG/Doc Ref: Not to Scale	Sheet No 1/1



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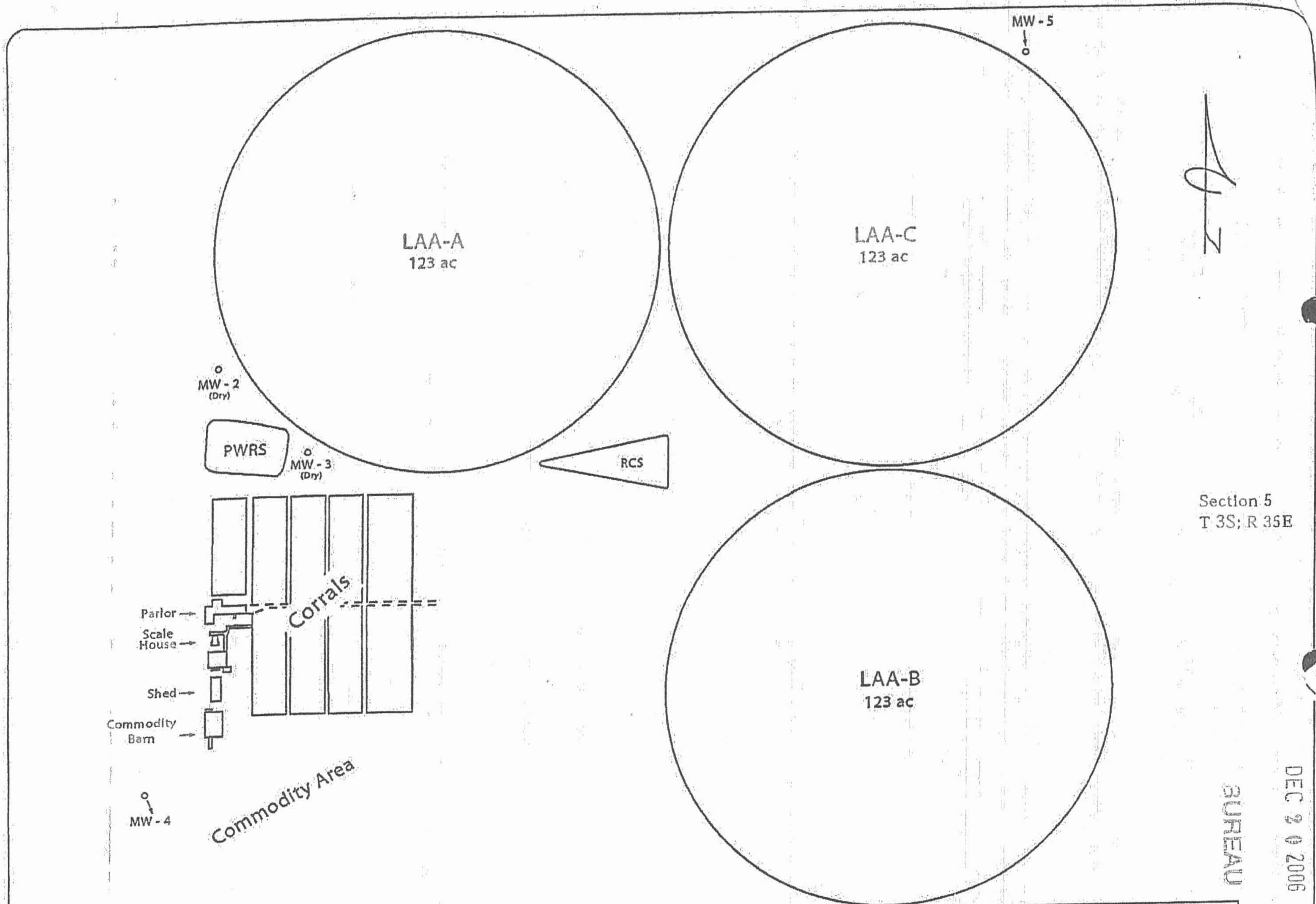
Title: Carter's Milk Factory Overall Site Layout		DP-926
Date: 6/9/2004	DWG/Doc Ref: Scale 1" = 700'	Sheet No: 1/1



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Services, Inc.
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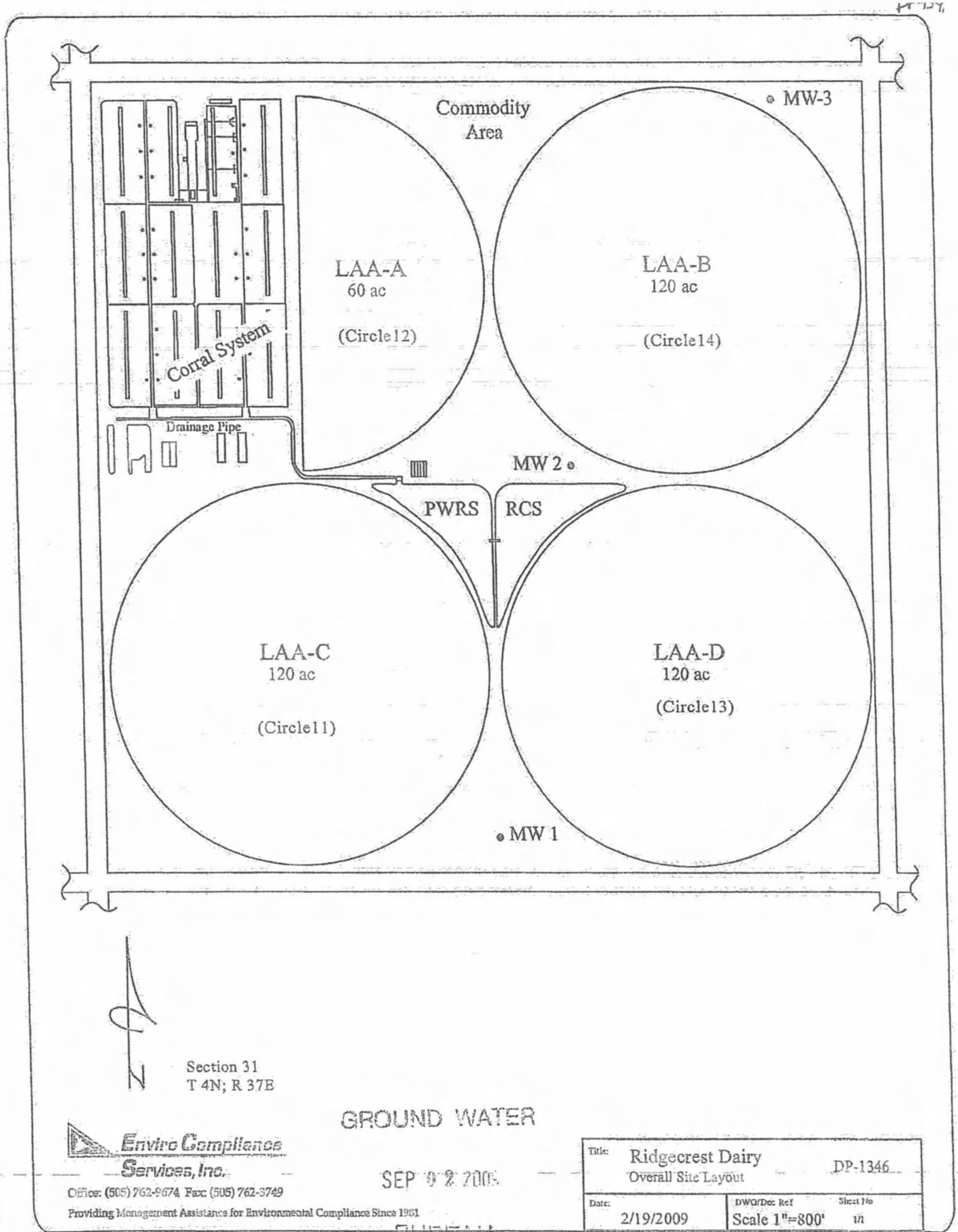
Title: Carter's Milk Factory Overall Site Layout		DP-926
Date: 5/22/2003	DWG/Doc Ref	Sheet No 1/1



GROUND WATER

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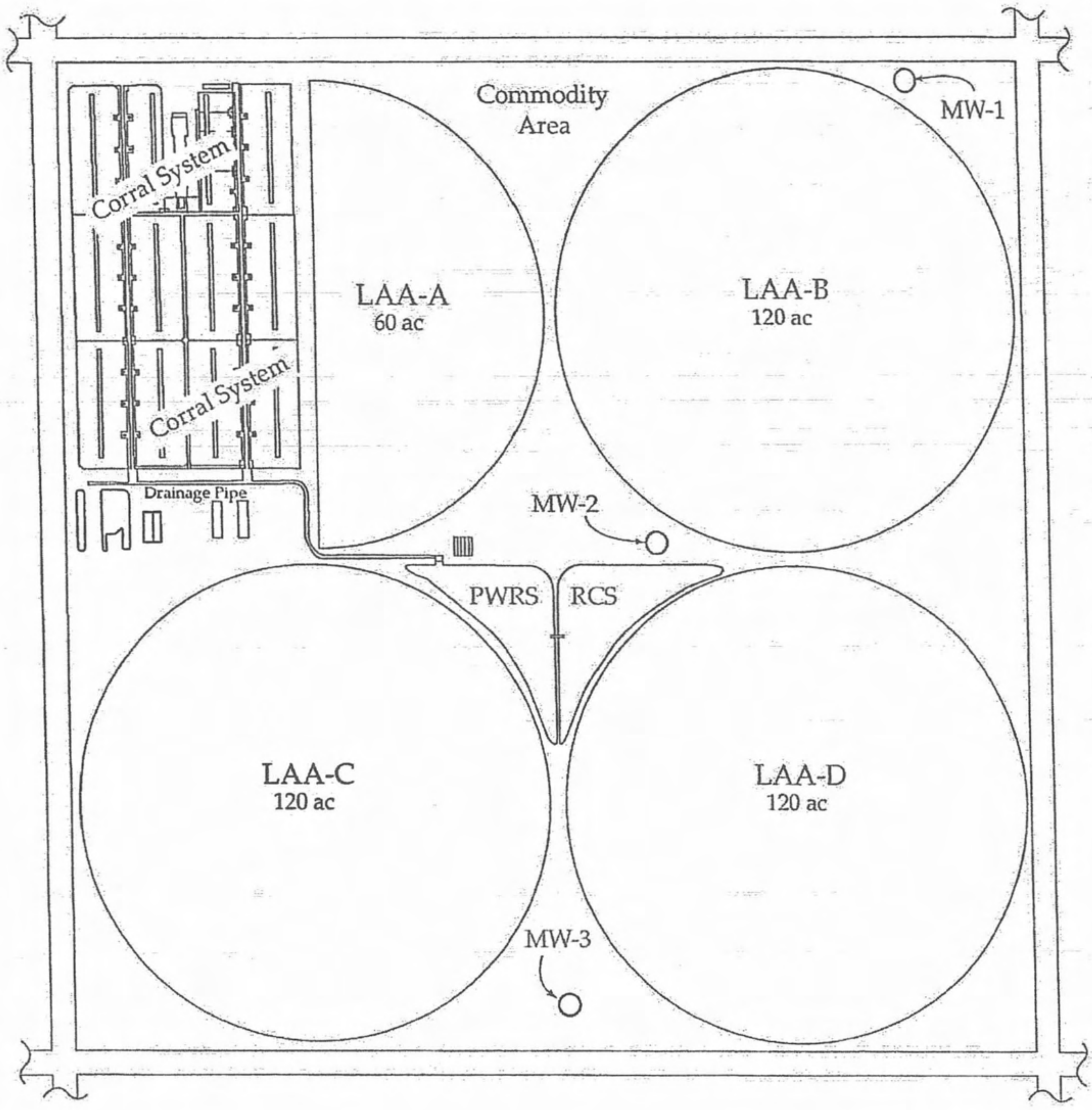
DP-1346



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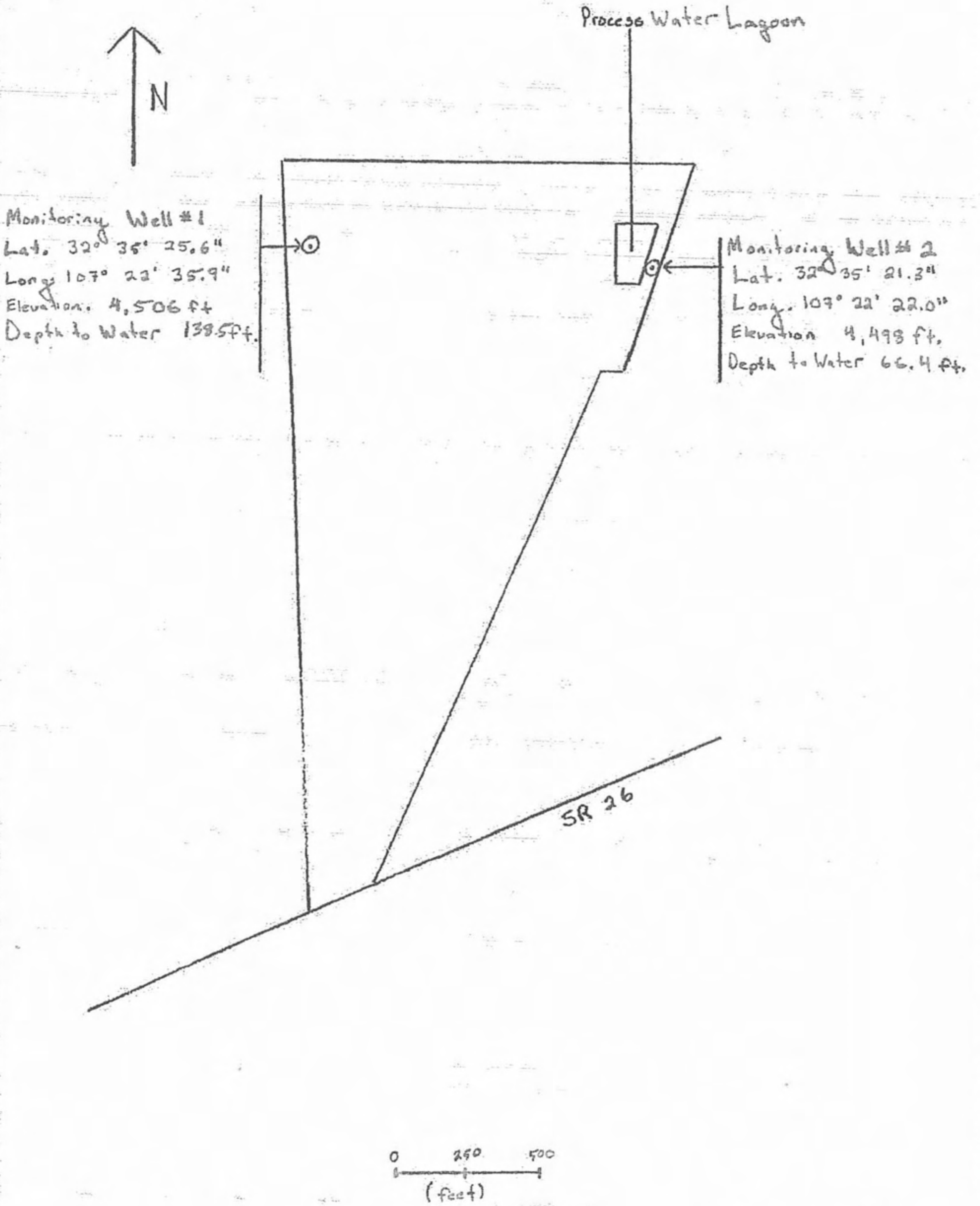
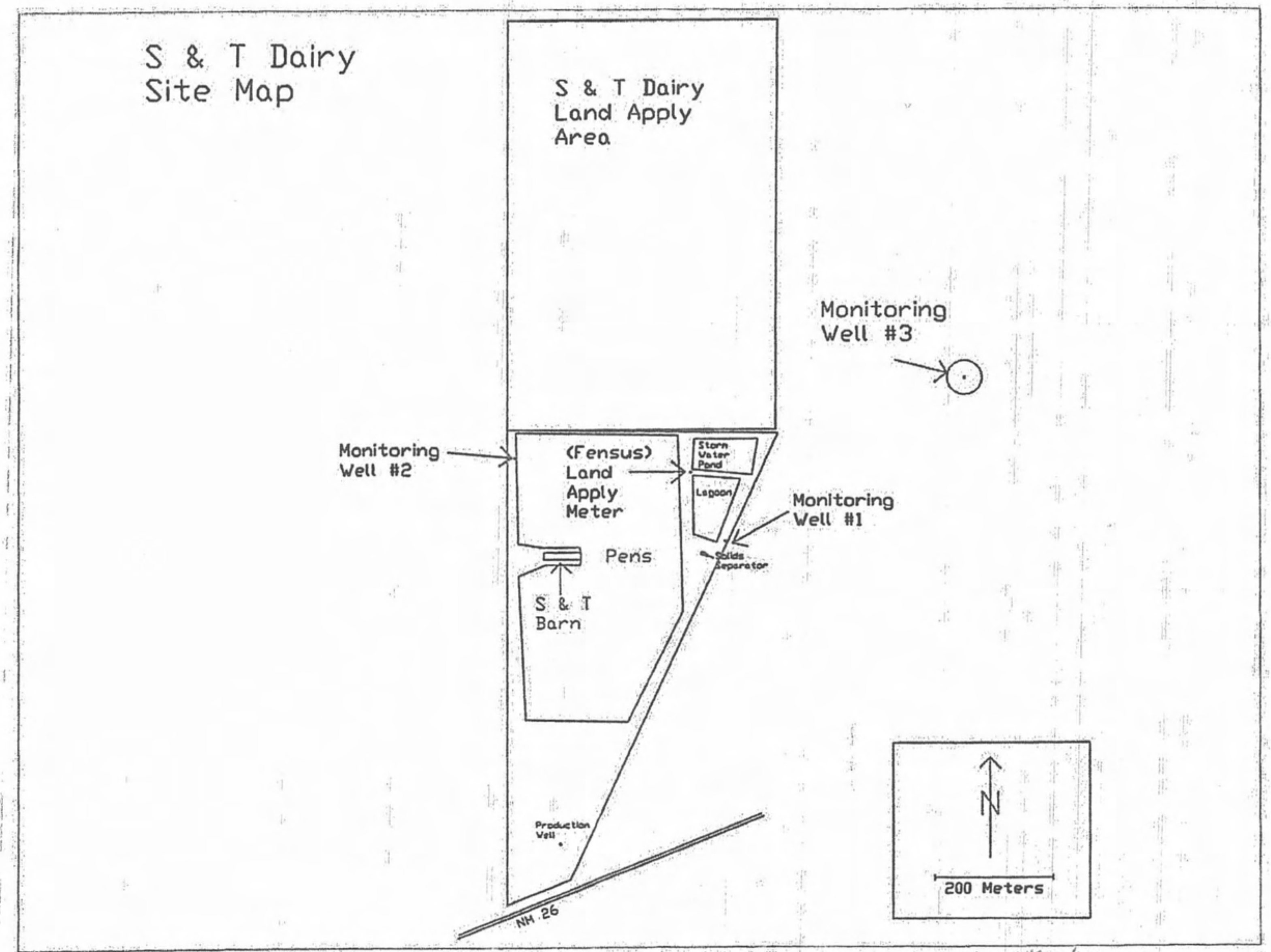
Title: Ridgecrest Dairy Overall Site Layout		DP-1346
Date: 9/1/2004	DWG/Doc Ref Scale 1"=800'	Sheet No 1/1

S&T Dairy DP-1391

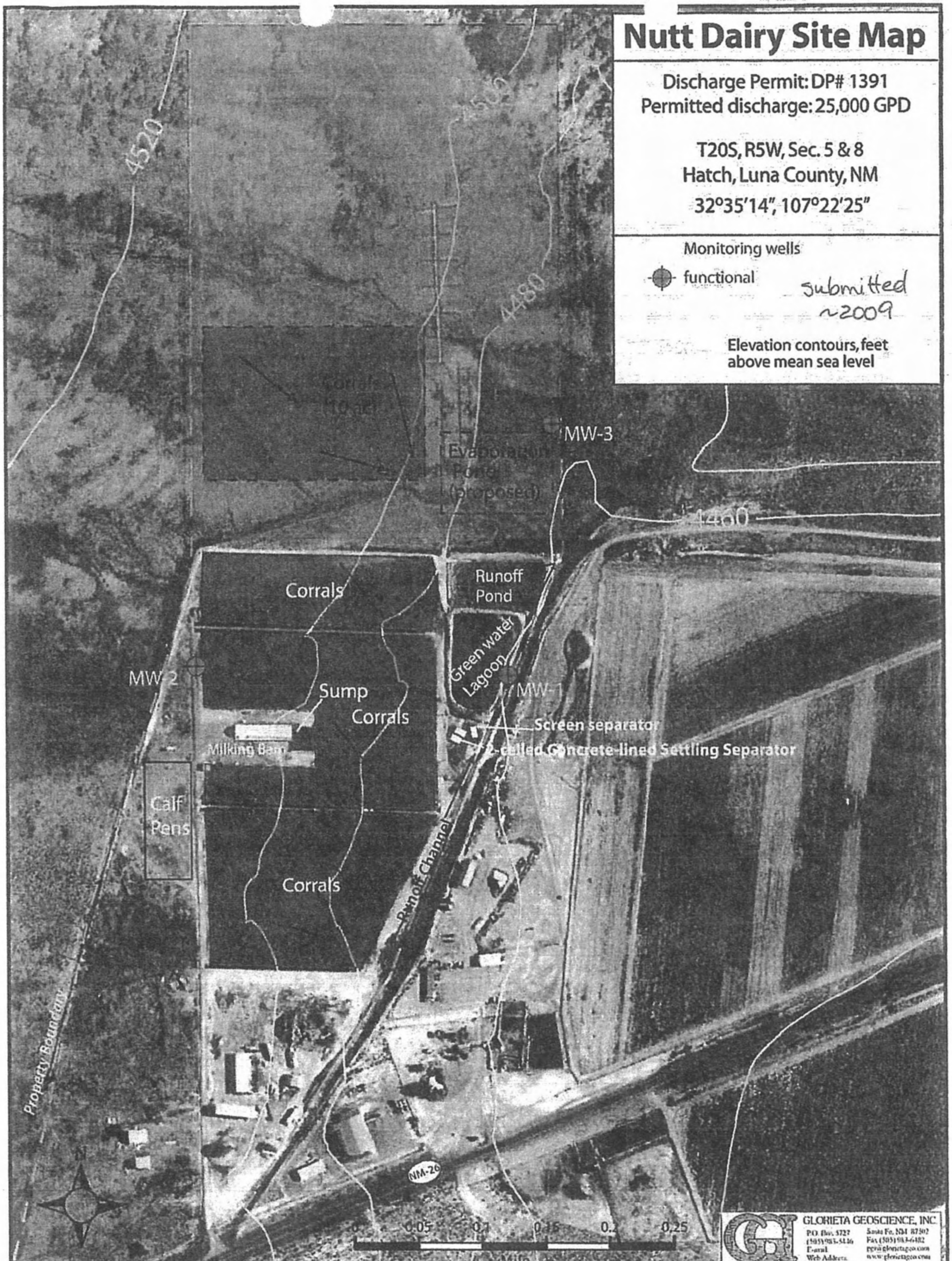


Submitted ~2003



Submitted ~2005

DP-1591



Contact Info: Nutt Dairy, P.O. Box 751, Hatch, NM 87937 Office: 505-267-9217 Cell: 505-869-0837