THE IOWA STATE-WIDE RURAL WELL-WATER SURVEY:
Site and Well Characteristics and Water Quality

Technical Information Series 23

Iowa Department of Natural Resources
Larry J. Wilson, Director
December 1992

THE IOWA STATE-WIDE RURAL WELL-WATER SURVEY: Site and Well Characteristics and Water Quality

Technical Information Series 23

Prepared by:

G.R.Hallberg[1], K.Woida[1], R.D.Libra[1], K.D.Rex[1], K.D.Sesker[2], B.C.Kross[2], L.S.Seigley[1], B.K.Nations[1], D.J.Quade[1], D.R.Bruner[1], H.F.Nicholson[2], J.K.Johnson[2], and K.L.Cherryholmes[3]

[1]Iowa Department of Natural Resources
The University of Iowa, Center for Health Effects of Environmental Contamination:
[2] Department of Preventive Medicine and Environmental Health
[3] University Hygienic Laboratory

Supported, in part, by: the Iowa Groundwater Protection Act of 1987; The Iowa Department of Agriculture and Land Stewardship, Laboratory Division, Pesticide Bureau, through grants from the U.S.Environmental Protection Agency, Region VII, Toxics and Pesticide Branch, and the Division of Soil Conservation through the Integrated Farm Management Demonstration Project; and through grants from the U.S. Environmental Protection Agency, Region VII, Nonpoint Source Program

December 1992

Iowa Department of Natural Resources
Larry J. Wilson, Director

TABLE OF CONTENTS

ABSTRACT 1

INTRODUCTION 5
SWRL REVIEW 5

DATA ANALYSIS AND PRESENTATION 7

WELL AND WATER SYSTEM FACTORS 9
WELL-CONSTRUCTION TYPE 9
WELL CASING 11
WELL AGE 13
GROUTING 17
OTHER WELL-HEAD FEATURES 17
WATER DISTRIBUTION AND STORAGE SYSTEM 19
Sample Collection Location 19

PAST WATER-QUALITY PROBLEMS 22

WELL LOCATION AND SITE FACTORS 22
MULTIPLE WELLS 23
OTHER ON-SITE FEATURES 25
ON-SITE REFUSE DISPOSAL 27
OTHER LANDUSE 27

AGRICULTURAL MANAGEMENT FACTORS 29
CHEMICAL HANDLING FACTORS 30
Pesticide Formulation And Rinse Disposal 34
Pesticide Container Disposal 34

SUMMARY AND CONCLUSIONS 35

ACKNOWLEDGMENTS 41

REFERENCES 43

LIST OF FIGURES

Figure 1. Generalized hydrogeologic regions (bold outlines) used to summarize data in the SWRL reports. 7

LIST OF TABLES

Table 1. Well-site landuse observations and water-quality data. 8

Table 2. Water-quality data summarized by well type and well depth. 10

Table 3. Proportion of wells by well depth; mean well depths; and mean casing depths; state-wide and by hydrogeologic regions (for sites reporting both well depth and casing depth). 11

Table 4. Water quality related to well depth and casing depth (for sites reporting casing depth). 12

Table 5. Well age observations (state-wide by decade) and water-quality data. 13

Table 6. Well age (year of construction) and mean well depth, by hydrogeologic region. 14

Table 7. Well age and well-construction type. 14

Table 8. Well age, well-construction type, and water-quality data. 15

Table 9. Well age, well-construction type, and water-quality data. 16

Table 10. Responses to Question 7h ("Is the well grouted?"), and water-quality data. . . . 17

Table 11. Well head features, well type and water-quality parameters. 18

Table 12. Responses to "Where does the drinking water go from the pump?", and water-quality data. 20

Table 13. Water sample collection points, observed water-quality problems and relation to water-quality results. 21

Table14. Responses to "Have you had any past water quality problems?", and water-quality data. 23

Table 15. Number of operable wells on site, depth of sampled well used as primary water supply and water-quality data. 24

Table 16. Percentage of well-construction types according to the number of operable wells at the site. 24

Table17. Distance of abandoned wells, chemical storage areas, and septic systems from water supply well, and water quality water data (see also, Kross et al., 1990, Tables 76 and 77). 26

Table 18. Relationships among refuse disposal, dumpsites on the property, and water-quality. Responses to "Do you have refuse disposal dumpsites on your property?", and method of disposal of household and farm garbage/solid-waste. 27

Table 19. Water-quality data for sites in "Other" category for "landuse in immediate adjacent area" to well and for "Other" "landuse in 0.5 mile radius" (see Table 1, also). 28

Table 20. Farm operation, farm enterprises, and water-quality data. 29

Table 21. Nitrogen application rates to corn for most recent growing season, and water-quality data. 30

Table 22. Fertilizer and pesticide use since 1980, and water-quality data. 31

Table 23. Percentage of sites where pesticides were detected in relation to the active ingredients applied at the sites. 32

Table 24. Pesticide mixing, spills, distance from well, and water quality data. 33

Table 25. Method of disposal of empty pesticide containers in relation to water quality data. 35

Table 26. Summary of SWRL water-quality results. 36

THE IOWA STATE-WIDE RURAL WELL-WATER SURVEY: Site and Well Characteristics and Water Quality

Iowa Department of Natural Resources, Geological Survey Bureau
Technical Information Series 23, 1992, 43 p.

G.R.Hallberg, K.Woida, R.D.Libra, K.D.Rex, K.D.Sesker, B.C.Kross, L.S.Seigley, B.K.Nations, D.J.Quade, D.R.Bruner, H.F.Nicholson, J.K.Johnson, and K.L.Cherryholmes

ABSTRACT

The Iowa Department of Natural Resources (DNR), in conjunction with the University of Iowa, Center for Health Effects of Environmental Contaminants (CHEEC), conducted the State-Wide Rural Well-Water Survey (SWRL) between April 1988 and June 1989. The SWRL survey provided a statistically valid assessment of the proportion of private rural wells and rural Iowa residents affected by various environmental contaminants. Previous reports reviewed the SWRL design, water-quality results, and relationships among individual site characteristics and water-quality. Few site factors occur in isolation, hence, this report focuses on analysis of combinations and interactions of site characteristics, well-siting and well-construction features, and their relationship with water-quality, to refine possible causal associations. This assessment also uses "gradient" measures to evaluate the associations of various factors at varying distances from a well. If a point source is a major causal factor, its association with contamination should be stronger as proximity to the well increases. Many trends and associations are not statistically significant (at 95% confidence) but are presented if logically consistent.

While several site/well system factors are associated with water quality, most are subordinate to, or interrelated with the overriding factors of well (and casing) depth and well-construction type. Shallow (<50 feet deep) wells of any construction type show the greatest proportions of all contaminants. Large-diameter seepage wells, which are typically open to the water table, account for over half of the wells that are <50 feet deep. Thus, they exhibit greater proportions of contamination, particularly for total coliform positives. Drilled, cased wells are generally much deeper and exhibit lower contamination rates. Drilled wells with less than 50 feet of casing are functionally shallow wells, regardless of depth, and have contamination rates for chemical constituents similar to state-wide averages. Drilled wells that are cement grouted are generally deeper wells and show statistically better water quality. Older wells are often presumed to produce water with greater contamination than younger wells, because of aging effects on the well materials and/or less rigorous construction and siting considerations. But this trend is inconsistent, not significant, and is confounded because older wells are also more shallow and because a large percentage are seepage wells. There is no indication that wells constructed after 1982 (initiation of new well-construction standards) produce any better water quality than older cohorts, though the sample size of newer wells is small and little analysis possible.

Sites with sealed wellheads show somewhat less contamination than average, while unsealed wellheads are characterized by somewhat higher contamination rates. Large-diameter seepage wells, even with a sealed well head or with pitless adapter (buried-slab) construction, still show

greater than average proportions of most contaminants. For drilled wells the difference between sealed and unsealed conditions was more significant, but this accounts for only a small portion of contaminated wells (about 1%). Water distribution and storage systems did not significantly affect water-quality results, with the exception of the high proportion of coliform positives that are associated with cisterns and other outside water-storage structures (even concrete tanks). Sites where more than one operable well is present showed greater than average occurrences for NO_3-N >10mg/L and coliform positives. However, this is largely a function of the use of multiple seepage wells at the majority of these sites. Sites with only one operable well were dominated (70%) by deeper drilled wells.

Previous analysis of the SWRL data showed minor differences in the rates of some contaminants at sites with abandoned wells, no septic systems, or chemical storage on the property. When these factors are stratified by distance to the water-supply well, and by number of abandoned wells, consistent proximity effects are not apparent. For example, wells located within 15 feet of chemical storage and handling areas are uncommon, occurring at <0.6% of rural sites, and *none* of these wells contained pesticides or NO_3-N >10mg/L. One of the most striking associations is that water quality is significantly better in non-farm, suburban housing tracts than agricultural areas. Even though the suburban wells are located closest to septic systems they had significantly fewer sites with >10mg/L NO_3-N and coliform positives. A prime example of the confounding of variables is that wells with the greatest distance (>200 feet) from septic tanks and chemical storage and handling areas often exhibited the greatest degree of contamination. This relationship results from the high proportion of seepage wells in the greatest distance categories. These wells tend to be located along waterways, or other areas with a high water table (to promote seepage), often quite distant from houses, cattle-yards, storage buildings and chemical-mixing sites. Site studies show that these wells are located an average of one-quarter of a mile from such likely point-sources. While such wells are highly susceptible to impacts from accidents and point sources, the majority are located so far from such sources that there is limited potential for direct impact. Hence, these wells are "under-represented" in point-source cases.

The effects of sinkholes or agricultural drainage wells (ADWs) are not significant in a state-wide context. Sinkholes were identified in the vicinity of only 2.1% of sites and only 0.6% of sites were near ADWs. No sites with ADWs had pesticide detections or NO_3-N >10 mg/L.

Onsite disposal of home and farm refuse shows no effect on water-quality in the SWRL survey. For farmed sites neither the crop nor livestock enterprises, rates of N-fertilization, nor the herbicides applied were reflected in the water quality at the on-farm well. However, these patterns are relatively ubiquitous in Iowa. Neither methods nor locations of disposing of excess pesticide formulation, rinseate, or pesticide containers exhibited any significant association with water-quality results. Wells located *in* feedlots showed significantly higher concentrations of nitrate, but *not* bacteria problems. Such sites comprise only about 3% of wells state-wide, and account for only about 1% of the wells with >10 mg/L NO_3-N.

Sites that reported the formulation of pesticides at a hydrant at or near the wellhead and/or spills of pesticides were related to greater than state-wide averages for pesticide detections. However, when the results are stratified by distance from the well, and by well depth and well type, consistent proximity trends are absent. Sites where residents reported that all the herbicides were custom applied showed the *same* proportion of pesticide detections as those where they mixed all the herbicides on-site.

About 5.4% of farms reported spills, back-siphoning, or other accidents with pesticides and/ or fertilizers near their wells. As expected, these sites show a greater proportion of pesticide detections. However, of the detections at these sites, *only 36% contained the pesticide involved in the mishandling incident.* The relationship between the proximity (i.e., the actual potential for an effect on the well) of mixing and handling of pesticides to the well-head and pesticide detections, while inconsistent, does indicate a significant association within a distance of about 50 feet. The high proportion of pesticide detections at sites where pesticides are mixed (and spilled) within 50 feet of the well head stands up throughout the analysis of the many confounding variables, e.g., the sites are not dominated by seepage wells or inordinately shallow wells. This relationship is a strong indication that such handling, over time, has likely impacted these wells adversely. Spills and mixing near the wellhead still only explains a small portion of the total occurrence of pesticides, however. When *all* detections from wells within 50 feet of mixing sites are considered, they account for about 1.5% of pesticide detections state-wide; combined with other known spill and accident sites (whether the compound found was *related* to the spill or *not*), they account for about 3-3.5% of detections state-wide (of the 13.6% measured). Such detailed analysis is requisite for understanding the magnitude of such impacts. While there is little question that point-source problems (e.g., spills, back-siphoning, repeated mishandling near a well) occur and contaminate wells, it is easy to overstate their occurrence from anecdotes. The estimates of the extent of such incidents derived from the detailed data collected in the SWRL study are similar to the values derived from other detailed field investigations in Iowa. The review of sites where pesticide concentrations exceeded HALs provided similar insights: 25%, were clearly "point- source" cases, one a spill and one back-siphoning accident; the majority, 62.5%, were probable nonpoint sources related to pesticide occurrences in shallow groundwater; 1 case, 12.5%, was equivocal.

Neither simple proximity nor susceptibility are cause and effect. Neither the proximity of handling and mixing to a well, nor the use of a susceptible well-type dictate that point sources are the cause of a pesticide detection. The continuing analysis of the SWRL survey data reinforce prior findings, that: 1. point-source problems clearly contribute to the occurrence of pesticides in water-supply wells; *but,* 2. they account for a small portion of the problems; and, 3. nonpoint sources also account for many pesticide detections in water-supply wells, which is supported by other detailed research.

INTRODUCTION

As part of the implementation of the Iowa Groundwater Protection Act of 1987 the Iowa Department of Natural Resources (DNR), in conjunction with the University of Iowa, Center for Health Effects of Environmental Contaminants (CHEEC), conducted a survey of the quality of private drinking-water supplies used by rural Iowans. Overall responsibility for project management was shared by principal investigators from the DNR and The University of Iowa, Department of Preventive Medicine and Environmental Health (PM&EH). The State-Wide Rural Well-Water Survey (SWRL) was conducted between April 1988 and June 1989. Previous reports have presented the SWRL survey design and implementation (Hallberg et al., 1990), reviewed details of the hydrologic conditions during the survey, the water-quality results, statistical and hydrological relationships among water-quality parameters, and the first-stage analysis of relationships among site characteristics and water-quality findings (Kross et al., 1990, 1992). Results were presented on both a state-wide basis, and by individual hydrogeologic regions. This report discusses further relational analysis among site characteristics, well-siting and construction features, and the water-quality data.

SWRL Review

A brief review of SWRL findings provides an introduction and background for the further analysis presented in this report. The SWRL survey was designed to provide a statistically valid assessment of the proportion of private rural wells and rural Iowa residents affected by various environmental contaminants. The survey was a systematic sample, stratified by rural population density. SWRL demographic data indicate the sample is clearly representative of rural Iowans.

Primary samples were analyzed for total coliform bacteria; nitrate (+nitrite)-N, ammonium-N, and organic-N; major inorganic ions; 27 pesticides, and 5 pesticide metabolites. Existing agency and laboratory USEPA quality assurance, quality control plans were utilized and verified for SWRL. SWRL collected and analyzed 1,048 water samples from 686 sites.

The SWRL data provide a population-based summary of the drinking water used by rural Iowans, and a cross-section of the quality of Iowa groundwater. The variations in water quality exhibited in the SWRL data, both regionally and particularly with depth, show consistent and predictable geochemical patterns, which are related to natural processes, contaminant sources, transport, and age effects. Iowa well waters show near neutral pH values, and dissolved ions are dominated by calcium, magnesium, bicarbonate, and occasionally sulfate. Mean concentrations for all ions, except chloride (Cl) and nitrate (NO_3-N), increase or remain fairly constant with depth. The higher concentrations of Cl and NO_3-N at shallow depths are related to their surficial sources. State-wide, 1.3 % of private well waters exceeded the USEPA maximum contaminant level (MCL) for fluoride (F), and 2.5% exceeded the secondary standard of 2 mg/L.

About 18% of Iowa's private, rural drinking-water wells contained NO_3-N >10 mg/L, the recommended health advisory level (HAL); 37% of wells have >3 mg/L, typically considered indicative of anthropogenic pollution. Approximately 14% of wells had detections of pesticides: 16 pesticide compounds were detected, including 11 parent compounds and 5 environmental metabolites; 16 pesticides were not detected. Atrazine and its metabolites were found in 8% of wells. Multiple residues were detected in all regions of the state. The mean concentrations were generally <1 ug/L. Lifetime HALs were exceeded in 1.2 % of private, rural wells in Iowa.

Approximately 45% of the sites tested positive for total coliform bacteria. Total coliforms are ubiquitous constituents of soils, surface water, and shallow groundwater and cannot be equated to fecal coliforms. Only 7% of water systems were positive for fecal coliform bacteria. The only sound, general interpretation of a persistent presence of total coliforms is that the water system is allowing interaction with soil, soil-water, shallow groundwater, or possibly surface water. This can indicate that the system is prone to other forms of contamination.

Individually, or in combination, nearly 55% of rural water supplies exhibited total coliform positives, NO_3-N >10 mg/L, and/or pesticide detections. For fecal coliforms, this reduces to about 30% of well-water supplies. Based on 1980 Census data, about 130,000 rural Iowa residents consume drinking water from private wells with >10 mg/L, NO_3-N; 94,000 use water with one or more pesticides; 5,400 use water with a pesticide concentration above an HAL.

Statistical analyses show significant associations between many water-quality parameters (e.g., between nitrate-N and pesticides) but based on state-wide data these associations are not strong predictors. By far the most significant factor explaining water-quality variations is well depth. An apparent relationship among total coliforms, NO_3-N, and pesticides is primarily a function of their co-occurrence in shallow wells. Total coliform bacteria are very poor predictors of these chemical contaminants. If a prediction were based on the presence of total coliform, the probability is better that they would not occur in the water supply.

The effects of sinkholes or agricultural drainage wells are not significant in a state-wide context. Sinkholes were identified in the vicinity of only 2.1% of sites and only 0.6% of sites were near agricultural drainage wells (ADW). No sites reporting ADWs had any pesticide detections or NO_3-N >10 mg/L. Non-farm, suburban housing tracts exhibited the most significant association between landuse and water quality; proportionately, these areas showed substantially fewer wells with >10 mg/L NO_3-N and total coliform bacteria. Wells located <50 feet from septic systems, showed *lower* nitrate and significantly fewer positives for total and fecal coliform bacteria. These sites were dominantly in the "suburban" areas as opposed to agricultural areas.

Typical point-source problems affect a relatively small proportion of wells state-wide. Wells located *in* feedlots had significantly higher concentrations of nitrate, but not bacteria problems. Such sites comprise only about 3% of wells state-wide, and account for only about 1% of the wells with >10 mg/L NO_3-N. Sites where herbicides have been mixed within 15 feet of the well showed greater pesticide detections, but again the proportion of wells is low, about 3%, state-wide. Wells located within 15 feet of chemical storage and handling areas are uncommon, occurring at <0.6% of rural sites, and *none* of these wells contained pesticides or NO_3-N >10 mg/L.

About 5.5% of private water wells in Iowa have experienced a spill or back-siphoning accident with pesticides or fertilizers. These sites exhibit a greater proportion of pesticide detections and high nitrate concentrations than average, as expected, but at the majority of sites the pesticides detected were *not* those involved in the accident. Sites exceeding HALs for pesticides occurred throughout the state. These sites were dominated by shallow wells; one deep well was involved and this was a point source case which could affect a well of any depth. Two of the sites, 25%, are clearly "point source" cases, one a spill and one back-siphoning accident (alachlor and trifluralin); the majority, 62.5%, are probable nonpoint sources related to pesticide occurrences in shallow groundwater (alachlor and atrazine); 1 case, 12.5%, is equivocal (atrazine).

Well depth is the major variable affecting the potential for surficial contaminants to enter a well. The degree of contamination is far greater in shallow wells and significant contamination occurs in wells up to 100 feet deep. Wells <100 feet deep comprise 50% of wells state-wide and account for 70% of total coliform positives, 80% of fecal coliform positives, 64% of pesticide detections and total atrazine detections, and 89% of wells with NO_3-N >10 mg/L. In NE Iowa contamination extends to greater depth because of deeper groundwater circulation (Fig. 1). The greatest proportions of contaminated wells occur in the SC, SW, and NW regions, paralleling the regional dependence on shallow wells. As alternative water sources are limited in these regions nearly 75% of wells are <100 feet deep and dominantly large diameter seepage wells.

Certain factors of well construction or placement may afford easy entry of shallow, contaminated groundwater, but these factors are not causes of contamination. If the contaminants were not in the environment they would not get into the soil

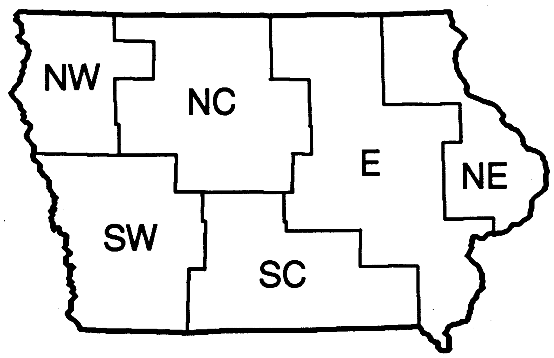

Figure 1. Generalized hydrogeologic regions (bold outlines) used to summarize data in the SWRL reports.

water and groundwater, or the well. Remediation of well construction or replacing current wells with deeper wells would undoubtedly reduce nitrate and pesticide contamination in many locations, but this would not address the cause of the contamination.

DATA ANALYSIS AND PRESENTATION

The data on site and well construction characteristics were derived from on-site observations and measurements by DNR and PM&EH staff who conducted the field well-water sampling and from detailed questionnaires filled out through interviews with site residents (and/or site owners). Table 1, repeated from Kross et al. (1990, Table 76), is illustrative of the first-stage analysis presented in prior reports. It summarizes observations by SWRL field staff concerning local landuse surrounding the wells in relation to summary water-quality results. These observations illustrate some of the complexities of assessing environmental-site factors and some conventions that will be used throughout this report. The first-stage analyses presented results for each factor individually, to begin to assess if certain factors may be associated with well contamination. Few factors occur in isolation, however. Typically there are many inter-related and confounding variables. For example, most wells with a feedlot in the adjacent vicinity will also have rowcrops nearby; many wells with forested areas or woodlots nearby will also be counted in some other landuse category. This report will focus on interactions, or combinations of factors, to further refine and isolate possible associations. Many factors, or categories of the site inventories, were set up to provide a "gradient" analysis, as shown on Table 1. If, for example, a given landuse occurring within a 0.5 mile radius exhibits a strong positive correlation with nitrate contamination, this association should be even stronger when that landuse is immediately adjacent to the well. This is particularly the case for well-head point sources.

To illustrate this initial assessment of possible associations, the tables in this report (see Table 1) show the state-wide proportions for the total SWRL sample and for wells <50 feet deep affected by various contaminants. The results shown for a given category are the relative state-wide, population-weighted proportions for that category only. These relative proportions afford comparison with the state-wide data. The state-wide proportion of sites in a landuse or site-characteristic category is also shown for perspective. While an association between landuse and water-quality parameters may have significance it may only explain a small portion of the total state-wide occurrence. The results summarized are also annotated with ++ and -- symbols. Data marked by a symbol are outside the 95% confidence interval (CI) for the state-wide proportions; a single + or - indicates that the data are between 1 and 5% outside the 95% CI (i.e., within a 90% CI); and two ++ or --, indicates they are more than 5% outside the 95% CI. These annotations provide a ready summary of the level of significance of the deviations shown. Various statistical methods were used to evaluate associations and predictive relations, including: SAS-General Linear Models; repeated measures analysis of variance; regression analysis, serial correlations; Spearman rank correlations; t-tests; and logistic probability analyses. The use of these methods is described in more detail in Kross et al., 1990.

As shown on Table 1, aggregated landuse adjacent the SWRL wells is, in part, too complex, and, in part, too invariant to provide definitive relation-

Table 1. Well-site landuse observations and water-quality data.

Well age/Well type	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%
Landuse within a 0.5 mile radius adjacent to the well:		Relative state-wide proportions in each category:			
feedlot;	40%	45%	15%	10%	26% +
farmland;	96%	45%	13%	8%	18%
rowcrop;	94%	44%	13%	8%	19%
pasture;	66%	47%	15%	8%	19%
forested;	22%	47%	14%	10%	18%
non-farm, "suburban" houses;	6%	31% --	17%	16% ++	20%
chemical handling/ storage facility;	2%	56% ++	24% ++	14% +	29% ++
other;	15%	50% +	13%	5% -	22% +
Landuse in the area immediately adjacent to the well:					
feedlot;	29%	44%	15%	11% +	24% +
farmland;	79%	43%	14%	9%	20%
rowcrop;	72%	42%	15%	9%	20%
pasture;	47%	47%	11%	6% -	17%
forested;	13%	47%	7% -	6%	17%
non-farm, "suburban" houses;	3%	14% --	13%	11%	8% --
chemical handling/ storage facility;	<1%	Can't compute, sample too small.			
other;	23%	49%	13%	7%	20%

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals; ++ and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

ships between land use and water quality. A few trends are apparent. The most prominent is the contrast between wells in farmland and rowcrop areas and those in suburban housing tracts. The wells associated with suburban housing tracts show significantly fewer detections of >10 mg/L NO_3-N and total coliform bacteria. This reduced occurrence becomes more pronounced moving from the 0.5 mile radius to the immediate vicinity of the wells. Curiously, these same sites show somewhat greater than average detections of atrazine at the 0.5 mile radius, but when viewed from the immediate vicinity of the wells this association is no longer significantly different than the state average.

At the 0.5 mile radius, the occurrence of chemical handling and storage facilities is associated with a greater proportion of all contaminants, coliform bacteria, nitrate, and pesticides. There is no logical relationship for the bacteria with such sites, however. Along the gradient to the immediate vicinity of the wells, this association becomes unclear. As shown on Table 1, there are too few sites with chemical handling or storage in the immediate vicinity of the wells (< 1%) to make meaningful estimates. However, *none* of these sites had any pesticides detected nor did any have NO_3-N >10 mg/L. This suggests that the 0.5 mile association is a function of an inter-correlation with other factors, such as well depth, for example. As noted, this report will focus on interactions, or combinations of factors, to further refine and isolate such associations and possible causal factors.

WELL AND WATER SYSTEM FACTORS

As discussed in previous reports (Kross et al., 1990), well depth is one of the most important factors affecting the quality of the derived well water. This section will discuss other aspects of well and water-supply systems that may have modified the effects of well depth, or otherwise affected water quality results from the SWRL survey.

Well-Construction Type

Three general types of water-supply wells are used in rural Iowa. These include small-diameter (<8") drilled wells (approximately 62% of wells state-wide), which are typically cased to some depth with iron or plastic pipe; large-diameter (>18") bored (or "dug") wells (34%), which are generally seepage wells completed in slowly permeable glacial materials and lined with stacked concrete tiles (see Kross et al., 1990); and driven sand-point wells (4%). Virtually all of the driven sand-point wells and large-diameter bored wells sampled were <100 feet deep. Approximately 90% of sand-points and 65% of the bored wells were <50 feet deep. Nearly 80% of all drilled wells were $\geq$100 feet.

Table 2 relates water quality to well-construction type and to well depth. Sites with drilled wells had significantly lower detections of coliforms than the state-wide proportions, regardless of well depth. Proportions of pesticide detections and nitrate-N >10 mg/L for samples from drilled wells <100 feet deep were comparable to state-wide averages, but were less than state-wide proportions for drilled wells >100 feet deep. None of the drilled wells <50 feet deep contained detectable atrazine (compared with 10% of shallow wells state wide), but very few wells were in this depth/construction class.

Proportions of contaminated sand point and bored wells exceeded the state-wide confidence limits in nearly all cases, regardless of depth. One exception is the small percentage (8%) of sand-point wells <50 feet deep that contained coliform bacteria. This may seem surprisingly low because sand-point wells are generally very shallow and are only used in areas with a shallow water table. However, because of their ease of installation sand-points are typically driven to some depth below the water table, thereby reducing the likely occurrence of generic total coliforms. For large-diameter bored wells, total coliform detections were very high and decreased only slightly with depth, from 87% of wells <50 feet deep to about 70% of wells 100 to 150 feet deep. Pesticide detections and nitrate concentrations were somewhat greater from bored wells in the 50-99 foot depth range than from those <50 feet deep. Most large diameter wells, regard-

Table 2. Water-quality data summarized by well type and well depth.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
State-wide proportions from:						
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative state-wide proportions in each category:				
Driven sand point wells:						
less than 50 ft.	90.1%	8.3% --	23.3% ++	23.3% ++	36.6% ++	10.1
50-99 ft.	9.9%	*	*	*	*	*
100 ft. or greater	0.0%					
(Approx. 4% of wells state-wide)	All	11.0% --	23.0% ++	19.0% ++	36.0% ++	9.6
Small diameter drilled wells:						
less than 50 ft.	4.2%	32.0% --	16.7%	<0.1% --	19.4%	4.9
50-99 ft.	16.2%	35.5% --	11.9%	6.8%	15.8%	5.4
100 ft. or greater	79.6%	26.8% --	9.2% -	5.4%	3.5% --	1.4
(Approx. 62% of wells state-wide)	All	27.0% --	10.0% -	6.0%	7.0% --	2.3
Large diameter bored or dug wells:						
less than 50 ft.	64.3%	87.3% ++	16.9%	8.0%	37.4% ++	12.2
50-99 ft.	33.1%	73.6% ++	20.7% +	17.4% ++	45.3% ++	16.6
100 ft. or greater	2.6%	68.9% ++	18.9% +	18.9% ++	18.9%	2.8
(Approx. 34% of wells state-wide)	All	83.0% ++	19.0% +	11.0% +	38.0% ++	13.0

Proportion of well types used for water supplies by hydrogeologic region:

	NE (1)	E (2)	SC (3)	SW (4)	NW (5)	NC (6)
Driven sand point wells:	2.0%	5.0%	3.0%	9.0%	9.0%	< 1.0%
Small diameter drilled wells:	97.0%	81.0%	25.0%	31.0%	29.0%	80.0%
Large diameter bored/dug wells:	< 1.0%	14.0%	73.0%	59.0%	63.0%	20.0%
% wells , 100 feet deep: (Approx. 49% state-wide)	9.0%	33.0%	79.0%	80.0%	74.0%	39.0%
Median well depth, feet: (Approx. 110 feet, state-wide)	190	130	40	40	40	130

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence interval;

++ and -- indicate proportions >5% above or below the 95% state-wide confidence intervals.

* Too few wells in category to calculate.

Table 3. Proportion of wells by well depth; mean well depths; and mean casing depths; state-wide and by hydrogeologic regions (for sites reporting both well depth and casing depth).

Well depth	Statewide	Hydrogeologic region NE (1)	E (2)	SC (3)	SW (4)	NW (5)	NC (6)
		Proportion of wells in well-depth category with reported casing depth					
< 50 ft.	10%	2%	6%	30%	20%	6%	8%
50-99 ft.	18%	8%	18%	11%	31%	18%	24%
100-149	22%	19%	25%	37%	13%	17%	21%
150-199	14%	18%	20%	4%	0%	0%	13%
200-299	21%	25%	21%	0%	24%	23%	20%
> = 300 ft.	16%	28%	11%	18%	11%	35%	16%
mean well depth (ft)	183	290	167	149	176	240	177
mean casing depth (ft)	149	181	140	116	173	224	152
		Mean casing depth (feet) by well-depth category					
< 50 ft.	28	21	28	21	34	15	32
50-99 ft.	68	19	72	7	68	26	67
100-149	110	65	112	96	137	59	109
150-199	134	103	137	36	-	-	123
200-299	193	106	173	-	245	228	225
> = 300 ft.	331	357	277	158	305	393	343
	% wells that have a difference between well depth and casing depth of > 25 ft						
	29%	69%	26%	17%	9%	6%	27%

less of depth, are seepage wells that are open to the water table and are therefore susceptible to any contaminant that can move from the land surface to the water table. In addition, the permeability of the glacial deposits that these wells tap generally decreases with depth, and most of the groundwater flowing into the bored wells typically comes from near the water table. Therefore, the quality of water from bored wells does not dramatically increase with greater well depths.

Well Casing

The effect of well depth on water quality is modified by the depth of casing present in the well. As discussed in Kross et al. (1990), a majority of rural residents give generally accurate information on the depth of their well, but only a minority are aware of the amount of casing in the well. Table 3 summarizes the available information on casing depths for SWRL wells. Large-diameter bored wells are generally lined with concrete tiles, and are not considered to be cased. Therefore, Table 3 summarizes information from small-diameter drilled wells.

Casing depths were reported by residents for about 35% of all wells state wide. Proportionately more information is available for the NE, E, and NC hydrogeologic regions because of the higher percentage of drilled (and cased) wells in these areas. State-wide, cased wells have an average depth of 183 feet, and have an average of 150 feet of casing. Regionally, cased-well depths vary from 150 feet in the SC region to 290 feet in the NE region. Casing depths vary from 116 feet in the SC region to 224 feet in the NW region. The small number of cased wells and the relatively great casing and well depths for the SW and NW regions are a result of the

Table 4. Water quality related to well depth and casing depth (for sites reporting casing depth).

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with > 10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
	Relative state-wide proportions in each category:					
Well depth:	Proportion of wells, by well-depth, for sites with reported casing depth;					
all depths	100.0%	30.6% --	9.9% -	6.2%	8.7% --	2.8
< 50 ft.	9.8%	30.4% --	13.0%	4.3% -	17.4%	4.6
50-99 ft.	18.1%	39.5% -	14.0%	14.0% +	23.3% +	6.6
> = 100 ft.	71.6%	28.6% --	8.6% -	4.6% -	4.0% --	1.4
Casing depth:	Proportions by reported casing depth;					
< 50 ft.	15.7%	28.9% --	15.8%	5.3%	21.1%	6.7
50-99 ft.	21.9%	30.2% --	13.2%	13.2% +	17.0%	4.4
> = 100 ft.	62.4%	31.1% --	7.3% -	4.0% -	2.6% --	1.1

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals; ++ and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

geologic setting in these areas. Most residents in these areas utilize shallow, large-diameter wells, because bedrock aquifers are usually absent or very deeply buried. Where buried sand and gravel units or the Dakota aquifer are present at reasonable depths, drilled wells are used. These wells are generally cased from the surface to the aquifer because they penetrate a thick sequence of relatively fine-textured glacial deposits; these deposits would cause wells to collapse or squeeze shut if uncased. Well depths only slightly exceed casing depths in these wells. In contrast, well depths exceed casing depths by over 100 feet in NE Iowa. Here, competent carbonate or sandstone bedrock is present at relatively shallow depths, and deep casings are not as necessary to insure well bores remain open. Some older wells in particular are cased only a short distance into more coherent rock; the well bore is left open to depth, with the rock forming the well shaft.

Table 4 relates water quality to the depth and casing depth of cased wells. Several overall trends are apparent in the data. First, cased wells tend to exhibit less contamination relative to state-wide averages, particularly with respect to nitrate and coliform bacteria. Second, contamination decreases significantly with increasing well and casing depth. Cased wells in excess of 100 to 150 feet deep, and with over 100 feet of casing, are proportionately less affected by nitrate, atrazine, or other pesticides, relative to wells state wide. Shallower wells with less casing show proportions of these contaminants that are similar to state wide data. Cased wells in general have less coliform contamination than wells state-wide, but the proportion of wells with detectable coliforms is not strongly related to well or casing depth.

Table 5. Well age observations (state-wide by decade) and water-quality data.

Well age	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative state-wide proportions in each category:				
1982 to present	10.5%	18.4% --	8.2%	6.1%	8.2% --	3.0
1980 to present	16.7%	24.4% --	12.8%	7.7%	9.0% --	3.1
1970-1979	23.8%	32.7% --	12.7%	6.4%	13.6% -	3.7
1960-1969	16.6%	40.3%	14.3%	7.8%	10.4% --	5.0
1950-1959	15.3%	36.6% -	11.3%	9.9%	14.1% -	4.7
1940-1949	6.5%	46.7%	16.7%	10.0%	10.0% --	3.3
1930-1939	7.5%	71.4% ++	17.1%	8.6%	25.7% +	10.6
pre-1930	13.6%	63.5% ++	11.1%	4.8% -	30.2% ++	8.7

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

Well Age

As well and water systems become older, components of the system may deteriorate. Defects, such as cracked casings, may allow water at the land surface or shallow groundwater to enter the wells and introduce contaminants. This may measurably affect the quality of the water older wells produce, particularly if the volume of shallow water entering the well is significant, relative to the volume of water pumped from the well. Relationships summarizing the age of well installation by decade are analyzed below. Summary data are also presented for wells installed before and after 1982. In 1982, new well-construction standards were established in Iowa; presumably better well construction should result in improved water quality (see Iowa Administrative Code, Environmental Protection [567]. Chapter 49, *Nonpublic Water Wells*).

There is an apparent relationship between well age and water quality, if the age of construction is assessed in isolation. State-wide, wells constructed before 1940 have the highest rates of coliform detection and nitrate >10 mg/L (Table 5), but show slightly lower atrazine detections than average. There are, however, inter-relations with other well factors. Table 6 summarizes the well age data by hydrogeologic region and mean well depth. There is no appreciable difference in the mean well age among regions, though the SC, SW, and NW regions have a greater proportion of pre-1940 wells than other areas. In these areas about 28% of all wells were installed before 1940. The mean well depth is also lowest for the 1930-1939 and pre-1930 classes. Hence, there is an interaction with well depth and, as can be inferred from the regional distribution, well construction type. For the pre- and post-1982 wells, the 1982-to-present wells actually are more shallow than average in four of the six regions, particularly in the areas where

Table 6. Well age (year of construction) and mean well depth, by hydrogeologic region.

Construction year	State-wide	NE (1)	E (2)	SC (3)	SW (4)	NW (5)	NC (6	State-wide mean well depth, ft
		---------------- Hydrogeologic region					----------------	
1982 to present	10.5%	11.2%	12.9%	7.9%	7.9%	2.7%	12.8%	157
pre-1982	89.5%	88.8%	87.1%	92.1%	92.1%	97.3%	87.2%	147
1980 to present	16.7%	16.7%	20.0%	19.3%	11.9%	10.8%	15.5%	156
1970-1979	23.8%	18.3%	22.6%	22.6%	29.6%	21.6%	24.7%	174
1960-1969	16.6%	22.1%	16.7%	11.8%	13.6%	27.0%	14.2%	179
1950-1959	15.3%	19.5%	14.8%	13.1%	11.3%	10.9%	19.4%	152
1940-1949	6.5%	4.3%	6.5%	6.7%	5.8%	2.7%	10.5%	121
1930-1939	7.5%	9.3%	6.4%	7.9%	12.4%	16.2%	4.0%	87
pre-1930	13.6%	9.8%	13.0%	18.6%	15.4%	10.8%	11.7%	101
Mean construction year	1958	1959	1959	1956	1955	1957	1958	
Mean well depth, feet								
1982 to present	157	139	167	36	68	31	226	
pre-1982	147	242	165	84	98	121	149	

Table 7. Well age and well-construction type.

Well Age (Year constructed)	State-wide	Sand-point	Drilled	Large-diameter Bored/dug
		% of wells, by well type, in age class:		
1982 to present	10.5%	31.6%	12.5%	3.1%
1980 to present	16.7%	42.1%	19.2%	7.0%
1970-1979	23.8%	10.5%	26.0%	19.4%
1960-1969	16.6%	5.3%	18.9%	13.2%
1950-1959	15.3%	21.1%	15.4%	14.7%
1940-1949	6.5%	15.8%	5.4%	7.0%
1930-1939	7.5%	5.3%	4.8%	14.7%
pre-1930	13.6%	0.0%	10.3%	24.0%
	Mean well depth, feet	% of well types in well-age class:		
1982 to present	157	13.0%	80.0%	6.9%
1980 to present	156	10.2%	79.3%	10.4%
1970-1979	174	1.9%	74.9%	23.2%
1960-1969	179	1.3%	75.8%	23.0%
1950-1959	152	5.7%	66.8%	27.6%
1940-1949	121	7.5%	63.2%	29.3%
1930-1939	87	3.2%	41.2%	55.6%
pre-1930	101	0.0%	51.3%	48.7%

Table 8. Well age, well-construction type, and water-quality data.

Well age/Well type	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative state-wide proportions in each category:				
1982 to present						
Driven sand-point wells	13.0%	0.0% --	0.0% --	0.0% --	0.0% -	3.3
Small-diameter drilled wells	80.0%	12.8% --	7.7% -	5.1%	7.7% -	2.7
Large-diameter bored wells	6.9%	100.0% ++	25.0% ++	25.0% ++	25.0%	7.5
pre-1982						
Driven sand-point wells	3.2%	7.7% --	23.1% ++	23.1% ++	38.5%	11.3
Small-diameter drilled wells	66.2%	28.9% --	11.0%	5.9%	5.5% -	2.0
Large-diameter bored wells	30.6%	79.2% ++	18.4% +	9.6%	37.6%	12.1

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

large-diameter seepage wells are dominant.

Table 7 shows the relationships between well age and well construction type. About 50% of the pre-1940 wells are large diameter wells, compared to 34% state-wide (for all regions, all ages). Over time, these large-diameter seepage wells have been replaced in many areas by more modern drilled wells. About 39% of all the large-diameter wells predate 1940; about 46% were installed prior to 1950, compared to only about 20% of the drilled and sand-point wells.

There is no indication that wells installed after 1982 are producing better quality water than their older counterparts, though the sample size for the newer wells is so small that little analysis is possible (Table 8). When the interaction of age and well type is reviewed in detail (Table 9) there is no clear indication of a consistent trend of degrading water quality with increasing well age, especially in the case of large-diameter wells. For these seepage wells, 90% of the samples from systems with wells older than 1930 are positive for total coliform; 89% of samples from wells installed since 1980 are positive. While there is a greater proportion of the oldest seepage wells with >10mg/L NO_3-N, the trend is not consistent (the 1940s group exhibits lower proportions), and the proportion with pesticide detections is lower. Small-diameter drilled wells exhibit an inconsistent trend of increasing coliform detections with age (by decade), but no other apparent trends stand out (Table 9). Even with this trend, the samples from pre-1930 wells showed lower coliform positives than the 1930-1939 or 1940-1949 groups. This relationship also involves well depth; the average depth of wells in the pre-1940 groups is less than the younger wells.

While the effects of aging on wells and water delivery systems can allow contaminants into an otherwise sound well or water system, these effects, on an aggregate basis, are overshadowed by the simple factors of well-construction type and well depth. Older drilled wells show somewhat greater proportions of total coliform positives, as might be expected. There is no apparent association between age and chemical contaminants; well depth and well type (which are also inter-related) remain the domi-

Table 9. Well age, well-construction type, and water-quality data.

Well age/Well type	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative state-wide proportions in each category:				
1982 to present						
Driven sand-point wells	13.0%	0.0% --	0.0% --	0.0% --	0.0% --	3.3
Small-diameter drilled wells	80.0%	12.8% --	7.7% -	5.1%	7.7% --	2.7
Large-diameter bored/dug wells	6.9%	100.0% ++	25.0% ++	25.0% ++	25.0% +	7.5
1980 to present						
Driven sand-point wells	9.2%	0.0% --	28.6% ++	28.6% ++	28.6% ++	7.3
Small-diameter drilled wells	78.9%	16.7% --	11.7%	5.0% -	6.7% --	2.3
Large-diameter bored/dug wells	11.8%	88.9% ++	11.1%	11.1% +	11.1% -	4.0
1970-1979						
Driven sand-point wells	1.9%	0.0% --	0.0% --	0.0% --	50.0% ++	9.2
Small-diameter drilled wells	75.0%	23.5% --	12.3%	7.4%	6.2% --	1.4
Large-diameter bored/dug wells	23.0%	64.0% ++	16.0%	4.0% -	36.0% ++	10.1
1960-1969						
Driven sand-point wells	1.3%		Sample too small to calculate			5.5
Small-diameter drilled wells	76.6%	27.1% --	13.6%	8.5%	3.4% --	1.6
Large-diameter bored/dug wells	22.1%	88.2% ++	17.6% +	5.9%	35.3% ++	10.6
1950-1959						
Driven sand-point wells	4.3%	0.0% --	33.3% ++	33.3% ++	33.3% ++	5.3
Small-diameter drilled wells	68.6%	22.9% --	4.2% --	2.1% -	4.2% --	2.3
Large-diameter bored/dug wells	27.1%	78.9% ++	26.3% ++	26.3% ++	36.8% ++	10.3
1940-1949						
Driven sand-point wells	7.4%	0.0% --	0.0% --	0.0% --	0.0% --	8.9
Small-diameter drilled wells	63.0%	41.2%	5.9% --	5.9%	5.9% --	2.2
Large-diameter bored/dug wells	29.6%	75.0% ++	37.5% ++	12.5% +	12.5% -	3.8
1930-1939						
Driven sand-point wells	2.9%		Sample too small to calculate			9.1
Small-diameter drilled wells	42.9%	60.0% ++	13.3%	0.0% --	6.7% --	2.2
Large-diameter bored/dug wells	54.3%	78.9% ++	21.1% +	15.8% ++	42.1% ++	16.5
Pre-1930						
Driven sand-point wells	0.0%		No occurrences			
Small-diameter drilled wells	50.8%	37.5% -	9.4% -	6.3%	9.4% --	4.2
Large-diameter bored/dug wells	49.2%	90.3% ++	12.9%	3.2% -	51.6% ++	13.1

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
++ and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

Table 10. Responses to Question 7h ("Is the well grouted?"), and water-quality data.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
	Relative state-wide proportions in each category:					
Is well grouted?						
YES;	11.5%	26.3% --	6.6% -	5.3%	3.9% --	2.8
NO;	61.0%	54.4% ++	16.7%	10.3%	24.8% +	7.7
DON'T KNOW	27.5%	31.7% --	10.4%	4.9% -	10.9% -	4.5

\+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
\+ + and -- indicate proportions >5% above or below the state-wide 95% confidence intervals.

nant factor associated with nitrate and pesticide occurrence in well water supplies. In summary, trends with age, either by decade or by year, were not statistically significant in aggregate or within a well-construction category.

Grouting

Wells that are "grouted" have cement (and/or bentonite) placed in the annular space between the well casing and the drilled bore hole. Grouting has become a commonly-used method of sealing small-diameter drilled wells. Grouting also serves to support the casing, prevent soil or rock from caving into the well, and to prevent water at the surface and shallow groundwater from entering the well. Some drilled wells, particularly older wells, were sometimes grouted with local soil materials. Large diameter bored wells and sand points are, by nature of their design, rarely grouted. Therefore, wells described as grouted for SWRL are relatively new drilled and cased wells. Newer bored wells are sometimes constructed using techniques that seal the wellhead and uppermost well bore in a manner analogous to grouting.

Table 10 presents water quality data categorized by the presence or absence of grout, based on owners comments and field inspection. Grouted wells produced groundwater with significantly lower coliform detections and nitrate concentrations, and somewhat lower pesticide and atrazine detections. Ungrouted wells showed higher than state-wide proportions for these contaminants. Ungrouted wells include virtually all bored and sand-point wells; these are open to the water table and therefore produce the most recently recharged, and most likely contaminated, groundwater. Undoubtedly more wells in the "no" category belong in the "don't know" category, because of the uncertainties in verifying the presence or absence of cement grout in many intact operating wells. The trend does verify an expected pattern of lower total coliform in grouted wells, which are typically deeper.

Other Well-Head Features

Simple first-stage analysis showed some association between water quality and other well-head features, such as pump type (e.g., Table 80, Kross et al., 1990). But many water-system and well-head construction features are directly related to the type of well. For example, sand points are generally too small in diameter to accommodate commonly-available submersible pumps, and above-ground pumps

Table 11. Well head features, well type and water-quality parameters.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with > 10mg/L nitrate-N %	Mean nitrate-N conc. mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative state-wide proportions in each category:				
Well-head features and well type:						
Large diameter bored/dug wells:						
Pitless adapter present - YES;	25.2%	78.2% ++	27.3% +	14.5% +	32.7% ++	12.3
Pitless adapter present - NO;	74.8%	55.0% ++	16.8%	10.8%	41.3% ++	13.7
Well head sealed - YES;	36.7%	82.1% ++	15.4%	9.0%	34.6% ++	13.0
Well head sealed - NO;	63.3%	81.3% ++	22.3% +	13.7% +	41.0% ++	13.1
Sealed frost pit - YES;	22.4%	87.8% ++	14.3%	14.3% +	44.9% ++	14.2
Sealed frost pit - NO;	77.6%	80.1% ++	21.1% +	11.1% +	37.4% ++	13.1
Unsealed frost pit - YES;	14.9%	81.3% ++	21.9% +	18.8% ++	43.8% ++	15.2
Unsealed frost pit - NO;	85.1%	81.9% ++	19.1% +	10.6%	38.3% ++	12.8
Small diameter drilled wells:						
Well head sealed - YES;	90.4%	24.7% --	9.2% -	5.2% -	6.4% --	2.4
Well head sealed - NO;	9.6%	41.0%	12.8%	5.1% -	7.7% --	2.3
Pitless adapter present - YES;	58.0%	22.2% --	8.8% -	5.0% -	7.2% --	2.5
Pitless adapter present - NO;	42.0%	31.8% --	11.6%	6.4%	5.9% --	2.4
Sealed frost pit - YES;	26.9%	33.9% --	8.9% -	3.6% -	4.5% --	2.7
Sealed frost pit - NO;	73.1%	23.1% --	10.4%	6.4%	7.4% --	2.4
Unsealed frost pit - YES;	10.4%	26.7% --	20.0% +	13.3% +	6.7% --	2.3
Unsealed frost pit - NO;	89.6%	26.0% --	8.8% -	4.7% -	6.6% --	2.4

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals; ++ and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

are almost always used with these wells. Over 85% of drilled wells and more than one-half of all bored wells are equipped with some type of submersible pump. A number of wells, from 5% to 16% by the different well types, have a pump jack present. These were commonly used in the past, in conjunction with wind-mills, to lift water to the surface. Virtually all the windmills have since been replaced by electric motors. Associations among such features and water quality parameters are generally explained by their inter-relationship with the well type.

Table 11 describes well-head features that may more directly affect water quality. The results require an explanation of some of the inventory protocols. Multiple questions were used on the inventory forms during the on-site inventory performed by DNR and PM&EH field staff to cover the range of conditions likely to be encountered. These questions also provide some cross-checks on the consistency of trends. Some inventory questions could have been answered in multiple fashion. *Yes* answers to, "was there a sealed frost pit," should show results similar to *no* answers to "was there an unsealed frost pit." Both questions were not always answered during all inventories because of the redundancies. Some terms have varied usage, as well. "Pitless adapter" style construction is commonly used to refer to a drilled well, that has a sealed well-head and a submersible pump, no frost pit at the well head, and that uses no storage or pressure tank (i.e., the pump automatically provides water pressure). Where used for large-diameter bored wells it may refer to "buried-slab" construction or other styles of improved, sealed construction. Also, a large-diameter well may not have what is commonly thought of as a frost pit, typically used with a drilled well to protect a pump and the pump rod at the well head from freezing. But it may have a pit, larger than the well-bore itself, that provides access into the well.

The multiple questions, as noted, provide some cross checks on trends. The most consistent usage by field crews were for the general observations of a sealed, protected well head. About 70% of sand points, 90% of drilled wells, and 37% of bored wells have sealed well heads. Bored wells commonly have a removable cover made of concrete or wood. These may effectively isolate the well head, but as the covers are removable these wells were not described by field crews as sealed. About one-third of the drilled and bored wells, and about one-half of the sand-points, were located in frost pits. From 6% to 14% of the wells, dependent upon type, were located in unsealed frost pits. Five per cent of drilled wells and 8% of bored wells had openings in their casing within a frost pit.

For most categories there is a somewhat greater proportion of wells with contaminants for unsealed well heads, as might be expected (Table 11). Large-diameter seepage wells still show greater proportions of contaminants in nearly all categories, including where the well head was sealed or where pitless adapter type construction was used. For drilled wells the differences between sealed and unsealed conditions were more pronounced, but in sum this accounts for only a small portion of contaminated wells (1% or less).

Water Distribution and Storage System

Table 12 gives the proportions of responses given by residents when they were asked where the water from their well is initially pumped to, within the water storage and distribution system, and relates the responses to the water quality data. Over 90% of the responses indicated a pressure tank was used. Half of the sites had pressure tanks located within the house and at 16% the tank was housed in another building. Twenty-six per cent utilized a pressure tank located within the well pit itself.

There was no general relationship between this aspect of the water-supply system and the range of water quality characteristics. However, sites where water was stored outside of the house, either in a storage structure or a pressure tank, consistently showed greater than average occurrence of total coliform positives (Table 12). Even sites with pressure tanks located in a building other than the house had a slightly higher proportion of coliform detections, relative to the state-wide data. Where the water storage/pressure tank was inside the house there was a lower proportion of coliform positives.

Cisterns were utilized at 4.2% of sites state-wide, and as might be expected, a high proportion (75%) of these had coliform detections. Detections of atrazine and nitrate-N >10mg/L were significantly lower at these sites relative to state-wide proportions, however. This is illustrative of the problems encountered when using *total* coliforms as indicators of other water-quality problems, particularly the improper inference that they indicate a well-construction problem. Total coliform positives often arise from points within the water system, and are simply related to water storage conditions.

Sample Collection Location

Table 13 relates water-quality observations to the on-site location where the water samples were collected. Sample-collection locations show little general relationship to water quality, and appear significant only where a small percentage of sites were involved. Samples were collected after cis-

Table 12. Responses to "Where does the drinking water go from the pump?", and water-quality data.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative proportions in each category:				
From the well pump the water goes to:						
Below ground cistern-YES	4.2%	75.0% ++	14.3%	3.6% -	7.1% --	5.2
Concrete storage tank-YES	0.9%	66.7% ++	16.7%	16.7% ++	16.7%	3.5
Pressure tank in house-YES	49.3%	37.9% -	12.4%	7.6%	19.4%	6.4
Pressure tank in pit-YES	25.9%	45.7%	14.5%	8.7%	15.6%	6.1
Other storage-YES	20.5%	53.6% ++	15.2%	9.4%	21.0%	7.2
Other storage-Pressure tank outside house		52.8% +	13.9%	9.3%	21.3%	7.7

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

terns at 2.3% of the sites, and over 80% of these contained coliform bacteria. However, *none* of these samples contained fecal coliforms. As noted above, this is indicative of the problems involved with using total coliforms as anything but a very general indicator. Other studies have shown that sampling after a cistern typically results in 80-90% total coliform positives even when samples from the well head itself are negative (Hallberg et al., 1983; Kross et al., 1990).

Kitchen taps were sampled at 5% of the sites, and these samples curiously showed high rates of nitrate exceedences and atrazine pesticide detections. These relationships are fortuitous and likely inter-related with well-depth factors.

Table 13 also relates water quality data to observable water-quality characteristics as documented by field crews. Observable water-quality characteristics included turbidity (3.3% of sites), color (7.4% of sites), and smell (4.7% of sites). Wells producing groundwater with these characteristics showed proportionately less contamination than the averages for wells state-wide, particularly with respect to nitrate. Only 3.1% of the samples with a noticeable smell contained detectable nitrates, and none of these exceeded 10 mg/L. Proportions for samples with color or turbidity were also more than 5% below the confidence limits for all wells. Smells in well water are almost always the result of hydrogen sulfide gas and colors result from the presence of reduced iron and/or manganese. These compounds are present in anaerobic groundwaters, and indicate that the requisite conditions for denitrification likely exist. Denitrification is a biogeochemical process that converts nitrate to gaseous nitrogen compounds; the lower concentrations of nitrate in well-water samples with noticeable smells or color may result from this nitrate loss. Additionally, these conditions are most prevalent in deep wells drawing from older groundwaters — those that recharged prior to the enhanced delivery of nitrate to shallow groundwater in historic times.

Table 13. Water sample collection points, observed water-quality problems and relation to water-quality results.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%
		Relative proportions in each category:			
Water samples collected:					
After the cistern-YES;	2.3%	81.3% ++	6.3% -	6.3%	12.5%
After water treatment-YES;	1.0%	28.6% --	57.1% ++	28.6% ++	14.3% -
At the wellhead-YES;	11.7%	45.0%	13.8%	7.5%	17.5%
At hydrant near well-YES	48.4%	41.6%	14.8%	9.3%	17.8%
At outside tap-YES	32.4%	45.0%	10.8%	5.9%	18.0%
At kitchen tap-YES	5.0%	52.9% +	23.5% ++	17.6% ++	35.3% ++
At other house tap-YES	1.5%	50.0% +	20.0% +	10.0%	10.0% --
At other location-YES	5.7%	57.9% ++	10.5%	2.6% -	15.8%
Obvious water quality problems:					
Turbidity-YES	3.3%	43.5%	8.7% -	8.7%	4.3% --
Turbidity-NO	96.7%	44.7%	13.7%	7.9%	18.7%
Color-YES	7.4%	49.0%	15.7%	11.8% +	7.8% --
Color-NO	92.6%	44.3%	13.5%	7.7%	19.1%
Smell-YES	4.7%	12.5% --	9.4% -	0.0% --	0.0% --
Smell-NO	95.3%	46.2%	13.9%	8.4%	19.1%
Other-YES	8.5%	50.0% +	10.3%	6.9%	6.9% --
Other-NO	91.5%	44.1%	14.0%	8.1%	19.3%

Responses to Field Measurement Form Question 9, "Where were the water samples collected?", and 11, "Are there any obvious water-quality problems?"

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals; + + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

These waters likely contained little nitrate initially, and a relatively minor loss of nitrate via denitrification would readily produce the low concentrations noted. Well waters having a noticeable smell also had proportionally lower detections of coliform bacteria, fecal coliforms, and pesticides, relative to the state-wide proportions. This is consistent with their deeper well, older groundwater origin.

The relatively low proportion of nitrate detections or exceedences in well waters described as having observable turbidity is also of note. Turbidity is general considered to arise from very small particles suspended in the water, giving the water a cloudy appearance. This is suggestive of well water that has been affected by surface runoff or leakage that is carrying sediment. However, the water quality data do not provide evidence of this. Descriptions of turbid samples may have resulted from some aspect of iron and/or manganese coloration.

The time of sampling after the well began pumping was also evaluated for its association with water-quality parameters. Before sampling, wells were pumped (or water at the hydrant/faucet was allowed to run) from a few minutes to over an hour. Whenever possible, the wells were pumped until on-site water-quality measures (temperature, conductivity, and pH) stabilized, indicating a flow of fresh water. The average time of pumping was about 20 minutes. At some sites this wasn't possible, because of the location or owner objections. There was no relationship between pumping/sampling time and chemical parameters. However, samples that had to be collected in 5 minutes or less showed a significantly greater proportion of total coliform positives. The proportion of coliform positives dropped considerably for times greater than 5 minutes. This relationship reinforces the standard protocols for letting a well/hydrant run for 10 minutes or more (if on-site measures aren't available) to obtain fresh water. As noted there was no apparent affect on any parameter other than total coliforms. This, again, indicates the complexity of interpreting total coliform occurrence. The elevated presence of total coliforms in this case is likely related to the occurrence of relatively stagnant water in the water system, or to the occurrence of bacterial films in the water system, as is known to complicate bacteria analysis is public water supply systems (see Kross et al., 1990, for discussion).

PAST WATER-QUALITY PROBLEMS

Residents were asked whether they had experienced any water-quality problems with their well in the past. Their responses and related water-quality data are given in Table 14. In general, wells that had produced water with noticeable tastes (11.4%) or that caused iron-stains (30.3%) had better quality water than the state-wide averages, particularly with respect to nitrate. These generally are deeper wells. Taste problems are generally related to iron or hydrogen sulfide. As previously discussed, these constituents indicate anaerobic groundwaters, where relative age and/or denitrification result in lower nitrate concentrations. The proportion of wells without a history of iron stains but which exceeded 10 mg/L NO_3-N during SWRL was greater than the state-wide proportion.

Wells at 7.1% of the sites were reported to have experienced problems with coliform bacteria in the past; 62.5% of these contained coliforms during SWRL. These wells also had nitrate-N >10 mg/L and atrazine detections in proportions greater than the state-wide proportions. Past high nitrate concentrations were reported to have occurred at 5.9% of the wells, and 45% of these yielded water with over 10 mg/L NO_3-N during SWRL. These wells also had a high proportion of coliform detections. These two groups of wells — those with past coliform problems and those with past nitrate problems — overlap to a significant degree.

WELL LOCATION AND SITE FACTORS

Rural residences may have a number of possible point sources of contamination present at varying distances from the water-supply well. Such sources

Table14. Responses to "Have you had any past water quality problems?", and water-quality data.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative state-wide proportions in each category:				
Reported past water quality problems:						
Turbidity-YES	8.7%	50.8% +	13.6%	8.5%	11.9%	4.6
Turbidity-NO	91.3%	44.1%	13.8%	8.1%	19.0%	6.4
Taste-YES	11.4%	36.4% -	9.1% -	5.2%	6.5% --	2.5
Taste-NO	88.6%	45.7%	14.4%	8.5%	19.9%	6.7
Iron stains-YES	30.3%	30.4% --	8.8% -	5.9%	3.4% --	1.5
Iron stains-NO	69.7%	50.9% +	16.0%	9.1%	24.9% +	8.2
Coliform bacteria-YES	7.1%	62.5% ++	14.6%	12.5% +	25.0% +	7.2
Coliform bacteria-NO	83.8%	43.2%	13.3%	7.6%	17.5%	5.9
Coliform bacteria-DON'T KNOW	9.0%	44.3%	18.0% +	9.8%	21.3%	9.1
Elevated nitrates-YES	5.9%	62.5% ++	12.5%	10.0%	45.0% ++	14.2
Elevated nitrates-NO	85.2%	43.4%	13.2%	7.7%	16.6%	5.4
Elevated nitrates-DON'T KNOW	8.9%	45.0%	20.0% +	11.7% +	18.3%	8.2
Detectable pesticides-YES	0.3%	100.0% ++	50.0% ++	0.0% --	50.0% ++	4.3
Detectable pesticides-NO	89.2%	44.3%	12.8%	7.7%	17.6%	5.8
Detectable pesticides-DON'T KNOW	10.5%	46.5%	21.1% +	12.7% +	23.9% +	10.4
Other problem-YES	17.0%	42.1%	12.3%	7.9%	19.3%	6.0
Other problem-NO	74.6%	44.9%	13.1%	7.6%	17.1%	5.8
Other problem-DON'T KNOW	8.4%	47.4%	22.8% ++	14.0% +	28.1% ++	12.1

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
++ and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

have the potential to negatively impact water quality. The affects of such point sources were discussed by Kross et al. (1990). This section will further evaluate the role of point sources and the placement of wells with respect to such sources.

Multiple Wells

Table 15 relates water quality to the number of operable wells at SWRL sites. About 25% of the sites sampled for SWRL had more than one operable well; 80% of these had two wells, and 14% had three wells. Sites with more than one well showed significantly higher nitrate concentrations and coliform detections than sites with only one well; detections of atrazine and other pesticides were comparable. Differences in well construction and depth explain some of the water-quality differences between these populations of sites. Table 16 describes the construction of the sampled wells, broken into categories of one, or more than one, operable well. Over 60% of the sites that had more than one well used large diameter bored wells (or sand points) as their primary water supply. These

Table 15. Number of operable wells on site, depth of sampled well used as primary water supply and water-quality data.

Well depth	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
	Relative state-wide proportions in each category:					
One operable well:	74.7%	41.2%	13.5%	7.7%	13.7% -	4.8
less than 50 ft.	22.8%	68.3% ++	17.8% +	8.9%	24.8% +	8.3
50-99 ft.	19.3%	55.3% ++	20.0% +	15.3% ++	27.1% ++	7.9
100 ft. or greater	57.8%	25.3% --	8.8% -	4.0% -	3.6% --	1.4
(Mean well depth = 149 ft.)						
More than one operable well:	25.3%	55.0% ++	14.6%	9.4%	32.2% ++	10.2
less than 50 ft.	42.6%	69.8% ++	22.2% ++	11.1% +	46.0% ++	14.9
50-99 ft.	25.1%	54.1% ++	8.1% -	5.4%	43.2% ++	16.2
100 ft. or greater	32.3%	41.7%	16.7%	14.6% +	6.3% --	1.7
(Mean well depth = 104 ft.)						

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

Table 16. Percentage of well construction types according to the number of operable wells at the site.

Well construction type	One operable well	> 1 operable well
	Percentage in each well type category:	
Driven sand-point	2.6%	7.8%
Small-diameter drilled	70.5%	38.1%
Large-diameter bored/dug	26.9%	54.1%
Other	0.4%	0.6%

relatively shallow wells are open to the water table and therefore are susceptible to contamination. Large-diameter wells are common in areas where no dependable aquifer is available at a reasonable depth. These wells yield water relatively slowly, and because they are shallow they are directly affected by low water tables during dry years. These factors explain why many sites that relied on such wells had more than one available for use. Large diameter or sand-point wells were used — and therefore sampled — at less than 30% of the sites with just one well. Drilled wells were used at 70% of the sites with only one well.

The tendency for greater contamination at sites with more than one well is not consistent for all contaminants, or across all well-depth ranges. The occurrence of a greater proportion of contaminants is largely explained by the greater number of shallow, large-diameter and sand-point wells used at sites with more than one well.

Other On-Site Features

Table 17 relates water-quality data to the distance from abandoned wells, chemical storage areas, and septic systems—potential point sources of contamination. Past review showed that sites with abandoned wells had slightly, but not significantly, lower proportions of most contaminants, relative to sites without abandoned wells (Kross et al., 1990). Sites with chemical storage areas showed higher proportions of pesticide, but not atrazine, detections. Sites without septic systems were characterized by a large proportion of nitrate contamination. As noted initial analysis showed no relationship among these factors: wells located <50 feet from septic tanks had lower than average proportions of coliform positives, no fecal positives, and nitrate-N >10 mg/L; wells located less than 15 feet from chemical storage showed no pesticide detections. These data were analyzed compared to wells located >50 feet and >15 feet from such sources. Here we analyze these data in more detail, in relation to a gradient of distances from the wells estimated during on-site inspection.

There are no consistent relationships between distance from these potential point sources and water quality (Table 17). As distances increase, the proportions of wells with the various contaminants alternatively increase, decrease, or remain unchanged in an inconsistent manner. There is not any significant contamination from these potential point sources apparent in the SWRL data as indicated by the absence of distance-related trends.

Higher than state-wide average coliform detections occurred in wells >200 feet from abandoned wells, chemical storage areas, or septic systems. This is a result of the high percentage (50% or more) of shallow, large-diameter wells in this distance category. Conversely, lower than average percentages of the various contaminants in some distance categories are also partly attributable to smaller (than state-wide) proportions of large-diameter wells. This pattern fits with other detailed work in west-central Iowa. In Audubon County, an area dominated by the use of large-diameter seepage wells, detailed work shows that these wells are far removed from possible point-source problems because they tend to be located along waterways or other areas with a high water table (to promote seepage). These areas are often quite distant from areas preferred for the siting of houses, cattle-yards, storage buildings and chemical mixing sites. Site studies show that on average these wells are located nearly one-quarter of a mile from such likely point-sources (Seigley et al., in press), and hence their dominance in the >200 ft category in this analysis.

The absence of any significant trend in the proportion of contaminated wells (for any of the contaminants) with distance between these potential contaminant sources (abandoned wells, etc.) and the well suggests that there is no direct, consistent relationship between these factors. In fact, when some of these factors are in the immediate vicinity of the well water-quality parameters are often much better than average. As noted, none of the sites where chemical storage was at the well head had any pesticides detected, regardless of well-type. The generally better water-quality from wells in proximity to these varied sources also is an artifact of other relationships, as well as the lack of any consistent source effect.

Table 17. Distance of abandoned wells, chemical storage areas, and septic systems from water supply well, and water quality water data (see also, Kross et al., 1990, Tables 76 and 77).

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
Occurrence and distance from water-supply well:		Relative proportions in each category:				
Abandoned well(s)						
YES;	36.1%	43.4%	12.7%	6.1%	17.6%	6.4
1 abandoned well;	76.8%	41.8%	11.5%	4.9% -	17.0%	6.1
2 or more abandoned wells;	23.2%	49.1%	16.4%	10.9%	21.8%	7.7
1-24 ft. from well	16.7%	25.6% --	2.6% --	2.6% -	17.9%	9.1
25-49 ft.	8.6%	30.0% --	20.0% +	10.0%	15.0%	4.5
50-74 ft.	7.3%	41.2%	11.8%	11.8% +	5.9% --	4.5
75-99 ft.	4.3%	10.0% --	0.0% --	0.0% --	0.0% --	1.1
100-149 ft.	9.4%	31.8% --	13.6%	4.5% -	18.2%	4.5
150-200 ft.	13.3%	35.5% --	12.9%	3.2% -	19.4%	8.8
>200 ft.	40.3%	63.8% ++	16.0%	7.4%	21.3%	6.8
Chemical storage area(s)						
YES;	14.0%	48.9%	19.1% +	10.6%	19.1%	8.1
1-24 ft. from well	4.6%	50.0% +	25.0% ++	0.0% --	0.0% --	0.0
25-49 ft.	4.6%	50.0% +	0.0% --	0.0% --	25.0% +	6.2
50-74 ft.	13.8%	58.3% ++	41.7% ++	8.3%	8.3% --	11.8
75-99 ft.	2.3%	50.0% +	0.0% --	0.0% --	50.0% ++	12.0
100-149 ft.	17.2%	33.3% --	26.7% ++	26.7% ++	20.0%	6.0
150-200 ft.	24.1%	47.6%	19.0% +	9.5%	23.8% +	10.2
>200 ft.	33.3%	58.6% ++	13.8%	10.3%	24.1% +	8.2
Septic systems						
YES;	96.6%	44.9%	13.5%	8.1%	17.7%	6.1
1-24 ft. from well	2.9%	41.4%	11.1%	5.6%	22.2%	7.2
25-49 ft.	7.5%	27.7% --	8.5% -	6.4%	19.1%	6.6
50-74 ft.	11.3%	32.4% --	9.9% -	8.5%	11.3% -	4.2
75-99 ft.	10.2%	35.9% --	15.6%	6.3%	7.8% --	3.8
100-149 ft.	21.9%	41.3%	12.3%	8.7%	17.4%	5.1
150-200 ft.	18.4%	41.4%	12.1%	6.0%	14.7%	5.1
>200 ft.	27.8%	64.0% ++	18.3% +	10.9%	24.0% +	8.7

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
++ and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

Table 18. Relationships among refuse disposal, dumpsites on the property, and water-quality. Responses to "Do you have refuse disposal dumpsites on your property?", and method of disposal of household and farm garbage/solid-waste.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative state-wide proportions in each category:				
Refuse dumpsite(s) on property	23.7%	40.9%	12.6%	8.2%	13.2% -	5.6
No refuse dumpsite(s) on property	76.3%	46.1%	14.1%	8.0%	19.9%	6.4
Dispose of garbage by:						
Sending to county landfill-YES		45.7%	13.1%	8.3%	19.6%	6.9
Sending to county landfill-NO		44.0%	14.3%	7.7%	16.7%	5.5
Storing it on own property-YES		41.4%	15.9%	9.0%	10.3% --	4.1
Storing it on own property-NO		46.0%	13.1%	7.8%	20.5%	6.9
Refuse pickup service-YES		37.6% -	16.5%	10.1%	14.7%	5.7
Refuse pickup service-NO		46.4%	13.2%	7.7%	18.9%	6.4
Burning it-YES		46.5%	13.7%	8.0%	18.4%	6.0
Burning it-NO		41.5%	13.5%	8.0%	18.0%	7.5
Other-YES		42.9%	14.3%	7.1%	22.9% +	7.2

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

On-Site Refuse Disposal

Table 18 relates water quality to the presence or absence of refuse disposal dumpsites on the property. For sites with dumpsites on the property (24%), the proportions of wells with total coliform, any pesticide, any atrazine, and nitrate-N >10 mg/L are all within or below the state-wide 95% CI's for each of the contaminants. Comparing sites with and without refuse disposal dumpsites, sites with dumpsites actually have the *smaller* proportion of wells with total coliform, any pesticide, and nitrate-N > 10 mg/L. Thus, the data do not suggest any correlation between presence of refuse disposal dumpsites on the property and diminished water quality.

Table 18 also relates water quality to method of disposal of household and farm refuse and garbage. For all methods of disposal, the proportions of wells with detections of coliform, pesticide, atrazine, and nitrate-N > 10 mg/L are all within or below the state-wide 95% CI for each contaminant. Sites using refuse pickup service (16%) show coliform detection slightly below the state-wide 95% CI. With this possible exception, there does not appear to be any relationship between water quality and method of disposing of household and farm refuse.

Other Landuse

In the first-stage analysis of landuse (Table 1), a substantial percentage of sites had "other" uses

Table 19. Water-quality data for sites in "Other" category for "landuse in immediate adjacent area" to well and for "Other" "landuse in 0.5 mile radius" (see Table 1, also).

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative proportions in each category:				
"Other" use in "immediately adjacent area."	8.7%	44.8%	15.5%	6.9%	15.5%	4.2
"Other use in 0.5 mile radius."	9.1%					
	% of "Other"					
River, creek, floodplain, wetland, lake	72.9%	53.5% ++	16.3%	2.3% -	23.3% +	7.3
Yard/farmyard	11.9%	28.6% --	0.0% --	0.0% --	14.3% -	6.3
Landfill, sewage lagoon, quarry, strip mine	8.5%	80.0% ++	40.0% ++	20.0% ++	40.0% ++	11.4
Commercial buildings	6.8%	0.0% --	0.0% --	0.0% --	0.0% --	2.5

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

present than those specified in the survey format. For most of the sites "other" was indicated in addition to the standard classes. Where "other" was indicated the SWRL field staff wrote in what the "other" uses were. In this further analysis the "other" category was examined in more detail, reviewing the written records from the field inventories. For the majority of sites the "other" uses simply noted a clarification of landuse that was present in a standard category (i.e., specifying the type of row crop, noting CRP or forested pasture for pasture or forest). These sites already were included in their standard categories and hence the assessment did not change any findings (as presented in Table 1). The remaining "other" uses were then analyzed in this stage of the study.

Table 19 gives water-quality data for the remaining sites (9%) that responded "other" in describing landuse in the immediate area around the well. About 85% of these specified farmyard/yard/house and yard. All water-quality data for these sites are within the typical state-wide averages.

Table 19 also groups remaining "other" responses (9%) for "land in the surrounding 0.5 mile radius" into four groups and gives water quality for these groups; 73% of the "other" responses specified river, creek, floodplain, wetland, or lake. For these wells, coliform detections and nitrate exceedences were higher than the state-wide averages, while atrazine detections were lower. These were dominantly sand-point and large-diameter shallow wells.

Sites that specified "yard" and "commercial buildings" (19% of "others") had significantly better water quality; all detections and exceedences were significantly below state averages. These are

Table 20. Farm operation, farm enterprises, and water-quality data.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
Farm Enterprises:		Relative state-wide proportions in each category:				
Corn-YES	92.4%	42.6%	15.3%	9.8%	20.2%	6.7
Corn-NO	7.6%	50.0% +	11.1%	8.3%	11.1% -	4.2
Soybeans-YES	79.2%	43.0%	15.7%	10.0%	20.5%	6.8
Soybeans-NO	20.8%	43.8%	12.5%	8.3%	15.6%	5.8
Alfalfa hay-YES	63.6%	43.7%	15.7%	9.6%	20.1%	7.3
Alfalfa hay-NO	36.4%	41.9%	14.0%	9.9%	18.6%	5.3
Dairy cattle-YES	11.1%	42.0%	10.0% -	8.0%	10.0% --	3.0
Dairy cattle-NO	88.9%	43.1%	15.7%	9.9%	20.7%	6.9
Beef cattle-YES	50.9%	47.9%	17.2% +	10.1%	23.5% +	8.1
Beef cattle-NO	49.1%	37.9% -	12.8%	9.3%	15.4%	5.0
Poultry-YES	9.4%	35.6% --	22.2% ++	11.1% +	17.8%	7.7
Poultry-NO	90.6%	43.8%	14.3%	9.5%	19.8%	6.4
Swine-YES	51.8%	41.7%	13.8%	9.2%	20.0%	6.1
Swine-NO	48.2%	44.4%	16.4%	10.2%	19.1%	7.1

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

mainly suburban sites having less adjacent land devoted to row-crop agriculture. Sites near landfills, sewage lagoons, quarries, and strip mines had coliform, pesticide, and atrazine detections and nitrate exceedences that were double the state-wide proportions. However, these relations are also confounded by well types, and <1% of all sites fall in this category. Hence, these relationships are tenuous, at best.

AGRICULTURAL MANAGEMENT FACTORS

As noted in the initial analysis, agricultural landuse in Iowa is so ubiquitous that there is no apparent relationship with water quality, except for the *inverse* relationship, showing *better* water quality in non-farm, suburban areas. To further test the relationships Table 20 shows the relation of major crops and livestock enterprises present on site to water-quality parameters; Table 21 shows nitrogen fertilizer rates applied to lands at each site for continuous corn and corn following soybeans; Table 22 shows the relation to farmers' (well owner) changes in fertilizer and insecticide use over recent years. There is no consistent or logical relationships among these factors and water quality. The more significant water-quality patterns are often inverse to what might be expected if these factors actually influenced water quality in the well on-site.

Table 23 shows the percentage of sites where pesticides were detected in relation to the pesticides reported used at the sites during the year of, and the year prior to, sampling. The compilation of active

Table 21. Nitrogen application rates to corn for most recent growing season, and water-quality data.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
Lbs-N/acre applied:		Relative state-wide proportions in each category:				
Continuous corn						
0-99	11.0%	36.8% -	0.0% --	0.0% --	15.8%	4.3
100-124	22.6%	47.4%	18.4% +	15.8% ++	34.2% ++	9.6
125-149	22.4%	38.5% -	17.9% +	12.8% +	17.9%	6.0
150-174	33.7%	34.5% --	19.0% +	13.8% +	13.8% -	5.8
> = 175	10.2%	33.3% --	11.1%	5.6%	22.2%	14.1
Corn after soybeans:						
0-99	15.1%	57.8% ++	24.4% ++	15.6% ++	28.9% ++	9.6
100-124	32.6%	46.5%	12.1%	9.1%	27.3% ++	8.8
125-149	20.8%	42.6%	11.5%	6.6%	13.1% -	5.0
150-174	27.4%	29.1% --	19.0% +	10.1%	15.2%	5.2
> = 175	4.0%	33.3% --	16.7%	16.7% ++	16.7%	3.2

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

ingredients reported was compiled from product and trade names reported by participants in the site inventories. The low proportions of detections, related to the number of sites where applied, relates to the relatively low proportion of wells with detections. Atrazine was used at about 66% of the sites where it (or its metabolites) was detected; which means that it was not reported as used at about one-third of all sites where it was detected. Alachlor (the active ingredient in Lasso and other products) use was not reported at any of the sites where detected, as was the case for picloram and propachlor. These relations may be related to the past use and carryover of residues at these sites, the transport through groundwater of residues from other areas of use or possibly, of course, from errors in reporting. As noted in previous discussion (Kross et al., 1990) detailed investigations of sites where HALs were exceeded also showed these relations. Sites with no history of recent use (non-farms, for example) had detections that could be related to the non-point source, general use of these herbicides on surrounding land. In some settings pesticide occurrence in rainfall may contribute to shallow groundwater contamination, as well (Nations and Hallberg, 1992).

Chemical Handling Factors

Considerable information was obtained at each SWRL site dealing with pesticide use, handling

Table 22. Fertilizer and pesticide use since 1980, and water-quality data.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
	Relative state-wide proportions in each category:					
Nitrogen fertilizer:						
Reduced	23.5%	41.9%	15.2%	10.5%	19.0%	6.6
No change	68.9%	46.0%	14.9%	9.4%	20.1%	6.6
Increased	7.6%	32.4% --	11.8%	8.8%	20.6%	7.2
P & K fertilizers:						
Reduced	21.5%	42.7%	15.6%	11.5% +	21.9%	8.1
No change	68.8%	45.6%	15.2%	9.7%	18.8%	6.3
Increased	9.7%	34.9% --	9.3% -	4.7% -	23.3% +	6.2
Herbicide use:						
Reduced	16.3%	44.6%	14.9%	8.1%	17.6%	8.0
No change	76.8%	44.0%	14.6%	9.9%	19.5%	5.9
Increased	6.9%	41.9%	16.1%	9.7%	29.0% ++	10.3
Insecticide use:						
Reduced	16.6%	43.4%	13.2%	7.9%	22.4% +	8.7
No change	81.6%	44.0%	14.8%	9.9%	19.2%	6.3
Increased	1.8%	50.0% +	25.0% ++	12.5% +	25.0% +	4.4

\+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
\+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

practices, and specific locations of chemical-related activities. These were used to assess possible relationships to water quality at the site. Table 24 reviews pertinent results from the first-stage analysis (reported in Kross et al., 1990) as well as further detailed results. The first-stage analysis pointed out that point-source problems clearly contribute to the occurrence of pesticides in water-supply wells, but that they only account for a minor portion of the problems. As supported by other detailed research, the findings also clearly point to the non-point source for many pesticide detections. About 5.4% of farms reported spills, back-siphoning, or other accidents with pesticides and/or fertilizers near their wells, and, as would be expected, these sites show a greater proportion of pesticide detections. However, of the well samples that had pesticides detected from these sites, only 36% contained the pesticide involved in the mishandling incident. Sites where residents reported they mixed all the herbicides applied on-site and those where all the herbicides where custom applied showed the same proportion of pesticide detections. Sites where herbicides were mixed at a hydrant within 15 feet of the well did show greater-than-average pesticide detections than sites where mixing was done at a hydrant further away. However, sites where mixing and handling was *not* done near the well, where all herbicides were reported as mixed in the field where they were to be applied, also showed a greater than

Table 23. Percentage of sites where pesticides were detected in relation to the active ingredients applied at the sites.

Active ingredient	% of sites where ingredient was applied and detected	% of sites where ingredient was detected that it was applied
2,4-D	0.6%	50.0%
alachlor	0.0%	0.0%
atrazine (total)	12.7%	65.8%
cyanazine	2.1%	35.8%
metolachlor	3.0%	56.2%
metribuzin	2.2%	18.8%
pendamethalin	5.7%	20.1%
picloram	0.0%	0.0%
propachlor	0.0%	0.0%
trifluralin	0.9%	50.0%

average occurrence of pesticides. If local mishandling of pesticides were the *only* factor involved in well contamination, sites where all herbicides are custom applied or where all are mixed in the field would be expected to show significantly less incidence of herbicide contamination. In fact, such sites exhibit proportions equal to, or *greater* than state-wide averages.

About 64% of the reported spills took place within 15 feet of the well head. Some of the wells included in the spill sites are also in the category "where mixing was done within 15 feet of the well." To further refine the understanding of these occurrences, the sites where herbicides were mixed at a hydrant "near" the well (in italics, Table 24) were further subdivided using on-site inventory data on the distance between the hydrant used and the well head, and were again subdivided by well depth and well type.

Table 24 shows the relationship between water quality and the distance between the drinking-water well and the hydrant where pesticides were mixed. In this summary table only wells with a known depth are included to strengthen the analysis. Detections of coliform bacteria for wells that are 51 to 150 feet from the hydrant, and detections of nitrate-N >10 mg/L for wells that are less than 25 feet from the hydrant, are well below the state-wide 95% CI's for each. In both well groups, however, the proportions of shallow (<100 feet deep) wells and large-diameter wells are significantly smaller than the state-wide proportions. This is important because, state-wide, wells <100 feet deep account for about 70% of total coliform positives and 89% of wells with nitrate-N >10 mg/L. Likewise, large-diameter wells exhibit coliform and nitrate contamination rates that are nearly double the state averages.

Wells that are 26 to 50 feet from the mixing hydrant exhibit pesticide detections almost three times greater than the state average, and even greater proportions than the wells within 15 feet, even though the proportions of shallow wells and large-diameter wells in this group are less than the state-wide average. Further breakdown of data in this distance group shows greater than average rates of detection in all the well-subgroups analyzed. Only about one-third are large-diameter wells; of the drilled wells many are shallow or have shallow casing, so that nearly all the wells are effectively less than 150 feet deep, and, hence, are logically susceptible to impact from such mishandling. Sites with reported spills occur in both this group and the 0-15 feet distance group. Deleting these sites from the general analysis (Table 24) the 26-50 feet group still has a significantly greater proportion of detections.

Table 24. Pesticide mixing, spills, distance from well, and water quality data.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with >10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
From first-stage relational analysis (see Kross et al., 1990, Table 78):						
		Relative state-wide proportions in each category:				
Sites with reported pesticide or fertilizer spills or back siphoning accidents:	5%	32% --	29% ++	14% +	27% ++	
Mix all herbicides used on-site:	28%	45%	15%	9%	24% +	
Don't mix all, mix some on-site:	14%	36% --	18% +	13% +	14% -	
All herbicides custom applied:	16%	42%	14%	8%	18%	
Mix herbicides at hydrant within 15 feet of well:	3%	53% ++	23% ++	13% +	7% --	
Mix herbicides at hydrant "near" well, BUT > 15 feet away:	25%	37% -	16%	8%	15%	
Mix herbicides in field where applied:	22%	38% -	18% +	12% +	23% +	
For those sites that mix at a hydrant within 15 feet, or "near" the well:						
		Relative proportions in each category:				
Distance of hydrant from well, <u>for wells of known depth:</u>						
0-15 ft.	11.3%	43.8%	18.8% +	12.5% +	12.5% -	2.0
16-25	3.5%	40.0%	0.0% --	0.0% --	0.0% --	3.2
26-50	15.5%	40.9%	40.9% ++	13.6% +	4.5% --	2.5
51-100	21.8%	22.6% --	9.7% -	6.5%	12.9% -	2.8
101-150	12.7%	22.2% --	11.1%	5.6%	22.2%	6.4
> = 151 ft.	35.2%	44.0%	12.0%	8.0%	22.0%	7.4
With reported spills removed:						
0-15 ft.	10.6%	40.0%	13.3%	6.7%	13.3% -	2.1
26-50	14.1%	35.0%	35.0% ++	10.0% +	0.0% --	2.2

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

For the categories >50 feet from the well the occurrence of many parameters is below state averages. The increase in total coliform, nitrate, and pesticide occurrences in the sites >151 feet from the well is related to the increased proportion of large-diameter wells in this category. For the sites where mixing was "near" the well, 59% of the large-diameter wells are in the >151 ft from the well category; these wells constitute about 39% of the wells in the category. As noted previously, detailed studies on large-diameter seepage wells in Audubon County also support this observation. Results from a survey of over 200 wells in Audubon County, indicate that <3% of the wells were within 50 feet of the site used for mixing pesticides (Seigley et al., in press); further detailed studies around the Bluegrass watershed (Seigley and Hallberg, 1991) show the average distance from such wells to mixing and handling sites was nearly 0.25 miles. While such wells are highly susceptible to contamination, because they are typically open to the water table, their general placement in areas that enhance seepage-recharge has removed them from locations prone to accidents or the impact of poor chemical handling.

The elevated occurrences of pesticide detections at sites where pesticides are mixed within 50 feet of the well head stands up throughout the analysis of the many confounding variables that can come into play. This is a strong indication that such handling, over time, has likely impacted these wells adversely. However, this relationship explains only a small portion of the total occurrences of pesticides. Considering all the detections from the wells within 50 feet of mixing sites accounts for about 1.5% of pesticide detections state-wide; combined with known spills, this accounts for about 3-3.5% of detections state-wide (of the 13.6% measured). Such detailed analysis is requisite for understanding the magnitude of such impacts. While there is little question that point-source problems — spills, back-siphoning, repeated mishandling near a well — occur and contaminate wells, it is easy to overstate their occurrence from anecdotal knowledge. The estimates of the extent of such incidents derived from the detailed data collected in the SWRL study are essentially identical to the values derived from other detailed field investigations in Iowa, in the Big Spring basin, in Floyd and Mitchell counties, Audubon County, and elsewhere. Neither the proximity of handling and mixing to a well, nor the use of a susceptible well-type dictate that point sources are the cause of a pesticide detection, as illustrated by the analysis above. The potential for chemical handling to impact a well is affected by many factors, such as the gradient from the site to the well ("uphill" or "downhill"), the amount of fluid involved, as well as the depth and nature of construction of the well. A distance of 15 feet from a well may be of little consequence if the point-source is downhill/downgradient or if the well is cased to significant depth and doesn't allow inflow around the well head. This is clear from the small portion of wells exhibiting contamination where chemical mixing sites were within 25 feet of the well relative those with mixing sites 25 to 50 feet away. As discussed, the vast majority of large-diameter seepage wells, which are highly susceptible to localized impacts, are located so far from chemical handling and mixing sites that there is little potential for a direct impact.

Pesticide Formulation and Rinse Disposal

In the first-stage analysis water quality findings were related to the locations where "excess" pesticide formulations were disposed. No relationships were apparent from pesticide detections or other water-quality parameters. Even more detailed analysis of various "other" categories show that all data are within 95% CI's or below the state-wide averages. The location(s) used to rinse tanks, equipment, and/or pesticide containers and to dispose of the rinseate was also evaluated. In the first-stage analysis the only apparent association was slightly greater proportions of pesticide and atrazine detections at sites where rinsing occurred within 15 feet of the well. In addition, pesticides were mixed within 15 feet of the well at nearly all of these sites.

The majority of farmers noted (for both conditions) that they made another pass on the field, sprayed on the road, road ditch, fence rows, or other location distant from the well. For both categories a portion indicated that the excess formula or rinse water was sprayed or drained in the "farmyard" or around farm buildings. Contrary to what might be expected, these groups had the smallest proportions of pesticide and atrazine detections of the groupings analyzed, well below state averages. These data indicate no outstanding relationship between location of formulation or rinse disposal and water quality at the scale of SWRL.

Pesticide Container Disposal

Table 25 relates water quality to the method of disposing of pesticide containers. At the time of SWRL, the vast majority of containers were either burned (54%), sent to the county landfill (21%), or returned to the dealer (14%). The proportion of wells with pesticide or atrazine detections is within the state-wide 95% confidence interval for all meth-

Table 25. Method of disposal of empty pesticide containers in relation to water quality data.

Observations:	Proportion of sites in category %	Wells with total coliform detected %	Wells with any pesticide detection %	Wells with any atrazine detection %	Wells with > 10 mg/L nitrate-N %	Mean nitrate-N concentration mg/L
Total SWRL sample:	100.0%	44.6%	13.6%	8.0%	18.3%	6.2
Wells < 50 ft deep:	27.9%	71.5%	17.9%	9.6%	35.1%	11.2
		Relative proportions in each category:				
Method of pesticide container disposal:						
Send to county landfill-YES	20.8%	50.0% +	12.7%	6.4%	21.8%	8.1
Send to county landfill-NO	79.2%	41.6%	15.8%	10.2%	17.0%	5.7
Store on own property-YES	8.8%	45.8%	12.5%	6.3%	25.0% +	9.2
Store on own property-NO	91.2%	42.9%	15.4%	10.0%	17.2%	5.9
Return to dealer-YES	13.7%	35.6% --	15.1%	9.6%	9.6% --	2.9
Return to dealer-NO	86.3%	44.5%	14.9%	9.4%	19.3%	6.6
Place in garbage pickup-YES	3.1%	31.3% --	18.8% +	12.5% +	6.3% --	2.3
Place in garbage pickup-NO	96.9%	43.6%	14.8%	9.4%	18.4%	6.2
Burn them-YES	53.8%	41.8%	16.0%	10.8%	18.5%	6.0
Burn them-NO	46.2%	45.3%	13.6%	7.8%	17.3%	6.3
Other-YES	23.8%	46.8%	12.9%	7.3%	16.9%	5.6

+ and - indicate relative proportions that are between 1 and 5% above or below the state-wide 95% confidence intervals;
+ + and -- indicate proportions 5% above or below the 95% state-wide confidence intervals.

ods of disposal, with one exception. A slightly greater-than-average proportion of sites that placed containers in the garbage pickup had pesticide/ atrazine detections (2.5% above the 95% CI). This unlikely association is probably fortuitous in light of the small number of responses in this category (3.1% of the total). The data do not suggest any overall relationship between the method of disposal of pesticide containers and pesticide detections in the well waters.

SUMMARY AND CONCLUSIONS

This report summarizes further relational analysis between site characteristics and water quality for the SWRL data base. Table 26 summarizes pertinent water-quality data from the SWRL survey, for all sites and by well-depth categories. While several site/well system factors are shown to affect water quality, these factors are subordinate to, or co-related to, the overriding factor of well (and casing) depth and well-construction type. Shallow (<50 feet deep) wells, of any construction type, show the greatest proportions of all contaminants. Large-diameter seepage wells account for over half of the wells that are <50 feet deep. Thus, they have somewhat greater proportions of contamination, particularly for total coliform positives because they are typically open to the water table. Most drilled, cased wells are generally much deeper and, hence, exhibit lower contamination rates. Cased wells with less than 50 feet of casing are functionally shallow wells, regardless of depth, and have contamination rates similar to state-wide averages for chemical constituents. Coliform bacteria were present in about 30% of the samples from cased wells, regardless of casing depth. Drilled wells that are cement grouted tend to be deeper wells and show

Table 26. Summary of SWRL water-quality results.

Parameter	All sites	Wells < 50 ft Deep	Wells 50-99 ft Deep	Wells > =100 ft Deep
Wells:				
% wells of known depth:		28%	21%	51%
Nitrate-N:				
% wells >10 mg/L	18%	35%	32%	4%
% wells >3 mg/L	37%	67%	56%	15%
mean conc., mg/L	6.2	11.2	11.0	1.6
Total Coliform Bacteria:				
% sites positive for TCB	45%	72%	52%	27%
Fecal Coliform Bacteria:				
% sites positive for FCB	7%	8%	12%	2%
Pesticides:				
% sites with any pesticide detection	14%	18%	14%	9%
Atrazine (total)				
% sites with detections	8%	10%	12%	6%
mean conc., ug/L	1.1	1.7	1.0	0.7
Atrazine (parent only)				
% sites with detections	4%	5%	6%	3%
mean conc., ug/L	0.9	1.1	0.9	0.6

statistically better water quality than state-wide averages for coliforms, pesticides and nitrates. Older wells are often presumed to produce water with a greater degree of contamination than younger wells, because of aging effects to the well casing and other features. But this trend is inconsistent, not significant, and confounded because older wells tend to be more shallow and because a large percentage are large-diameter seepage wells. There is no indication that wells constructed after 1982 (year of establishment of new well-construction standards) are producing any better water quality than their older counterparts, though the sample size of newer wells is so small that little analysis is possible.

Sites with various categories of sealed wellheads show somewhat lower proportions of contaminants than state-wide averages, while unsealed wellheads are characterized by somewhat higher contamination rates. Large-diameter seepage wells still show greater proportions of contaminants in nearly all categories, including where the well head was sealed or where pitless adapter (buried-slab) type construction was used. For drilled wells the differences between sealed and unsealed conditions were more pronounced, but in sum account for only a small portion of contaminated wells (1% or less).

Facets of the water distribution and storage system, and locations of sample-collection points within the system, do not significantly affect water-quality results, with the exception of the high total coliform rates that are associated with cisterns and other outside water-storage structures (including concrete tanks). High proportions of coliform detections were also noted for wells that were sampled after less than 5 minutes of pumping. Over 80% of sites using cisterns were positive for total coliform but detections of atrazine and nitrate-N >10 mg/L were significantly lower than average at these sites. This is illustrative of the problems with using *total* coliforms as indicators of other water-quality problems, particularly the improper inference that they indicate a well-construction problem. Total coliform positives often arise from points within the water *system*, and are simply related to water storage conditions. Approximately 45% of all sites were positive for total coliform bacteria. Total coliforms are ubiquitous constituents of soils, surface water, and shallow groundwater and cannot be equated to fecal coliforms. Only 7% of water systems were positive for fecal coliform bacteria. The only sound, general interpretation of a persistent presence of total coliforms is that the water system is allowing interaction with soil, soil-water, shallow groundwater, or possibly surface water. This may indicate that the system is prone to other forms of contamination.

Wells with observable or past water-quality problems, such as odor, taste, and color have significantly lower rates of contamination, which are related to the presence of relatively old water and/or conditions which degrade contaminants. Wells with a history of high nitrates and coliform positives showed high proportions of these contaminants during SWRL.

Sites where more than one operable well was present showed higher than state-wide averages for nitrate-N >10mg/L and coliform positives. However, this is largely a function of the use of multiple shallow, large-diameter seepage wells at the majority of these sites. Sites with only one operable well were dominated (70%) by deeper drilled wells.

Previous analysis of the SWRL data (Kross et al., 1990) showed minor differences in the rates of some contaminants at sites with abandoned wells, no septic systems, or chemical storage on the property. When these factors are stratified by distance to the sampled well, and by number of abandoned wells, there are no consistent proximity effects apparent. For example, wells located within 15 feet of chemical storage and handling areas are uncommon, occurring at <0.6% of rural sites, and *none* of these wells contained pesticides or NO_3-N >10 mg/L. One of the most significant associations with water quality is exhibited by the location of wells in non-farm, suburban housing tracts. These sites show substantially fewer wells with >10 mg/L NO_3-N and total coliform bacteria. Wells located closest to septic systems, showed *lower* nitrate and significantly fewer positives for total and fecal coliform bacteria; these sites were dominantly in the "suburban" areas as opposed to agricultural areas. Of note is that the wells in the category indicating the greatest distance (> 200 feet) from septic tanks and chemical storage and handling areas often exhibited the greatest degree of contamination, particularly for total coliform. This relationship results from the high proportion of large-diameter seepage wells in the greatest distance categories. These wells tend to be located along waterways, or other areas with a high water table (to promote seepage), often quite distant from areas preferred for the siting of houses, cattle-yards, storage buildings and chemical-mixing sites. Site studies show that, on average, these wells are located nearly one-quarter of a mile from such likely point-sources. While such wells are highly susceptible to localized impacts from accidents and point sources, the majority are located so far from such sources that there is little potential for direct impact.

The effects of sinkholes or agricultural drainage wells are not significant in a state-wide context. Sinkholes were identified in the vicinity of only 2.1% of sites and only 0.6% of sites were near agricultural drainage wells (ADW). No sites with ADWs had pesticide detections or NO_3-N >10 mg/L.

On-site disposal of home and farm refuse shows no effect on water-quality in the SWRL survey. For farmed sites neither the crop types, crop and livestock enterprises, rates of N-fertilization nor the herbicides applied were reflected in the water quality at the on-farm well. Neither methods nor locations of disposing of excess pesticide formulation, rinseate, or pesticide containers exhibited any significant association with water-quality results from SWRL. Wells located *in* feedlots showed significantly higher concentrations of nitrate, but *not* bacteria problems. Such sites comprise only about 3% of wells state-wide, and account for only about 1% of the wells with >10 mg/L NO_3-N.

Sites that reported the formulation of pesticides at a hydrant near the wellhead and/or spills of pesticides were related to greater than state-wide averages for pesticide detections. However, when the results are stratified by distance from the well, and by well depth and well type, consistent proximity trends are absent. The continuing, detailed analysis of the SWRL survey data reinforce prior findings, that: 1. point-source problems clearly contribute to the occurrence of pesticides in water-supply wells; *but*, 2. they only account for a portion of the problems; and, 3. nonpoint sources also account for many pesticide detections in water-supply wells, which is supported by other detailed research.

About 5.4% of farms reported spills, back-siphoning, or other accidents with pesticides and/or fertilizers near their wells, and, as would be expected, these sites show a greater proportion of pesticide detections. However, of the well samples that had pesticides detected from these sites, *only 36% contained the pesticide involved in the mishandling incident.* Sites where residents reported they mixed all the herbicides applied on-site and those where all the herbicides were custom applied showed the *same* proportion of pesticide detections. Sites where herbicides were mixed at a hydrant within 15 feet of the well did show greater-than-average pesticide detections and greater proportions than sites where mixing was done at a hydrant further away. However, sites where mixing and handling was *not* done near the well, where *all* herbicides were reported as mixed in the field where they were to be applied, also showed a greater than average occurrence of pesticides. If local mishandling of pesticides were the *only* factor involved in well contamination, sites where all herbicides are custom applied or where all are mixed in the field would be expected to show significantly fewer incidences of herbicide contamination. In fact, such sites exhibit proportions equal to, or *greater* than state-wide averages.

The review of sites where pesticide concentrations exceeded HALs provided similar insights (Kross et al., 1990). The sites exceeding HALs for pesticides occurred throughout the state. These sites were dominated by shallow wells; one deep well was involved, and this was a point- source case which could affect a well of any depth. Two of the sites, 25%, were clearly "point- source" cases, one a spill and one back-siphoning accident; the majority, 62.5%, were probable nonpoint sources related to pesticide occurrences in shallow groundwater; 1 case, 12.5%, was equivocal.

From the continued analysis reviewed in this report, the relationship between the proximity (i.e., the actual potential for an effect on the well) of mixing and handling of pesticides to the well-head and pesticide detections, while inconsistent, does indicate a significant association within a distance of about 50 feet. The elevated occurrences of pesticide detections at sites where pesticides are mixed within 50 feet of the well head stands up throughout the analysis of the many confounding variables that can come into play, e.g., the sites are not dominated by seepage wells or inordinately shallow wells. This relationship is a strong indication that such handling, over time, has likely impacted these wells adversely. Several of these sites are known spill sites as well. Spills and mixing near the wellhead still only explains a small portion of the total occurrences of pesticides, however. When *all* the detections from the wells within 50 feet of mixing sites are considered, they account for about 1.5% of pesticide detections state-wide; combined with other known spill and accident sites (whether the compound found was *related* to the spill or *not*), they account for about 3-3.5% of detections state-wide (of the 13.6% measured). Such detailed analysis is requisite for understanding the magnitude of such impacts. While there is little question that point-source problems — spills, back-siphoning, repeated mishandling near a well — occur and contaminate wells, it is easy to overstate their occurrence from anecdotal knowledge. The estimates of the extent of such incidents derived from the detailed data collected in the SWRL study are essentially identical to the values derived from other detailed field investigations in Iowa.

Neither simple proximity nor susceptibility are cause and effect. The potential for chemical handling to impact a well is affected by many factors, such as the gradient from the site to the well ("uphill" or "downhill"), the amount of fluid involved, as well as the depth and nature of construction of the well. A 15 foot distance from a well may be of little consequence if the site is downhill/downgradient or if the well is cased to significant depth and doesn't allow any inflow around the well head. The complexities involved are evident from the far smaller portion of wells exhibiting contamination where chemical mixing sites occurred within 25 feet of the well, relative to those with mixing sites 25 to 50 feet away. Also, the vast majority of large-diameter seepage wells, which are highly susceptible to localized impacts, are located so far from handling and mixing sites that there is little potential for direct impact. Because of this distance relationship, these wells are "under-represented" in the point-source cases. Neither the proximity of handling and mixing to a well, nor the use of a susceptible well-type dictate that point sources are the cause of a pesticide detection.

ACKNOWLEDGMENTS

The Iowa State-Wide Rural Well-Water Survey was supported, in part, through the Iowa Goundwater Protection Act and the contributed time of the many cooperating agencies and institutions. Also, the Iowa Department of Agriculture and Land Stewardship (IDALS), Pesticide Bureau, through grants from the U.S. Environmental Protection Agency (USEPA), Region VII (Kansas City), Toxics and Pesticide Branch, supported this continuing analysis. Grants from the U.S. Environmental Protection Agency (USEPA), Region VII, Nonpoint Source Program, supported various parallel efforts which contributed to the success of SWRL. The Integrated Farm Management Demonstration Project, through the Iowa Department of Agriculture and Land Stewardship (IDALS), provided some staff support for the project, as part of Iowa's Agricultural Energy Management programs. Without the direct services and cooperative efforts of the Iowa State University Cooperative Extension Service (CES) the survey would not have been possible. The excellent cooperation of most county CES staff in providing the initial screening and evaluation of sites was invaluable.

Thanks are due the many staff and external reviewers and contributors to this report. Acknowledgments are also due the many staff, who week after week, conducted the field sampling and inventories. Thanks are due the staff of the laboratories with UHL, ATL, and EEL who maintained rigorous schedules and quality control to keep up with the pace of the survey. Similar thanks are in order for the data management units related to the labs, and particularly the data managers with PM&EH, who undertook the task of developing the master data handling procedures on behalf of the Center for Health Effects of Environmental Contaminants at the University of Iowa.

Many other agencies and staff are noted in this and previous reports. The authors would particularly like to thank the following people for their cooperation and contributions to the study: Dr. Keith Long and Dr. Peter Isaacson, Emeritus Professors, PM&EH, for their stimulation toward the need and design of this study; Julie Elfving, USEPA - Region 7; Matt Lorber and Mike Barrett, USEPA, Washington, D.C.; James Gulliford and Dan Lindquist, IDALS; Dr. Jerry De Witt, Dr. Gerald Miller, Dr. Steven Padgitt, Dr. Mike Duffy, and Craig Chase, CES; and Dr. Cheryl Contant, University of Iowa, Public Policy Center and Department of Urban and Regional Planning.

Perhaps the greatest thanks must go out to the people of Iowa who collaborated in this study. The many private citizens who participated, and gave willingly of their time, were the key to the success of this survey, and indeed are the key to the continued success of Iowa's groundwater protection programs.

REFERENCES

Hallberg, G. R., Hoyer, B. E., Bettis, E. A. III, and Libra, R. D., 1983, Hydrogeology, water quality, and land management in the Big Spring basin, Clayton County, Iowa: Iowa Geological Survey Open-file Report 83-3, 191p.

Hallberg, G.R., Kross, B.C., Libra, R.D., Burmeister, L.F., Weih, L.M.B., Lynch, C.F., Bruner, D.R., Lewis, M.Q., Cherryholmes, K.L., Johnson, J.K., and Culp, M.A., 1990, The Iowa state-wide rural well-water survey: design report: a systematic sample of domestic drinking water quality: Iowa Dept. of Natural Resources, Geological Survey Bureau, Technical Information Series 17, 135p.

Kross, B.C., Hallberg, G.R., Bruner, D.R., Libra, R.D., Rex, K.D., Weih, L.M.B., Vermace, M.E., Burmeister, L.F., Hall, N.H., Cherryholmes, K.L., Johnson, J.K., Selim, M.I., Nations, B.K., Seigley, L.S., Quade, D.J., Dudler, A.G., Sesker, K.D., Culp, M.A., Lynch, C.F., Nicholson, H.F., and Hughes, J.P., 1990, The Iowa state-wide rural well-water survey, water-quality data: initial analysis: Iowa Dept. of Natural Resources, Geological Survey Bureau, Technical Information Series 19, 142p.

Kross, B.C., Selim, M.I., Hallberg, G.R., Bruner, and Cherryholmes, K.L., 1992, Pesticide contamination of private well water, a growing rural health concern: Environment International, vol. 18, p. 231-141.

Nations, B.K. and Hallberg, G.R., 1992, Pesticides in Iowa precipitation: Journal of Environmental Quality: vol. 21, p. 486-492.

Seigley, L.S. and Hallberg, G.R., 1991, Groundwater quality observations from the Bluegrass watershed, Audubon County, Iowa: Iowa Dept. of Natural Resources, Geological Survey Bureau, Technical Information Series 20, 50p.

Seigley, L.S., Hallberg, G.R., Walther, P.R., and Miller, G.A., in press, Summary of water quality data from a volunteer sampling program: Audubon County, Iowa: Proceedings of the Iowa Academy of Science, in press.

Iowa Department of Natural Resources
Energy and Geological Resources Division
Geological Survey Bureau
109 Trowbridge Hall
Iowa City, Iowa 52242-1319
(319) 335-1575