Application of a geographic information system in analyzing the occurrence of atrazine in groundwater of the mid-continental United States

M.R. BURKART

Agricultural Research Service, National Soil Tilth Laboratory, 2150 Pammel Drive, Ames, Iowa 50010, USA

D.W. KOLPIN

US Geological Survey, Water Resources Division, Box 1230, Iowa City, Iowa 52244, USA

Abstract The US Geological Survey, US Department of Agriculture, and US Environmental Protection Agency are conducting research and regional assessments in support of policy alternatives intended to protect water resources from agricultural chemical contamination. The mid-continent was selected because of the intense row crop agriculture and associated herbicide application in this region. An application of a geographic information system is demonstrated for analyzing and comparing the distribution of estimated atrazine use to the detection rate of atrazine in groundwater. Understanding the relations between atrazine use and detection in groundwater is important in policy deliberations to protect water resources. Relational analyses between measures of chemical use and detection rate by natural resource units may provide insight into critical factors controlling the processes that result in groundwater contamination from agricultural chemicals.

INTRODUCTION

Increased yields for row crop agriculture in North America can, in part, be attributed to the increased use of herbicides. Herbicide use also has affected the quality of groundwater in many parts of the continent. Current research reflects the increasing concern over herbicide contamination of the Nation's water resources. The question of how agricultural practices can be modified to obtain a balance between production and water quality protection is currently being examined. Use of a geographic information system (GIS) facilitates the spatial integration and interpretation of numerous sources of information required when dealing with problems such as contamination of groundwater by herbicides.

The region of interest, the mid-continental United States, includes the states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin (Fig. 1). This is an area of intense agricultural production where almost 60% of the nation's herbicides are applied (Gianessi & Puffer, 1990). This region is also where the US Geological Survey, US Department of Agriculture, and the US Environmental Protection Agency are planning and conducting multi-scale research to evaluate the effects of various farming practices on water resources (Burkart *et al.*, 1990).

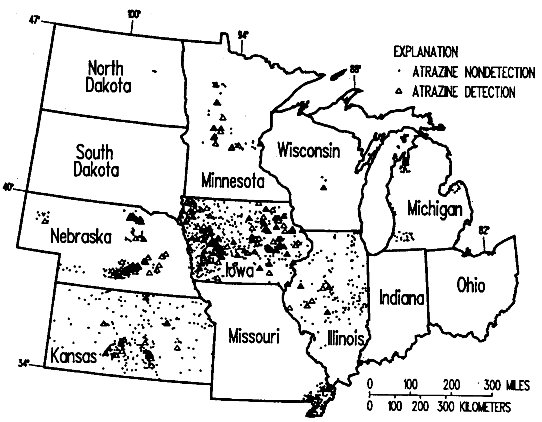

Fig. 1 Location of wells from where atrazine analyses are available from WATSTORE (common reporting limit of 0.1 mg l^{-1}).

Purpose

The purpose of this paper is to demonstrate an application of a GIS to analyze the occurrence of atrazine in groundwater in the mid-continent. Atrazine was the chemical selected for this demonstration because it is the most extensively used herbicide in the region, has been continuously used for more than 30 years, and is the most frequently detected herbicide in groundwater. Because information is needed to answer both scientific and policy questions, there is a need to analyze the extent of contamination in as many contexts and scales as possible. A GIS provides for flexible methods of assessment and analysis. Using common geographic references, several layers of information can be combined and compared and the results studied from several perspectives.

Approach

The application of a GIS is demonstrated in the complex topic of atrazine contamination of groundwater. For this example, atrazine use estimates were selected to make spatial comparisons with well-specific detections of atrazine in groundwater. These end points will be analyzed at two scales, regional and subregional, using polygon coverages derived from classifications of soils and hydrogeological factors.

Atrazine use was obtained from county use estimates determined by Gianessi & Puffer (1990). The GIS was used to convert these estimates from political units into natural resource- based units. The total atrazine use in each natural resource polygon was divided by the polygon area to obtain atrazine use in units of mass per unit area so that polygons of different sizes could be compared.

Atrazine detection data were obtained from results of water-quality analyses in the US Geological Survey's National Water Data Storage and Retrieval System (WATSTORE). Latitude and longitude of the water-quality sampling locations were used to generate a GIS point coverage (Fig. 1). This point coverage was overlain onto polygon coverages to estimate the frequency of atrazine detection for each natural resource polygon. A detection of atrazine is defined as a concentration equal to or exceeding the laboratory reporting limit of 0.1 μg l^{-1}.

REGIONAL OCCURRENCE OF ATRAZINE

The estimated atrazine use (in kg km^{-2}) was reaggregated into "Major Land Resource Areas" (MLRA) (US Department of Agriculture, 1981) from the county-based estimates by summing the area-weighted atrazine use of all counties wholly or partly within the boundaries of each MLRA polygon. MLRA are large areas with similar soil, climate and vegetation attributes. A GIS display of this information shows the distribution of atrazine use in the mid-continent (Fig. 2). The working hypothesis for this demonstration is that atrazine use is proportional to atrazine detection. In other words, in areas where more atrazine is used to enhance crop production, atrazine will be detected more frequently in groundwater.

Detection in groundwater

To determine the spatial distribution of atrazine detection in groundwater resources of the mid- continental United States, approximately 3000 atrazine analyses collected from about 1700 wells sampled during 1979 to 1989 were

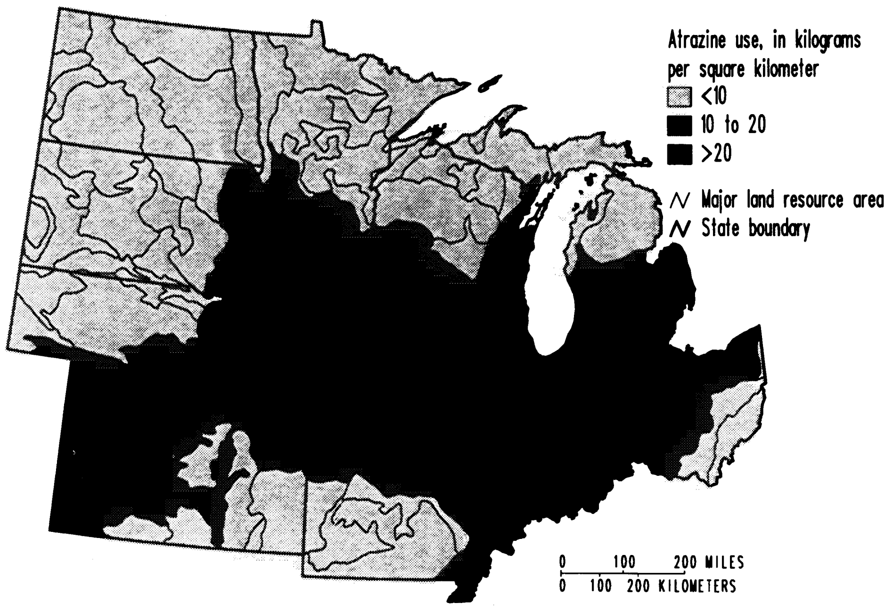

Fig. 2 Atrazine use aggregated by Major Land Resource Areas (MLRA).

retrieved from WATSTORE. A plot of the points in this coverage can provide a visual assessment of their spatial distribution. This can be used, for example, to determine if the data are evenly distributed within a particular MLRA, clustered, or thinly scattered. As can be seen in Fig. 1, these point data are not evenly distributed in all MLRA. Limiting the analysis to MLRA that include at least 10 wells tested for atrazine detection, a GIS display of the frequency of atrazine detections by natural resource units can quickly show where the smallest and largest atrazine detection frequencies occurred and where more information on atrazine detection is needed (Fig. 3).

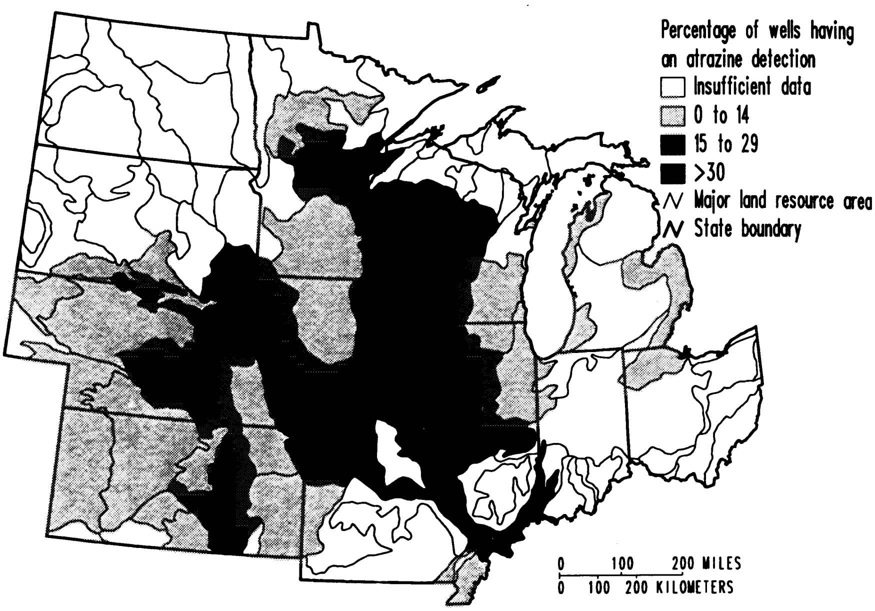

Fig. 3 Frequency of atrazine detections aggregated by Major Land Resource Areas (MLRA) (polygons with fewer than 10 wells tested for atrazine contained insufficient data).

Regional susceptibility

A visual comparison of Figs 2 and 3 gives a general perception as to where the working hypothesis is true. Specifically, a GIS can clearly display areas where large atrazine use corresponds to large frequencies of atrazine detection.

For this demonstration, the atrazine use rate for the entire mid-continent and the atrazine detection frequency for the entire region were standards used to define large and small use and detection frequencies. The atrazine use for the region (13.3 kg km^{-2}) was the quotient of the sum of all atrazine used and the area of the region. The regional atrazine detection frequency (26.2%) included all atrazine analyses available in the WATSTORE data base. Large use or detection values were those which exceeded these regional values and small use or detection was less than these values. The GIS can then be used to reselect and display the four permutations of atrazine use and detection. The permutations were ranked to produce the following index of hypothetical susceptibility to groundwater contamination by atrazine:

(a) small susceptibility (large use/small detection): Occurs where the relation appears to be opposite to the working hypothesis and large atrazine use does not correspond to large frequencies of atrazine contamination;

(b) intermediate susceptibility (small use/small detection): Occurs under conditions where the working hypothesis appears valid but the susceptibility is low because use is low;

(c) large susceptibility (large use/large detection): Occurs under conditions where the working hypothesis appears valid and atrazine detection is large;

(d) critical susceptibility (small use/large detection): Occurs under conditions where the relation appears to be opposite the working hypothesis and even small atrazine use corresponds to large frequencies of atrazine detection.

In Fig. 4, areas where atrazine detections were either greater or less than expected relative to atrazine use can be identified. The presence of larger frequencies of atrazine detection affords more opportunities for research on the causes of contamination. Conversely, the processes or factors that inhibit atrazine contamination can best be investigated in areas of large use but small detection frequencies. Also, if regulatory agencies adopt policies about a wide variety of agricultural practices designed to improve water quality, the areas of

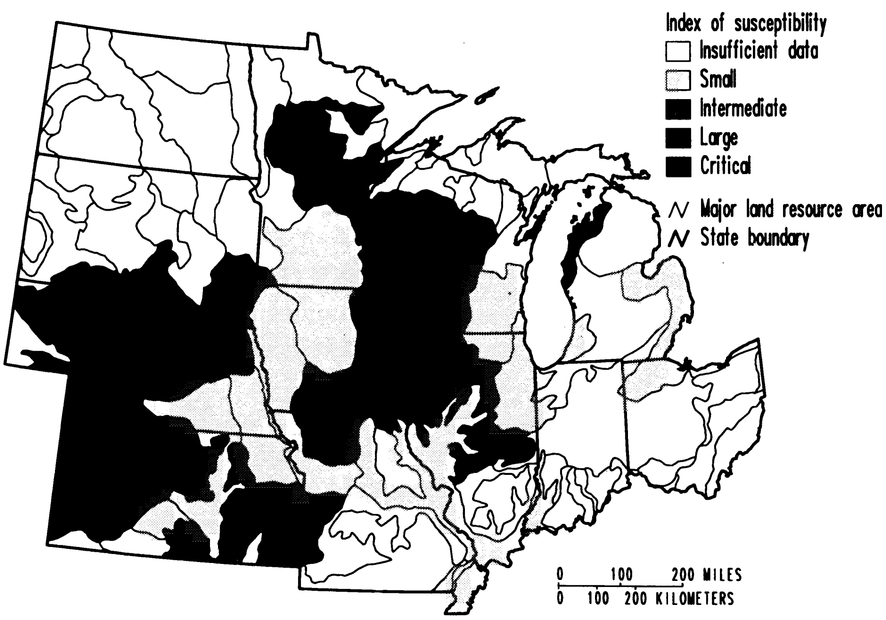

Fig. 4 Groundwater susceptibility to atrazine contamination based on detection frequency and atrazine use, displayed by Major Land Resource Areas (MLRA).

critical susceptibility may provide positive results in the shortest amount of time. If policy is to be limited only to a decrease in chemical use without considering other factors, success in improving water quality will most likely be in those areas where both the atrazine use and atrazine detections are large. Such policy may have little effect in the areas of small susceptibility because even a large use of atrazine does not appear to greatly increase the atrazine detection.

SUBREGIONAL ATRAZINE OCCURRENCE

More specific research and policy questions will require more detailed information at a larger scale to investigate the occurrence of atrazine in groundwater. The State of Iowa was selected as an example to illustrate the application of a GIS at this scale. Analysis was restricted to a subregion defined by political boundaries because detailed digital landscape data bases such as those used in this example are being developed using State rather than natural resource boundaries. Iowa was selected because it has the most densely and evenly distributed set of groundwater atrazine analyses in the mid-continent (1745 atrazine analyses from 817 wells in WATSTORE) and it has multiple landscape subdivisions available in digital geographic format. Eventually, these landscape data will be available for much of the mid-continent.

Susceptibility using state soil geographic data base

There are substantial variations in critical geological, hydrological and pedological factors that influence the potential for groundwater contamination within each MLRA. The "State Soil Geographic Data Base" (STATSGO) (US Department of Agriculture, 1991) includes a polygon coverage in which atrazine detection can be defined in relation to pedological factors at a scale considerably finer than, but using factors similar to those used for MLRA. Iowa is separated into 2032 polygons in 84 STATSGO units but only nine polygons in 7 MLRA units. Reaggregating the atrazine and atrazine detection data by STATSGO units shows more spatial variability in susceptibility to atrazine contamination than shown by the MLRA units alone (Fig. 5). An atrazine use rate for Iowa and an atrazine detection frequency for Iowa were standards used to define large and small use and detection values at the subregional scale. The atrazine use for Iowa (24 kg km^{-2}) was the quotient of the sum of all atrazine used in the State and the area of the State. The atrazine detection frequency for wells tested for atrazine in Iowa was 24%.

In general, the STATSGO units associated with major alluvial systems, represented by the network of dendritic patterns, have greater hypothetical susceptibility to atrazine contamination than immediately surrounding areas and are responsible for much of the appearance of local variability within the

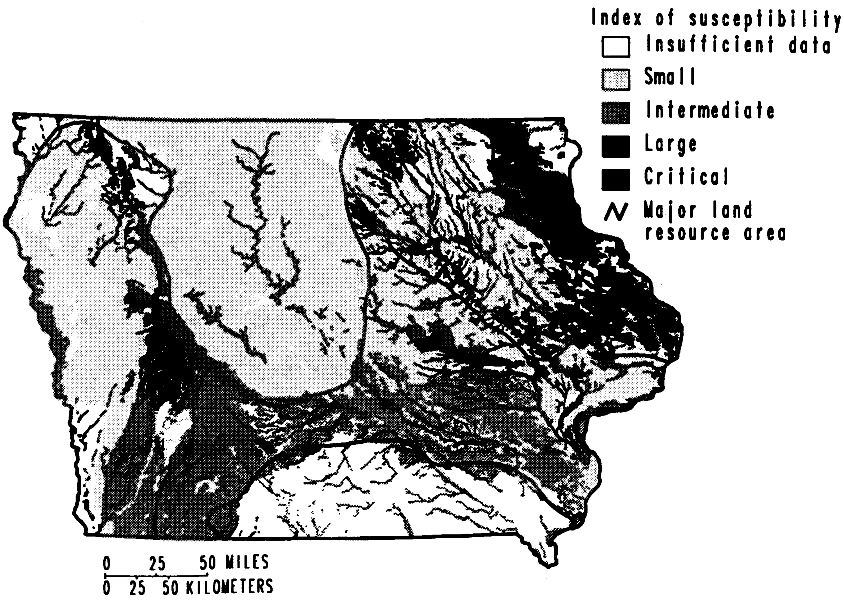

Fig. 5 Groundwater susceptibility to atrazine contamination for Iowa based on detection frequency and atrazine use, displayed by State Soil Geographic Data Base (STATSGO).

MLRA polygons. There are gross similarities in susceptibility between Figs 4 and 5 but the increased detail using STATSGO also reveals substantial differences. For example, the north-central part of the State is an area with the small susceptibility in both figures. However, in the southern part of the State, Fig. 4 shows an MLRA with an intermediate susceptibility, but this same MLRA in Fig. 5 shows intermediate susceptibility for only those STATSGO units associated with major alluvial systems. The remaining STATSGO polygons comprising this MLRA have insufficient information documenting atrazine detection. Coverages such as STATSGO can be used to isolate smaller areas of interest for conducting research or implementing management strategies.

Susceptibility using groundwater vulnerability regions

Another landscape perspective at the subregional scale is provided by the Iowa "Groundwater Vulnerability Regions Data Base" (GVR) (Hoyer & Hallberg, 1991). This coverage includes polygons with similar hydrogeological characteristics affecting the susceptibility of aquifers to contamination from surface applied sources. Iowa is separated into 3344 polygons using 9 GVR units. The pattern of hypothetical susceptibility index to atrazine contamination for the GVR (Fig. 6) has similarities and differences to the pattern determined for STATSGO. The differences were expected because the GVR units are explicitly defined by aquifer characteristics, whereas STATSGO uses soil

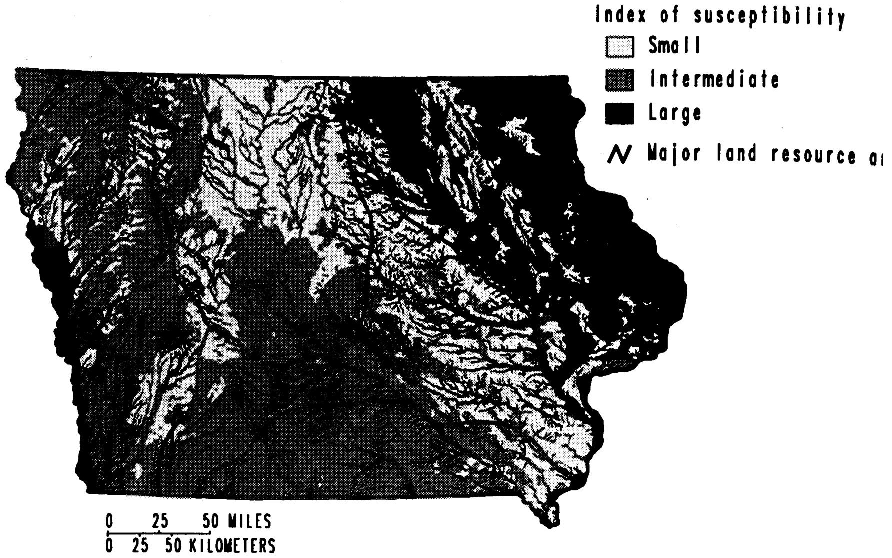

Fig. 6 Groundwater susceptibility to atrazine contamination for Iowa based on detection frequency and atrazine use, displayed by Groundwater Vulnerability Regions (GVR).

characteristics, which are only indirectly associated with aquifer properties. The GVR display clearly isolates alluvial aquifers and the karstic bedrock region of northeast Iowa as areas where large atrazine use corresponded to large atrazine detection. Independent, unpublished research by the authors, and other research (Detroy & Kuzniar, 1988; Libra *et al.*, 1991) has also shown these hydrogeological areas to be susceptible to sources of herbicide contamination resulting from application of agricultural chemicals.

DISCUSSION AND CONCLUSIONS

The value of using multiple polygon coverages for the type of spatial analysis demonstrated in this paper lies in the differing perspectives by which aggregated data can be analyzed. Each coverage will likely have similarities and differences in the distribution of susceptibility. These similarities and differences are useful to more realistically display the degree of confidence in conclusions drawn from the reaggregation of data. The consistent large to critical susceptibility shown for northeast Iowa at both regional and subregional scales is an example of multiple perspectives yielding similar conclusions. However, the larger susceptibility shown for alluvial aquifer systems in both the state Groundwater Vulnerability Regions Data Base (GVR) and the State Soil Geographic Data Base (STATSGO) could not be derived from the regional scale "Major Land Resource Area" (MLRA) display.

A direct comparison of the resolution attained by two scales of analysis (Fig. 7) shows that with an ideal distribution of water quality data, the

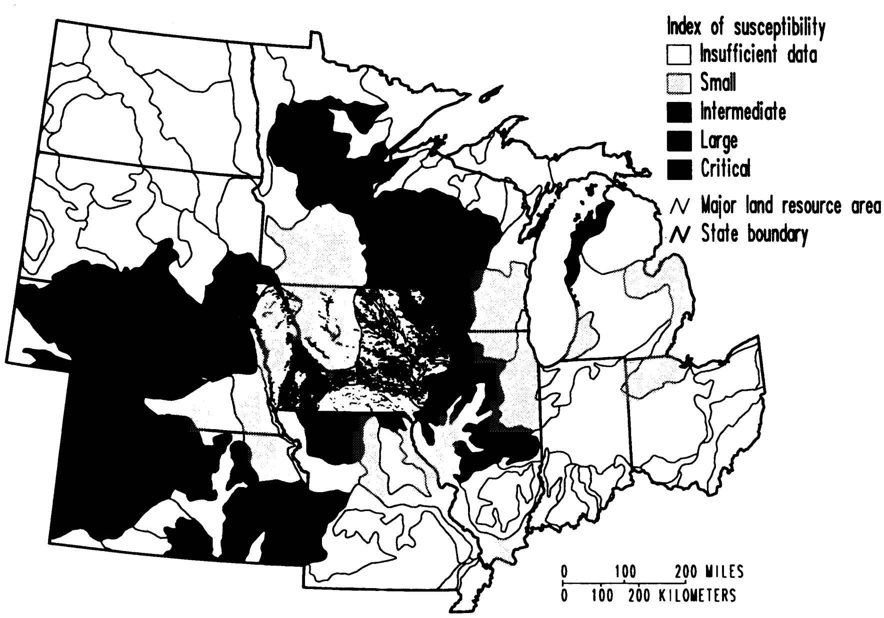

Fig. 7 Groundwater susceptibility comparing State Soil Geographic Data Base (STATSGO) of Iowa and Major Land Resource Areas (MLRA) of the mid-continent.

resolution shown for Iowa will be attainable when the STATSGO data base for the entire mid-continent is finalized. The STATSGO polygons also have attribute files associated with them which allow for extensive relational analysis of water quality and pedological data.

This type of spatial analysis presented in this paper is expected to lead to a better understanding of groundwater contamination from non-point sources of herbicides. STATSGO and GVR include many of the factors critical to the fate and transport of chemicals applied to the land-surface. With a better definition of the spatial distribution of contamination, it will be possible to concentrate research, monitoring, and policy efforts to maximize the information and results leading to protection of groundwater resources.

REFERENCES

Burkart, M.R., Onstad, C.A. & Bubenzer, G.D. (1990) Research on agrichemicals in water resources. *EOS, Trans. Am. Geophysical Union* **71**(29), 980-988.

Detroy, M.G. & Kuzniar, R.L. (1988) Occurrence and distribution of nitrate and herbicides in the Iowa River alluvial aquifer, Iowa-May 1984 to November, 1985. US Geological Survey Water-Resources Investigations Report 88-4117.

Gianessi, L.P. & Puffer, C.M. (1990) Herbicide use in the United States: Washington, D.C., Resources for the Future, [Inc.], Quality of the Environment Division. (Revised April 1991)

Hoyer, B.E. & Hallberg, G.R. (1991) Groundwater vulnerability regions of Iowa. Geological Survey Bureau, Iowa Dept. Natural Resources, Special Map Series 11.

Libra, R.D., Hallberg, G.R., Littke, J.P., Nations, B.K., Quade, D.J.& Rowden, R.D. (1991) Groundwater monitoring in the big spring basin, 1988-1989. Iowa Department of Natural Resources, *Technical Information Series*, **29**.

US Department of Agriculture (1981) Land resource regions and major land resource areas of the United States. Agric. Handbook 296.

US Department of Agriculture (1991) State soil geographic data base (STATSGO) data users guide. Soil Conservation Service, Miscellaneous Publication Number 1492.