Minnesota Spring Inventory

Guidance Document

The Spring – College of St. Catherine. Used with permission from St. Catherine University

DEPARTMENT OF NATURAL RESOURCES

County Geologic Atlas Program

2017

Contents

Section 1: Introduction

The purpose of this document is to provide a framework for statewide data gathering and processing for the Minnesota Spring Inventory (MSI). The inventory is being conducted to help provide information and protection for a valuable yet poorly understood resource. The information can be used to identify sampling locations, monitor groundwater conditions, guide fish stocking locations, site park trails, identify and monitor critical habitat, and identify conditions for building construction.

Spring data are collected from historical information, existing surveys, on tablets in the field using an ESRI Survey 123 web mapping application, by citizens using the web based Minnesota Spring Inventory Recording Application, stream surveys from DNR Division of Fisheries and Wildlife, Minnesota Geological Survey Karst Features Database, postcard surveys, and other available sources. Legacy data is incorporated though compilation of historical documents and surveys.

Once the spring data are entered into the MSI, it can be accessed via Quicklayers and a web interface. The system is based on the known diversity of Minnesota springs using a Minnesota Geological Survey Karst Features Database classification as the starting point. The protocol is adapted from existing historical inventories based on Sada and Pohlmann (2002), and is similar to other widely used spring inventories (See Appendix B). The steps are as follows:

1. Compiling existing information (Data mining): existing inventories and spring legacy data are collected into the database.
2. Level I field survey (mapping): springs are mapped and georeferenced in the field and basic data is recorded.
3. Level II field survey (sampling): springs are sampled for selected geochemicals as a baseline for future studies.
4. Level III field survey (monitoring): selected reference or sentinel springs are monitored on an on-going basis.

The first two steps have been underway since 2015 and will extend into 2019 with current funding. Level II and III surveys would occur if funding becomes available. Deliverables to date include the MSI database, the survey tool (Survey 123), the MSI Reporting App (citizen app), this guidance document, and the data entered to date.

Potential users of the MSI include the Minnesota Department of Health; Minnesota Department of Natural Resources; Minnesota Department of Transportation; Minnesota Pollution Control Agency; county, city, and township governments; soil and water conservation districts; watershed management organizations; environmental and engineering consulting firms, and the University of Minnesota departments of Earth Science, Ecology and Behavioral Biology, and Soil, Water, and Climate. Users among the general public who have a natural interest in this topic include those interested in trout fishing, potable spring water, nature studies, and photography.

1.1 Need for a Statewide Spring Inventory

A Minnesota Spring Inventory (MSI) was recommended in the Environmental Quality Board's report, *Managing for Water Sustainability: Report of the EQB Water Availability Project* (December 2008). Spring mapping is listed as an action item in the DNR's "Long-Term Protection of the State's Surface Water and

Groundwater Resources" report to the Legislature (January 2010). The existence and location of springs is one of the questions in the Environmental Assessment Worksheet/Environmental Impact Statement process.

Springs are considered "waters of the state." According to Minnesota statute Chapter 103G, "Waters of the State means surface or underground waters, except surface waters that are not confined but are spread and diffused over the land." As groundwater, springs are given protections as laid out in Chapter 103H.

Springs support coldwater fisheries and ecological systems dependent on cold groundwater. Springs help ecologists study biodiversity and test hypotheses about the distribution of organisms. Many streams, including trout streams, would not exist were it not for the presence of springs. Springs can serve as hotspots of biodiversity. Some rare Minnesota plants are seepage dependent, as are calcareous fens. Unregulated or even regulated use of spring water can deprive groundwater-dependent ecosystems (GDEs) of their sustaining resource, causing degradation. Springs serve as indicators of groundwater quality and quantity supplementary to monitoring wells or water wells. Without a comprehensive inventory, government units at all levels may make water and land-use decisions without knowing of these groundwater dependent resources.

1.2 Definition of a Spring

A spring is a focused[1] natural discharge[2] of flowing[3] groundwater[4].

1. A spring has **focused** flow from a discrete source (as opposed to a pool of accumulation). By contrast *seeps* do not have noticeable flow.

2. Springs are **natural discharges**. This inventory does not map artificial situations such as flowing artesian wells and groundwater that appears in excavations.

   On the other hand, pipes that are installed in natural springs to improve their flow should be mapped as springs. The distinction depends on whether the pipe establishes the connection with underlying groundwater or merely enhances it, and if that can be determined by historical records or by measuring the depth of the well. The deeper the pipe, the better chance that it is actually a well and not a modified spring.

3. **Flowing** water distinguishes springs from seeps. A seep is caused by diffuse discharge and does not involve noticeable flow at its outlet, except where seepage forms pools of accumulation, where it often mixes with surface water.

   The flow rate of a spring typically varies over a range that can change with the weather, season, and over rainfall/drought cycles of many years. Spring discharge after a rainy spring season will often exceed discharge after a dry summer. But there are also long-term declines, when springs "dry up" due to climatic changes, paving of their recharge zones, or groundwater appropriation by nearby wells or quarries.

   Discharge can be to the land surface or underwater into a lake or stream. For the purposes of this inventory, lake and stream springs are only mapped if the submerged discharge is strong enough to suspend ("boil") particles, ripple the surface, or melt holes in winter ice cover. Spring-fed lakes and streams are not mapped as springs.

   The definition of springs can be context dependent: what constitutes a spring in the desert might be considered unworthy of mapping in a humid region.

This guidance document proposes an average discharge rate of 1 gpm as the lower limit for springs in Minnesota. The flow will be estimated or measured during field mapping. Even if the flow drops below 1 gpm at a later time, the feature will remain mapped as a spring. Flows less than 1 gpm are still springs, but not ones that we intend to map systematically. See Appendix C for more details.

4. **Groundwater** will include other terms such as "water" or "underground water" within the present definition so as to include soil-water springs.

Seep—Seepage is an important form of groundwater discharge but it is not the intent of the inventory to create a complete inventory of seeps. Ecologically significant seepages should be included such as Black Ash Seeps that collectively form significant flows, or seepages that are the only form of natural groundwater discharge in an area otherwise devoid of springs, should be included when they are encountered in the search for springs. For the purposes of this inventory, there is a seep corresponding to each type of spring.

For alternative spring definitions, see Appendix A.

Section 2: Survey Protocols

This spring monitoring protocol is adapted from Sada and Pohlmann (2002) but is similar in form to widely used spring inventories. For a description of this and other spring inventories, see Appendix B.

Such protocols are arranged into four stages.

1. Compiling existing information (data mining): existing inventories and spring legacy data are added to a database.
2. Level I field survey (mapping): springs are georeferenced in the field and some basic data recorded.
3. Level II field survey (sampling): selected springs are sampled for geochemicals to serve as a baseline for future studies.
4. Level III field survey (monitoring): selected reference or sentinel springs are monitored on an ongoing basis.

2.1 Compiling Existing Information (data mining)

2.1.1 Existing Spring Inventories

The present Karst Features Database (KFD) is a relational GIS database (contains 2,991 recorded springs as of October 25, 2016), accessible remotely by approved users. A current version is available on the Minnesota Geological Survey (MGS) FTP site. Features include sinkholes, stream sinks, springs, and caves, although the caves are not listed in the public data set. Though the vast majority of the features are located in the southeastern karst counties of Minnesota, there are a scattering of points elsewhere, especially the Minneapolis-St. Paul area and Pine County. The Minnesota Department of Natural Resources is currently producing the hydrogeology plates of the county atlases and is responsible for much of the karst mapping.

Outside of Minnesota, the Wisconsin Geological and Natural History Survey (WGNHS) has the most active program. Past surveys with a variety of goals have been conducted in California, Florida, Illinois, Kansas, and Missouri. For a description of this and other spring inventories, see Appendix B.

Minnesota historical surveys and data sources are as follows.

- Thaddeus Surber (Minnesota Game and Fish Department) hiked many miles of trout streams in southeastern Minnesota, recording spring locations in 1918 and 1920, and on the North Shore of Lake Superior in 1922.
- DNR Fisheries and Wildlife staff has recorded the locations of many Minnesota springs as part of their Stream Survey Reports, from the 1940s onwards.
- The Root River was resurveyed by Johnson and Moyle (Minnesota Department of Conservation) in the 1940s and by Mel Haugstad (DNR Fisheries) from the 1960s to 1990s.
- The most direct contributions from the 1970s onwards were from the efforts of Calvin Alexander (University of Minnesota), Jeff Green (Minnesota DNR), Bob Tipping (Minnesota Geological Survey), and others in establishing the Karst Features Database and delineating springsheds in the southeastern corner of the state.
- In the Minneapolis–Saint Paul area, Greg Brick (1997) mapped more than a hundred springs in seven spring lines in the early 1990s as part of an undergraduate thesis project at the University of Minnesota.
- During an informal voluntary email poll of DNR staff in December 2014, numerous state park rangers and wildlife managers submitted information about springs in the areas they were responsible for.

The locations of many springs are already published in technical literature, such as USGS topographic maps and Water-Supply Papers, and MGS Annual Reports and Bulletins. Recording these spring locations before any fieldwork is done and using them to guide future fieldwork is an effective cost-saving measure. When chemistry, flow rates, or other legacy data are found, they offer the possibility of comparison with modern values and concluding something about long-term trends (Brick, 2015). Listed below are some of the sources of legacy data and places where spring information has been acquired, in addition to the Karst Features Database:

- Original Public Land Surveys
- DNR Quick Layers coverage in ArcMap
- U.S. Geological Survey:
  - Geographic Names Information System (GNIS)
  - Hydrologic Investigations Atlases (HA)
  - National Water Information System (NWIS)
  - 7.5-Minute Quadrangles
  - Water-Supply Papers
- U.S. Forest Service—hydrologic reports
- Minnesota Geological Survey publications
  - County geologic reports and atlases
  - Miscellaneous Map Series
- Minnesota Pollution Control Agency spring studies for Watershed Restoration and Protection (WRAP) projects.
- DNR Fisheries—Stream Survey Reports
- Minnesota County Biological Survey—seepage indicator plants, list of rich (groundwater) fens.
- County Soil Surveys
- Watershed Management Organizations reports sometimes include maps of spring locations.
- Colleges and university researchers, especially environmental, geology, geography, and water resources departments.
- Angler groups

- Lake associations
- Historical societies
- Voluntary email poll of state agencies with relevant stakeholders, DNR, Minnesota Pollution Control Agency, Minnesota Department of Agriculture, and Minnesota Department of Transportation.
- Citizen input from the DNR public information webpage.

2.1.2 Locational Data Accuracy and Location Certainty

Springs data has come over time from a variety of sources with a varied accuracy. Therefore, spring locations are characterized in the database according to *locational accuracy*. Several factors relating to how the spring location information was acquired affect the reliability of the locations. Therefore, spring locations in the database are also characterized according to *locational certainty.*

Locational accuracy

DNR field staff have logged springs since January 2016 using GPS units or field data collection tablets with an accuracy of approximately 1 to 3 meters. However, a large number of spring location information was obtained with field GPS units with ±3 to 15 meter accuracy. Other locations were determined with GPS units during the initial time period when the GPS signal available to civilians was deliberately degraded to ±30 to 100 meter accuracy for national security reasons. Older data were plotted on paper quadrangles in the field and then manually digitized with varying levels of accuracy, while other locations were loosely estimated as part of other studies. The various data have been adjusted with the help of persons knowledgeable about the field areas with tools such as 1-meter resolution LiDAR and aerial photography (black and white, color and color infrared CIR).

Locational certainty

Springs are classified in the database from most certain to least certain to the following hierarchy (The letter is the third character in the *relate ID* database.).

1. "A" spring
2. "S" spring
3. Candidate spring
4. Citizen spring

"A" spring is highest level of location certainty. These are field confirmed spring locations. The MSI team (staff from the DNR, Minnesota Geological Survey, and the University of Minnesota Department of Earth Sciences) know the location is valid because they have been there. The spring inventory team may promote a location to "A" if the data are from a professional and reliable source with some key data (GPS location, date, approximate flow rate, etc.). These situations will be considered on a case by case basis.

"S" springs are probable locations based on evidence. The majority of these spring locations were imported into the MSI from the KFD. Much of the KFD data was originally plotted on paper quadrangles in the field and then manually digitized with varying levels of accuracy. Someone with field and map experience should be able to find "S" springs in most cases. These legacy data have a range of accuracy and certainty depending on the techniques, tools, and experience of the professionals who originally mapped them.

Candidate springs are possible locations. The location could vary significantly from the database or the spring may not exist. A major source of legacy data is the DNR Fisheries stream surveys, whose collection is governed by successive editions of the *Fisheries Stream Survey Manual*. Ongoing operations employ GPS units to collect data, but older spring records beginning in the 1940s have generally not been updated with GPS. According to Jeff Green (pers. comm.), these early surveys involved fisheries staff steel-taping their way upstream, measuring distance from the mouth of the stream, and noting whether the spring (or spring run) was on the right or left bank. These data were extracted by EWR staff from stream survey reports and transferred into the database using an automation script as candidate springs. Candidate springs have the least locational certainty and do not have unique numbers until they are promoted to "S" springs by qualified MSI database users.

Citizen springs are the least certain source. Locations are entered through a web based reporting application (**mndnr.gov/MnSpringInventory**) from anyone in the state. Springs that are sent in by citizens require an extra level of examination and are rejected if found to be duplicates, or if situated in improbable locations (such as hilltops) without other information to verify (e.g., photo or contact information). If the other information is found to be plausible they can be promoted to candidate status or an "A" spring though field location.

Other locational issues can include:

1. Spring orifices occasionally move substantial distances, both from natural and human causes.
2. Springs are typically larger than the coordinates recorded by modern, sub meter, accurate GPS units. The precise location points record where the GPS instrument was when the location was recorded. That location is rarely in the middle of any but the smallest springs.
3. Many, even very large springs, can be ephemeral and may not be flowing when a spring is visited.

2.2 Level I Surveys - Mapping

Level I surveys locate, map, and record basic data for the springs. This can constitute a 10–20 minute site visit. The information collected can help resource managers prioritize which springs deserve further study. As funding becomes available, the use of other available technology could be possible, such as thermal remote sensing or drones (Appendix G).

2.2.1 Field Preparation

Permission

The initial focus of the inventory has been the springs of public lands. The managers of these units will often have some good ideas about where to look for springs. They need to be informed before fieldwork begins that you will be operating in their terrain. Sometimes there are places even within public land units that are out of bounds, such as wildlife breeding areas.

Springs on private land require owner permission prior to inventory. Property ownership information is available on-line for many Minnesota counties through the Minnesota Geospatial Information Office (http://mngeo.state.mn.us) or the Minnesota Assessor's website (http://minnesotaassessors.com). Once a likely corridor of springs has been identified, property owners must be contacted and permission secured on a voluntary basis before entry. This can be done through phone calls or direct mailings.

Season

Fieldwork in **winter** is probably the most advantageous for detecting springs, which leave melted patches in snow and holes in lake ice. Icicles and ice domes may mark impermeable horizons in rock outcrops, suggesting that springs could be nearby. Winter is also when baseflow is easily gauged. However, it is a poor time to record biota, and snow may conceal other concerns such as trampling by livestock. **Summer or fall** is most practical in terms of access and identifying biota, but variations in weather can influence the hydrology and water chemistry. Field technicians should also stay out of the woods during hunting season in fall. Fieldwork in **spring** may be problematic because vernal pools can easily be confused with forest seepages. Meltwater runoff impacts spring discharge and chemical analyses. When prospecting along rivers, springs may be entirely drowned by seasonal high water, and real time flood stage data, as from the USGS website, should be consulted before scheduling a trip.

Wet and dry weather each have different but complementary advantages. Wet weather sometimes brings out intermittent or overflow springs that are not visible at other times. Dry weather lowers stream levels revealing springs that were not visible otherwise.

Other factors to consider are accessibility or remoteness of the field area and availability of field help.

Equipment

Limited field equipment is required for Level I reconnaissance surveys. It should readily fit inside a backpack, or two backpacks when a field assistant is available. Key equipment necessary for a Level I survey includes the following:

- Tablet for data entry with customized ESRI survey software and GPS capability. The tablet also has a built in camera, and automatic syncing of data to a server based database. The tablet also provides aerial imagery and road maps for navigation to and from the site. The most useful ArcMap layers have been found to be LiDAR hillshade, Public Recreation Information Map (PRIM), karst features, and calcareous fens, at a scale of 1:24,000. The TRIMBLE GeoXT (handheld GPS unit) includes some of these capabilities and is more rugged than the tablet.

Tile packages. Depending on the software and file size, selected areas of coverage may need to be uploaded to the tablet before leaving the office. Tile packages can be downloaded at different scales so the user can zoom in on them as necessary. The procedure is detailed in Appendix F.

- Multi-parameter probe to rapidly measure water parameters such as temperature, pH, conductivity, and dissolved oxygen
- Clipboard and blank survey forms as a backup in case of tablet or GPS unit malfunction (Appendix C)
- Container of known volume, such as a gallon jug or graduated bucket, preferably collapsible
- Short length of plastic pipe
- Plastic dropcloths can be used to collect or route spring water
- Stopwatch or other time device to measure spring flow rates
- Discharge estimation chart (Appendix D)
- Identification charts for the more common biota of interest (Appendix E and others)
- Compass for measuring the orientations of various features such as spring alcoves, cave entrances, spring brooks, the inclination of slopes or strata, etc
- Tape measure or survey rod for miscellaneous field measurements, such as the dimensions of stream channels
- Vial of hydrochloric acid for determination of limestones, calcareous deposits, and lime-rich fen soils, by the effervescence reaction
- Safety goggles for eye protection when using acids and when breaking trails through dense brush.
- Knee boots, hip boots, or waders for stream traverses
- Bug spray and tick gators
- Cell phone for emergencies
- Appropriate clothing and emergency equipment for winter field work

2.2.2 Field Data Entry

The following elements comprise a Level I survey and are recorded on an electronic field tablet and/or the data sheet provided in Appendix C. Fields required to be completed are specially marked on the tablet. Other fields are intended to be left blank until the requested data are readily available.

There is a minimum requirement for inclusion in the database.

- Springs with an estimated discharge of *1 gpm or more are georeferenced*.
- Springs with a flow rate *greater than 5 gpm have additional data collected* provided their physical configuration is favorable to measuring the parameters without extensive preparation. Lower flows present challenges to recording valid water parameters.

The following data should be collected approximately in the order given below. Glossaries on select spring attributes follow. Some items on the tablet will provide more options after selecting "yes." Appendix C contains the printable Field Sheet as a backup to the tablet.

Spring Name—The official name is used, listed for example on USGS quads. The name given by the locals is recorded as an alias if it is different. Most springs do not have official names and should be recorded as "unknown." Some springs have multiple aliases and to avoid confusion these should be recorded. Sometimes the names of springs will change over time to match the name of the current landowner, reinforcing the value of a unique identifying code.

Location—(found at the bottom of the list) Springs are marked with the GPS unit at the head of the spring, after following up the spring run. Seeps are marked with the GPS in the approximate center of the seepage or seepage complex. DNR field staff use GPS units with submeter accuracy or field data collection tablets to find and log springs. The field data collection tablets have positional accuracies of approximately 1 to 3 meters.

Subtype—A spring has focused flow from a discrete source. By contrast seeps do not have noticeable flow.

Feature Arrangement—Single or cluster of seeps and springs. If the discharge of springs from the same source is confluent, it is recorded as a single spring (Figure 1). However, they should be recorded separately if it is apparent that a confluent flow has contributing springs of differing character (as by differing spring deposits or measurements with a multi-parameter probe). Springs with separate runs but very close together can be mapped as a cluster. Springs with distantly spaced runs are mapped as separate springs.

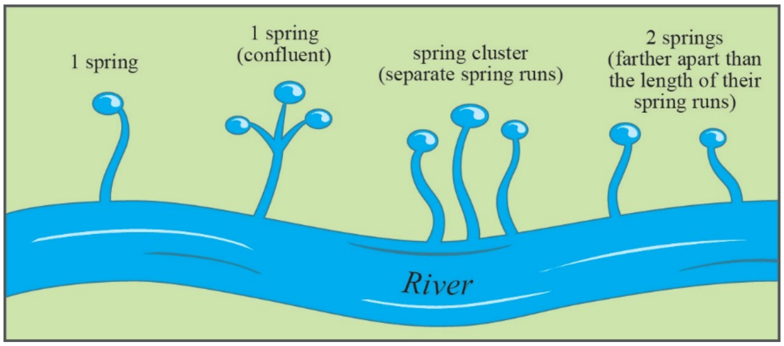

Figure 1 – Map view of single and clusters of springs with spring runs.

Spring Type (Classification)

Many spring classifications have been proposed over the years, such as whether they discharge deep crustal waters or derive from meteoric sources (Bryan, 1919), their discharge magnitude (Meinzer, 1923), or their ecological "sphere of discharge"[1] (Alfaro and Wallace, 1994; Springer and Stevens, 2009). Glazier (2014) provides an elaborate review of different criteria.

In Minnesota, DNR Fisheries has been carrying out stream surveys since the 1940s. While no formal spring classification has been applied, springs have been usually grouped as bed, bank, or cave springs (Brick, 2015). Schwartz and Thiel (1954) divided Minnesota's springs into four types: contact, depression/water table, fracture, and artesian. Muck and Newman (1992), working in Minnesota's southeastern counties, divided springs into conduit (limestone) and diffuse (sandstone) flow springs.

[1] The Sphere of Discharge terminology originally began with the three terms *limnocrene, helocrene*, and *rheocrene*. First proposed by Bornhauser (1913) for the springs of Basel, Switzerland, this terminology was revived more recently by Hynes (1970) and is currently in use by various entities conducting spring inventories, such as the National Park Service, and by consultants in Minnesota. Springer and others (2008) expanded the categories to twelve. An example of a confusing situation is their category of "cave spring." The common acceptation of this term in Minnesota's Karst Features Database (KFD) and among geologists generally is where a stream exits a spring cave, and this is the preferred usage proposed in this Guidance Document. According to Sphere of Discharge terminology, however, a cave spring would be called a "gushette." On the other hand, a cave spring in Sphere of Discharge terminology means a spring resurging into a cave chamber; and so by definition, the groundwater has not reached the Earth's surface, as most definitions of springs require. *Hypocrene* is another category of "spring" without direct surface expression, important in deserts, but outside the spring definition adopted in this document.

An eclectic system is applied for this inventory based on the known diversity of Minnesota springs, with the existing Karst Features Database (KFD) classification as its starting point. Once the spring data has been entered into a relational database, any number of searches can be performed, allowing for the construction of classifications based on other criteria. Both seeps and springs can have the same geological settings. Thus, there are seeps emanating from contacts and springs emanating from contacts.

The following choices for type of spring are ranked in a general way, so that in cases where there is more than one possible valid choice for a given seep or spring, the one nearer the top is the better or more exact choice, whereas the other less exact terminology is near the bottom of the list. Specific examples are from Minnesota.

Contact or bedding plane—Contact seeps and springs issue from the contacts between geologic formations or members (unconsolidated or bedrock layers) whether those formations are horizontal or inclined. Examples are the dozens of glacial—Decorah Shale contact springs in St. Paul. Also included are seeps and springs emanating from bedding planes within a single geologic formation. Examples are the Magnolia—Hidden Falls springs of the Platteville Formation in Minneapolis. Icicles frequently form in winter where seeps issue along contacts. If the actual contact is obscured by something like colluvium or vegetation, the choice is *inferred* versus *observed*.

Fault, fracture, or joint—Seeps and springs that issue from secondary discontinuities in rock masses. An example is Gasworks Bluff Spring in Minneapolis, which issues from a vertical fracture in the Platteville Limestone.

Cave—Seeps and springs that occur in karst and pseudokarst, where the water issues from the mouth of a natural cave. An example of a solutional cave spring is Tyson's Spring Cave, near Wykoff, Minn. While rare, examples of pseudokarst caves include the springs in Carver's Cave and the former Fountain Cave, both in St. Paul (Pseudokarst mimics karst but is nonsolutional in origin).

Fen—A seep complex with possible springs within that issues on a known fen or related ecosystem, flowing by gravity or artesian pressure. Gun Club Fen in Eagan is an example. Subtypes of features within fens are: **fen spring (flowing)**—a spring within a fen complex; **fen marl pool**—a groundwater-fed pool with calcium carbonate deposits in which flow may or may not be apparent; and **fen peat**—peat saturated to the surface by discharging groundwater.

Fluvial—A seep or spring at or near the water-line in the bank or bed of a stream, whether subaerial or subaqueous. Regardless whether stream level rises or falls, the spring will thus remain in this category. An example is the Lawndale Spring, Rothsay Wildlife Area, which "boils" from stream bed alluvium.

Littoral—Refers to the shoreline of a pond or lake, and includes subaerial seeps and springs along the beach as well as offshore boils and seepage. Regardless whether lake level rises or falls, the spring thus remains in this category. Examples are the shoreline springs of Lake Shingobee.

Depression or water table—Seeps and springs that issue where the water table meets the base level of an adjoining stream gorge or a low spot in the landscape. Examples are the Black Ash Seeps in Minneapolis, which marks the water table in the St. Peter Sandstone where it meets the level of Minnehaha Creek.

Pipe—When groundwater issues from an artificial pipe it is often unclear whether the feature is a spring or a flowing well. This category is only for cases where the pipe cannot immediately be traced back to a geologic feature in one of the other categories. An example is the Great Medicine Spring in Minneapolis.

Historical—Springs can decline and stop flowing entirely or nearly so. These should still be recorded as springs, but with a note that they are "historical." Historic plaques can indicate the location, as at Mankato Springs. Former springs can leave behind what Toth (1971) has called "discharge features" such as deposits and discolorations, which can be used to get an accurate location in the field. This does not apply where the actual location itself has been obliterated, as in the case of riverbank springs wiped out by meander migration.

Other—Includes such rare examples(for Minnesota) as mound springs, which issue from the top of low mounds built up from spring precipitates, such as tufa or iron oxides, as along the Kettle River in Pine County. Estavelles are sinkholes in karst which can temporarily reverse flow directions and overflow onto the land surface as a spring, but are not common enough in Minnesota to warrant a separate category.

Unknown*—Includes unusual circumstances, if none of the above apply.*

Artesian is a category seen frequently among spring classifications but is not used as a separate category because it is not a geologic or landscape feature, and because it often requires additional geological data to make a determination that is not available during a reconnaissance survey.

A *lake* should not to be mapped as a spring so there is no category for them. Most of the groundwater entering lakes does so in the littoral zone (Pfannkuch and Winter, 1984). If noticeable these seeps or springs should be mapped separately as littoral springs.

Attributes

Lithology—Choices for lithology are: limestone/dolomite, sandstone, basaltic, granitic, and unconsolidated. If a specific formation name is known it can be entered under lithology comments.

Mineral Precipitation—The most common mineral deposits encountered among Minnesota springs are a calcareous, often a whitish spongy deposit called tufa, which fizzes with acid. Iron oxides and hydroxides leave behind an orange or reddish staining or deposit, and sometimes a mound in extreme cases. Manganese is often present, occurring as a black coating on stream cobbles.

Flow Measurements—Discharge is to be *estimated* in a Level I survey, and only *measured* if it is readily accomplished, as from a pipe orifice, culvert, or other fixed geometry. Flow is recorded in gallons per minute (gpm) or cubic feet per second (cfs). One cfs is equal to 449 gpm. Flow can be measured by several methods: estimated, bucket, flume, weir, area velocity, or tracer dilution. Appendix D contains descriptions of estimation techniques and a table of rate conversions.

Field Measurements

Water quality parameter data can be used to indicate the general condition of springs and identify springs that may require additional characterization. For example, if the springs of a region are usually oxidizing, but one has a low dissolved oxygen, it may indicate special conditions that require chemical analysis in the Level II inventory. Daily calibration is required when collecting water quality parameters, consult the relevant owner's manuals for instructions.

Presence or absence of various organisms (fish, amphipods, plants)—While a scientific appraisal of these belongs to a Level II inventory requiring the expertise of a taxonomist, a brief note about their presence or absence is helpful, especially if they are of management concern (e.g., endangered, rare, or invasive species). Also note indicative species like watercress. The presence of fishes and macroinvertebrates (such as amphipods) will say something about the spring environment. There's a sharp dichotomy among temperate cold freshwater springs between crustacean-dominated and insect-dominated springs (Glazier, 1991). Crustacean-dominated springs, inhabited by freshwater shrimp (also known as amphipods or scuds) tend to be characterized by hard water and low pollutants. Insect springs are soft waters of low alkalinity. Muck and Newman (1992) reported that the common species of amphipod found at springs in southeastern Minnesota (*Gammarus pseudolimnaeus*) is an indicator of good water quality and water temperatures below 20 °C. As a quick check for amphipods, briefly shake vegetation or overturn a few stones in the spring, and if present they will be seen darting about. Appendix E provides visual aids to the identification of biota.

Cryptogams (nonflowering plants as indicators)—A loose but useful traditional category containing nonflowering plants. The groups included here capture some useful aspect of springs. Since most springs will have more than one group present, the question is really about which group predominates. Springs with abundant orange flocs or oil-like films are rich in iron bacteria, as seen in the shoreline springs of Lake Shingobee (Rosenberry and others, 2000). Springs rich in algae could indicate an excess of nutrients, such as nitrate or phosphorus, especially in agricultural areas, such as the headwaters springs of Beaver Creek State Park in Houston County. Fungus growths could indicate a contamination problem, as with the *Saprolegnia* infestation, appearing as white fuzz, at the Gasworks Bluff spring in Minneapolis, which drains groundwater from a Superfund site. Liverworts, on the other hand, form part of the so-called splash community that surrounds falling springs, as at Hajduk

Spring in Minneapolis. Mosses, especially those of the genus *Fontinalis*, are characteristic of many springs, especially on the North Shore of Lake Superior.

Temperature—This may provide insight into source waters and is recorded in degrees Celsius (C°).

pH—The acidity or alkalinity of a solution will influence speciation of the minerals in solution. It also forms part of the definition for calcareous fens. Measured with a multi-parameter probe in pH units.

Conductivity—Measures the ability of the water to conduct an electrical current and thus reflects the total dissolved solids. It also forms part of the definition for calcareous fens. Specific conductivity is recorded with a multi-parameter probe in micro-Siemens per centimeter (µS/cm).

Dissolved Oxygen (D.O.)—The amount of available oxygen in the spring water, indicating whether the groundwater system is oxidizing or reducing. Dissolved oxygen is measured with a multi-parameter probe in milligrams per liter (mg/L).

Oxidation Reduction Potential (ORP, redox potential, or Eh)—Measures an aqueous system's capacity to either release or accept electrons from chemical reactions. When a system tends to accept electrons, it is an oxidizing system. When it tends to release electrons, it is a reducing system. A system's reduction potential may change upon introduction of a new species or when the concentration of an existing species changes. ORP values are used much like pH values to determine water quality. Just as pH values indicate a system's relative state for receiving or donating hydrogen ions, ORP values characterize a system's relative state for gaining or losing electrons. ORP values are affected by all oxidizing and reducing agents, not just acids and bases that influence pH measurement." (Bier, 2009) ORP is recorded with a multi-parameter probe in millivolts (mv).

Other Useful Data

The following site attributes are reported by some other spring protocols. They are potential items to include in the remarks field:

Historical notes—May be derived from local residents.

Disturbance/improvements—Is the site pristine or is there a pipe, springhouse, walled basin, watering trough, etc.?

Compass orientation—If applicable for measuring the orientations of various features such as spring alcoves, cave entrances, spring brooks, the inclination of strata or slopes, etc.

Ease of access—Is the spring is near to roads or or does it require a lengthy hike through the bush to get there.

Watershed—Information which can be derived from maps at a later time, but is relevant because of the biota that may be found at the springs.

Landscape position—Is it in the middle of a field, on a hillslope, outcrop, etc.?

Local relief—Is it flat, rolling, rugged, relevant to whether artesian flow could be involved?

Surrounding/upgradient land use: What crops are grown, or if it is wilderness, a campground, etc.?

Where the water goes—Sinks again or flows into a stream, lake, wetland, etc.

Sedimentology—Does the bottom substrate consists of sand or gravel, silt, clay, etc.?

Literature references: Added at a later time if it is important and relevant to the data set.

Weather—This helps know impact to variables recorded like flow rate, water chemistry, and so forth. In practice, it may only be necessary to record this once per day, unless there is a significant change of weather.

Soil map unit—This can be determined back at the office, but by recording it certain patterns may come into focus. For example, the association of the spring with a hydric soil, revealing a pattern that can be examined for even more springs in further fieldwork.

Ecoregion—This can be determined back at the office, but it can place the biota and other observations at the spring into perspective.

2.2.4 Quality Assurance

As a check on the quality of data actually collected, a knowledgeable person should review field data for accuracy and consistency early in the field season. It is important to verify that the field technician is able to recognize springs and seepages of all types. Sometimes the only clue from a distance is a subtle difference in vegetation. The technician must also be able to recognize false springs such as tile drainage outlets or overland flow. Flows must be properly estimated.

2.2.5 Post-survey database work

Once data are entered, it is transmitted wirelessly to a geodatabase on the DNR server as a *candidate* spring . From there, the data is reviewed for accuracy and the spring can be promoted to a *published* spring location (denoted with an “A” in the relateID) by a database administrator. Springs are visible online to the general public in the form of a map, along with general information such as flow rate.

2.3 Level II Surveys - Sampling

Level II surveys[2] quantify physicochemical and biotic characteristics of springs and involve long-term monitoring and statistically validated sampling programs. As such, the design of these surveys usually involves extended interdisciplinary cooperation with ecologists and others. A typical spring visit could last from one to several hours.

A detailed base-line is provided for future studies such as the impact of climate change, land uses changes, new management strategies, and so forth. As noted by Sada and Pohlmann (2002), "Annual sampling should continue until the bounds of temporal variation in physicochemical and biotic characteristics are documented, which should be within three to five years."

Guidelines for monitoring water chemistry of Level II surveys are described below. Portions of the Level II surveys dealing with biota (aquatic and riparian vegetation), and aquatic habitat characteristics are beyond the scope of this project and should be designed and conducted by qualified personnel in those specialties according to discipline.

2.3.1 Flow Measurements

Flow should be measured according to the physical configuration of each site. Where the spring flow is too awkward or large for a direct volumetric approach, it will have to be measured in situ by means of stream gaging equipment, portable flume, weir, or the "floating stick" method. Rantz volume 1 (1982) is a good reference for conducting direct flow measurements.

2.3.2 Water Chemistry

The chemistry of spring water is important in its bearing on human and environmental health. It can also indicate the geologic materials the water has flowed through, the recharge environment, and residence time. Common analytes collected for spring water characterization include cations, anions, trace metals, stable isotopes, and tritium (Alexander and Alexander, 2008).

- Water should be collected in accordance with applicable DNR policies and procedures and analyzed by properly accredited laboratories following standard chain of custody procedures.
- Samples must be collected as close to the spring head as possible and standard field parameters must be recorded at the time of sampling.
- GPS coordinates of the sampling locations must be recorded at the time of collection.

[2] Level II and III surveys are not currently funded for Minnesota. This and the following section are for context.

2.4 Level III Survey - Monitoring

Level III surveys involve long-term monitoring of selected reference or sentinel springs, specifically chosen for some important reason.

Sentinel springs are typically representative of a particular aquifer, ecosystem, or region, and may have unusual characteristics such as its chemistry or biota.

The Level III survey uses the protocols defined above, except that the sampling is repeated annually or until a stable, baseline trend has been established, valid for future comparisons.

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Appendix A: Alternative Spring Definitions

Minnesota

"Springs are present where the water table intersects the land surface." (Alley and others, 2007, U.S. Geological Survey)

"A spring occurs when groundwater appears at the land surface." (Minnesota Department of Health, 2015)

"Any natural discharge of water from rock or overlying soil onto the surface of the land or into a body of surface water." (Minnesota Pollution Control Agency, 2015)

Other Historical Definitions

Included below are additional historical definitions of springs for comparison, arranged chronologically.

The definition by Tolman (1937) is conceptually closest to that suggested in this Guidance Document. "A spring is a place where water issues from the ground and flows or where it lies in pools that are continually replenished from below, except that wholly artificial openings, such as artesian wells, are not regarded as springs…. A seep is a variety of spring in which the water comes, not from any definite opening, but through the pores of the ground over a considerable area. The amount of water yielded by most seeps is small. Many marshes and swamps are actually seeps on a large scale." (Bryan, 1919)

"A *spring* is place where, without the agency of man, water flows from a rock or soil upon the land or into a body of surface water…. The term *seepage spring* is often limited to springs with small discharge… Any considerable area in which water is seeping to the surface is called a *seepage area*." (Meinzer, 1923)

"A spring is a concentrated ground-water flow issuing at the surface as a current of flowing water…. Diffuse effluent seepage may occur without giving rise to springs, although slow seepage may be accompanied by outflow sufficiently concentrated and localized to form springs…. Water collected in depressions or stream courses by drainage from a swamp probably should not be classified as spring water, as it is supplied by drainage of surface water and not wholly by ground water." (Tolman, 1937: 435)

"An issue of water from the earth." (*Webster's Second International Dictionary*, 1949)

"Springs are places on the surface of the earth where underground water issues and flows away in a distinctive current. Where the water issues at the surface but does not flow away it is called a seep." (Schoewe, 1953)

"A spring is defined as a phenomenon in which a discernible flow of water is issuing through a natural opening in rock or soil…. Seepage is the phenomenon of diffuse discharge of groundwater in the liquid state to the land surface at an average rate equal to, or exceeding that of the local evapotranspiration….it is often difficult to justify the use of one or the other term for a given feature. Yet, a separation of the two phenomena is warranted if only to emphasize that various discharge-associated features may exist without a concentrated emergence of water being present." (Toth, 1971)

"A flow of water rising or issuing naturally out of the earth; a similar flow obtained by boring or other artificial means." (*Oxford English Dictionary*, 2nd Ed., 1971)

"A spring is a natural discharge with a perceptible current at the land surface or in the bed of a stream, lake, or sea; water that emerges at the surface without a perceptible current is called a seep." (*Encyclopaedia Britannica*, 15th Ed., 1976)

“Springs, or points of natural, concentrated groundwater discharge,…” (Van Everdingen, 1991)

“Springs are a natural source of groundwater discharge at a rate high enough to form a channel on the earth’s surface.” (Webb and others, 1998)

“spring—A point where underground water emerges onto the Earth’s surface (including the bottom of the ocean).” (Florida Geological Survey, 2003)

“Springs are currently afforded protection under [Wisconsin] Act 310 if they meet the definition of ‘an area of concentrated groundwater discharge occurring at the surface of the land that results in a flow of at least one cubic foot per second at least 80 percent of the time.’…. There was no established definition as to what was being called a spring during the [1956-1962] survey…. This [2007] study found the average flow rate of springs to be 0.2 CFS [cubic feet per second] and a median flow rate of 0.03 CFS.” (Macholl, 2007)

“Since 2003, Wisconsin has statutorily defined springs as having a discharge of greater than 1 CFS for >80% of the time. However, owing to a recent Wisconsin Supreme Court case, which more broadly interpreted the Wisconsin DNR’s powers to protect the “Waters of the State,” this discharge value for practical purposes is more nearly 0.25 CFS. As a general guideline, the water should be coming from a discrete point, rather than diffuse.” (Susan Swanson, personal communication, January 14, 2015)

“Springs are places where groundwater is exposed at the earth’s surface, often flowing naturally from bedrock or soil onto the surface of the land or into a body of surface water (Wilson and Moore, 1998).” (Springer and others, 2008)

“Springs are places where underground water emerges onto the Earth’s surface, often forming a stream, pond, or marsh.” (Glazier, 2009)

“There isn't one official definition of springs agreed on and used by NPS [National Park Service] in this [western U.S.] region, however, many in this region have been working on developing monitoring protocols in addition to the spring inventories that have been going on. Here is a brief definition of springs from one of our protocols: "For the purposes of this protocol, *springs* are defined as groundwater dependent ecosystems with measurable flow or stage and *seeps* are groundwater dependent ecosystems without measurable flow or stage. Springs and seeps vary tremendously in their surface expression. The essential driver of springs ecosystems is the source of the water and the geologic structure that brings it to the surface (Bryan, 1919). The topographic setting of the spring emergence further diversifies available habitat and environmental conditions, resulting in a rich array of possible spring types." (Stephen Monroe, Southern Colorado Plateau I&M Network, National Park Service, personal communication, January 6, 2015)

“We do have [in northern Minnesota] a fair number of what I'd call springs as opposed to what I often call seeps, which are basically focused groundwater discharge that I don't think is sufficient to constitute a spring…. But in my book, if there's visible flow for discharge on land next to a lake or wetland or stream, or if submerged discharge is strong enough to suspend (‘boil’) particles then that's what I call a spring. If an area has spring characteristics (very soft sediment, iron staining, wet surface, vegetation that grows in persistently wet areas) but there's no visible flow then I'd call that a seep.” (Donald Rosenberry, USGS, personal communication, January 14, 2015)

Appendix B: Other Spring Inventories

During the years 1956-1962, **Wisconsin Conservation Department (WCD)** officers were instructed to map the springs in their own areas of Wisconsin, and this information was compiled. However, according to Sue Swanson (pers. comm., 2015), who leads the Level II activities of the latest spring survey for the WGNHS, only about two-thirds of the state was surveyed; with much of the central to northeast being omitted. Moreover, many of the "springs" actually mark the locations of reputed spring-fed lakes. Swanson reported that many of the locations have not been confirmed or visited since then. Her present program involves monitoring selected springs intensively (Swanson, 2013).

The Wisconsin springs inventory is maintained in an ACCESS database with the following 9 tables: WCD Survey; GPS & Geology; Site Description; Spring Type; Water Quantity and Quality; Image Log; Aquatic Habitat; Vegetation Species; Vegetation and Geomorphic Type.

The historical WCD data forms a single large table with 43 fields encompassing the historical data from the 1956-62 survey, described by Macholl (2007), who digitized the data. As such, it contains data in flat file format for all of the springs that were mapped in that survey. Examples of the important fields include location, access, discharge, temperature, presence of fishes, land use, and remarks.

The remaining 8 tables were created by more recent workers as part of the Level II surveys. As such, only a subset (the larger springs) of the original number of springs is included in these additional tables.

The **Iowa Geological Survey** has focused its attention on Big Spring and the Upper Iowa River basin. Libra (2011) mapped 838 springs in this watershed. Big Spring, located on the Turkey River, in Clayton County, has an average flow rate of 15,000 gallons per minute, and based on underground dye-traces, is known to drain an area of 100 square miles.

The Illinois Natural History Survey was active in mapping and studying the biodiversity of Illinois springs in the 1990s. Of the 300 springs mapped, most of them occur in the Shawnee Hills of southern Illinois and along the western border of the state (Wetzel and others, 2007). According to their website, the information will be made available as a survey bulletin.

The Desert Research Institute has developed a protocol that is used by the U.S. National Park Service and others. This protocol and its background are described by Sada and Pohlmann (2002).

The Springs Stewardship Institute, associated with the Museum of Northern Arizona, maintains an online database of springs at www.springsdata.org. Stevens and others (2011) have published a narrative concerning their inventory and monitoring protocols.

The U.S. Forest Service has inventory protocols (U.S. Forest Service, 2012) based on that of the Desert Research Institute (Sada and Pohlmann, 2002).

Appendix C: Spring Inventory Field Sheet

Spring Name: ____

____

Location ____

____

Field Check Date ____

Feature Code:
- ❍ Spring
- ❍ Spring - not field checked

Feature Type:
- ❍ Spring
- ❍ Seep

Feature Arrangement
- ❍ Single
- ❍ Cluster

Spring Type
- ❍ Contact Bedding Plane – visible
- ❍ Contact Bedding Plane - inferred
- ❍ Joint Fracture Fault
- ❍ Cave
- ❍ Fen
- ❍ Fluvial
- ❍ Littoral
- ❍ Depression water table
- ❍ Pipe
- ❍ Historical
- ❍ Other
- ❍ Unknown

Comment or Other

Lithology
- ❍ Limestone / Dolomite
- ❍ Sandstone
- ❍ Basaltic
- ❍ Granitic
- ❍ Unconsolidated
- ❍ Other
- ❍ Unknown

Comment or Other

Mineral Precipitation
- ❍ None
- ❍ Calcareous
- ❍ Iron
- ❍ Manganese
- ❍ Other
- ❍ Unknown

Comment or Other

Photo
- ❍ Yes
- ❍ No

Flow Measure
- ❍ Yes
- ❍ No

Flowing?
- ❍ Yes
- ❍ No

Flow Rate ________________________

Flow Units
- ❍ GPM
- ❍ CFS
- ❍ Liters/Minute
- ❍ Unknown

Flow Method
- ❍ Estimated
- ❍ Bucket
- ❍ Flume
- ❍ Weir
- ❍ Area-Velocity
- ❍ Tracer Dilution
- ❍ Unknown

Field Measure

❍ Yes
❍ No

Odor

❍ None
❍ Metallic
❍ Sulfur
❍ Metallic / Sulfur
❍ Other
❍ Unknown
Comment or Other

Fish Seen?

❍ Yes
❍ No

Amphipods Seen?

❍ Yes
❍ No

Plants

❍ Marsh Marigolds
❍ Watercress
❍ Other
❍ Unknown
Comment or Other

Cryptogams

❍ None
❍ Bacteria
❍ Algae
❍ Fungi
❍ Mosses
❍ Uknown

Temperature Celsius ________________ Method ____

Conductivity Value _________________ Method ____

pH Value __________________________ Method ____

ORP Value _________________________ Method ____

Turbidity __________________________ Method ____

Dissolved Oxygen Value _____________ Method ____

Chemistry Measure

❍ Yes
❍ No

General Comments ____

____

Surveyor ____

____

Organization ____

____

Remarks ____

____

Appendix D: Flow Estimation and Conversions

Estimation of discharge is both a science and an art. Using a reference value to estimate spring flow rate will assist in normalizing values.

Using a fully open ¾ inch garden hose as the standard reference value is preferable, as most people can relate to a fully flowing garden hose. An average fully open ¾ inch garden hose flows at approximately 10 gallons per minute (GPM). Some spring geometries allow for simple and quick measurements using a container of known volume and a stop watch. In instances like these, an average of several measured values is preferable to an estimate.

CFS	**GPM***	**GPS**	**LPM**	**LPS**
Feet3/Second	**Gallon/Minute**	**Gallon/Second**	**Liter/Minute**	**Liter/Second**
1.00	449.0	7.48	1699.01	28.32
0.90	404.1	6.74	1529.11	25.49
0.80	359.2	5.99	1223.29	20.39
0.70	314.3	5.24	856.30	14.27
0.60	269.4	4.49	513.78	8.56
0.50	224.5	3.74	256.89	4.28
0.40	179.6	2.99	102.76	1.71
0.30	134.7	2.25	30.83	0.51
0.20	89.8	1.50	6.17	0.10
0.10	44.9	0.75	0.62	0.01
0.05	22.5	0.37	0.03	0.0005
0.03	11.2	0.19	0.0008	0.00001
0.01	4.5	0.07	0.00001	-
0.005	2.2	0.04	-	-
0.0025	1.1	0.02	-	-
0.001	0.4	0.01	-	-

* Garden hose flow ~ 10 GPM

1 cup~ 250 mL

250mL/sec ~ 3.75 GPM

Appendix E: Biota Identification

Amphipod, scud, or freshwater shrimp. They are usually gray in color and the size of a seed, darting about when stones or vegetation is stirred up in the spring. Photo courtesy of Wikipedia.

Marsh Marigold (*Caltha palustris*). The large yellow flowers are most conspicuous in May. Photo courtesy of John Almendinger.

Watercress (*Nasturtium officinale*) frequently retains its green color even in winter, making it conspicuous at springs. Photo courtesy of *planetearthdiversified.com*.

Orange bacterial flocs with black mats of cyanobacteria in Norrie's Spring, Lake Shingobee. Photo courtesy of Greg Brick.

Toxic algae in spring pool, courtesy of *petaluma360.com*.

Appendix F: Creating Tile Packages for Survey 123

The tablet can be useful for guiding prospecting for springs only if there is some kind of geographic map coverage, especially LiDAR. Large data layers, requiring a large amount of memory, are difficult to transfer to a portable tablet. Instead, selected areas of coverage can be uploaded to the tablet before conducting fieldwork. The packages are tiled at different scales so the user can zoom in on them as necessary.

Create the Tile Package

Open ArcMap.

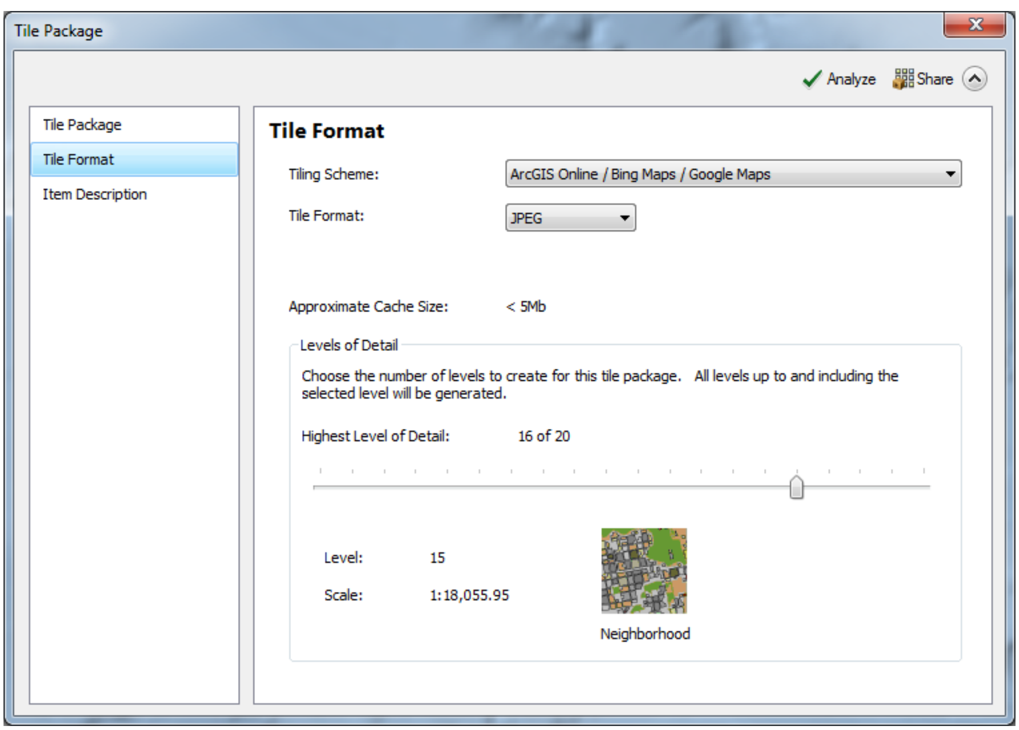
- Use I:\EWR\Spring inventory\gis\mn_hillshade_tile_packages.mxd as a starting point.
- Add additional data as needed, such as MBS fens.

Center on your work area and zoom to 1:24,000

Select: File/Share As/Tile Package

Tile Package window

- Tile Package tab:
  Save package to file (browse)- I:\EWR\Spring inventory\gis\tile_packages\[**new_name**].tpk
- Tile Format tab
  - Tiling Scheme: ArcGIS Online / Bing Maps / Google Maps
  - Tile Format: JPEG
  - Levels of Detail:
    - Highest Level of Detail: 16 of 20
    - Level: 15

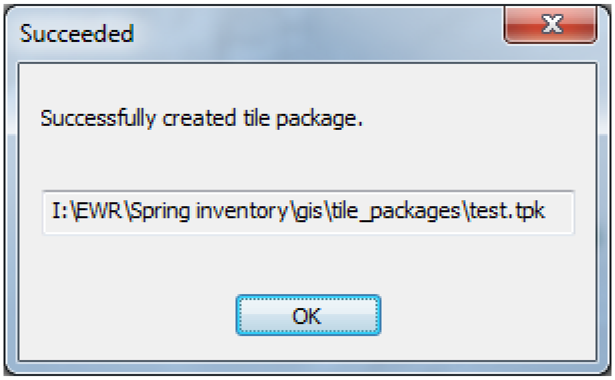


- Item Description tab
  Fill out the Summary and Tags and provide other information

Click on the Analyze button

Attend to Errors. You should be able to ignore the Warnings and Messages

Click on the Share button (upper right)

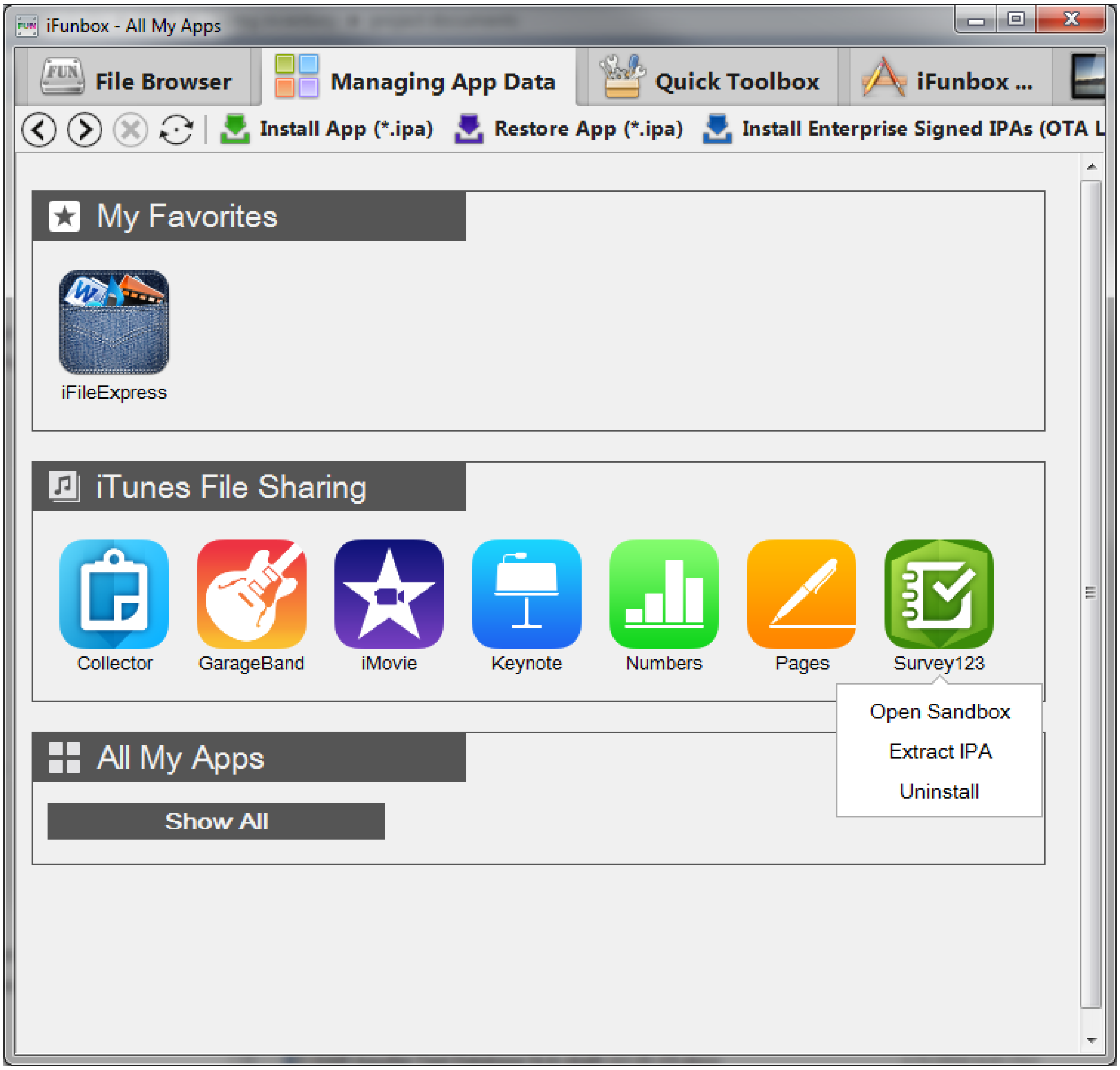


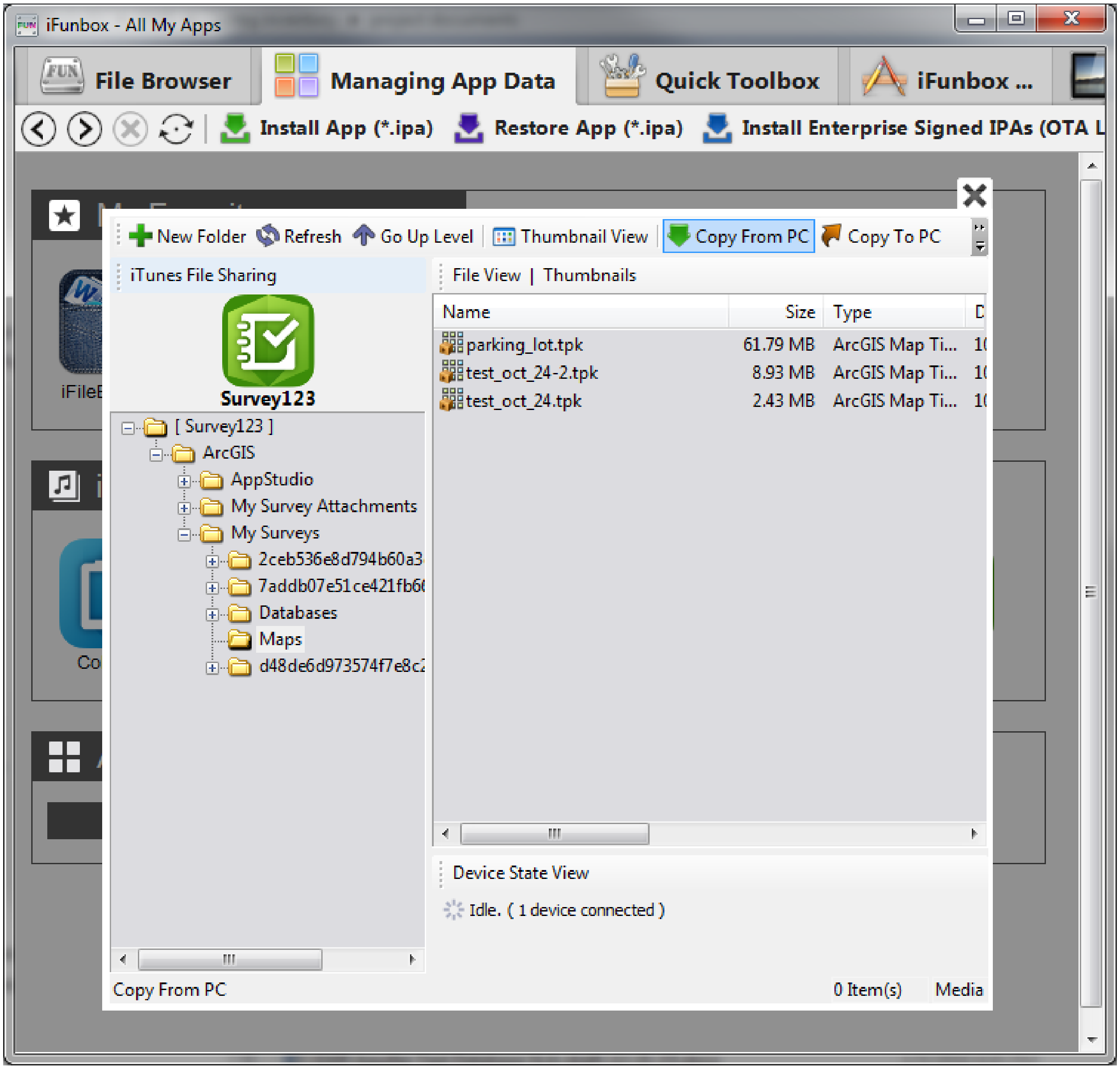
If the process fails, it probably ran out of room where the file is being saved. Pick a new location with plenty of space and try it again. Saving it your computer is usually the best bet. It should be around 5 MB

Transfer the tile package to the iPad

Open iFunbox on your computer (http://www.i-funbox.com/). This is free file management software for moving files from Windows to an iPad.

- Click the Managing App Data > Click the Survey123 > icon, choose Open Sandbox
  If the subfolders don't open, choose Open Sandbox for the Collector app first, and then do it for Survey123
- Browse to the **Maps** folder in Survey123: [Survey123]/ArcGIS/My Surveys/**Maps**
- Select **Copy from PC** and browse to the location of the tile packages
- Select the tile package files and Open. The files will copy onto the iPad





Select the Tile Package in Survey123

Open on the iPad:

- Survey123 > the form you want to use > the map in the form > Map Types options menu (upper right) > your tile package

Helpful Hint - If your tile package doesn't show up on the list, quit and restart Survey123
Note – the same Tile Package can also be used in Collector.

Open on your computer:

- iTunes > Applications > Collector > Add File > browse to the tile package
- After the file has been uploaded, drag it to the Basemap folder

Appendix G: Potential Technologies

Thermal imaging is a remote sensing technology that can be used to locate springs. The technique involves sensing the difference between the spring water temperature and the land surface and stream or lake it is discharging too. The technique has been applied in Minnesota by using airborne thermal scanners. The results have been varied (Ostazeski and Schreiner, 2004; Leaf, 2005). Covering large areas of the state would be prohibitively expensive and would generate large amounts of data that would need to be field-verified.

The advent of unmanned aerial vehicles (drones) may make thermal imagery data acquisition more affordable and more easily applied to specific areas. While using drones would be more cost-effective than using airplane-mounted scanners, there are many logistical and legal issues that would need to be addresses prior to using one for spring data acquisition (Deitchman, 2009).

A third option are handheld thermal scanners. A demonstration of a FLIR model E40bx, with a discrimination of 0.045 °C, was given for us by Deserae Hendrickson (DNR-Fisheries) at a Duluth trout stream. The screen provided a vivid color contrast based on differences in stream temperature. These scanners still require site access either by canoe/boat or by walking along stream or lake banks.

References

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Deitchman, R.S. (2009). Thermal Remote Sensing of Stream Temperature and Groundwater Discharge: Applications to Hydrogeology and Water Resources Policy in the State of Wisconsin. Master's Thesis for the University of Wisconsin. hydroecology.cee.wisc.edu/EBP/pubs/Thesis_Deitchman_2009.pdf.