USDA

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July 8, 2015

IOWA INSTRUCTION 180-393 – SCREENING/ASSESSING WATER QUALITY DEGRADATION – EXCESS NUTRIENTS IN GROUNDWATER RESOURCE CONCERN AND CONSERVATION PRACTICES TO ADDRESS THE CONCERN

IA393.0 PURPOSE

This Iowa Instruction is to explain how to access and use the "2015 Water Quality Degradation – Groundwater" GIS layer (available May 18, 2015) to screen or identify the WATER QUALITY DEGRADATION – Excess nutrients in groundwater resource concern and to provide guidance for the conservation plan to protect the source water of municipal, other public, and private wells.

IA393.1 SCOPE

These instructions will be followed by NRCS employees when working with producers to address WATER QUALITY DEGRADATION – Excess nutrients in groundwater.

IA393.2 FILING INSTRUCTIONS

This Iowa Instruction will be posted on the Iowa NRCS Employee Website, which can be accessed under the Topics/People/NRCS Employees/Iowa NRCS eDirective, or at this link Iowa NRCS eDirectives website.

IA393.3 EXHIBITS

See attachment.

Jon A. Hubbert
Acting State Conservationist

Attachment

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(IA Instruction 180 – 393 First Edition – July 2015)

Natural Resources Conservation Service
210 Walnut Street, Room 693
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IOWA INSTRUCTION 180-393 – SCREENING/ASSESSING WATER QUALITY DEGRADATION – EXCESS NUTRIENTS IN GROUNDWATER RESOURCE CONCERN AND CONSERVATION PRACTICES TO ADDRESS THE CONCERN

1. PURPOSE:

   This Iowa Instruction is to explain how to access and use the "2015 Water Quality Degradation – Groundwater" GIS layer (available May 18, 2015) to screen or identify the WATER QUALITY DEGRADATION – Excess nutrients in groundwater resource concern and to provide guidance for the conservation plan to protect the source water of municipal, other public, and private wells.

2. EXPLANATION:

   This Iowa Instruction must be followed to ensure all field offices are utilizing.

Approved By: Jon Hubbert Acting STC Date: July 8, 2015

Jon A. Hubbert
Acting State Conservationist
Natural Resources Conservation Service
210 Walnut Street, Room 693
Des Moines, IA 50309-2180

Attachment
Exhibit A - Conservation Planning to Protect the Source Water of Municipal, Other Public, and Private Wells

Exhibit A

Conservation Planning to Protect the Source Water of Municipal, Other Public, and Private Wells

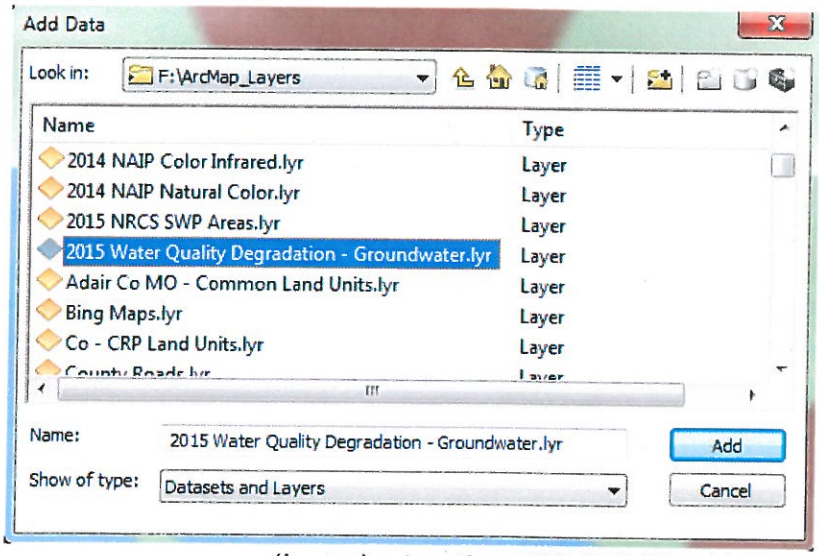
Purpose:

- Introduce the "2015 Water Quality Degradation – Groundwater" GIS layers which can be used to screen for or identify the **WATER QUALITY DEGRADATION – Excess nutrients in groundwater** resource concern.
  - **NRCS SWP Areas** identifies public well Source Water Protection (SWP) areas. Management decisions on cropland, farmsteads, and other land could impact municipal or other public drinking water supplies.
  - **Groundwater Vulnerability Regions of Iowa** identifies areas of Iowa where private wells are likely to be susceptible to contamination.
  - **Potential Karst Geology of Iowa** identifies areas where there may be fractured bedrock (Karst) and, thus, all wells are at risk of contamination.
- Provide conservation planning options to address the resource concern.
  - For cropland conservation practices use ***Cropland Conservation Practices to protect groundwater sources of drinking water*** (DrinkingWater.pdf), attached.
  - For farmstead and developed land conservation practices guidance see sections below.
  - For Karst areas note special guidance.

How to Access the *2015 Water Quality Degradation – Groundwater* GIS Layers

The *2015 Water Quality Degradation – Groundwater* files and associated data have been provided by the Iowa Department of Natural Resources (see Iowa Source Water Protection Program), modified, and loaded on each field office server. Any ArcMap user in our field offices will be able to access this data layer.

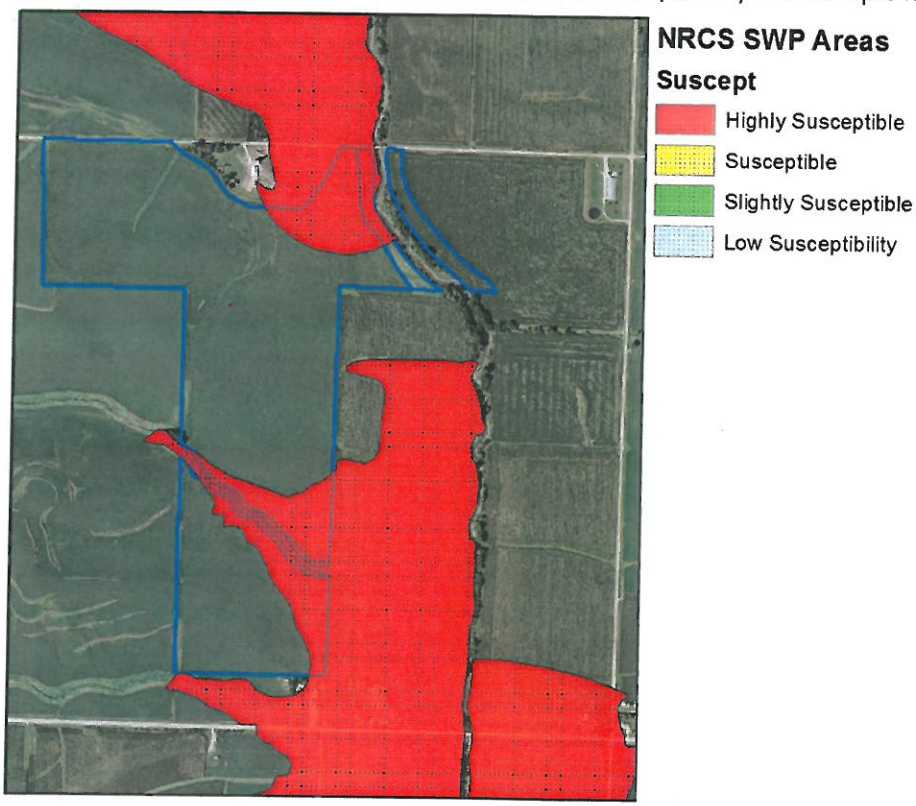
1. Click the Add Data icon
2. Navigate to the "F:\ArcMap_Layers" folder and
3. Select the "2015 Water Quality Degradation – Groundwater.lyr" file
4. Click the "Add" button to place the data layer into the current ArcMap Project



The layer file will appear as follows:

- ☑ 2015 Water Quality Degradation - Groundwater
  - ☑ NRCS SWP Areas
    - Suscept
      - Highly Susceptible
      - Susceptible
      - Slightly Susceptible
      - Low Susceptibility
  - ☐ Potential Karst Geology of Iowa
    - No Known Karst Risk
    - Sinkhole: 1000 Foot Buffer
    - Potential Karst Risk Areas
  - ☑ Groundwater Vulnerability Regions of Iowa
    - Risk
      - Susceptible
      - Low Susceptibility

The *NRCS SWP Areas* is a statewide coverage of public well **S**ource **W**ater **P**rotection (SWP) Areas. It includes digitized polygon features in 87 of Iowa's 99 counties. The categories of susceptibility are differentiated by colors of transparent, shaded polygons. Overlaying this layer above other layers in the ArcMap Table of Contents (Listing on far left of ArcMap window) will enable users to clearly identify fields and farmsteads within one of four areas of susceptibility. See sample map below.



Using *NRCS SWP Areas* to Screen and Assess Water Quality Degradation for Public Wells

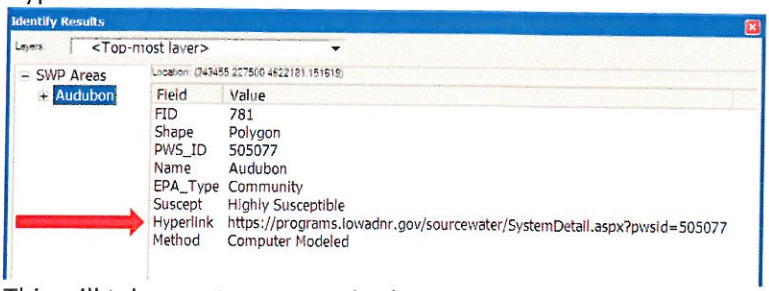
The shaded polygons represent the **10-year time of travel source water protection area** (rain falling on this area and infiltrating the ground will take 10-years or less to reach the well). Each dot (not the pattern dots) on the map represents a well (in the example the wells are off the map).

The layer is categorized into four groups using the susceptibility field [Suscept]. Susceptibility to groundwater contamination is based on the cumulative thickness of a confining layer, such as glacial till or clay, above an aquifer.

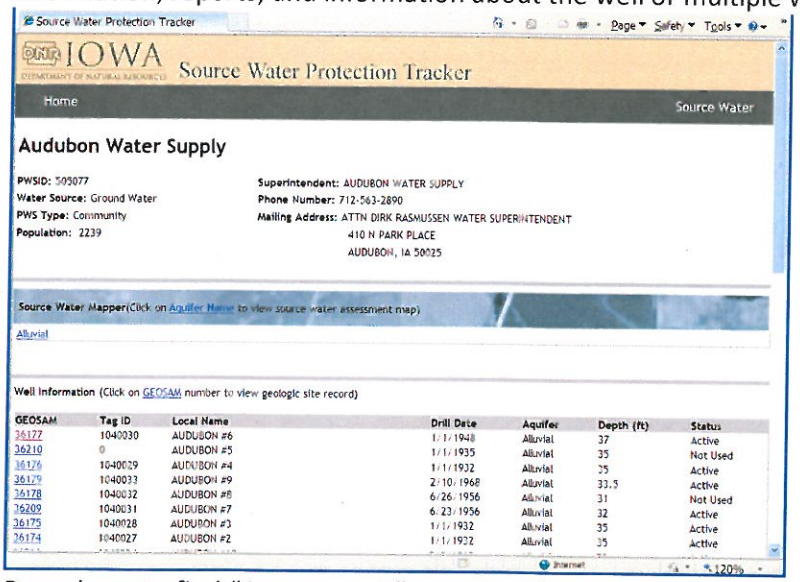
1) Highly Susceptible (Red): <25 feet of confining layer thickness above aquifer - target
2) Susceptible (Yellow): 25 to 50 feet of confining layer thickness above aquifer - target
3) Slightly Susceptible (Green): 50 to 100 feet of confining layer thickness above aquifer – target
4) Low Susceptibility (Blue): > 100 feet of confining layer thickness above aquifer

WATER QUALITY DEGRADATION – Excess nutrients in groundwater *is a resource concern for the first three susceptibility classes – Highly Susceptible, Susceptible, and Slightly Susceptible. Target these for conservation practices that will protect groundwater.*

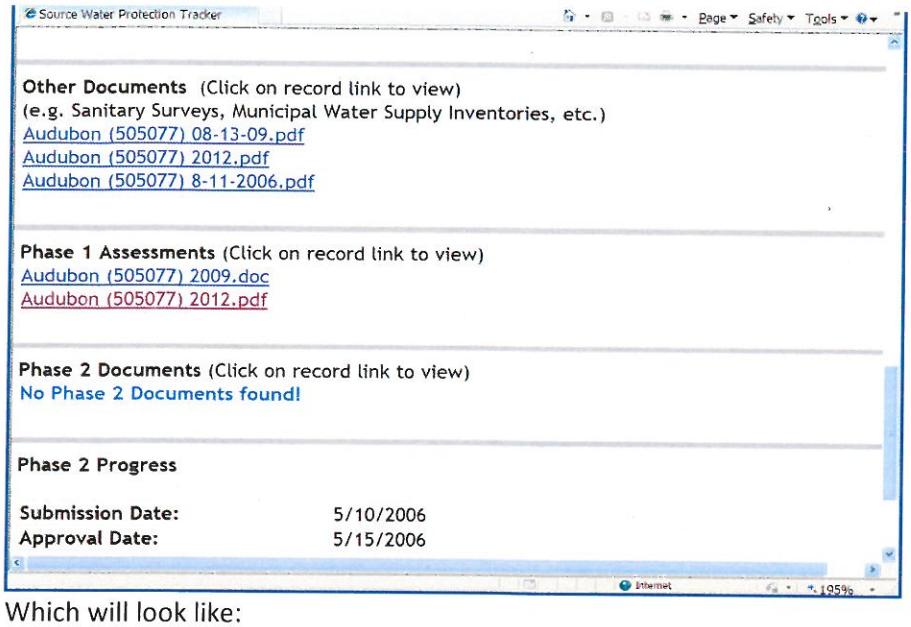
To obtain more information about the public water system, open the information table and click on the hyperlink.



This will take you to a report in the IDNR Source Water Tracker application that includes facility contact information, reports, and information about the well or multiple wells, located within the capture zone.



Page down to find "Assessments" reports. Choose the highest phase and most recent report.


Source Water Protection Tracker

Other Documents (Click on record link to view)
(e.g. Sanitary Surveys, Municipal Water Supply Inventories, etc.)
Audubon (505077) 08-13-09.pdf
Audubon (505077) 2012.pdf
Audubon (505077) 8-11-2006.pdf

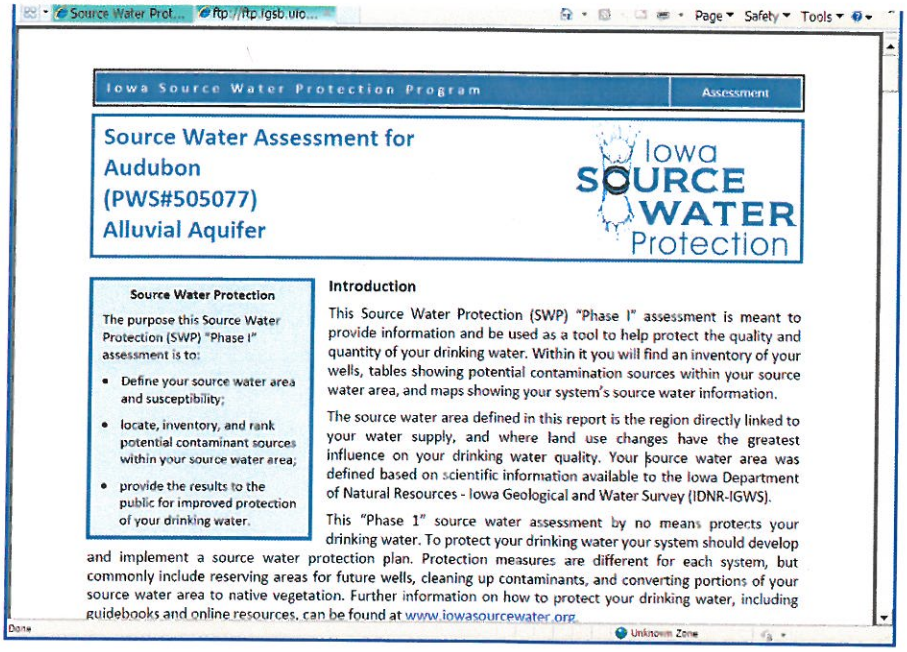
Phase 1 Assessments (Click on record link to view)
Audubon (505077) 2009.doc
Audubon (505077) 2012.pdf

Phase 2 Documents (Click on record link to view)
No Phase 2 Documents found!

Phase 2 Progress

Submission Date: 5/10/2006
Approval Date: 5/15/2006

Which will look like:


Iowa Source Water Protection Program — Assessment

Source Water Assessment for
Audubon
(PWS#505077)
Alluvial Aquifer

Iowa SOURCE WATER Protection

Source Water Protection

The purpose this Source Water Protection (SWP) "Phase I" assessment is to:

- Define your source water area and susceptibility;
- locate, inventory, and rank potential contaminant sources within your source water area;
- provide the results to the public for improved protection of your drinking water.

Introduction

This Source Water Protection (SWP) "Phase I" assessment is meant to provide information and be used as a tool to help protect the quality and quantity of your drinking water. Within it you will find an inventory of your wells, tables showing potential contamination sources within your source water area, and maps showing your system's source water information.

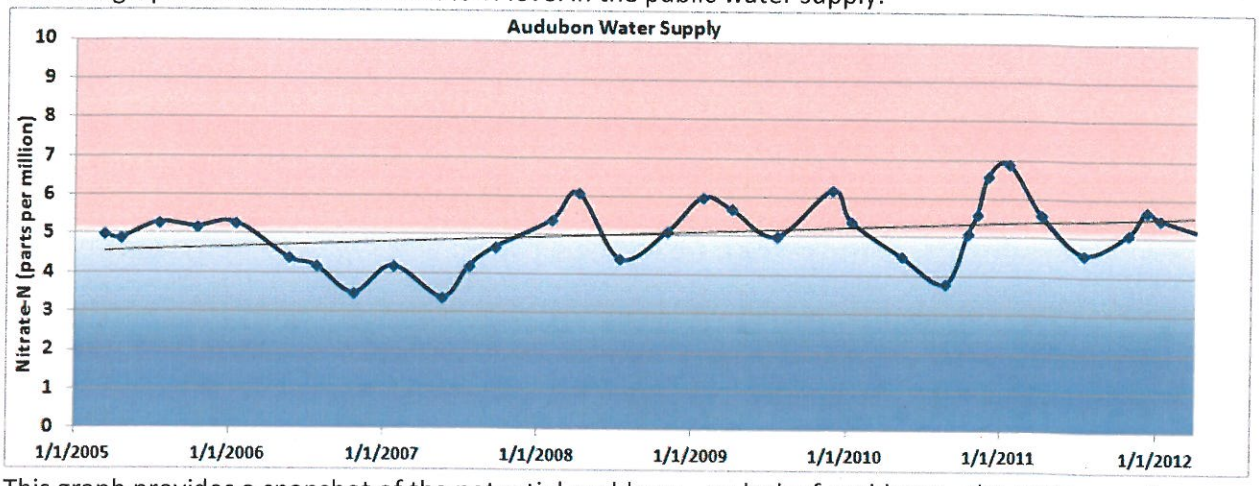
The source water area defined in this report is the region directly linked to your water supply, and where land use changes have the greatest influence on your drinking water quality. Your source water area was defined based on scientific information available to the Iowa Department of Natural Resources - Iowa Geological and Water Survey (IDNR-IGWS).

This "Phase 1" source water assessment by no means protects your drinking water. To protect your drinking water your system should develop and implement a source water protection plan. Protection measures are different for each system, but commonly include reserving areas for future wells, cleaning up contaminants, and converting portions of your source water area to native vegetation. Further information on how to protect your drinking water, including guidebooks and online resources, can be found at www.iowasourcewater.org

The reports can be accessed independently on the Iowa Source Water Protection Program website. See the Source Water Protection Tracker link.

These documents contain an abundance of useful information. Each report consists of general information about source water protection as well as specific details about the public water supply. Also incorporated, is a Source Water Glossary and an explanation of why the well was assigned its susceptibility rating.

Find the graph which shows the nitrate-N level in the public water supply.



This graph provides a snapshot of the potential problems – or lack of problems – the water supply may be experiencing. Note the graph is for the *finished water*, the water distributed by the water supply after any treatment. Individual wells may have higher or lower nitrate-N concentrations.

This report and graph are a quick source of useful information to further assess the extent of the **WATER QUALITY DEGRADATION – Excess nutrients in groundwater** resource concern.

- Nitrate-N rates above 3 ppm are considered greater than background (what could naturally occur) and therefore may demonstrate land management impacts on water quality.
- 10 ppm nitrate-N is the health limit.
- Pay attention to the nitrate-N trend line (is it generally moving up or down over time?).

Keep in mind this graph may be a function not just of nitrates in the source water aquifer, but also of the treatment and mixing of water from multiple wells prior to sampling.

The nitrate-N concentration data from raw (unblended and untreated) well water would be a better indicator of water quality of an aquifer. If you want this or additional information about the water system, contact the local well operator. In some cases the operator may be able to identify specific wells with elevated nitrate-N and other information useful to better target your efforts to mitigate problems associated with the water supply.

- Use the *NRCS SWP Areas* layer to target fields and operators for conservation planning to protect the capture zone for a public well.
- Use a map of a field with the *NRCS SWP Areas* as an overlay and well information from the report to demonstrate to the producer that decisions they make can impact an at-risk public water supply.

Several Source Water Protection Pilot Projects have been conducted to illustrate potential SWP project partners as well as available funding and resources to implement SWP practices. See the Source Water Protection (SWP) For Targeted Community Water Supplies website for more information.

Using *Groundwater Vulnerability Regions of Iowa* layer to Screen **Private** Wells

The *NRCS SWP Areas* layer does not cover private wells. The *Groundwater Vulnerability Regions of Iowa* map layer[1] can be used to screen the risk of contamination of private wells. This layer identifies regions in Iowa having similar hydrogeological characteristics affecting the vulnerability of aquifers and wells to contamination from the land surface. The original Groundwater Vulnerability Regions of Iowa (1991) map and key are available if you want to see the original interpretations (key in Appendix A). Some notes are added for special consideration.

We have added a susceptibility rating to the GIS layer to screen the potential water quality as a resource concern for a private well. The original 1991 vulnerability classification system is not the same as the susceptibility rating developed for public wells. Using the thickness of the confining layer as a guide, we labelled the areas with a "moderate" or "high" potential for well contamination as "Susceptible" (). "Low Potential" is now "Low Susceptibility" (). If susceptible, there could be a groundwater quality resource concern the client may want to address. In most places in Iowa, shallow private wells are susceptible to contamination.

Use this layer for initial screening and to inform your clients about the susceptibility of their well. Clients concerned about the quality of the water used for human or livestock consumption should test their well (see IDNRs Private Well Testing site for more information).

Conservation Planning to Address a *WATER QUALITY DEGRADATION – Excess nutrients in groundwater* resource concern...

... on **Cropland**

The document *Cropland Conservation Practices to protect groundwater sources of drinking water* lists conservation practices targeted to protect groundwater. These practices can reduce contamination at the source for a contaminated or to protect a vulnerable well. Promote a suite of these practices on all fields identified as highly susceptible, susceptible, or slightly susceptible. The document is available on the Iowa NRCS website: Newsroom/Publications & Fact Sheets.

... on the **Farmstead**

For the farmstead (e.g. animal feeding operation, manure storage, pesticide storage, fuel storage, etc.) we recommend using the Farmstead Assessment System, aka Farm*A*Syst. This is a self-evaluation farmers and rural landowners can use to evaluate how farmstead farm management practices and activities might contaminate groundwater and, consequently, possibly risking nearby public source water as well as their own livestock and drinking water wells. Farm*A*Syst has been adapted to Iowa and is available on the Iowa Farm Bureau's Farm*A*Syst website. Start with *Assessing Your Farmstead Characteristics*. If beneficial, work directly with the producer on the assessment.

... on **Developed Land** (Urban)

The Iowa Source Water Protection Program website provides information to address risk assessment and conservation planning for developed land. Typically, this is accomplished by a Source Water Protection Community Planning Team. In urban areas look for receptors (e.g. abandoned wells that can

[1] Click Groundwater Vulnerability Regions for the original, unedited GIS layer.

Protection Community Planning Team. In urban areas look for receptors (e.g. abandoned wells that can allow contamination from the land surface to enter into aquifers) and potential contaminant sources such as leaking underground storage tanks, airports, mines, chemical storage facilities, above ground fuel storage tanks (specifically those without secondary containment), etc. A list of additional conservation practices (e.g. native landscaping, bioswales, rain gardens) may be developed if needed.

...in Karst

Wells located in Karst areas of the state are at elevated risk of contamination. Surface runoff and shallow groundwater can quickly enter aquifers through fractures and sinkholes without any filtering from the soil.

Identifying the Resource Concern. A GIS layer, *Potential Karst Geology of Iowa*, developed by the Iowa DNR – Iowa Geological Survey (2005, Iowa City, IA) is included. The *Potential Karst Risk Areas* are where carbonate bedrock is within 50 feet of the surface or within 5,280 feet of a known sinkhole. Use this layer to determine where the fractured bedrock of Karst is likely to be found and, therefore, **WATER QUALITY DEGRADATION – Excess nutrients in groundwater** is a resource concern. 1000 feet buffers are indicated around known sinkholes. Not all sinkholes are inventoried, though, the producer may be aware of additional sinkholes. Watch for sinkholes when inventorying the farm and plan accordingly. Consult the soil survey for additional information about the soils on the farm and the potential for Karst.

Addressing the Resource Concern. Use *Cropland Conservation Practices to protect groundwater sources of drinking water* lists as in non-Karst areas. However, since within the Karst landscape surface runoff water can enter groundwater where there are cracks and holes, also favor conservation practices which control sheet, rill, and concentrated flow erosion and control the runoff and delivery of contaminants to fractures and sinkholes. Use perennials and small grains in rotation, reduced tillage, no-tillage, cover crops, strip cropping, nutrient management, integrated pest management, etc.

If there is considerable runoff into a sinkhole, consider using the Iowa Phosphorus Index to estimate the risk of sediment delivery to the sinkhole and to develop appropriate conservation practices to reduce that delivery. When estimating the "distance from the center of the field to the perennial or intermittent stream (ft.)," estimate to the sinkhole instead. This is not a standard use of the Iowa P-Index, but can be used to generate conservation ideas and to estimate effectiveness of a suite of conservation practices. Consider applying conservation practice standard Karst Sinkhole Treatment (527). Additionally, consider the location of sinkholes when siting and designing livestock facilities to avoid runoff to the sinkhole.

Final Notes

When the National and State Resource Concerns and Planning Criteria in the Field Office Technical Guide is next revised, this information will be embedded in the screening and assessments. Watch for these changes.

As you use this new tool for conservation if you have questions or concerns contact the State Resource Conservationist.

Additional Resources

For a primer on groundwater and the risk to our drinking water, see Iowa's Groundwater Basics: A geological guide to the occurrence, use, & vulnerability of Iowa's aquifers.

Acknowledgements

Most of the GIS layer information was provided by the Iowa Department of Natural Resources.

Individual help to access and interpret the data was provided by:
Rebecca Ohrtman, Source Water Protection Program Coordinator, Contaminated Sites Section - Land Quality Bureau, Iowa DNR
Chad Fields, Geologist III, Water Supply Engineering Section, Iowa DNR
Bob Rowden, Geologist III, Coordinator Non-Targeted Source Water Protection Program, Iowa DNR
Andy Asell, Environmental Specialist, Watershed Improvement Section, Iowa DNR
Chris Ensminger, Supervisor – GIS Section, Iowa DNR
Calvin Wolter, GIS Analyst - Hydrologic modeling and SWAT, Iowa DNR

Attachments:

Cropland Conservation Practices to protect groundwater sources of drinking water.

Authors

Eric G. Hurley, Nutrient Management Specialist
Jim Phillips, GIS Specialist

Conservation Planning to Protect the Source Water of Municipal, Other Public, and Private Wells

Appendix A

Groundwater Vulnerability Regions of Iowa

Special Map Series 11[2]

Prepared by: Bernard E. Hoyer and George R. Hallberg,
Energy and Geological Resources Division, Geological Survey Bureau
June 1991

This program was supported, in part, through the Groundwater Protection Fund to fulfill requirements of the Iowa Groundwater Protection Act.

Iowa Department of Natural Resources
Larry J. Wilson, Director

This map identifies regions of Iowa which have similar hydrogeological characteristics affecting the relative vulnerability of aquifers and wells to contamination from surface and near-surface sources and activities. It is designed to help Iowans understand the complex issue of groundwater contamination and provides a general framework for understanding the distribution of known contamination. The map is based on an unprecedented compilation of hydrogeologic data, yet it represents a regional synthesis and should not be used to address site-specific issues except as a supplement to site evaluations.

The map units are defined by physical characteristics that affect groundwater recharge and contaminant transport. The units are primarily delineated by the distribution of mappable aquifers and the degree to which the soil and rock which overlie the aquifers confine and protect them. Aquifers are saturated soil and rock materials which readily yield groundwater to wells. Aquitards are soil and rock materials that retard groundwater recharge and confine aquifers. In Iowa, shale and glacial drift, especially till, are the primary aquitards. Where aquitards are thick, they effectively decrease the vulnerability of underlying aquifers to contamination. Map units were further subdivided based on information about well development and water quality. Sinkholes and agricultural drainage wells, special features which allow contamination to enter aquifers, are also identified.

Map users should be aware that although glacial drift generally retards groundwater recharge, and confines and protects the aquifers below, the drift itself, is widely exploited by domestic wells. Drift source wells generally yield small quantities of water and are most common where regional aquifers are not readily available or yield naturally poor-quality water. Locally, moderate to large quantities of water are developed from aquifers contained within the drift. Inadequate information prevents delineation of these aquifers on this map.

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[2] This information was transcribed by Iowa NRCS from a pdf file, Groundwater Vulnerability Regions of Iowa. The key applies to the Groundwater Vulnerability Regions of Iowa map layer provided. Formatting has been changed. Items in color have been added to the original document.

EXPLANATION

Map Unit	*Risk Category*
[20, 21, 22, 23] **ALLUVIAL AQUIFERS:** Area underlain by sand and gravel aquifers situated beneath floodplains along stream valleys and includes alluvial deposits associated with stream terraces and benches, contiguous wind-blown sand deposits, and glacial outwash deposit; natural water quality generally excellent (less than 500 mg/L total dissolved solids) and yields vary with texture and thickness of alluvium (commonly greater than 100 gallons/minute in larger valleys, less in smaller valleys); most wells are very shallow; high potential for aquifer contamination; high potential for well contamination. Some of the areas underlain by alluvial aquifers are not shown because of map scale.	Susceptible[3]
GOOD BEDROCK AQUIFERS: Area underlain by regional bedrock aquifers, primarily fractured carbonate units; other regional aquifers usually available at various depths; natural water quality usually excellent (less than 500 mg/L total dissolved solids) and high yields commonly available (greater than 100 gallons/minute).	
[1] GOOD BEDROCK AQUIFERS: **Thin Drift Confinement:** Less than 100 feet (30 meters) of glacial drift overlie regional aquifers; most wells are deep and completed in the bedrock aquifers; high potential for aquifer contamination; high potential for well contamination.	Susceptible

[3] Different risk assessment categories were used on the Groundwater Vulnerability Regions of Iowa map than for public wells. This map is more generalized. In general, private wells are shallower and more at risk. "Susceptible" here in effect combines the "Highly Susceptible," "Susceptible," and "Slightly Susceptible" categories used to assess the contamination risk to public wells. It suggests that the well is at risk and further testing should be done and/or conservation practices be installed.

[2] GOOD BEDROCK AQUIFERS: **Moderate Drift Confinement:** 100 to 300 feet (30 to 90 meters) of glacial drift overlie regional aquifers; most wells are deep and completed in the bedrock aquifers; low potential for aquifer contamination; low potential for well contamination.	Low Susceptibility
[3] GOOD BEDROCK AQUIFERS: **Shale Confinement:** Thin drift and Brainard Shale overlie Galena carbonate aquifer; most wells are deep and completed in the bedrock aquifer; moderate potential for aquifer contamination; moderate potential for well contamination.	Susceptible The susceptibility of a bedrock well will depend on the thickness of the confining layer. For more information use GEOSAM (http://geosam.iihr.uiowa.edu/). Select a nearby well to identify the "Bedrock Depth." If the well being considered is >100 ft. below the bedrock depth, it has a low susceptibility.
VARIABLE BEDROCK AQUIFERS: Area underlain by regional bedrock aquifers including carbonate and sandstone units; aquifers vary considerably in natural water quality (500 to 2000 mg/L total dissolved solids) and yields (although generally above 20 gallons/minute).	
[4] VARIABLE BEDROCK AQUIFERS: **Thin Drift Confinement:** Less than 100 feet (30 meters) of glacial drift overlie bedrock aquifers; most wells are deep and completed in the bedrock aquifers; moderate to high potential for aquifer contamination; moderate to high potential for well contamination.	Susceptible
[5] VARIABLE BEDROCK AQUIFERS: **Moderate Drift Confinement:** 100 to 300 feet (30 to 90 meters) of glacial drift overlie bedrock aquifers; many wells are deep and completed in the bedrock aquifers, and many are shallow and completed in the drift; low potential for aquifer contamination; low potential for contamination of bedrock wells; high potential for contamination of drift wells.	Susceptible

[6] VARIABLE BEDROCK AQUIFERS: **Shale Confinement:** Cherokee shales or Upper Cretaceous shales overlie Mississippian carbonate or Dakota Sandstone aquifers, respectively; most wells are shallow and developed in the drift, some wells are deep and completed in the bedrock aquifers; low potential for aquifer contamination; high potential for contamination of drift wells; moderate potential for contamination of bedrock wells.	☐ Susceptible The susceptibility of a bedrock well will depend on the thickness of the confining layer. For more information use GEOSAM (http://geosam.iihr.uiowa.edu/). Select a nearby well to identify the "Bedrock Depth." If the well being considered is >100 ft. below the bedrock depth, it has a low susceptibility.
[7] DRIFT GROUNDWATER SOURCE: Bedrock aquifers are absent or overlain by greater than 300 feet (90 meters) of glacial drift; wells are completed in thin, discontinuous deposits of sand and gravel within the till or at the interface between overlying loess and till; natural water quality is highly variable (250 - 2500 mg/L total dissolved solids) and yields are generally low (less than 10 gallons/minute); most wells are shallow and completed in the drift; low potential for bedrock aquifer contamination; high potential for well contamination. Drift-source wells are developed in the glacial deposits which overlie each confined bedrock aquifer and can be found statewide.	☐ Susceptible

Special Features Affecting Potential Contamination
[10] **SINKHOLES:** Naturally occurring depressions in the landscape caused by solution or the collapse of carbonate rocks; common where limestone is less than 30 feet (10 meters) below land surface; contaminated surface water may enter the aquifer via the sinkholes, contaminating the aquifer in a localized area; contaminant levels can fluctuate significantly during periods varying from minutes to weeks; increases contamination potential in areas with thin drift confinement; mapped from county soil survey publications.
[11] **AGRICULTURAL DRAINAGE WELLS**: Wells drilled to drain surface water and soil water into carbonate aquifers; their presence allows contaminants in surface or tile water to enter the aquifers at much higher rates than naturally would be possible; increases contamination potential much like sinkholes; mapped from registration records at the Iowa Department of Natural Resources. [Since this map was made, most drainage wells have been closed.]
Other Map Features [30] **LAKES:** Selected reservoirs and natural lakes

ACKNOWLEDGEMENTS

Nearly a century of applied geological and groundwater research by staff at the Geological Survey Bureau and elsewhere is synthesized on this map. Recognized for direct contributions to the map's production: RR Anderson, LL Bean, E.A. Bettis, D.R. Bruner, M.C. Culp, J.D. Giglierano, M.P. Heitman, M.R. Howes, K.F. Irelan, T.J. Kemmis, D.L. Koch, R.D. Libra, P.J. Lohmann, G.A. Ludvigson, R.M. McKay, M. Mohan, O.W. Plocher, J.C. Prior, D.J. Quade, R.S. Rosenberg, L.S. Seigley, C.A. Thompson, P.E. Van Dorpe, B.J. Witzke, and many graduate assistants at the University of Iowa, Department of Geology.