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ADDITIONAL REGIONAL GROUNDWATER QUALITY DATA FROM THE KARST-CARBONATE AQUIFERS OF NORTHEAST IOWA

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INTRODUCTION

Since completion of the phase-one regional karst groundwater quality assessment (Hallberg and Hoyer, 1982) other data on groundwater quality from the carbonate aquifer areas have become available. These data provide further useful background information on the karst groundwater problems. These additional data were not directly part of the second phase (Big Spring Study) of this project, and thus are presented here in a separate report. This report is essentially a supplement to the phase-one report (Hallberg and Hoyer, 1982), and the data presented here will be merged with the first report for later publication.

ADDITIONAL ANALYSIS OF THE UHL NITRATE DATA

In the phase-one report, Hallberg and Hoyer (1982) summarized the results of over 6,000 UHL nitrate analyses from groundwater. This data was summarized by geologic setting--Karst, Shallow Bedrock, and Deep Bedrock--and by well depth categories--<50, 50-99, 100-149, 150-499, and >500 feet. The basic conclusions of this review were that groundwater in the Karst and Shallow Bedrock settings show significant levels of nitrate contamination on a regional level, particularly to depths of 150 feet, or perhaps slightly deeper. To refine the conclusions regarding the depth of nitrate contamination, the data set was revised to analyze the depth increments below 150 feet in greater detail. The data was again aggregated in 50 foot increments, but this time down to 300 feet. The resultant tabulation of median nitrate concentrations by depth is shown on Table 1.

The data were evaluated using the same non-parametric statistical techniques (Kolmogorov-Smirnov test) used in the original study. The evaluation

Table 1. Summary of median nitrate values (in mg/l) from UHL analyses from the 22 county northeast Iowa study area, for 1977-1980.

Well Depth (feet)	Geologic Setting: Karst	Shallow Bedrock	Deep Bedrock
0-49	28	26	33
50-99	34	19	6
100-149	23	16	0
150-199	10	6	0
200-249	2	3	0
250-299	2	5	0
300-499	4	1	0
>500	0	0	0
unknown	22	7	0
TOTAL (N)	19 (1104)	9 (2719)	0 (2217)

does not change any of the conclusions from the prior report, but does afford some refinement of the depth relationships. The results are summarized schematically on figure 1.

The issue needing clarification concerned how nitrates varied at depths immediately beneath 150 feet. The original study showed a major drop beneath 150 feet, but because well depths were aggregated between 150 and 499 feet, further effects with depth could not be evaluated. By inspection of figure 1, large drops in median nitrate values are observed in both the Karst and Shallow Bedrock regions between the 100-149 and 150-199 foot depth classes. Appendix A reveals that the drop is accompanied by a statistically significant change in the nitrate data distributions. Thus, it seems that regionally the biggest change in nitrates from both Karst and Shallow Bedrock regions occurs between 150 and 200 feet. This is in agreement with the earlier report.

It is interesting to note that there is no significant difference between the Karst and Shallow Bedrock regions in the well depth class 150-199 feet

(Appendix B). This suggests that the effects of the open, cavernous, karst groundwater system is muted beneath 150 feet, at least on a regional basis. The elevated nitrate concentrations are mostly related to diffuse infiltration. Again, this agrees with the earlier report which revealed the major effect of karst on nitrate contamination occurred in the 50-99 feet well depth class, and that a somewhat muted effect occurred to depths of 100 to 149 feet.

ADDITIONAL WATER-QUALITY AND HYDROGEOLOGIC DATA

The first new data set is comprised of 47 nitrate analyses from well water samples from the Galena and Devonian-Cedar Valley karst areas in Allamakee and Winneshiek Counties. The samples were collected by IGS staff in October of 1975 for a preliminary survey of water quality in these karst areas (see also Hallberg and Hoyer, 1982, p. 46).

Table 2 presents a summary of the nitrate data. These data reaffirm many prior conclusions. The nitrate content (median and quartiles) of the Galena aquifer, where it is protected by a thick cover of Maquoketa shales (and in one case additional Devonian rocks), is less than detectable (<5 mg/l). This again confirms that the natural level of nitrates in the groundwater of these carbonate aquifers is very low. This is in sharp contrast to the nitrate concentration (median-20 mg/l) where the Galena forms the surficial aquifer, and is exposed to contamination from the land surface. The nitrate concentration of the other surficial bedrock aquifers is similarly elevated, with a median nitrate concentration of 25 mg/l.

The background nitrate concentration of other deep, or buried rock aquifers (St. Peter, Prairie du Chien, and Jordan) can be determined from properly constructed wells which case out the surficial bedrock aquifer such as the Galena. Again, their background nitrate concentration is less than detectable.

MEDIAN NITRATE VALUES FROM WELL DEPTHS IN GEOLOGIC SETTINGS

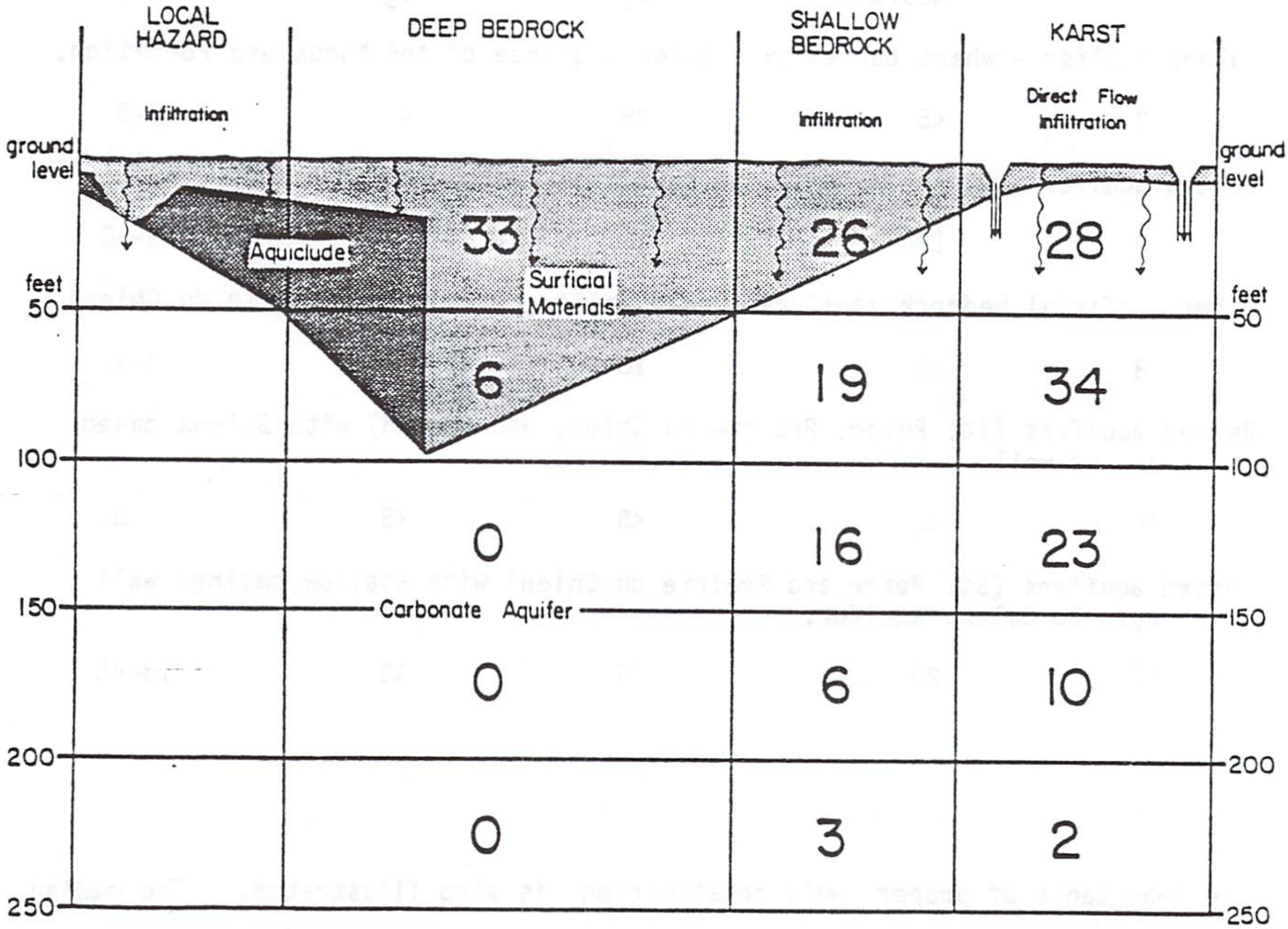

Figure 1. Summary of median nitrate concentrations for the different geologic settings and by well depth in northeast Iowa. In all areas, wells less than 50 feet deep show high levels of nitrate contamination. In the Karst and Shallow Bedrock regions, where the soil cover is less than 50 feet thick over the carbonate bedrock, significant levels of nitrate contamination occur to depths of 150 feet and locally to 200 feet. The problem is most pronounced in the Karst regions where the soil mantle is generally thinner, allowing greater infiltration, and because sinkholes allow the direct in-flow of surface water into the groundwater. Even where an aquiclude (e.g.--shale) covers the carbonate aquifer, local hazards may exist where the soil and aquiclude mantle are thin.

Table 2. Summary data of nitrate concentrations in ground water from 1975 well inventory in Allamakee and Winneshiek Counties.

N	median	Q_1	Q_3	range
		Nitrate-mg/l		
Galena aquifer - where buried by a thick sequence of the Maquoketa Formation.				
8	<5	<5	<5	<5-8
Galena aquifer - where it forms the surficial bedrock aquifer.				
9	20	13	30	9-40
Other surficial bedrock aquifers (Cedar Valley, Maquoketa, Prairie du Chien).				
8	25	10	35	8-40
Buried aquifers (St. Peter, Prairie du Chien, and Jordan) with Galena cased out of well.				
10	<5	<5	<5	<5
Buried aquifers (St. Peter and Prairie du Chien) with shallow casing; well open to Galena aquifer.				
12	20	16	30	10-40

The importance of proper well construction is also illustrated. The median nitrate concentration in water from wells finished in these buried aquifers (St. Peter and Prairie du Chien), but which are also open to the Galena aquifer, is 20 mg/l. In these settings nothing is gained, from a water-quality standpoint, by drilling into deeper aquifers. In these settings there is also the risk of contaminating these lower aquifers, by exchange with water from the Galena.

Other points may be better demonstrated graphically. Figure 2 summarizes the nitrate data by well depth. There is not a very good relationship between nitrate and well-depth, which is in contrast to other data sets (see Hallberg and Hoyer, 1982). However, well construction information was available for these wells, which were sampled in 1975. This information provides an opportunity to evaluate other factors which influence the water quality.

In figure 3, total well depth is plotted against the depth of casing in each well. There is, as shown on figure 3, generally a relationship between the depth of the casing and the depth of the well. This general pattern is what allows the establishment of a relationship between nitrate concentration and total well depth in most data sets (even when casing depths are not available). Also, note on figure 3 that the wells with detectable nitrates are restricted to wells with casing less than 150 feet in depth. Thus, when the data in figure 2 is replotted as nitrate concentration versus casing depth in the well (figure 4) there is a much more obvious relationship. The deeper wells which exhibit nitrate problems have shallow casings which allow high nitrate Galena water into the well. This again emphasizes the need for proper well-construction guidelines.

The second data set of interest involves nitrate data collected during a study of the Silurian-Devonian carbonate aquifers in the Linn and Benton County areas (Wahl and Bunker, in preparation). This was a cooperative study between the IGS and USGS and much of the water-quality data was collected from research wells drilled by IGS. Thus, the data provide another degree of control not available in some other data sets. Many of the individual bore holes were packer tested, providing information about the aquifer and water-quality analyses from discrete portions of the aquifer at different depths. The Linn-Benton County areas do not exhibit strong surficial development of karst features but are part of the shallow-carbonate aquifer hazard area described by Hallberg and Hoyer (1982).

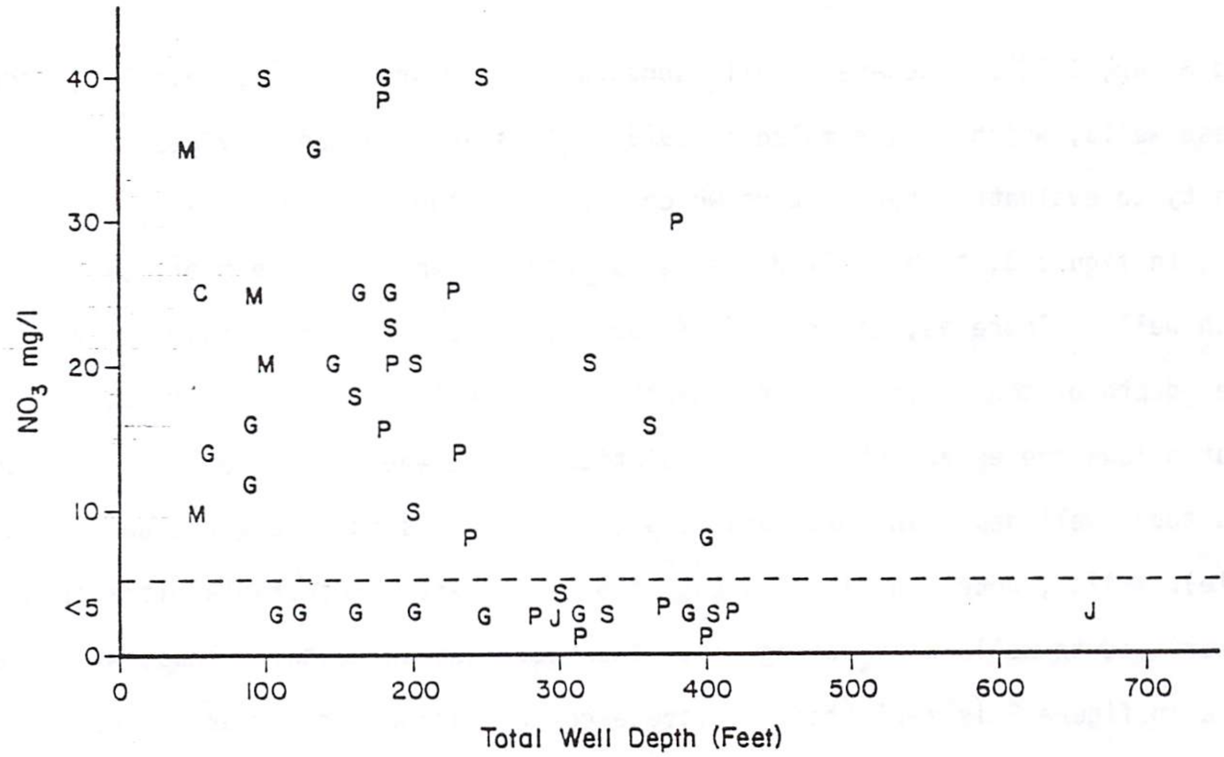

Figure 2. Nitrate concentration in groundwater sample versus depth of the well, from samples collected in October, 1975, in Allamakee and Winneshiek Counties. Letters indicate hydrostratigraphic unit well is finished in: C-Cedar Valley; G-Galena; J-Jordan; M-Maquoketa; P-Prairie du Chien; S-St. Peter.

Figure 5 shows a summary of the groundwater nitrate concentrations versus well depth. In this instance, total well depth indicates either: 1) total well depth, for a single open-hole sample; or 2) the bottom depth of the packer interval of the sample. Nearly all of these samples were from uncased holes. Note also that the nitrate concentrations are, in general, quite low (note the changes in scale for the nitrate data). There is not a good relationship between nitrate and well-depth. Again, other factors may be evaluated.

Figure 6 shows a plot of nitrate concentration versus the depth to rock for these uncased wells. In this case, the nitrate concentrations shown are

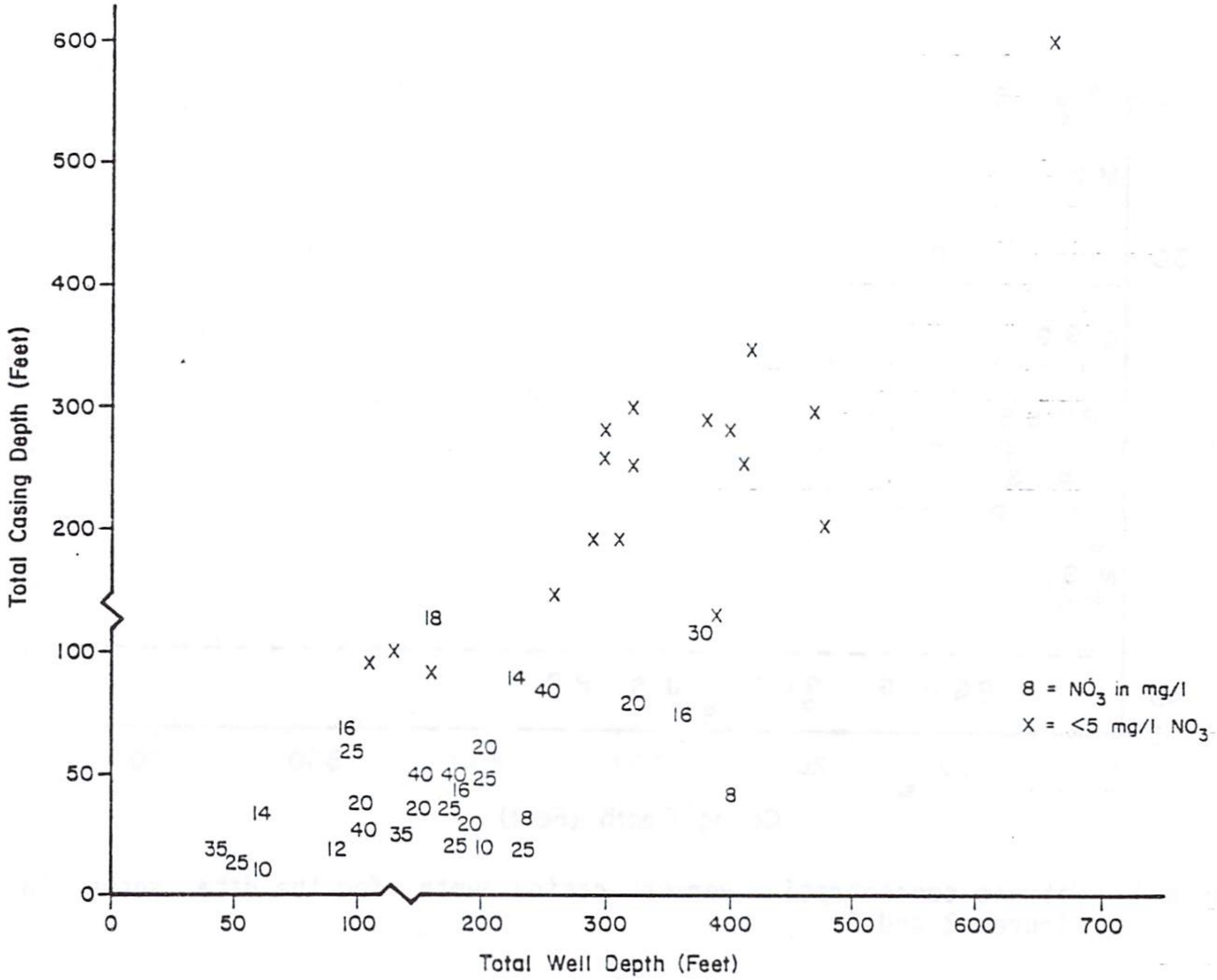

Figure 3. Casing depth versus total well depth (and nitrate concentration of water samples from the wells) for the same sites as in figure 2.

from either: 1) the uppermost water-quality sample; or 2) a single sample from a fully open bore-hole. As with the prior example on casing depth, the nitrates more clearly show a relationship with the depth to the bedrock below the land surface.

These data also reveal some other interesting patterns. Figure 7 shows a plot of the nitrate concentration versus the depth to the top of the packer horizon sampled in the Silurian carbonate aquifer. The deeper samples with

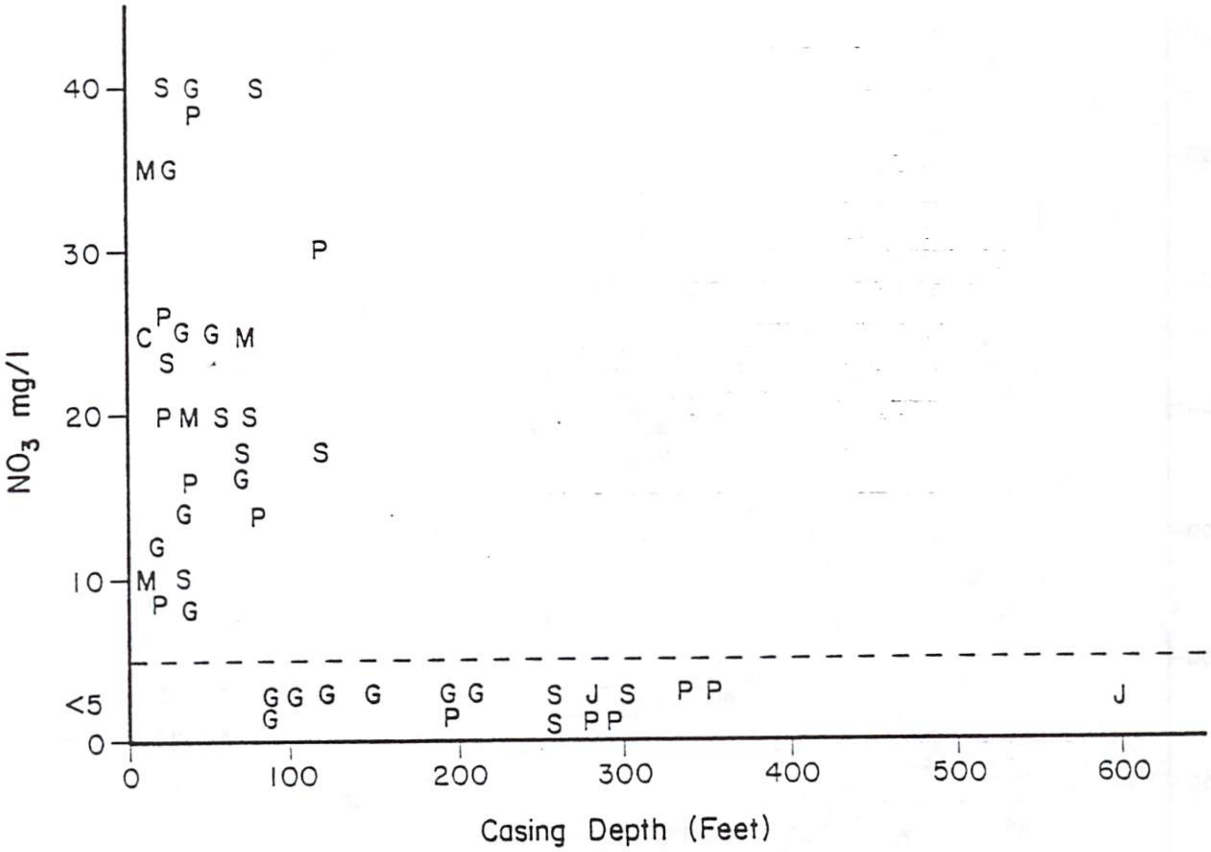

Figure 4. Nitrate concentration versus casing depth for the data shown in figures 2 and 3.

elevated nitrate concentrations all come from intervals which include the *Cyclocrinites* beds. Within the Silurian rocks, the *Cyclocrinites* beds are particularly susceptible to solution and development of secondary permeability. When near the land surface, these beds control the development of many of the major cave systems in the Silurian (Bounk, 1983). Even deep in the subsurface these beds form zones of high porosity and higher transmissivity when encountered in water wells (Wahl and Bunker, in prep.). In this regard, figure 8 reveals an interesting relationship between the nitrate concentration and the average specific capacity per foot of the aquifer sampled in these packer tests.

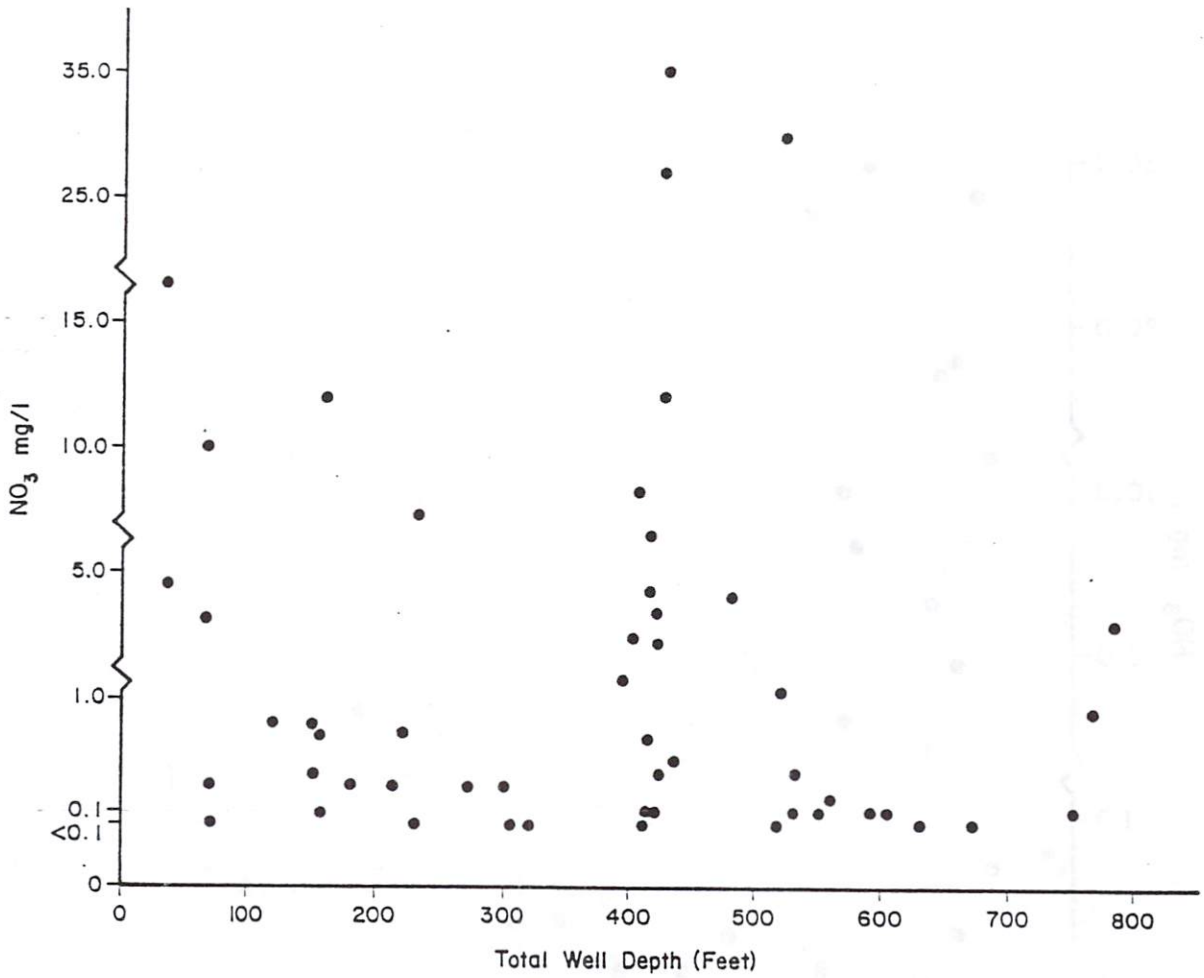

Figure 5. Nitrate concentration versus total well depth for samples from carbonate-aquifer study in Linn and Benton Counties. See text for details.

All these data suggest that the more open and hydraulically conductive that a particular zone of the aquifer is (because of secondary solution porosity), the higher the nitrate concentration is likely to be, even at considerable depth in the aquifer. The flow through these carbonate aquifers takes place through interconnected solutional openings along vertically enlarged joints and fractures and horizontally enlarged stratigraphic features, such as the *Cyclocrinites* beds. Where a particular horizontal zone is

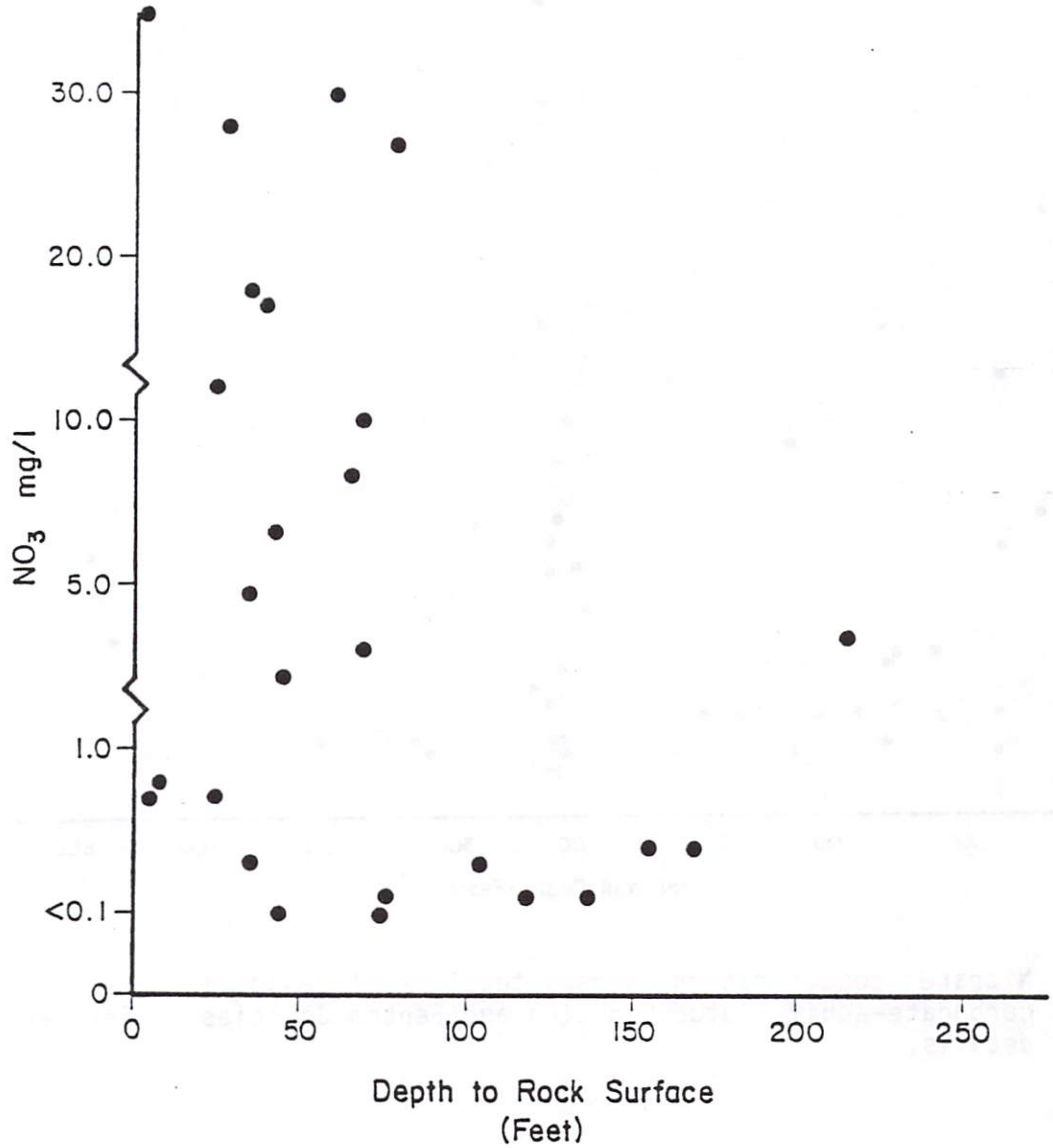

Figure 6. Nitrate concentration versus depth to bedrock below the land surface for Linn-Benton County research wells.

preferentially opened by solution (and thus has a higher horizontal conductivity) over large areas, it has a greater opportunity to intercept more and larger vertical conduits which then may conduct nitrate-enriched water deeper into the aquifer. Obviously, various factors will affect this interchange, such as the vertical head relationships in the aquifer, etc.

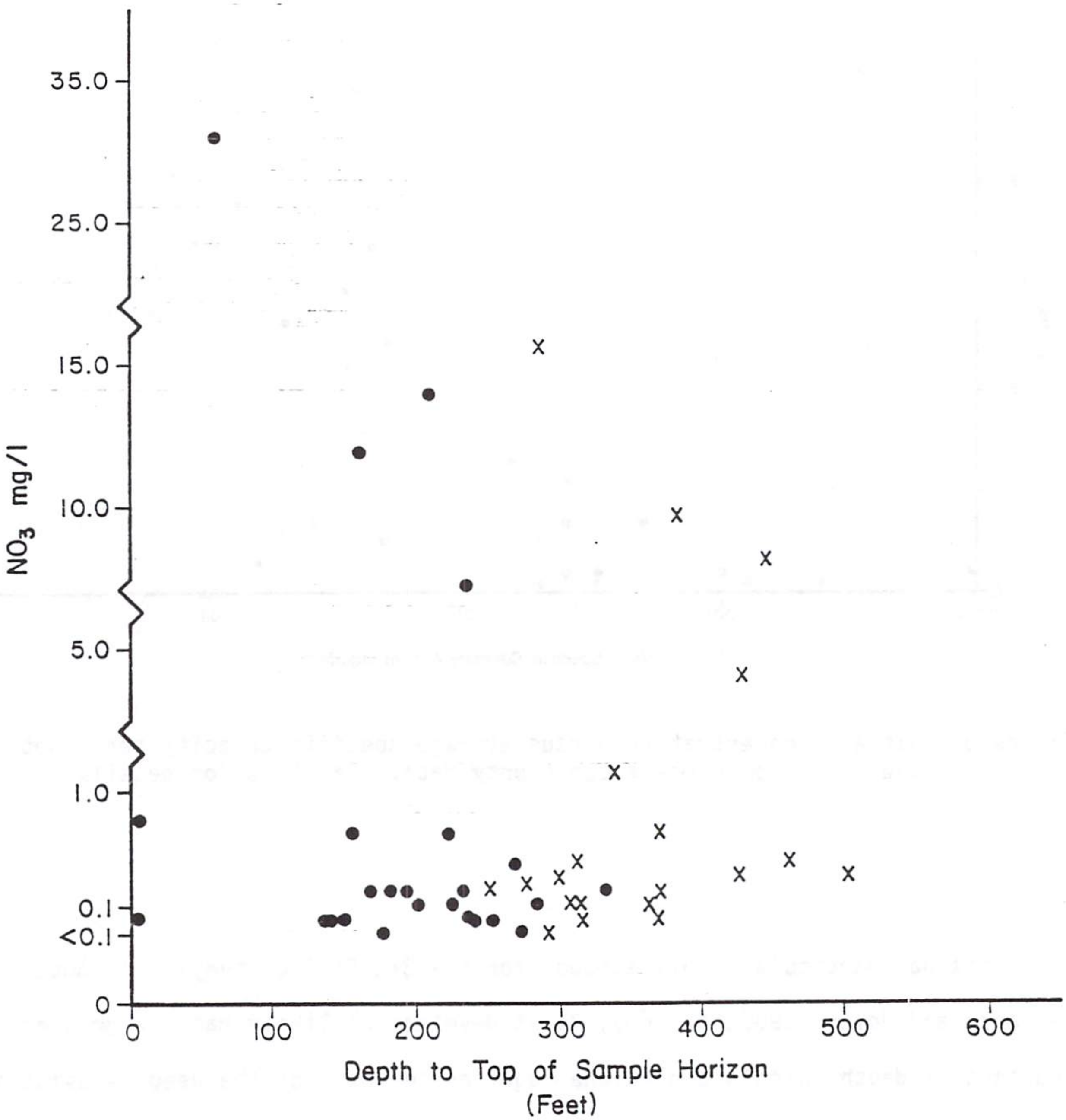

Figure 7. Nitrate concentration versus depth to top of sampling horizon, for Linn-Benton County data. X-indicate samples which include *Cyclocrinites* beds. See text for details.

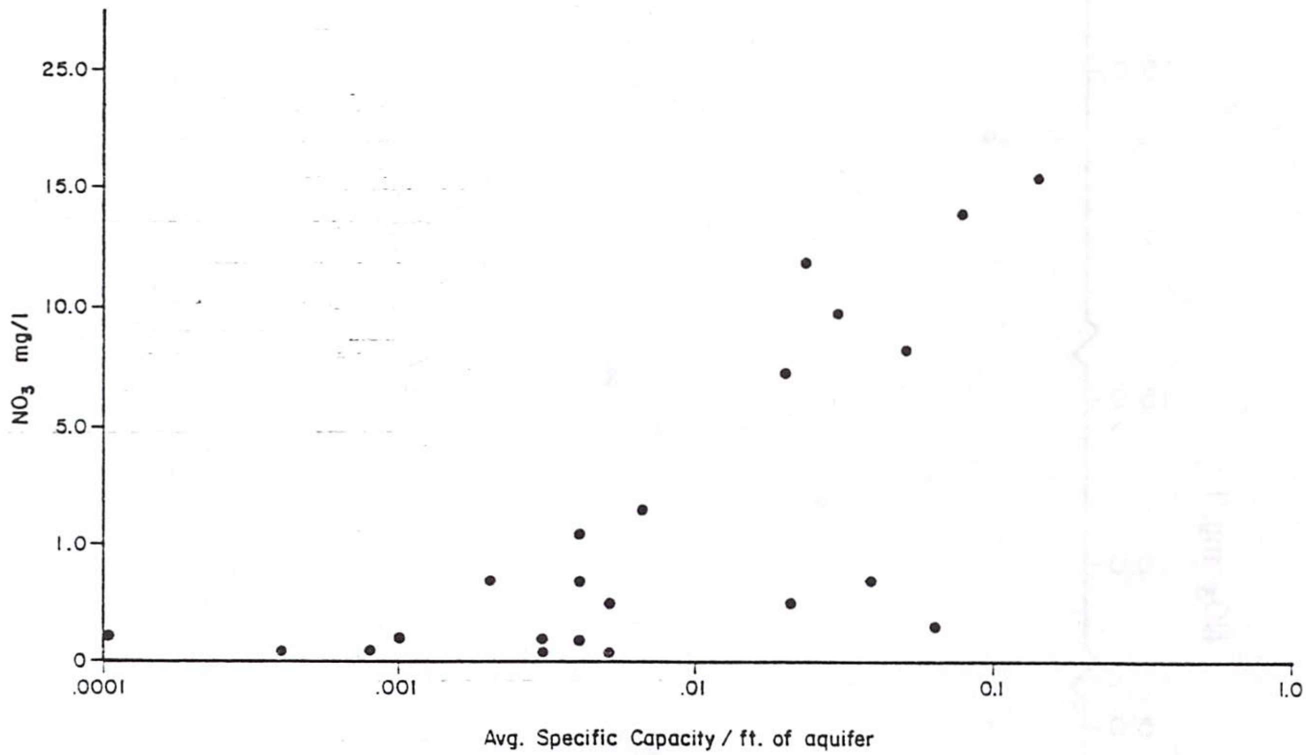

Figure 8. Nitrate concentration versus average specific capacity per foot of aquifer, from Linn-Benton County data. See text for details.

This has particular implications for the Big Spring study. As noted in Hallberg and Hoyer (1982, p. 60), karst development likely has progressed to substantial depth within the Galena aquifer because of the deep erosion in northeast Iowa during the Quaternary. Even though water levels in the aquifer are likely higher than they were in the geologic past (when master streams such as the Turkey River were downcut more deeply), the prevalence of karst development at depth within the aquifer would suggest that nitrates and other surface contaminants may penetrate more deeply into the aquifer. Thus, in such settings, there may be little or no relationship between depth within the aquifer and the nitrate concentration.

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APPENDIX A:

Results of Kolmogorov-Smirnov test on distributions of nitrate analyses. The data was stratified by well depth within a geologic setting. Data was obtained from the University Hygienic Laboratory on analyses conducted between 1977 and 1980.

Geologic Setting	Well Depths Compared	Significance Level
Karst	<50 & 50-99 feet	>.1
	50-99 & 100-149 feet	.005
	140-149 & 150-199 feet	.005
	150-199 & 200-249 feet	>.1
	200-249 & 250-299 feet	>.1
	250-299 & 300-499 feet	>.1
	300-499 & >500 feet	-----
Shallow	<50 & 50-99 feet	>.1
	50-99 & 100-149 feet	>.1
	140-149 & 150-199 feet	.001
	150-199 & 200-249 feet	>.1
	200-249 & 250-299 feet	>.1
	250-299 & 300-499 feet	.1
	300-499 & >500 feet	>.1
Deep	<50 & 50-99 feet	.001
	50-99 & 100-149 feet	.001
	140-149 & 150-199 feet	>.1
	150-199 & 200-249 feet	>.1
	200-249 & 250-299 feet	>.1
	250-299 & 300-499 feet	>.1
	300-499 & >500 feet	>.1

APPENDIX B:

Results of Kolmogorov-Smirnov test on distributions of nitrate analyses. The data was stratified by well depth and compared between geologic settings. Data was obtained from the University Hygienic Laboratory on analyses conducted between 1977 and 1980.

Geologic Settings Compared	Well Depths	Significance Level
Karst & Shallow	<50 feet	>.1
	50-99 feet	.001
	100-149 feet	.10
	150-199 feet	>.1
	200-249 feet	>.1
	250-299 feet	>.1
	300-499 feet	>.1
	>500 feet	>.1
Karst & Deep	<50 feet	>.1
	50-99 feet	.001
	100-149 feet	.001
	150-199 feet	.001
	200-249 feet	.01
	250-299 feet	.005
	300-499 feet	.001
	>500 feet	>.1
Shallow & Deep	<50 feet	.025
	50-99 feet	.001
	100-149 feet	.001
	150-199 feet	.001
	200-249 feet	.001
	250-299 feet	.001
	300-499 feet	.001
	>500 feet	>.1