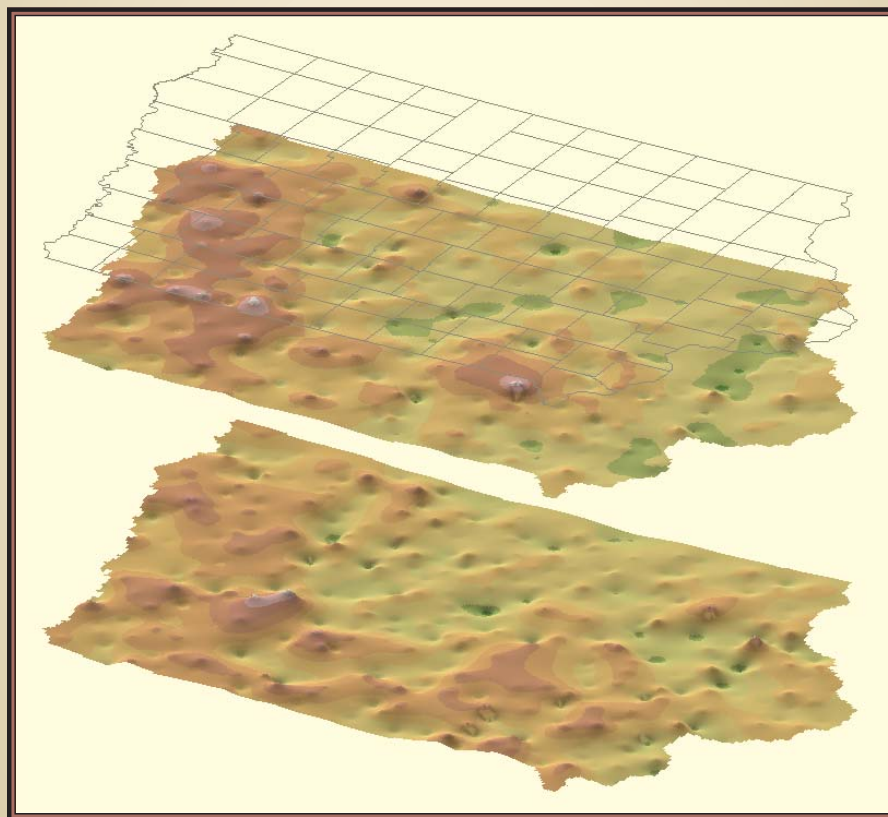# The Iowa State-Wide Trace Element Soil Sampling Project: Design and Implementation

A Report of the Iowa Component of the United States Geological Survey National Geochemical Survey

Open-File Report 10-1

COVER

Three-dimensional view of contour maps of
atomic absorption spectrometry arsenic concen-
trations, in parts per million, from the shallow
and deep trace element sample sets in Iowa. The
county outlines within Iowa are shown above
the maps for reference.

The Iowa State-Wide
Trace Element Soil Sampling Project:
Design and Implementation

**A Report of the Iowa component of the United States Geological Survey
National Geochemical Survey**

Open-File Report 10-1

Prepared by

Robert D. Rowden, Geologist

Iowa Geological and Water Survey

June 2010

**Iowa Department of Natural Resources
Richard Leopold, Director**

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The United States Geological Survey (USGS), in collaboration with other state and federal agencies, industry, and academia, is conducting a National Geochemical Survey (NGS) to produce a database of geochemical information for the United States based primarily on stream sediments, analyzed using a single set of methods. This data set will comprise a national-scale geochemical coverage of the U.S., and will enable construction of geochemical maps, refine estimates of baseline chemical element concentrations in the sampled media, and provide context for a wide variety of geological and environmental studies. The goal of the NGS is to analyze at least one stream-sediment sample within every 289 km^2 area across the U.S., using a consistent set of analytical methods, substituting soil samples where necessary. The survey incorporates geochemical data from a variety of sources, including existing analyses in USGS databases, reanalyses of samples in USGS archives, and analyses of recently collected samples. Currently, the NGS data covers ~71% of the land area of the U.S., and includes samples from all 50 states.

The Iowa Geological and Water Survey (IGWS) of the Iowa Department of Natural Resources (IDNR) entered into an agreement with the USGS in September of 2002 whereby the IGWS would design a database for field parameters and collect two soil sample sets. One set for the USGS to process and analyze, and one set to reposit. Field parameters included ambient site conditions, GPS location, elevation, landscape position, vegetation type, National Resources Conservation Service (NRCS) soil type, sample depth, and soil horizon, texture, color, and moisture. Digital photographs were taken of the site and samples at each location. The samples were sieved to -100 mesh, then analyzed for 40 elements using inductively coupled plasma-atomic emission spectrometry/acid dissolution (ICP40), and 6 elements using atomic absorption spectrometry (AA). Arsenic (As) and gold (Au) were analyzed for using both methods. Analyses were performed by an approved lab, using standard methods and a U.S. Environmental Protection Agency approved quality assurance/quality control plan.

To maximize statistical reliability, sample collection in Iowa was based on a 17 km x 17 km grid, displayed on USGS 1:250,000 quad maps. Each grid or cell was identified by quad name and cell column and row position, and divided into four 72 km^2 quadrants, and one was selected at random for sampling. The IGWS selected specific sampling sites within the selected quadrants. To separate leached horizons from those accumulating CO_3, one shallow (0-8 inches) and one deep (12-24 inches) sample were collected from 463 regular and 72 analysis of variance (AOV) sites from May through August of 2003 and shipped to the USGS in August. Randomly selected AOV sites were sampled to provide a data set for statistical analysis to test the adequacy of the samples to measure differences of sediment chemistry between cells, within cells, within sites, and between chemical analyses. "AOV1" was collected within the designated quadrant of the cell, then one of the three other quadrants of the cell were selected at random for "AOV2" and "AOV3" which were collected about 10 feet apart, preferably within the same soil type.

The field data were described on data collection sheets and later transferred to the IGWS network through an entry routine on a daily to weekly basis. The visual Dbase® entry routine and database were developed and maintained by IGWS personnel, then after the analyses were performed, the data were joined with the soil sample analyses by the USGS. The joined data can be accessed from the USGS at http://tin.er.usgs.gov/geochem/doc/home.htm, or the IGWS website at www.igsb.uiowa.edu. For a detailed description of the NGS, visit the NGS website.

INTRODUCTION

Minerals are naturally formed chemical elements that form the building blocks of the earth's crust. These rocks weather, erode, and mix with organic material and are transported and redeposited and eventually become the soils that we use to grow crops. Some minerals are transferred from the soil to plants, then to animals, and then are returned to the soil. Minerals have always been a precious commodity for human life. The word "mineral" is derived from the word "mine" which is of Celtic origin and means to get from the earth by excavation. To utilize our mineral resources in the most efficient and sustainable ways, while improving and protecting our environment, requires proper development and management of these resources, based on basic geochemical data.

The availability of minerals and the chemical elements they contain, in appropriate proportions and combinations, plays a vital role in the lives of humans and animals and in the soils that support plant life. Some elements, such as carbon, hydrogen, oxygen, magnesium, potassium, and phosphorus, are required in relatively large quantities for life. Other trace elements are required by most organisms in much smaller quantities. Diseases may occur in animals and plants due to deficiencies of various elements. Conversely, when elements occur in quantities great enough, various types of toxicity can result. When an element or assemblage of elements occurs in the environment at concentrations above what are considered to be background, or baseline levels, it may be considered a contaminant and possibly a health hazard. The quantitative difference between essential and toxic concentrations of some elements can be very small.

Elements that are required for life by animals and plants are termed essential, while those not required are termed nonessential. Essential trace elements such as fluorine, copper, selenium, and molybdenum can be hazardous to life forms if present at high concentrations. Nonessential elements such as arsenic, lead, mercury, cadmium, and chromium are usually toxic to organisms at much lower levels than trace essential elements (From USGS Circular 1105; http://usgs.gov/faq/faq.asp?id=249&category_id=27).

Most forms of life are affected by the occurrence, distribution, and availability of the chemical elements that comprise the earth. As mentioned, environmental hazards may exist in areas where some of these chemical elements occur in excessive or deficient quantities. The ability to accurately quantify the abundance, concentration, and spatial distribution of many of these elements across the earth's surface is critical for assessing potential environmental hazards and for making environmentally and economically sound management and development decisions concerning mineral resources.

In the United States, regional- and national-scale geochemical data have been collected for numerous studies for many years in order to locate areas where geologic processes have left mineral deposits containing elements of value in quantities great enough to mine economically. If the sample sets for these geochemical exploration studies are collected at appropriate densities and analyzed for a wide variety of elements using consistent methods, the resulting data set or coverage could also be used to establish geochemical baselines and provide context for a wide variety of geological and environmental studies.

Many countries have completed, or are in the process of conducting, national-scale geochemical inventories. For a brief review of some of these studies, as well as some US studies, see the background and history section of the United States Geological Survey National Geochemical Survey (USGS NGS) Open-File Report 2004-1001 (version 1) website at http://tin.er.usgs.gov/geochem/doc/home.htm. Much of the following introductory material is from this USGS report, which contains references for the various geochemical studies.

There are two datasets from the U.S. that can be considered national geochemical coverages. One of these by Shacklette and Boerngen (1984) contains analyses of ~40 elements from a suite of ~1,300 soils collected across the 48 contiguous states, achieving a sample density of 1/6,000 km^2, equivalent to the collection of samples on a 75-km grid across the country. The low sample density of this dataset limits its usefulness for mineral and environmental studies except at very small scales, but the data can be used to

establish broad trends in elemental concentrations in soils across the contiguous states.

During the late 1970s and early 1980s, the National Uranium Resource Evaluation (NURE) program collected airborne gamma-ray spectrometry data across the conterminous states (Duval and Riggle, 1999) and Alaska (Duval, 2001) for K and "equivalent" Th and U at an effective resolution of a few km. This study provides a much greater resolution national geochemical coverage, but is limited to only the three radioactive elements. A component of this program, the "Hydrogeochemical and Stream Sediment Reconnaissance" (HSSR) program, resulted in the collection of several hundred thousand samples of stream sediment, soils, lake sediments, and other solid sample media, and a similar number of stream and well water samples covering ~65% of the land area of the U.S. The average density of this data set is ~1/20 km^2, equivalent to sampling on a 4-5 km grid. Unfortunately, the NURE data set is difficult to use because the program did not use a single set of analytical protocols. Four different laboratories analyzed samples, each using a different set of methods, and each analyzing for a different set of elements. This inconsistency, along with poor quality control, limits the usefulness of the data as a national coverage (Grossman, 1998), but the sample archive is a valuable resource that can be used in conjunction with other programs.

The USGS became involved in a wide variety of geochemical sampling projects at scales ranging from a few km to statewide in the 1960s. These studies have resulted in a number of fairly dense sample coverages scattered across ~10% of the contiguous states and ~50% of Alaska (Bailey and others, 1999). Regrettably, inconsistent sampling and analytical methods were used for these studies, and the majority of the analyses were done using imprecise and sometimes inaccurate procedures. In addition, these samples, as a group, are poorly documented, not having readily accessible field notes and precise geographic coordinates. Since this data is not archived in a central database, there is no convenient way to access the information.

The USGS began using the NURE sample archive in the mid 1980s for various research and mineral assessments, and when the original analyses were considered inadequate for these studies, the samples were reanalyzed using improved methods. This reanalyzed data set includes several tens of thousands of samples and covers <10% of the U.S.

The Mineral Resources Program (MRP) of the USGS began providing mineral-resource assessments on a regional basis in the early 1990s. One of the initial priorities of this effort focused on the southeastern coastal states from Virginia to Mississippi. An important part of this assessment was the compilation of existing geochemical data on stream sediments and other surficial materials. Initially, the only available data were in the original NURE program. Most of these samples were stream sediments processed in a single way and analyzed by a single lab, using only two main analytical methods (neutron activation and atomic absorption). Unfortunately, the sample set did not cover most of Florida and Mississippi and large parts of Georgia and Alabama, and many of the elements analyzed by atomic absorption, such as Pb, were only determined in about half of the area that was covered.

In 1997, the MRP began to collaborate with state agencies to collect and analyze new stream sediment and soil samples in order to extend geochemical coverage in the southeastern US beyond the areas already covered by NURE. This sample collection was based on a 10x10 km grid of collection cells, providing a density ~5 times lower than that of NURE, but still dense enough to delineate large-scale regional geochemical trends while being affordable. At the same time, the MRP also began to reanalyze the NURE samples in the southeastern states to make them compatible in terms of analytical methodology and spatial density with the new samples being collected by state governments.

The National Geochemical Survey

During 1998-1999, the MRP decided to combine the assessments from the southeastern states with other regional assessments being conducted in the western U.S. (e.g., Folger, 2000) and expand them to a national scale. This new national effort became the National Geochemical Survey (NGS). When finished, this study will be a complete national geochemical

coverage of samples, analyzed by an internally consistent set of analytical methods and principally based on stream sediments. The minimum sample density will be 1/289 km^2 across the country (based on a 17x17 km sampling grid). The analytical methods chosen included a 40-element ICP package plus single-element determinations of As, Se, and Hg by atomic absorption for every sample. Documentation of these methods is available at http://tin.er.usgs.gov/geochem/doc/analysis.htm.

The NGS incorporates NURE samples that have been reanalyzed, as well as a subset of existing NURE stream sediments and other solid samples that will be reanalyzed by the selected methods in all other areas covered by the NURE program. Software was designed and used to randomly select NURE samples within a grid framework, and to select samples for quality control. The program also uses data from previous USGS geochemical sampling programs for stream sediments if the collection and analytical methods are compatible with those of the NGS. Appropriate data from the MPR National Geochemical Database are also utilized, and samples from the archives of stream sediments collected by earlier USGS sampling programs will be reanalyzed to fill in any areas not already covered. For areas where geochemical data are not currently available, the NGS has been collaborating with state agencies, and private industry to collect and analyze new samples. A major goal of the project is to combine data from all of these sources into a single national database.

Stream sediments were chosen as the principal sample medium for the NGS because streams integrate all sources of sediment within their drainage basins and provide an average geochemical signature from the rocks and soils within the basin. By using stream sediments, bedrock or mineral specimens of interest could be analyzed to determine a "fingerprint" which could then be compared with the stream sediment analyses in order to identify terranes consistent with a particular mineral deposit type. Conversely, soil samples are more likely to represent a much smaller volume of source material and are considered point-source data. Soil sampling is probably less useful for determining the overall elemental constituents of an area, but provides more site-specific geochemistry. This type of data is valuable to soil scientists and agricultural stakeholders. An additional advantage of stream sediment sampling is that it potentially allows the detection of geochemical anomalies due to mineralization or anthropogenic point-sources of contamination, using a much lower sampling density than is possible with soil sampling. Since stream sediments are not available in all locations, other sample types are also included in the NGS.

For NURE, stream sediments were collected at ~80% of all sites where solid samples were taken, but soils (~12%) and pond sediments (~8%, mostly in Alaska) were also collected out of necessity. Because the NGS relies on NURE as the principal source of samples in much of the U.S., all of these media were included in the database and for reanalysis. In parts of the county where the NGS and collaborators collected new samples, soils were substituted for stream sediments where necessary. This includes areas of very low relief and poor drainage, such as in southern Florida and the lowlands of southwestern Alaska, where standing water or tundra dominates the landscape. Farmlands, where local streams have been channelized and diverted for agricultural purposes, were also sampled for soil rather than stream sediments.

The USGS personnel responsible for managing the NGS are all members of the Eastern Mineral Resources Group (EMRG) and include: Andrew Grosz - project concept, design, and leadership; Jeffery Grossman - database design and data processing; Paul Schruben - GIS support; report generation; and Peter Schweitzer - development of data retrieval software.

The Iowa Geochemical Survey

In September of 2002, the Iowa Geological and Water Survey (IGWS) of the Iowa Department of Natural Resources (IDNR) entered into a cooperative agreement with the USGS to conduct the Iowa portion of the ongoing NGS whereby the IGWS would design a database for field parameters and collect two soil sample sets. One set for the USGS to process and analyze, and one set for them to reposit. The USGS agreed to process and analyze the samples, then combine the analytical and site data, and supply the results to the IGWS. In essence, the IGWS

covered the cost of designing the Iowa database, determining specific sampling locations and sample collection, and the USGS covered the cost of processing and analyzing the samples.

Soils were chosen by the IGWS for the Iowa study, rather than stream sediments because soil sampling should render a more even distribution of site-specific geochemistry across the state, and allow comparison of a "shallow" and "deep" set of samples from each sampling location. Since most environmental problems in Iowa are related to non-point source pollution from agricultural chemicals, a symmetrical distribution of point data is probably more desirable than the ability to detect potential geochemical anomalies within individual watersheds.

The major goals of the Iowa study were to determine baseline, or at least background concentrations of naturally occurring chemical elements across Iowa based on soil samples, and to use the resulting data set to provide context for a number of geological and environmental studies. The data set will be used to make statistically reliable geochemical Geographic Information System (GIS) coverages, or maps, for individual elements and possibly mineral assemblages. These coverages will then be compared with other GIS coverages in order to identify possible relationships with geologic sources, geologic provinces, geomorphic features, land use practices, etc. The shallow and deep sample sets will be compared in order to identify any possible differences in the data sets, and to discern any possible relationships to agricultural and/or other anthropogenic activities. This study is the first statewide soil sampling project in Iowa to examine trace elements in soils.

In order to make this information more useful and available to the public, this report may be accessed as a pdf file on the IGWS website at www.igsb.uiowa.edu/. The Iowa database and associated ArcView® map coverages are available through the IGWS Natural Resources Geographic Information System (NRGIS) Library at www.igsb.uiowa.edu/nrgislibx/. An Interactive Map Server (IMS) application is also available to facilitate use of the data using free online software from the NGS website at http://tin.er.usgs.gov/geochem/select.php?place=fUS19&div=fips&map=on.

IOWA GEOCHEMICAL SURVEY DESIGN

There were a number of elements involved in designing a study to achieve the project's objectives. The first involved choosing a preferred medium to sample. As discussed, soils were chosen for the Iowa study because they would render a more even distribution of site-specific geochemistry across the state. Next, was the selection of a statistically valid sample population. For this design element, the number and approximate location of sampling sites and sampling methods were based on USGS protocol. Additional project elements included locating specific sites within the USGS sampling grid and contacting landowners for permission to access the sites; designing a sampling protocol and field sampling forms; designing a database, data entry program, and sample tracking program; hiring and training staff; obtaining sampling equipment; logistical planning for site visits; and storing the samples prior to shipment. This section summarizes the design of the sampling grid and the data collection forms used in Iowa.

The USGS Sampling Grid

To remain consistent with existing geochemical data in the NGS and to maximize the statistical reliability of the project, the selection of potential sampling areas was based on a 17 km x 17 km sampling grid, displayed on USGS 1:250,000 quadrangle maps (Figure 1). Each grid or cell was identified by a quadrangle name and a cell column and row position. The quadrangles were divided into 9 columns labeled from A-I from west to east, and 7 rows labeled from 1-7 from south to north, producing 63 cells. For example, the cell in the northwest corner of the Des Moines quadrangle was labeled DMA7, while the cell in the southeast corner was labeled DMI1. After being identified, each 289 km^2 cell was divided into four 72 km^2 quadrants, and one was selected at random for sampling.

Within Iowa, 487 potential sampling areas were identified. Twenty-four of these areas, or about 5 percent, were chosen at random for

Trace Element Sampling Grid in Iowa
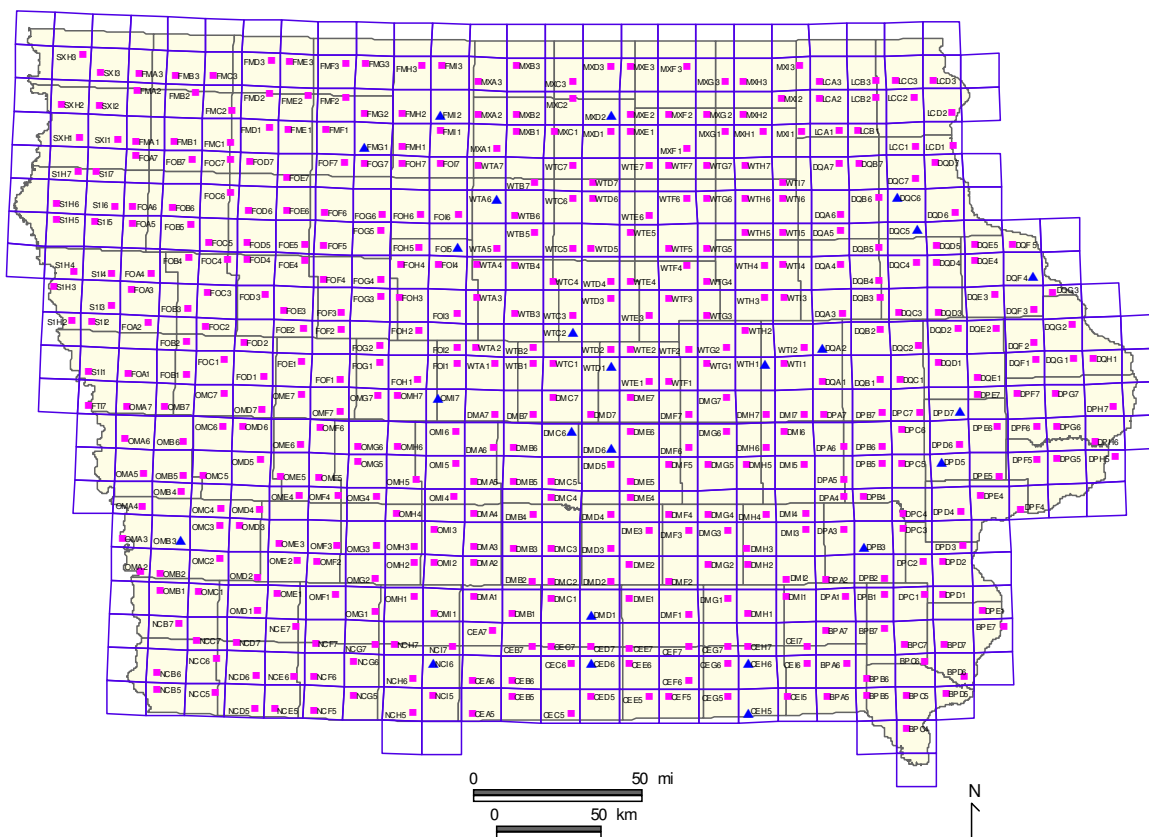
Selected Soil Sampling Quadrants within the 289 square km Grid Cells

- Regular (463)
- ▲ Analysis of Varience (24)

Figure 1. USGS sampling cell grid and selected trace element soil sampling quadrants and site types in Iowa.

analysis of variance (AOV) sampling. Analysis of variance sampling helps to identify sources of variability from one or more potential sources. This method is widely used to help identify the source of potential problems in the sample collection process and identify whether variation in measured output values is due to variability between sampling sites, or within them. Randomly selected AOV sites were sampled to provide a data set for statistical analysis to test the adequacy of the samples to measure differences of sediment chemistry between cells, within cells, within sites, and between chemical analyses.

The AOV method generates two additional sampling sites for each original sampling area. The original "AOV1" sample is collected within the designated quadrant of the cell, then one of the three other quadrants of the cell is selected at random for "AOV2" and "AOV3" which are collected about 10 feet apart, preferably within the same soil type as that collected at "AOV1."

Data Collection Forms

Most site information was collected in the field, except that for landowners, which was re-

corded on landowner contact forms (Figure 2) during telephone interviews prior to site visits, and the National Resources Conservation Service (NRCS) soil type, which was determined by comparing the site's GPS location with an NRCS soil coverage using ArcView®. The township, range, and section information for the site, while not collected in the field, was later refined using the sample's GPS location, which was collected at the site.

Field data for the sampling sites and soil samples, were described on data collection sheets (Figure 3), and later transferred, on a daily to weekly basis, to the project database on the IGWS network using an entry routine. The field parameters included site identification; date and time; the collector's name or names; ambient site conditions; landowner name, address and telephone number; landowner contact date; county name; quadrangle name; township, range, and section to three quarter sections; Global Positioning System (GPS) location and datum used; latitude and longitude; land surface elevation; amount of relief near the site; National Resources Conservation Service (NRCS) soil type; setting; landscape position; slope; vegetation type; contamination degree, potential and source; sample identification; sample depth; soil horizon, texture, color, and moisture; and drainage conditions. The form also included an area to record ID numbers of digital photographs taken of the site and soil samples, and an area for comments.

All soil sampling information was collected in the field. The sampling information was very basic since the field crews, although trained, were not soil scientists. It was reasoned that if additional information about a particular sample was desired, the reposited sample could be examined later, in greater detail. Also, since digital photographs were taken of each site and each sample, it was thought that some information might be gleaned from these at a later time.

PROJECT MANAGEMENT

The responsibility for managing the Iowa sampling program was shared by: Stephanie Tassier-Surine - development of sampling protocols and field methods; John Schmidt - development of the Iowa data entry program and da-

tabase support; and Bob Rowden - Iowa database design, GIS support, and sample tracking. Stephanie Tassier-Surine and Bob Rowden are members of the Groundwater and Groundwater (GAG) Studies Section of the IGWS, while John Schmidt is a member of the Information and Technology Bureau (ITB) of the IDNR.

Project Personnel

After meeting with Andrew Grosz of the EMRG, it was determined that the entire Iowa soil sampling should be completed in one field season during the summer of 2003. Because of this time constraint and limitations in the project budget, as well as limitations in IGWS staff time available for the project, a decision was made to hire six students that would work full time over the summer to help conduct the project. Those hired included: Ben Belgarde, an undergraduate geology major at the University of Iowa (UI); Wendy Bower, a biology graduate from Coe College; Eric Conrad, an undergraduate business major at UI; Leah Johnson, a geologygraduate from Cornell College; Marcelo Mena, an environmental engineering PhD student at UI; and Loreto Stambuk, an urban planning MS student at UI.

Project Coordination

Since the project involved contacting landowners, locating specific sampling sites, tracking landowner contacts, logistical planning for site visits, visiting the sites and recording site specific information and taking soil samples, temporarily housing and tracking the samples and entering the field information in a database, project staff were required to perform a wide variety of tasks.

Because the students had very diverse educational backgrounds and work experiences, their individual skill sets and training requirements were quite variable. In order to give the students a wide range of job experience, a decision was made early in the project to involve all of them in all aspects of the project, rather than have some do only field work, while others do only office work. To accomplish this goal, the students did field work in teams of two, with two teams being out simultaneously, while one team

Figure 2. Landowner contact form showing sampling quadrants, landowner contact information and approximate soil sampling areas in Sioux County, Iowa.

remained in the office to make contacts, schedule field trips, track samples, and enter data. The field trip schedules were generally rotated so that the teams would average about two weeks in the field for, every week in the office. Although all tasks were shared, Marcelo Mena took charge of most of the organizing and scheduling of the field trips, and was instrumental in refining the sample tracking spreadsheet.

During the first weeks of the project, the students became familiar with the IGWS computer network, and received training in using various scale topographic maps and county plat books. They also gained experience in using a variety of web-based telephone directory and mapping applications, and learned how to generate basic site maps using ArcView® GIS software. The students also learned how to use hand held Global Positioning System (GPS) equipment to record Universal Transverse Mercator (UTM) coordinates of sampling locations. Andrew Grosz came back to Iowa for a few days to instruct the students in aspects of sampling site selection and proper soil sampling techniques.

One of the student's first tasks involved transferring the USGS sampling grid onto 1:100,000 scale county topographic maps. These maps were compared with county plat books and used to locate landowners within the pre-selected quadrants of the sampling grid, and then were used later on field trips to locate selected sampling sites. The next major task involved contacting the selected landowners to ask for permission to access their property, and tracking these contacts. Once permission for access was granted, then the selection of more specific sampling locations could begin prior to visiting the sites.

Identification of Sampling Sites

After the original 463 regular and 24 AOV sampling quadrants were identified within the sampling grid, IGWS project staff needed to identify specific sampling sites within the selected quadrants and also select specific sites for the additional 48 "AOV2" and "AOV3" samples. The additional AOV sites could not be selected until after the "AOV1" sites were selected, since they would be located within one of the three other quadrants of the same sampling cell.

To aid in site selection and tracking, a GIS coverage of county boundaries was used in combination with a coverage of the sampling grid to determine the distribution of the selected quadrants within the county boundaries. A large-scale map of Iowa showing the selected sampling quadrants was generated and used to track the progress of landowner contacts, and record sampling locations approved for access. The map was also used later to track the progress of data entry from site visits into the project database. The landowner contact forms used to track contacts, approximate site locations, and specific landowner comments and instructions were filed by county as the project progressed, then later used on site visits.

As mentioned, the site selection process involved using county plat books to identify landowners within the selected quadrants, then calling them and briefly describing the project, and asking for permission to access and sample their property. Landowners were informed of the general nature of the project, and that the purpose of the project was to provide background information on the concentration of the selected analytes in soils across the state. Landowners were also told that the sampling would be done using hand tools, and that care would be taken to avoid any crop damage. Participants were also informed of the non-regulatory nature of the project, and assured that if any contamination problems became evident, that they would be reported to the landowner. To maintain scheduling flexibility, landowners were not provided with a specific sampling date, unless they requested one. If the first contacted landowner chose not to participate in the program, other landowners in the area were identified and contacted. In instances when a contact could not be made in advance in an area, landowners were contacted in person during scheduled field trips to other sites.

In addition to locating sites on privately owned property, a GIS coverage of lands owned by the IDNR, and a coverage of other public lands were used to identify publicly owned property within selected quadrants. When available, publicly owned areas were sampled. Some of these areas included, city-, county-, and state-

Iowa Geological Survey/USGS Soil Sampling Data Collection Sheet

Site ID: _____ **Site Type:** regular   AOV

Date: _____ **Time (24hr format):** _____

Collectors (last names): _____ **Weather:** 1 :sunny 2: p.cloudy 3: cloudy 4: raining

Owner Name: _____ **Contact Date:** _____

Address: _____ **Phone:(** _____ **)** _____

County: _____ **Quadrangle:** _____

Location: T_____ **N, R**_____ **E/W, Section** _____ , ____1/4 ____1/4 ____1/4 ____1/4 (large to small)

GPS Location: **Datum:** <u>NAD27</u>
       UTMX: _____ **UTMY:** _____

       Latitude (ddmmss): _____ **Longitude (ddmmss):** _____

Topo Elevation (ft): _____ **Relief (ft):** _____ **NRCS Soil Type:** _____

Setting: 1: woods   2: meadow/prairie   3: marsh   4: farm field   5: suburban   6: urban
       7: other (specify: _____)
Landscape Position: 1: upland   2: level surface   3: hillside   4: valley
Slope: A: 0-5%   B: 5-15%   C: 15-30%   D: >30%
Vegetation: 1: corn   2: beans   3: pasture   4: grass   5: trees   6: other_____
Contamination degree: 1: none   2: some   3: moderate   4: heavy
Contamination potential: 1: none apparent   2: possible   3: probable   4: definite
Contamination source: 1: none   2: mining   3: farming   4: livestock
                              5: power plant   6: industry   7: sewage   8: urban
                              9: suburban   10: other_____

Surface sample: ID _____
Bottom Depth: _____ inches (generally 0 to 8)
Soil Horizon: A (dark organic)   B   C (parent material)
Texture: 1: crs sand   2: sand   3: sand with silt   4: silt   5: silt with sand
             6: silt with clay   7: clay with silt   8: clay
Color: 1: black   2: dk brown   3: brown   4: yel-brown   5: orange-brown
             6: gray   7: light gray   8: blue-gray   9: other: _____
Moisture: 1: wet   2: moist   3: dry   **Drainage:** 1: good   2: poor

Deep sample: ID _____
Bottom Depth: _____ inches (generally 12 to 24)
Soil Horizon: A (dark organic)   B   C (parent material)
Texture: 1: crs sand   2: sand   3: sand with silt   4: silt   5: silt with sand
             6: silt with clay   7: clay with silt   8: clay
Color: 1: black   2: dk brown   3: brown   4: yel-brown   5: orange-brown
             6: gray   7: light gray   8: blue-gray   9: other: _____
Moisture: 1: wet   2: moist   3: dry   **Drainage:** 1: good   2: poor

---

Photographs (sitename, photo#-#): _____
Comments: _____
_____
_____

Figure 3. Iowa Geological and Water Survey/USGS soil sampling data collection form used to collect site and sampling information.

owned parks, nature preserves, wildlife areas, state forests, rest areas, county homes, and public school properties.

For logistical purposes, landowner contacts were made on a county-by-county basis, beginning in Johnson, and surrounding counties, then moving progressively farther out. The reason for using this approach was to let the students gain field experience and test equipment and procedures nearby, before participating in trips farther away. The process of contacting landowners and identifying sampling sites continued from May through August of 2003.

FIELD PROCEDURES

An unbiased sample set is required to produce stable geochemical maps that can be used to determine geochemical baselines that are statistically reliable. Standardized sampling procedures were used at each collection site in an effort to keep the sampling process as uniform as possible and keep sampling errors to a minimum so that an unbiased sample set was collected.

As mentioned, a soil sampling data collection sheet was completed at each site in order to characterize the setting and samples using parameters thought to be useful for the project and for future reference. Digital photographs were taken of the site, the samples, and the sample bags at each location to help document site and sample characteristics and to possibly capture details that might have been overlooked at the time of sampling. The sampling equipment, site selection criteria, and sampling protocol used during the project are discussed in the following sections.

Sampling Equipment

In an effort to promote consistent sampling methods, each sampling team traveled with a standard set of sampling equipment. Since different teams shared the same vehicles and equipment, items could be misplaced, used up, broken, or forgotten. In an attempt to avoid problems related to missing equipment, an equipment checklist was used to inventory equipment before departing on field trips (Figure 4).

The GPS units used to record the site locations were Magellan® GPS 315s, and the digital cameras used for site and sample photographs were Canon® Power Shot A60s. The GPS units and cameras used rechargeable NiMH 1,800 mAh AA batteries, and the teams traveled with DC to AC transformers that could be plugged into the vehicle's cigarette lighter outlet and used with a battery charger to recharge a spare set of batteries.

So they could be replaced easily, teams carried spades, shovels, hand augers, and posthole diggers that could be purchased at most hardware stores anywhere across Iowa. The students tried using smaller stainless steel and plastic hand tools supplied by the USGS, but found them ineffective for digging. The yardsticks, folding rules, tape measures, plastic buckets, tarps, permanent markers, and pens and pencils used, were also items that could be purchased almost anywhere across the state.

Items not easily purchased in the field were the topographic maps and the sample bags. As mentioned before, teams carried the county topographic maps overlain with the USGS sampling grid that they had used earlier to locate landowners, and site maps that they generated with ArcView®. The large sample bags used for archival measured 10" x 17" and the small bags used for geochemical analyses measured 5" x 7". Both large and small bags were constructed of spun olefin and had white cloth drawstrings and sewn-in 2 x 3 inch yellow label tags. Early in the project cloth bags were used, but these became moldy, so synthetic bags were used during the remainder of the project. All topographic maps were provided by the IGWS and all sample bags were supplied by the USGS.

Site Selection Criteria

To give the IGWS flexibility at the sites, the NRCS soil types of the soil to be sampled were not predetermined, although an attempt was made to try to locate sites within major, extensive soil types, rather than in unusual or uncommon soils. The main reason for this was to try to collect the same NRCS soil type at sites "AOV2" and "AOV3," as was collected at site "AOV1," which was collected in one of the other quadrants of the same sampling cell. Since the students were not soil scientists, they mostly relied on sampling similar landscape positions

Figure 4. Iowa Geological and Water Survey/USGS soil sampling data collection form equipment checklist used to inventory sampling equipment.

for the AOV sample sets in an effort to collect the same soil type at all three sites.

The basic site selection criteria that was used as much as was practical, included the following;

1. Avoid sites 5 miles down wind from power plants
2. Avoid sites within 200 meters from U.S. and State highways
3. Avoid sites within 100 meters from rural roads
4. Avoid sites within 100 meters from current or abandoned buildings
5. Avoid sites within 50 meters from crop end rows or other areas where large amounts of fertilized may have been deposited
6. Avoid any atypical or unusual landscapes, landforms, etc.

Field crews also avoided sampling within feedlots or confined areas with large concentrations of farm animals. If any unusual color or texture was observed on the land surface, the location was avoided.

Sampling Protocol

As discussed, soils were chosen for the Iowa study, rather than stream sediments because soil sampling would render a more even distribution of site-specific geochemistry across the state, and allow comparison of a "shallow" and "deep" set of samples from each sampling location. In an attempt to separate leached horizons from those accumulating CO_3, field crews collected 1,070 sample sets, one shallow (0-8 inches) and one deep (12-24 inches), from 463 regular and 72 AOV sites from May through August of 2003 (Figure 5). These depth intervals were chosen so that the shallow sample would be collected within the plow zone, while the deep sample would be collected below the plow zone. Since

11

Trace Element Sampling Sites in Iowa
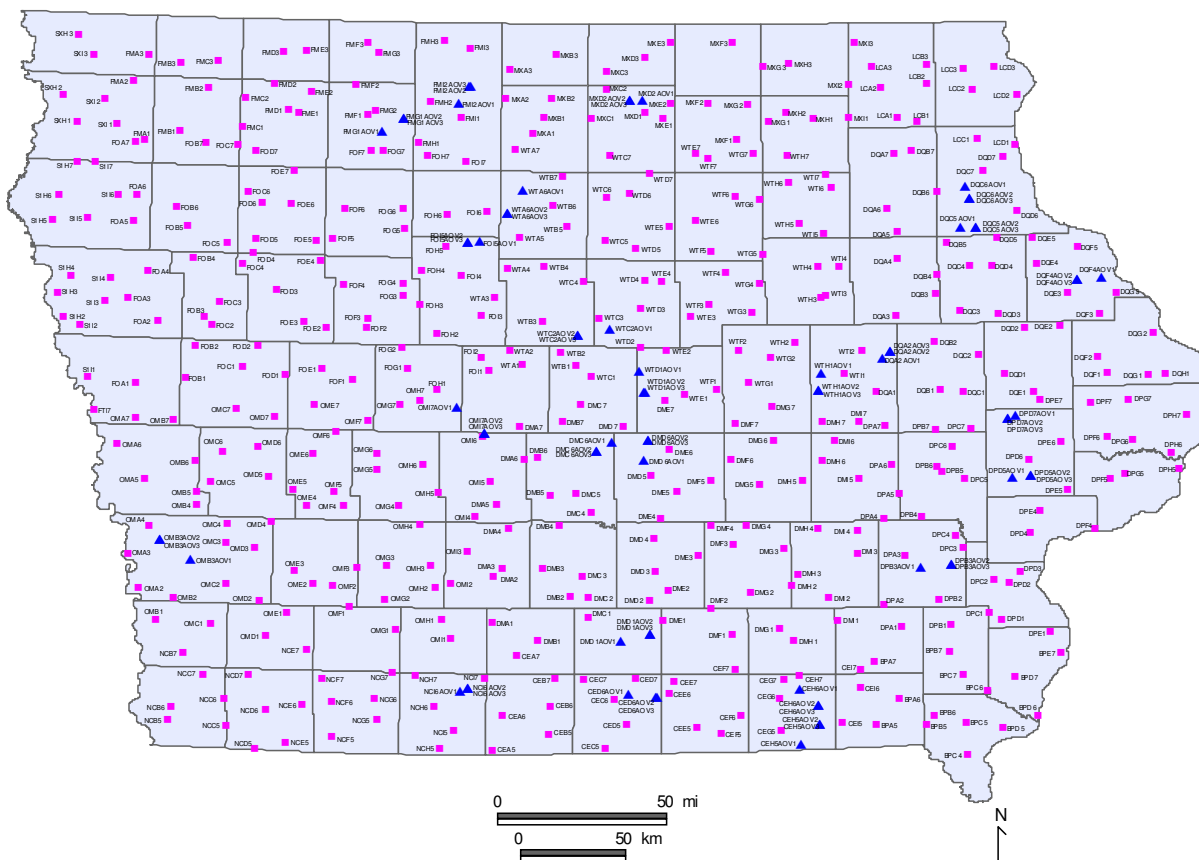
Trace Element Soil Sampling Sites in Iowa

■ Regular (463)
▲ Analysis of Varience (72)

Figure 5. Trace element soil sampling locations and site types in Iowa.

the students were not soil scientists, they usually used color as an indicator of soil horizon, with black or dark browns approximating the plow zone, and lighter grays and browns approximating less disturbed sediment below the plow zone. In the planning stages of the project, it was surmised that a depth of 12-24 inches was probably too shallow to assure that the sample would be collected below of the plow zone, but for practical and logistical purposes, this depth interval was used for the deep sample set.

Upon arrival at a sampling site, a sampling team would check and complete the top portion of the data collection form, including site identi-fication; site type, date and time in 24 hour for-mat, the collector's name or names, site weather conditions, landowner name, address, and tele-phone number, landowner contact date county name, quadrangle name, and township, range, and section to three quarter sections. After re-viewing the basic site selection criteria and se-lecting the exact sampling location, the GPS co-ordinates and latitude and longitude in degrees, minutes, and seconds were read from the GPS unit and recorded for the site, the location was marked on the field map, and the topographic elevation of the site was picked off the map and recorded on the form. The amount of relief of

the site in feet, site setting, landscape position, slope, type of vegetation, contamination degree, contamination potential, and contamination source were also recorded at this time.

One team member would take digital photographs of the site and label sample bags, as the other would auger or dig a hole to collect the sample. The site photographs usually included a view of the surrounding landscape and a view showing the soil to be sampled laid out on a tarp with the labeled sample bags and sometimes a scale adjacent to the soil. These images proved useful for identifying mislabeled sample bags and matching them with the correct sampling sites when the samples were inventoried, prior to shipping them to the lab. The images were usually stored in the camera with the site ID and sequence number, which were also recorded on the data collection sheets. The sample bags were labeled with the site name followed by a "D" to indicate deep, or an "S" to indicate shallow, using large block style letters written directly on the bags, rather than on the bag labels. This prevented problems that might occur if the labels became separated from the bags. The labeling for the AOV sites was the same as for the regular sites followed by AOV1, AOV2, or AOV3. An example would be the sample name CED6SAOV1.

The information recorded for each sample included the sample ID, bottom depth of the sampled interval in inches, the soil horizon, soil color, soil moisture, and drainage conditions. The soil to be sampled was laid out horizontally on a tarp, from the top to the bottom of the hole, as it was collected. When bagging the samples (one small and one large bag for each set), an attempt was made to avoid metal contamination by sampling the sediment that had the least contact with whatever implement was used to collect it.

For the analysis of variance sites, after the "AOV1" samples were collected within the designated quadrant of the cell, then one of the three other quadrants of the cell that were previously selected at random for "AOV2" and "AOV3" were collected about 10 feet apart, preferably within the same NRCS soil type. As mentioned, since the soil types were not predetermined, the sampling teams mostly relied on sampling similar landscape positions for the

AOV sample sets in an effort to collect the same NRSC soil type at all three sites.

SAMPLE TRACKING AND DATA ENTRY

After returning from field trips, the sample bags were stored on pallets at the IGWS Oakdale Rock Library and Research Facility. The USGS requested that the large bulk archival sample bags be packaged separately from the smaller geochemical analyses sample bags, so prior to shipping to the USGS storage facility in Denver, the bags were separated, inventoried by box and pallet number using a spreadsheet, then the packed cardboard boxes were put back on pallets and shrink rapped. The first shipment to the Denver storage facility departed from Oakdale on 08/11/03, and contained 1,046 sample sets from 523 sites. The second and final shipment to Denver departed on 08/22/03 and contained 24 sample sets from 12 sites. A copy of the sample inventory sheet was packed with the first shipment, and also emailed to the USGS on 08/11/03. An updated inventory sheet of all 1,070 sample sets was emailed to the USGS on 08/20/03.

The field parameters from the data collection sheets were entered into the project database using a visual Dbase® entry program developed by John Schmidt, a member of the IDNR ITB. The program used coded fields, and pull down menus as much as possible in an attempt to avoid data entry errors. The students were encouraged to enter their own data in order to encourage them to collect complete and legible information when in the field. As mentioned, the NRCS soil types for the sites could not be identified and entered into the database until the sample locations could be compared with a GIS coverage of the NRCS soil types. To accomplish this, the UTM x and y coordinates for each sample were entered into the database, then the Dbase® table was imported into Arc View® and used as an event theme. The NRCS soils coverage was then overlain by the point coverage event theme, to determine the soil type. The point coverage was also lain on topographic map coverages and aerial photographs to confirm and refine the sample locations and land surface elevations picked off the topographic field maps.

Once the location was confirmed, the UTM x and y coordinates were entered into the Iowa PLSS Township-Range-Section Generator on the IGWS website (www.igsb.uiowa.edu/getutm/), and the township, range, and section information to four quarter sections was generated and used to compare and refine the previously recorded location. On the rare occasions when the GPS units failed, or when the UTM coordinates recorded on the field sheets were obviously wrong, the x and y coordinates were picked off a topographic map coverage using ArcView®. The UTM coordinates could also be generated from township, range and section information by using the Iowa UTM coordinate generator on the IGWS website (www.igsb.uiowa.edu/gettrs/).

The digital cameras used in the field contained cards with only 16 megabytes of memory, so it was necessary to download the images to the IGWS computer network between trips to avoid overrunning the memory of the cards. As it turned out, the frequent downloads were beneficial, since the images were reviewed and properly renamed, if necessary, before too much time had passed and the details of site visits were forgotten.

The database and data collection sheets were checked for errors and completeness, and after corrections were made, copies of the data collection sheets were archived at the IGWS. At the request of the USGS, the original field sheets were shipped to Denver on 09/17/2003. A copy of the updated Iowa database was also emailed to the USGS at this time.

LABORATORY ANALYSES

After arriving in Denver, the samples were sieved by EMRG personnel to -100 mesh, then later analyzed for 40 elements using inductively coupled plasma-atomic emission spectrometry/acid dissolution (ICP40), and 6 elements using atomic absorption spectrometry (AA; Table 1). Arsenic and gold were analyzed for using both methods. All samples were analyzed by an approved laboratory, using standard methods and a U.S. Environmental Protection Agency (USEPA) approved quality assurance/quality control plan. Documentation concerning the analytical methods and database fields used for the

NGS is available from the USGS-NGS website at http://tin.er.usgs.gov/geochem/doc/analysis.htm.

For the Iowa Geochemical Survey, a complete set of analyses would include results for 463 shallow and 463 deep samples from the 463 regular sampling sites, and 72 shallow and 72 deep samples from the 24 AOV1, 24 AOV2, and 24 AOV3 sites. In addition, as part of a quality assurance, quality control plan, laboratory splits are made from the AOV3 samples by the contracting laboratory to test sample homogeneity. These replicate samples, which are identified as AOV4 samples, add 24 shallow and 24 deep sample analyses to the 1,070 field samples, for a total data set of 1,118 analyses.

The first set of Iowa soil sample analyses from the NGS was emailed from the EMRG to the IGWS in June 2004, and included a partial and unchecked set of 684 analyses of 345 deep samples and 339 shallow samples. Following a number of requests from the IGWS, an updated set containing 1,063 analyses of 531 deep samples and 532 shallow samples was emailed to the IGWS from the EMRG in September 2005. This data set contained 11 shallow and 11 deep AOV4 replicate analyses.

The latest and current set of analyses from the NGS was emailed to the IGWS in February 2006. At approximately the same time, the Iowa data set became available for downloading from the USGS-NGS website. This data set is essentially the same as the one received in September 2005, but includes nine additional NURE stream sediment samples that were collected in August 1979, and five stream sediment samples that were collected in July 2002 by personnel from the University of Illinois at Urbana-Champaign (UIUC). This possibly final data set is missing analyses for 13 shallow and 14 deep samples from 15 regular sites, and 1 shallow AOV1 sample, and 1 deep AOV3 sample (Table 2). Also missing are 13 shallow and 13 deep AOV4 analyses out of a possible 48. In total, there are 55 analyses, or 4.9% of a complete data set missing. By site type, this is equivalent to, 2.9% of the regular analyses, 2.1% of the AOV1 analyses, 2.1% of the AOV3 analyses, and 54% of the AOV4 replicate laboratory splits.

After numerous requests from the IGWS as to the status of the missing analyses, the EMRG has to date, not explained why the missing sam-

Table 1. Reporting limits and units used for the 40 elements analyzed for by inductively coupled plasma-atomic emission spectrometry/acid dissolution methods (ICP40), and the 6 elements analyzed for by atomic absorption spectrometry (AA) methods.

Constituents analyzed for using ICP 40 methods							
Element	Units	Lower limit	Upper limit	Element	Units	Lower limit	Upper limit
Aluminum	weight %	0.005	50	Holmium	ppm	4	5,000
Calcium	weight %	0.005	50	Lanthanum	ppm	2	50,000
Iron	weight %	0.02	25	Lead	ppm	4	50,000
Potassium	weight %	0.01	50	Lithium	ppm	2	50,000
Magnesium	weight %	0.005	5	Manganese	ppm	4	50,000
Sodium	weight %	0.005	50	Molybdenum	ppm	2	50,000
Phosphorus	weight %	0.005	50	Niobium	ppm	4	50,000
Titanium	weight %	0.005	25	Neodymium	ppm	9	50,000
Arsenic	ppm	10	50,000	Nickel	ppm	3	50,000
Barium	ppm	1	35,000	Scandium	ppm	2	50,000
Beryllium	ppm	1	5,000	Silver	ppm	2	10,000
Bismuth	ppm	10	50,000	Strontium	ppm	2	15,000
Cadmium	ppm	2	25,000	Tantalum	ppm	40	50,000
Cerium	ppm	5	50,000	Tin	ppm	5	50,000
Cobalt	ppm	2	25,000	Thorium	ppm	6	50,000
Chromium	ppm	2	25,000	Uranium	ppm	100	100,000
Copper	ppm	2	15,000	Vanadium	ppm	2	30,000
Europium	ppm	2	5,000	Yttrium	ppm	2	25,000
Gallium	ppm	4	50,000	Ytterbium	ppm	1	5,000
Gold	ppm	8	50,000	Zinc	ppm	2	15,000
Constituents analyzed for using AA methods							
Element	Units	Lower limit	Upper limit	Element	Units	Lower limit	Upper limit
Arsenic	ppm	0.6*	20*	Gold	ppb	1*	10,000*
Selenium	ppm	0.2*	4*	Palladium	ppb	1*	10,000*
Mercury	ppm	0.02*	1.8*	Platinum	ppb	0.5*	10,000*

ppm = parts per million; equivalent to miligrams per liter (mg/L)   ppb = parts per billion; equivalent to micrograms per liter (µg/L)

1ppm = 1 gram/tonne = 0.001 wt %   * = optimum concentration range

ples have not been processed, and has not confirmed whether or not these samples will be processed in the future. It also remains unclear as to why only one sample, DMG4D, out of the second shipment from Iowa of 24 sample sets from 12 sites, was processed and analyzed, while the remainder of the shipment was not. The EMRG did recently confirm that the missing AOV4 laboratory splits would not be processed in the future, due to a miscommunication between the EMRG and the contracting laboratory.

In order to make the Iowa data available and accessible to the public in a timely manner, the IGWS decided to utilize the existing data set, rather than wait for the missing analyses or con-

firmation that the missing analyses would or would not be forthcoming from the EMRG.

Iowa and National Geochemical Survey Data Sets

After reviewing the Iowa portion of the NGS data set, the IGWS decided to support a data set, which excludes the additional NURE and UIUC data, since these were analyses of stream sediments that were not collected by the IGWS for the Iowa study. The IGWS data set is available from the Iowa Geological and Water Survey Natural Resources Geographic Information System (NRGIS) Library at www.igsb.uiowa.edu/nrgislibx/ under the category of state-wide, geo-

Table 2. Iowa trace element soil samples that have not been analyzed. Also shown are site names, sample depths, site types, sampling dates, counties sampled, and shipment dates.

Site Name	Sample ID	Depth	Site Type	Sampling Date	County Name	Shipment Date
CED6AOV4	CED6DAOV4	Deep	AOV4	7/25/2003	Wayne	8/11/2003
CEH5AOV4	CEH5SAOV4	Shallow	AOV4	7/30/2003	Davis	8/11/2003
CEH6AOV4	CEH6DAOV4	Deep	AOV4	7/24/2003	Davis	8/11/2003
CEH6AOV4	CEH6SAOV4	Shallow	AOV4	7/24/2003	Davis	8/11/2003
DMA5	DMA5D	Deep	Regular	7/17/2003	Dallas	8/11/2003
DMA5	DMA5S	Shallow	Regular	7/17/2003	Dallas	8/11/2003
DMC6AOV4	DMC6SAOV4	Shallow	AOV4	7/14/2003	Polk	8/11/2003
DMD1AOV4	DMD1DAOV4	Deep	AOV4	7/29/2003	Lucus	8/11/2003
DMD1AOV1	DMD1SAOV1	Shallow	AOV1	7/30/2003	Lucus	8/11/2003
DMD1AOV4	DMD1SAOV4	Shallow	AOV4	7/29/2003	Lucus	8/11/2003
DMD6AOV4	DMD6DAOV4	Deep	AOV4	7/16/2003	Jasper	8/11/2003
DMD6AOV4	DMD6SAOV4	Shallow	AOV4	7/16/2003	Jasper	8/11/2003
DMD7	DMD7D	Deep	Regular	7/14/2003	Story	8/11/2003
DMF3	DMF3D	Deep	Regular	8/12/2003	Mahaska	8/22/2003
DMF3	DMF3S	Shallow	Regular	8/12/2003	Mahaska	8/22/2003
DMF4	DMF4D	Deep	Regular	8/9/2003	Mahaska	8/22/2003
DMF4	DMF4S	Shallow	Regular	8/9/2003	Mahaska	8/22/2003
DMF6	DMF6D	Deep	Regular	8/11/2003	Poweshiek	8/22/2003
DMF6	DMF6S	Shallow	Regular	8/11/2003	Poweshiek	8/22/2003
DMG4	DMG4S	Shallow	Regular	8/12/2003	Mahaska	8/22/2003
DMG5	DMG5D	Deep	Regular	8/11/2003	Poweshiek	8/22/2003
DMG5	DMG5S	Shallow	Regular	8/11/2003	Poweshiek	8/22/2003
DMG6	DMG6D	Deep	Regular	8/11/2003	Poweshiek	8/22/2003
DMG6	DMG6S	Shallow	Regular	8/11/2003	Poweshiek	8/22/2003
DMH5	DMH5D	Deep	Regular	8/11/2003	Poweshiek	8/22/2003
DMH5	DMH5S	Shallow	Regular	8/11/2003	Poweshiek	8/22/2003
DPB3AOV4	DPB3DAOV4	Deep	AOV4	6/3/2003	Washington	8/11/2003
DPB4	DPB4D	Deep	Regular	8/12/2003	Johnson	8/22/2003
DPB4	DPB4S	Shallow	Regular	8/12/2003	Johnson	8/22/2003
DPD7AOV4	DPD7SAOV4	Shallow	AOV4	7/1/2003	Cedar	8/11/2003
DPE5	DPE5D	Deep	Regular	8/14/2003	Cedar	8/22/2003
DPE5	DPE5S	Shallow	Regular	8/14/2003	Cedar	8/22/2003
DPE6	DPE6D	Deep	Regular	8/14/2003	Cedar	8/22/2003
DPE6	DPE6S	Shallow	Regular	8/14/2003	Cedar	8/22/2003
DPH5	DPH5D	Deep	Regular	8/14/2003	Scott	8/22/2003
DPH5	DPH5S	Shallow	Regular	8/14/2003	Scott	8/22/2003
DQA2AOV4	DQA2DAOV4	Deep	AOV4	8/4/2003	Benton	8/11/2003
DQC5AOV4	DQC5SAOV4	Shallow	AOV4	8/4/2003	Clayton	8/11/2003
DQC6AOV4	DQC6SAOV4	Shallow	AOV4	7/9/2003	Clayton	8/11/2003
DQF4AOV4	DQF4SAOV4	Shallow	AOV4	6/10/2003	Dubuque	8/11/2003
FMG1AOV4	FMG1DAOV4	Deep	AOV4	7/29/2003	Palo Alto	8/11/2003
FMI2AOV4	FMI2DAOV4	Deep	AOV4	6/16/2003	Kossuth	8/11/2003
FMI2AOV4	FMI2SAOV4	Shallow	AOV4	6/16/2003	Kossuth	8/11/2003
MXD2AOV4	MXD2DAOV4	Deep	AOV4	7/8/2003	Cerro Gordo	8/11/2003
MXD2AOV4	MXD2SAOV4	Shallow	AOV4	7/8/2003	Cerro Gordo	8/11/2003
NCG7	NCG7D	Deep	Regular	8/18/2003	Taylor	8/22/2003
NCG7	NCG7S	Shallow	Regular	8/18/2003	Taylor	8/22/2003
NCI6AOV3	NCI6DAOV3	Deep	AOV3	7/29/2003	Ringold	8/11/2003
NCI6AOV4	NCI6DAOV4	Deep	AOV4	7/29/2003	Ringold	8/11/2003
NCI6AOV4	NCI6SAOV4	Shallow	AOV4	7/29/2003	Ringold	8/11/2003
OMB3AOV4	OMB3DAOV4	Deep	AOV4	6/23/2003	Pottawattamie	8/11/2003
OMG4	OMG4D	Deep	Regular	6/30/2003	Guthrie	8/11/2003
WTA6AOV4	WTA6DAOV4	Deep	AOV4	7/9/2003	Wright	8/11/2003
WTA6AOV4	WTA6SAOV4	Shallow	AOV4	7/9/2003	Wright	8/11/2003
WTH1AOV4	WTH1DAOV4	Deep	AOV4	6/12/2003	Benton	8/11/2003

logic data. The USGS data set, which includes the additional NURE and UIUC analyses is available from the NGS website at http://tin.er.usgs.gov/geochem/select.php?place=fUS19&div=fips&map=on. The two data sets also vary somewhat in format and content, as the IGWS set contains more fields related to land-owner information, while the NGS set contains many additional fields related to stream parameters, stream sediments, hydrologic unit codes, sample preparation, and analyses methods.

PRELIMINARY RESULTS

Table 3 summarizes the preliminary results for the analyzed constituents from the Iowa soil samples. As mentioned, 40 elements were analyzed for using inductively coupled plasma-atomic emission spectrometry/acid dissolution (ICP40), and 6 elements were analyzed for using atomic absorption spectrometry (AA). Arsenic and gold were analyzed for using both methods. The elements aluminum, calcium, iron, potassium, magnesium, sodium, phosphorous, titanium, barium, cerium, cobalt, chromium, copper, gallium, lanthanum, lithium, manganese, niobium, nickel, lead, strontium, vanadium, yttrium, and zinc were detected in all samples analyzed by the ICP40 method. The elements gold, bismuth, holmium, tin, tantalum, and uranium were not detected in any of the samples analyzed by the ICP40 method. For other elements analyzed using the ICP40 method, silver was detected in 0.85% of all samples, arsenic in 47.7%, beryllium in 80.71%, cadmium in 0.38%, europium in 1.22%, molybdenum in 11.19%, neodymium and scandium in 99.91%, thorium in 99.53%, and ytterbium was detected in 99.72% of all samples analyzed.

For the elements analyzed for by AA methods, arsenic was detected in all samples, selenium in 96.61%, mercury in 96.99%, gold in 65.16%, palladium in 5.18%, and platinum was detected in 65.44% of all samples analyzed. In comparison, using the ICP40 method, arsenic was detected in only 47.70% of all samples, and as mentioned, gold was not detected in any of the samples. This significant difference is due to the lower detection limits of 0.6 ppm for arsenic and 1.0 ppb for gold using AA methods, versus lower detection limits of 10 ppm for arsenic and

8 ppm for gold using the ICP40 method. In addition, according to documentation from the NGS website (tin.er.usgs.gov/geochem/method.php), the quality of results for arsenic using the AA method is excellent, while the quality of results for arsenic using the ICP40 method is poor. For gold, the quality of results from using the AA method is very good, while the quality of results from using the ICP40 method is poor.

In order to compare the concentrations of aluminum, calcium, iron, potassium, magnesium, sodium, phosphorous, and titanium, which are shown as weight percent (wt%), with concentrations of elements shown in parts per million (ppm), the conversion is 1 ppm is equivalent to 1 gram/tonne which in turn is equivalent to 0.0001 wt%, or more simply, wt% x 10,000 = ppm. For example, the mean concentration of all samples for aluminum, 5.61 by wt%, is equivalent to 56,100 ppm. To compare the concentrations of gold, palladium and platinum, which are shown in parts per billion, with concentrations of elements shown in ppm, the conversion is 1 ppm = 1,000 ppb, or ppb/1,000 = ppm.

Geochemical Contour Maps

Geochemical contour maps for all analyzed constituents with at least one detection were made using the spatial analyst tools in ArcGIS[®] 9 (figures 6-43). The locations of samples with detectable concentrations of constituents are shown with a red symbol, while the locations of samples with non-detectable concentrations of constituents are shown with a green symbol. The mapped constituent, method of analysis, and lower detection limit for the constituent are shown for each sample set, with the shallow (0-8 inches) sample set map shown above the deep (12-24 inches) sample set map on each figure.

The purpose of this report is to describe the design and implementation of the Iowa State-Wide Trace Element Soil Sampling Project, and the acquisition and compilation of the resulting data. The most potentially interesting aspects of the project, the analysis and interpretation of the data, will be discussed in a subsequent report(s).

A preliminary overview of the geochemical contour maps of the individual trace elements reveals that while the mean concentrations for the shallow and deep sample sets are often simi-

Table 3. Summary of results, including units and analytical methods, for the analyzed constituents from the Iowa soil samples. Shown are the mean, median, number of non-detections, percent of analyte detected, minimum and maximum concentration detected, standard deviation, and number of samples, for all samples, shallow samples, and deep samples.

Constituent Units Analytical method	Aluminum wt% AL_ICP40	Calcium wt% CA_ICP40	Iron wt% FE_ICP40	Potassium wt% K_ICP40	Magnesium wt% MG_ICP40	Sodium wt% NA_ICP40	Phosphorous wt% P_ICP40	Titanium wt% TI_ICP40
Mean of all samples	5.61	*0.96*	2.51	1.64	0.60	**0.81**	0.07	0.29
Median of all samples	5.58	0.67	2.50	**1.65**	0.55	0.80	0.06	*0.29*
Number of non-detections for all samples	0	0	0	0	0	0	0	0
% of analyte detected in all samples	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Minimum concentration for all samples	2.59	0.29	0.68	0.69	0.15	0.35	0.02	0.06
Maximum concentration for all samples	15.11	9.79	8.96	2.68	5.66	2.26	0.31	1.27
Standard deviation for all samples	0.86	0.95	0.55	0.20	0.33	0.14	0.03	0.05
Number of all samples	1063	1063	1063	1063	1063	1063	1063	1063
Mean of shallow samples	*5.39*	**0.97**	2.34	1.64	*0.57*	*0.80*	**0.08**	*0.28*
Median of shallow samples	*5.37*	**0.71**	2.37	*1.64*	0.52	0.80	**0.07**	0.29
Number of non-detections for shallow samples	0	0	0	0	0	0	0	0
% of analyte detected in shallow samples	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Minimum concentration for shallow samples	**2.68**	**0.34**	**0.99**	**0.95**	**0.22**	**0.46**	0.02	**0.12**
Maximum concentration for shallow samples	14.55	**9.79**	4.09	2.16	5.65	1.36	**0.31**	*0.38*
Standard deviation for shallow samples	*0.76*	*0.86*	*0.43*	*0.19*	*0.31*	*0.11*	0.03	*0.03*
Number of shallow samples	532	532	532	532	532	532	532	532
Mean of deep samples	**5.84**	*0.96*	**2.67**	1.64	**0.64**	**0.81**	*0.06*	**0.30**
Median of deep samples	**5.83**	*0.64*	**2.67**	**1.65**	**0.59**	0.80	*0.05*	**0.30**
Number of non-detections for deep samples	0	0	0	0	0	0	0	0
% of analyte detected in deep samples	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Minimum concentration for deep samples	*2.59*	*0.29*	*0.68*	*0.69*	*0.15*	*0.35*	0.02	*0.06*
Maximum concentration for deep samples	**15.11**	8.73	**8.96**	2.68	5.66	2.26	*0.25*	**1.27**
Standard deviation for deep samples	**0.90**	**1.02**	**0.60**	**0.21**	**0.35**	**0.16**	0.03	**0.06**
Number of deep samples	531	531	531	531	531	531	531	531

ppm = parts per million; equivalent to miligrams per liter (mg/L)   ppb = parts per billion; equivalent to micrograms per liter (µg/L)   1ppm = 1 gram/tonne = 0.001 wt %

nd = non detection   Bold numbers are the highest values, and italic numbers are the lowest values, of comparable data for each parameter from the shallow and deep sample sets.

lar, there can be significant differences in the spatial distribution of the elements from the shallow and deep sample sets. The maps for the shallow sample sets for titanium, cerium, and lanthanum display patterns of lower trace element concentrations that roughly outline the Des Moines Lobe landform region. The maps for barium and potassium show groupings of higher trace element concentrations in western Iowa in the proximity of the Missouri Alluvial Plain and Loess Hills landform regions. Yttrium and ytterbium trace element concentrations tend to be higher in areas just east of the Loess Hills, and the shallow sample sets for nickel and vanadium concentrations also tend to be higher in western Iowa, east and north of the Loess Hills. The trace element concentrations for niobium, neodymium, thorium and arsenic tend to be higher in areas of the Northwest Iowa Plains and Southern Iowa Drift Plain landform regions. The anomalously high lead concentration (1,450 ppm) found in the deep sample set in Plymouth County may be due to a fragment of lead shot, according to the lab that did the trace element analyses.

Some things to consider for analysis and interpretation of the data might include looking at the spatial distribution of individual trace elements and comparing them with other trace elements (ratios) and groups of trace elements in an effort to discover possible relationships. The distribution of the trace elements and ratios of trace elements could also be examined within geomorphic, geologic, and hydrologic frameworks to see if relationships within these environments exist. It may also be interesting to analyze differences in concentrations and spatial distribution between the shallow and deep sample sets for each trace element. It is possible that the distribution of trace elements may be related to differing soil types, various landform settings, the distribution of varying types of underlying unconsolidated materials and various underlying rock compositions. A USGS aeroradiometric

Table 3. Continued

Constituent Units Analytical method	Silver ppm AG_ICP40	Arsenic ppm AS_ICP40	Gold ppm AU_ICP40	Barium ppm BA_ICP40	Beryllium ppm BE_ICP40	Bismuth ppm BI_ICP40	Cadmium ppm CD_ICP40	Cerium ppm CE_ICP40
Mean of all samples	1.02	8.50	4.00	638.19	1.15	25.00	**1.01**	63.67
Median of all samples	1.00	*5.00*	4.00	635.00	1.00	25.00	1.00	64.00
Number of non-detections for all samples	1054	556	1063	0	205	1063	1059	0
% of analyte detected in all samples	0.85	47.70	0.00	100.00	80.71	0.00	0.38	100.00
Minimum concentration for all samples	nd	nd	nd	298.00	nd	nd	nd	13.00
Maximum concentration for all samples	6.00	23.00	nd	1110.00	4.00	nd	3.00	350.00
Standard deviation for all samples	*0.26*	3.89	0.00	98.35	0.53	0.00	0.10	12.37
Number of all samples	1063	1063	1063	1063	1063	1063	1063	1063
Mean of shallow samples	1.02	*7.76*	4.00	*632.73*	*1.08*	25.00	**1.01**	*62.13*
Median of shallow samples	1.00	*5.00*	4.00	*626.00*	1.00	25.00	1.00	*63.00*
Number of non-detections for shallow samples	528	321	532	0	116	532	529	0
% of analyte detected in shallow samples	*0.75*	*39.66*	0.00	100.00	*78.20*	0.00	**0.56**	100.00
Minimum concentration for shallow samples	nd	nd	nd	304.00	nd	nd	nd	27.00
Maximum concentration for shallow samples	6.00	*21.00*	nd	*857.00*	*2.00*	nd	**3.00**	87.00
Standard deviation for shallow samples	**0.27**	3.58	0.00	*89.37*	*0.49*	0.00	**0.13**	*7.74*
Number of shallow samples	532	532	532	532	532	532	532	532
Mean of deep samples	1.02	**9.24**	4.00	**643.67**	**1.22**	25.00	*1.00*	**65.23**
Median of deep samples	1.00	**10.00**	4.00	**642.00**	1.00	25.00	1.00	**65.00**
Number of non-detections for deep samples	526	235	531	0	89	531	530	0
% of analyte detected in deep samples	**0.94**	**55.74**	0.00	100.00	**83.24**	0.00	*0.19*	100.00
Minimum concentration for deep samples	nd	nd	nd	298.00	nd	nd	nd	13.00
Maximum concentration for deep samples	6.00	**23.00**	nd	**1110.00**	**4.00**	nd	*2.00*	**350.00**
Standard deviation for deep samples	*0.26*	**4.04**	0.00	**106.40**	**0.56**	0.00	*0.04*	**15.55**
Number of deep samples	531	531	531	531	531	531	531	531

ppm = parts per million; equivalent to miligrams per liter (mg/L)   ppb = parts per billion; equivalent to micrograms per liter (µg/L)   1ppm = 1 gram/tonne = 0.001 wt %

nd = non detection   Bold numbers are the highest values, and italic numbers are the lowest values, of comparable data for each parameter from the shallow and deep sample sets.

Constituent Units Analytical method	Cobalt ppm CO_ICP40	Chromium ppm CR_ICP40	Copper ppm CU_ICP40	Europium ppm EU_ICP40	Gallium ppm GA_ICP40	Holmium ppm HO_ICP40	Lanthanum ppm LA_ICP40	Lithium ppm LI_ICP40
Mean of all samples	9.48	33.33	18.50	1.02	14.26	2.00	32.58	23.80
Median of all samples	*9.00*	35.00	18.00	1.00	14.00	2.00	33.00	23.00
Number of non-detections for all samples	0	0	0	1050	0	1063	0	0
% of analyte detected in all samples	100.00	100.00	100.00	1.22	100.00	0.00	100.00	100.00
Minimum concentration for all samples	3.00	4.00	2.00	nd	6.00	nd	7.00	5.00
Maximum concentration for all samples	74.00	257.00	101.00	3.00	25.00	nd	74.00	65.00
Standard deviation for all samples	3.37	13.24	6.01	0.14	2.30	0.00	4.29	5.19
Number of all samples	1063	1063	1063	1063	1063	1063	1063	1063
Mean of shallow samples	*8.94*	*33.03*	*18.10*	*1.00*	*13.54*	2.00	*32.04*	*22.48*
Median of shallow samples	*9.00*	**36.00**	18.00	1.00	*13.00*	2.00	*32.00*	*22.00*
Number of non-detections for shallow samples	0	0	0	530	0	532	0	0
% of analyte detected in shallow samples	100.00	100.00	100.00	*0.38*	100.00	0.00	100.00	100.00
Minimum concentration for shallow samples	3.00	*4.00*	**6.00**	nd	6.00	nd	**13.00**	**7.00**
Maximum concentration for shallow samples	*19.00*	*56.00*	**101.00**	*2.00*	*20.00*	nd	*45.00*	*44.00*
Standard deviation for shallow samples	*1.90*	*10.74*	*5.96*	*0.06*	*1.86*	0.00	*3.81*	*4.20*
Number of shallow samples	532	532	532	532	532	532	532	532
Mean of deep samples	**10.02**	**33.63**	**18.90**	**1.03**	**14.99**	2.00	**33.13**	**25.12**
Median of deep samples	**10.00**	*34.00*	18.00	1.00	**15.00**	2.00	**34.00**	**25.00**
Number of non-detections for deep samples	0	0	0	520	0	531	0	0
% of analyte detected in deep samples	100.00	100.00	100.00	**2.07**	100.00	0.00	100.00	100.00
Minimum concentration for deep samples	3.00	**6.00**	*2.00*	nd	6.00	nd	*7.00*	*5.00*
Maximum concentration for deep samples	**74.00**	**257.00**	*84.00*	**3.00**	**25.00**	nd	**74.00**	**65.00**
Standard deviation for deep samples	**4.30**	**15.36**	**6.04**	**0.19**	**2.46**	0.00	**4.67**	**5.72**
Number of deep samples	531	531	531	531	531	531	531	531

ppm = parts per million; equivalent to miligrams per liter (mg/L)   ppb = parts per billion; equivalent to micrograms per liter (µg/L)   1ppm = 1 gram/tonne = 0.001 wt %

nd = non detection   Bold numbers are the highest values, and italic numbers are the lowest values, of comparable data for each parameter from the shallow and deep sample sets.

Table 3. Continued

Constituent Units Analytical method	Manganese ppm MN_ICP40	Molybdenum ppm MO_ICP40	Niobium ppm NB_ICP40	Neodymium ppm ND_ICP40	Nickel ppm NI_ICP40	Lead ppm PB_ICP40	Scandium ppm SC_ICP40	Tin ppm SN_ICP40
Mean of all samples	744.54	1.24	16.49	26.28	24.00	20.86	7.58	25.00
Median of all samples	737.00	1.00	16.00	27.00	23.00	19.00	8.00	25.00
Number of non-detections for all samples	0	944	0	1	0	0	1	1063
% of analyte detected in all samples	100.00	11.19	100.00	99.91	100.00	100.00	99.91	0.00
Minimum concentration for all samples	124.00	nd	5.00	nd	7.00	8.00	nd	nd
Maximum concentration for all samples	2440.00	6.00	52.00	54.00	173.00	1450*	22.00	nd
Standard deviation for all samples	242.79	0.72	3.03	3.86	7.43	44.52	1.37	0.00
Number of all samples	1063	1063	1063	1063	1063	1063	1063	1063
Mean of shallow samples	761.07	1.21	15.97	25.71	22.51	20.72	7.17	25.00
Median of shallow samples	762.50	1.00	16.00	26.00	22.00	19.00	7.00	25.00
Number of non-detections for shallow samples	0	482	0	0	0	0	0	532
% of analyte detected in shallow samples	100.00	9.40	100.00	100.00	100.00	100.00	100.00	0.00
Minimum concentration for shallow samples	205.00	nd	9.00	11.00	10.00	8.00	3.00	nd
Maximum concentration for shallow samples	2040.00	5.00	23.00	39.00	42.00	109.00	11.00	nd
Standard deviation for shallow samples	219.73	0.68	2.52	3.34	4.70	8.82	1.08	0.00
Number of shallow samples	532	532	532	532	532	532	532	532
Mean of deep samples	727.97	1.27	17.01	26.85	25.50	21.00	7.99	25.00
Median of deep samples	713.00	1.00	17.00	27.00	25.00	18.00	8.00	25.00
Number of non-detections for deep samples	0	462	0	1	0	0	1	531
% of analyte detected in deep samples	100.00	12.99	100.00	99.81	100.00	100.00	99.81	0.00
Minimum concentration for deep samples	124.00	nd	5.00	nd	7.00	8.00	nd	nd
Maximum concentration for deep samples	2440.00	6.00	52.00	54.00	173.00	1450*	22.00	nd
Standard deviation for deep samples	263.05	0.75	3.39	4.25	9.16	62.41	1.50	0.00
Number of deep samples	531	531	531	531	531	531	531	531

ppm = parts per million; equivalent to miligrams per liter (mg/L)   ppb = parts per billion; equivalent to micrograms per liter (µg/L)   1ppm = 1 gram/tonne = 0.001 wt %

nd = non detection   Bold numbers are the highest values, and italic numbers are the lowest values, of comparable data for each parameter from the shallow and deep sample sets.

Constituent Units Analytical method	Strontium ppm SR_ICP40	Tantalum ppm TA_ICP40	Thorium ppm TH_ICP40	Uranium ppm U_ICP40	Vanadium ppm V_ICP40	Yttrium ppm Y_ICP40	Ytterbium ppm YB_ICP40	Zinc ppm ZN_ICP40
Mean of all samples	131.92	20.00	11.35	50.00	91.07	17.47	2.07	69.06
Median of all samples	127.00	20.00	11.00	50.00	91.00	17.00	2.00	67.00
Number of non-detections for all samples	0	1063	5	1063	0	0	3	0
% of analyte detected in all samples	100.00	0.00	99.53	0.00	100.00	100.00	99.72	100.00
Minimum concentration for all samples	63.00	nd	nd	nd	18.00	4.00	nd	15.00
Maximum concentration for all samples	649.00	nd	31.00	nd	253.00	30.00	4.00	288.00
Standard deviation for all samples	28.19	0.00	1.79	0.00	19.39	2.67	0.37	20.63
Number of all samples	1063	1063	1063	1063	1063	1063	1063	1063
Mean of shallow samples	129.22	20.00	11.11	50.00	85.64	16.95	2.02	71.04
Median of shallow samples	126.00	20.00	11.00	50.00	85.00	17.00	2.00	67.00
Number of non-detections for shallow samples	0	532	2	532	0	0	2	0
% of analyte detected in shallow samples	100.00	0.00	99.62	0.00	100.00	100.00	99.62	100.00
Minimum concentration for shallow samples	76.00	nd	nd	nd	31.00	8.00	nd	26.00
Maximum concentration for shallow samples	249.00	nd	15.00	nd	139.00	24.00	3.00	288.00
Standard deviation for shallow samples	20.22	0.00	1.49	0.00	16.25	2.39	0.30	24.54
Number of shallow samples	532	532	532	532	532	532	532	532
Mean of deep samples	134.64	20.00	11.60	50.00	96.50	17.98	2.12	67.08
Median of deep samples	129.00	20.00	12.00	50.00	96.00	18.00	2.00	66.00
Number of non-detections for deep samples	0	531	3	531	0	0	1	0
% of analyte detected in deep samples	100.00	0.00	99.44	0.00	100.00	100.00	99.81	100.00
Minimum concentration for deep samples	63.00	nd	nd	nd	18.00	4.00	nd	15.00
Maximum concentration for deep samples	649.00	nd	31.00	nd	253.00	30.00	4.00	162.00
Standard deviation for deep samples	34.17	0.00	2.02	0.00	20.74	2.84	0.43	15.55
Number of deep samples	531	531	531	531	531	531	531	531

ppm = parts per million; equivalent to miligrams per liter (mg/L)   ppb = parts per billion; equivalent to micrograms per liter (µg/L)   1ppm = 1 gram/tonne = 0.001 wt %

nd = non detection   Bold numbers are the highest values, and italic numbers are the lowest values, of comparable data for each parameter from the shallow and deep sample sets.

Table 3. Continued

Constituent Units Analytical method	Arsenic ppm AS_AA	Selenium ppm SE_AA	Mercury ppm HG_AA	Gold ppb AU_AA	Palladium ppb PD_AA	Platinum ppb PT_AA
Mean of all samples	9.19	0.53	0.03	2.04	0.60	0.73
Median of all samples	9.00	0.50	0.03	*1.00*	0.50	**0.70**
Number of non-detections for all samples	0	36	32	370	1007	131
% of analyte detected in all samples	100.00	96.61	96.99	65.16	5.18	65.44
Minimum concentration for all samples	1.00	nd	nd	nd	nd	nd
Maximum concentration for all samples	21.70	2.80	0.40	112.00	21.00	5.60
Standard deviation for all samples	3.03	0.21	*0.02*	4.19	0.84	0.56
Number of all samples	1063	1063	1063	1062	1062	379
Mean of shallow samples	*8.72*	**0.56**	0.03	*1.89*	*0.54*	*0.70*
Median of shallow samples	*8.40*	0.50	0.03	*1.00*	0.50	*0.60*
Number of non-detections for shallow samples	0	8	13	201	508	71
% of analyte detected in shallow samples	100.00	**98.50**	97.56	*62.22*	4.51	*63.21*
Minimum concentration for shallow samples	**2.20**	nd	nd	nd	nd	nd
Maximum concentration for shallow samples	*18.50*	*1.40*	**0.40**	*34.00*	*3.00*	*3.00*
Standard deviation for shallow samples	*2.70*	*0.18*	**0.03**	*2.47*	*0.23*	*0.51*
Number of shallow samples	532	532	532	532	532	193
Mean of deep samples	**9.67**	*0.50*	0.03	**2.20**	**0.66**	**0.75**
Median of deep samples	**9.50**	0.50	0.03	**2.00**	0.50	**0.70**
Number of non-detections for deep samples	0	28	19	169	499	60
% of analyte detected in deep samples	100.00	*94.73*	96.42	**68.11**	5.85	**67.74**
Minimum concentration for deep samples	1.00	nd	nd	nd	nd	nd
Maximum concentration for deep samples	**21.70**	**2.80**	*0.21*	**112.00**	**21.00**	**5.60**
Standard deviation for deep samples	**3.25**	**0.23**	*0.02*	**5.39**	**1.16**	0.60
Number of deep samples	531	531	531	530	530	186

ppm = parts per million; equivalent to miligrams per liter (mg/L)   ppb = parts per billion; equivalent to micrograms per liter (µg/L)   1ppm = 1 gram/tonne = 0.001 wt %

nd = non detection   Bold numbers are the highest values, and italic numbers are the lowest values, of comparable data for each parameter from the shallow and deep sample sets.

survey of North America generated data from aerial sensing of gamma-ray radiation emanating from the earth's surface (http://tin.er.usgs.gov/radiometric/). The survey was intended to provide general estimates of the geographic distribution of uranium, thorium, and potassium in surficial and bedrock units. A color composite image of the data, made by combining separate color bands for each element reveals a variety of landforms across the US, and within Iowa, the Des Moines Lobe and Iowan Surface landform regions are clearly visible (www.igsb.uiowa.edu/browse/landform.htm).

The delineation of relationships between the spatial distribution of trace elements and landform regions, as well as possible relationships with soil types and the underlying unconsolidated and consolidated parent materials would probably be enhanced by the comparison of combinations and ratios of trace elements with these features, rather than by comparison of the individual trace elements with the features.

The timing of igneous, volcanic, and metamorphic activity generating parent material, type and source area of parent material, mode of erosion, climactic and weathering conditions, mode and distance of travel, length of transport time, depositional environment of sediments, structural changes in geology and depositional environment, and current and past in situ soil conditions are a few factors that may influence the spatial distribution and concentration of trace elements.
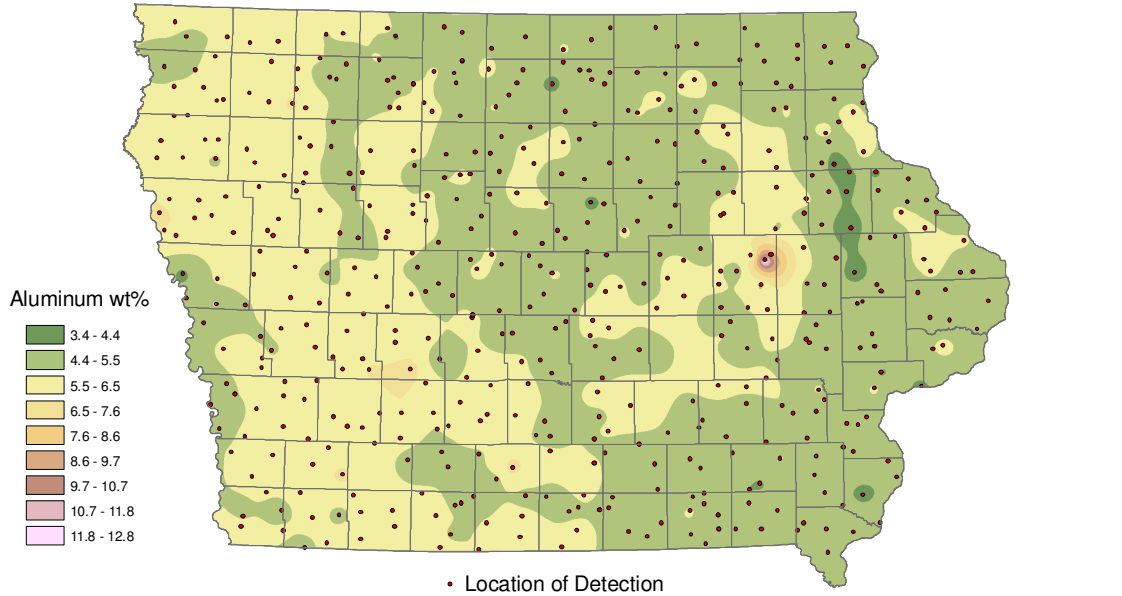
FINAL COMMENTS

Because of growing public concern about environmental contamination, it is becoming increasingly important to better understand the natural and human processes that control the movement of elements at the land surface. When water comes into contact with rocks and soils, some of the minerals dissolve and enter the water. The resulting elements can be quite mobile in water, resulting in environmental problems associated with the contamination of surface and groundwater.

Natural sources of chemical elements include rocks, volcanoes, sediments, and soils. Human activities that may add chemical elements to the

Aluminum Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Aluminum wt%
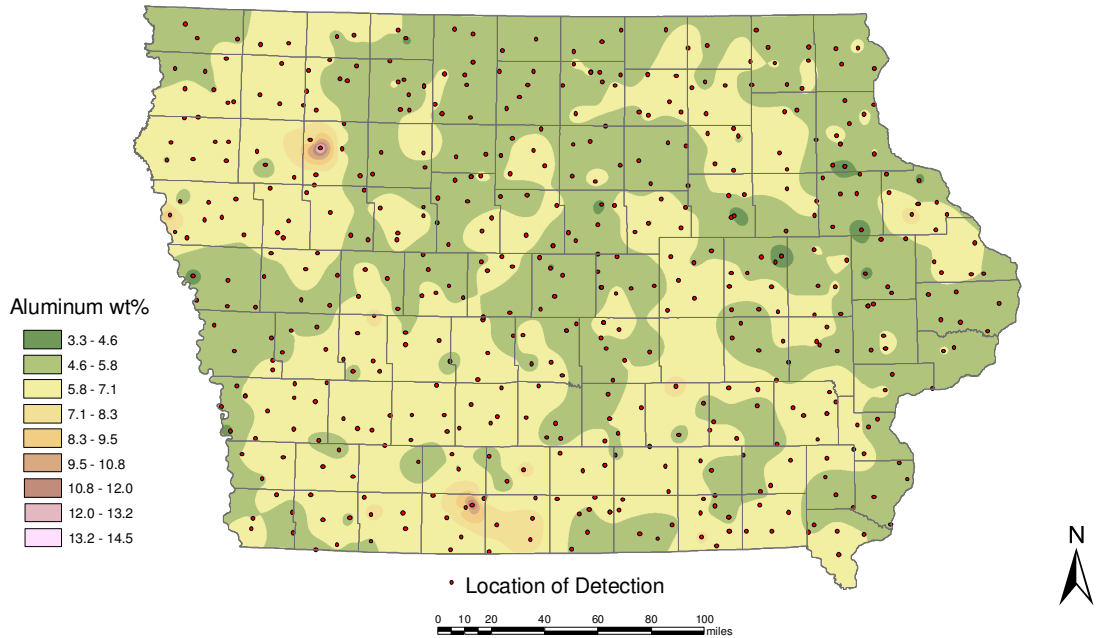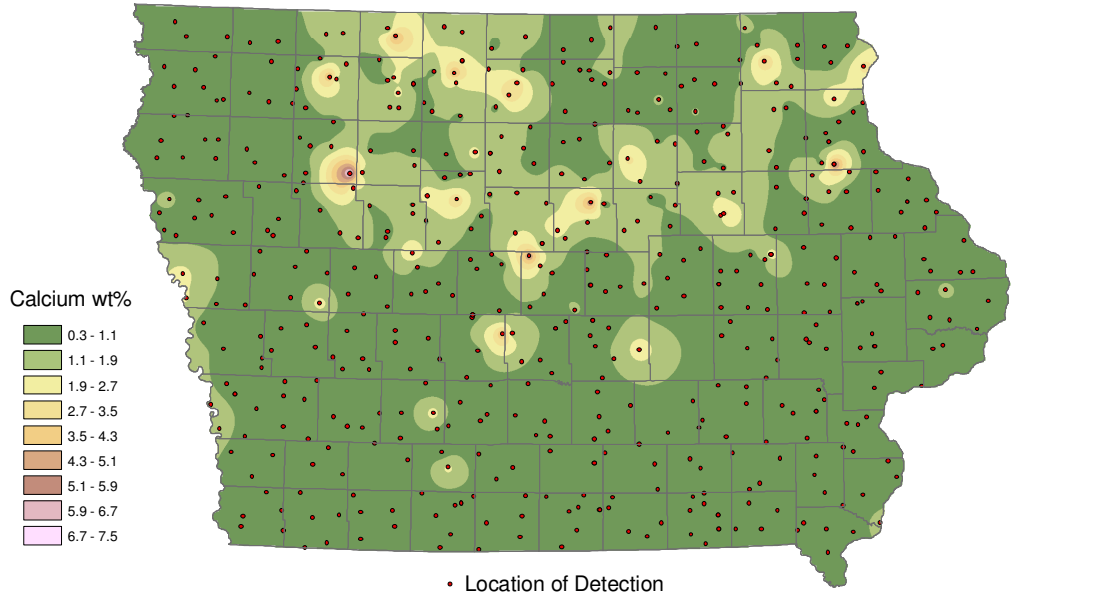
- 3.4 - 4.4
- 4.4 - 5.5
- 5.5 - 6.5
- 6.5 - 7.6
- 7.6 - 8.6
- 8.6 - 9.7
- 9.7 - 10.7
- 10.7 - 11.8
- 11.8 - 12.8

• Location of Detection

Lower Detection Limit = 0.005 wt%

Deep Sample Set

Aluminum wt%

- 3.3 - 4.6
- 4.6 - 5.8
- 5.8 - 7.1
- 7.1 - 8.3
- 8.3 - 9.5
- 9.5 - 10.8
- 10.8 - 12.0
- 12.0 - 13.2
- 13.2 - 14.5

• Location of Detection

N

0 10 20 40 60 80 100 miles

Figure 6. Contour maps of aluminum concentrations in weight % from the shallow and deep sample sets in Iowa.

22

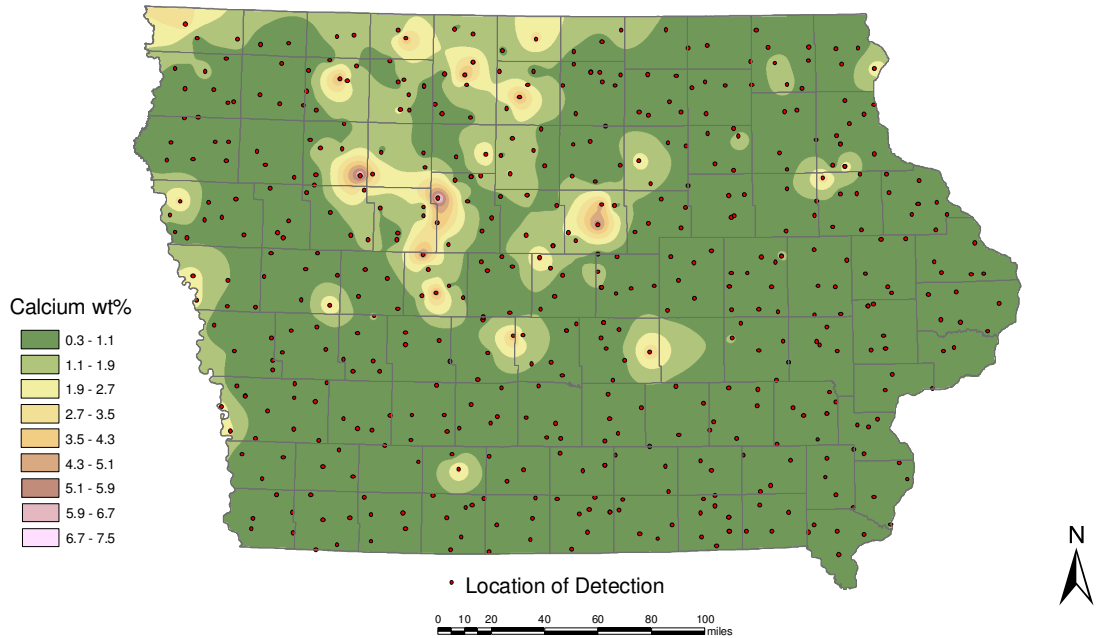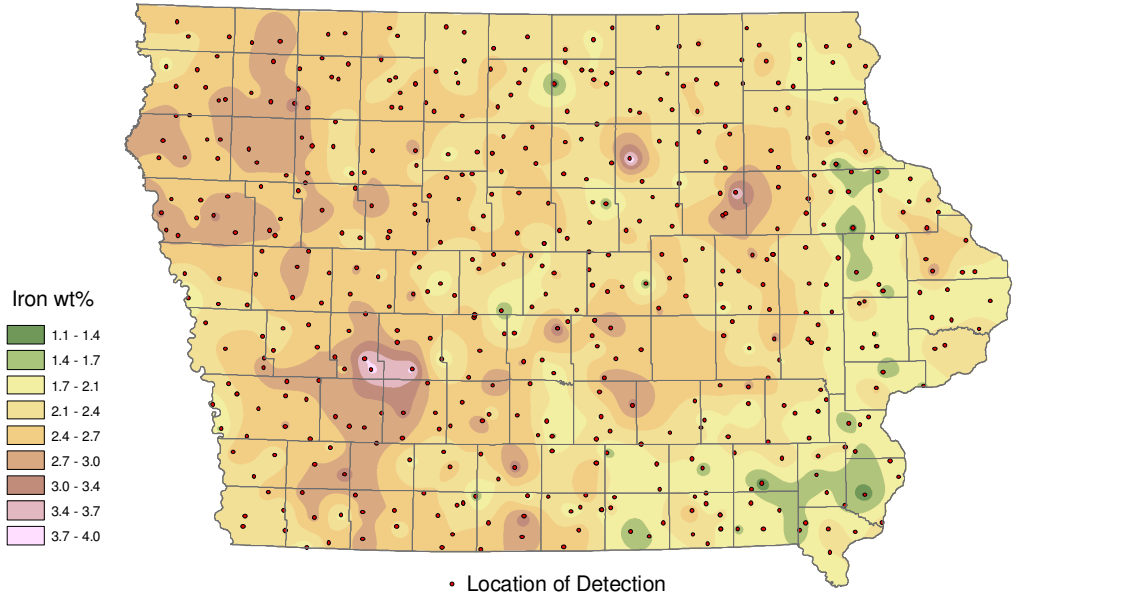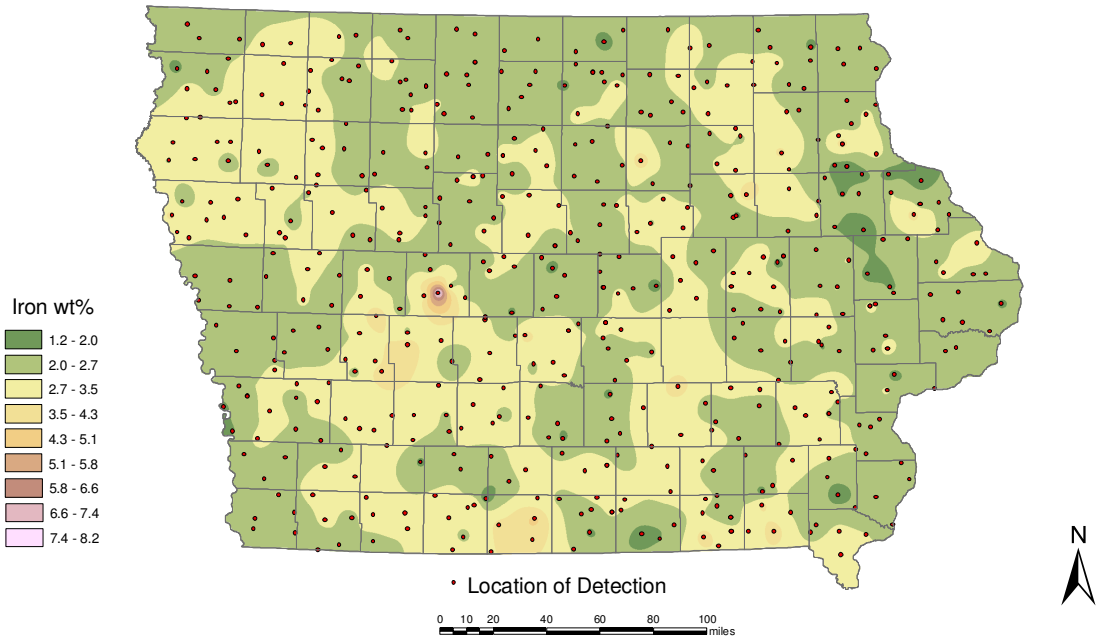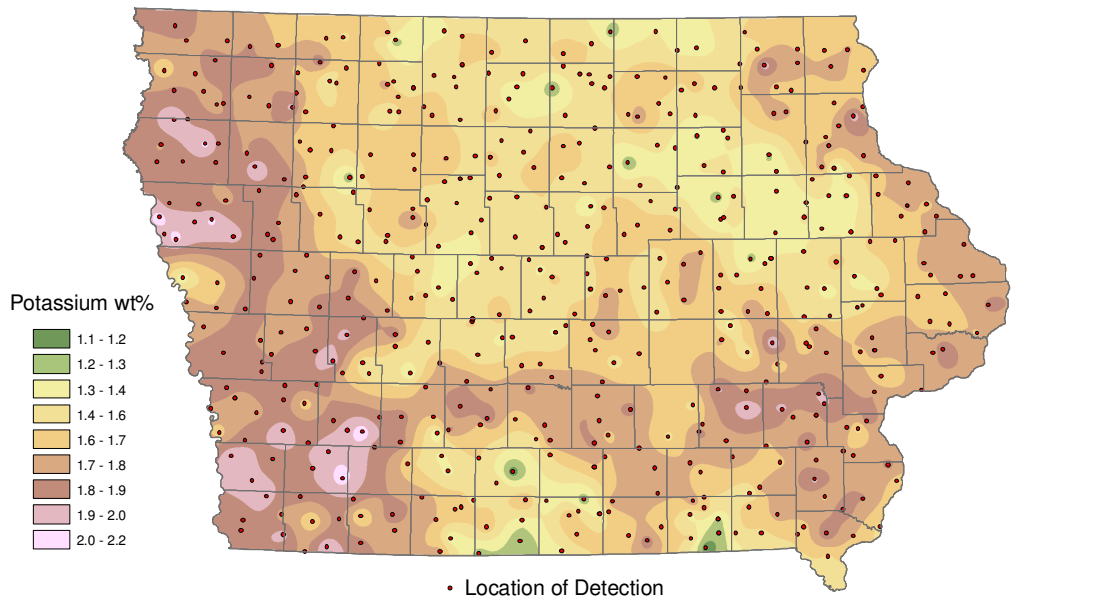# Calcium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Calcium wt%

- 0.3 - 1.1
- 1.1 - 1.9
- 1.9 - 2.7
- 2.7 - 3.5
- 3.5 - 4.3
- 4.3 - 5.1
- 5.1 - 5.9
- 5.9 - 6.7
- 6.7 - 7.5

• Location of Detection

Lower Detection Limit = 0.005 wt%

Deep Sample Set

Calcium wt%

- 0.3 - 1.1
- 1.1 - 1.9
- 1.9 - 2.7
- 2.7 - 3.5
- 3.5 - 4.3
- 4.3 - 5.1
- 5.1 - 5.9
- 5.9 - 6.7
- 6.7 - 7.5

• Location of Detection
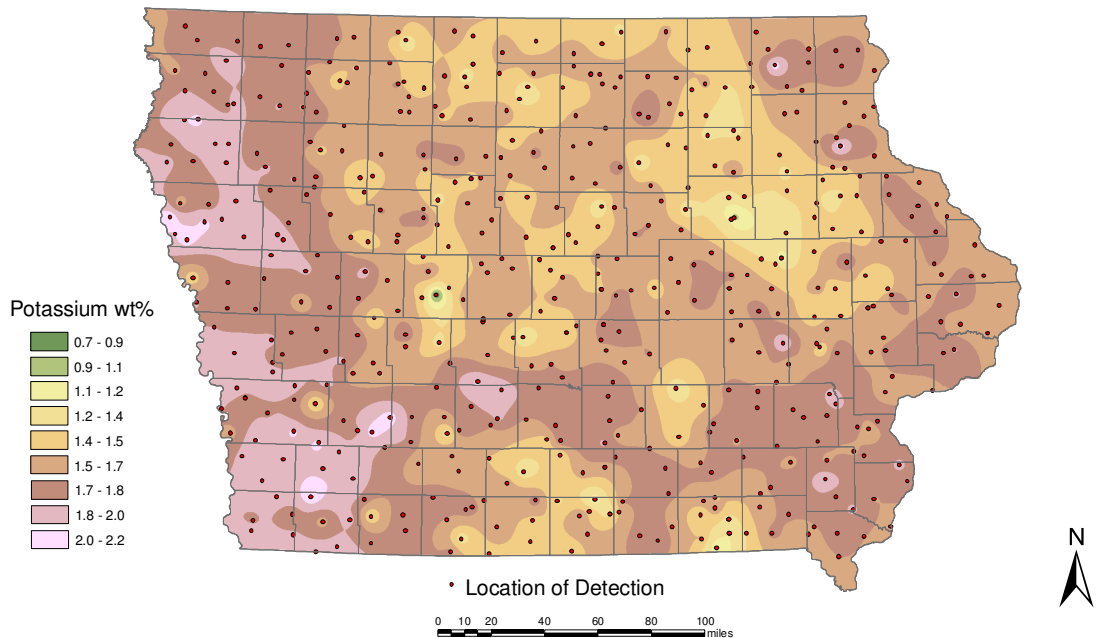
N

0 10 20   40   60   80   100
miles

Figure 7. Contour maps of calcium concentrations in weight % from the shallow and deep sample sets in Iowa.

Iron Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Iron wt%

- 1.1 - 1.4
- 1.4 - 1.7
- 1.7 - 2.1
- 2.1 - 2.4
- 2.4 - 2.7
- 2.7 - 3.0
- 3.0 - 3.4
- 3.4 - 3.7
- 3.7 - 4.0

• Location of Detection

Lower Detection Limit = 0.02 wt%

Deep Sample Set

Iron wt%

- 1.2 - 2.0
- 2.0 - 2.7
- 2.7 - 3.5
- 3.5 - 4.3
- 4.3 - 5.1
- 5.1 - 5.8
- 5.8 - 6.6
- 6.6 - 7.4
- 7.4 - 8.2

• Location of Detection

N

0 10 20 40 60 80 100 miles

Figure 8. Contour maps of iron concentrations in weight % from the shallow and deep sample sets in Iowa.

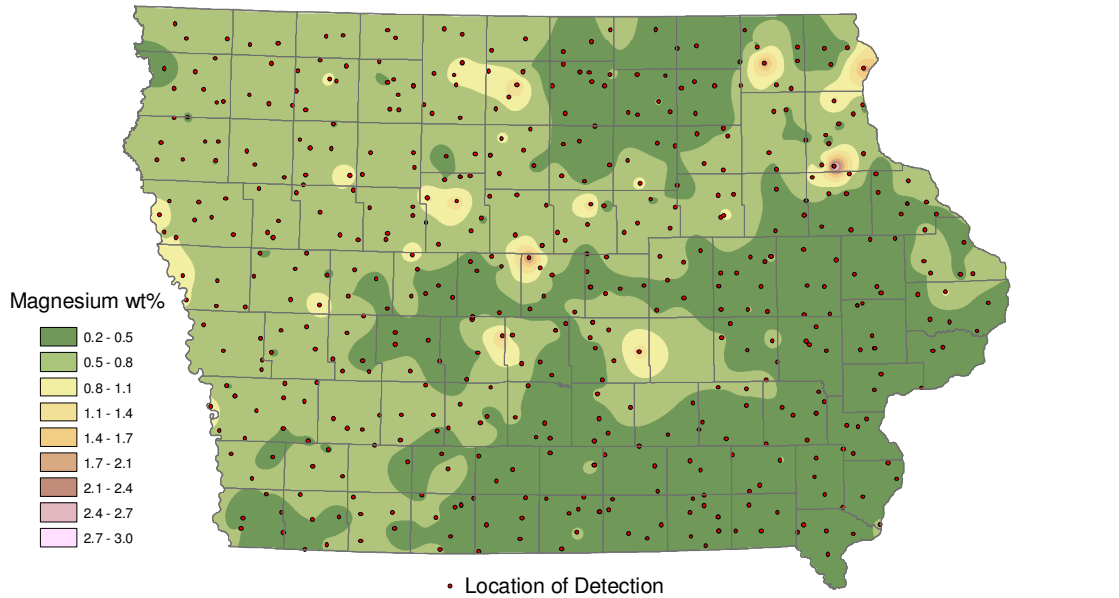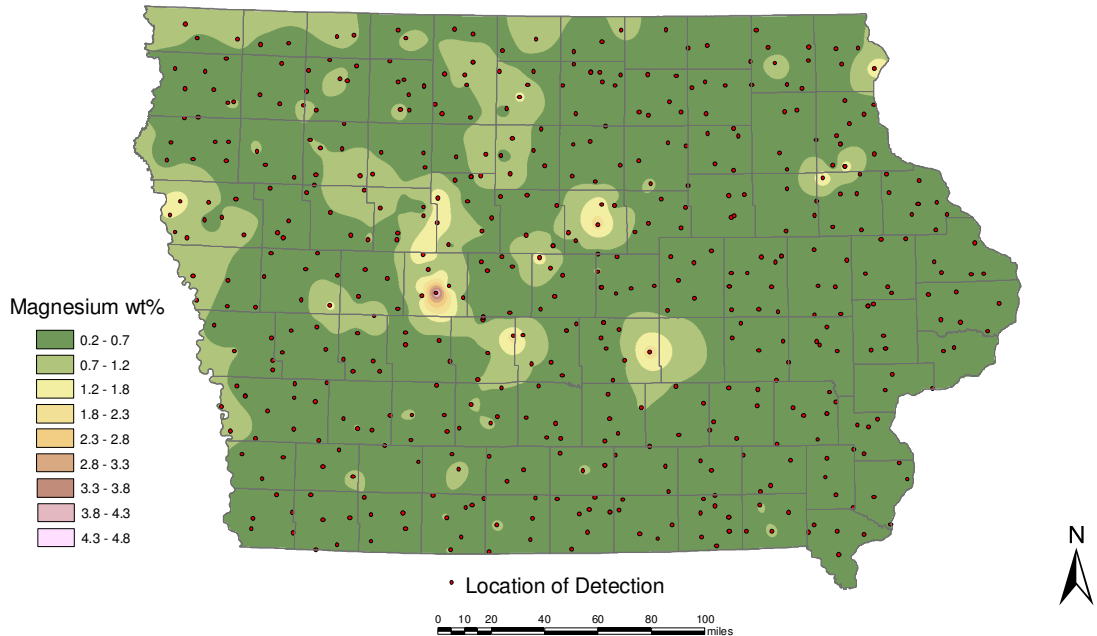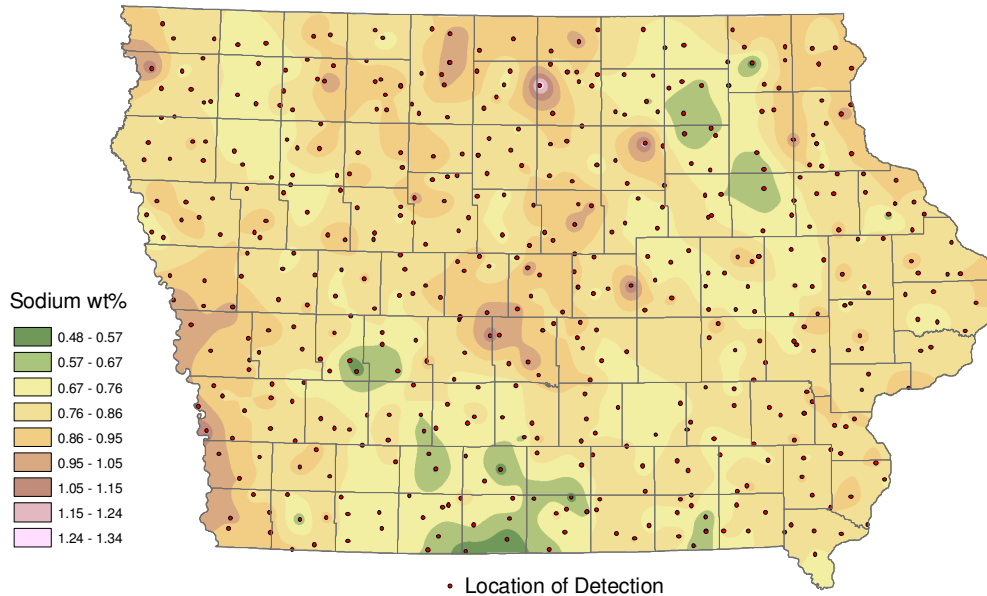# Potassium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Potassium wt%

- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- 1.4 - 1.6
- 1.6 - 1.7
- 1.7 - 1.8
- 1.8 - 1.9
- 1.9 - 2.0
- 2.0 - 2.2

• Location of Detection

Lower Detection Limit = 0.01 wt%

Deep Sample Set

Potassium wt%

- 0.7 - 0.9
- 0.9 - 1.1
- 1.1 - 1.2
- 1.2 - 1.4
- 1.4 - 1.5
- 1.5 - 1.7
- 1.7 - 1.8
- 1.8 - 2.0
- 2.0 - 2.2

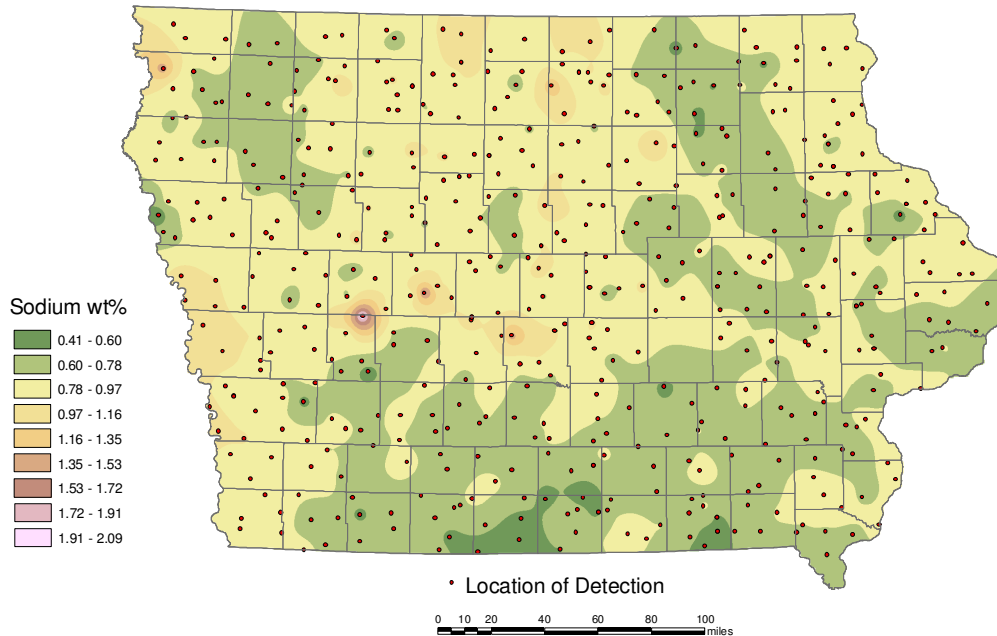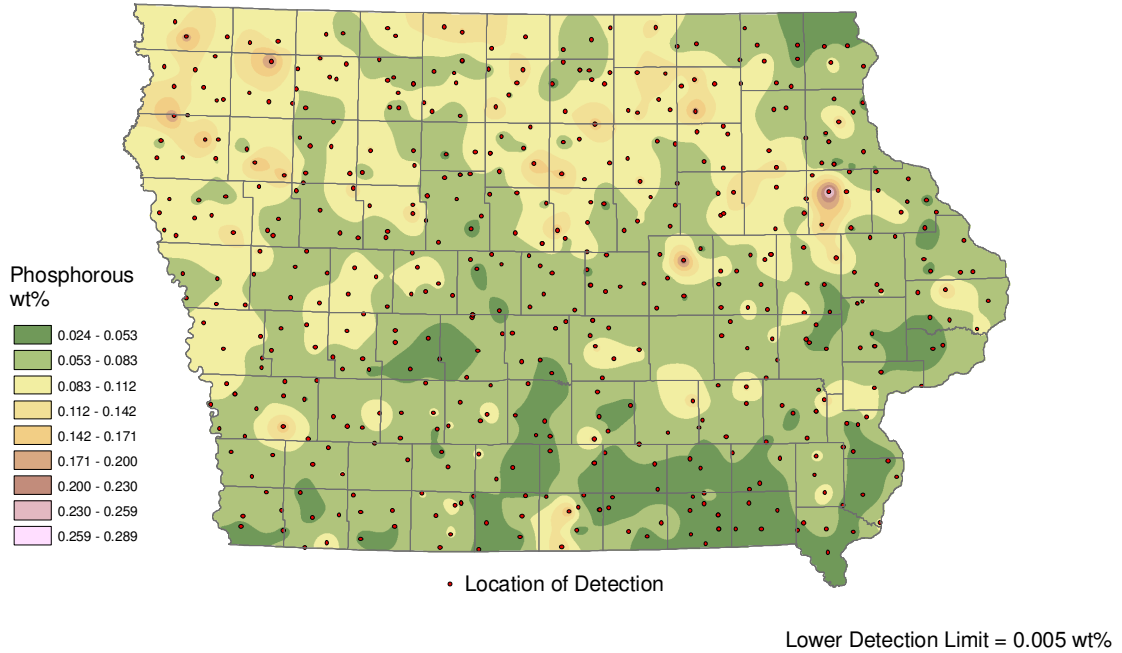• Location of Detection

0 10 20 40 60 80 100 miles

N

Figure 9. Contour maps of potassium concentrations in weight % from the shallow and deep sample sets in Iowa.

Magnesium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Magnesium wt%

- 0.2 - 0.5
- 0.5 - 0.8
- 0.8 - 1.1
- 1.1 - 1.4
- 1.4 - 1.7
- 1.7 - 2.1
- 2.1 - 2.4
- 2.4 - 2.7
- 2.7 - 3.0

• Location of Detection

Lower Detection Limit = 0.005 wt%

Deep Sample Set

Magnesium wt%

- 0.2 - 0.7
- 0.7 - 1.2
- 1.2 - 1.8
- 1.8 - 2.3
- 2.3 - 2.8
- 2.8 - 3.3
- 3.3 - 3.8
- 3.8 - 4.3
- 4.3 - 4.8

• Location of Detection
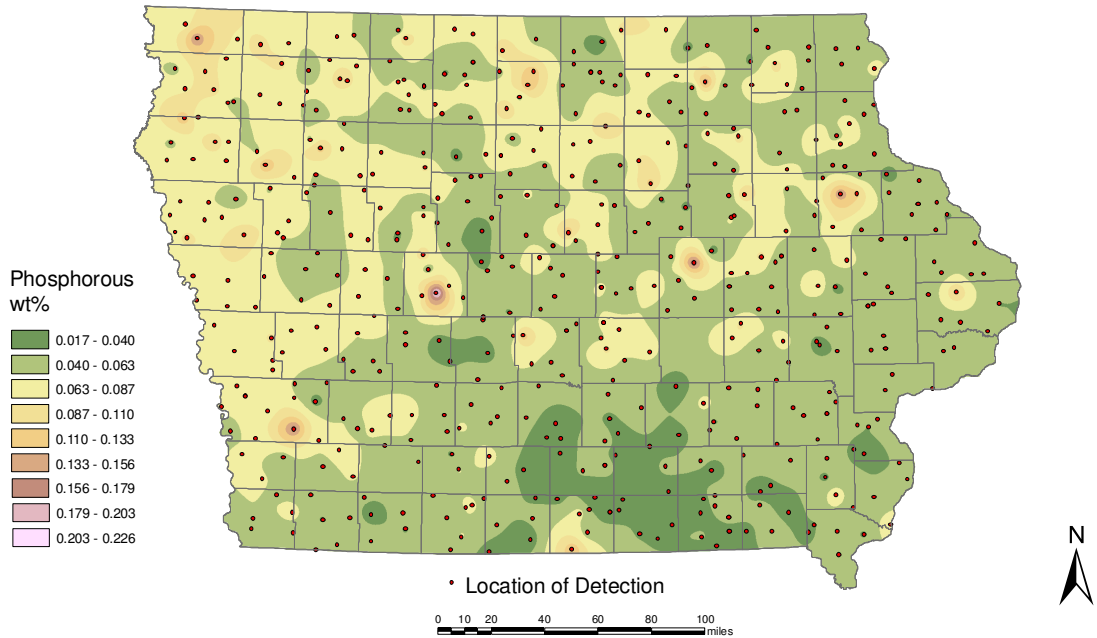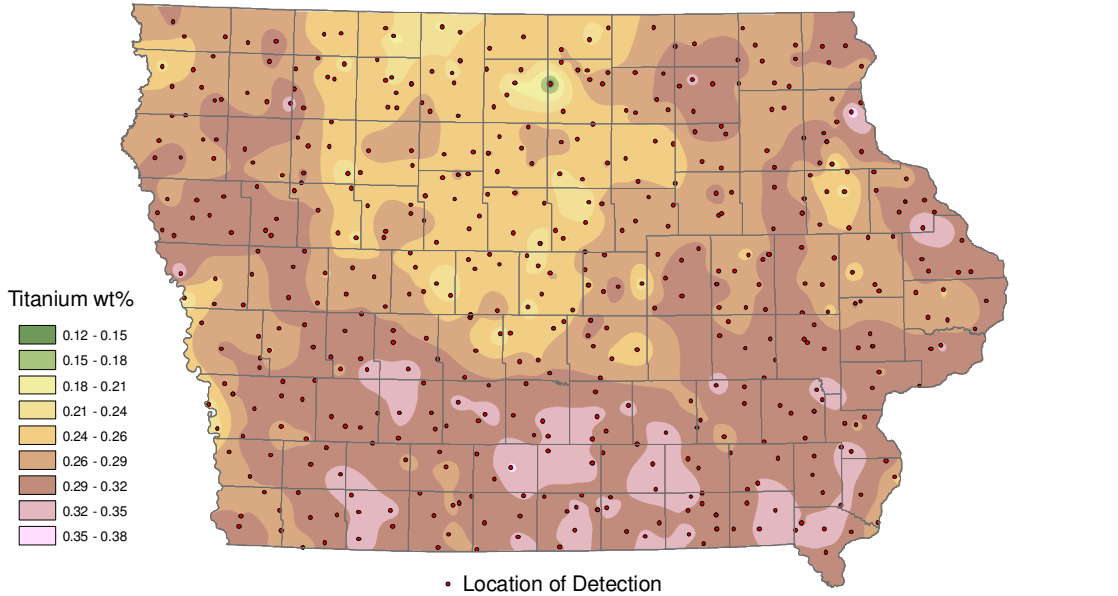
N

0 10 20   40   60   80   100
miles

Figure 10. Contour maps of magnesium concentrations in weight % from the shallow and deep sample sets in Iowa.

Sodium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Sodium wt%

- 0.48 - 0.57
- 0.57 - 0.67
- 0.67 - 0.76
- 0.76 - 0.86
- 0.86 - 0.95
- 0.95 - 1.05
- 1.05 - 1.15
- 1.15 - 1.24
- 1.24 - 1.34

• Location of Detection

Lower Detection Limit = 0.005 wt%

Deep Sample Set

Sodium wt%

- 0.41 - 0.60
- 0.60 - 0.78
- 0.78 - 0.97
- 0.97 - 1.16
- 1.16 - 1.35
- 1.35 - 1.53
- 1.53 - 1.72
- 1.72 - 1.91
- 1.91 - 2.09

• Location of Detection

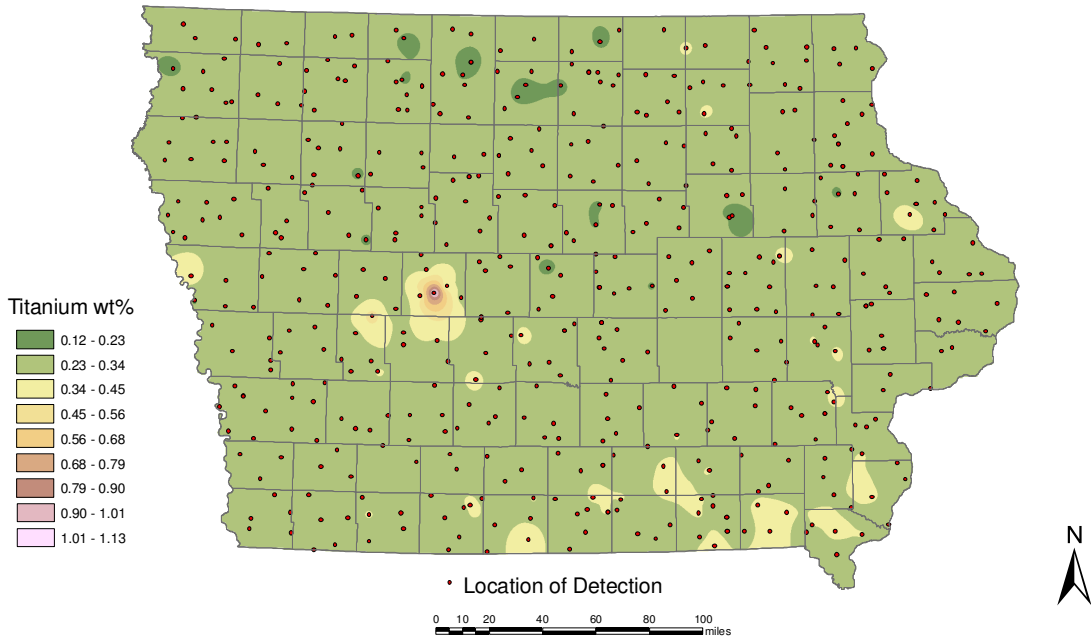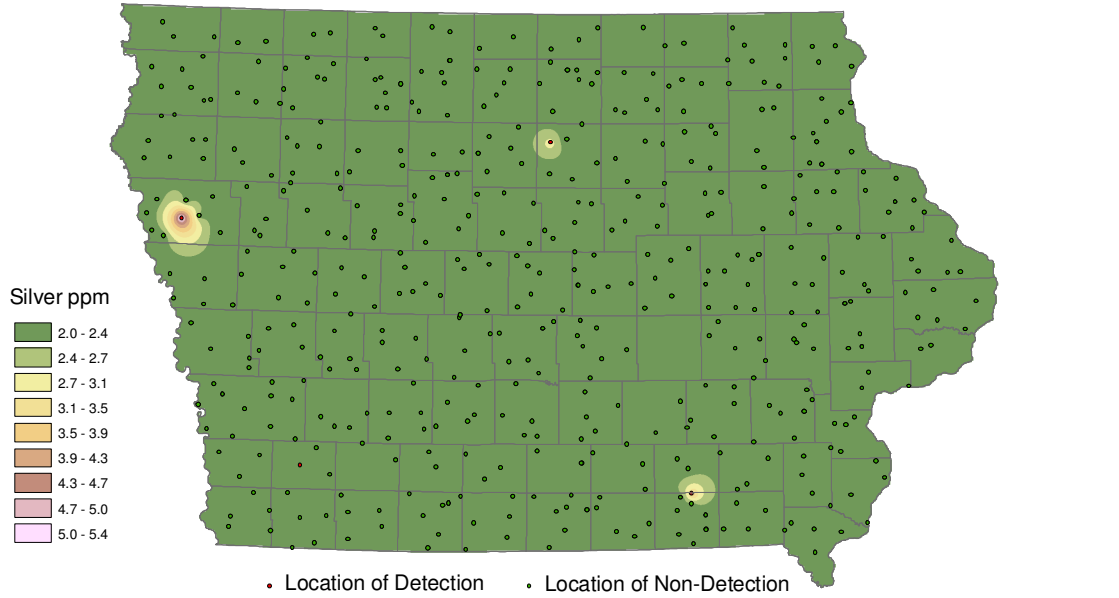0 10 20 40 60 80 100 miles

N

Figure 11. Contour maps of sodium concentrations in weight % from the shallow and deep sample sets in Iowa.

27

Phosphorous Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Phosphorous wt%

- 0.024 - 0.053
- 0.053 - 0.083
- 0.083 - 0.112
- 0.112 - 0.142
- 0.142 - 0.171
- 0.171 - 0.200
- 0.200 - 0.230
- 0.230 - 0.259
- 0.259 - 0.289

• Location of Detection

Lower Detection Limit = 0.005 wt%

Deep Sample Set

Phosphorous wt%

- 0.017 - 0.040
- 0.040 - 0.063
- 0.063 - 0.087
- 0.087 - 0.110
- 0.110 - 0.133
- 0.133 - 0.156
- 0.156 - 0.179
- 0.179 - 0.203
- 0.203 - 0.226

• Location of Detection

N

0 10 20   40   60   80   100
miles

Figure 12. Contour maps of phosphorous concentrations in weight % from the shallow and deep sample sets in Iowa.

28

Titanium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

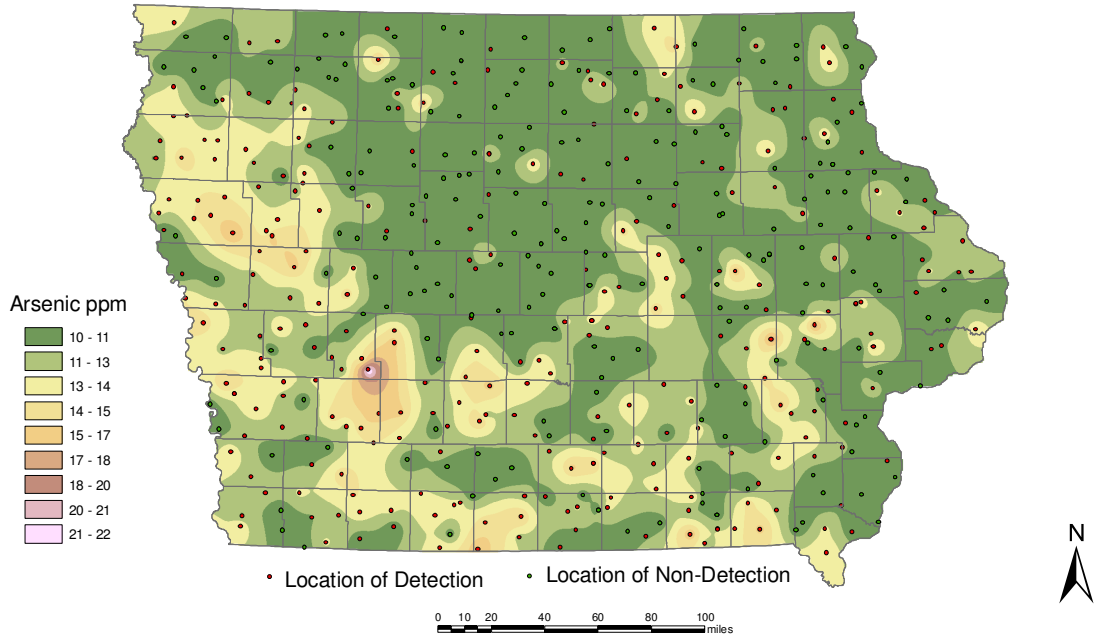Titanium wt%

- 0.12 - 0.15
- 0.15 - 0.18
- 0.18 - 0.21
- 0.21 - 0.24
- 0.24 - 0.26
- 0.26 - 0.29
- 0.29 - 0.32
- 0.32 - 0.35
- 0.35 - 0.38

• Location of Detection

Lower Detection Limit = 0.005 wt%

Deep Sample Set

Titanium wt%

- 0.12 - 0.23
- 0.23 - 0.34
- 0.34 - 0.45
- 0.45 - 0.56
- 0.56 - 0.68
- 0.68 - 0.79
- 0.79 - 0.90
- 0.90 - 1.01
- 1.01 - 1.13

• Location of Detection

0 10 20   40   60   80   100
miles

N

Figure 13. Contour maps of titanium concentrations in weight % from the shallow and deep sample sets in Iowa.
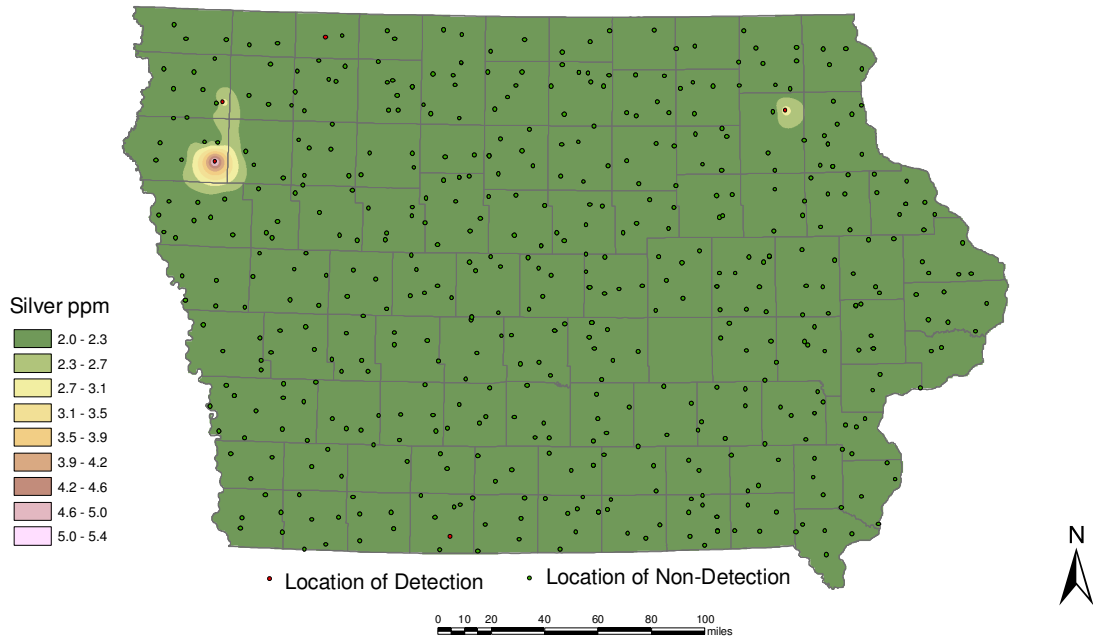
Figure 14. Contour maps of silver concentrations in ppm from the shallow and deep sample sets in Iowa.

Arsenic Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Arsenic ppm
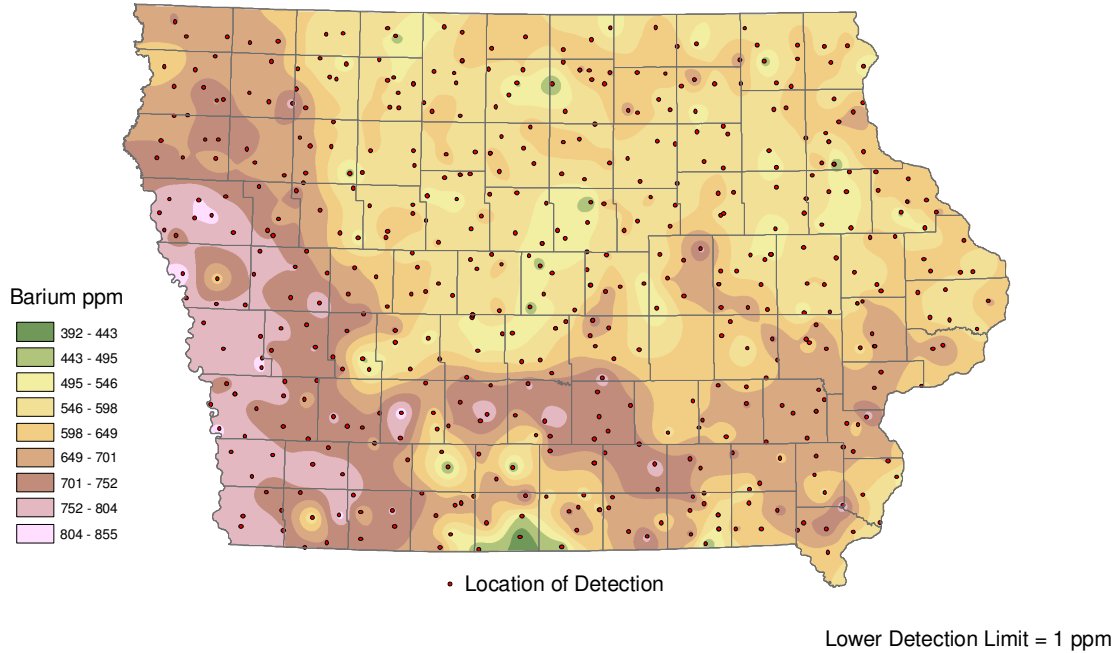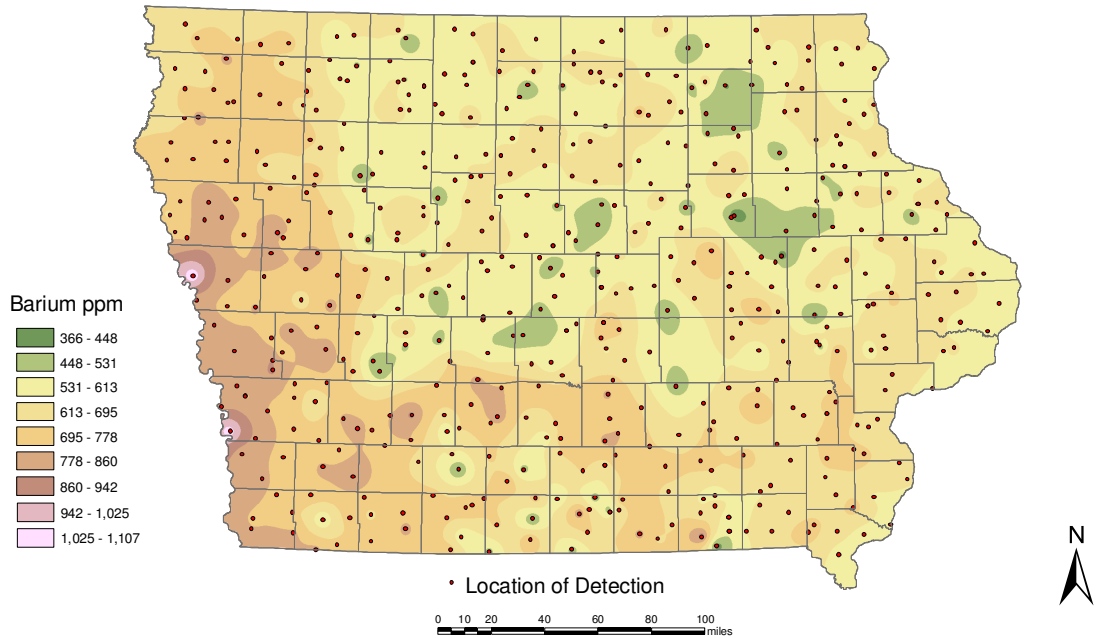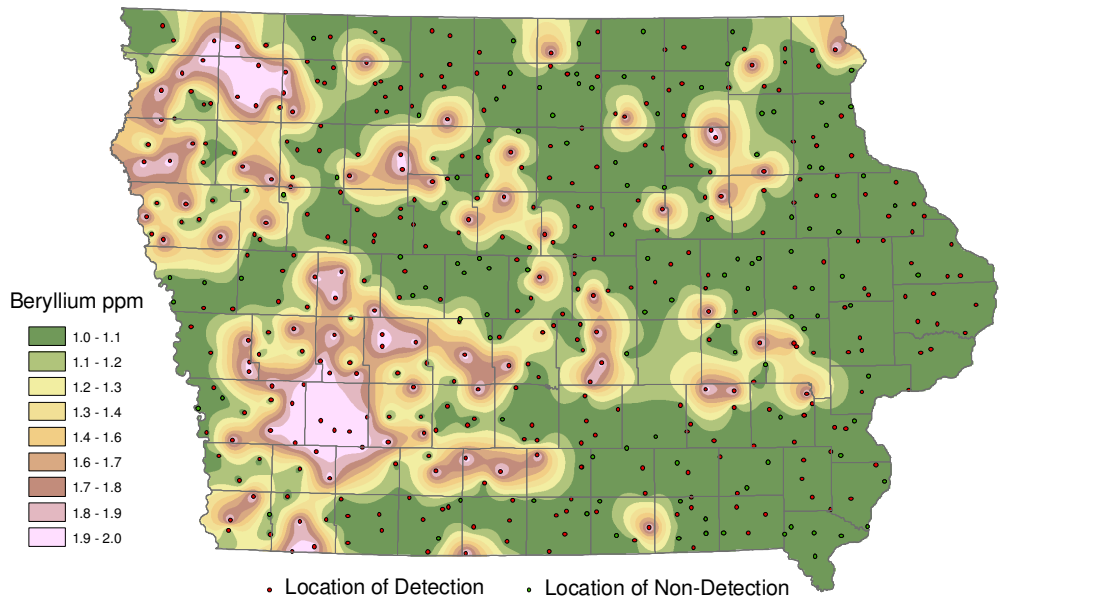- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 15
- 15 - 16
- 16 - 17
- 17 - 18
- 18 - 19
- 19 - 21

• Location of Detection   • Location of Non-Detection

Lower Detection Limit = 10 ppm

Deep Sample Set

Arsenic ppm
- 10 - 11
- 11 - 13
- 13 - 14
- 14 - 15
- 15 - 17
- 17 - 18
- 18 - 20
- 20 - 21
- 21 - 22

• Location of Detection   • Location of Non-Detection
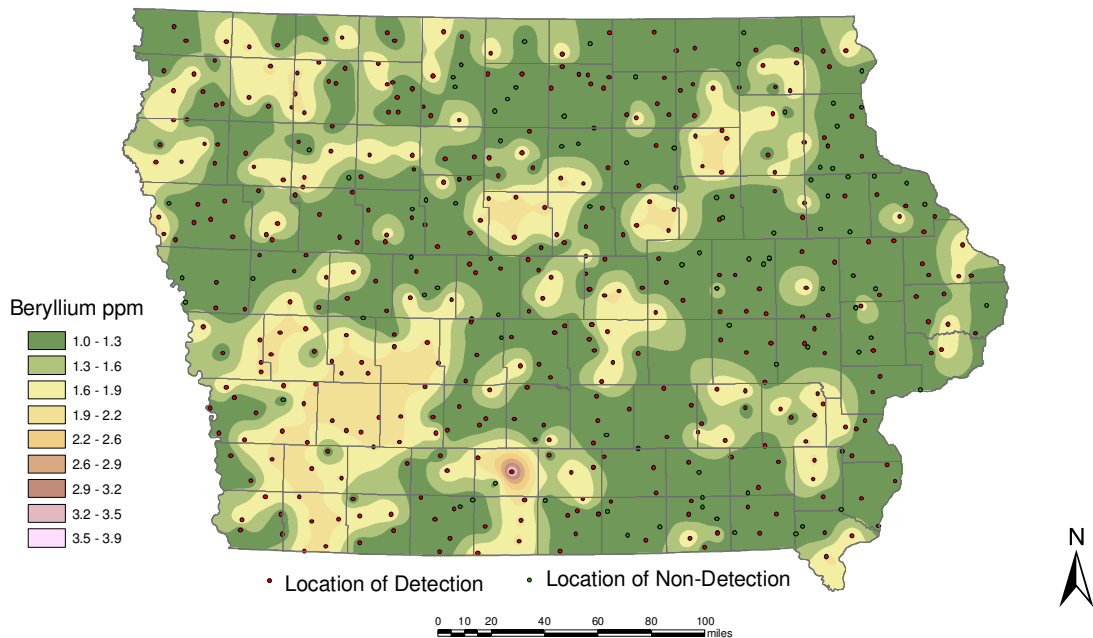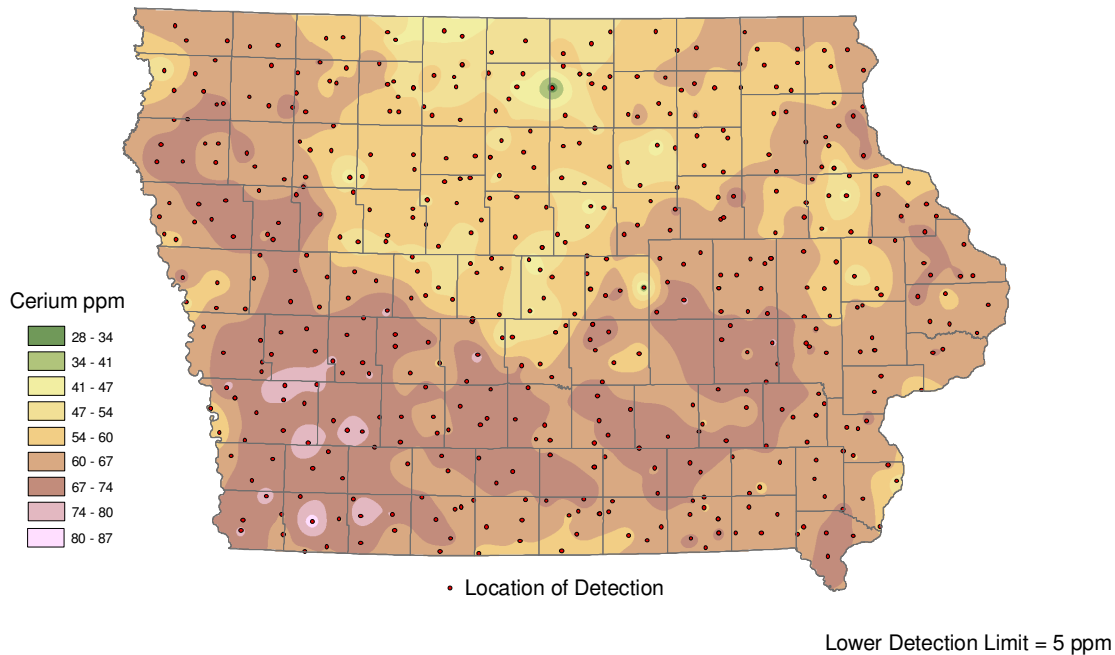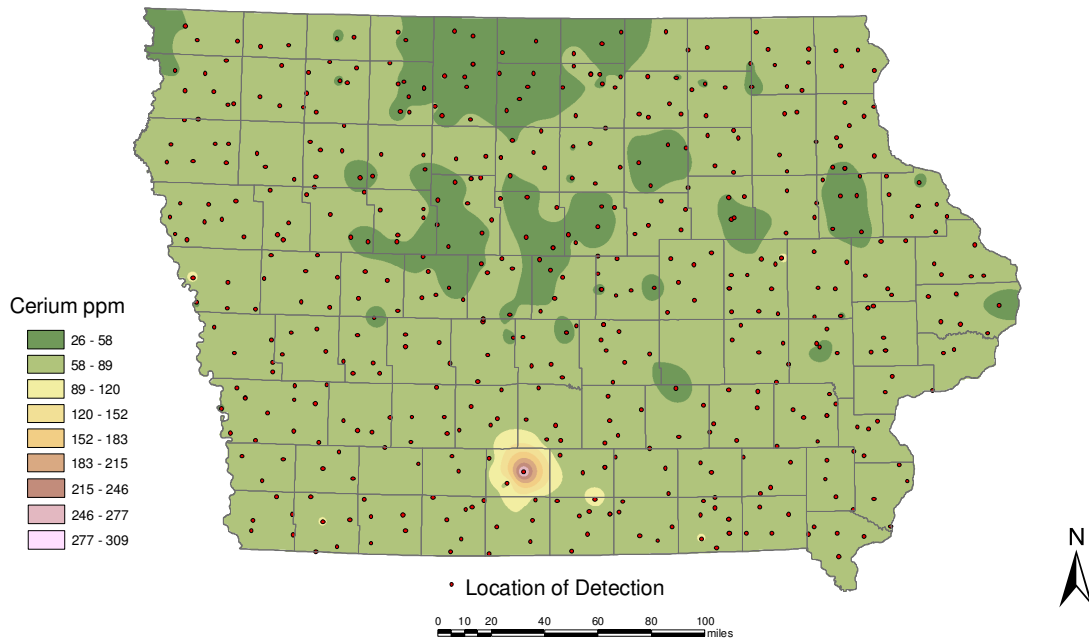
N

0 10 20   40   60   80   100
miles
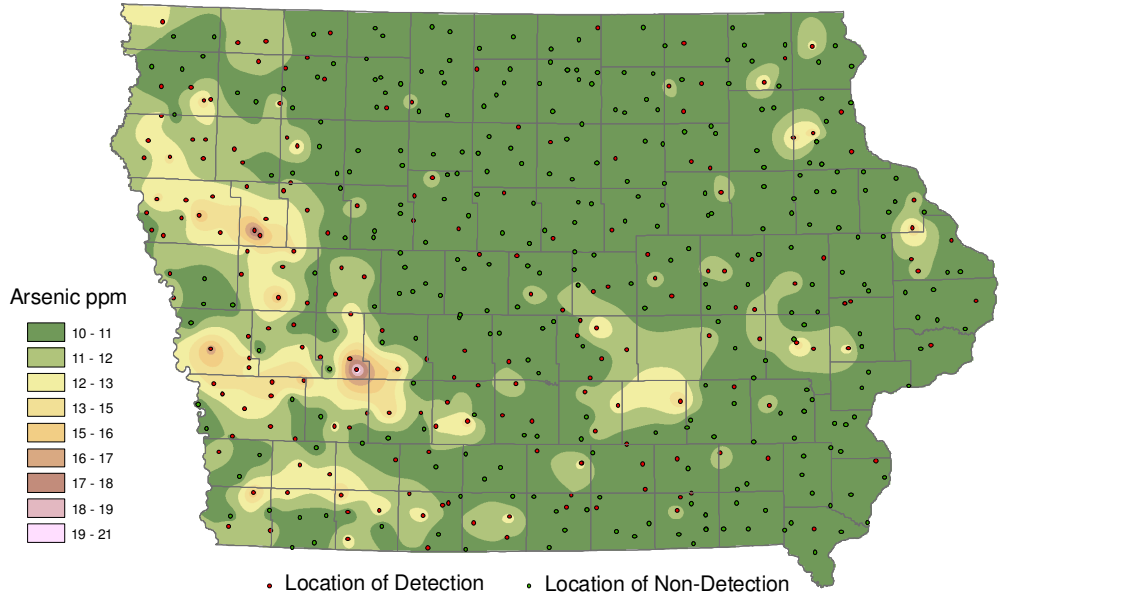
Figure 15. Contour maps of arsenic concentrations in ppm from the shallow and deep sample sets in Iowa.

Barium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Barium ppm
- 392 - 443
- 443 - 495
- 495 - 546
- 546 - 598
- 598 - 649
- 649 - 701
- 701 - 752
- 752 - 804
- 804 - 855

• Location of Detection

Lower Detection Limit = 1 ppm

Deep Sample Set

Barium ppm
- 366 - 448
- 448 - 531
- 531 - 613
- 613 - 695
- 695 - 778
- 778 - 860
- 860 - 942
- 942 - 1,025
- 1,025 - 1,107

• Location of Detection

N

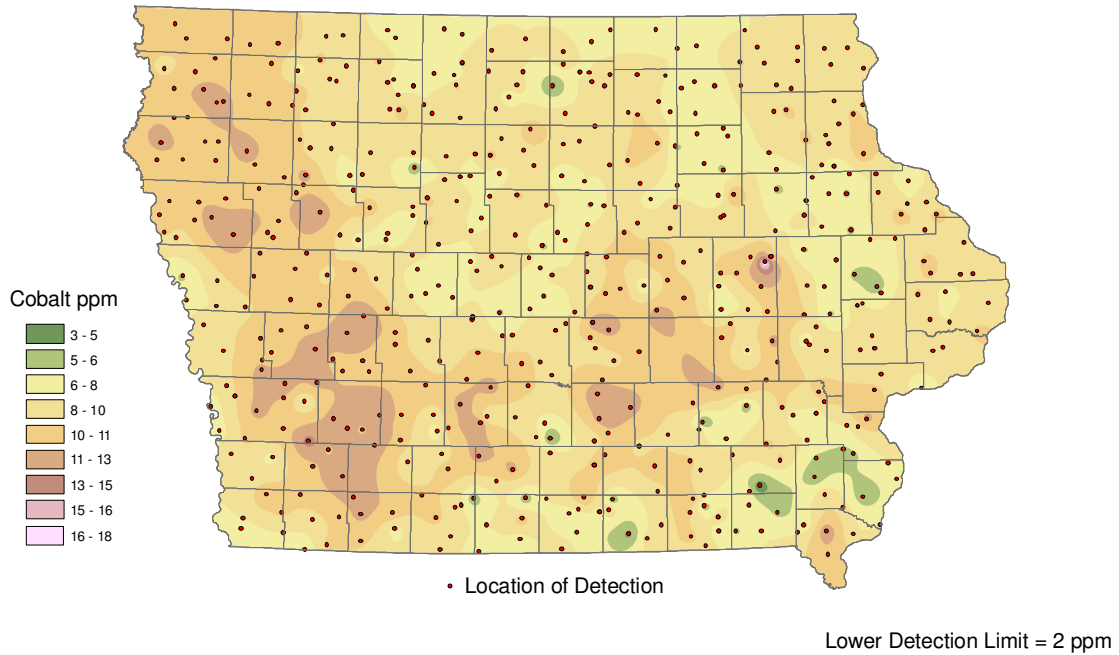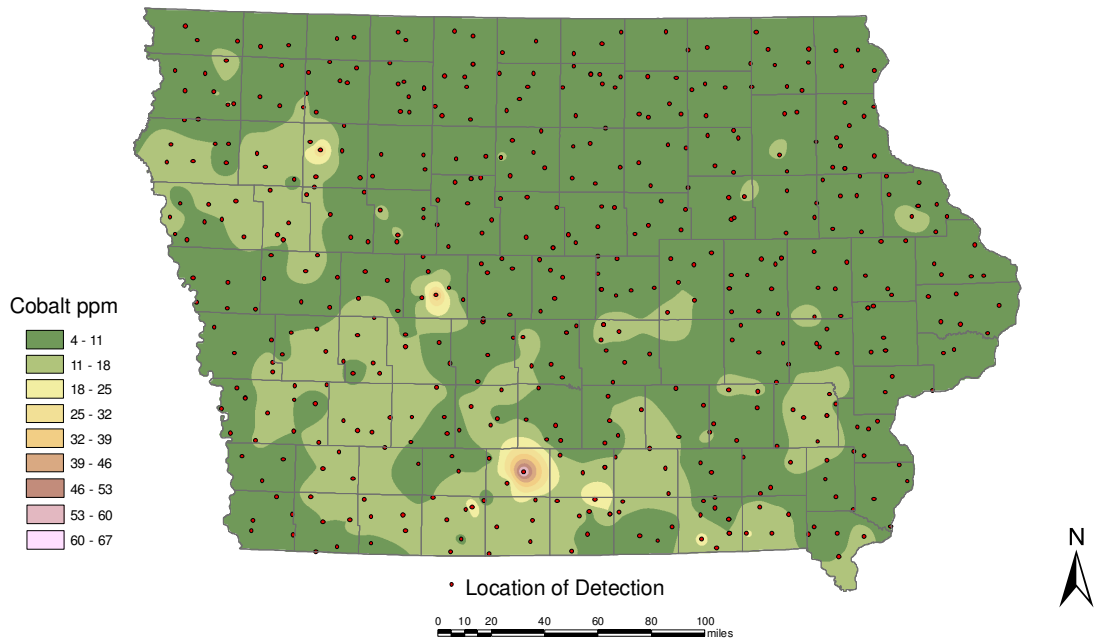0 10 20   40   60   80   100
miles

Figure 16. Contour maps of barium concentrations in ppm from the shallow and deep sample sets in Iowa.

Beryllium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Beryllium ppm

- 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- 1.4 - 1.6
- 1.6 - 1.7
- 1.7 - 1.8
- 1.8 - 1.9
- 1.9 - 2.0

• Location of Detection   • Location of Non-Detection

Lower Detection Limit = 1 ppm

Deep Sample Set

Beryllium ppm

- 1.0 - 1.3
- 1.3 - 1.6
- 1.6 - 1.9
- 1.9 - 2.2
- 2.2 - 2.6
- 2.6 - 2.9
- 2.9 - 3.2
- 3.2 - 3.5
- 3.5 - 3.9

• Location of Detection   • Location of Non-Detection
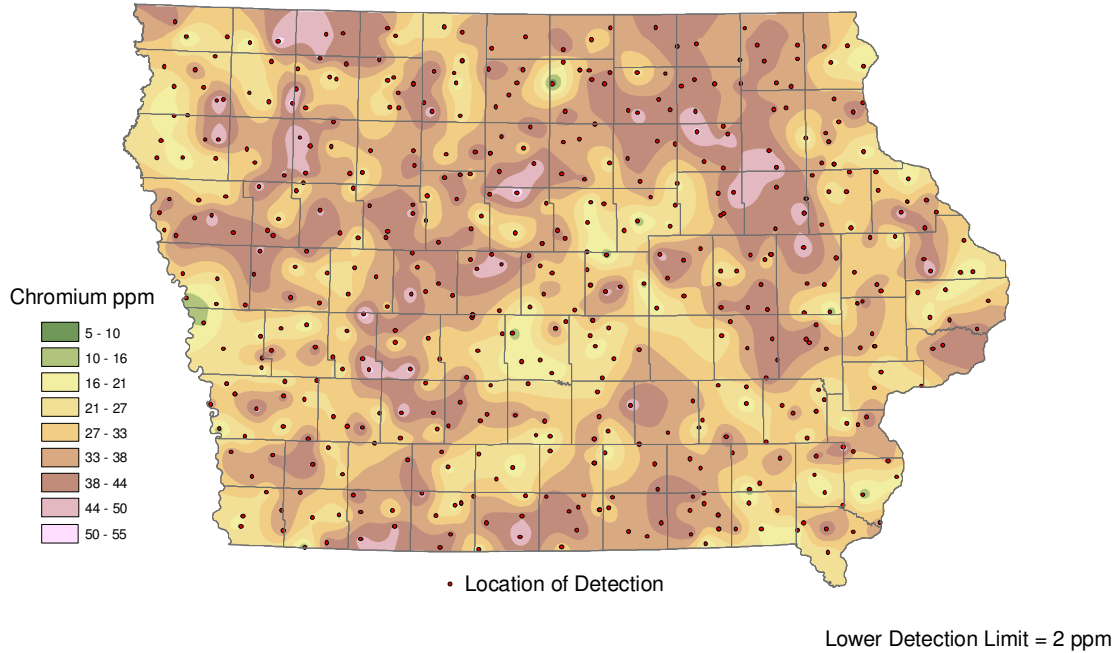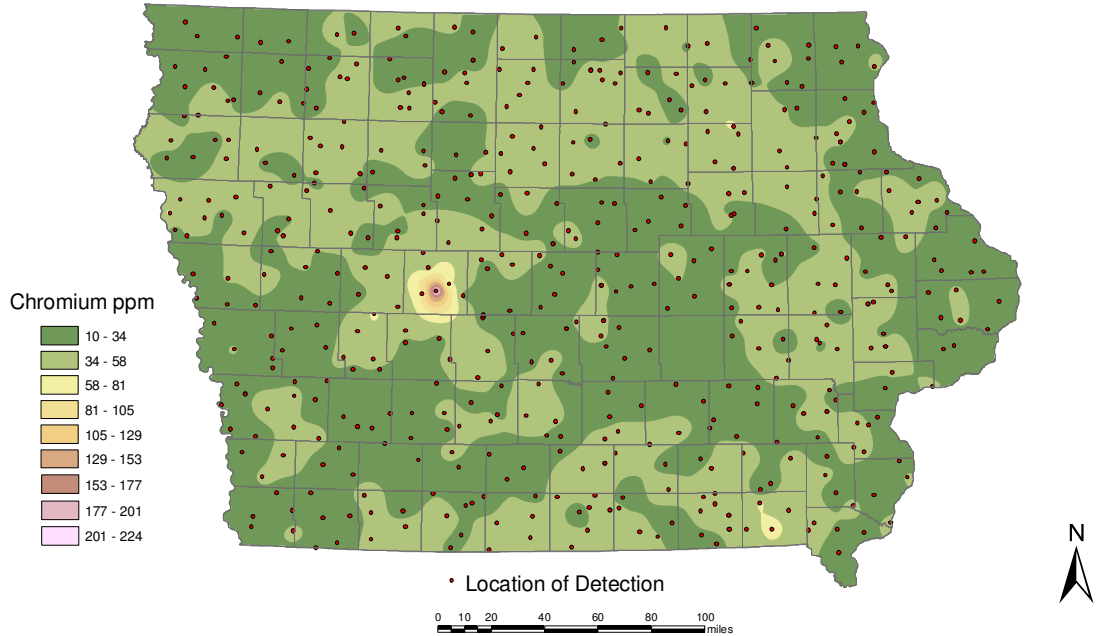
N

0 10 20   40   60   80   100
miles

Figure 17. Contour maps of beryllium concentrations in ppm from the shallow and deep sample sets in Iowa.

33

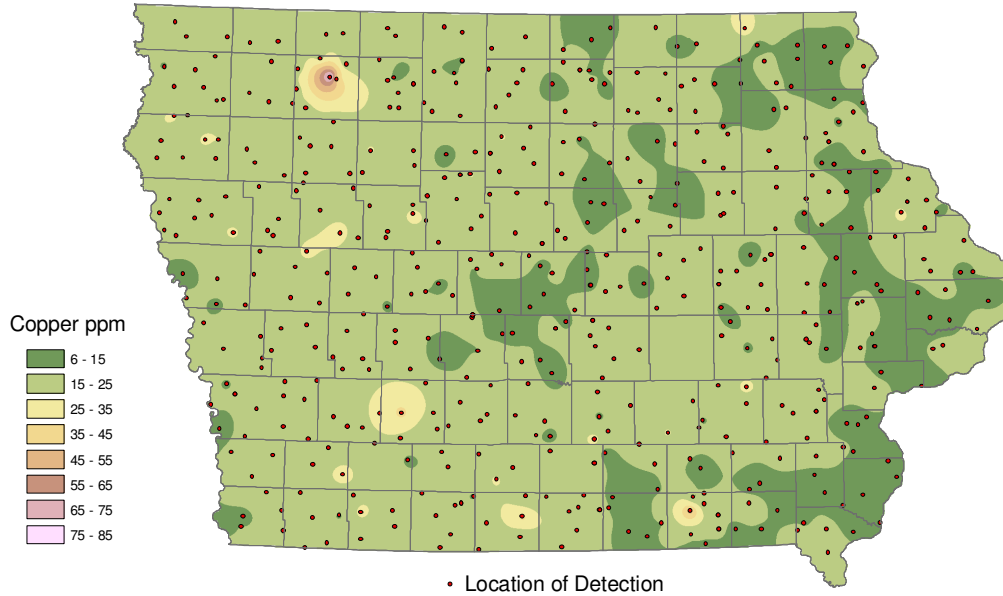# Cerium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Cerium ppm
- 28 - 34
- 34 - 41
- 41 - 47
- 47 - 54
- 54 - 60
- 60 - 67
- 67 - 74
- 74 - 80
- 80 - 87

• Location of Detection

Lower Detection Limit = 5 ppm

Deep Sample Set

Cerium ppm
- 26 - 58
- 58 - 89
- 89 - 120
- 120 - 152
- 152 - 183
- 183 - 215
- 215 - 246
- 246 - 277
- 277 - 309

• Location of Detection

0 10 20   40   60   80   100
miles

N

Figure 18. Contour maps of cerium concentrations in ppm from the shallow and deep sample sets in Iowa.

Cobalt Concentrations in Iowa from ICP40 Analyses
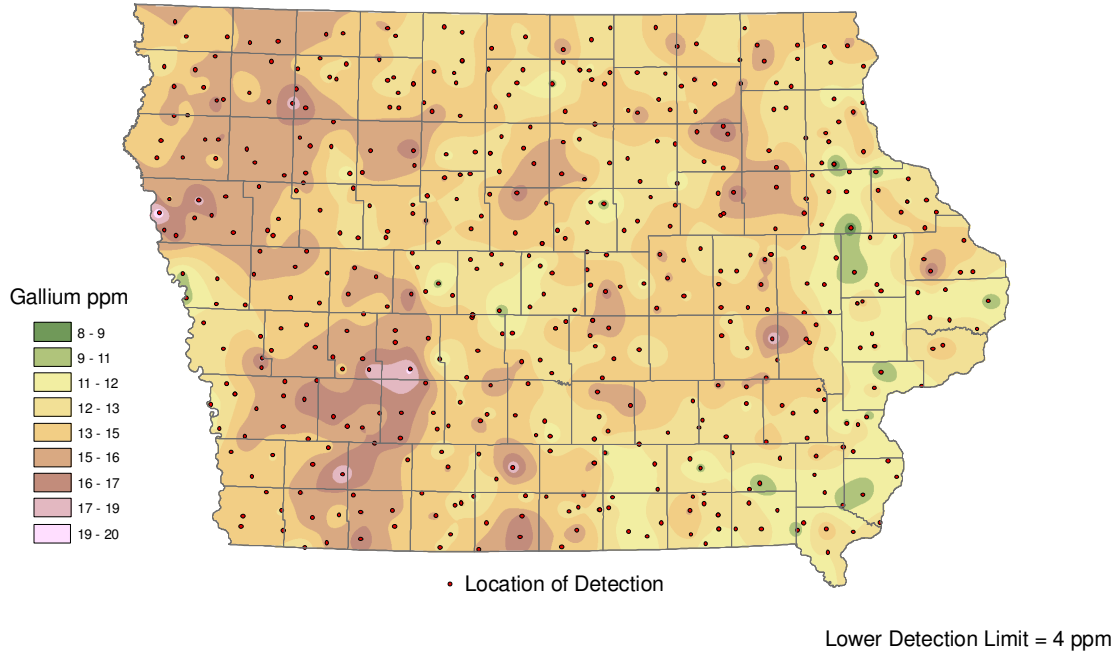
Shallow Sample Set

Cobalt ppm

- 3 - 5
- 5 - 6
- 6 - 8
- 8 - 10
- 10 - 11
- 11 - 13
- 13 - 15
- 15 - 16
- 16 - 18

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Cobalt ppm

- 4 - 11
- 11 - 18
- 18 - 25
- 25 - 32
- 32 - 39
- 39 - 46
- 46 - 53
- 53 - 60
- 60 - 67

• Location of Detection

N
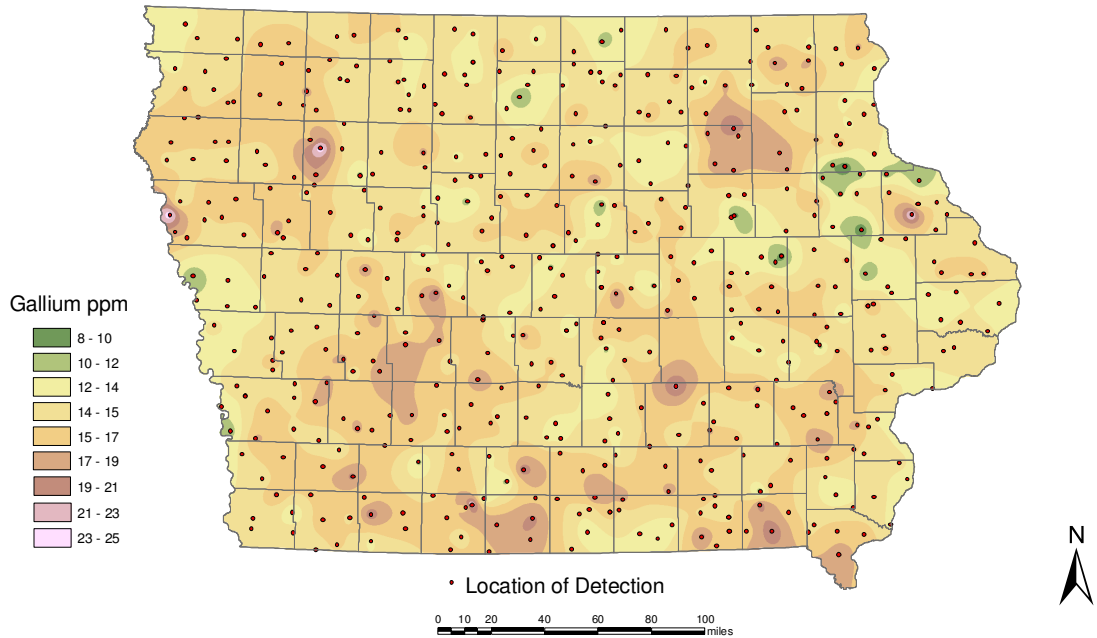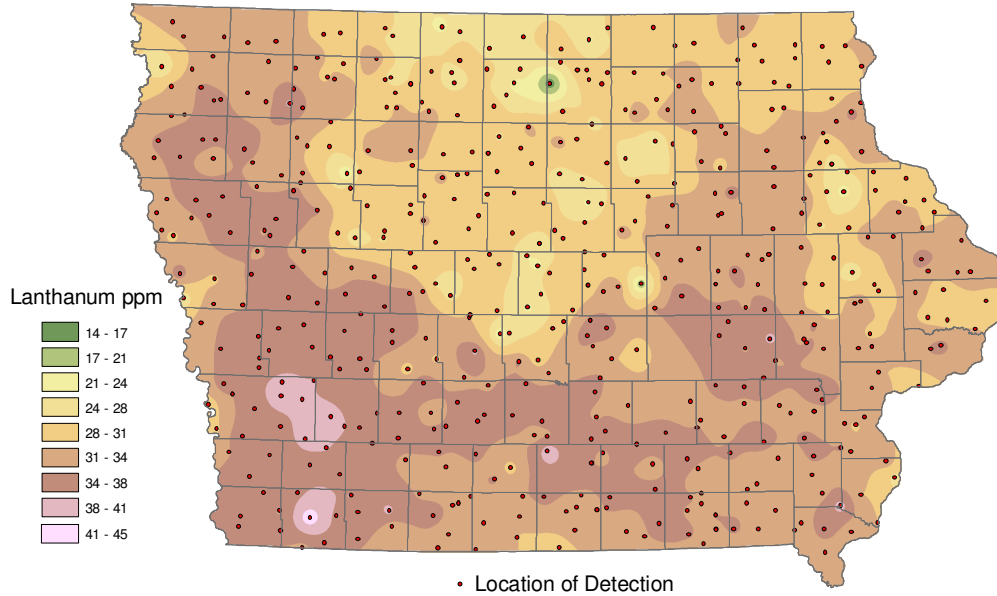
0 10 20 40 60 80 100 miles

Figure 19. Contour maps of cobalt concentrations in ppm from the shallow and deep sample sets in Iowa.

35

Chromium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Chromium ppm

- 5 - 10
- 10 - 16
- 16 - 21
- 21 - 27
- 27 - 33
- 33 - 38
- 38 - 44
- 44 - 50
- 50 - 55

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Chromium ppm

- 10 - 34
- 34 - 58
- 58 - 81
- 81 - 105
- 105 - 129
- 129 - 153
- 153 - 177
- 177 - 201
- 201 - 224

• Location of Detection

N

0 10 20   40   60   80   100
miles

Figure 20. Contour maps of chromium concentrations in ppm from the shallow and deep sample sets in Iowa.

Copper Concentrations in Iowa from ICP40 Analyses
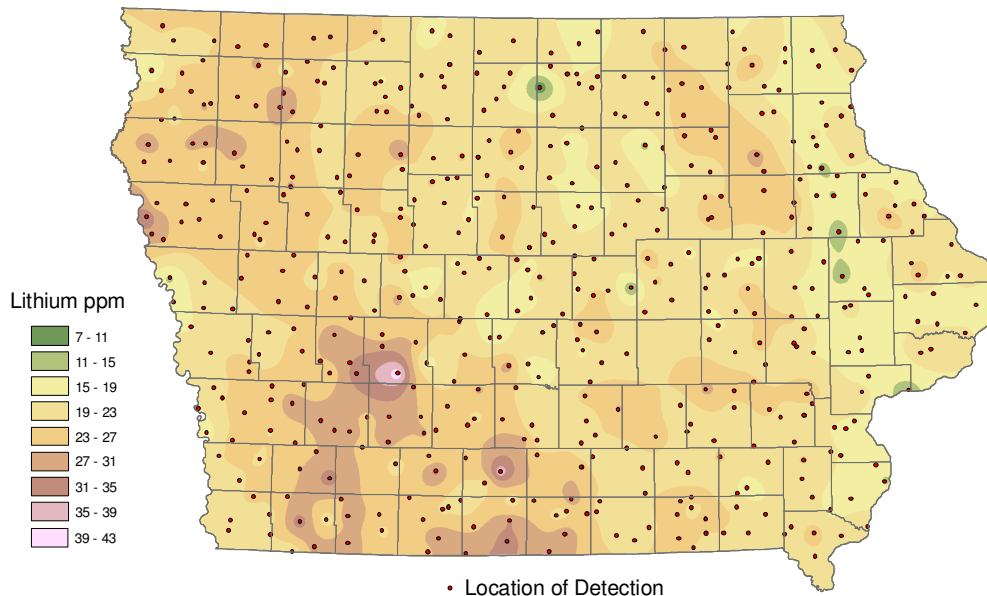
Shallow Sample Set

Copper ppm

- 6 - 15
- 15 - 25
- 25 - 35
- 35 - 45
- 45 - 55
- 55 - 65
- 65 - 75
- 75 - 85

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Copper ppm

- 5 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 71

• Location of Detection
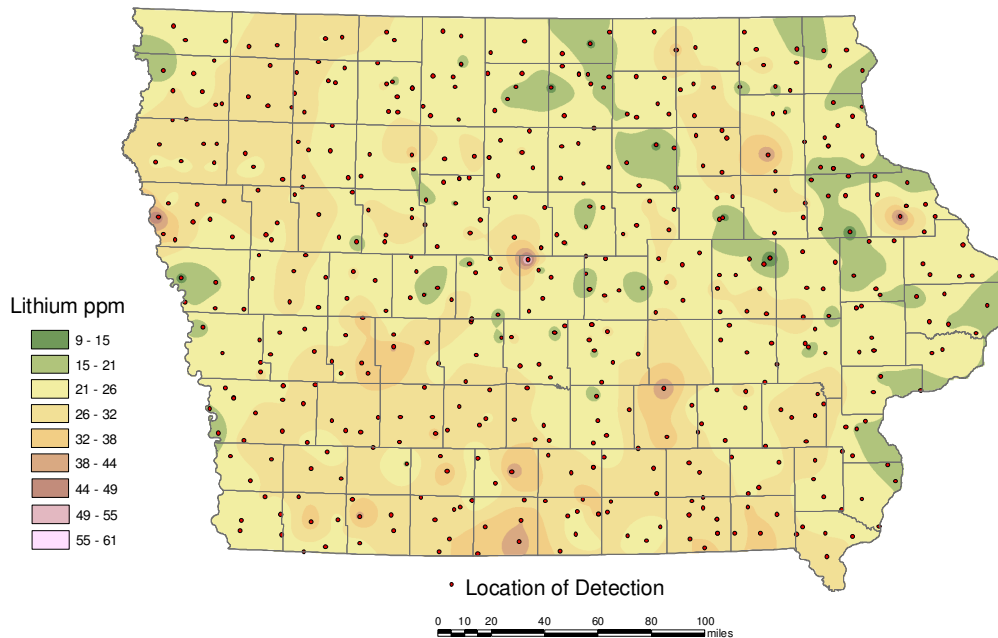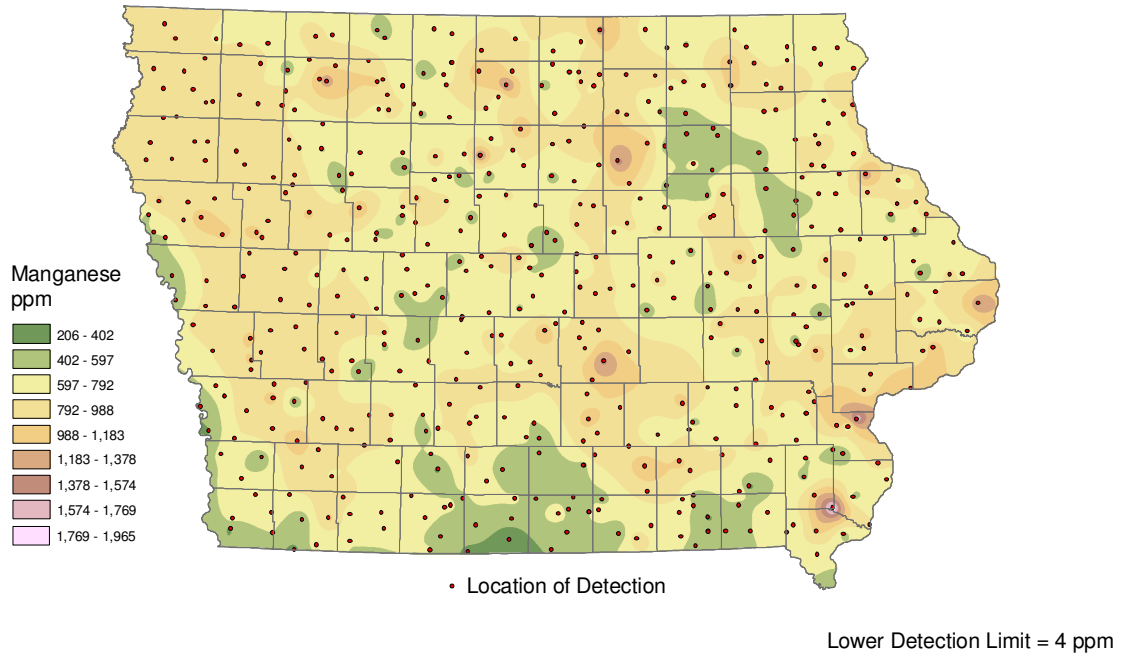
N

0 10 20   40   60   80   100
miles
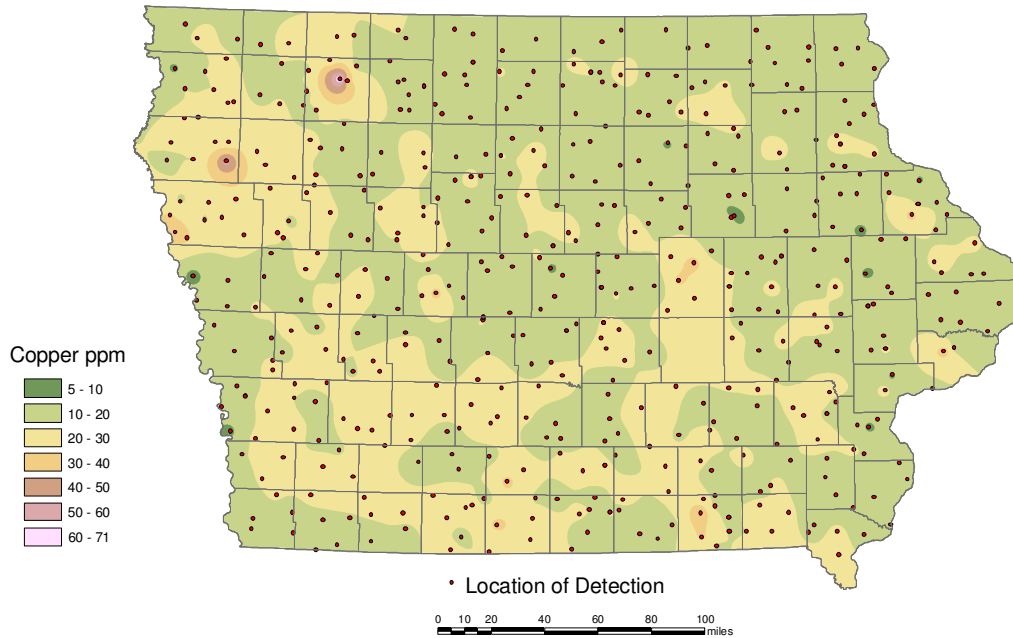
Figure 21. Contour maps of copper concentrations in ppm from the shallow and deep sample sets in Iowa.

37

Gallium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Gallium ppm
- 8 - 9
- 9 - 11
- 11 - 12
- 12 - 13
- 13 - 15
- 15 - 16
- 16 - 17
- 17 - 19
- 19 - 20

• Location of Detection

Lower Detection Limit = 4 ppm

Deep Sample Set

Gallium ppm
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 15
- 15 - 17
- 17 - 19
- 19 - 21
- 21 - 23
- 23 - 25

• Location of Detection
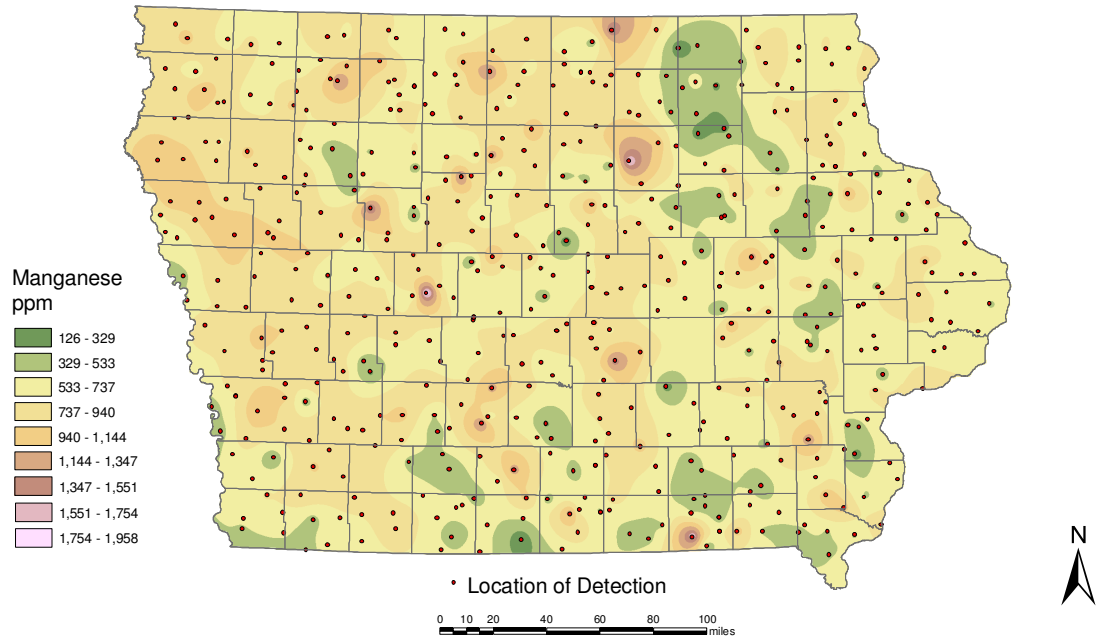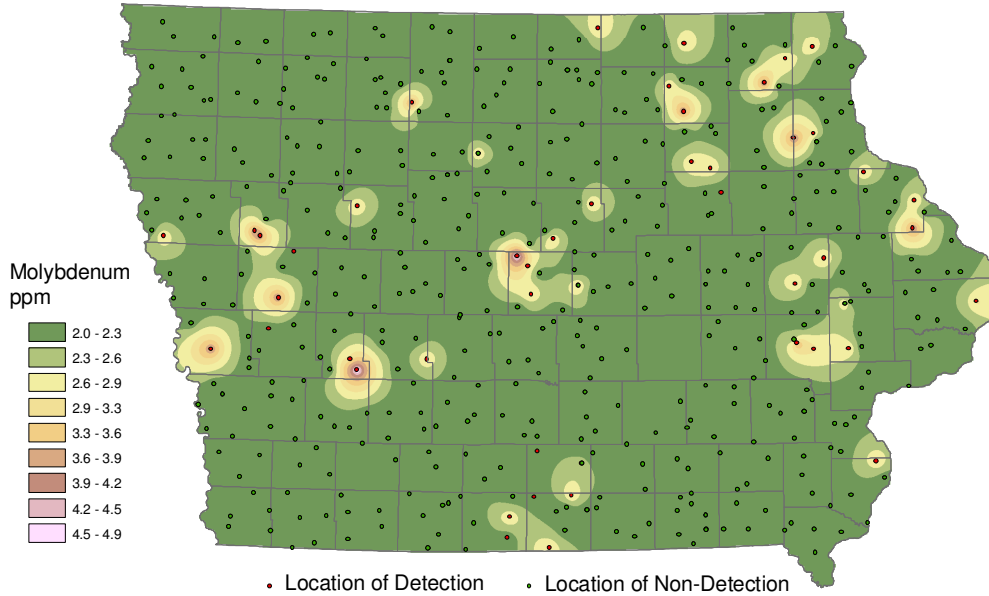
N

0 10 20   40   60   80   100 miles

Figure 22. Contour maps of gallium concentrations in ppm from the shallow and deep sample sets in Iowa.

Lanthanum Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Lanthanum ppm

- 14 - 17
- 17 - 21
- 21 - 24
- 24 - 28
- 28 - 31
- 31 - 34
- 34 - 38
- 38 - 41
- 41 - 45

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Lanthanum ppm

- 16 - 20
- 20 - 24
- 24 - 28
- 28 - 32
- 32 - 36
- 36 - 40
- 40 - 44
- 44 - 48
- 48 - 52

• Location of Detection
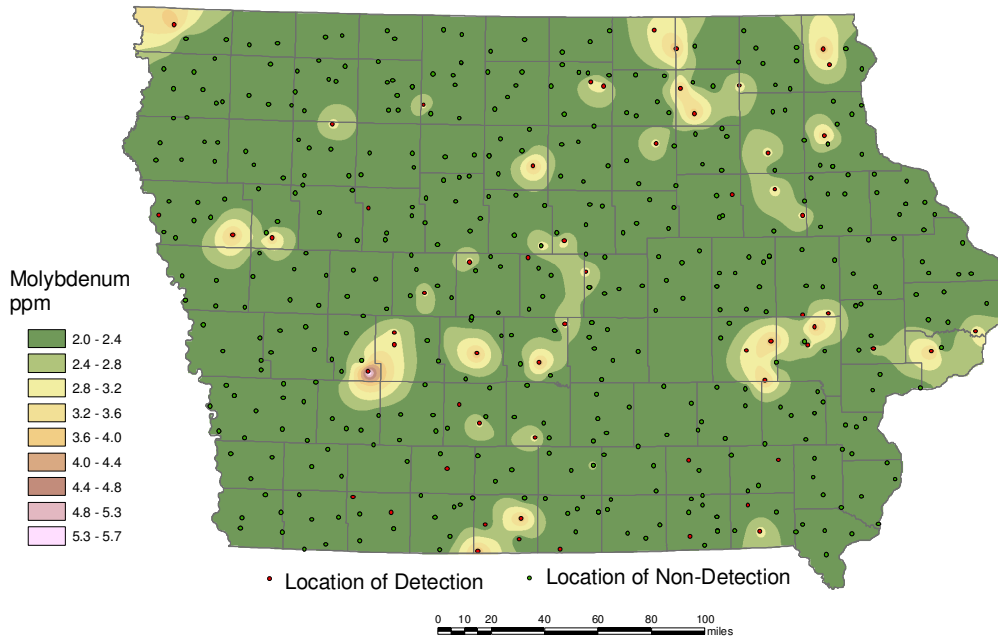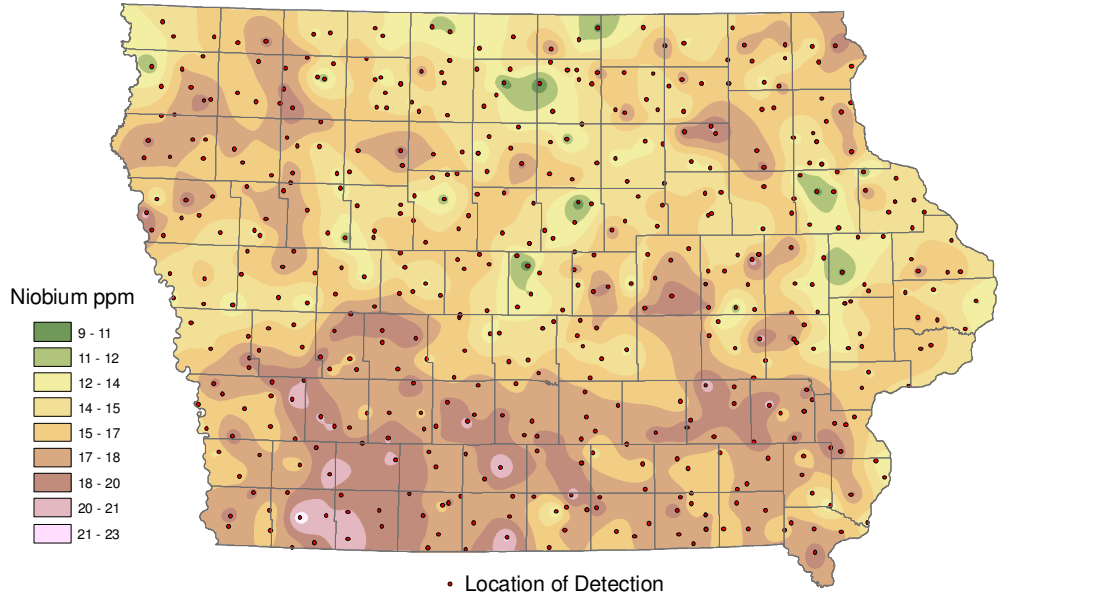
N

0 10 20 40 60 80 100 miles
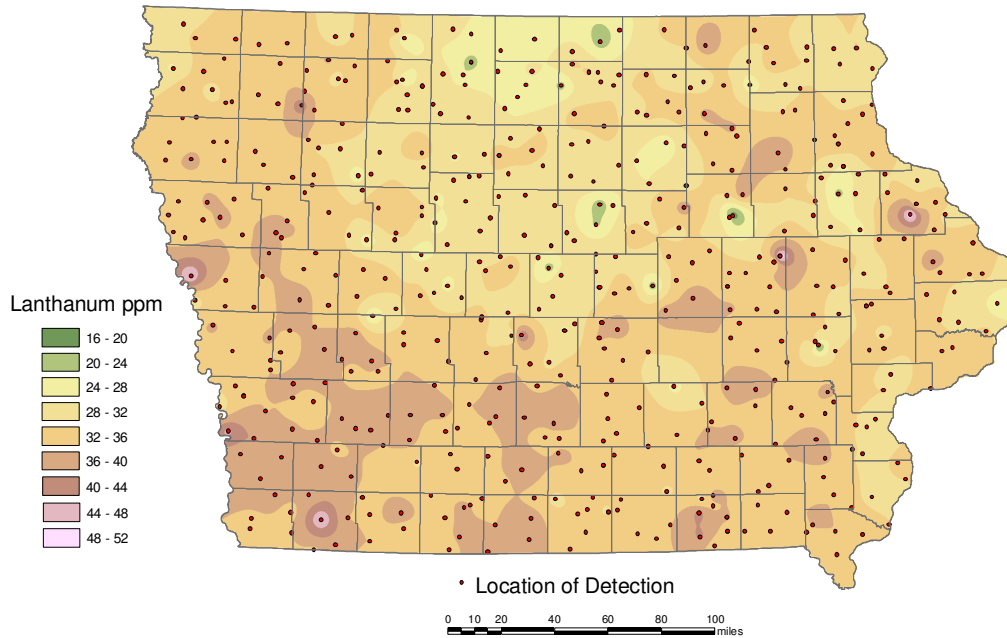
Figure 23. Contour maps of lanthanum concentrations in ppm from the shallow and deep sample sets in Iowa.

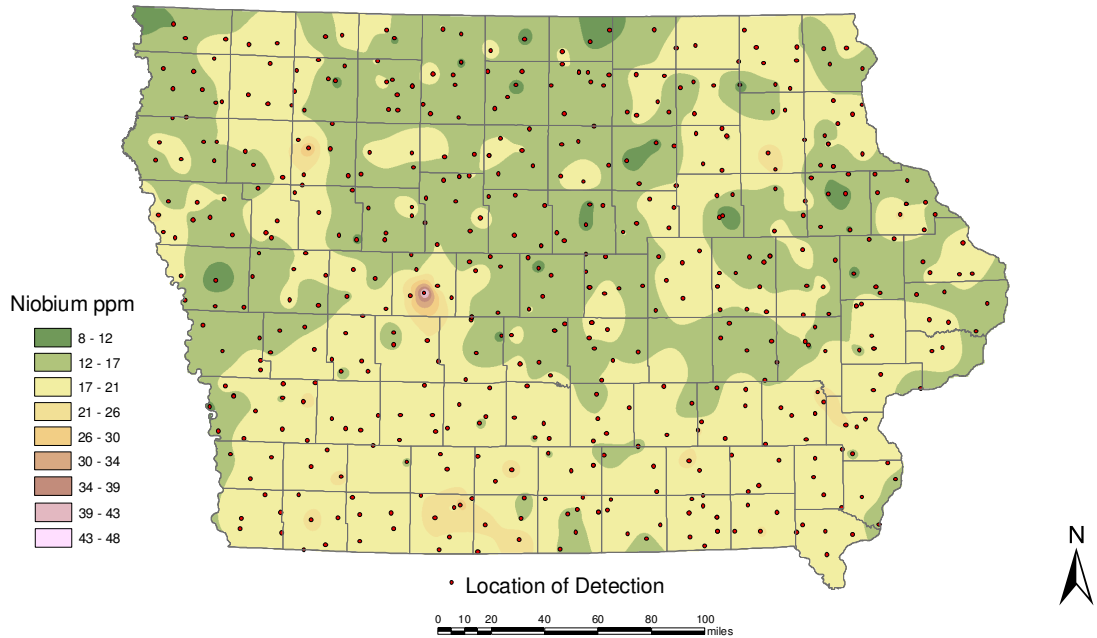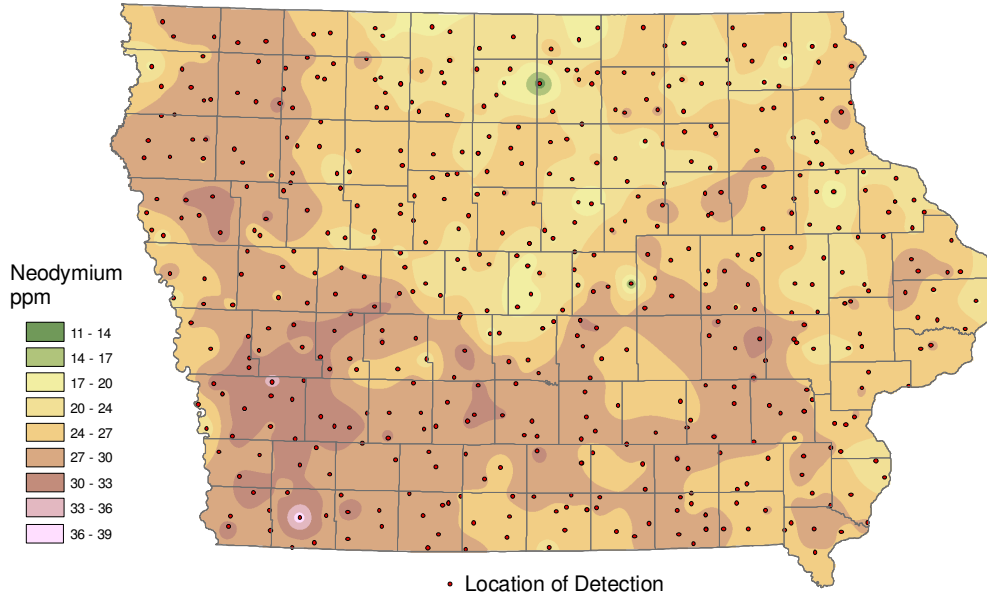# Lithium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Lithium ppm

- 7 - 11
- 11 - 15
- 15 - 19
- 19 - 23
- 23 - 27
- 27 - 31
- 31 - 35
- 35 - 39
- 39 - 43

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Lithium ppm

- 9 - 15
- 15 - 21
- 21 - 26
- 26 - 32
- 32 - 38
- 38 - 44
- 44 - 49
- 49 - 55
- 55 - 61

• Location of Detection

N

0 10 20   40   60   80   100
miles

Figure 24. Contour maps of lithium concentrations in ppm from the shallow and deep sample sets in Iowa.

Manganese Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Manganese ppm

- 206 - 402
- 402 - 597
- 597 - 792
- 792 - 988
- 988 - 1,183
- 1,183 - 1,378
- 1,378 - 1,574
- 1,574 - 1,769
- 1,769 - 1,965

• Location of Detection

Lower Detection Limit = 4 ppm

Deep Sample Set

Manganese ppm

- 126 - 329
- 329 - 533
- 533 - 737
- 737 - 940
- 940 - 1,144
- 1,144 - 1,347
- 1,347 - 1,551
- 1,551 - 1,754
- 1,754 - 1,958

• Location of Detection

N

0 10 20   40   60   80   100
miles

Figure 25. Contour maps of manganese concentrations in ppm from the shallow and deep sample sets in Iowa.

Molybdenum Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Molybdenum ppm

- 2.0 - 2.3
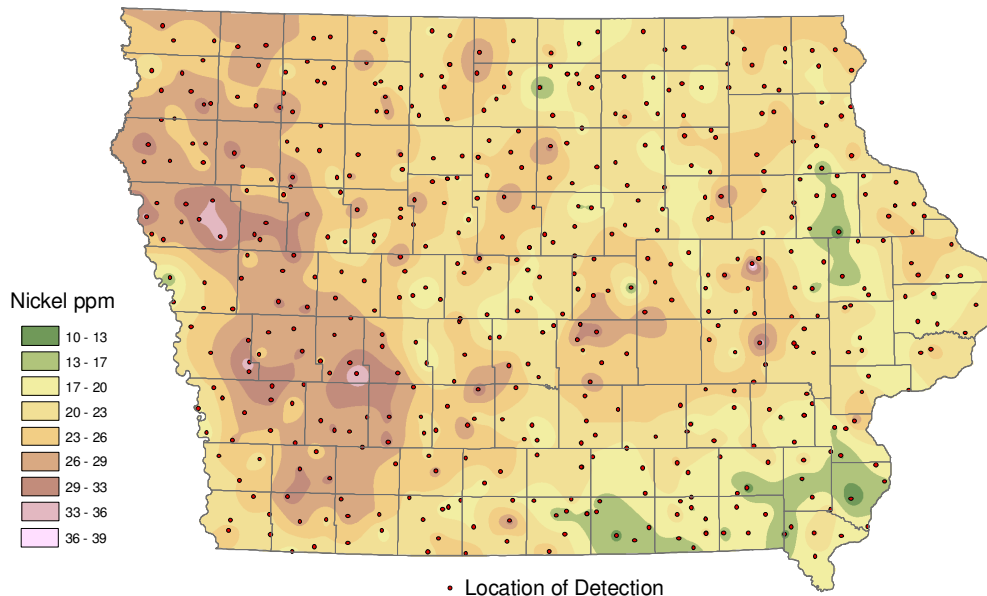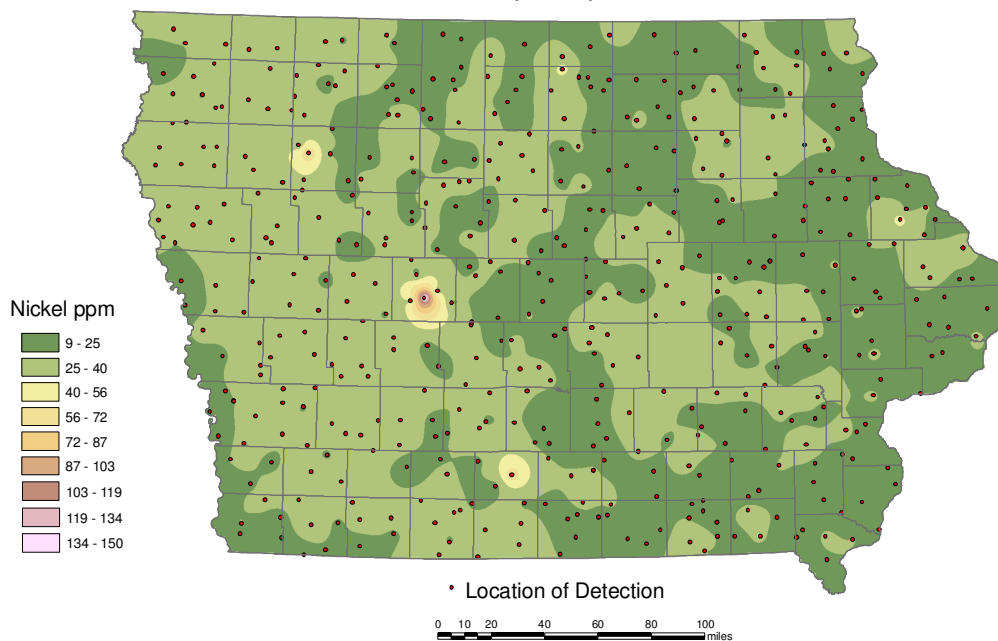- 2.3 - 2.6
- 2.6 - 2.9
- 2.9 - 3.3
- 3.3 - 3.6
- 3.6 - 3.9
- 3.9 - 4.2
- 4.2 - 4.5
- 4.5 - 4.9

· Location of Detection   · Location of Non-Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Molybdenum ppm

- 2.0 - 2.4
- 2.4 - 2.8
- 2.8 - 3.2
- 3.2 - 3.6
- 3.6 - 4.0
- 4.0 - 4.4
- 4.4 - 4.8
- 4.8 - 5.3
- 5.3 - 5.7

· Location of Detection   · Location of Non-Detection

N

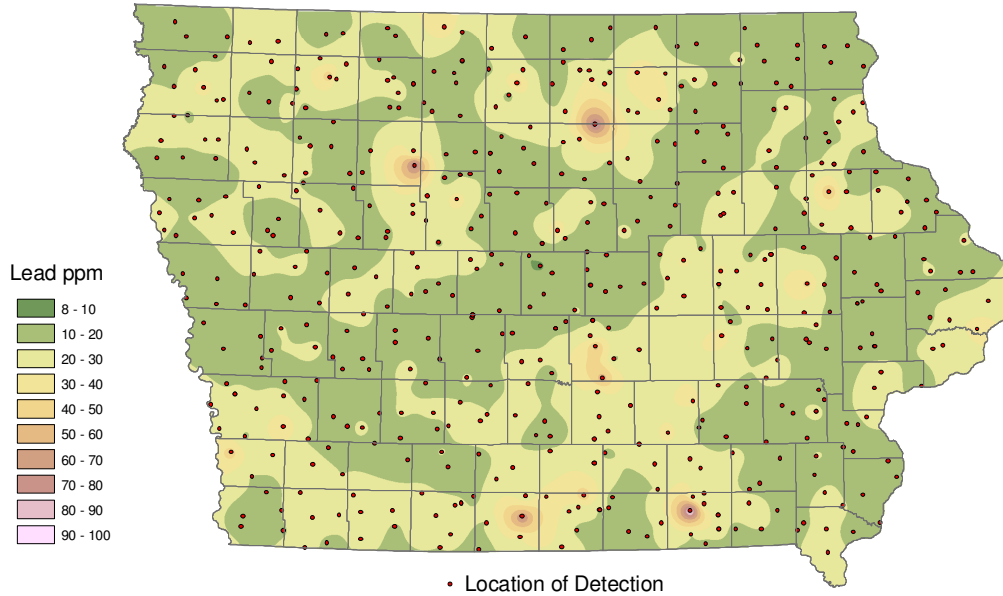0 10 20   40   60   80   100
miles

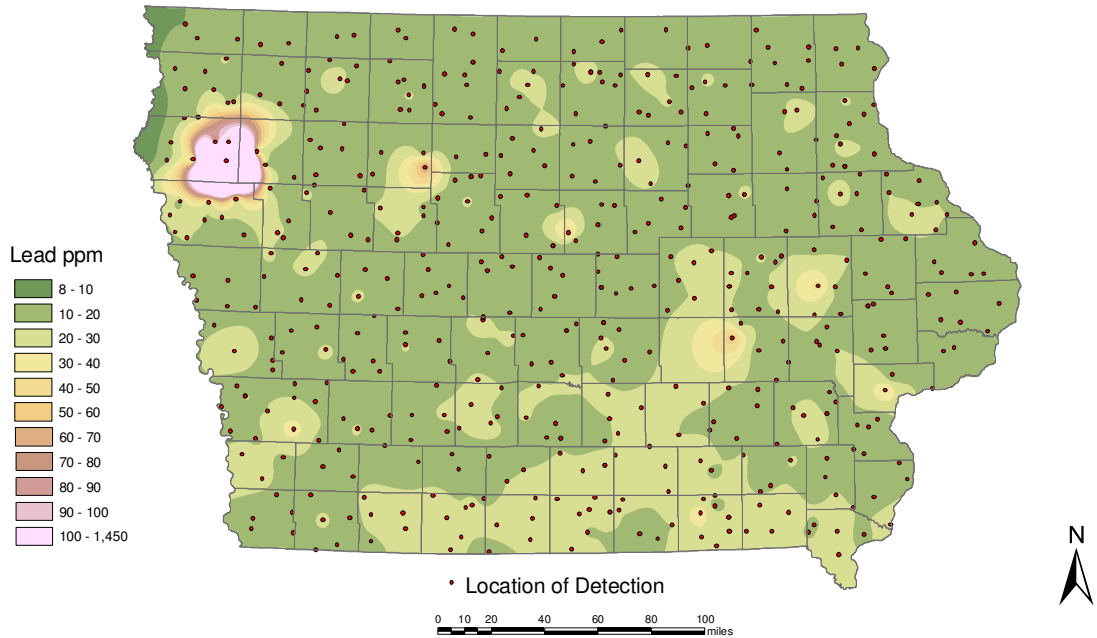**Figure 26.** Contour maps of molybdenum concentrations in ppm from the shallow and deep sample sets in Iowa.

Niobium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Niobium ppm

- 9 - 11
- 11 - 12
- 12 - 14
- 14 - 15
- 15 - 17
- 17 - 18
- 18 - 20
- 20 - 21
- 21 - 23

• Location of Detection

Lower Detection Limit = 4 ppm

Deep Sample Set

Niobium ppm

- 8 - 12
- 12 - 17
- 17 - 21
- 21 - 26
- 26 - 30
- 30 - 34
- 34 - 39
- 39 - 43
- 43 - 48

• Location of Detection

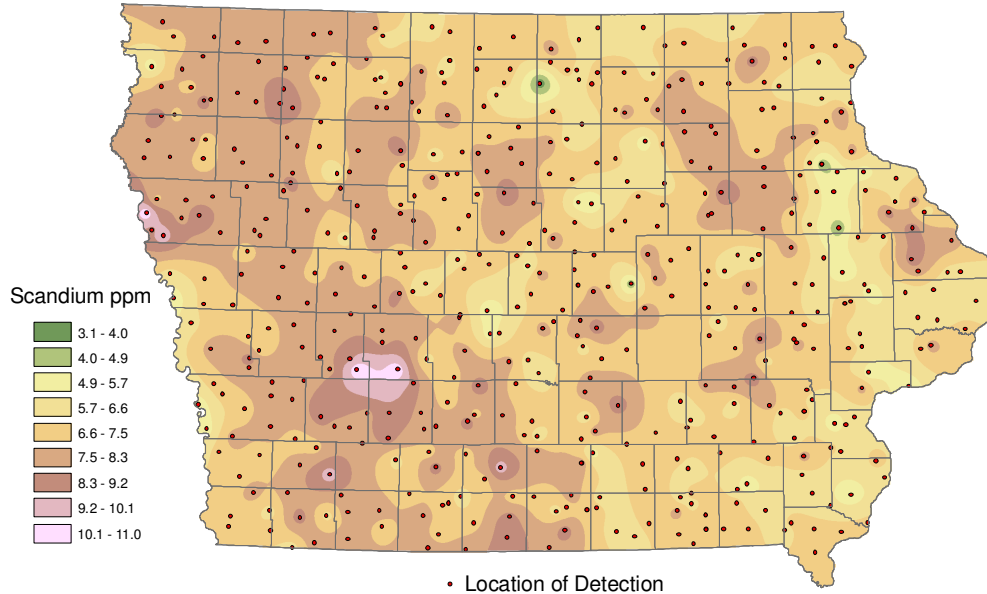0 10 20   40   60   80   100
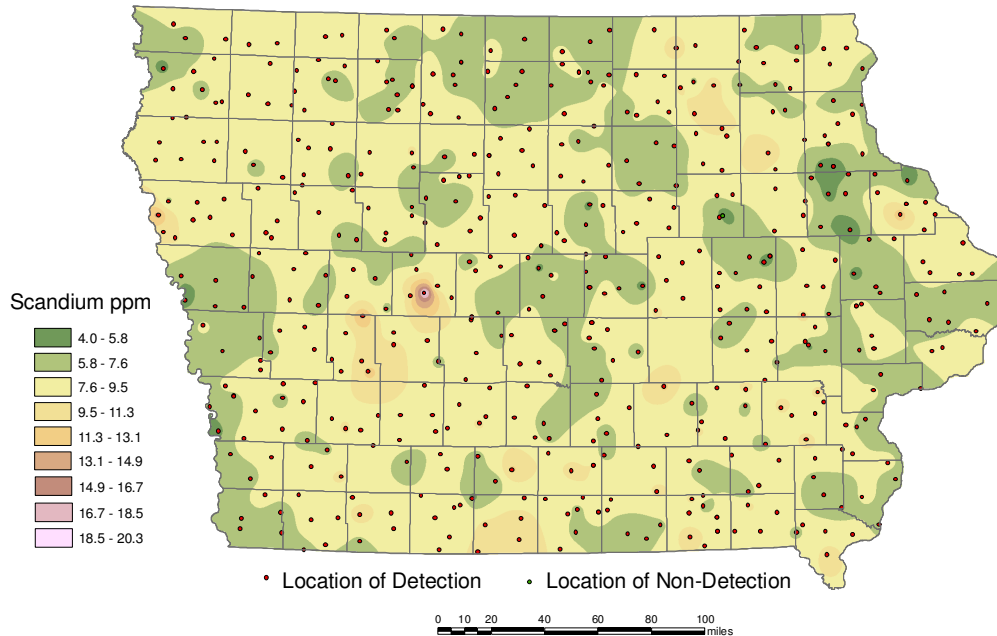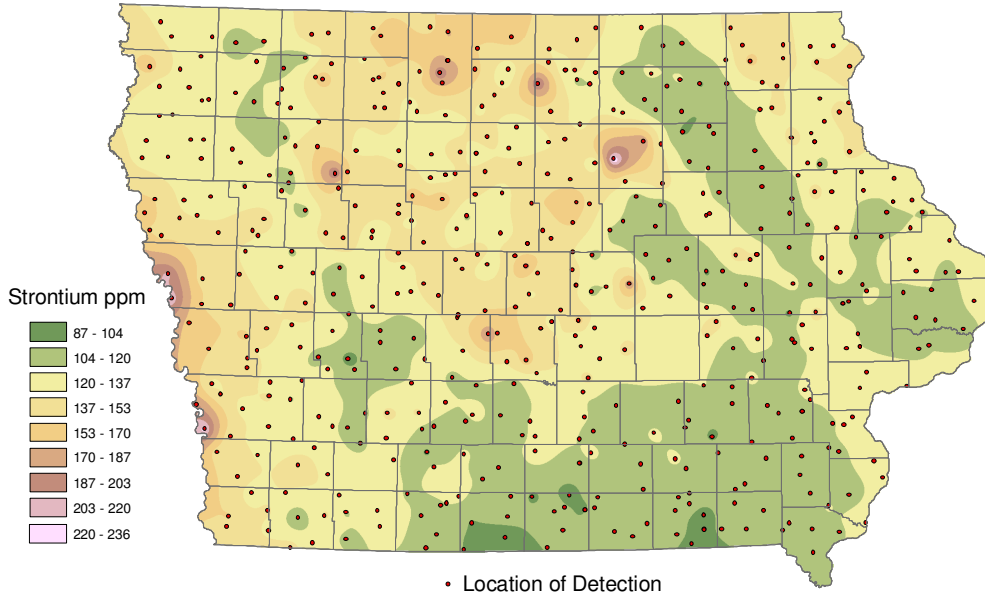miles

N

Figure 27. Contour maps of niobium concentrations in ppm from the shallow and deep sample sets in Iowa.

Neodymium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Neodymium
ppm

- 11 - 14
- 14 - 17
- 17 - 20
- 20 - 24
- 24 - 27
- 27 - 30
- 30 - 33
- 33 - 36
- 36 - 39

• Location of Detection

Lower Detection Limit = 9 ppm

Deep Sample Set

Neodymium
ppm

- 14 - 17
- 17 - 21
- 21 - 24
- 24 - 27
- 27 - 31
- 31 - 34
- 34 - 37
- 37 - 41
- 41 - 44

• Location of Detection   • Location of Non-Detection

N

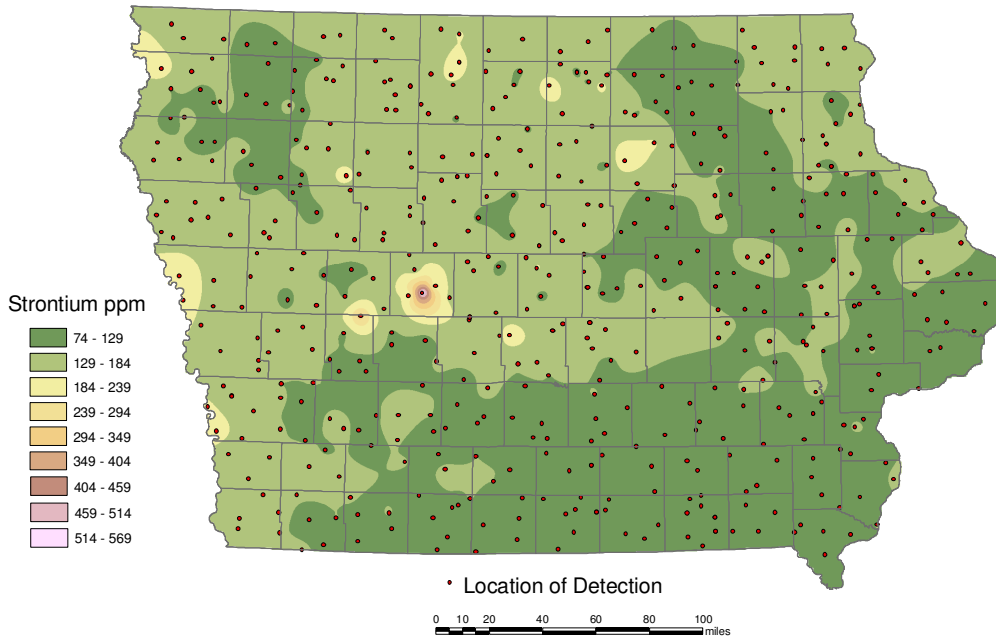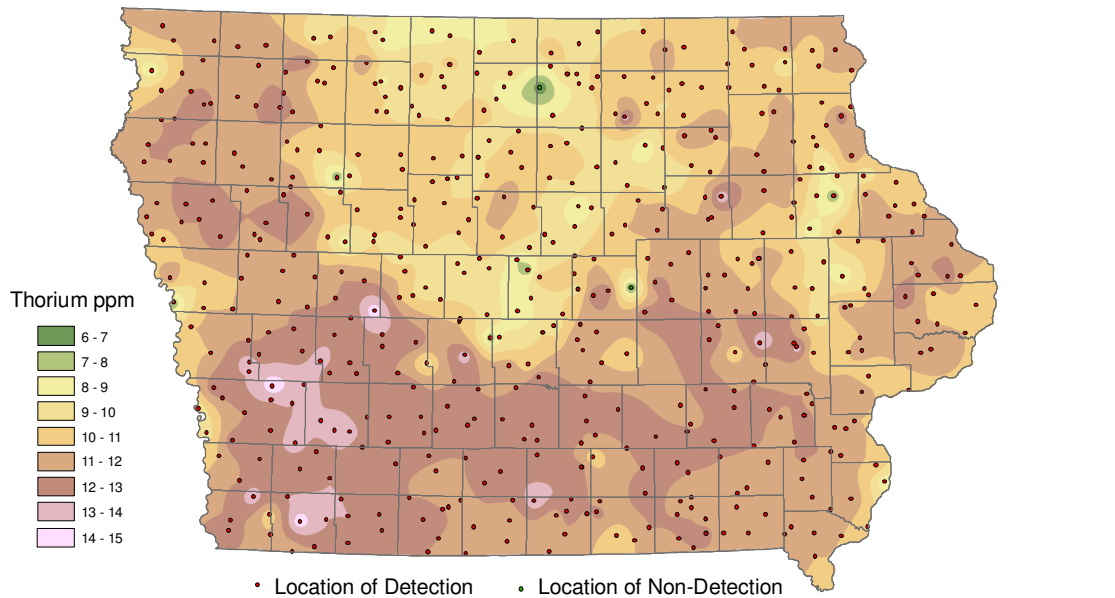0 10 20   40   60   80   100
miles
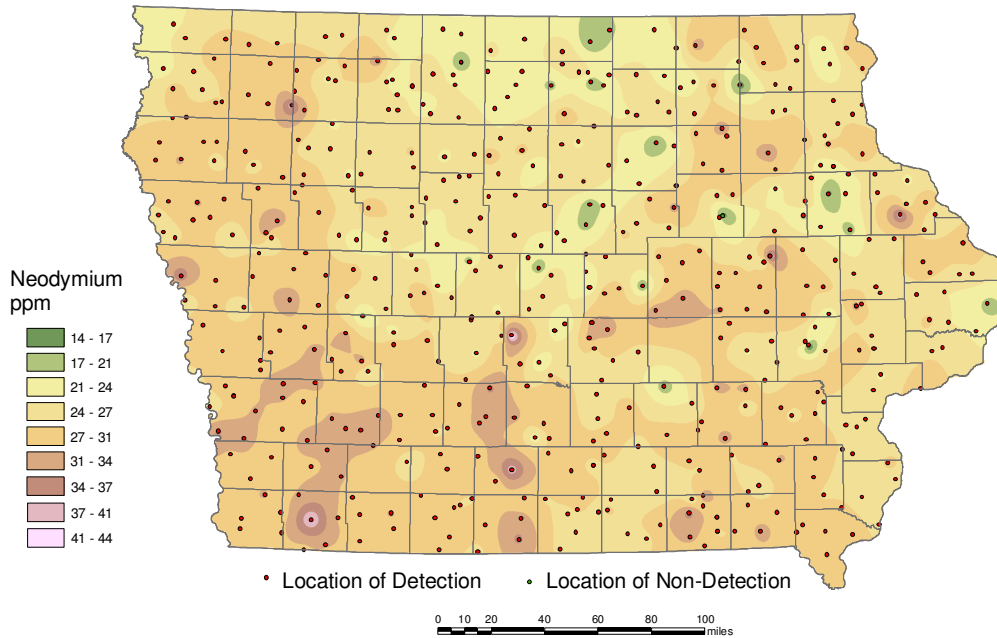
Figure 28. Contour maps of neodymium concentrations in ppm from the shallow and deep sample sets in Iowa.

Nickel Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Nickel ppm
- 10 - 13
- 13 - 17
- 17 - 20
- 20 - 23
- 23 - 26
- 26 - 29
- 29 - 33
- 33 - 36
- 36 - 39

• Location of Detection

Lower Detection Limit = 3 ppm

Deep Sample Set

Nickel ppm
- 9 - 25
- 25 - 40
- 40 - 56
- 56 - 72
- 72 - 87
- 87 - 103
- 103 - 119
- 119 - 134
- 134 - 150

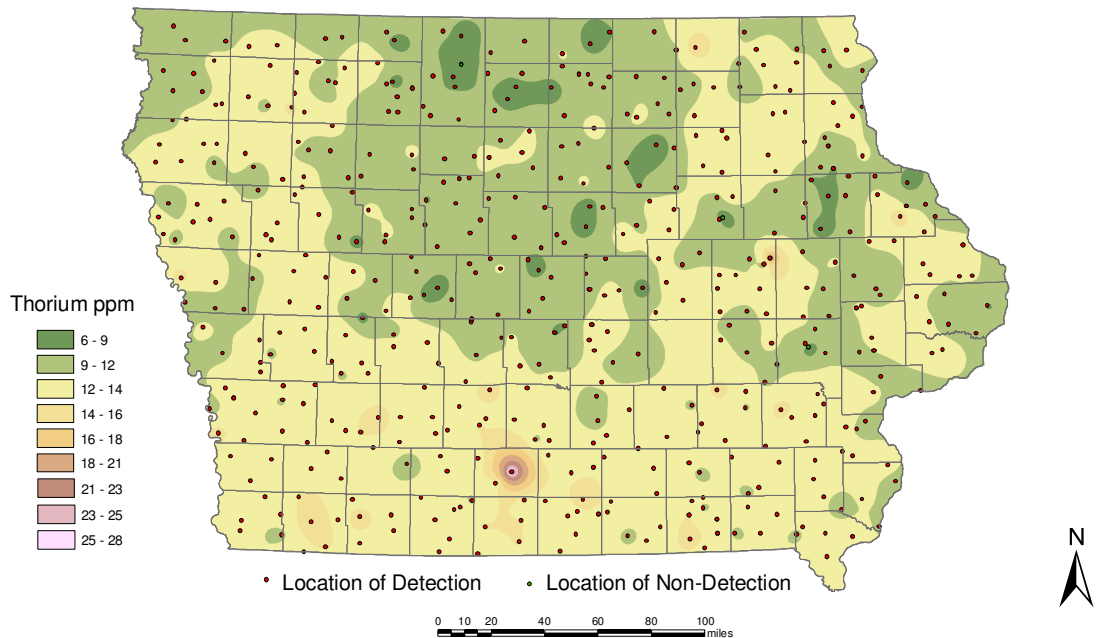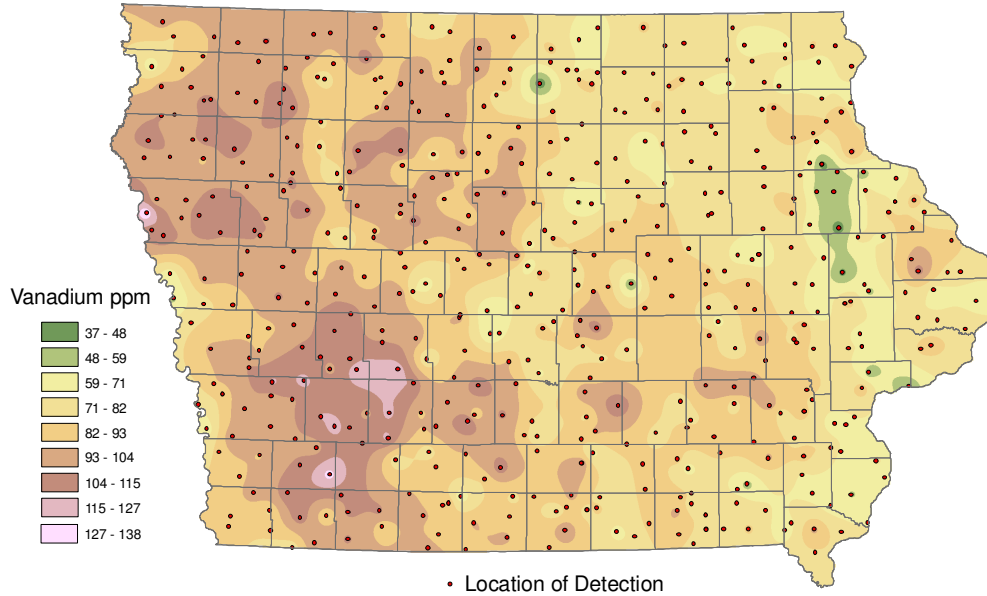• Location of Detection

N

0 10 20   40   60   80   100
miles

Figure 29. Contour maps of nickel concentrations in ppm from the shallow and deep sample sets in Iowa.

Lead Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Lead ppm

- 8 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100

• Location of Detection

Lower Detection Limit = 4 ppm

Deep Sample Set

Lead ppm

- 8 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- 100 - 1,450

• Location of Detection
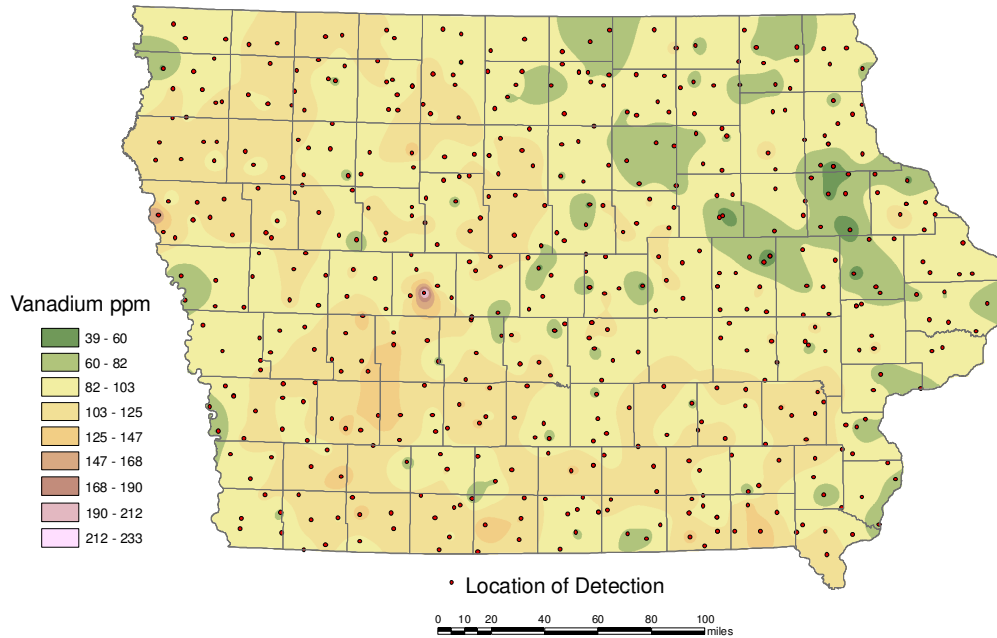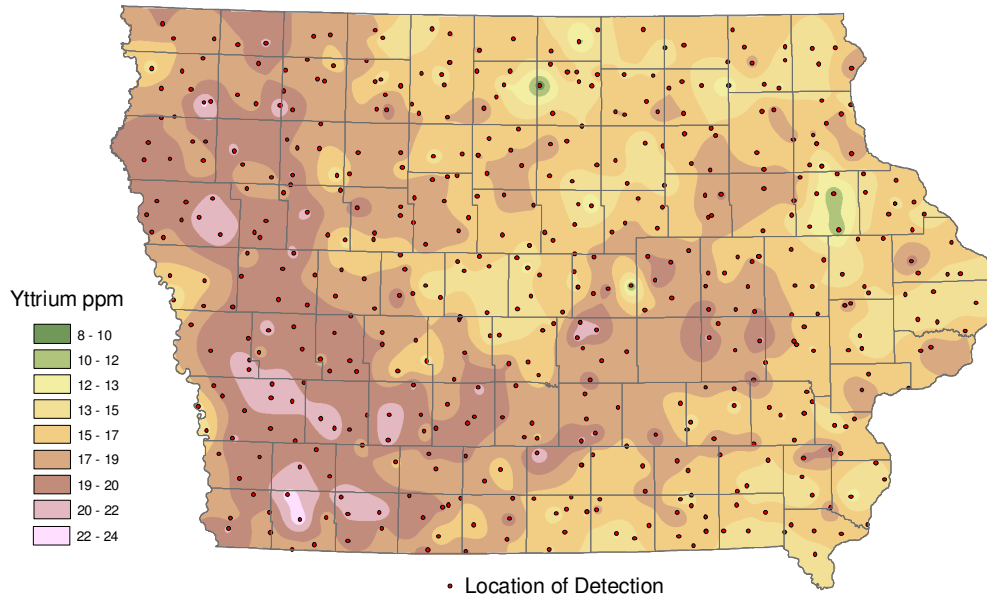
N

0 10 20   40   60   80   100
miles

Figure 30. Contour maps of lead concentrations in ppm from the shallow and deep sample sets in Iowa.

46

Scandium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Scandium ppm

- 3.1 - 4.0
- 4.0 - 4.9
- 4.9 - 5.7
- 5.7 - 6.6
- 6.6 - 7.5
- 7.5 - 8.3
- 8.3 - 9.2
- 9.2 - 10.1
- 10.1 - 11.0

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Scandium ppm

- 4.0 - 5.8
- 5.8 - 7.6
- 7.6 - 9.5
- 9.5 - 11.3
- 11.3 - 13.1
- 13.1 - 14.9
- 14.9 - 16.7
- 16.7 - 18.5
- 18.5 - 20.3

• Location of Detection   • Location of Non-Detection
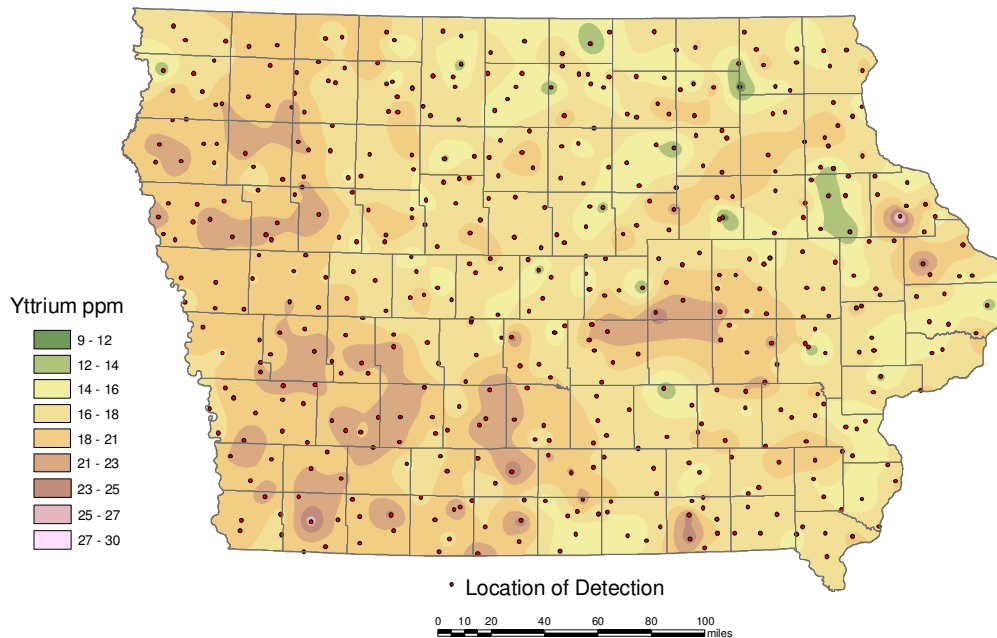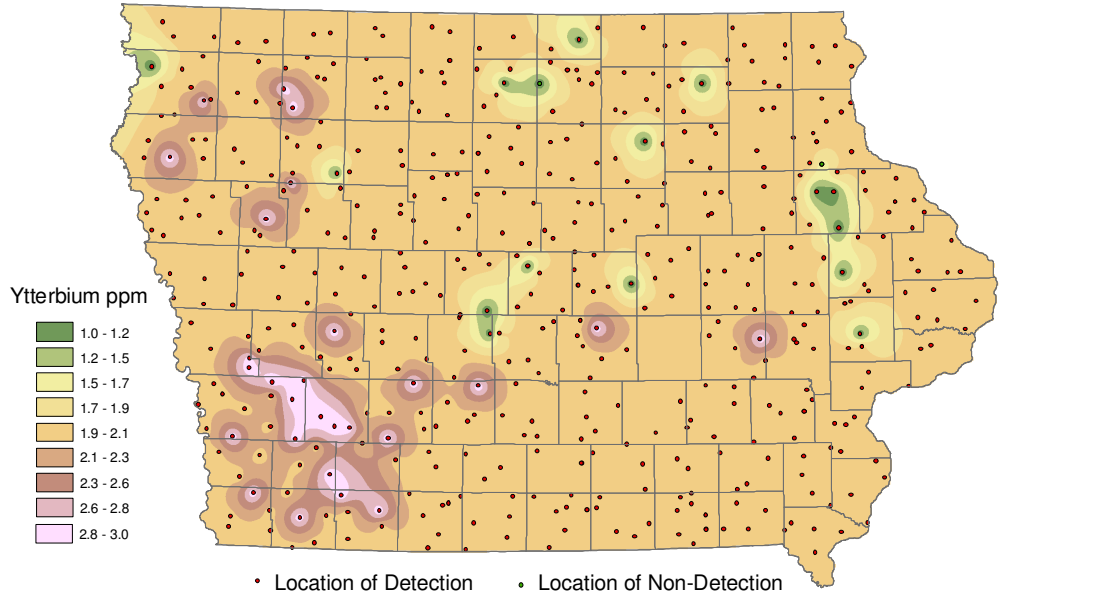
N

0 10 20   40   60   80   100
miles

Figure 31. Contour maps of scandium concentrations in ppm from the shallow and deep sample sets in Iowa.

Strontium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Strontium ppm
- 87 - 104
- 104 - 120
- 120 - 137
- 137 - 153
- 153 - 170
- 170 - 187
- 187 - 203
- 203 - 220
- 220 - 236

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Strontium ppm
- 74 - 129
- 129 - 184
- 184 - 239
- 239 - 294
- 294 - 349
- 349 - 404
- 404 - 459
- 459 - 514
- 514 - 569

• Location of Detection

N

0 10 20   40   60   80   100
miles

Figure 32. Contour maps of strontium concentrations in ppm from the shallow and deep sample sets in Iowa.

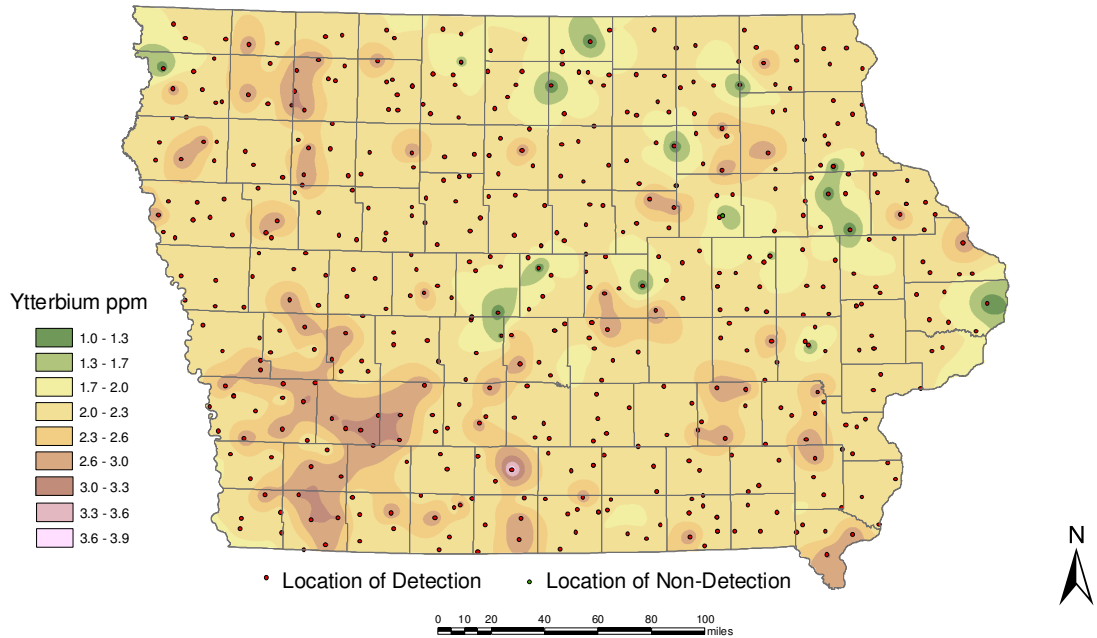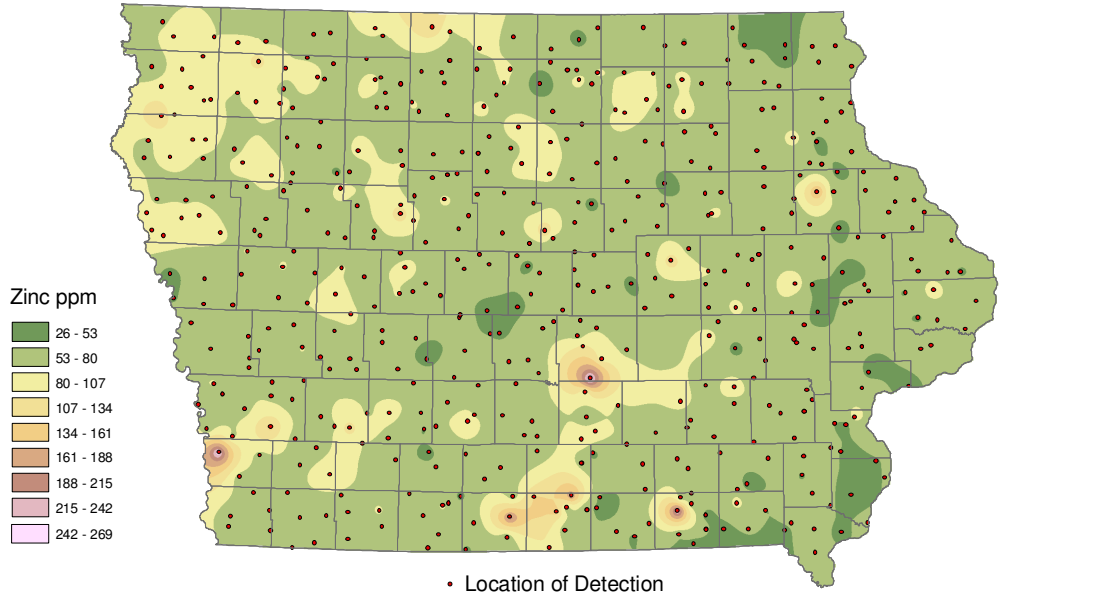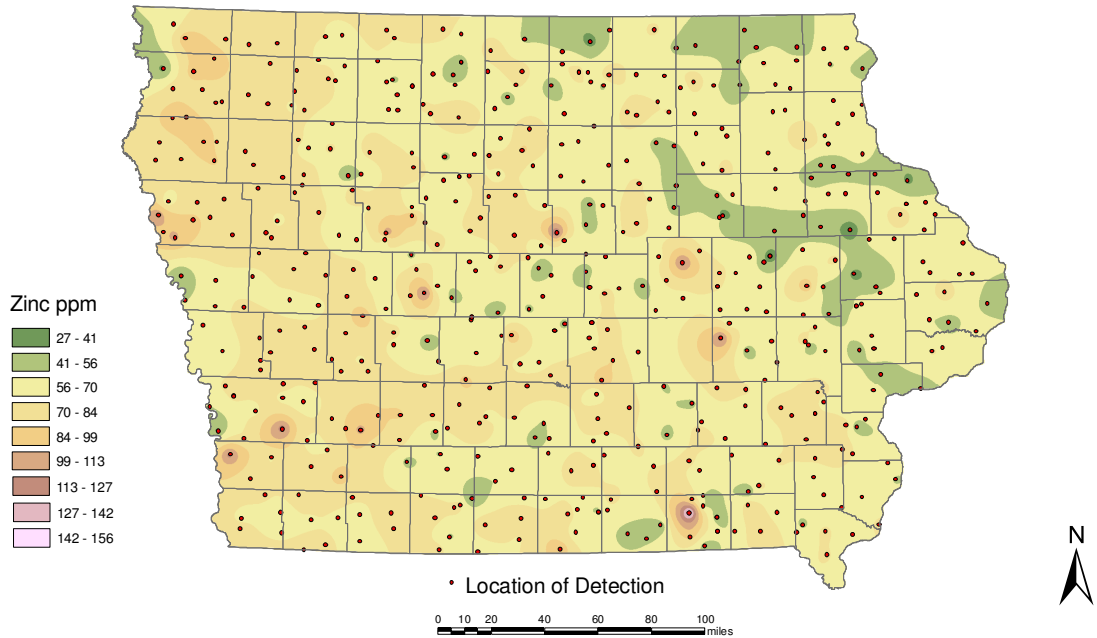# Thorium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Thorium ppm

- 6 - 7
- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14
- 14 - 15

• Location of Detection   • Location of Non-Detection

Lower Detection Limit = 6 ppm

Deep Sample Set

Thorium ppm

- 6 - 9
- 9 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 21
- 21 - 23
- 23 - 25
- 25 - 28

• Location of Detection   • Location of Non-Detection

N

0 10 20   40   60   80   100
miles

Figure 33. Contour maps of thorium concentrations in ppm from the shallow and deep sample sets in Iowa.

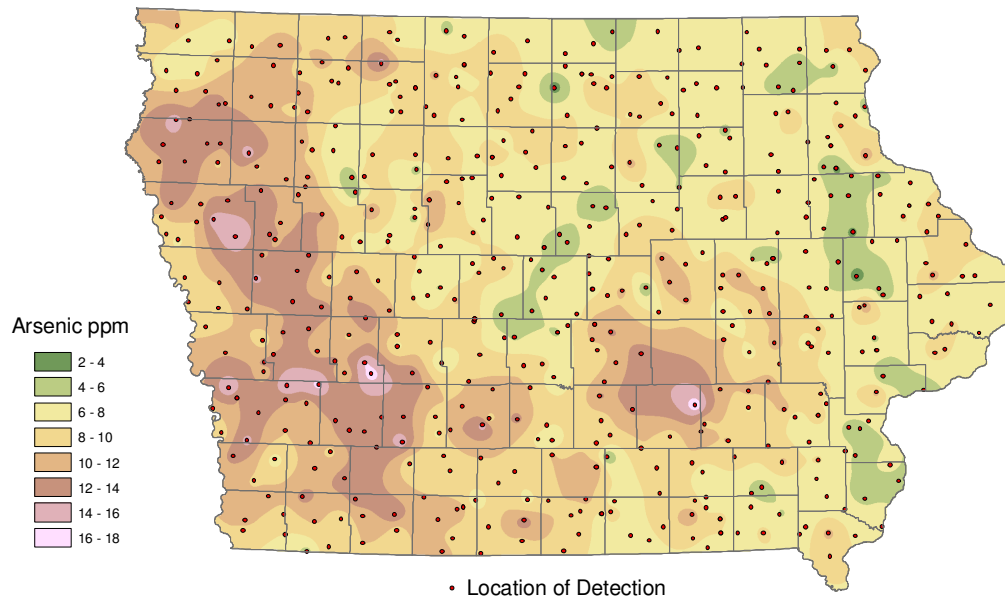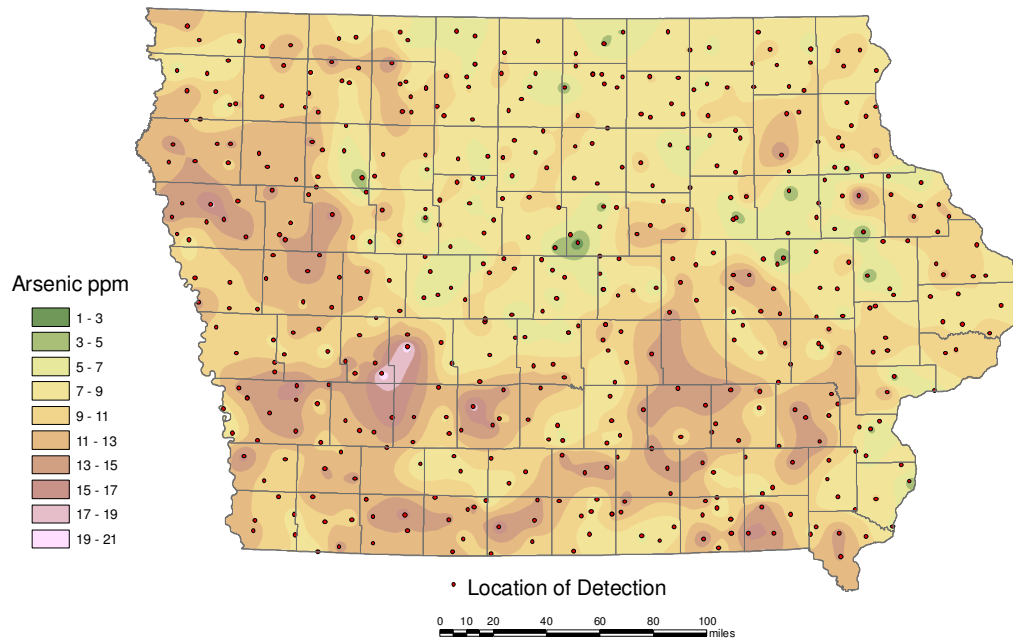# Vanadium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Vanadium ppm

- 37 - 48
- 48 - 59
- 59 - 71
- 71 - 82
- 82 - 93
- 93 - 104
- 104 - 115
- 115 - 127
- 127 - 138

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Vanadium ppm

- 39 - 60
- 60 - 82
- 82 - 103
- 103 - 125
- 125 - 147
- 147 - 168
- 168 - 190
- 190 - 212
- 212 - 233

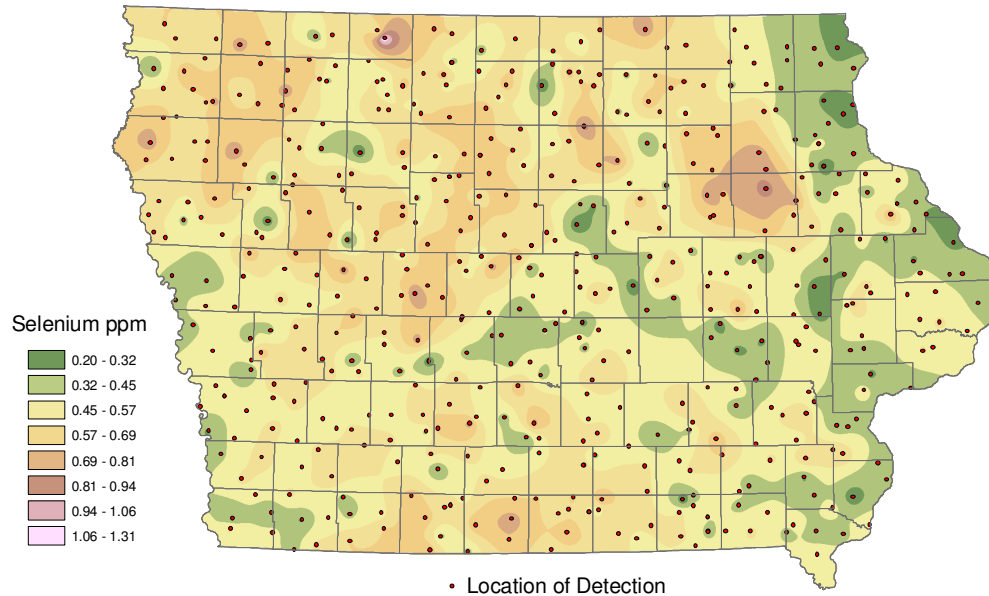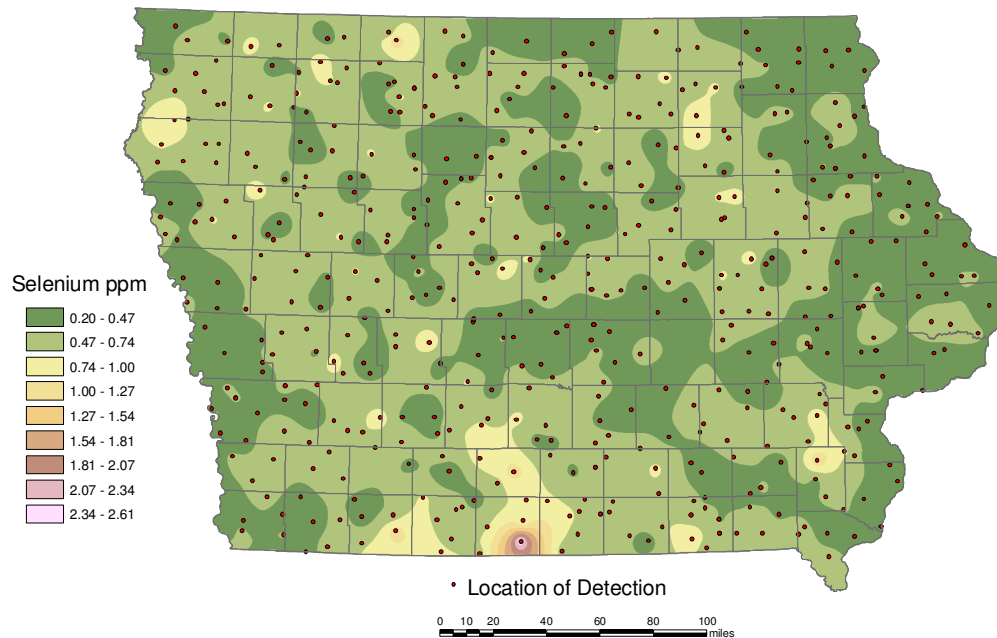• Location of Detection

0 10 20   40   60   80   100
miles

N

Figure 34. Contour maps of vanadium concentrations in ppm from the shallow and deep sample sets in Iowa.

Yttrium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Yttrium ppm

- 8 - 10
- 10 - 12
- 12 - 13
- 13 - 15
- 15 - 17
- 17 - 19
- 19 - 20
- 20 - 22
- 22 - 24

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Yttrium ppm

- 9 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 21
- 21 - 23
- 23 - 25
- 25 - 27
- 27 - 30

• Location of Detection
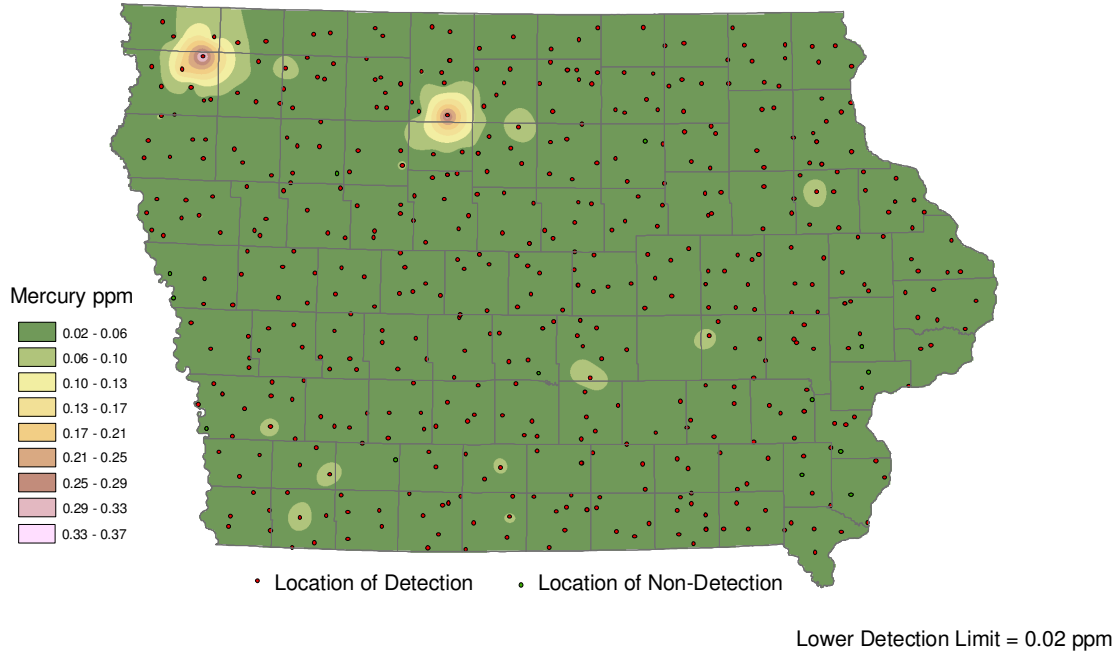
N

0 10 20   40   60   80   100
miles

Figure 35. Contour maps of yttrium concentrations in ppm from the shallow and deep sample sets in Iowa.

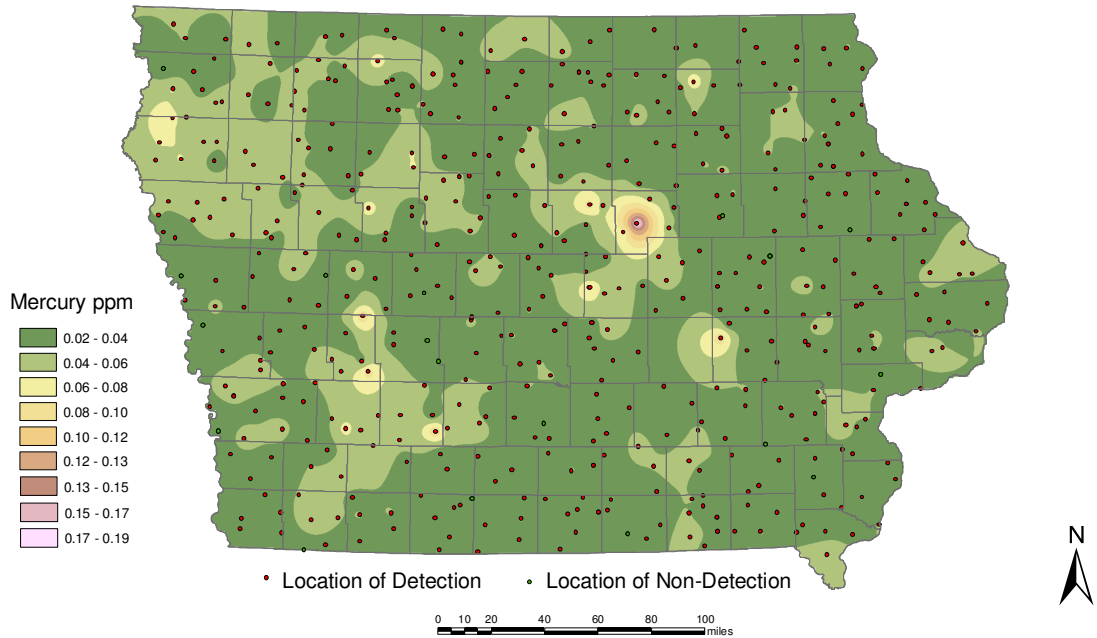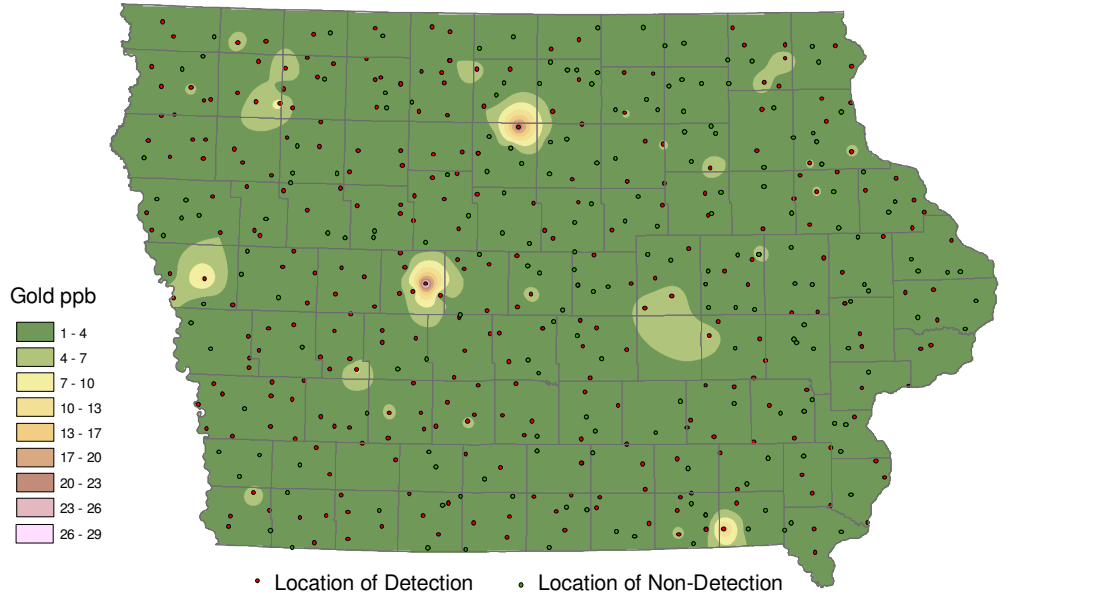# Ytterbium Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Ytterbium ppm

- 1.0 - 1.2
- 1.2 - 1.5
- 1.5 - 1.7
- 1.7 - 1.9
- 1.9 - 2.1
- 2.1 - 2.3
- 2.3 - 2.6
- 2.6 - 2.8
- 2.8 - 3.0

• Location of Detection   • Location of Non-Detection

Lower Detection Limit = 1 ppm

Deep Sample Set

Ytterbium ppm

- 1.0 - 1.3
- 1.3 - 1.7
- 1.7 - 2.0
- 2.0 - 2.3
- 2.3 - 2.6
- 2.6 - 3.0
- 3.0 - 3.3
- 3.3 - 3.6
- 3.6 - 3.9

• Location of Detection   • Location of Non-Detection

N

0 10 20   40   60   80   100
miles

Figure 36. Contour maps of ytterbium concentrations in ppm from the shallow and deep sample sets in Iowa.

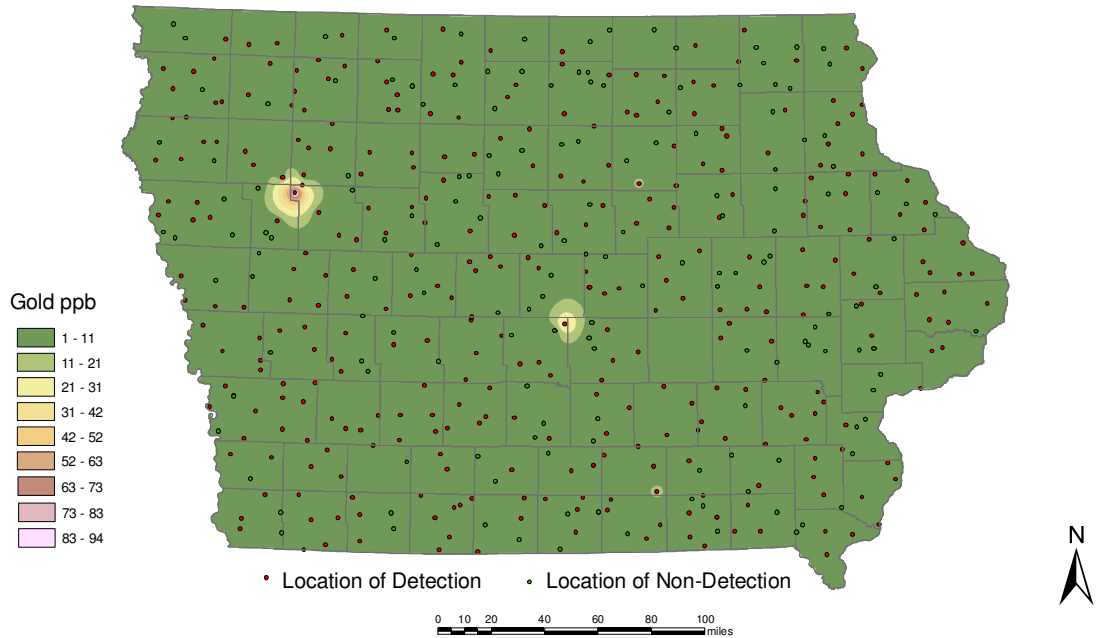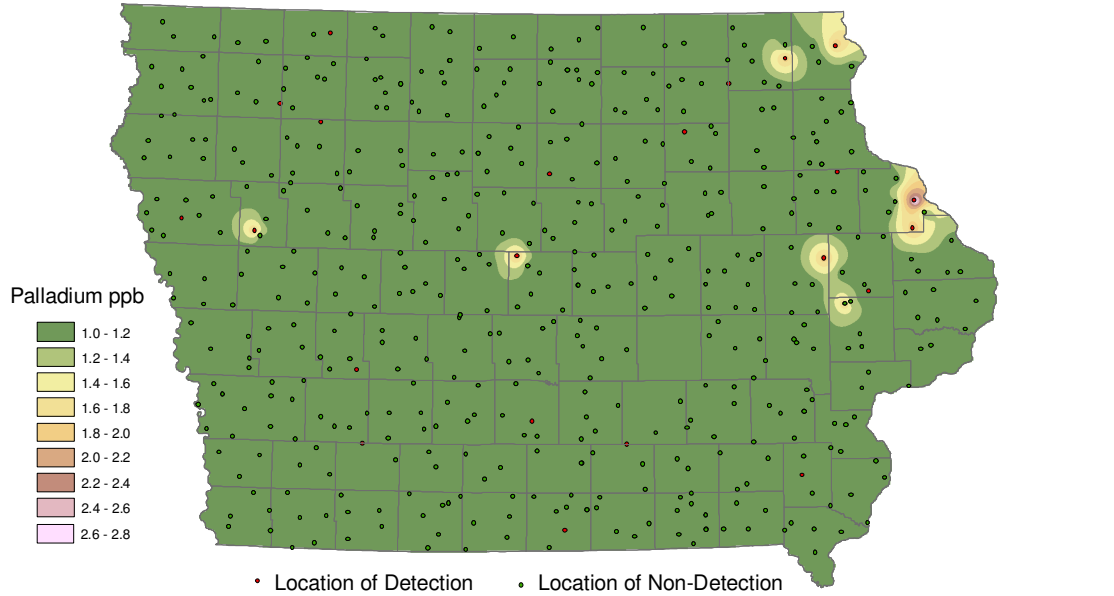# Zinc Concentrations in Iowa from ICP40 Analyses

Shallow Sample Set

Zinc ppm

- 26 - 53
- 53 - 80
- 80 - 107
- 107 - 134
- 134 - 161
- 161 - 188
- 188 - 215
- 215 - 242
- 242 - 269

• Location of Detection

Lower Detection Limit = 2 ppm

Deep Sample Set

Zinc ppm

- 27 - 41
- 41 - 56
- 56 - 70
- 70 - 84
- 84 - 99
- 99 - 113
- 113 - 127
- 127 - 142
- 142 - 156

• Location of Detection
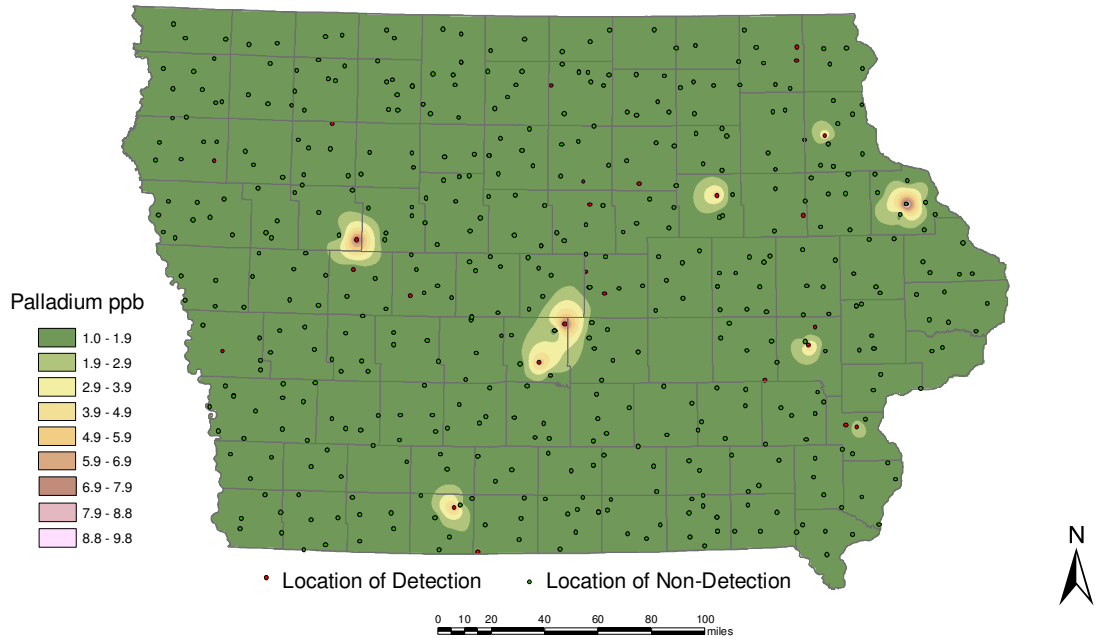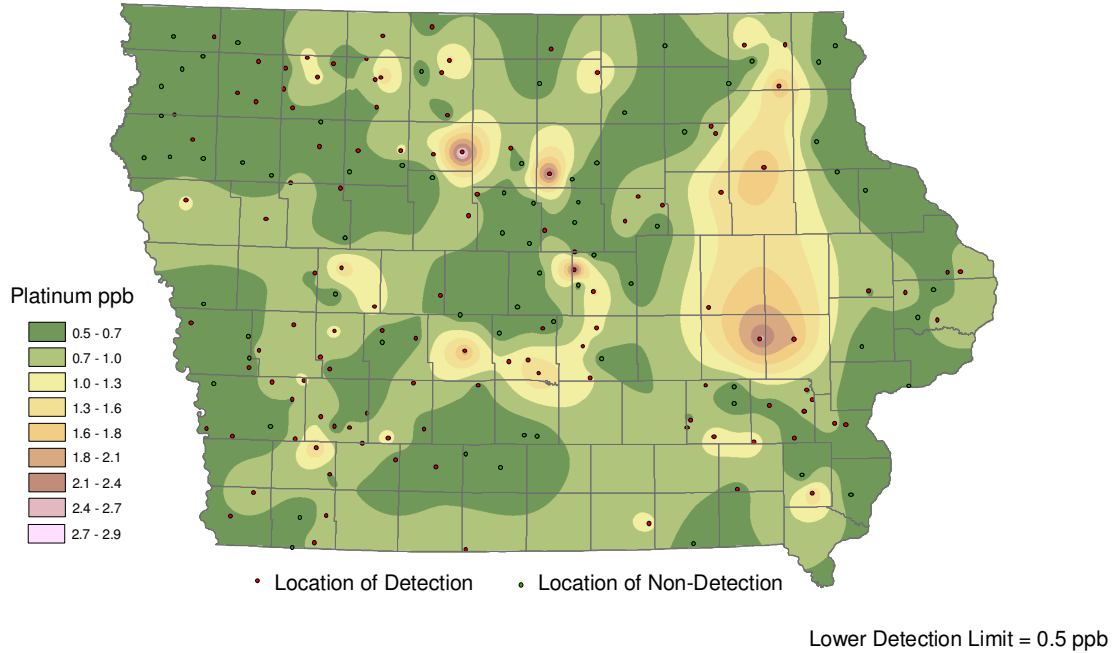
N

0 10 20   40   60   80   100
miles

Figure 37. Contour maps of zinc concentrations in ppm from the shallow and deep sample sets in Iowa.

53

Arsenic Concentrations in Iowa from AA Analyses

Shallow Sample Set

Arsenic ppm
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18

• Location of Detection

Lower Detection Limit = 0.6 ppm

Deep Sample Set

Arsenic ppm
- 1 - 3
- 3 - 5
- 5 - 7
- 7 - 9
- 9 - 11
- 11 - 13
- 13 - 15
- 15 - 17
- 17 - 19
- 19 - 21

• Location of Detection

0 10 20 40 60 80 100 miles

N

Figure 38. Contour maps of arsenic concentrations in ppm from the shallow and deep sample sets in Iowa.

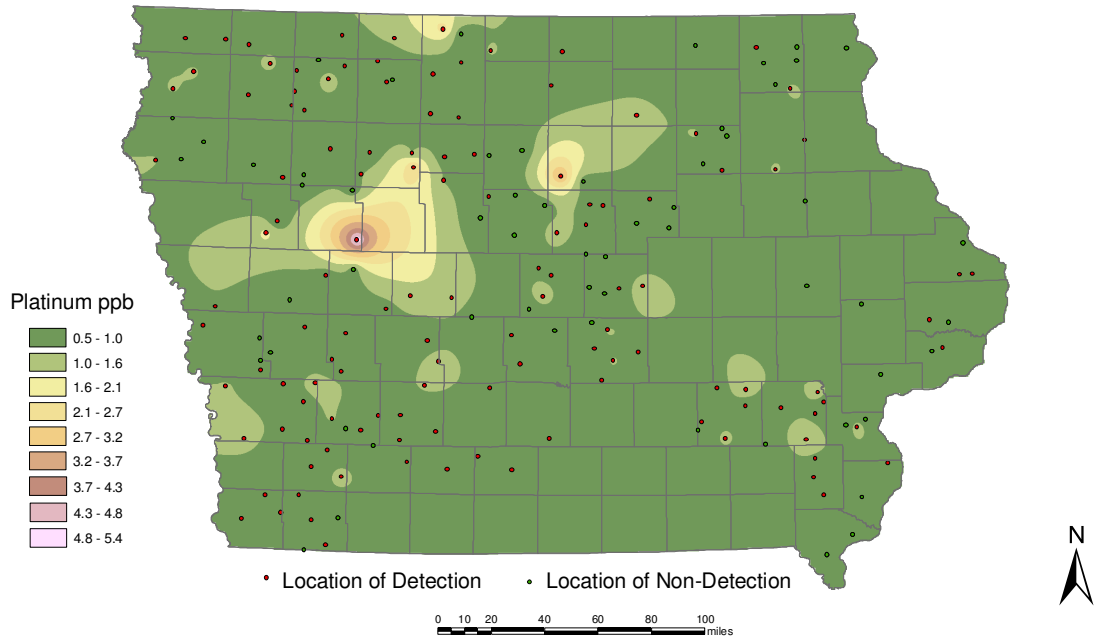# Selenium Concentrations in Iowa from AA Analyses

Shallow Sample Set

Selenium ppm

- 0.20 - 0.32
- 0.32 - 0.45
- 0.45 - 0.57
- 0.57 - 0.69
- 0.69 - 0.81
- 0.81 - 0.94
- 0.94 - 1.06
- 1.06 - 1.31

• Location of Detection

Lower Detection Limit = 0.2 ppm

Deep Sample Set

Selenium ppm

- 0.20 - 0.47
- 0.47 - 0.74
- 0.74 - 1.00
- 1.00 - 1.27
- 1.27 - 1.54
- 1.54 - 1.81
- 1.81 - 2.07
- 2.07 - 2.34
- 2.34 - 2.61

• Location of Detection

N

0 10 20   40   60   80   100
miles

Figure 39. Contour maps of selenium concentrations in ppm from the shallow and deep sample sets in Iowa.

Mercury Concentrations in Iowa from AA Analyses

Shallow Sample Set

Mercury ppm

- 0.02 - 0.06
- 0.06 - 0.10
- 0.10 - 0.13
- 0.13 - 0.17
- 0.17 - 0.21
- 0.21 - 0.25
- 0.25 - 0.29
- 0.29 - 0.33
- 0.33 - 0.37

• Location of Detection   • Location of Non-Detection

Lower Detection Limit = 0.02 ppm

Deep Sample Set

Mercury ppm

- 0.02 - 0.04
- 0.04 - 0.06
- 0.06 - 0.08
- 0.08 - 0.10
- 0.10 - 0.12
- 0.12 - 0.13
- 0.13 - 0.15
- 0.15 - 0.17
- 0.17 - 0.19

• Location of Detection   • Location of Non-Detection

N

0 10 20   40   60   80   100
miles

Figure 40. Contour maps of mercury concentrations in ppm from the shallow and deep sample sets in Iowa.

Gold Concentrations in Iowa from AA Analyses

Shallow Sample Set

Gold ppb

- 1 - 4
- 4 - 7
- 7 - 10
- 10 - 13
- 13 - 17
- 17 - 20
- 20 - 23
- 23 - 26
- 26 - 29

• Location of Detection   • Location of Non-Detection

Lower Detection Limit = 1 ppb

Deep Sample Set

Gold ppb

- 1 - 11
- 11 - 21
- 21 - 31
- 31 - 42
- 42 - 52
- 52 - 63
- 63 - 73
- 73 - 83
- 83 - 94

• Location of Detection   • Location of Non-Detection

0 10 20   40   60   80   100
miles

N

Figure 41. Contour maps of gold concentrations in ppb from the shallow and deep sample sets in Iowa.

Palladium Concentrations in Iowa from AA Analyses

Shallow Sample Set

Palladium ppb

- 1.0 - 1.2
- 1.2 - 1.4
- 1.4 - 1.6
- 1.6 - 1.8
- 1.8 - 2.0
- 2.0 - 2.2
- 2.2 - 2.4
- 2.4 - 2.6
- 2.6 - 2.8

• Location of Detection   • Location of Non-Detection

Lower Detection Limit = 1 ppb

Deep Sample Set

Palladium ppb

- 1.0 - 1.9
- 1.9 - 2.9
- 2.9 - 3.9
- 3.9 - 4.9
- 4.9 - 5.9
- 5.9 - 6.9
- 6.9 - 7.9
- 7.9 - 8.8
- 8.8 - 9.8

• Location of Detection   • Location of Non-Detection

N

0 10 20   40   60   80   100
miles

Figure 42. Contour maps of palladium concentrations in ppb from the shallow and deep sample sets in Iowa.

Platinum Concentrations in Iowa from AA Analyses

Shallow Sample Set

Platinum ppb

- 0.5 - 0.7
- 0.7 - 1.0
- 1.0 - 1.3
- 1.3 - 1.6
- 1.6 - 1.8
- 1.8 - 2.1
- 2.1 - 2.4
- 2.4 - 2.7
- 2.7 - 2.9

• Location of Detection   • Location of Non-Detection

Lower Detection Limit = 0.5 ppb

Deep Sample Set

Platinum ppb

- 0.5 - 1.0
- 1.0 - 1.6
- 1.6 - 2.1
- 2.1 - 2.7
- 2.7 - 3.2
- 3.2 - 3.7
- 3.7 - 4.3
- 4.3 - 4.8
- 4.8 - 5.4

• Location of Detection   • Location of Non-Detection

N

0 10 20   40   60   80   100
miles

Figure 43. Contour maps of platinum concentrations in ppb from the shallow and deep sample sets in Iowa.

59

environment include smelting, manufacturing, refining, chemical processing, fertilizer application, irrigation, and waste disposal. The combination of some natural processes with human activities may increase the concentration of some elements to harmful or toxic levels. Consequently, environmental hazards from chemical elements may have both natural and human sources.

Arsenic is a naturally occurring chemical element in Iowa soils that may be considered an environmental hazard. The statewide mean concentration for arsenic in soil samples collected for the trace element project was 9.19 ppm, with arsenic being detected in 100% of the soil samples. Because of the high percentage of detections and the state-wide distribution of arsenic in the soil, it is thought to be naturally occurring from the breakdown of arsenic bearing minerals, such as pyrite, in the glacial till and rock parent material.

The mean concentration of arsenic in the soil samples was three orders of magnitude greater than typical arsenic concentrations found in surface water samples collected across Iowa by the USGS and the IDNR (www.igsb.uiowa.edu/web apps/iastoret/).

In a recent groundwater study, forty-eight percent of the water samples from Iowa rural drinking water wells contained arsenic, with eight percent of the samples containing arsenic at levels above the USEPA maximum contaminant level (MCL) of 10.0 ppb for public water supplies (http://iowaindependent.com/22257/iowa-study-finds-worrisome-arsenic-levels-in-private-water-wells).

Because the State of Iowa has a much more stringent health criterion for arsenic than the USEPA, problems in complying with environmental regulations may occur in the future. The Code of Iowa, Chapter 61, Table 1, lists the Class C human health criterion for arsenic as 0.18 ppb (www.legis.state.ia.us/IACODE/). This criteria was written into the Iowa Code before most laboratories had the analytical capabilities to detect arsenic at these levels, so in the past, this has not been an issue. Even currently, the University of Iowa Hygienic Laboratory (UHL) uses a detection level for arsenic of 10.0 ppb for the IDNR ambient surface water-monitoring network. When the detection level used to evaluate surface water samples in Iowa approaches the 0.1 ppb range, most streams in Iowa will contain arsenic concentrations exceeding the Iowa standard, and will be considered to be impaired by arsenic.

Geochemical data have been collected for numerous studies for many years for the purpose of locating areas where geologic processes have left mineral deposits containing elements of value in quantities great enough to mine economically. When the sample sets for geochemical studies are collected at appropriate densities and analyzed for a wide variety of elements using consistent methods, the resulting data set or coverage can also be used to establish geochemical baselines, and provide context for a wide variety of geological and environmental studies.

For this study, the IGWS designed a database for field parameters and collected two soil sample sets. The USGS processed and analyzed one sample set and reposited the other. The collected field parameters included ambient site conditions, GPS location, elevation, landscape position, vegetation type, NRCS soil type, sample depth, and soil horizon, texture, color, and moisture. Digital photographs were taken of the sampling site and samples at each location. The USGS sieved the samples to -100 mesh, then analyzed for 40 elements using inductively coupled plasma-atomic emission spectrometry/acid dissolution (ICP40) and 6 elements using atomic absorption spectrometry (AA). Arsenic (As) and gold (Au) were analyzed using both methods. The analyses were performed by an approved lab, using standard methods and a USEPA approved quality assurance/quality control plan.

To maximize statistical reliability, sample collection was based on a 17 km x 17 km grid displayed on USGS 1:250,000 quad maps. Each grid or cell was identified by quad name and cell column and row position, and divided into four 72 km^2 quadrants, and one quadrant was selected at random for sampling. The IGWS selected specific sampling sites within the selected quadrants.

To separate leached soil horizons from those accumulating CO_3, one shallow (0-8 inches) and one deep (12-24 inches) sample were collected from the 463 regular and 72 analysis of variance

(AOV) sites from May through August 2003 and shipped to the USGS in August 2003. Randomly selected AOV sites were sampled to provide a data set for statistical analysis to test the adequacy of the samples to measure differences of sediment chemistry between cells, within cells, within sites, and between chemical analyses. "AOV1" was collected within the designated quadrant of the cell, then one of the three other quadrants of the cell were selected at random for "AOV2" and "AOV3" which were collected about 10 feet apart, preferably within the same soil type.

The field data were described on data collection sheets and later transferred to the IGWS network through an entry routine on a daily to weekly basis. The visual Dbase® entry routine and database were developed and maintained by IGWS personnel. After the analyses were performed, the field data were joined with the soil sample analyses by the USGS. The joined data can be accessed from the USGS at http://tin.er.usgs.gov/geochem/doc/home.htm, or the IGWS website at www.igsb.uiowa.edu. For a detailed description of the USGS National Geochemical Survey database, visit http://tin.er.usgs.gov/geochem/.

As discussed, this report only describes the design and implementation of the Iowa State-Wide Trace Element Soil Sampling Project, and the acquisition and compilation of the resulting data. The most potentially interesting aspects of the project, the analysis and interpretation of the data, have not begun. The spatial distribution of individual trace elements will be compared with other trace elements (ratios) and groups of trace elements in an effort to discover possible relationships. The distribution of the trace elements and ratios of trace elements will also be examined within geomorphic, geologic and hydrologic frameworks to see if relationships within these environments exist. Differences in concentrations and spatial distribution between the shallow and deep sample sets for each trace element will also be investigated. The distribution of trace elements may be related to differing soil types, various landform settings, and the distribution of varying types of underlying unconsolidated materials and various underlying rock compositions.

The timing of igneous, volcanic, and metamorphic activity generating parent material, type and source area of parent material, mode of erosion, climactic and weathering conditions, mode and distance of travel, length of transport time, depositional environment of sediments, structural changes in geology and depositional environment, and current and past in situ soil conditions are a few factors that may influence the spatial distribution and concentration of trace elements.

The analysis of various trace element ratios may yield interesting and useful results. A USGS aeroradiometric survey of North America generated data from aerial sensing of gamma-ray radiation emanating from the earth's surface. The survey was intended to provide general estimates of the geographic distribution of uranium, thorium, and potassium in surficial and bedrock units. A color composite image of the data, made by combining separate color bands for each element, reveals a variety of landforms across the U.S. Within Iowa, the Des Moines Lobe and Iowan Surface landform regions are clearly visible.

A preliminary overview of the geochemical contour maps of the individual trace elements reveals that while the mean concentrations for the shallow and deep sample sets may be similar, there can be significant differences in the spatial distribution of the elements from the shallow and deep sample sets. The maps for the shallow sample sets for titanium, cerium, and lanthanum display patterns of lower concentrations that roughly outline the Des Moines Lobe, while maps for barium and potassium show groupings of higher trace element concentrations in western Iowa in the proximity of the Missouri Alluvial Plain and Loess Hills landform regions. Yttrium and ytterbium trace element concentrations tend to be higher in areas just east of the Loess Hills, and the shallow sample sets for nickel and vanadium concentrations also tend to be higher in western Iowa, east and north of the Loess Hills. The trace element concentrations for niobium, neodymium, thorium, and arsenic tend to be higher in areas of the Northwest Iowa Plains and Southern Iowa Drift Plain landform regions. An anomalously high lead concentration found in the deep sample set in Plymouth

County is thought to be due to a fragment of lead shot, according to the lab that did the trace element analyses.

The discovery of relationships among the spatial distribution of trace elements and landform regions, as well as possible relationships with soil types and the underlying unconsolidated and consolidated parent materials would probably be enhanced by the comparison of combinations and ratios of trace elements with these features, rather than by comparison of the individual elements with the features.

In its current form, the data from this project provide valuable baseline information on the natural quantity, spatial distribution, and vertical variation of the assessed trace elements within Iowa. The information is also an important component of the larger NGS database. Future environmental changes caused by agricultural practices, waste disposal, urbanization, industrial activities, mineral exploration and mining, as well as changes from environmental remediation and restoration, and other land-use practices can be compared with this information. The trace element databases will also help improve our understanding of the relationships between geologic processes and human health, ecosystem structure and function, and the distribution of our mineral resources. There are numerous possibilities for future studies of this data.

Anthropogenic changes affecting the quantity and distribution of trace elements occur on a landscape in which natural background concentrations can vary several orders of magnitude over short distances, both vertically and horizontally. These spatial variations in geology, hydrology, and geochemistry are often poorly understood and often overlooked when setting public policy. It is difficult to recognize and understand changes in natural systems if we do not understand the present composition of the land surface and the range of natural baseline values within it.

Most forms of life are affected by the occurrence, distribution, and availability of the chemical elements that comprise the earth. As mentioned, environmental hazards may exist in areas where some of these chemical elements occur in excessive or deficient quantities. The ability to accurately quantify the abundance, concentration and spatial distribution of many of these elements across the earth's surface is critical for assessing potential environmental hazards, and for making environmentally and economically sound management and development decisions concerning mineral and water resources.

Everything we do on the land affects the quality and quantity of our natural resources and the natural systems around us. As a result, our natural resources and the quality of our lives are directly affected by the way we plan for and manage our land and waters. A better understanding of our mineral and water resources, and their occurrence in and movement through the earth's geologic, hydrologic, and geochemical framework, will lead to better use, protection, and management of Iowa's natural resources.

ACKNOWLEDGEMENTS

REFERENCES

Bailey, Eizabeth A., Smith, David B., Abston, Carl C., Granitto, Matthew, and Burleigh, Kuuipo A., 1999, National Geochemical Database: U.S. Geological Survey RASS (Rock Analysis Storage System) geochemical data for Alaska: U.S. Geological Survey Open-File Report 99-433.

Duval, J. S., 2001, Aerial gamma-ray surveys in Alaska: U.S. Geological Survey Open-File Report 01-128, two CD-ROMs.

Duval, J. S. and Riggle, F. R., 1999, Profiles of gamma-ray and magnetic data from aerial surveys over the conterminous Unites States: U.S. Geological Survey Digital Data Series DDS-0031, 3 CD-ROMs.

Folger, H. W., 2000, Analytical results and sample locations of reanalyzed NURE stream-sediment and soil samples for the Humboldt River Basin mineral-environmental resource assessment, northern Nevada. U.S. Geological Survey Open-File Report 00-421

Grossman, J.N., 1998, National Geochemical Atlas: The geochemical landscape of the conterminous United States derived from stream sediment and other solid sample media analyzed by the National Uranium Resource Evaluation (NURE) program: U.S. Geological Survey Open File Report 98-622, 1 CD-ROM.

Shacklette, H. T. and Boerngen, J. G., 1984, Element concentrations in soils and other surficial materials in the conterminous United States: U.S. Geological Survey Professional Paper 1270, 105 p.

Iowa Department of Natural Resources

Geological and Water Survey

109 Trowbridge Hall

Iowa City, Iowa 52242-1319

(319) 335-1575

www.igsb.uiowa.edu